FINAL REPORT

Study on Reliability Support System for CGPs and Additional Burden Borne by OPTCL

(Grid Support Charges)

Submitted to

ODISHA POWER TRANSMISSION CORPORATION LIMITED

(A Government of Odisha Undertaking)

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Internal Approval

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EXECUTIVE SUMMARY

OPTCL being the State Transmission Utility (STU) is responsible to provide reliable Grid connectivity to CGPs with connectivity agreement as per Grid Code Regulation (OGC) 2015. Over the period STU realized, CGPs enjoy a few quality linked benefits of Grid support without any financial return to OPTCL. The CGP tries to meet the power requirement for production and auxiliaries on its own. In case of deficit, emergency, contingency & start up power, the CGPs choose to remain connected parallel to the grid for a profitable production & continuous power supply. These CGPs having grid connectivity have operational support both during intended and unintentional events which enhances the reliability of the system and can be quantified for various events or operations. CGPs which are connected to grid are automatically entitled to grid support in event of exigencies such as transients or switching.

The CPPs continue to get connected to the utility system and operate their plant in synchronism with the grid mainly due to the following reasons:

- The grid provides stability to the plant to start large motors
- The dip in the voltage and frequency at the time of starting large motors is minimized as the grid supply acts as an infinite bus
- In some cases, the slow responses of the CPP's governors and excitation system will make the plant sluggish without the support of the grid
- The shocks created by sudden load throw off and consequent tripping of CPP's generator on over speeding is avoided with the grid support
- The connection with the grid helps CPP's connected to steel mills and arc furnaces i.e., the system with fluctuating loads in stabilizing their units.

Grid acts as the supporting system for the CPPs for its successful operation in terms of electrical performances. This reliability support is provided as an instantaneous support (24x7) to the plant from the grid because of parallel connectivity which is chargeable. These charges are against dedicated infrastructure support, wear and tear of grid side equipment and above all the services provided instantaneously to avert connected industries from production losses. These also help the CGP in improving their system efficiency, plant load factor, power factor etc.

Under the above circumstances, OPTCL had filed an application before commission on 23/09/2020 registered as Case No 52 /2020 for determination and approval for levy of Grid Support Charges (GSC) for industries having CGPs and running in parallel with OPTCL

Grids. Hon'ble High Court of Orissa ordered on 06/07/2023 upon challenge by CGP on the above case and the inference as below.

OPTCL needs to file a separate application urging the commission for examining whether the levy of GSC/POC is justifiable and if found justifiable, to frame the appropriate regulation in exercise of the powers conferred upon the Commission, that Commission shall do so not by initiating a proceeding but by invoking it's powers under section 181 of the electricity act, 2003.

Further, OPTCL had registered its application once again before OERC vide Case no 44/2024, which was approved by the commission on 9/7/2024. Hon'ble OERC after hearing the above case, asked OPTCL to submit a comprehensive report including the points mentioned below.

- To furnish a consolidated study report that includes an analysis of impact of Inertia, Harmonics, Reactive Power, Power factor at PCC & Generator output terminals both in isolated and grid connection mode.
- To clarify that levying GSC/POC will not contradict the existing provisions of Charges/Payment under Odisha Grid Code Regulations, 2015 particularly regulation 1.7.
- To study / identify if harmonics and other grid pollutants are attributable to industries without CGP.
- To justify the GSC/POC methodology for different Capacity, Contract Demand, Power exports to Grid.
- To apportion GSC/POC between DISCOM & OPTCL, since it's an integrated network.
- To give views on GSC/POC of RE based CGP, or CGP becoming IPP.
- To study impact of GSC on Transmission Tariff & Retail Tariff
- To suggest a methodology for recovery of GSC in case of default. (Section 56 of EA 2003)

OPTCL entrusted the above task to M/s PRDC to prepare a detailed report covering the above points to further submit before Hon'ble OERC.

Initially M/s PRDC has examined the GSC levied by other states and the charges as below.

- Andhra Pradesh: Rs. 52.13 per kW per month (Rs 50 for conventional generators)
- Madhya Pradesh- Rs. 20/- per KVA per month on the capacity of CPP
- Gujarat: Rs 26.50 per KVA per month on the capacity of CPP
- Chhatisgarh: 13 paise /kWh for its captive and non-captive load

Following methods are discussed for the state of Odisha to examine the suitable and appropriate methods to levy GSC on the CGPs.

- Base MVA method (proposed in previous report)
- Spinning reserve method (proposed in previous report)
- Peak Instantaneous Demand based methods
- Specific Energy Consumption based method
- An 'adaption' of reliability model from CERC's point of connection framework.*

*Point of connection framework is proposed by Task Force to Review Framework of Point of Connection (2019), CERC

It is concluded in this technical study that a basis exists and an amount can be imposed for the reliability support enjoyed by the industries having CGP in their captivity. The load flow analysis, short circuit study and transient stability studies are also included in the report to support the argument of grid support charge on CGPs. Harmonic data are captured from different CGPs to support the fact that CGPs are contributing significant amounts of pollution into the grid which are not accounted for. In the transient stability part, damping index and other formulas are described in the report, which help in quantifying the transient phenomena occurring in grid and CGP.

After detailed technical study on 59 CGPs, M/s PRDC has recommended grid support charge at a rate of Rs 27.5 per KVA per month to be levied on the CGP base MVA. It is also recommended that the charge should be imposed on the CGPs uniformly as mentioned in the report.

Note: PRDC has prepared this report with the available data collected from SLDC. CGPs response have been poor in providing required data for the study.

Abbreviation

CD	Contract Demand
CESU	Central Electricity Supply Utility
CGP	Captive Generation Plant
D/C	Double Circuit
DISCOM	Distribution Companies
LFA	Load Flow Analysis
LILO	Line-in Line-out
LTOA	Long Term Open Access
GSC	Grid Support Charges
OERC	Odisha Electricity Regulatory Commission
OPTCL	Odisha Power Transmission Corporation Limited
MTOA	Medium Term Open Access
PCC	Point of Common Contact/Coupling
PLF	Plant Load Factor
POC	Parallel Operation Charges
PRDC	Power Research and Development Consultants
ROI	Return on Investment
S/C	Single Circuit
SCL	Short Circuit Level
SCS	Short Circuit Study

SEC	Specific Energy Consumption
SEC_e	Specific Electrical Energy Consumption
SLD	Single Line Drawing
SLDC	State Load Despatch Centre
STOA	Short Term Open Access

TABLE OF CONTENTS

EXECUTIVE SUMMARY iii

Abbreviation vi

Table of Contents viii

1. Introduction 1

2. Scope of Work 1

3. CAPTIVE POWER PLANTS 2

3.1. Characteristics of a Steel Industry 3

3.2. Characteristic Aluminum Industries 3

3.3. Paper Mills 4

3.4. Sponge Iron Industries 4

3.5. Cement/ Clinker Grinding Unit 4

4. PARALLEL OPERATION, GRID CONNECTIVITY & OTHER CHARGES 5

4.1. Parallel Operation & Grid connectivity 5

4.2. Tariffs or Charges 6

4.3. Contracts & Allotments of power 6

5. QUANTIFICATION OF RELIABILITY SUPPORT 7

5.1. Reliability Support 7

5.2. Utilization of Transmission System 7

5.3. Inertia & Power Factor 8

5.3.1. Power Factor 8

5.3.2. Inertia 9

5.4. Difference between Reliability Support & Ancillary Support (in context) 10

6. System Study 11

6.1. Load flow observations 11

6.2. Short circuit observations 12

6.3. Observations from Short Circuit Study 13

6.4. Transient Studies for NINL CGP 17
6.5. Transient Stability study for Aditya Alumina 34
6.6. Transient Stability study for Jindal Steel Works Bhusan 59
6.7. Transient Stability of JSW Bhusan under no grid connectivity 84
6.8. Transient Stability study for JSPL 87
6.9. Transient Stability study for Vedanta Jharsuguda 111
6.10. Transient Stability study for Rourkela Steel Plant 136
6.11. Transient Stability of RSP under no grid connectivity 156
6.12. General inferences from studies 159
7. Harmonic Analysis (on-site) 159
7.1. Vedanta 400kV Feeder in Lapanga 400/220/132kV GSS 162
7.2. JSW Bhusan 220kV feeder from Budhipadar 220/132/33kV GSS 165
7.3. Bhubaneswar Power 132kV feeder at Chandaka 220/132/33kV feeder 167
7.4. IMFA 132kV feeder at ICCL Switching Station 171
7.5. Jindal 220kV Feeder from Duburi New 400/220kV GSS 174
7.6. NBVL 132kV feeder from Kharagprasad Switching Station 177
7.7. Tata Steel Bhusan 220kV feeder from Meramunduli 400/220/132kV GSS 180
7.8. Utkala Alumina 220kV feeder from Laxmipur GSS 183
7.9. Arcelor Mittal 220kV feeder from Paradeep GSS 186
7.10. Summary of Harmonic measurement results 189
8. CASE No-52 of 2020 190
8.1. Case Summary 190
8.2. PRDC's Views on the Case 191
9. GRID SUPPORT CHARGES 194
9.1. Survey of GSC/POC in different states 194
9.2. Andhra Pradesh Electricity Regulatory Commission (APERC) 194
9.3. Gujarat Electricity Regulatory Commission (GERC) 195
9.4. Madhya Pradesh Electricity Regulatory Commission (MPREC) 197

9.5. Chhattisgarh State Electricity Regulatory commission (CSERC) 197
9.6. GSC/POC Calculation Methodology 199
9.6.1. Base MVA method 199
9.6.2. Spinning reserve method 200
9.6.3. Basis of methods proposed by PRDC 200
9.6.4. Peak Instantaneous Demand based GSC 202
9.6.5. Specific energy consumption based GSC 203
10. Impact of Reactive Power, Inertia, and Solar penetration in CGP 209
10.1. Reactive Power Analysis 209
10.2. Inertia support analysis for NINL CGP 214
10.3. Inertia support analysis for Vedanta CGP 218
10.4. Impact of Solar contribution in CGP 223
10.5. Transient support calculation using damping index 228
10.6. Waveform Distortion from PCC for CGPs 231
10.7. Power factor measurement of CGP at the PCC 234
10.8. Reactive power measurement at PCC 236
11. Proposed GSC calculation 239
11.1. Comparison of methods for the calculation of GSC 239
11.2. Empirical formula for Grid Support charge based on Base MVA method (proposed in previous report) 240
11.3. Calculation of unit transmission charge 241
11.4. Proposed Grid Support Charge 242
11.5. Calculation of Support MVA Using Rs.39 as unit Transmission Charge 249
11.6. The basis of imposing the Grid Support Charge 253
12. CONCLUSIONS 254
13. References 255
Annexures 258
Annexure 1 259

Annexure 2 260

Annexure 3 261

Annexure 4 262

Annexure 5 263

Annexure 6 264

List of Figures

Figure 5-1 ATC,TTC,TRM [13] 8

Figure 6-1 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 18

Figure 6-2 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 19

Figure 6-3 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 19

Figure 6-4 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 20

Figure 6-5 Reactive power of generating bus for three phase to ground fault at the power evacuation bus during floating mode of plant operation 20

Figure 6-6 Voltage profile of load bus with strong and weak grid connectivity plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 21

Figure 6-7 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 22

Figure 6-8 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 22

Figure 6-9 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 23

Figure 6-10 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 23

Figure 6-11 Reactive power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 24

Figure 6-12 Voltage profile of load bus with strong and weak grid connectivity plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 24

Figure 6-13 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant 25

Figure 6-14 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant 26

Figure 6-15 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant 26

Figure 6-16 Active power plot for highest generating unit outage inside the plant during floating mode of operation of plant 27

Figure 6-17 Reactive power plot for highest generating unit outage inside the plant during floating mode of operation of plant 27

Figure 6-18 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant. 28

Figure 6-19 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant. 29

Figure 6-20 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant. 29

Figure 6-21 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant. 30

Figure 6-22 Reactive power plot for sudden increase in load inside the plant during floating mode of operation of plant. 30

Figure 6-23 Voltage profile of the load bus plot for sudden increase in load inside the plant during floating mode of operation of plant. 31

Figure 6-24 Motor terminal Voltage profile with strong and weak grid connectivity during floating mode of operation of plant. 31

Figure 6-25 Current drawn by the motor with strong and weak grid connectivity during floating mode of operation of plant. 32

Figure 6-26 Voltage profile of cyclic load bus with strong and weak grid connectivity during floating mode of operation of plant. 32

Figure 6-27 Swing curve of generating bus with strong and weak grid connectivity during floating mode of operation of plant. 33

Figure 6-28 Frequency profile of generating bus with strong and weak grid connectivity during floating mode of operation of plant. 33

Figure 6-29 Active power drawn from the generating bus during floating mode of operation of plant. 34

Figure 6-30 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 35

Figure 6-31 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 35

Figure 6-32 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 36

Figure 6-33 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 37

Figure 6-34 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 37

Figure 6-35 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 38

Figure 6-36 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 38

Figure 6-37 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 39

Figure 6-38 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant 39

Figure 6-39 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant 40

Figure 6-40 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant 40

Figure 6-41 Active power for generating bus plot for highest generating unit outage inside the plant during floating mode of operation of plant 41

Figure 6-42 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant. 41

Figure 6-43 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant. 42

Figure 6-44 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant 42

Figure 6-45 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant 43

Figure 6-46 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 43

Figure 6-47 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 44

Figure 6-48 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 44

Figure 6-49 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 45

Figure 6-50 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 45

Figure 6-51 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 46

Figure 6-52 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 46

Figure 6-53 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 47

Figure 6-54 Voltage plot for highest generating unit outage inside the plant during import mode of operation of plant 47

Figure 6-55 Frequency plot for highest generating unit outage inside the plant during import mode of operation of plant 48

Figure 6-56 Swing curve plot for highest generating unit outage inside the plant during import mode of operation of plant 48

Figure 6-57 Active power plot for highest generating unit outage inside the plant during import mode of operation of plant 49

Figure 6-58 Voltage plot for sudden increase in load inside the plant during import mode of operation of plant. 49

Figure 6-59 Frequency plot for sudden increase in load inside the plant during import mode of operation of plant. 50

Figure 6-60 Swing curve plot for sudden increase in load inside the plant during import mode of operation of plant 50

Figure 6-61 Active power plot for sudden increase in load inside the plant during import mode of operation of plant 51

Figure 6-62 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 51

Figure 6-63 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 52

Figure 6-64 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 52

Figure 6-65 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 53

Figure 6-66 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 53

Figure 6-67 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 54

Figure 6-68 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 54

Figure 6-69 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation 55

Figure 6-70 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant..... 55

Figure 6-71 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant 56

Figure 6-72 Swing curve plot for highest generating unit outage inside the plant during export mode of operation of plant 56

Figure 6-73 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant 57

Figure 6-74 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant...... 57

Figure 6-75 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant 58

Figure 6-76 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant 58

Figure 6-77 Active power plot for sudden increase in load inside the plant during export mode of operation of plant..... 59

Figure 6-78 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation..... 60

Figure 6-79 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 60

Figure 6-80 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 61

Figure 6-81 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 61

Figure 6-82 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 62

Figure 6-83 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 63

Figure 6-84 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 63

Figure 6-85 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 64

Figure 6-86 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant 65

Figure 6-87 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant 65

Figure 6-88 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant 66

Figure 6-89 Active power for generating bus plot for highest generating unit outage inside the plant during floating mode of operation of plant 66

Figure 6-90 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant. 67

Figure 6-91 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant. 67

Figure 6-92 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant 68

Figure 6-93 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant 68

Figure 6-94 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 69

Figure 6-95 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 69

Figure 6-96 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 70

Figure 6-97 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 70

Figure 6-98 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 71

Figure 6-99 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 71

Figure 6-100 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 72

Figure 6-101 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 72

Figure 6-102 Voltage plot for highest generating unit outage inside the plant during import mode of operation of plant 73

Figure 6-103 Frequency plot for highest generating unit outage inside the plant during import mode of operation of plant 73

Figure 6-104 Swing curve plot for highest generating unit outage inside the plant during import mode of operation of plant 74

Figure 6-105 Active power plot for highest generating unit outage inside the plant during import mode of operation of plant 74

Figure 6-106 Voltage plot for sudden increase in load inside the plant during import mode of operation of plant. 75

Figure 6-107 Frequency plot for sudden increase in load inside the plant during import mode of operation of plant. 75

Figure 6-108 Swing curve plot for sudden increase in load inside the plant during import mode of operation of plant 76

Figure 6-109 Active power plot for sudden increase in load inside the plant during import mode of operation of plant 76

Figure 6-110 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 77

Figure 6-111 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 77

Figure 6-112 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 78

Figure 6-113 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 78

Figure 6-114 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 79

Figure 6-115 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 79

Figure 6-116 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 80

Figure 6-117 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation 80

Figure 6-118 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant 81

Figure 6-119 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant 81

Figure 6-120 Swing curve plot for highest generating unit outage inside the plant during export mode of operation of plant 82

Figure 6-121 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant 82

Figure 6-122 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant...... 83

Figure 6-123 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant 83

Figure 6-124 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant..... 84

Figure 6-125 Active power plot for sudden increase in load inside the plant during export mode of operation of plant..... 84

Figure 6-126 Frequency response of Bhusan generator..... 85

Figure 6-127 Voltage response 86

Figure 6-128 Swing curve of Bhusan generator 86

Figure 6-129 Active Power for Bhusan Generator 87

Figure 6-130 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 88

Figure 6-131 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 88

Figure 6-132 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 89

Figure 6-133 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 89

Figure 6-134 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 90

Figure 6-135 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 90

Figure 6-136 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 91

Figure 6-137 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 91

Figure 6-138 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant 92

Figure 6-139 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant 92

Figure 6-140 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant 93

Figure 6-141 Active power for generating bus plot for highest generating unit outage inside the plant during floating mode of operation of plant 93

Figure 6-142 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant 94

Figure 6-143 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant 94

Figure 6-144 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant..... 95

Figure 6-145 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant..... 95

Figure 6-146 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 96

Figure 6-147 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 96

Figure 6-148 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 97

Figure 6-149 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during import mode of plant operation..... 97

Figure 6-150 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 98

Figure 6-151 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 98

Figure 6-152 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 99

Figure 6-153 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation..... 99

Figure 6-154 Voltage plot for highest generating unit outage inside the plant during import mode of operation of plant 100

Figure 6-155 Frequency plot for highest generating unit outage inside the plant during import mode of operation of plant 100

Figure 6-156 Swing curve plot for highest generating unit outage inside the plant during import mode of operation of plant 101

Figure 6-157 Active power plot for highest generating unit outage inside the plant during import mode of operation of plant 101

Figure 6-158 Voltage plot for sudden increase in load inside the plant during import mode of operation of plant...... 102

Figure 6-159 Frequency plot for sudden increase in load inside the plant during import mode of operation of plant...... 102

Figure 6-160 Swing curve plot for sudden increase in load inside the plant during import mode of operation of plant..... 103

Figure 6-161 Active power plot for sudden increase in load inside the plant during import mode of operation of plant..... 103

Figure 6-162 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 104

Figure 6-163 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 104

Figure 6-164 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 105

Figure 6-165 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 105

Figure 6-166 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 106

Figure 6-167 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 106

Figure 6-168 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 107

Figure 6-169 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation 107

Figure 6-170 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant 108

Figure 6-171 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant 108

Figure 6-172 Swing curve plot for highest generating unit outage inside the plant during export mode of operation of plant 109

Figure 6-173 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant 109

Figure 6-174 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant...... 110

Figure 6-175 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant 110

Figure 6-176 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant..... 111

Figure 6-177 Active power plot for sudden increase in load inside the plant during export mode of operation of plant..... 111

Figure 6-178 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation..... 112

Figure 6-179 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation..... 113

Figure 6-180 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation..... 113

Figure 6-181 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 114

Figure 6-182 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation..... 115

Figure 6-183 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation..... 115

Figure 6-184 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 116

Figure 6-185 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation..... 116

Figure 6-186 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant 117

Figure 6-187 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant 117

Figure 6-188 Active power for generating bus plot for highest generating unit outage inside the plant during floating mode of operation of plant 118

Figure 6-189 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant 118

Figure 6-190 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant...... 119

Figure 6-191 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant...... 119

Figure 6-192 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant..... 120

Figure 6-193 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant..... 120

Figure 6-194 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 121

Figure 6-195 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 121

Figure 6-196 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 122

Figure 6-197 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 122

Figure 6-198 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 123

Figure 6-199 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 123

Figure 6-200 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation..... 124

Figure 6-201 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 124

Figure 6-202 Frequency plot for highest generating unit outage inside the plant during import mode of operation of plant 125

Figure 6-203 Active power plot for highest generating unit outage inside the plant during import mode of operation of plant 125

Figure 6-204 Swing curve plot for highest generating unit outage inside the plant during import mode of operation of plant 126

Figure 6-205 Voltage plot for sudden increase in load inside the plant during import mode of operation of plant...... 126

Figure 6-206 Frequency plot for sudden increase in load inside the plant during import mode of operation of plant...... 127

Figure 6-207 Active power plot for sudden increase in load inside the plant during import mode of operation of plant..... 127

Figure 6-208 Swing curve plot for sudden increase in load inside the plant during import mode of operation of plant..... 128

Figure 6-209 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 129

Figure 6-210 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 129

Figure 6-211 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 130

Figure 6-212 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation..... 130

Figure 6-213 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 131

Figure 6-214 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 131

Figure 6-215 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation 132

Figure 6-216 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation..... 132

Figure 6-217 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant 133

Figure 6-218 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant 133

Figure 6-219 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant 134

Figure 6-220 Swing curve plot for highest generating unit outage inside the plant during export mode of operation of plant 134

Figure 6-221 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant...... 135

Figure 6-222 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant 135

Figure 6-223 Active power plot for sudden increase in load inside the plant during export mode of operation of plant..... 136

Figure 6-224 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant 136

Figure 6-225 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 137

Figure 6-226 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 138

Figure 6-227 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 138

Figure 6-228 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation 139

Figure 6-229 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 140

Figure 6-230 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 140

Figure 6-231 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 141

Figure 6-232 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation 141

Figure 6-233 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant. 142

Figure 6-234 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant. 142

Figure 6-235 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant 143

Figure 6-236 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant 143

Figure 6-237 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 144

Figure 6-238 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 144

Figure 6-239 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 145

Figure 6-240 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation 145

Figure 6-241 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 146

Figure 6-242 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 146

Figure 6-243 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 147

Figure 6-244 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation 147

Figure 6-245 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 148

Figure 6-246 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 148

Figure 6-247 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 149

Figure 6-248 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation 149

Figure 6-249 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation 150

Figure 6-250 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation 150

Figure 6-251 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation 151

Figure 6-252 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation 151

Figure 6-253 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant 152

Figure 6-254 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant 152

Figure 6-255 Swing curve plot for highest generating unit outage inside the plant during export mod e of operation of plant 153

Figure 6-256 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant 153

Figure 6-257 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant 154

Figure 6-258 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant 154

Figure 6-259 Active power plot for sudden increase in load inside the plant during export mode of operation of plant..... 155

Figure 6-260 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant..... 155

Figure 6-261 Voltage response of Generator terminal bus during 3-Phase to ground fault 156

Figure 6-262 Frequency response of Generator terminal bus during 3-Phase to ground fault 157

Figure 6-263 Reactive power of Generator terminal bus during 3-Phase to ground fault..... 157

Figure 6-264 Reactive power of Generator terminal bus during 3-Phase to ground fault..... 158

Figure 6-265 Swing curve in degree Generator terminal bus during 3-Phase to ground fault 158

Figure 7-1 Voltage response 162

Figure 7-2 Current in Ampere..... 163

Figure 7-3 Frequency response in Hz..... 163

Figure 7-4 Total Harmonic distortion in percentage 164

Figure 7-5 Harmonic components (upto 50th order of fundamental) at a sample time..... 164

Figure 7-6 Voltage response 165

Figure 7-7 Current in Ampere..... 166

Figure 7-8 Frequency response in Hz..... 166

Figure 7-9 Total Harmonic distortion in percentage 167

Figure 7-10 Harmonic components (upto 50th order of fundamental) at a sample time..... 167

Figure 7-11 Voltage response..... 168

Figure 7-12 Current in Ampere 169

Figure 7-13 Frequency response in Hz 169

Figure 7-14 Total Harmonic distortion in percentage 170

Figure 7-15 Harmonic components (upto 50th order of fundamental) at a sample time 170

Figure 7-16 Voltage response 171

Figure 7-17 Current in Ampere 172

Figure 7-18 Frequency response in Hz 172

Figure 7-19 Total Harmonic distortion in percentage 173

Figure 7-20 Harmonic components (upto 50th order of fundamental) at a sample time 173

Figure 7-21 Voltage response 174

Figure 7-22 Current in Ampere 175

Figure 7-23 Frequency response in Hz 175

Figure 7-24 Total Harmonic distortion in percentage 176

Figure 7-25 Harmonic components (upto 50th order of fundamental) at a sample time 176

Figure 7-26 Voltage response 177

Figure 7-27 Current in Ampere 178

Figure 7-28 Frequency response in Hz 178

Figure 7-29 Total Harmonic distortion in percentage 179

Figure 7-30 Harmonic components (upto 50th order of fundamental) at a sample time 179

Figure 7-31 Voltage response 180

Figure 7-32 Current in Ampere 181

Figure 7-33 Frequency response in Hz 181

Figure 7-34 Total Harmonic distortion in percentage 182

Figure 7-35 Harmonic components (upto 50th order of fundamental) at a sample time 182

Figure 7-36 Voltage response 183

Figure 7-37 Current in Ampere 184

Figure 7-38 Frequency response in Hz 184

Figure 7-39 Total Harmonic distortion in percentage 185

Figure 7-40 Harmonic components (upto 50th order of fundamental) at a sample time 185

Figure 7-41 Voltage response 186

Figure 7-42 Current in Ampere 187

Figure 7-43 Frequency response in Hz 187

Figure 7-44 Total Harmonic distortion in percentage 188

Figure 7-45 Harmonic components (upto 50th order of fundamental) at a sample time 188

Figure 9-1 An example of Specific Thermal & Electrical Energy Consumption in a forming & press process of Paper industry (source: Ref [24]) 204

Figure 10-1 Swing curve for three phase to ground fault in import mode 209

Figure 10-2 Frequency response for three phase to ground fault in import mode 210

Figure 10-3 Active power for three phase to ground fault in import mode 210

Figure 10-4 Reactive power for three phase to ground fault in import mode 211

Figure 10-5 Voltage response for three phase to ground fault in import mode 211

Figure 10-6 Swing curve for three phase to ground fault in export mode 212

Figure 10-7 Frequency response for three phase to ground fault in export mode 212

Figure 10-8 Active power for three phase to ground fault in export mode 213

Figure 10-9 Reactive power for three phase to ground fault in export mode 213

Figure 10-10 Voltage response for three phase to ground fault in export mode 214

Figure 10-11 Voltage response due to change in inertia support in the grid 215

Figure 10-12 Frequency response due to change in inertia support in the grid 215

Figure 10-13 Active Power due to change in inertia support in the grid 216

Figure 10-14 Swing curve in degree due to change in inertia support in the grid 216

Figure 10-15 Swing curve in degree for SLG fault with strong and weak inertia grid 217

Figure 10-16 Frequency response for SLG fault with strong and weak inertia grid 217

Figure 10-17 Active power flow for grid having strong and weak inertia during SLG fault ... 218

Figure 10-18 Active power flow for grid having strong and weak inertia during SLG fault ... 218

Figure 10-19 Swing curve in degree due to change in inertia support in grid during three phase to ground fault condition 219

Figure 10-20 Frequency response due to change in inertia support in grid during three phase to ground fault condition 219

Figure 10-21 Active power due to change in inertia support in grid during three phase to ground fault condition 220

Figure 10-22 Voltage response due to change in inertia support in grid during three phase to ground fault condition 220

Figure 10-23 Swing curve due to change in inertia support in grid during Single line to ground fault condition 221

Figure 10-24 Swing curve due to change in inertia support in grid during Single line to ground fault condition 221

Figure 10-25 Swing curve due to change in inertia support in grid during Single line to ground fault condition 222

Figure 10-26 Swing curve due to change in inertia support in grid during Single line to ground fault condition 222

Figure 10-27 Voltage response of CGP generator having solar penetration with strong and weak grid connectivity 223

Figure 10-28 Reactive power response of CGP generator having solar penetration with strong and weak grid connectivity 224

Figure 10-29 Reactive power requirement by plant having 0% solar contribution with strong and weak grid connectivity during three phase to ground fault 225

Figure 10-30 Reactive power requirement by solar plant having 100% solar contribution with strong and weak grid connectivity during three phase to ground fault 225

Figure 10-31 Variation of NCDI based on the ratio 228

Figure 10-32 Distorted waveform measured at PCC 231

Figure 10-33 Distorted waveform measured at PCC 232

Figure 10-34 Distorted waveform measured at PCC 232

Figure 10-35 Distorted waveform measured at PCC 233

Figure 10-36 Distorted waveform measured at PCC 233

Figure 10-37 Distorted waveform measured at PCC 234

Figure 10-38 Power factor of JSW 234

Figure 10-39 Power factor of IMFA 235

Figure 10-40 Power factor of Jindal 235

Figure 10-41 Power factor of Tata Steel Bhusan 236

Figure 10-42 Reactive Power of JSW 236

Figure 10-43 Reactive Power of IMFA 237

Figure 10-44 Reactive Power of Jindal 237

Figure 10-45 Reactive Power of Utkal Alumina 238

Figure 10-46 Reactive Power of Arcelor Mittal 238

Figure 10-47 Reactive Power of Tata Steel Bhusan 239

List of Tables

Table 6-1 Load flow results 11

Table 6-2 Short Circuit Analysis results for Peak Load condition at Grid side 13

Table 6-3 Short Circuit Analysis results for Peak Load condition at CGP side 14

Table 7-1 IEEE STD. 519 VOLTAGE DISTORTION LIMITS 159

Table 7-2 IEEE STD. 519 CURRENT DISTORTION LIMITS 120V TO 69kV 160

Table 7-3 IEEE STD.519 CURRENT DISTORTION LIMITS 69kV TO 161 kV 160

Table 7-4 IEEE Std.519 Current distortion limits > 161 V 161

Table 7-5 Summary of Harmonic measurement results 189

Table 9-1 Grid support charges/parallel operation charges 195

Table 9-2 Sample calculation of TPEI for different modes of operation using strong and weak inertia support from Grid 207

Table 9-3 NCDI calculation for a floating mode 3 Phase to ground fault case for strong grid connectivity 207

Table 9-4 NCDI calculation for a floating mode 3 Phase to ground fault case for weak grid connectivity 207

Table 9-5 NCDI calculation for export mode 3 Phase to ground fault case for strong grid connectivity 208

Table 9-6 NCDI calculation for export mode 3 Phase to ground fault case for weak grid connectivity 208

Table 9-7 NCDI calculation for import mode 3 Phase to ground fault case for strong grid connectivity 208

Table 9-8 NCDI calculation for import mode 3 Phase to ground fault case for weak grid connectivity 208

Table 10-1 NCDI for 3PHG strong grid connectivity 226

Table 10-2 NCDI for 3PHG weak grid connectivity 226

Table 10-3 NCDI for 3PHG weak grid connectivity 226

Table 10-4 NCDI for 3PHG strong grid connectivity 226

Table 10-5 Summary of NCDI indices 227

Table 10-6 NCDI for strong grid and floating mode 229

Table 10-7 NCDI for weak grid and floating mode 229

Table 10-8 NCDI for strong grid and export mode 229

Table 10-9 NCDI for weak grid and export mode 229

Table 10-10 NCDI for strong grid and import mode 230

Table 10-11 NCDI for weak grid and import mode 230

Table 11-1 Comparison of GSC calculation methods 239

Table 11-2 Generation of State 241

Table 11-3 Transmission charge calculation 242

Table 11-4 Calculation of No-Load Loss 242

Table 11-5 Table for calculation of reliability support 244

Table 11-6 Table for calculation of Grid Support charge based on reliability support 249

1. INTRODUCTION

Power plant set up by any person/association to generate electricity primarily for his own bulk use called captive generating plant (CGP) is connected to the STUs with these open access agreements. This ensures drawal or injection through the dedicated 'transmission facility and availability'. There are 59 bulk consumers having CGPs of their own to meet their power requirement for the sake of safety, security, reliability and efficiency. Bulk consumers can also exercise their option to export their surplus power to the grid. OPTCL being the provider of the connectivity and open access facility proposed to levy parallel operation charges. With huge investment in the infrastructure for present load and future growth, OPTCL expects a share on the return on revenue from all entities connected to its transmission facility for secured and reliable operation, apart from wheeling charges. The justification for the same in terms of the reliability support provided by the transmission system is presented in this report. The reliability support through parallel operation is analyzed, modeled, simulated & thereafter quantified to give a basis for parallel operation (POC) or grid support charges (GSC).

2. SCOPE OF WORK

A 'Technical Study for Levying Grid Support Charges' has been carried out by Power Research and Development Consultants Ltd. being entrusted by OPTCL. Technical study includes (a) An analysis and understanding of current procedural measures adopted by stakeholders in context of charges, availability, usage & reliability of transmission system, for justification of the study (b) System Studies such as Load flow studies, Short circuit studies ,Transient studies, Real time measurements to understand the grid support to CGPs (c) Understanding operation of industries with CGP in terms of their product and energy consumption (d) Survey of Grid support charges in other states of India (e) Identifying Electricity Acts to support the cause of technical study (f) Identifying methodologies to formulate the quantification of reliability support provided by the Grid and form a basis for Grid support charges.

The scope of the study according to OPTCL work order is as follows:

a. Data collection, preparation of the Single Line Diagram and database for the existing OPTCL transmission network containing the connectivity of concerned CGPs.
b. Simulation of Load Flow Study for the existing OPTCL transmission network to determine the real and reactive power exchange of CGP with OPTCL at the point of common coupling.
c. Simulation of Short circuit study for the existing system to determine the fault level at the point of common coupling of CGPs to determine the fault MVA support given OPTCL network.
d. Quantifying the net reliability support received by CGPs from the OPTCL Transmission network considering their installed capacity, contracted demand, and type of connectivity.

e. Analyzing appropriate methods of grid support charges or parallel operation charges for reliability support extended by OPTCL to CGPs and suggesting the suitable methods for reliability support referring to the case study of other utilities where these charges are applicable.

f. The presentation before OERC and subsequent clarification thereof.

g. Data collection and modeling of CGPs connected in 33kV systems under DISCOMs.

h. Data collection and modeling of Renewable CGPs already connected/proposed to be connected in the OPTCL network.

i. Case studies on Transient stability studies of motor starting and its impact in OPTCL system.

j. Measurement and analysis of Reactive power and harmonic injection into the transmission network for all types of samples CGP (Voltage, type of industry, size of CGP both unit wise and installed capacity wise) on a sampling basis at the point of common coupling under each DISCOM.

k. Analyzing different mathematical methods of Grid Support charge calculation with adequate techno commercial aspects.

l. Analysis and justification of Grid Support charge corresponding to the cross-subsidy issue and existing grid codes.

m. Analysis of impact of inertia and power factor.

n. Justification to the objections raised by different industries in Case No 52 of 2020.

o. Any other analysis/study related to the subject to be carried out.

p. Submission of draft report by covering aforesaid points.

q. Submission of final report by incorporating suggestions and comments received on draft report.

3. CAPTIVE POWER PLANTS

Captive Power Generation was conceptualized at a time when there was a shortfall of electrical power for the commercial and industrial (C& I) consumers. Captive Power Plants (CPPs) / Captive Generation Plants (CGPs) are defined as the power plant set up or proposed to be set up by an industry, institution, a person, or a group of persons to meet their own power requirements. Captive power is the power generated by an agency to meet its needs in complementary or supplementary mode to the electricity obtained from the grid [1]. Any person/co-operative society who owns the CGP maintains and operates his own plant and has a right to open access subject to availability of transmission facility as determined by the STU. Power plant to be categorized ‘captive ‘must have minimum 50 % of its generation consumed by the industrial/ production unit as per Electricity rules,3(1) [2] .

There are 59 CGPs in Odisha which can be categorized based on the type of industry housed, as in:

a) Steel Industries
b) Aluminum Industries
c) Paper Mills
d) Ferrous/ Sponge Iron Industries
e) Cement Grinding Industries

3.1. Characteristics of a Steel Industry

Steel Industry processes are in three steps: Primary, Secondary and Tertiary. Primary step involves smelting iron into steel. Secondary step involves removing impurities such as alloy agents and dissolved gases. Tertiary step involves casting molten steel into steel rolls, sheets and other forms. Steel making being an energy intensive process which requires powering

different sub-processes such as electrical furnaces, drive mechanism for feeders, conveyors, DRI rotary kiln, and other supporting devices. Total electrical specific energy consumption (SEC) of a plant includes casting, rolling, and other secondary steel making sections and plant utilities. Specific electrical energy consumption is the ratio of units of electrical energy consumed to metric tons of production. Baseline SEC value depends upon variation in product mix (such as blooms, billets, rods, flats, sheets, wires, rails, wheel and axle etc.) & also on CGP within the plant injecting or drawing varying shares of electrical power to / from the grid[3]. The highly energy intensive heating, cooling, melting and solidification cycle creates a highly variable load demand and variable active and reactive power requirement. The nonlinear loading due to highly inductive furnaces, motor drives, starting smelter pot-lines etc. creates harmonics & poor power factor. This power quality is issues have detrimental effect on transformer, motor, cable, power factor, K-factor, capacitor bank and neutral conductor.

3.2. Characteristic Aluminum Industries

After steel aluminum is the most highly produced metal and the most produced non-ferrous metal. Aluminum plants involve energy intensive primary and secondary production. Aluminum sector has been divided into following four segments: Refinery, Smelter, Integrated, Cold sheet mill. Primary aluminum production involves two major steps: one, refining of bauxite to alumina and two, smelting of alumina to aluminum. Smelting is an energy intensive process and consumes about 85%–90% of the electrical energy consumption. Secondary aluminum production involves re-melting aluminum, in a variety of furnaces and forming alloy in integration & final product being made in a cold rolling mill. The common products processed in sheet rolling mills are ingots, billet or sow according to the customer's provided specification [4,5]. The smelter plant undergoes daily power swings, pot line start up and trip, voltage dip due to starting of motors. The pot line is fed through rectifier transformer whose uneven loading rates will cause voltage harmonics at PCC. Captive and Grid power mix and type of products will determine the electrical SEC.

3.3. Paper Mills

Paper Mills have varieties of process pulp cleaning, refining, dilution, pressurization & drying. The processes range from mechanical to chemical .The final product can be categorized as cultural paper, packaging paper and paper board, specialty paper , newsprint ect . Product mix, i.e., production of different grades of paper, where some products consume higher energy whereas other consumes comparatively less will have different SEC. The sectional motor drives used in the sheet making & drying process requires 'continuity, variability and accuracy' of speed. Along with internal captive generation, the paper industry requires it to be connected to a strong grid with high short circuit levels [6]. A momentary loss of line or starting of large motors in the industry can cause voltage to dip below a certain margin causing huge production & batch losses [7]. In modern paper mill with advanced equipment such as solid state based motor drive & control will lead to nonlinearity in the industrial power system which gets reflected at the PCC. This has detrimental effects such as overheating of transformers, failure of capacitor banks, increase in energy consumption & maloperation of relays etc. The need for captive – grid power mix is an obvious condition in paper industry which also changes the SEC based on injection and drawal needs [8].

3.4. Sponge Iron Industries

Sponge iron is a metallic mass with honeycomb structure. It is produced by direct reduction of iron ore in the presence of coal and air. Since last few years, sponge iron has emerged as an alternate raw material for steel making. Sponge Iron is also known as Direct Reduced Iron (DRI) & Hot Briquetted Iron (HBI). The HBI is the compact form of DRI produced for easy handling, shipping and storage purposes. The different routes for manufacturing steel are through Basic Oxygen Furnace (BOF), Electric Arc Furnace (EAF) and Induction Furnace (IF). Energy consumption in a sponge iron industry varies depending on the production route, raw material, fuel and technology [9]. These arc furnaces are characterized by violent change in power that happens during initial stage of melting. Electric arc furnace produces serious electrical disturbances in the power system. Flicker, harmonics and inter harmonics are the major power quality issues at PCC due to the same. If power quality issues are not mitigated locally then, a sponge iron industry connected to the grid may inject harmonics and imbalances .These also has impact on other equipment on the grid side.

3.5. Cement/ Clinker Grinding Unit

Cement industry processes include raw meal grinding, coal grinding, preheating, precalcining, clinkerization , cement grinding. Main production load accounts for around 60 % of the total load which includes equipments like raw mill, cement mill, ball mill, and rotary kiln, vertical kiln. Rest are auxiliaries support for the production requirements. Cement industry being an energy intensive process, has a huge power requirement in kilns, fans, medium voltage drives, variable speed drives , compressor fans, pumps etc. Energy requirement can vary based on what cement industry can process i.e, a variety of products like Ordinary Portland Cement, Portland Pozzolana Cement, Portland Slag Cement. Electricity consumption could be estimated in two stages: from mining to clinkerization and

for clinker grinding [10]. Total electrical SEC of a plant also includes packaging and plant utilities. The electrical SEC can vary depend power generation in captive, export-import of power and product mix. The non –linearity of motor starting, loading of kilns will cause power quality problems like voltage dips, harmonics etc.

4. PARALLEL OPERATION, GRID CONNECTIVITY & OTHER CHARGES

4.1. Parallel Operation & Grid connectivity

Under open access agreements, industrial consumers have the right to source energy from grid being connected in parallel. Grid here is the high voltage backbone system of transmission lines, substations and generating plants. Parallel operation of an industrial consumer is ensured with availability of a "stable grid" or "synchronized connectivity" to the grid. The industrial unit with it's own generating plant in captivity (CGP/CPP) tries to meet the power requirement for production and auxiliaries through the same. In case of deficit, emergency, contingency & start-up power, the industrial unit may choose to remain connected parallel to the grid for a profitable production & continuous power supply.

STUs (OPTCL in Odisha) have to abide by the regulatory compliance of grid discipline and thus serving as a wheeling medium helps State Load Dispatch Centre (SLDC) to provide the parallelly connected CGPs a regulated voltage, frequency and good power quality at PCC. The following are the advantages CGPs enjoy because of their grid connectivity:

a. It helps plants to run at higher plant load factor.
b. Grid relieves the CGPs from short circuit stresses
c. Grid provides an additional ground from their substation near PCC.
d. Load Fluctuations impacts are absorbed by the grid.
e. Wear and tear of plant equipment due to various electrical stresses is reduced.
f. CGPs have options to operate it's generating unit in constant power mode irrespective of load cycle.
g. Harmonics generated in the plants due to non-linear loads is injected towards grid if not mitigated locally.
h. Grid relieves the CGP's of the impact caused by negative phase sequence currents due to unbalanced loading in phases.
i. Highly variable reactive power can be imported from the grid.
j. Grid connectivity ensures indefinite instantaneous power supply to the plants with CGPs.

4.2. Tariffs or Charges

STOA, MTOA & LTOA consumers apply for open access to SLDC / RLDC with a condition that dedicated connectivity is provided by the STU. While connectivity is granted to the CGPs at the intra-transmission level, a “connection agreement” is made between CGP and transmission licensee in which both the parties will comply with the provisions of Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007 and Odisha Grid Code 2015[11]. The STUs provide a dedicated transmission line along with the substation, pooling station or switchyard near which point of connectivity is given. Commercial treatment of any kind of power exchange between the grid and the CGPs are included in the tariff (charges) decided by the commission [12] as:

a. Wheeling Charges
b. Cross Subsidy surcharge, Additional surcharge, if any
c. Stand-by charges, if any
d. Imbalance and Reactive Energy Charges, as applicable
e. Scheduling and system Operating Charges, as applicable
f. Transmission Charge (Intra-State and Inter State).

The above mentioned charges are imposed based on measurements in time block and should not have an overlap with grid support charges which need to be levied based on grid support.

4.3. Contracts & Allotments of power

The intention of grid connectivity should be clearly defined in terms of contracts and allotments. This brings in clarity about why and how parallel operation of CGPs takes place in terms of mutual benefits.

As defined by Hon’ble OERC,

"Contract demand" means maximum KW or KVA or HP as the case may be, agreed to be supplied by the licensee and reflected in the agreement executed between the parties [OERC definition].

“Allotted Capacity” means the power transfer in MW between the specified point(s) of injection and point(s) of drawl allowed to a long-term/medium-term customer on the intra-State transmission system / distribution system and the expression "allotment of capacity" shall be construed accordingly.

“Reserved Capacity” means the power transfer in MW between the specified point(s) of injection and point(s) of drawl allowed to a short-term customer on the transmission/distribution system depending on availability of transmission/distribution capacity and the expression "reservation of capacity" shall be construed accordingly.

"Demand charge" refers to a charge on the consumer based on the capacity reserved for him by the licensee, whether the consumer utilizes such reserved capacity in full or not.

5. QUANTIFICATION OF RELIABILITY SUPPORT

5.1. Reliability Support

Reliability is the probability of a product/entity/agent performing its intended function under specific operating conditions. The industries with CGPs have a demand of continuous, uninterrupted, stable, secured electric power in order to meet its production requirements. CGPs with it's grid connectivity has operational support both during intended functions and unintentional events which enhances the reliability of the system. Such reliability support can be quantified for functions or events as follows:

a) Starting of furnaces
b) Cyclic Loading of Smelter pots
c) Starting of auxiliary motors
d) Rolling Mill motor's speed Variability
e) Peak production Support
f) Plant start Up (Black and Cold)
g) Fault on CGP side
h) Breaker Tripping due to overload
i) Under and Over frequency event
j) Unit maintenance Support
k) Unit Outage support
l) Load Throw support

It is important to mention here that such reliability support helps us to differentiate between wheeling of energy to / from grid and parallel connectivity of CGPs to grid. The availability of a stable and synchronized grid connectivity is as important as using the transmission infrastructure for wheeling. CGPs which are connected to the grid are automatically entitled to grid support in event of exigencies such as transients or switching. Access to the grid is kept open through dedicated infrastructure which was designed for a pre specified MVA/KVA level as per connection agreement. Sudden discharge of unregulated power from / to the grid within 5 mins/ 15 minutes block cannot be accounted for. In case of a low import or export, the available transmission infrastructure remains unutilized. Industries having less contract demand from the utility will cause a loss of revenue with available non-utilized transmission infrastructure and have reliability support during various exigencies. This reliability is more because of the O & M charges and capital investment of the STUs.

5.2. Utilization of Transmission System

Transfer capability of a transmission system is available for scheduling commercial transaction in a specific direction taking into account network security. Total Transfer capability (TTC) is sum of available transfer capability (ATC) and Transmission Reliability Margin (TRM). TRM is kept to ensure that transmission network is secure under a reasonable range of security. {TTC = ATC+ TRM}[13].

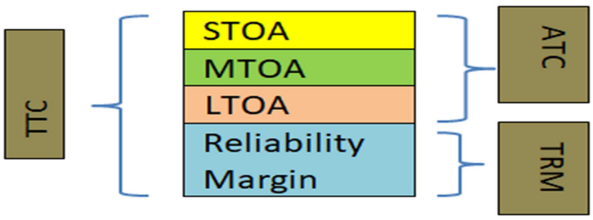

Figure 5-1 ATC,TTC,TRM [13]

CGPs having open access have a share in ATC which will be available to them based on their contract demand with a connection infrastructure of higher capacity if import / export is much less than CD. CGPs which remain floating for security though don't use their share in ATC or have more shares in TRM will still have a secured, stable synchronized parallel connectivity to the transmission system for their own reliability. An example is given in Annexure 1. Moreover TRM is for uncertain situations and can't be kept more than a certain margin at the cost of non-utilization of transmission system lowering efficiency and revenue.

Effects of Non-utilization of existing Transmission System at/near PCC

a) Vulnerability to over voltage scenarios
b) Transformers and machines operating less efficiently.
c) Substation equipment have more wear and tear because of need for voltage regulation.
d) System will tend to generate more reactive power because of capacitive effect w.r.t ground which needs to be absorbed.
e) If power flows are not optimized then there may be congestion in nearby transmission networks. The thermal limits of the concerned lines are exceeded due to these reasons.

5.3.Inertia & Power Factor

5.3.1. Power Factor

As per OERC "Average Power Factor" means the power factor resulting from variations of the quantum and duration of the consumer's load during a specific period and its value corrected to the nearest percent figure to be calculated as a ratio of the registration during the same period of kilowatt-hour and kilovolt-ampere hour. The consumer shall so arrange his installation that the average lagging power factor of his load during any billing period is not less than the percentage value as decided by the Commission from time to time in the Annual Tariff order. Power Factor Penalty shall be levied if there is a breach of the aforesaid requirement and supply of power may be disconnected if the power factor falls below the percentage value as decided by the Commission from time to time.

The above definition is based on the assumption that voltage-current relation is linear. CGP's functionality and operation can be categorized as non-linear. Power factor under non-linear scenario is not same as true power factor. So the overall power factor is the ratio of total power in the circuit to total volt ampere in the circuit which can be derived as product of displacement factor & distortion factor. Displacement factor is the ratio of fundamental active power to apparent power in volt- amperes. Distortion factor is the ratio of fundamental rms

current to total rms current (including harmonics). Distortion factor is less than unity and thus even displacement factor is near unity, power factor under harmonic environment is much less than true power factor. Displacement factors can be made close to unity by giving reactive power compensation using facts devices or capacitors at the supply and distortion factor can be made unity by reducing the injected current harmonics using harmonic mitigation devices. Grid helps the CGPs by absorbing the harmonics and demeaning the effects on the captive equipments. Reliability Quantification is for instantaneous support & power factor deviation from recommended value can only be identified with harmonic measurements. A true measurement of power factor can give an account of grid support received by absorbing harmonics.

5.3.2. Inertia

Inertia of a conventional power system primarily comprises of the energy stored in the rotating mass of synchronous generators & partially from frequency sensitive loads. The rotational energy stored in the synchronous machines, generally known as kinetic energy resists any sudden change in the grid frequency from its nominal/steady state value by releasing stored kinetic energy to the grid. System inertia helps arresting the fall of frequency. Amount of inertia present in the system will impact the rate of change of frequency (RoCoF). In Indian scenario, RoCoF influences the rate at which load shedding can be done.

The inertia constant of a synchronous machine can be theoretically defined as the time in seconds for which the machine can supply its rated power only form its stored kinetic energy in the rotor. Inertia constant of a synchronous generating unit varies typically between 2-10 seconds, depending on the type and size of the generating unit. Similarly, for a conventional power system, the aggregate equivalent inertia constant can be defined as the time in seconds for which the system can supply its aggregate online rated generation from its aggregate stored kinetic energy only. Small disturbances occur in the system dynamically and system adjusts itself without much impact on stability. The reduction of power system inertia reduces its ability to damp out the oscillations. Power system experiences mainly four types of power oscillation which include, intra plant (2-3 Hz), local mode (1-2 Hz), inter-area (1 Hz or less) and torsional mode oscillations (10-46 Hz). For a secure system, all the oscillations should be adequately damped under all the scenarios. The effect is more pronounced when there are large perturbations in steady state conditions of the system. The Critical clearing time (CCT) of faults is also decreased due to reduction in inertia [14].

The contribution to inertia of large generating units is more in the power system which helps in frequency stability, transient stability, power system protection, improving short circuit capacity of the system.

CGPs having large capacities with their stable operation contribute to system stability at and near PCC because of their large inertia. This needs to be quantified by the industry having CGPs so that STUs can calculate the trade-off between reliability support from Grid & CGP support to system inertia.

5.4. Difference between Reliability Support & Ancillary Support (in context)

As defined in Indian Grid code,
"Ancillary Service" or "AS" in relation to power system operation, means the service necessary to support the grid operation in maintaining power quality, reliability and security of the grid and includes Primary Reserve Ancillary Service, Secondary Reserve Ancillary Service, Tertiary Reserve Ancillary Service, active power support for load following, reactive power support, black start and such other services as defined in the Grid Code.
Ancillary Services consist of services required for: a) Maintaining load – generation balance (frequency control) b) Maintaining voltage and reactive power support c) Maintaining generation and transmission reserves.
According to the CERC, ancillary services regulation 2022, the regulations aim to provide mechanisms for procurement, through administered as well as market-based mechanisms, deployment and payment of Ancillary Services at the regional and national level for maintaining the grid frequency close to 50 Hz, and restoring the grid frequency within the allowable band as specified in the Grid Code and for relieving congestion in the transmission network, to ensure smooth operation of the power system, and safety and security of the grid[15]. CERC Power Market Regulations 2020, Regulation 2(c) defines "Ancillary Services Contracts [16]. These contracts are for ancillary services.
Ancillary Services are broadly classified as follows:

i. Frequency Control Ancillary Services (PRAS, SRAS, TRAS)
ii. Network Control Ancillary Services (NCAS) (i) Voltage Control Ancillary Service and (ii) Power Flow Control Ancillary Services
iii. System Restart Ancillary Services

According to CERC mandate, generating plants having un-requisitioned surplus can sell energy through short term open access mechanism. Other ancillary services such as voltage control or fast frequency control which has a very short time frame of response is yet to be a part of market –bid mechanism. These contracts include different stakeholders (independent power producers, generating stations with un-requisitioned power, national & regional load dispatch centers, industries requesting ancillary support) who are willing to participate in the scheduling of ancillary services within the ancillary pool accounted under deviation settlement mechanism (DSM).
In the context of the present CGP study, reliability support (Section 4.1) is provided as an instantaneous support (24x7) to the plant from the grid because of parallel connectivity. This support if quantified will be chargeable for the losses, infrastructural investment, wear and tear of grid side equipment and above all the services provided instantaneously to avert connected industries from production losses & also improving their system efficiency, plant load factor, power factor etc.

6. SYSTEM STUDY

The system study & analysis focuses on the nature of supports that the CGPs are availing from the grid interconnection Load flow and short circuit studies have been carried out for OPTCL system for Peak load conditions FY 23-24. Short circuit studies were performed to compute the currents and short circuit MVA at different nodes of the network after a fault occurs. Transient studies were carried out to study the impact of grid availability on CGP's reliability.

6.1. Load flow observations

The peak Load Flow Analysis provides the following information such as:-

(a) Active and reactive power flow in the network

(b) Bus voltage

(c) System loss

(d) Validation of simulation data with actual network.

In the context of Captive Generating Plants, the Load Flow Study is carried out by considering the generating units of the CGPs (excluding auxiliary consumption) and the infinite bus of OPTCL network. The generation and loads are considered based on the rated values.

Similarly, the determination of the reactive power demand in the load flow study determines whether the concerned CGP is drawing reactive power in the permitted limit or not.

Load Flow and Short Circuit Studies have been carried out for the OPTCL system for Peak Load conditions based on a particular time stamp.

Table 6-1 Load flow results

Summary of Load Flow Results		
Sl. No	**Description**	**Value**
1	Real Power Generation	11185 MW
2	Real Power Load	10839 MW
3	Real Power Loss	345 MW
4	Percentage Loss	3.09%

As per the analysis of the Odisha Transmission network the total generation is 11185 MW, total load is 10839 MW and the percentage loss is 3.09%. The SLD for Load Flow Analysis is given in Annexure-3.

6.2.Short circuit observations

Short Circuit Studies are performed to compute the magnitude of the currents flowing through the power system network after a fault occurs. This information is required to design an adequate protective system and the capacity of the interrupting requirements for circuit breakers at each switching location. Protection systems must recognize faults and initiate circuit breaker operation to disconnect faulted equipments or parts. This action is required to ensure minimum disruption of electrical service and to limit damage in the faulted equipments.

The study has been carried out to find the three-phase to ground fault level and single phase to ground fault level at PCC of all CGP's substation and is presented in Annexure 4.

Short Circuit Studies are carried out for Peak period during FY 23-24. In general, the Short Circuit Study is carried out in any Power System Network to achieve following objectives as mentioned below.

- To identify the Reliable Unit/ Source that contributes to the worst Contingency.
- To identify whether the CGP is self-capable or Grid Support is necessary to incur reliability.
- To determine the extra SCMVA support required for any worst contingency conditions at various distance from the CGP.
- To design the protection circuit parameter.
- Provision for improving the ground impedance
- Behavior of Electrical Equipments during a vulnerable condition.
- Fault bearing capability of the Power System Network

Short Circuit Study is carried out in a Power System Network to test the behavior of Generation and load units during worst vulnerability. Short Circuit Study has been carried for the OPTCL system for the Peak condition. Fault level for all the stations where CGPs are connected has been calculated for the generation schedule data collected from the load dispatch centre for the peak scenarios.

6.3.Observations from Short Circuit Study

Table 6-2 Short Circuit Analysis results for Peak Load condition at Grid side

Name of the Bus	Voltage level of the Bus	3PHG SCMVA	3PHG Current	SLG SCMVA	SLG Current
Nuapatna	132	2993.4	13.1	2885.7	12.6
Ultratech	132	1402.0	6.1	993.5	4.3
Bargarh Old	132	2306.0	10.1	2663.1	11.6
Jharsuguda	132	6239.0	27.3	5696.3	24.9
Lapanga	132	7324.9	32.0	7045.3	30.8
Brajabiharipur	132	3580.0	15.7	3723.0	16.3
Bidanasi	132	4141.6	18.1	4560.2	19.9
Chandaka	132	5926.7	25.9	7445.1	32.6
TS Alloys	132	1107.4	4.8	707.5	3.1
Meramunduli	220	0.0	0.0	0.0	0.0
Budhipadar	220	18834.9	49.4	17805.6	46.7
Somnathpur	132	1920.2	8.4	1874.6	8.2
Paradeep	220	6454.1	16.9	8722.6	22.9
Bhadrak	132	3401.4	14.9	3889.7	17.0
Katapalli	220	7340.5	19.3	6808.4	17.9
ICCL Switching Station	132	3676.5	16.1	4098.3	17.9
Choudwar	132	3811.7	16.7	3970.0	17.4
Paradeep	132	3835.0	16.8	4778.3	20.9
New Duburi	220	8298.3	21.8	9046.6	23.7
Meramunduli	400	28906.0	41.7	25434.4	36.7
NINL	220	6249.2	16.4	5793.7	15.2
Kalunga	33	825.2	14.4	164.8	2.9
Kharagprasad Switching station	132	4518.2	19.8	4053.3	17.7
Budhipadar	132	6918.6	30.3	6932.1	30.3
		6964.0	30.5	6972.7	30.5
Jayanagar	132	3150.6	13.8	3180.8	13.9
		724.3	3.2	532.5	2.3
Rajgangpur	132	3336.6	14.6	3230.7	14.1
Palasponga	132	554.5	9.7	71.8	1.3
Katapalli	33	790.6	13.8	221.0	3.9
Tarkera	220	8073.8	21.2	7727.2	20.3
Meramunduli	33	246.9	4.3	0.0	0.0
Kuchinda	132	1017.9	4.5	886.5	3.9
Kumarmunda	132	3230.5	14.1	3266.6	14.3

Name of the Bus	Voltage level of the Bus	3PHG SCMVA	3PHG Current	SLG SCMVA	SLG Current
Joda	220	3940.3	10.3	3536.6	9.3
Duburi	400	8298.3	21.8	9046.6	23.7
Lakshmipur	220	4706.6	12.4	4901.8	12.9
Jharsuguda	400	33948.8	49.0	24824.4	35.8
Lapanga	400	32834.1	47.4	27761.5	40.1
Kesinga	132	1892.8	8.3	2090.7	9.1
Muniguda	132	1280.4	5.6	1018.0	4.5
Jajpur Road	33	791.8	13.9	96.4	1.7
Tentulikhunti	33	450.9	7.9	74.2	1.3
Bolani	132	1443.6	6.3	1410.9	6.2
Barbil	132	1843.0	8.1	2117.3	9.3
Mania	33	283.3	5.0	0.2	0.0
Khuntuni	33	634.4	11.1	0.2	0.0
Dhenkanal	132	2993.4	13.1	2885.7	12.6
Budhipadar	33	339.9	5.9	47.6	0.8

Table 6-3 Short Circuit Analysis results (3PHG) for Peak Load condition at CGP side

SL NO.	NAME OF CGP	Voltage Level	Fault current at PCC in kA	Fault current from CGP in kA	Fault Level from PCC in MVA	Fault Level from CGP in MVA	Fault Level contribution from Grid in MVA
1	AARTI STEEL LIMITED,Ghantikhal	132	13.5	4.5	3076.0	1016.2	2059.8
2	ACC, BARGARH	132	10.1	0.5	2301.9	105.0	2196.8
3	ADHUNIK METALLIKS LTD,Jharsuguda	132	8.3	0.4	1890.8	98.2	1792.6
4	ACTION ISPAT & POWER PVT.LTD,Jharsuguda	132	27.3	1.0	6229.7	232.9	5996.7
5	ARYAN ISPAT & POWER PVT.LTD,Sambalpur	132	21.8	0.4	4969.1	84.5	4884.6
6	ADITYA ALUMINIUM LTD,Rengali	220	49.4	8.1	18809.3	3082.9	15726.4
7	AM NIPPON STEEL INDIA LTD,Paradeep(Earlier ESSAR)	220	21.6	0.5	8209.5	190.3	8019.2

SL NO.	NAME OF CGP	Voltage Level	Fault current at PCC in kA	Fault current from CGP in kA	Fault Level from PCC in MVA	Fault Level from CGP in MVA	Fault Level contribution from Grid in MVA
8	BHUBANESWAR POWER PVT.LTD.Athagarh	132	50.6	10.9	11543.6	2477.7	9065.9
9	TATA STEEL LTD. Meramundali	220	40.2	7.2	15307.7	2732.7	12575.0
10	BHUSHAN POWER &STEEL LTD.Jharsuguda	220	49.4	5.1	18809.3	1933.4	16875.8
11	EMAMI PAPER MILLS , Baleswar	132	8.6	0.6	1963.9	132.4	1831.4
12	FACOR POWER LTD. Bhadrak	132	15.2	1.0	3461.9	228.4	3233.6
13	HINDALCO INDUSTRIES LTD. Hirakud	220	19.3	3.0	7330.4	1141.8	6188.6
14	IMFA, Choudwar	132	16.2	5.0	3692.6	1130.4	2562.2
15	INDIA OIL CORPORATION LTD. , Paradeep	220	21.6	4.1	8209.5	1568.1	6641.5
16	IFFCO LIMITED ,Paradeep	132	19.3	1.2	4398.2	264.9	4133.3
17	JINDAL STAINLESS LTD.Duburi	220	27.2	3.1	10340.9	1183.7	9157.2
18	JINDAL STEEL & POWER LTD. Anugul	400	42.9	4.4	29700.6	3031.0	26669.7
19	KJS AHLUWALIA STEEL, Barbil	33	14.9	2.1	848.9	121.0	727.9
20	NINL,Duburi	220	22.7	0.5	8635.8	201.7	8434.1
21	MAHAVIR FERRO ALLOYS PVT. LTD. Rourkela	33	14.5	0.7	828.9	41.1	787.8
22	MAITHAN ISPAT NIGAM LTD.Jajpur	220	27.2	0.3	10340.9	106.6	10234.3
23	MSP METALICS LTD, Jharsuguda	132	30.3	0.7	6923.9	148.4	6775.4
24	MGM MINERALS LIMITED	132	19.9	0.3	4539.8	68.5	4471.3
25	NALCO, Angul	220	40.2	5.5	15307.7	2093.3	13214.4
26	NALCO, Damanjodi	220	13.1	0.8	4970.6	308.3	4662.4
27	NARBHERAM POWER & STEEL PVT. Dhenkanal	132	13.5	0.3	3073.7	68.5	3005.2

SL NO.	NAME OF CGP	Voltage Level	Fault current at PCC in kA	Fault current from CGP in kA	Fault Level from PCC in MVA	Fault Level from CGP in MVA	Fault Level contribution from Grid in MVA
28	NBVL, MERAMUNDULI	132	19.9	1.7	4539.8	397.3	4142.5
29	OCL INDIA LTD., RAJGANGPUR	132	14.9	0.8	3402.6	182.7	3219.9
30	OISL, Rajgangapur	132	14.9	0.5	3402.6	114.2	3288.4
31	ORISSA SPONGE IRON & STEEL LTD,Barbil	132	6.8	0.6	1541.4	137.0	1404.4
32	PARADEEP PHOSPHATES LTD,Paradeep	220	19.3	1.2	7330.4	471.9	6858.4
33	MGM Minerals Ltd,Keonjhar(Earlier Patnaik Steel)	132	9.9	0.7	2253.9	155.3	2098.6
34	RATHI STEEL & POWER LTD,Sambalpur	33	13.8	1.3	789.6	75.9	713.6
35	RSP ROURKELA	220	21.6	1.6	8205.7	601.3	7604.4
36	RUNGTA MINES-Dhenkanal or RML DSP	132	13.5	1.6	3073.7	360.8	2712.9
37	RUNGTA MINES-Barbil RML Karakhendra	132	10.6	4.6	2409.2	1059.6	1349.6
38	RUNGTA MINES - Kamanda Steel Plant	132	9.5	1.2	2164.9	274.0	1890.8
39	SEVEN STAR STEELS LTD, Jharsuguda	33	6.0	0.2	339.7	12.0	327.7
40	SHYAM METALICS LTD,Sambalpur	132	39.3	8.0	8963.1	1815.5	7147.7
41	SMC POWER GENERATION LTD,Hirma	132	36.3	4.3	8289.5	979.7	7309.8
42	SMC POWER GENERATION LTD-II,Badmal	132	49.4	0.6	11285.6	132.4	11153.1
43	SHREE GANESH METALICS LTD,Rourkela	132	20.2	6.0	4615.2	1370.2	3245.0
44	SHREE JAGANNATH STEEL & POWER, Barbil or Beekay Steel	132	5.4	0.6	1242.3	125.6	1116.7

SL NO.	NAME OF CGP	Voltage Level	Fault current at PCC in kA	Fault current from CGP in kA	Fault Level from PCC in MVA	Fault Level from CGP in MVA	Fault Level contribution from Grid in MVA
45	SIVA CEMENT LIMITED	132	19.4	2.9	4421.0	664.5	3756.5
46	TATA STEEL LONG PRODUCT LTD, Joda	220	10.9	0.3	4163.8	110.4	4053.4
47	TATA STEEL LTD,Kalinga Nagar	400	24.3	1.7	16787.9	1190.2	15597.7
48	UTKAL ALLUMINA,Laxmipur	220	13.1	0.8	4970.6	289.3	4681.4
49	VEDANTA LTD(SEZ),Jharsuguda	400	47.5	19.1	32835.4	13244.9	19590.5
50	VEDANTA LTD, Jharsuguda	220	49.4	8.8	18809.3	3334.1	15475.2
51	VEDANTA LTD,Langigarh	132	13.9	4.3	3174.2	970.5	2203.7
52	VISA STEEL LTD, New Duburi	220	27.2	1.2	10340.9	441.5	9899.4
53	VIRAJ STEEL & ENERGY PVT LTD, Sambalpur	132	21.8	0.4	4969.1	95.9	4873.2
54	YAZDANI STEEL & POWER LTD, Jajpur	33	13.9	0.6	794.7	32.0	762.7

6.4.Transient Studies for NINL CGP

CGP system study is carried out by considering generating units of CGP and infinite bus of OPTCL network. Transient analysis was carried out on system with different grid- CGP scenarios i.e, floating, power import & power export cases.

The transient stability study for NINL plant is carried out which is connected to Duburi 220kV Bus of OPTCL. In the stability study, necessary conditions are simulated in Mi-Power platform to draw conclusions. The simulation study is carried out considering the floating mode of NINL plant operation with OPTCL grid. During simulation, four types of disturbances are considered for both strong and weaker grid connectivity. In the first two scenarios, a three phase to ground fault and single phase to ground fault are considered in the power evacuation bus of NINL plant. Another simulation scenario is considered in the simulation, where high amount of load increase is considered inside the NINL plant followed by a generation increase or load reduction after one second. A scenario of highest generation

unit outage is also considered for all these plant operating scenarios followed by generator restoration after a period of 1 second. Similarly, two numbers of scenarios with motor starting and smelter cyclic load operations are also simulated in the study for finding necessary comparative margins associated to strong and weaker grid scenario.

Floating Mode

Case 1: Three Phase to ground fault at the power evacuation bus inside the plant for a duration of 160ms with strong and weak grid connectivity

The simulation results representing the voltage, frequency, and angle plot of load bus are presented in Figure 6-1 to 6-3 for a three phase to ground fault at the power evacuation bus during floating mode of operation of plant. The voltage response graph indicates a comparative slow response in case of weak grid as compared to the strong grid connectivity.

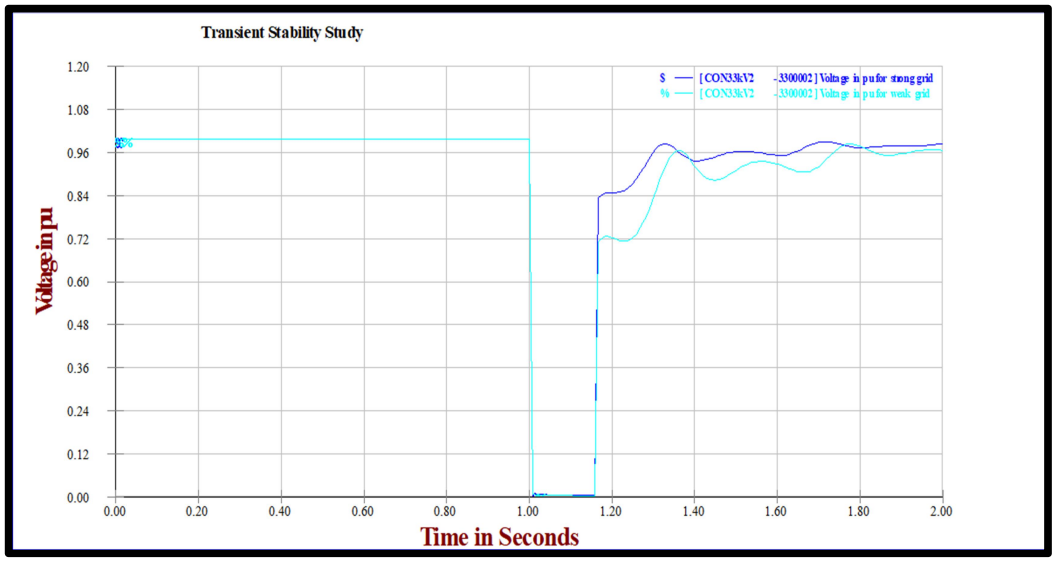

Figure 6-1 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

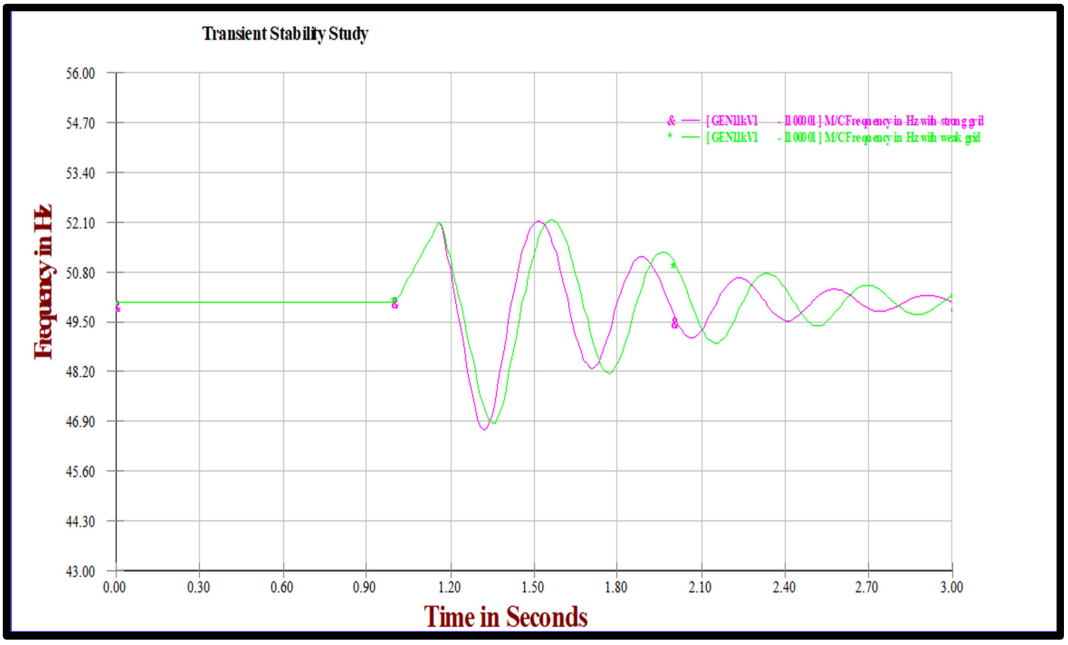

Figure 6-2 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

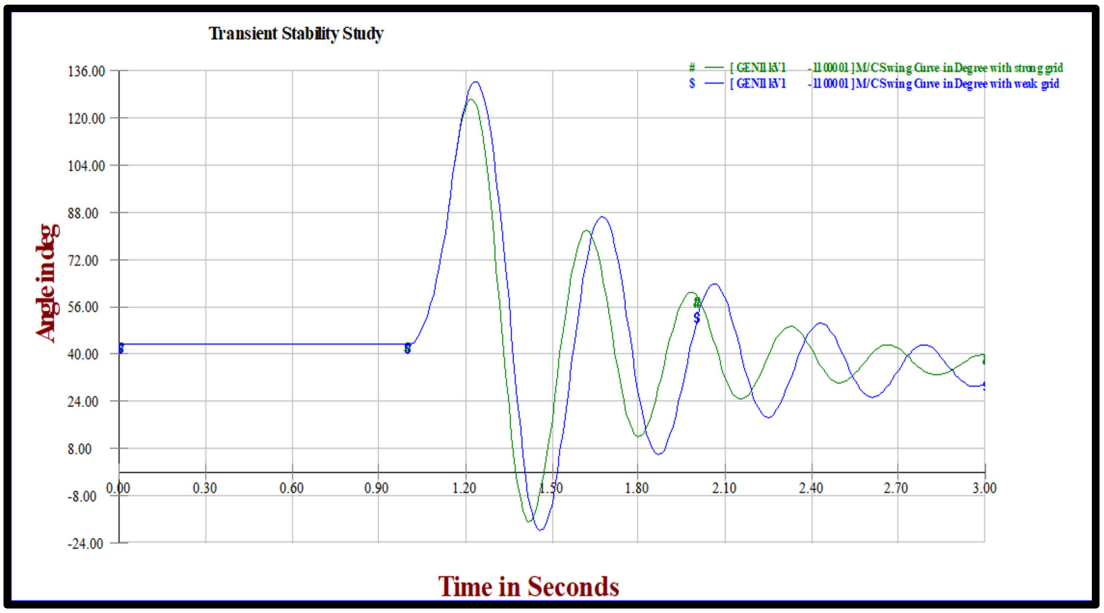

Figure 6-3 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Active and reactive power of the generating bus with respect to time is presented in Figure 6-4 to 6-5 with strong and weak grid connectivity. Similarly, the voltage profile of the load bus is presented in Figure 6-6.

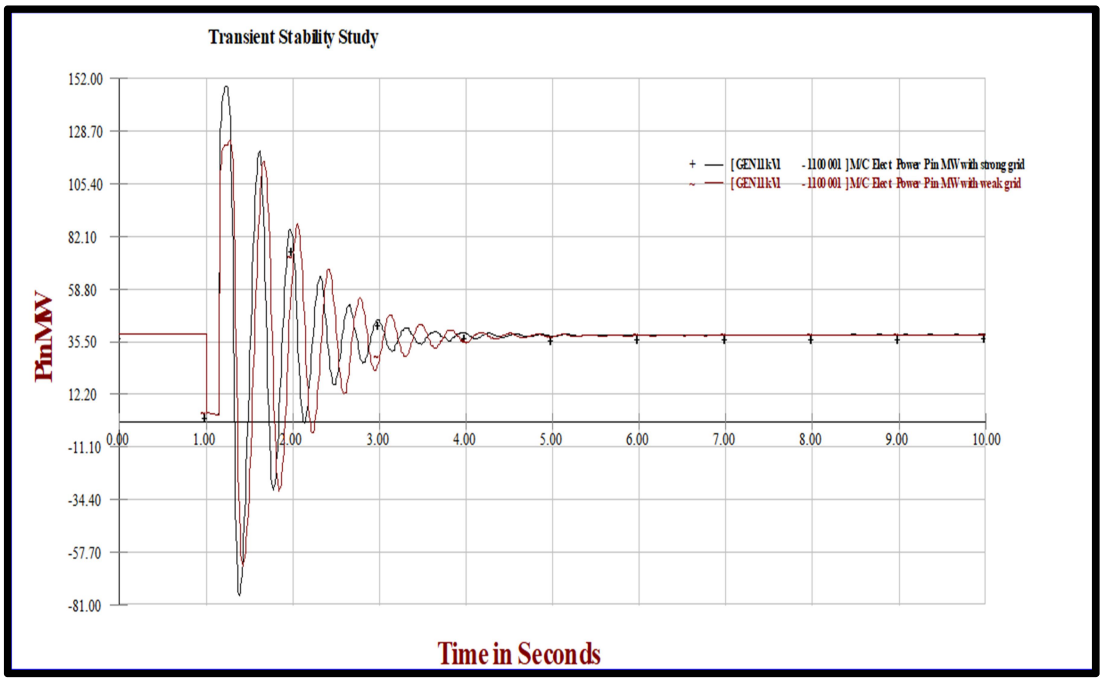

Figure 6-4 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

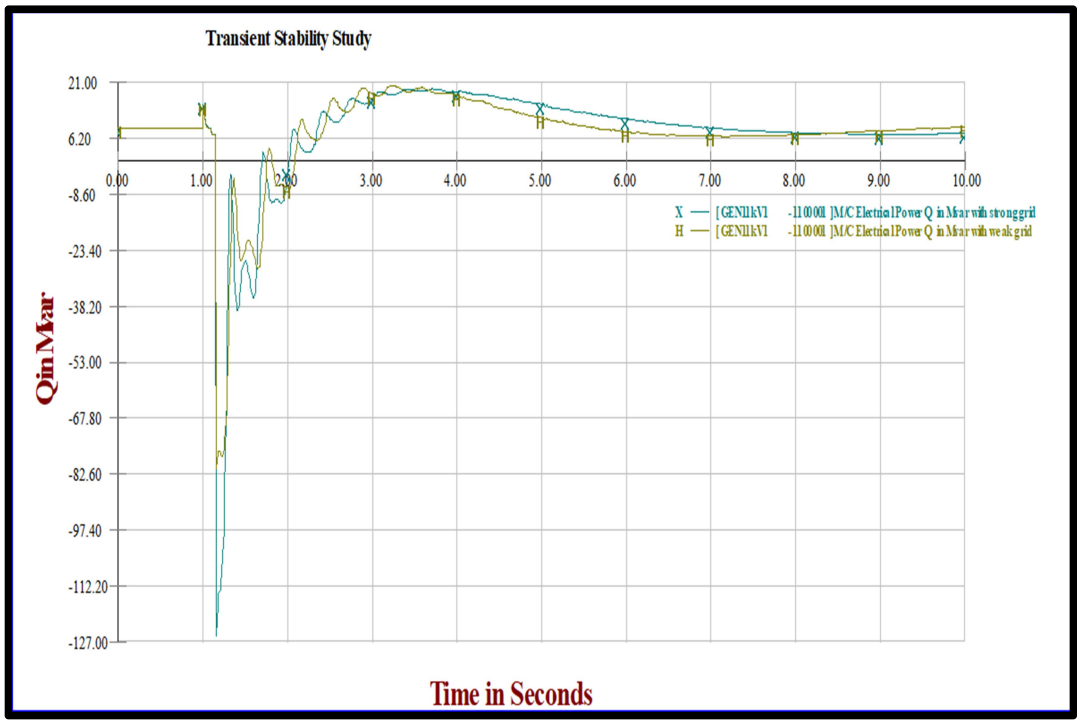

Figure 6-5 Reactive power of generating bus for three phase to ground fault at the power evacuation bus during floating mode of plant operation

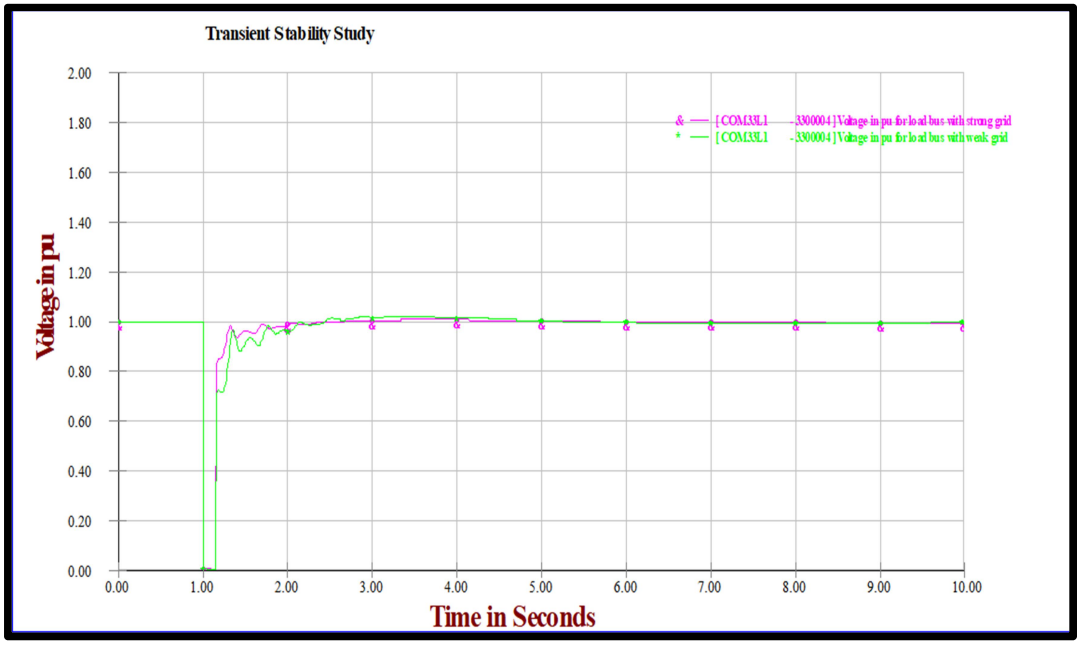

Figure 6-6 Voltage profile of load bus with strong and weak grid connectivity plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Case 2: Single Line to ground fault at the power evacuation bus inside the plant for duration of 160ms with strong and weak grid connectivity

The simulation results representing the voltage, frequency, and angle plot of load bus are presented in Figure 6-7 to 6-9 for a single line to ground fault at the power evacuation bus during floating mode of operation of plant. Active and reactive power of the generating bus with respect to time is presented in Figure 6-10 to 6-11 with strong and weak grid connectivity. Similarly, the voltage profile of the load bus is presented in Figure 6-12.

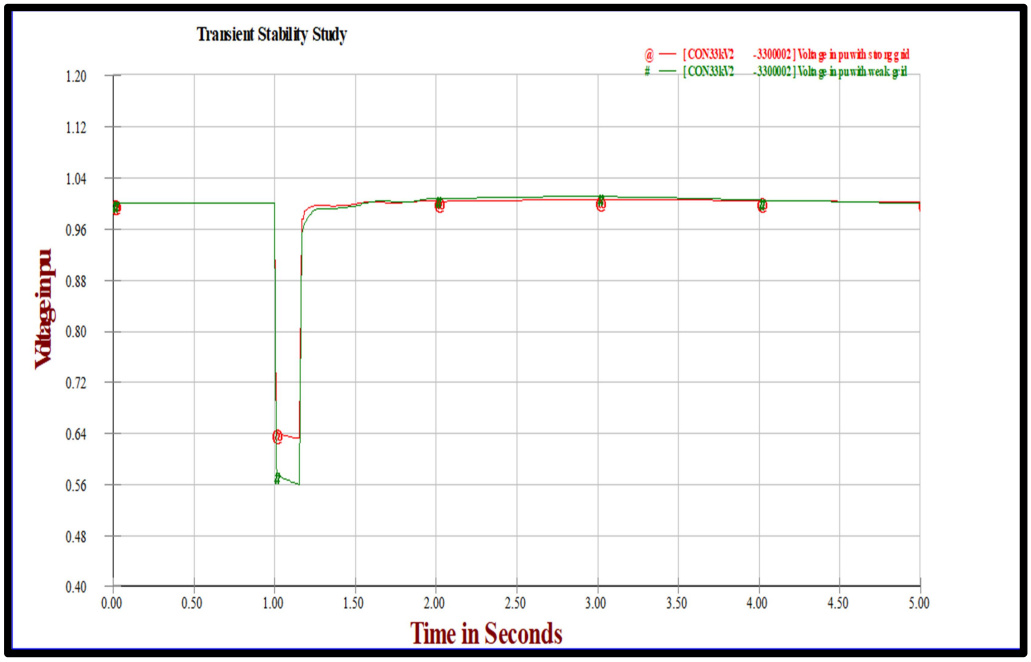

Figure 6-7 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

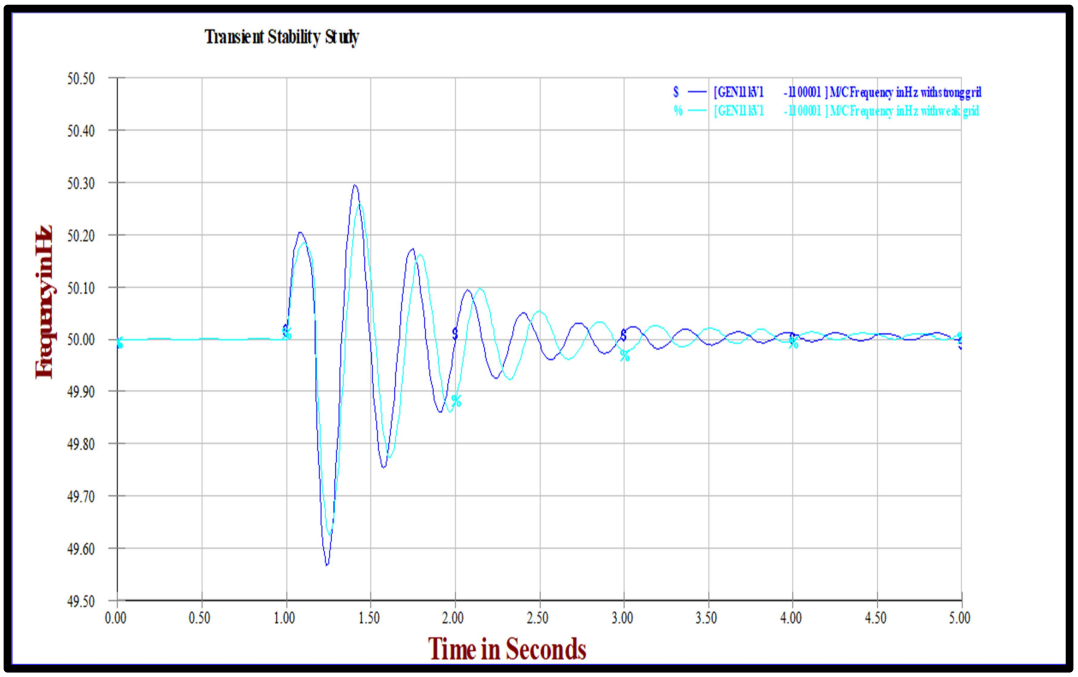

Figure 6-8 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

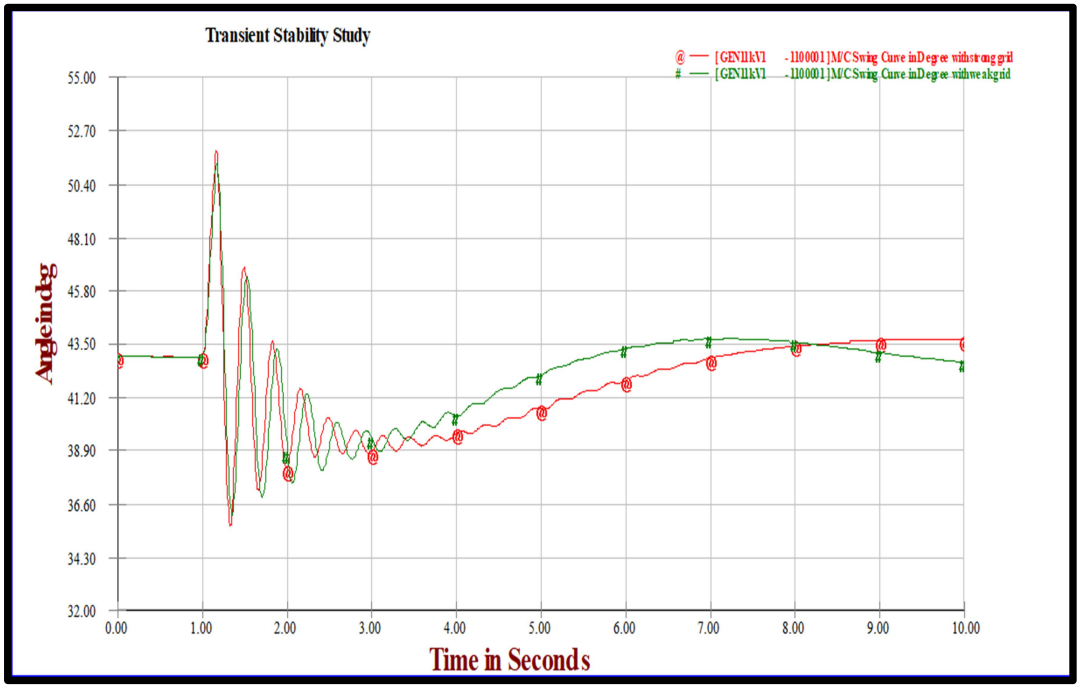

Figure 6-9 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

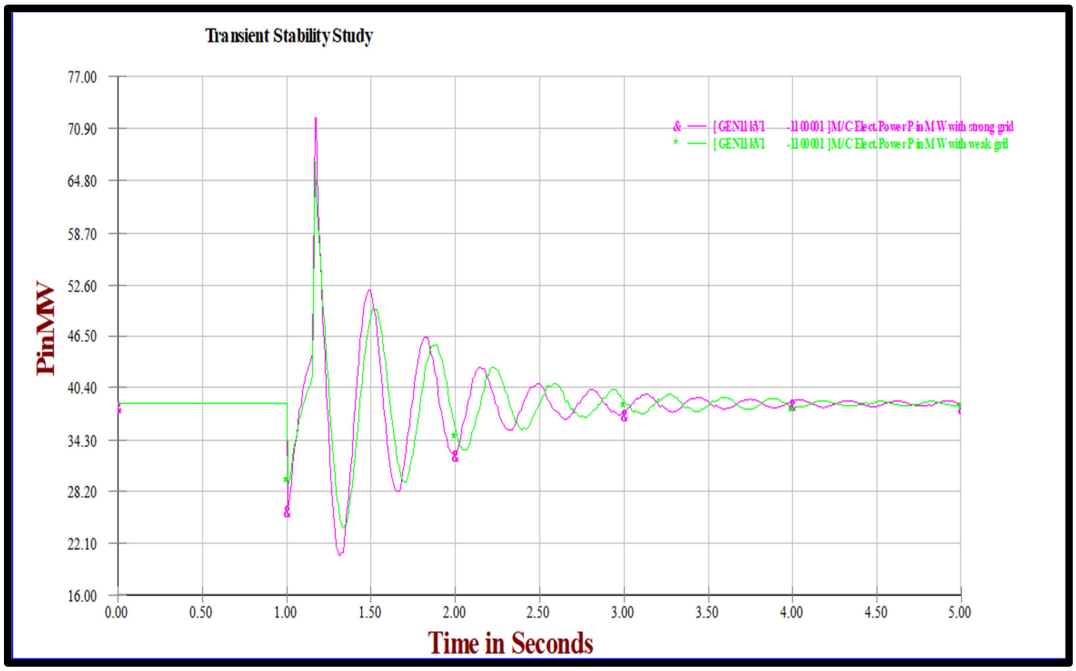

Figure 6-10 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

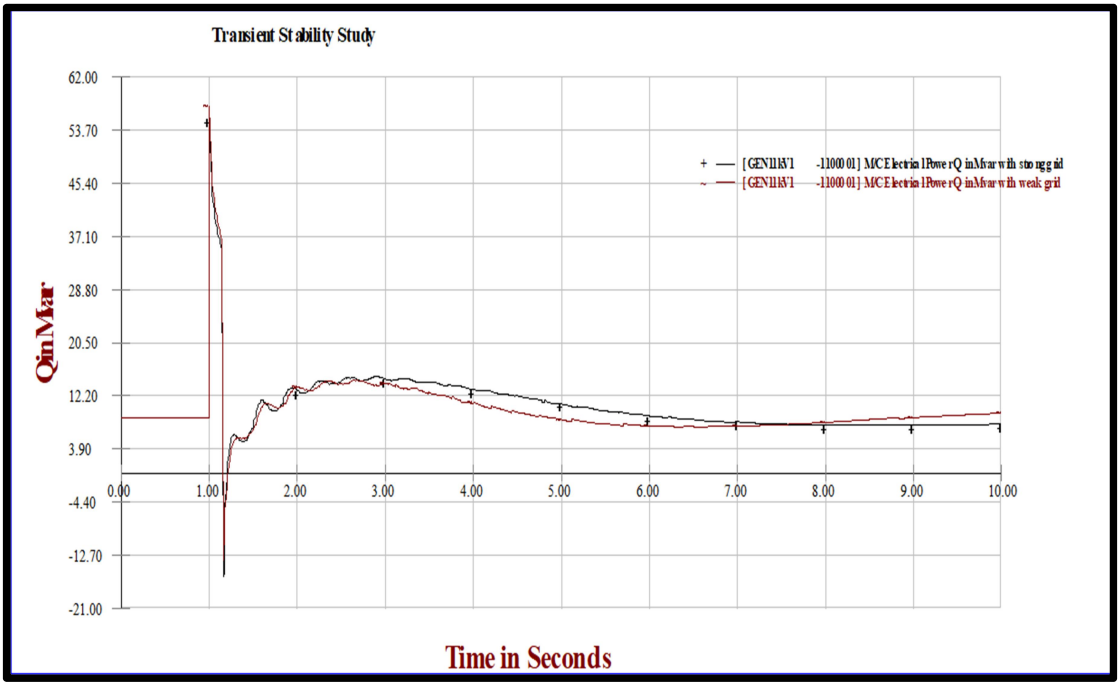

Figure 6-11 Reactive power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

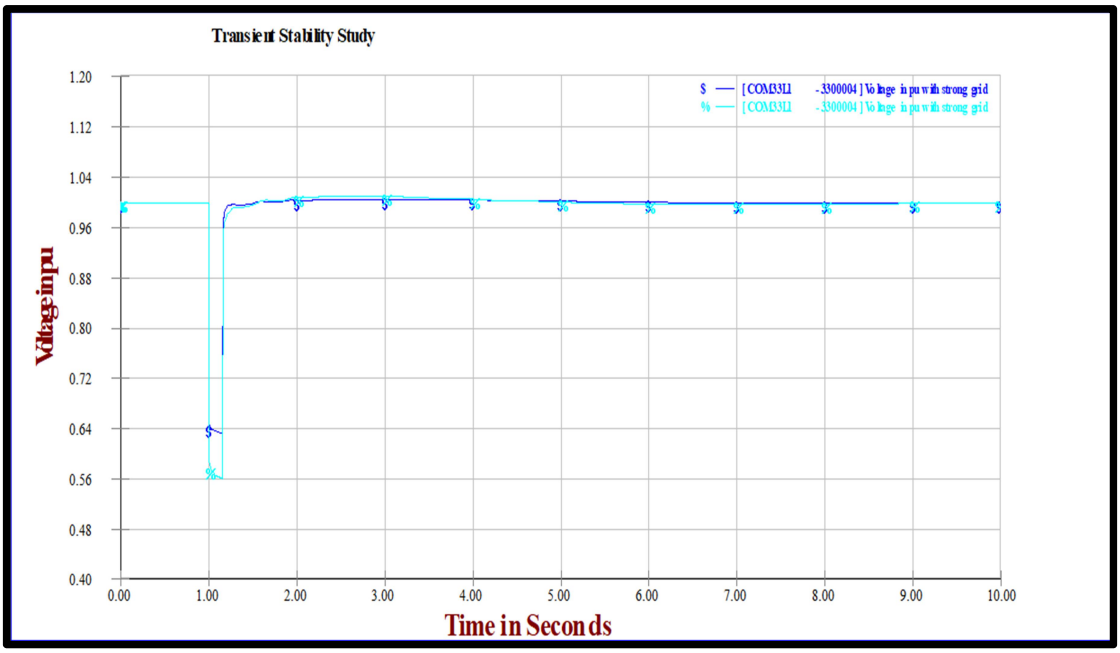

Figure 6-12 Voltage profile of load bus with strong and weak grid connectivity plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Case 3: Highest generating unit outage inside the plant with strong and weak grid connectivity

The simulation results representing the voltage, frequency, and angle plot of load bus are presented in Figure 6-13 to 6-15 for highest generating unit outage inside the plant during floating mode of operation of plant. Active and reactive power of the generating bus with respect to time is presented in Figure 6-16 to 6-17 with strong and weak grid connectivity. The swing curve clearly indicates that the swing angle is comparatively more as compared to the case of a weak grid.

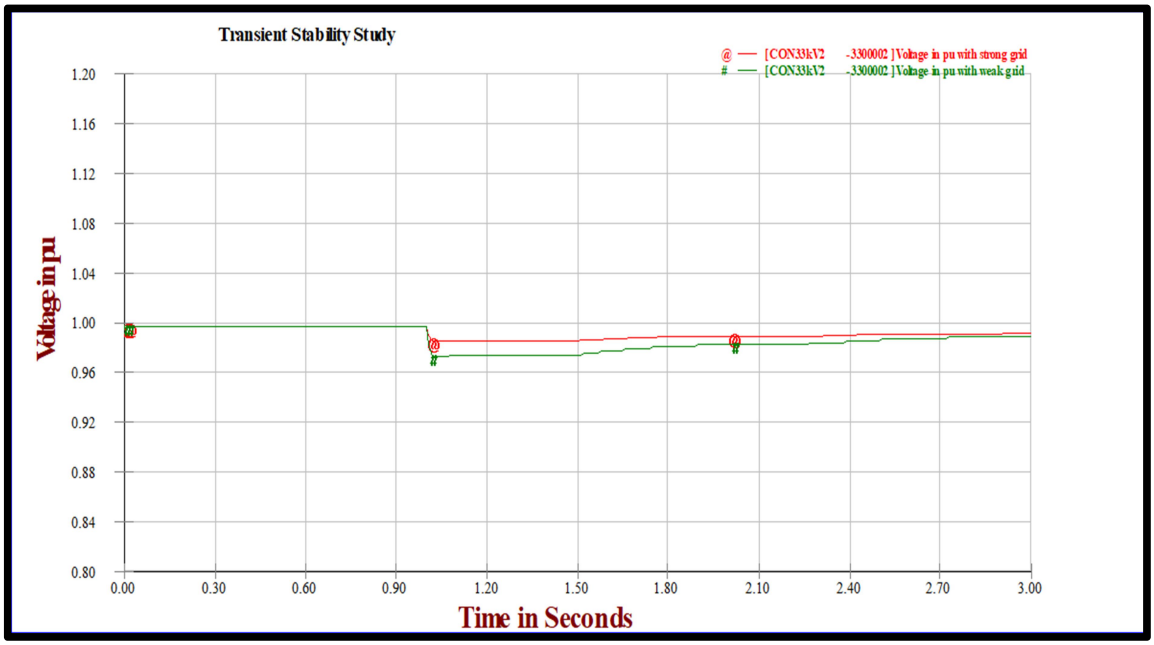

Figure 6-13 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant

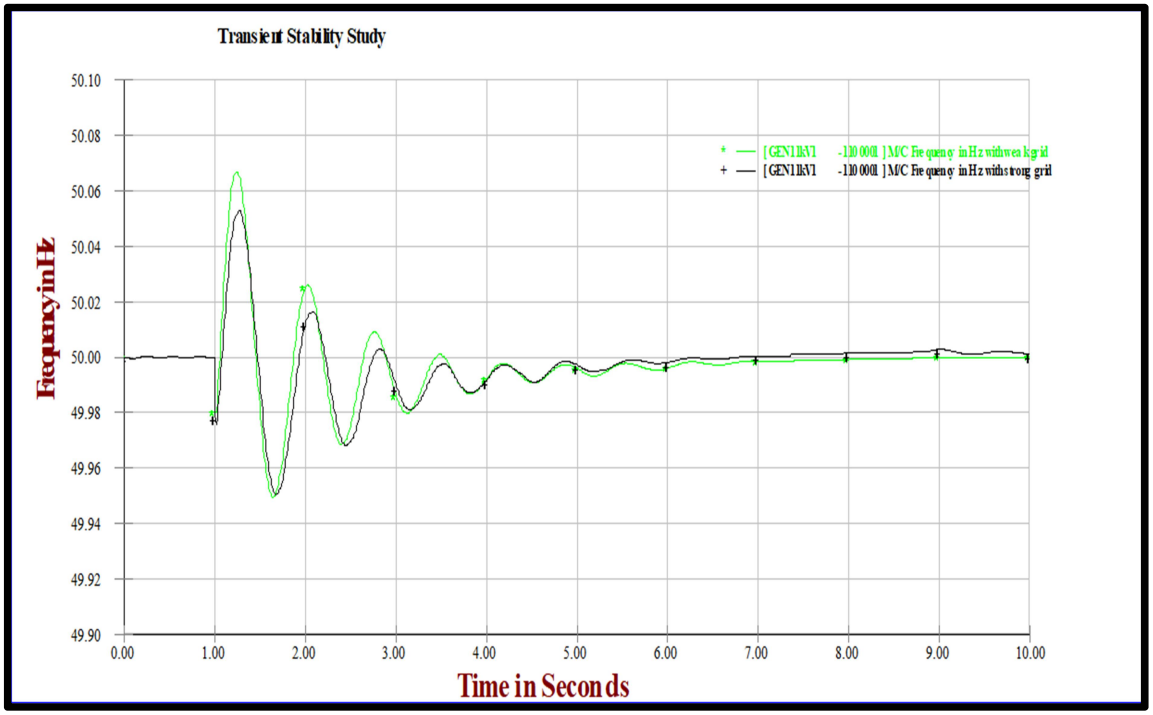

Figure 6-14 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant

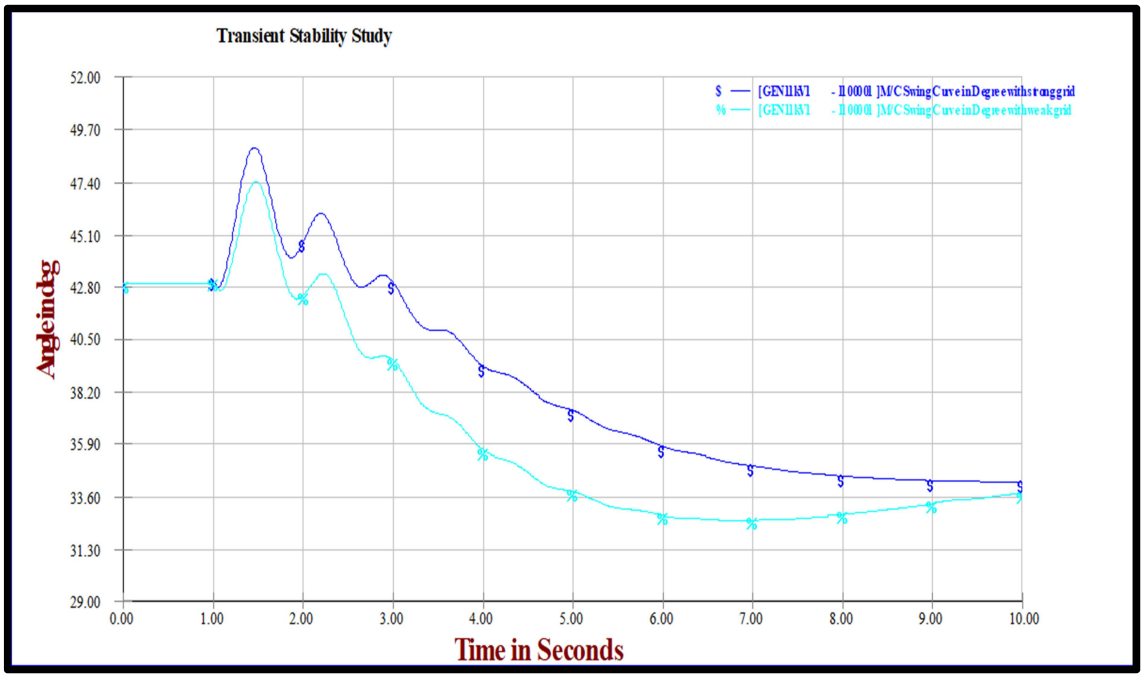

Figure 6-15 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant

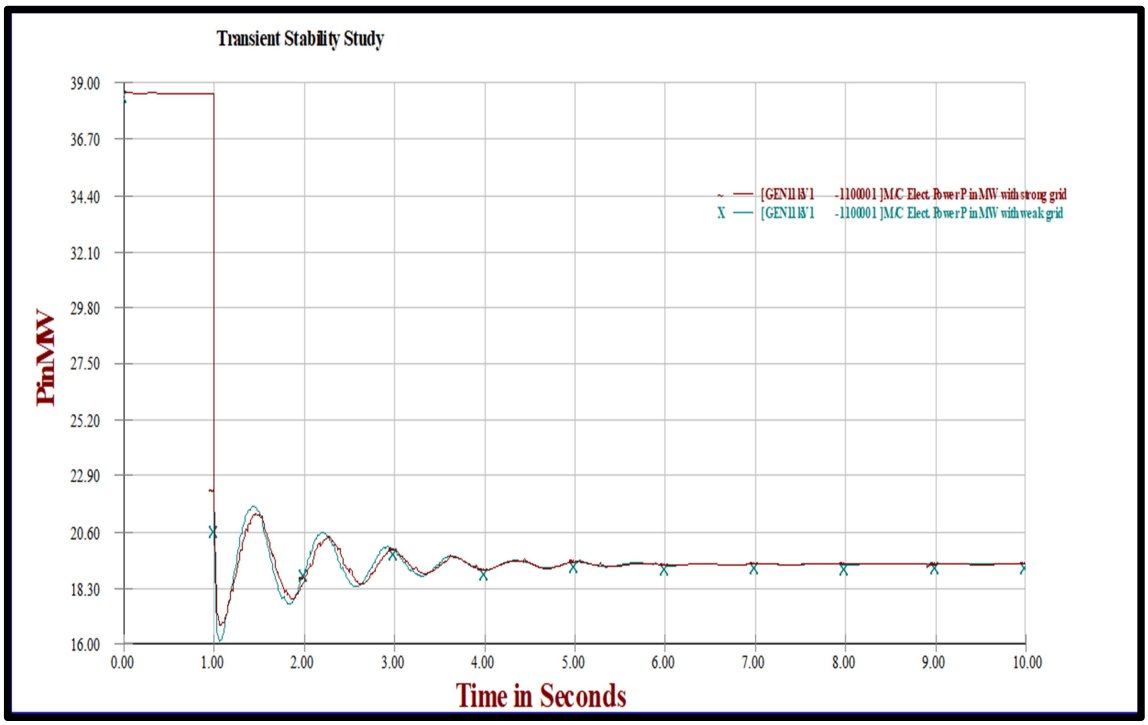

Figure 6-16 Active power plot for highest generating unit outage inside the plant during floating mode of operation of plant

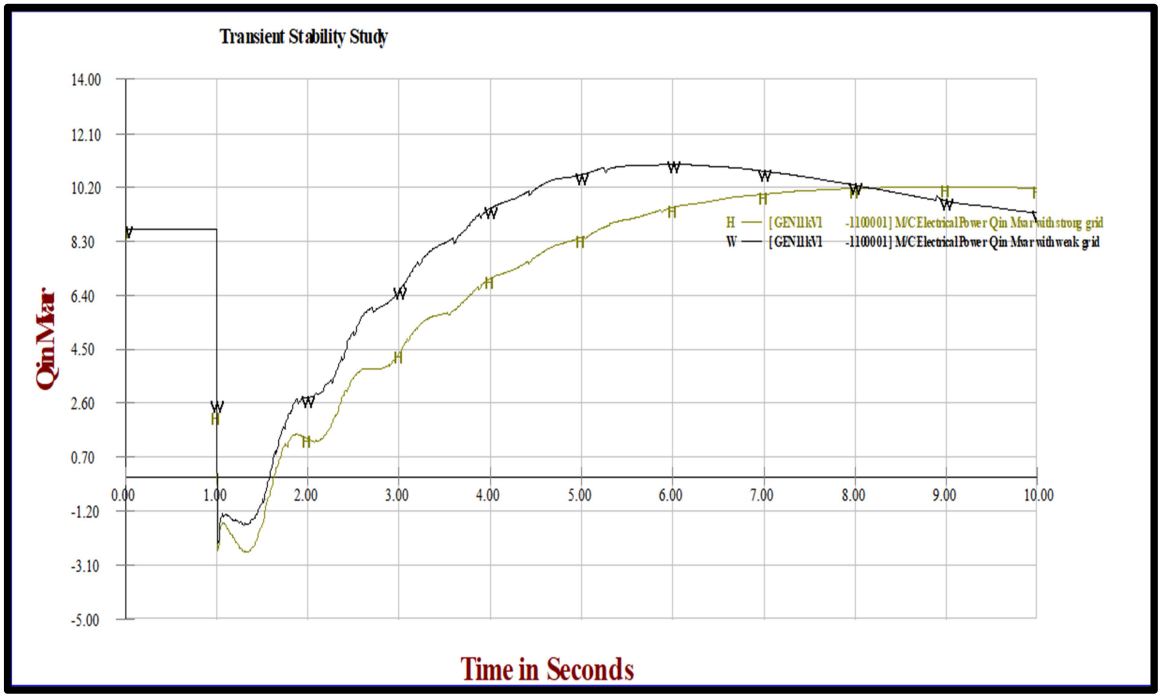

Figure 6-17 Reactive power plot for highest generating unit outage inside the plant during floating mode of operation of plant

Case 4: Scenario with sudden increase in load inside the plant with strong and weak grid connectivity

The simulation results representing the voltage, frequency, and angle plot of load bus are presented in Figure 6-18 to 6-20 for a Scenario with sudden increase in load inside the plant during floating mode of operation of plant. Active and reactive power of the generating bus with respect to time is presented in Figure 6-21 to 6-22 with strong and weak grid connectivity. Voltage profile of the load bus is presented in Figure 6-23. The reactive power response indicate a higher excursion in reactive power in case of a weak grid connectivity as compared to a strong grid connectivity.

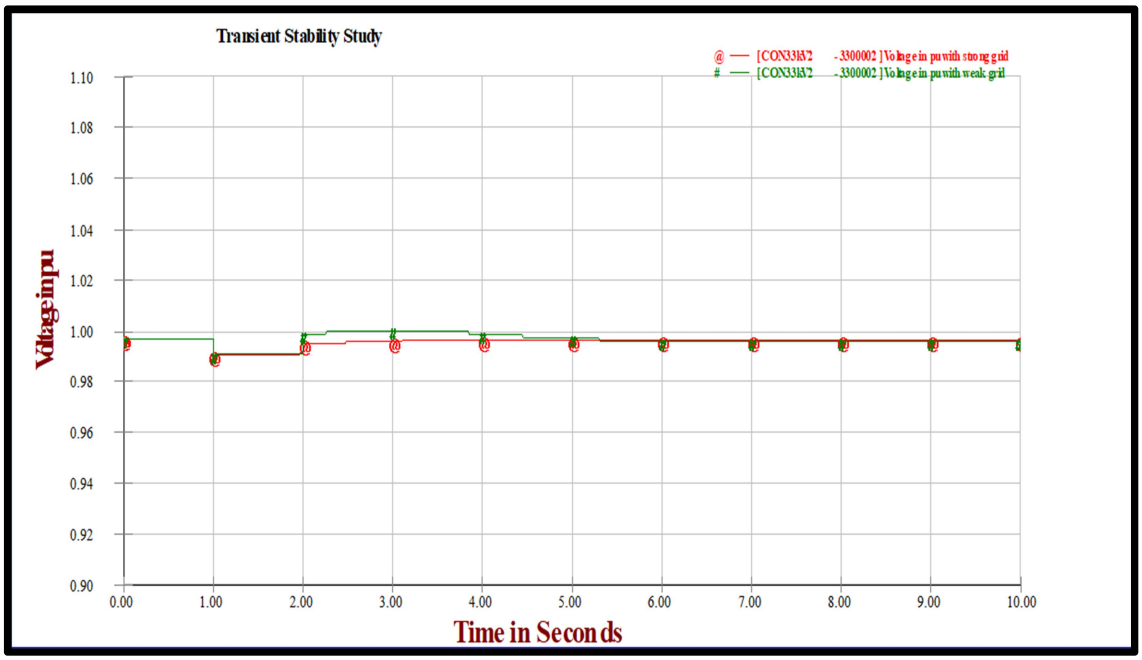

Figure 6-18 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant.

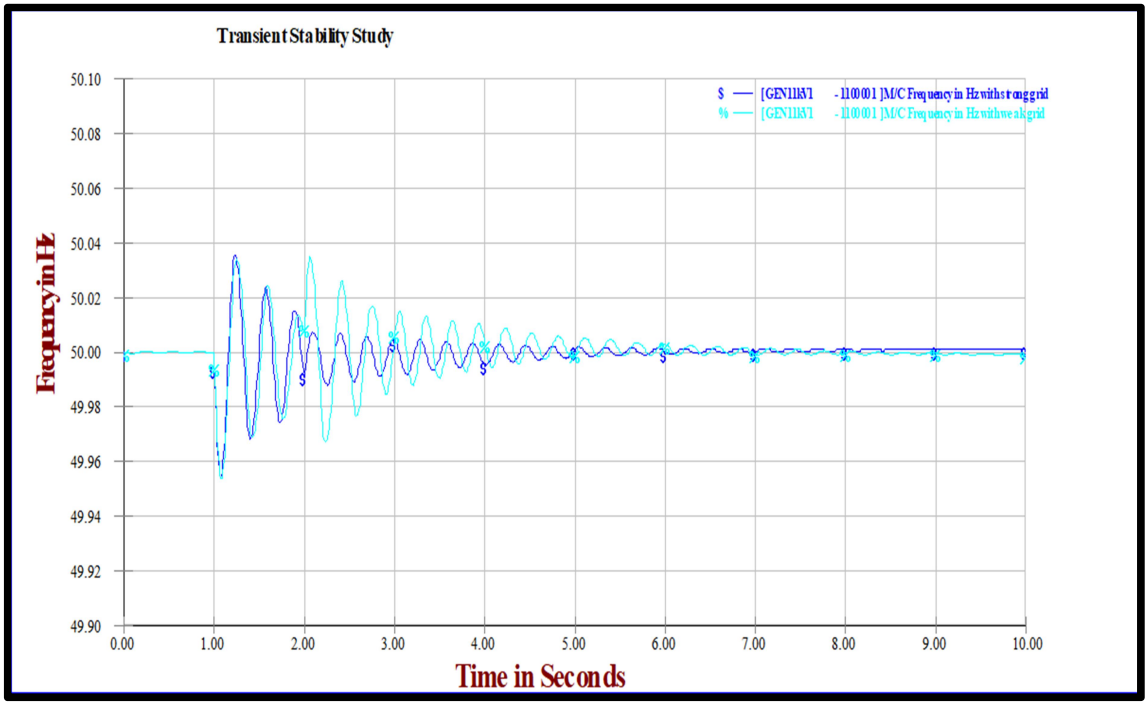

Figure 6-19 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant.

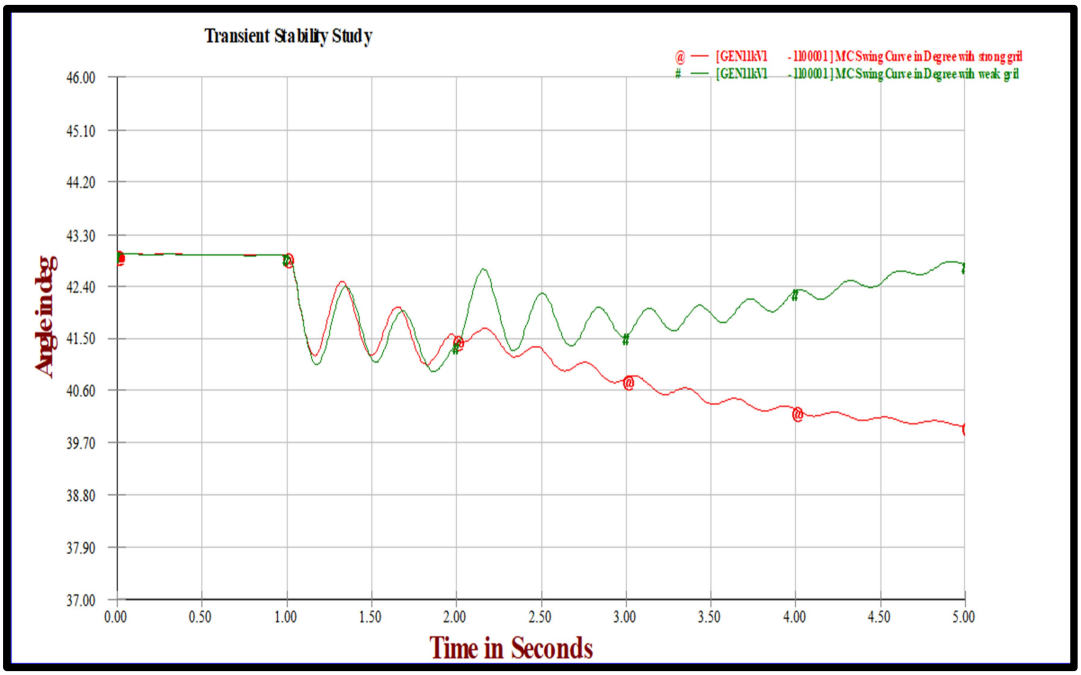

Figure 6-20 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant.

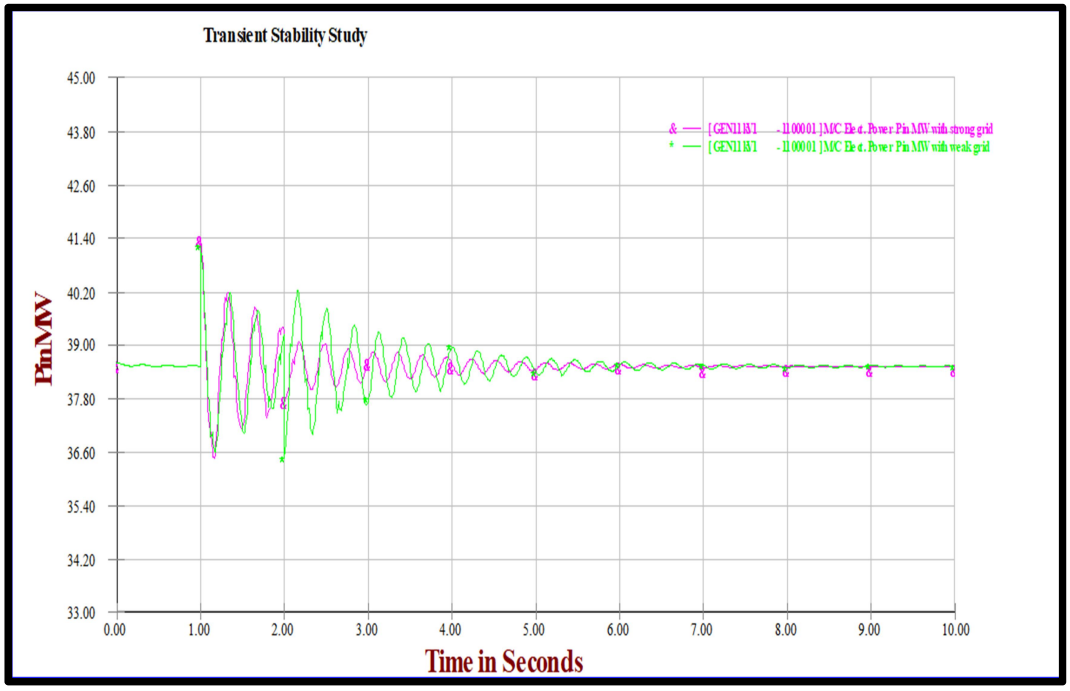

Figure 6-21 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant.

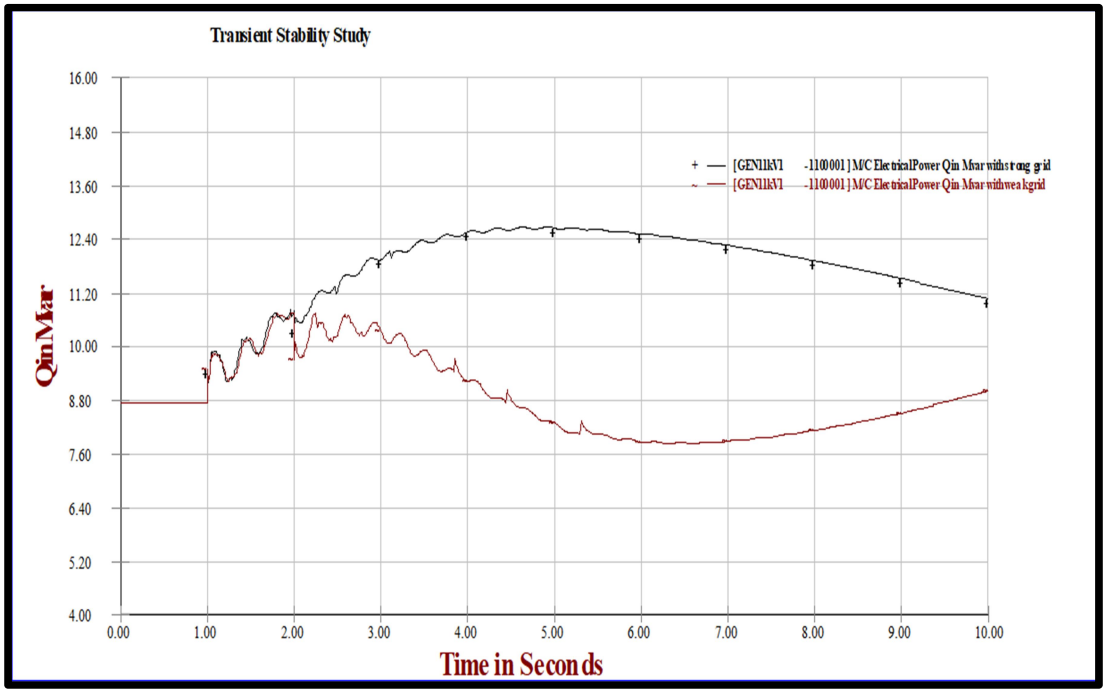

Figure 6-22 Reactive power plot for sudden increase in load inside the plant during floating mode of operation of plant.

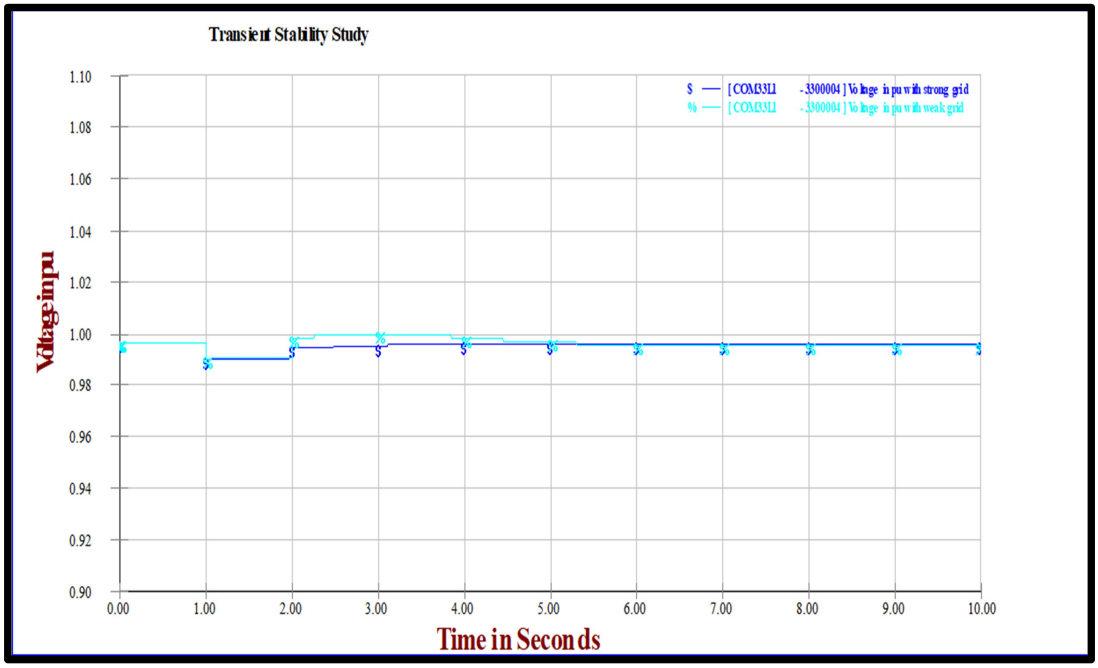

Figure 6-23 Voltage profile of the load bus plot for sudden increase in load inside the plant during floating mode of operation of plant.

Case 5: Scenario with motor starting with strong and weak grid connectivity

In motor starting scenario, as per the graph, it indicates high voltage dips at start and swell after the start of motor in case of a weak grid connectivity. However, the voltage dip is less in case of a strong grid connectivity.

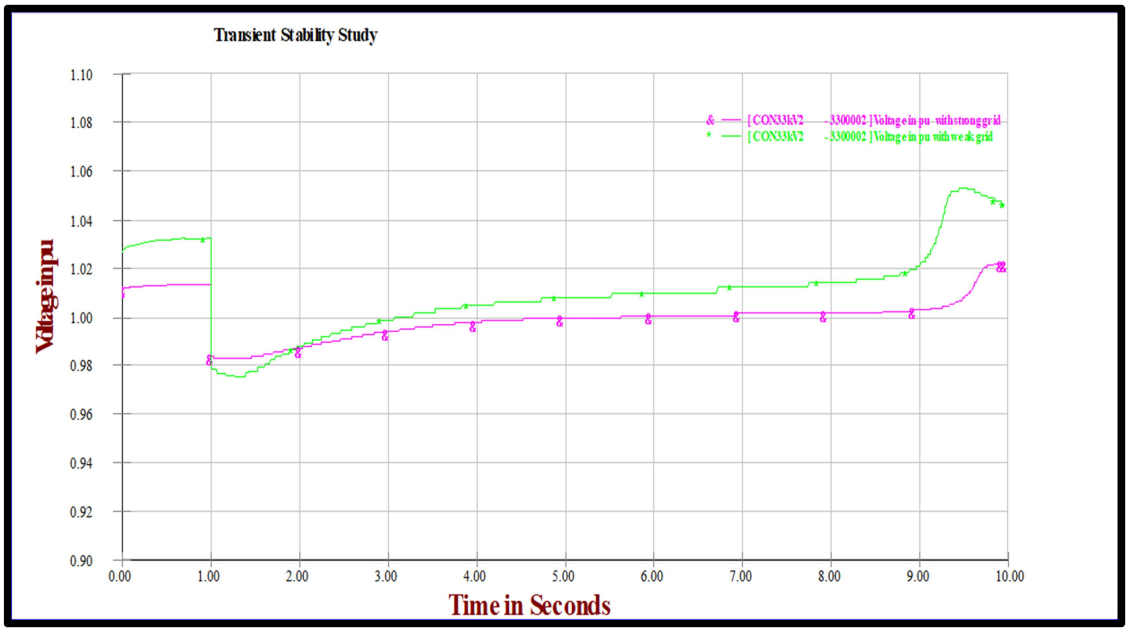

Figure 6-24 Motor terminal Voltage profile with strong and weak grid connectivity during floating mode of operation of plant.

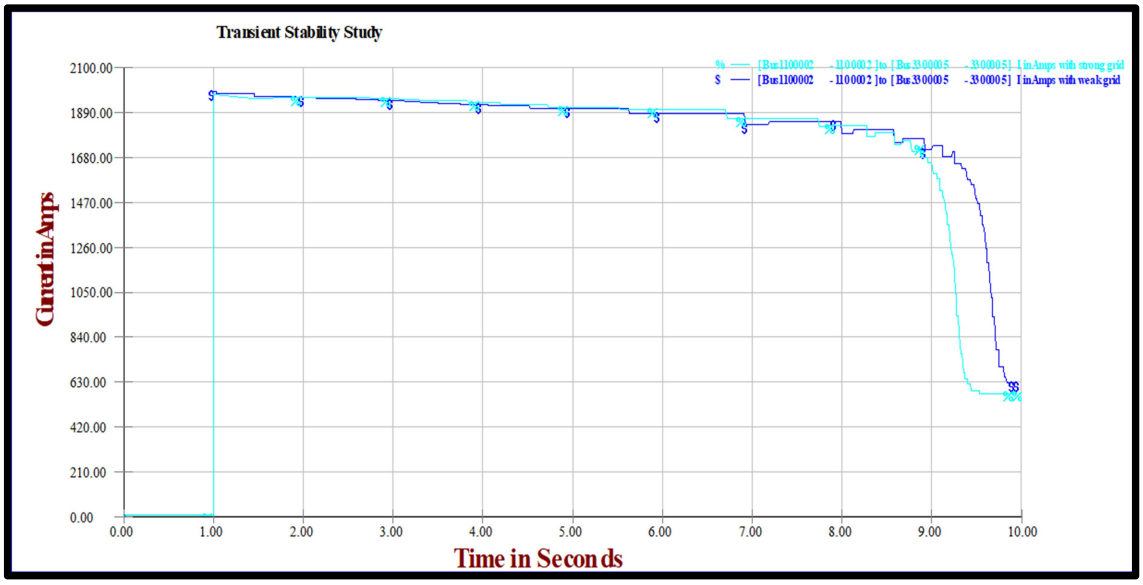

Figure 6-25 Current drawn by the motor with strong and weak grid connectivity during floating mode of operation of plant.

Case 6: Scenario with cyclic loading with strong and weak grid connectivity

In case of cyclic loads with strong and weak grid connectivity, the graph indicates the dips are higher in case of weak grid as compared to the strong grid. Similarly, the relative angle swings are higher in weak grid connectivity as compared to the strong grid connectivity.

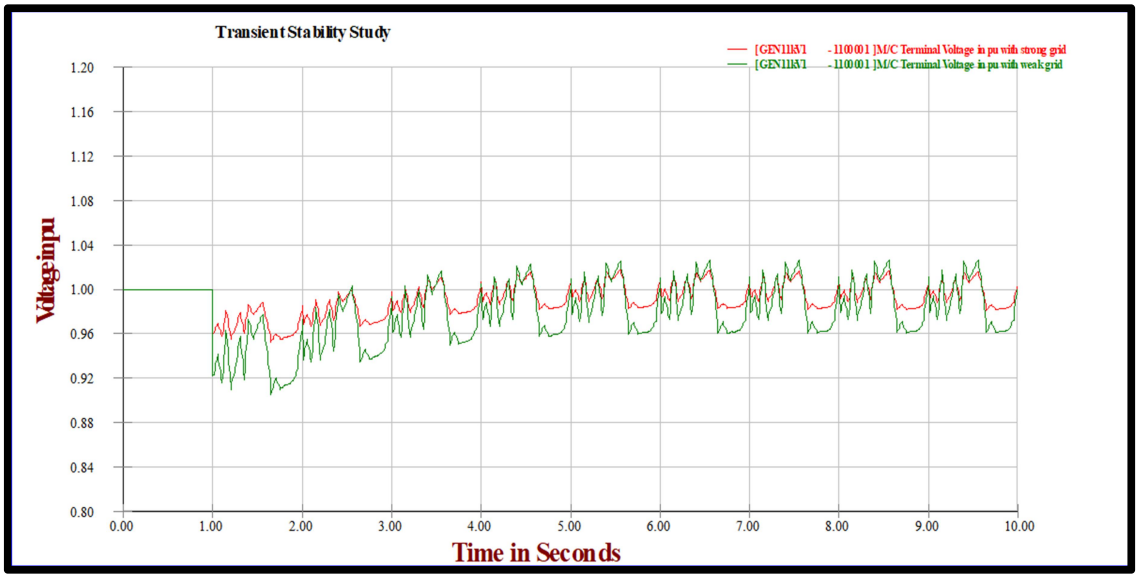

Figure 6-26 Voltage profile of cyclic load bus with strong and weak grid connectivity during floating mode of operation of plant.

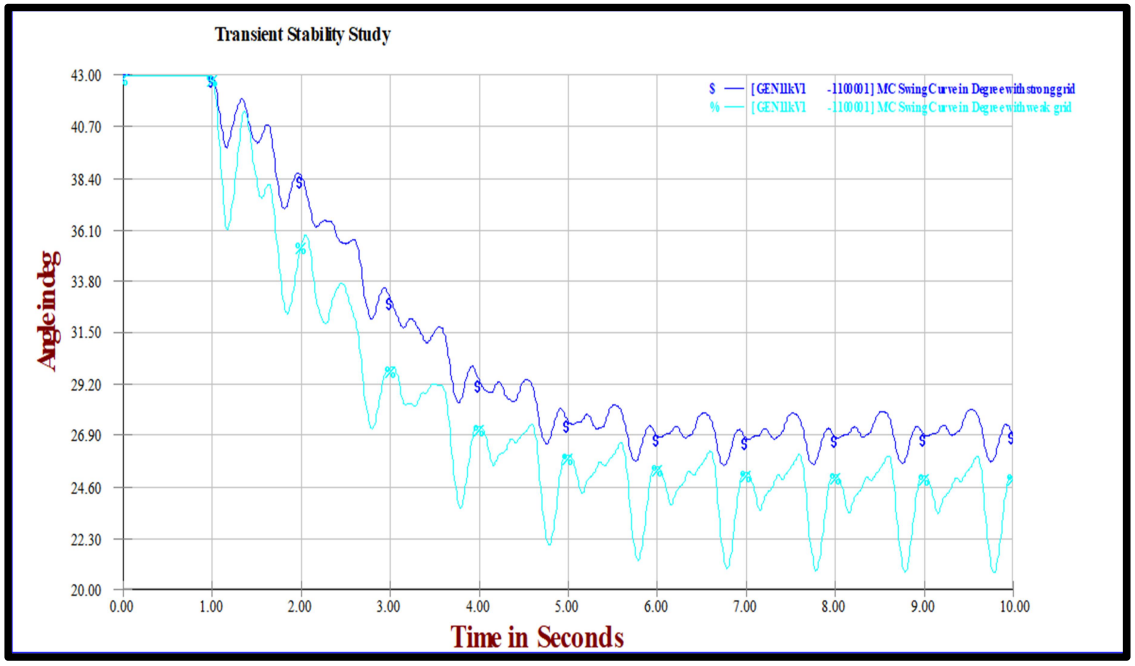

Figure 6-27 Swing curve of generating bus with strong and weak grid connectivity during floating mode of operation of plant.

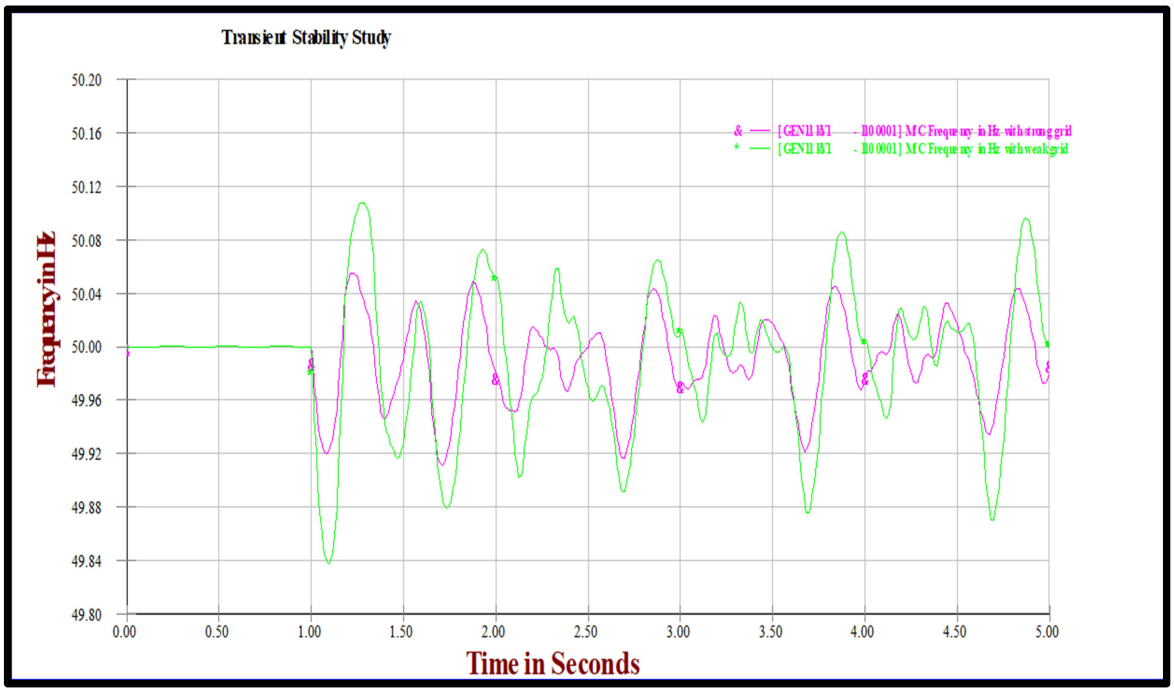

Figure 6-28 Frequency profile of generating bus with strong and weak grid connectivity during floating mode of operation of plant.

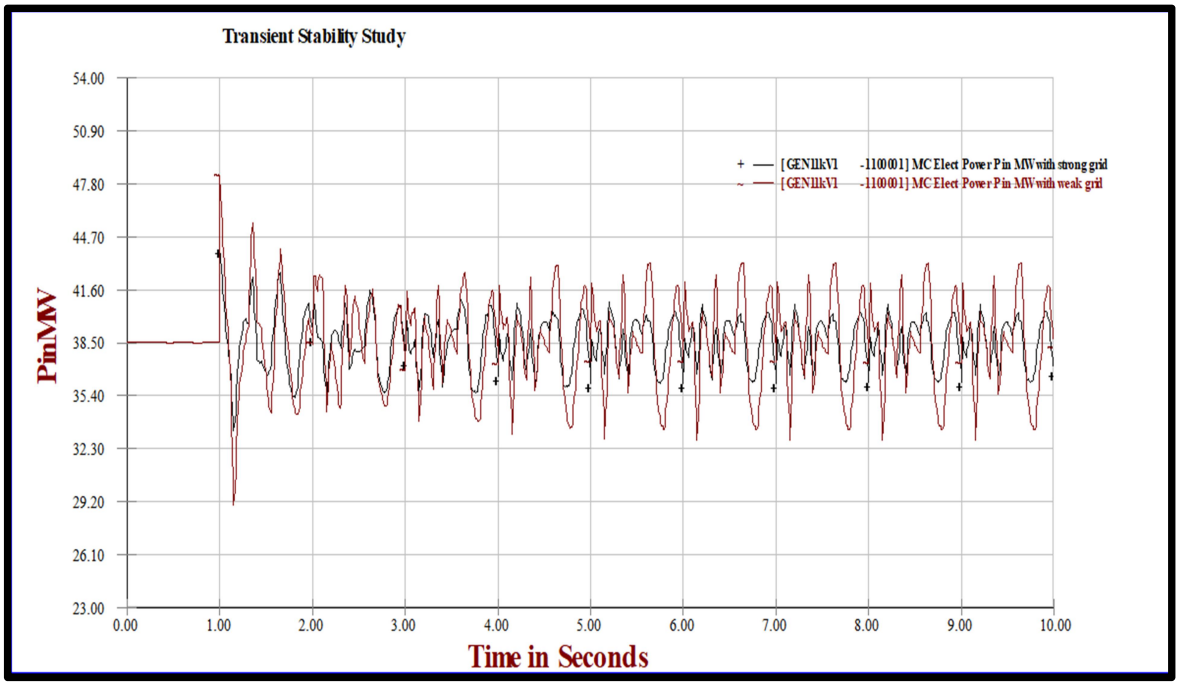

Figure 6-29 Active power drawn from the generating bus during floating mode of operation of plant.

6.5. Transient Stability study for Aditya Alumina

Aditya Alumina is a Captive generating plant in Jharsuguda area having 6x150MW generation capacity which is primarily connected to Budhipadar 220kV Bus and Lapanga 400kV Bus of OPTCL. In the stability study of Aditya Alumina plant, three important scenarios are simulated using in MiPSCT. In the first scenario, the Plant is operating in floating mode while assuming the full load operation inside the plant. Similarly, the second and third scenario is simulated by considering the contracted demand of the plant operation. In each of the three scenarios, four different disturbance conditions are simulated to study the transient behaviour of CGP generators.

Floating Mode

Case 7: Three Phase to ground fault at the power evacuation bus inside the AAL plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-30 to 6-31 for a three phase to ground fault at the power evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

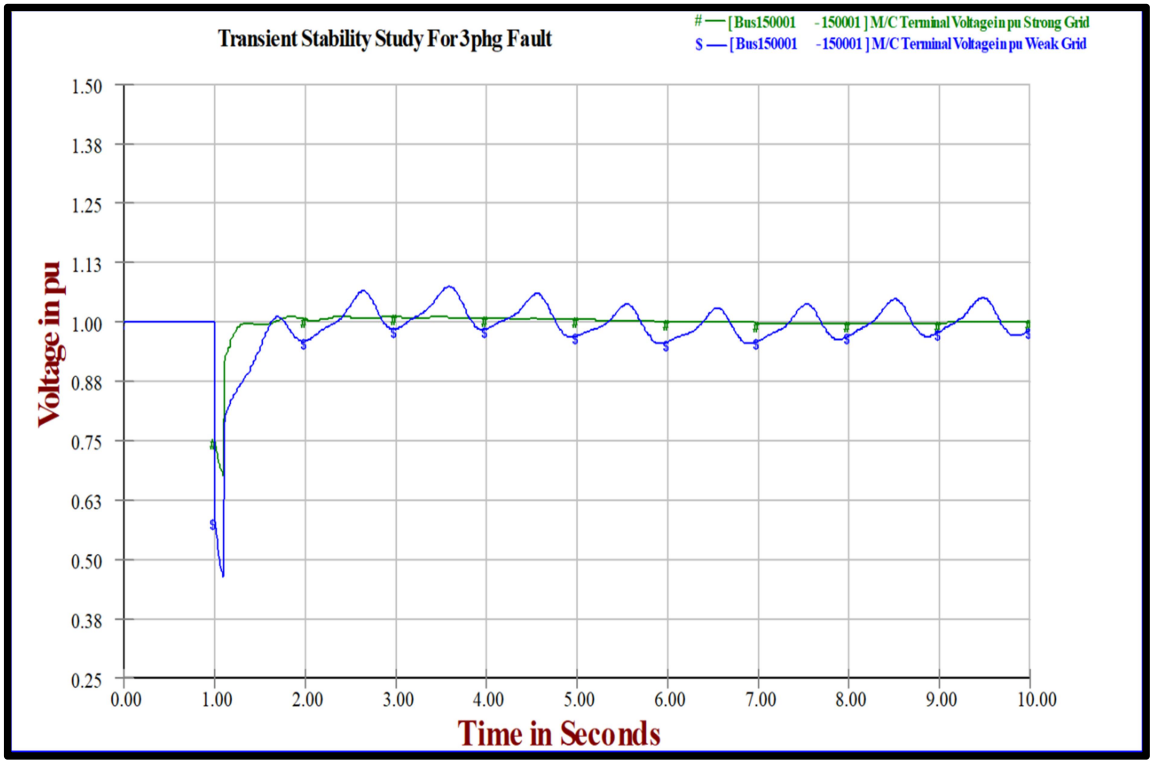

Figure 6-30 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

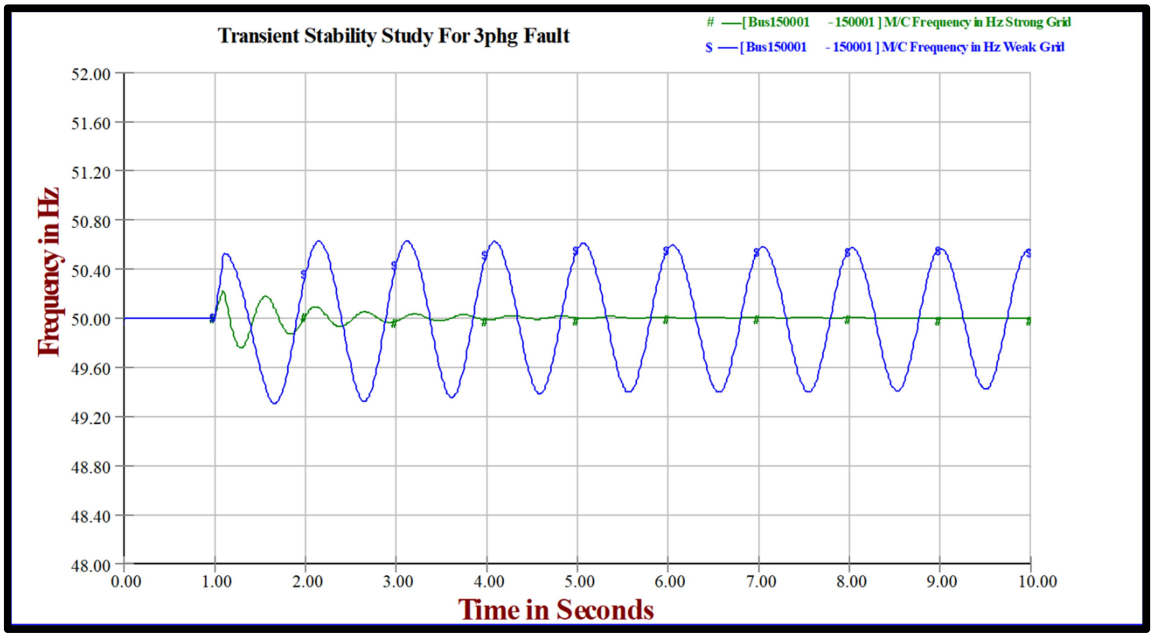

Figure 6-31 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-32 and Figure 6-33.

The frequency plot clearly distinguishes a distinction between the post fault frequency response in the power evacuation bus with strong and weak grid connectivity. The graph also indicates a possible low damping with oscillations in case of weak grid connectivity.

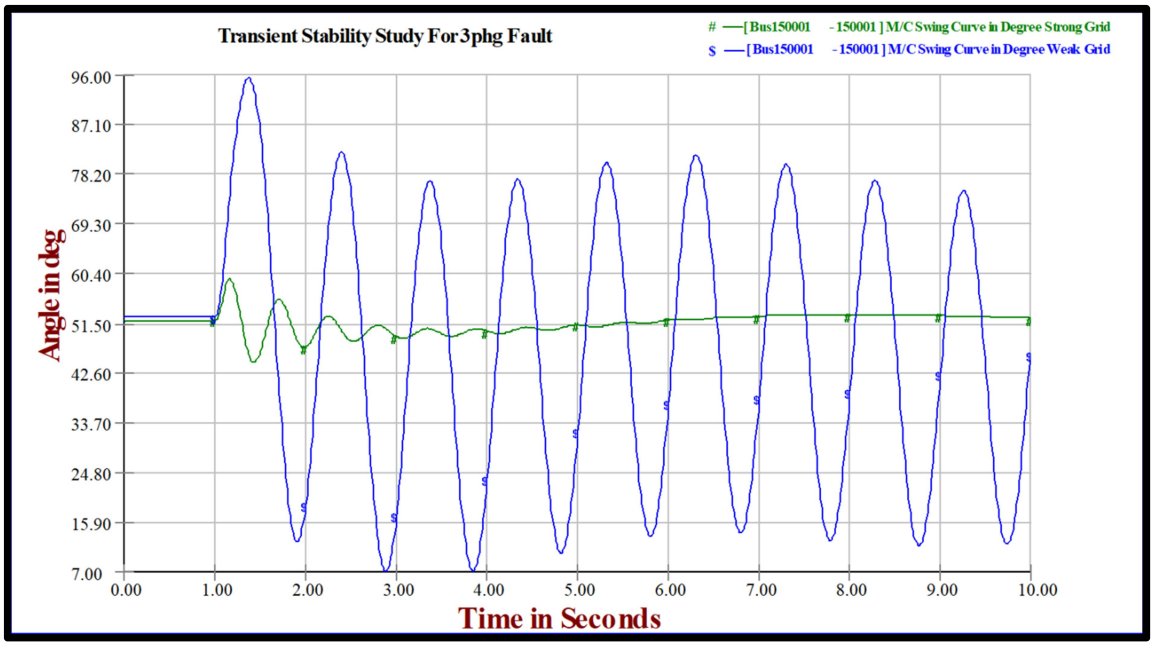

Figure 6-32 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

The active power response indicates that the CGP may lead to tripping in case of a weak grid connectivity due to high fluctuations in the load.

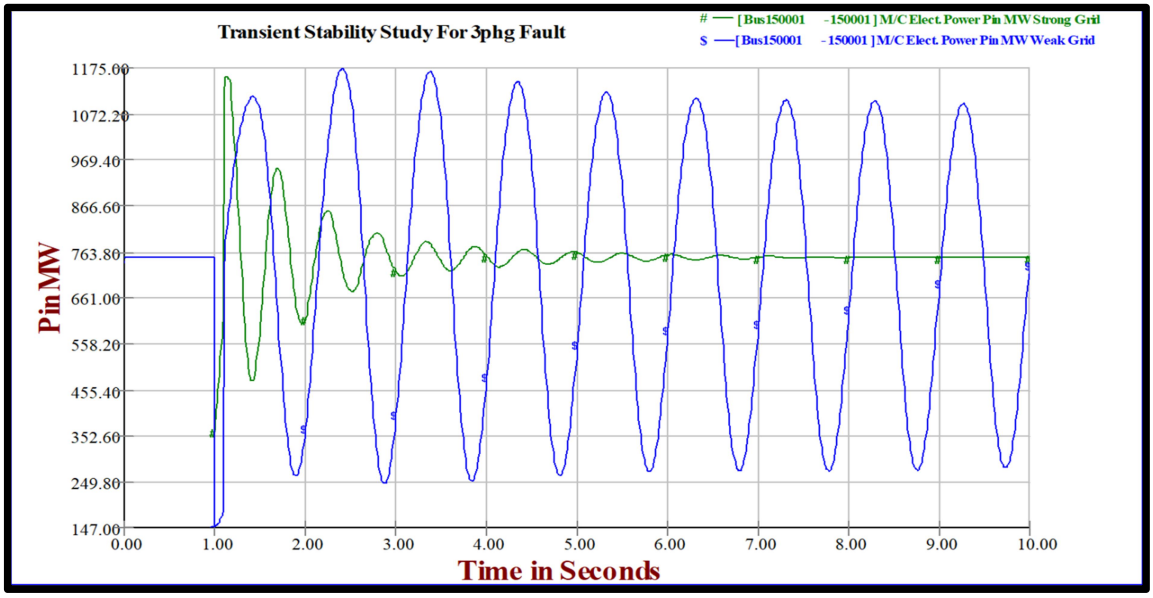

Figure 6-33 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Case 8: Single Line to ground fault at the power evacuation bus inside the AAL plant for duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-34 to 6-35 for a Single line to ground fault at the power evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation. The frequency responses indicate a poor stabilization in case of weak grid connectivity.

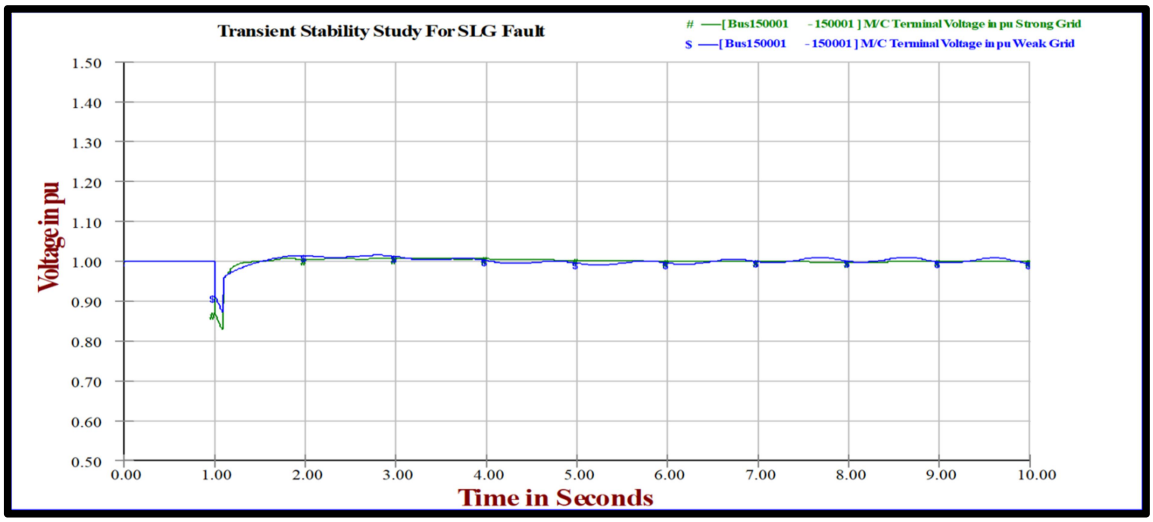

Figure 6-34 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

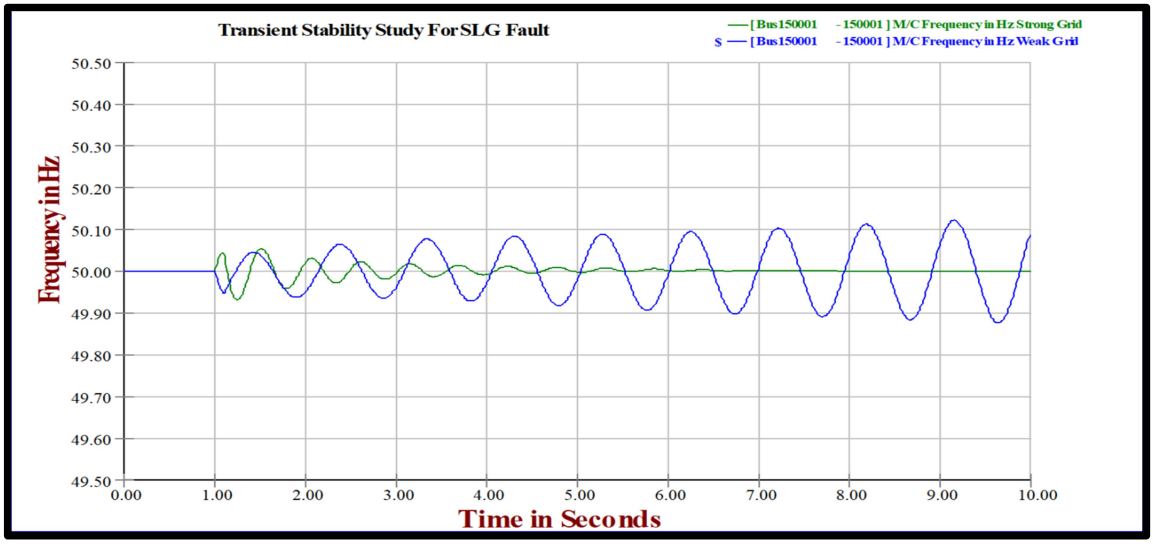

Figure 6-35 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-36 and Figure 6-37. The active power response in weak grid indicates a poor damping which may lead to tripping.

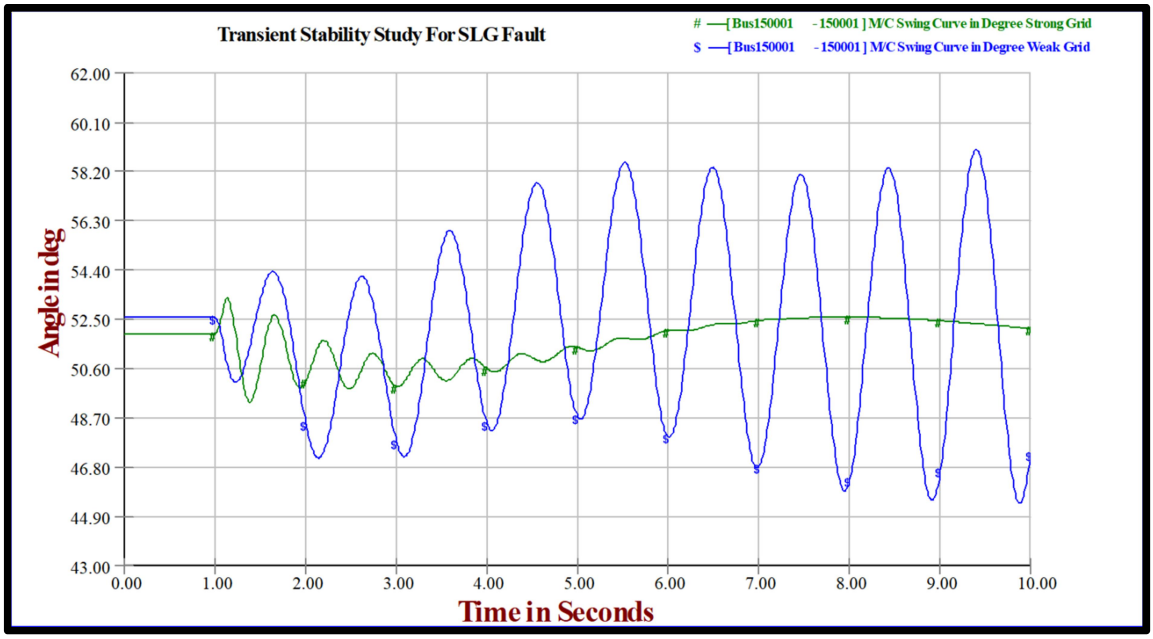

Figure 6-36 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

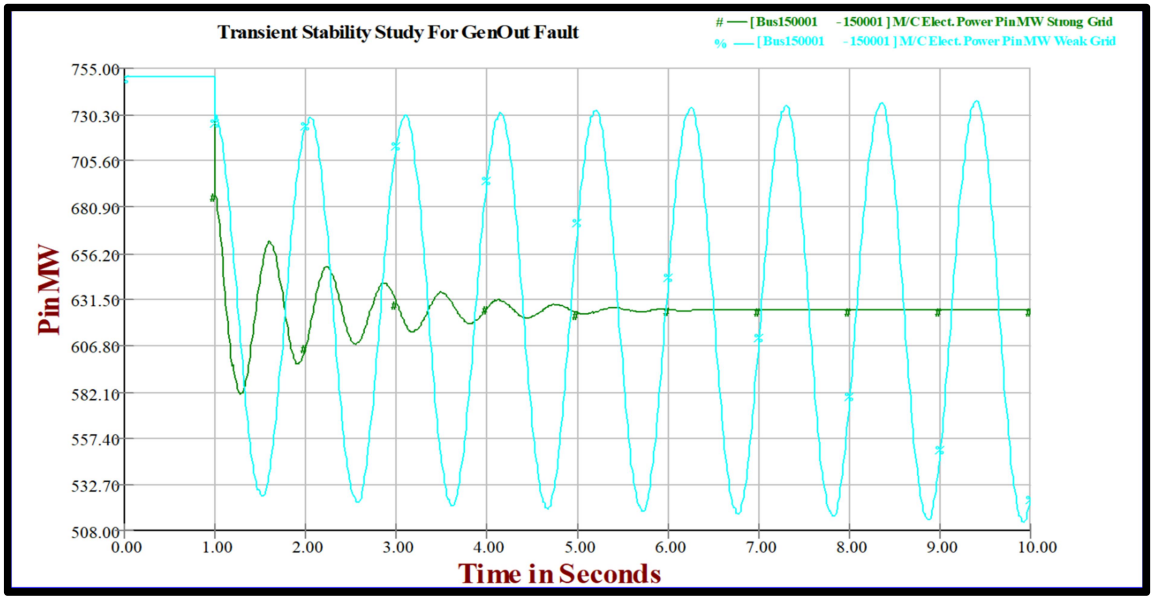

Figure 6-37 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Case 9: Highest Generating unit Outage in the AAL plant for duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-38 to 6-39 for a disturbance initiated due to generator outage during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

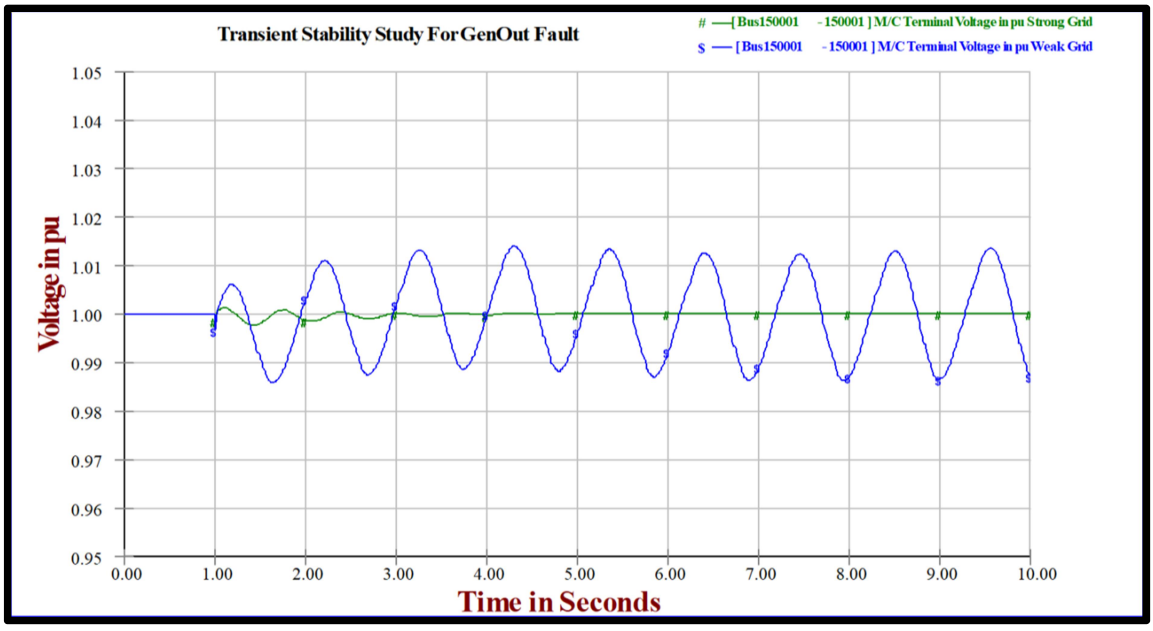

Figure 6-38 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant

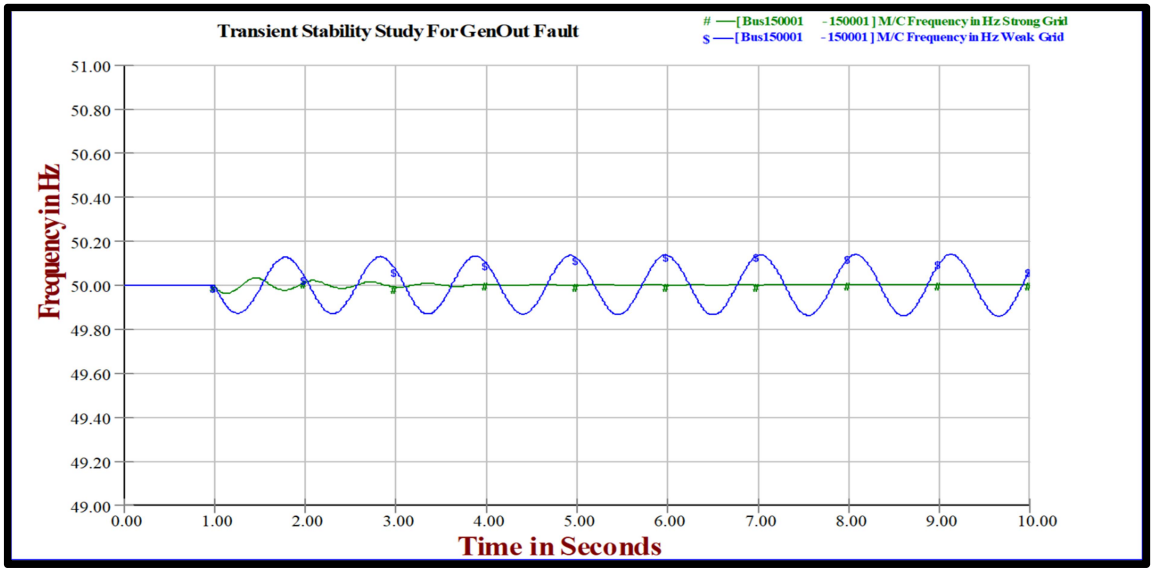

Figure 6-39 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during floating mode of operation of plant is presented in Figure 6-40 and Figure 6-41.

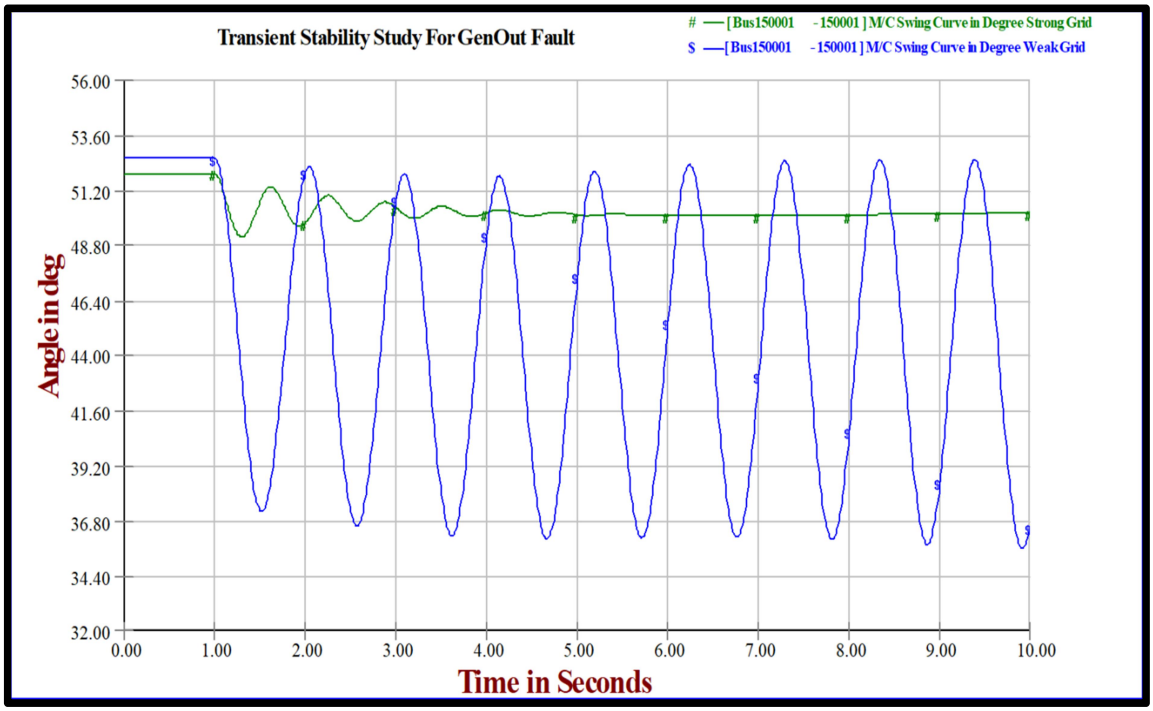

Figure 6-40 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant

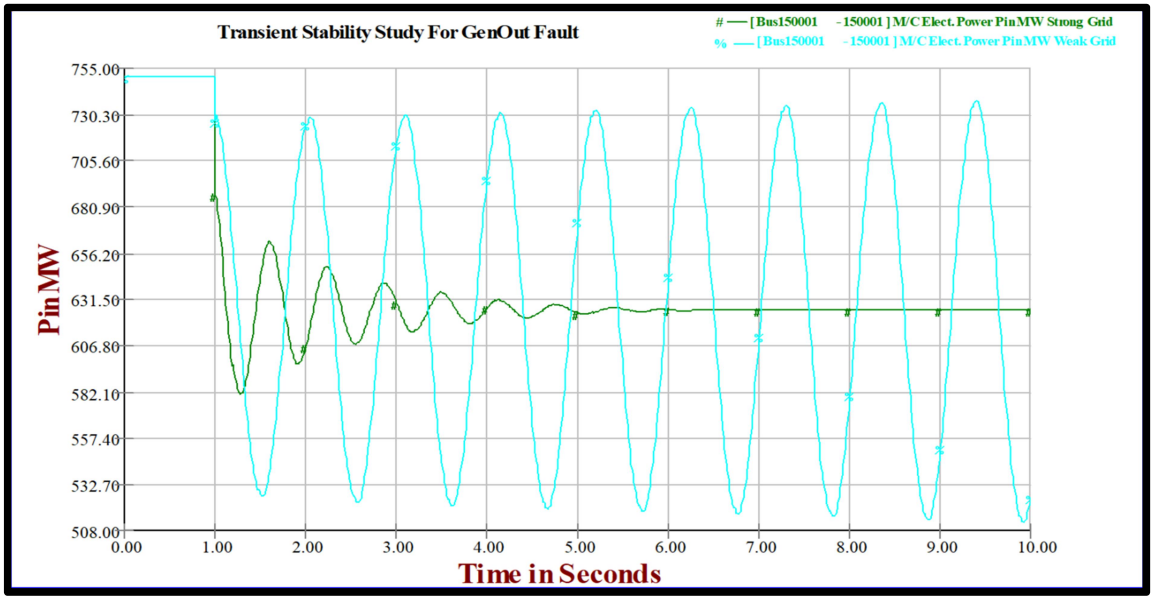

Figure 6-41 Active power for generating bus plot for highest generating unit outage inside the plant during floating mode of operation of plant

Case 10: Load throw off at the AAL plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-42 to 6-43 for a disturbance initiated due to sudden load throw off during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation. According to the voltage response graph, higher dip may lead to tripping of plant generations.

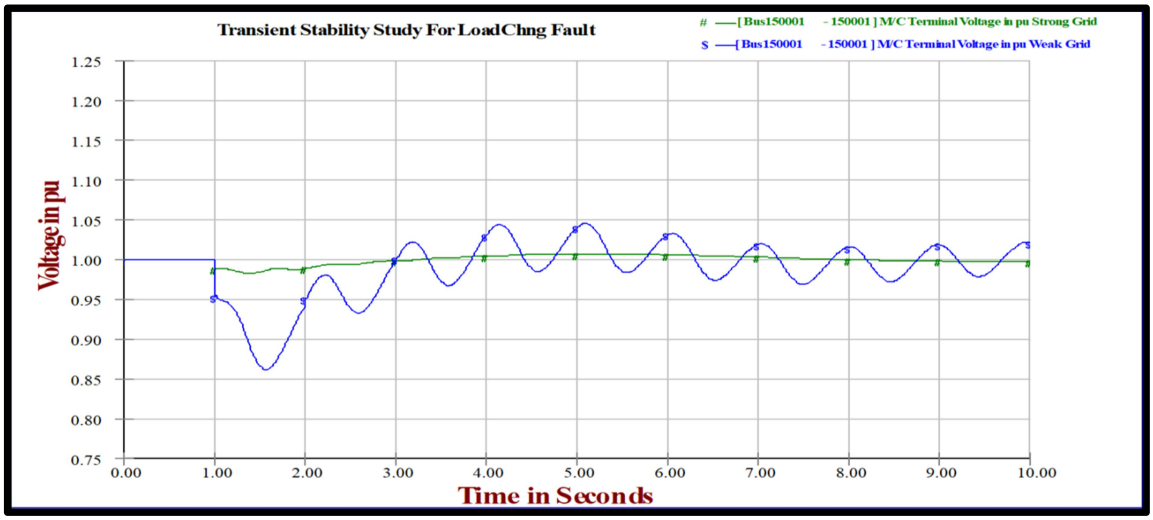

Figure 6-42 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant.

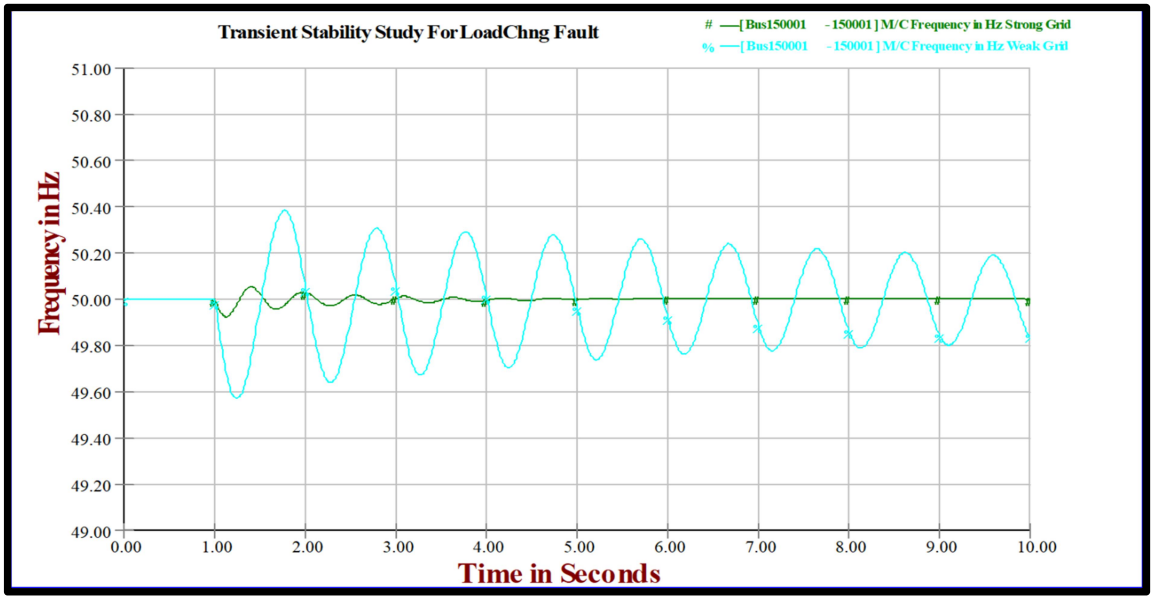

Figure 6-43 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant.

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during floating mode of plant operation of plant is presented in Figure 6-44 and Figure 6-45.

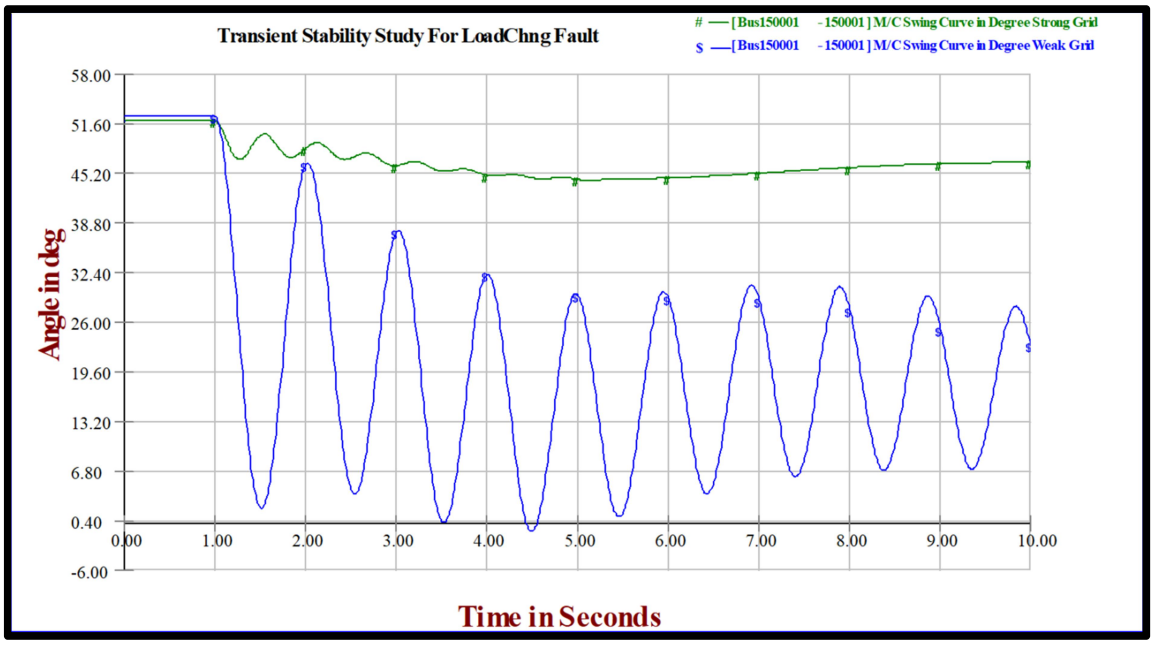

Figure 6-44 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant

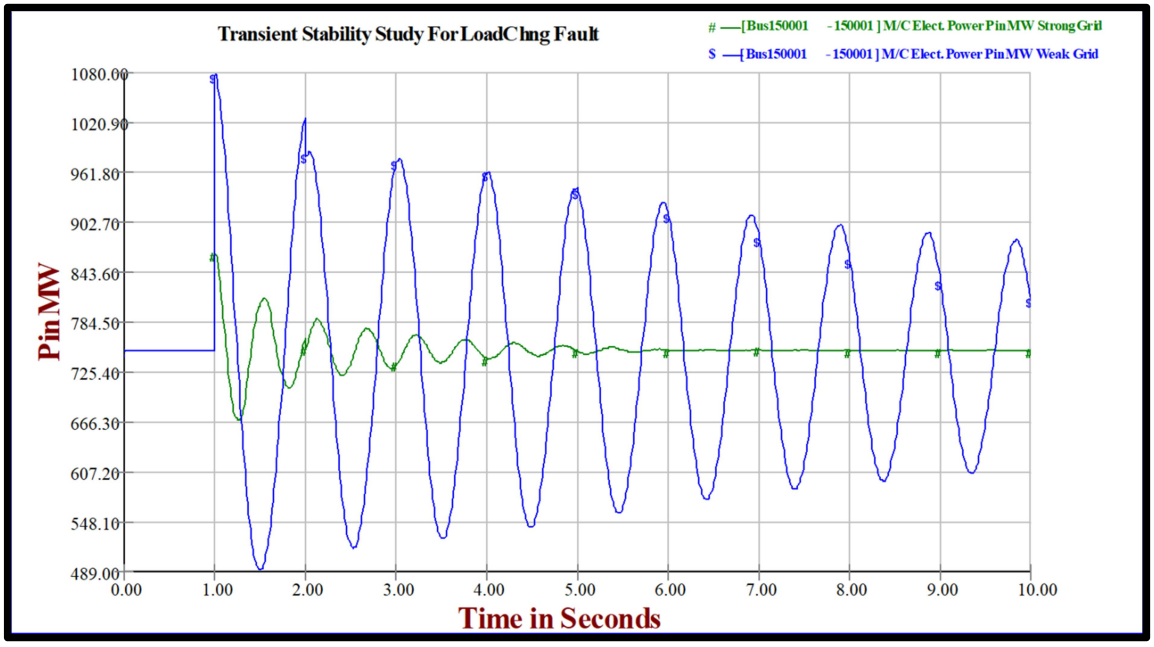

Figure 6-45 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant

Import mode

Case 11: Three Phase to ground fault at the AAL plant for a duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-46 to 6-47 for a three phase to ground fault at the power evacuation bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

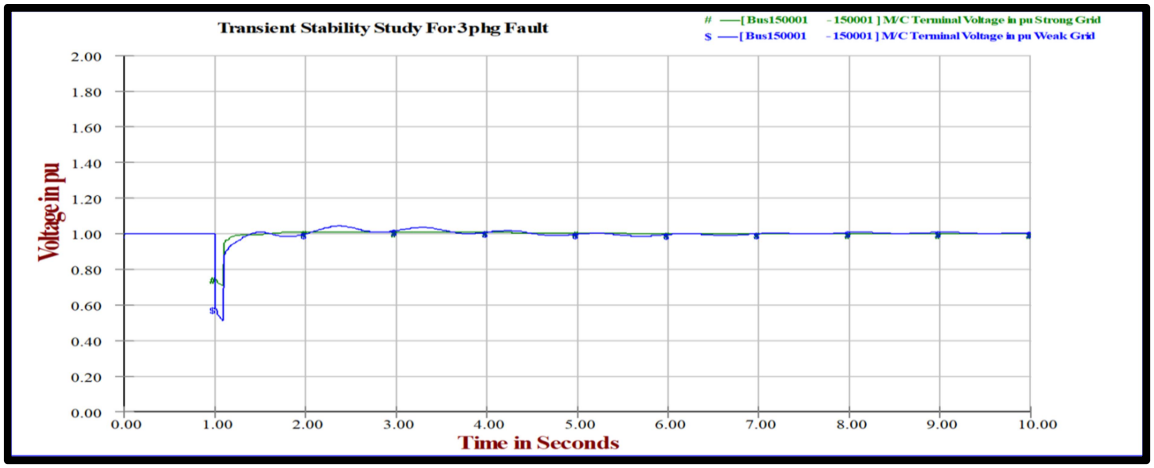

Figure 6-46 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

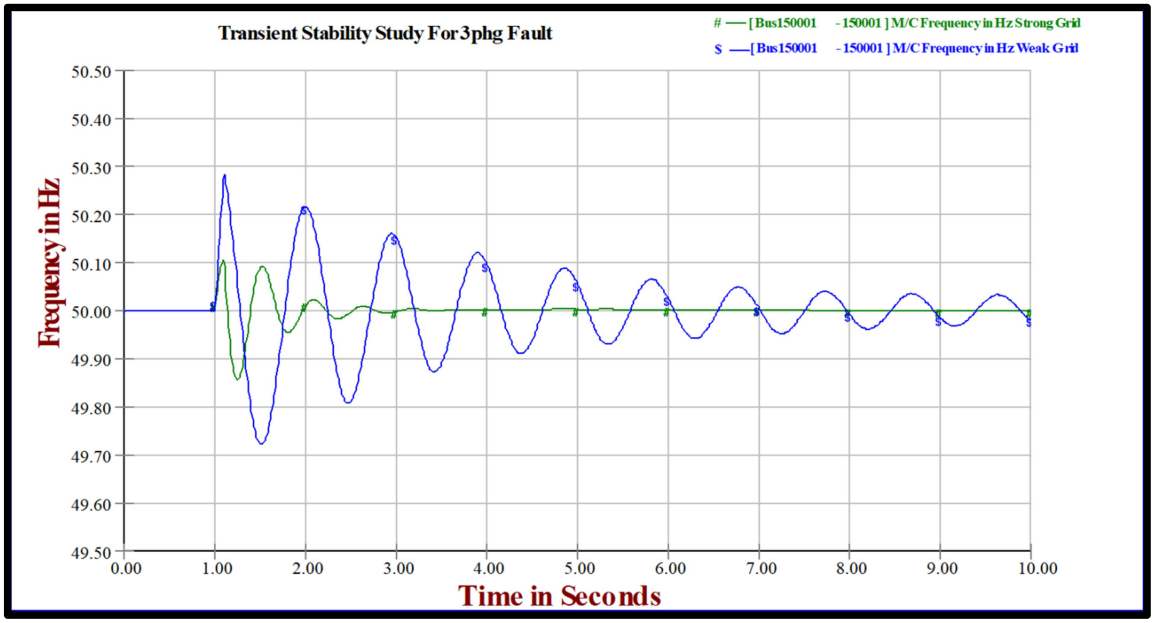

Figure 6-47 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-48 and Figure 6-49.

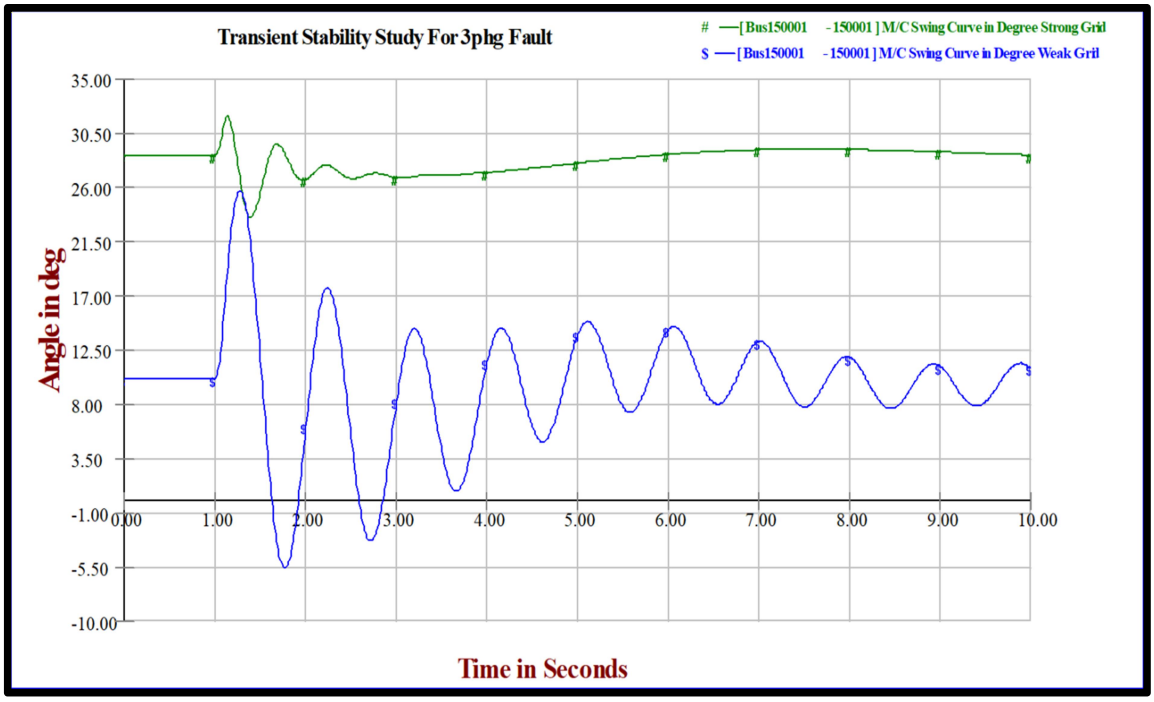

Figure 6-48 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

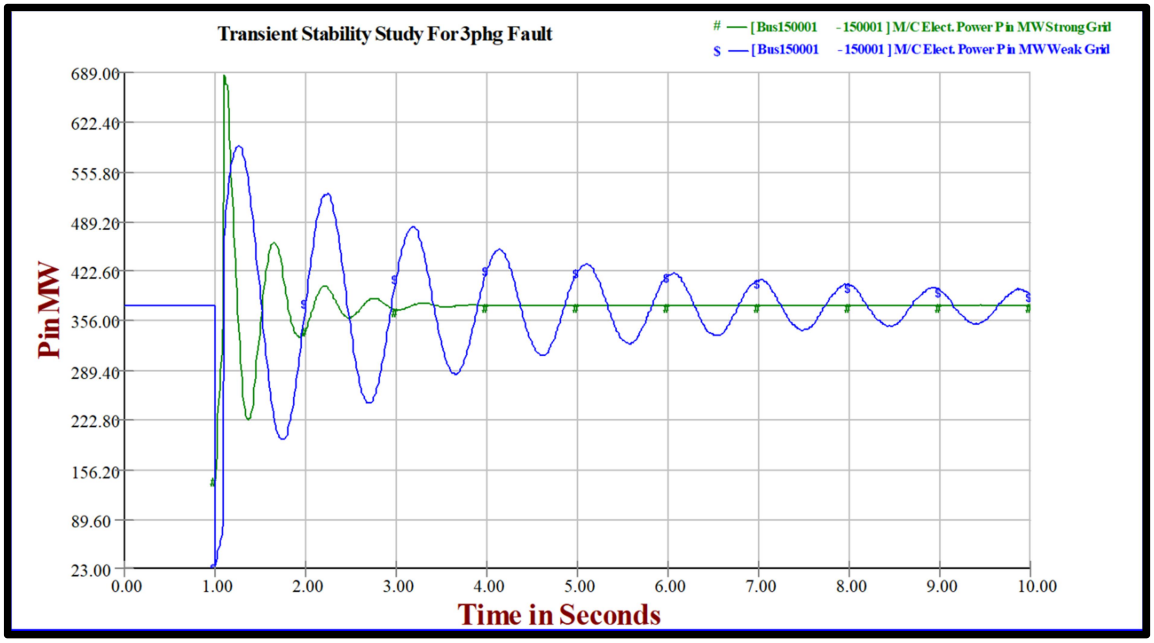

Figure 6-49 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Case 12: Single Line to ground fault at the AAL plant for a duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-50 to 6-51 for a Single line to ground fault at the power evacuation bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

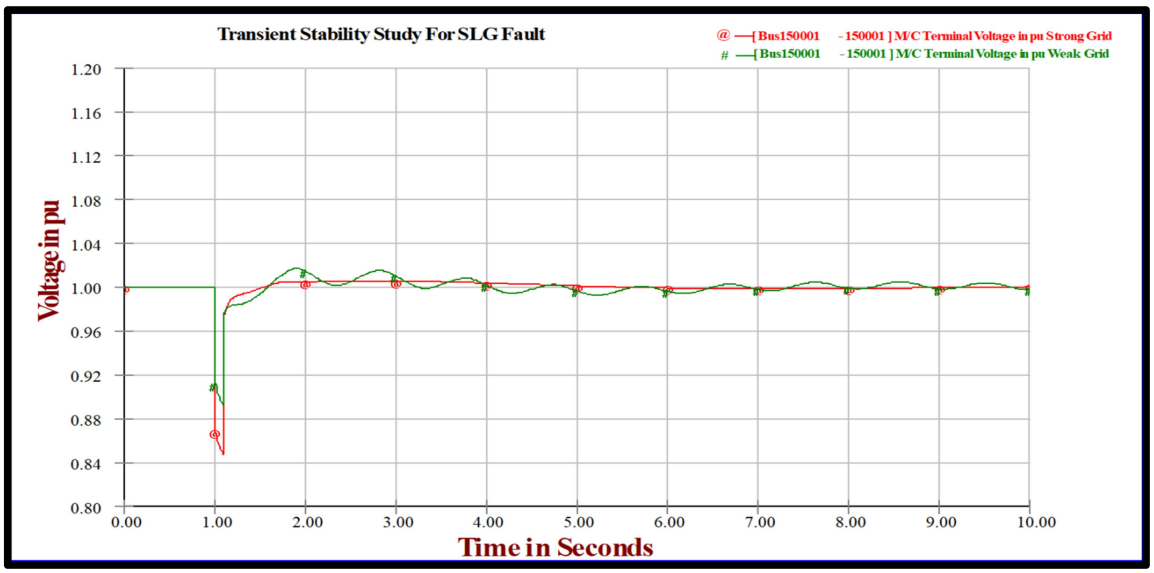

Figure 6-50 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

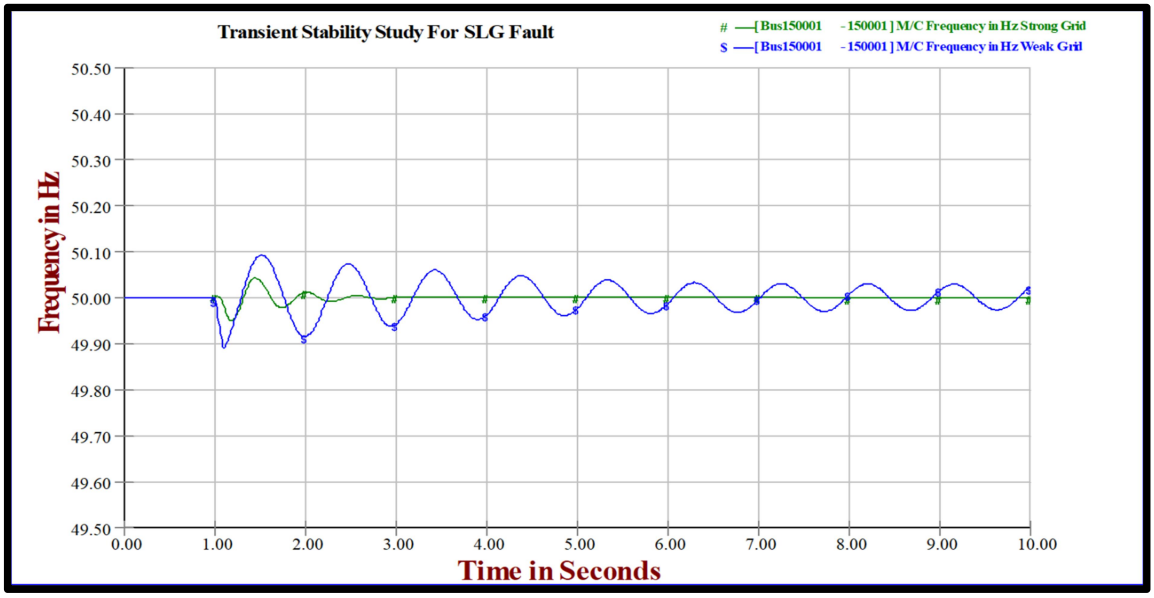

Figure 6-51 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-52 and Figure 6-53.

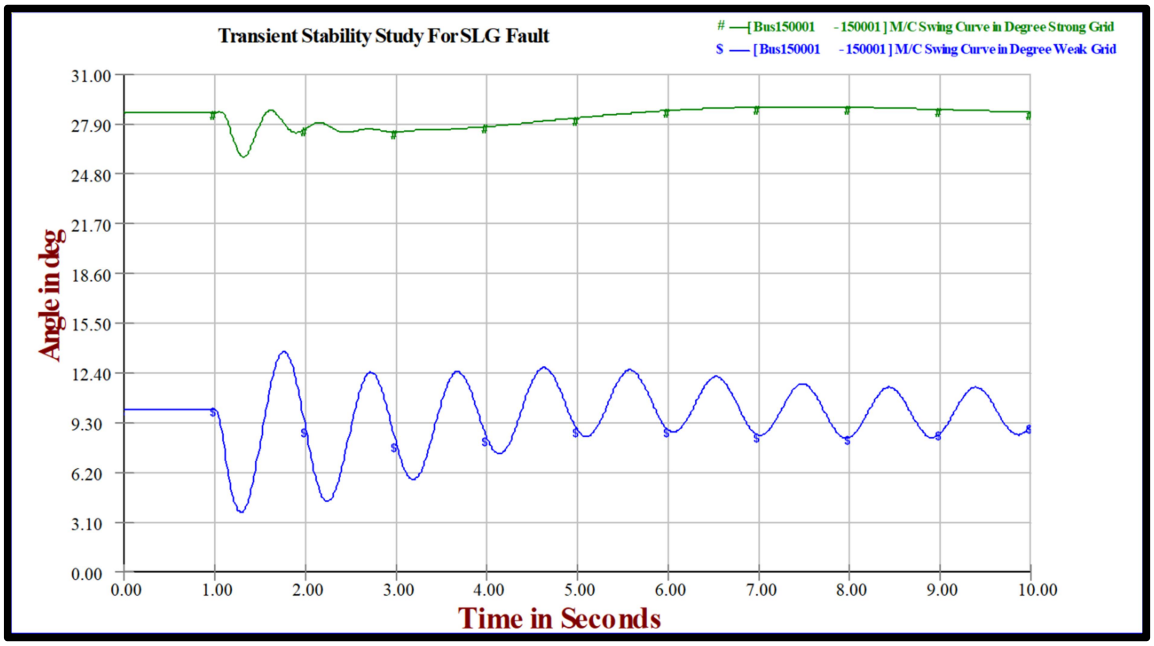

Figure 6-52 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

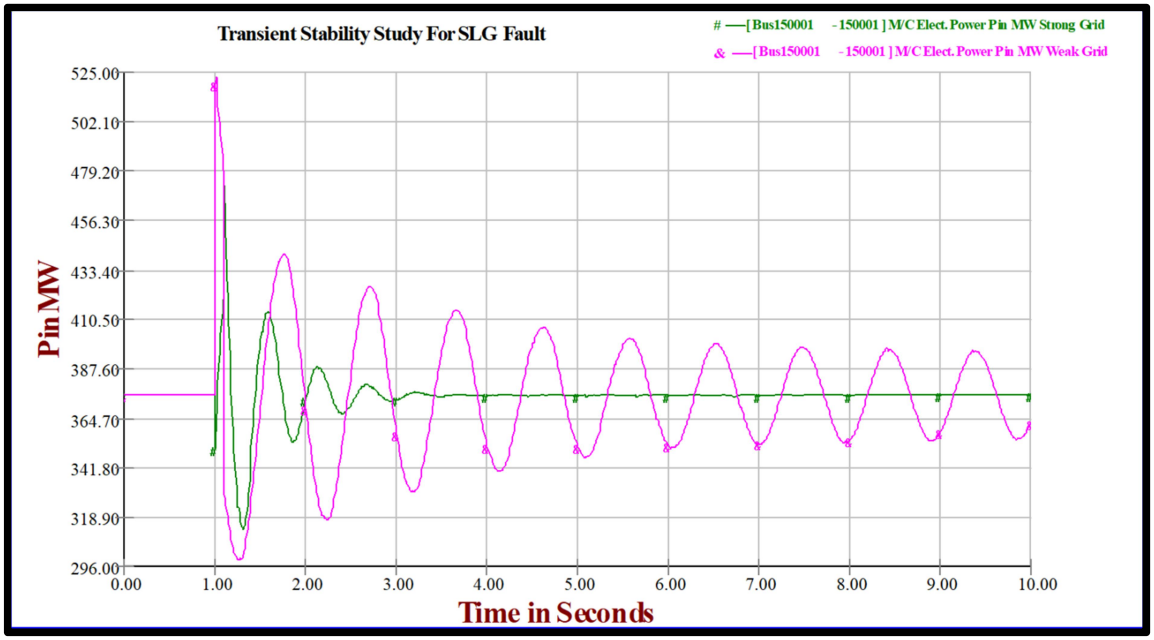

Figure 6-53 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Case 13: Outage of Largest Generator set at the AAL plant with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-54 to 6-55 for a disturbance initiated due to generator outage during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

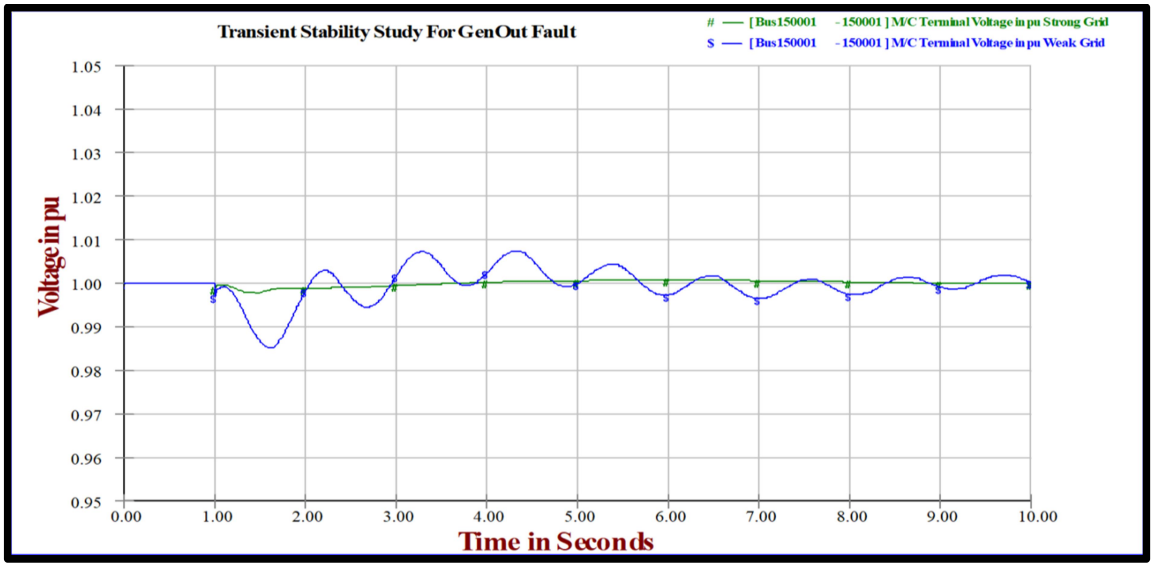

Figure 6-54 Voltage plot for highest generating unit outage inside the plant during import mode of operation of plant

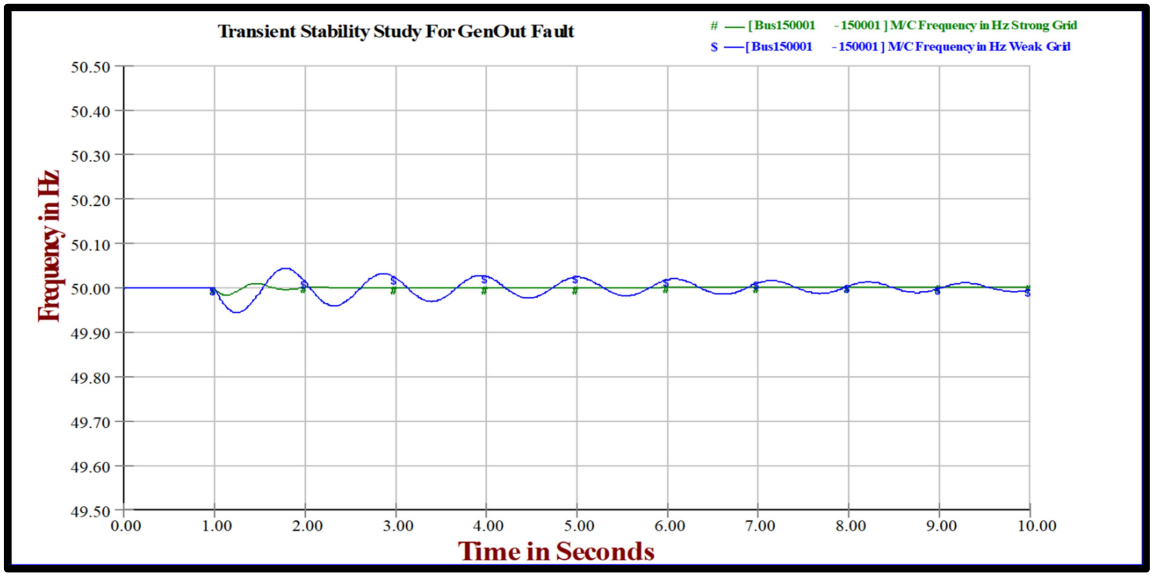

Figure 6-55 Frequency plot for highest generating unit outage inside the plant during import mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during import mode of operation of plant is presented in Figure 6-56 and Figure 6-57.

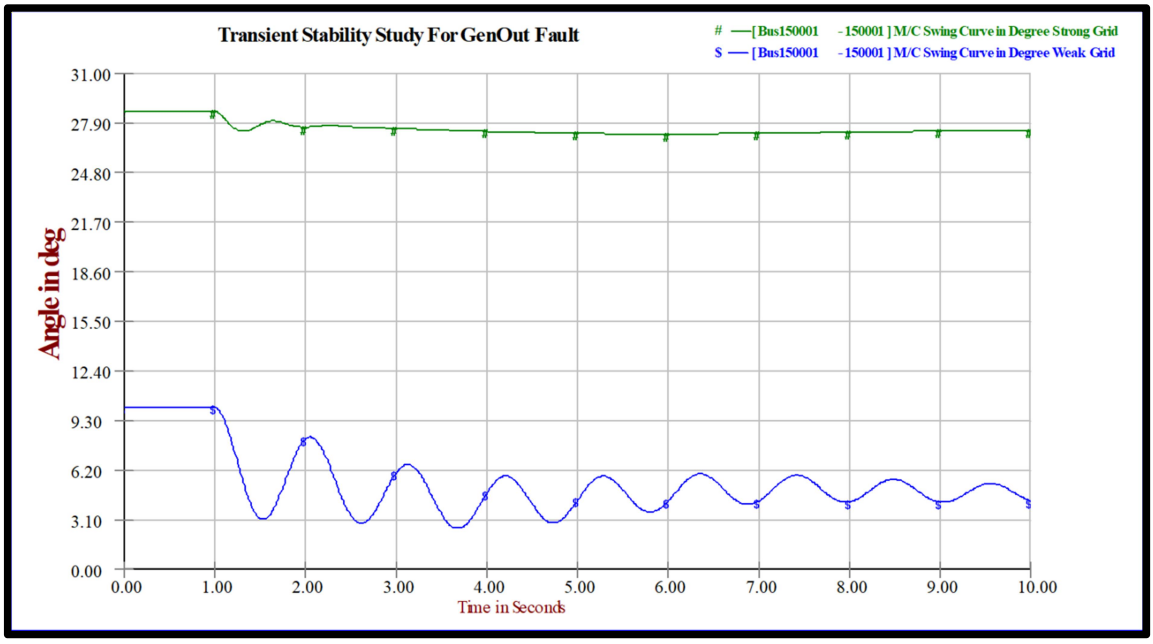

Figure 6-56 Swing curve plot for highest generating unit outage inside the plant during import mode of operation of plant

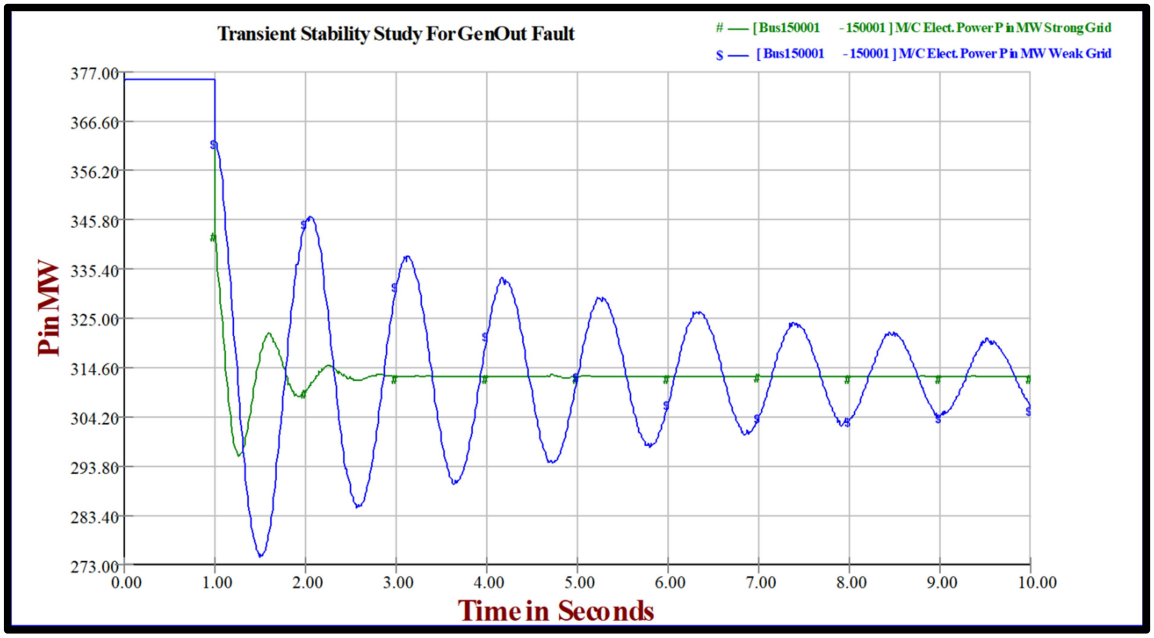

Figure 6-57 Active power plot for highest generating unit outage inside the plant during import mode of operation of plant

Case 14: Load throw off at the AAL plant with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-58 to 6-59 for a disturbance initiated due to sudden load throw off during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

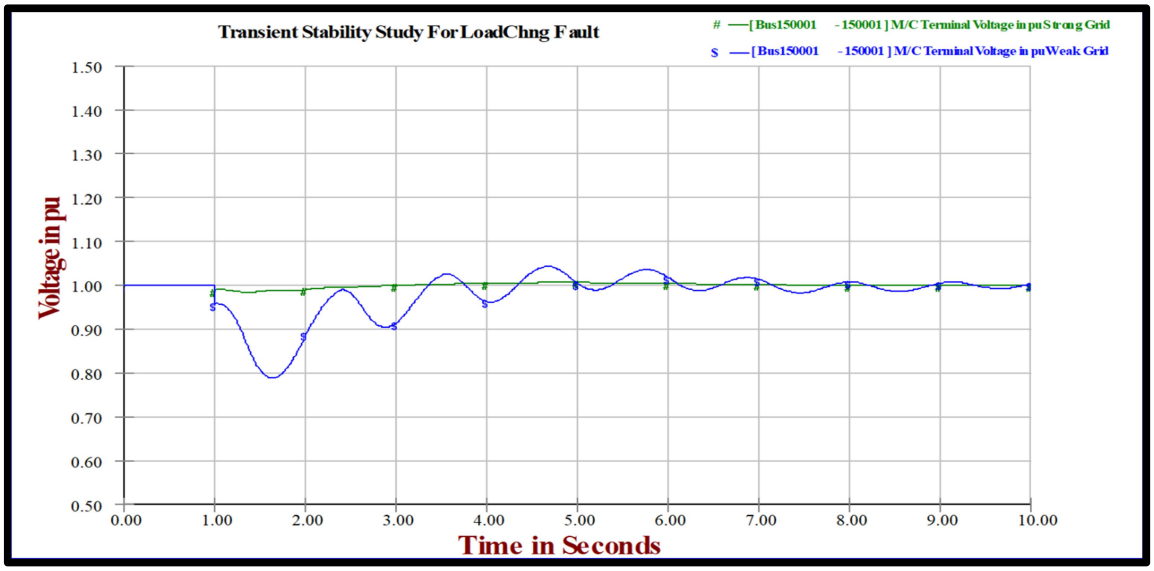

Figure 6-58 Voltage plot for sudden increase in load inside the plant during import mode of operation of plant.

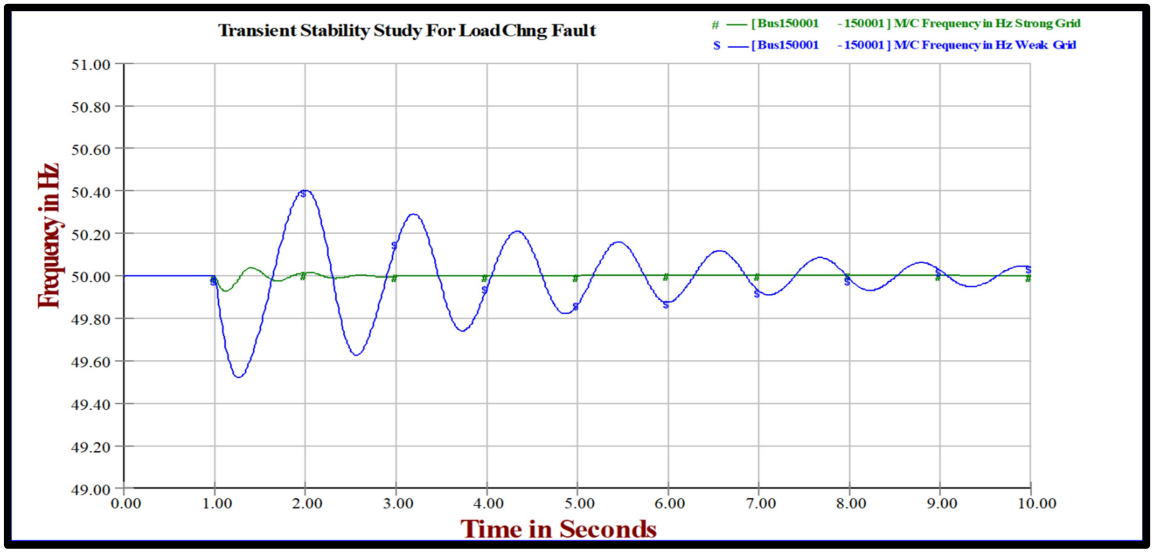

Figure 6-59 Frequency plot for sudden increase in load inside the plant during import mode of operation of plant.

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during import mode of plant operation of plant is presented in Figure 6-60 and Figure 6-61.

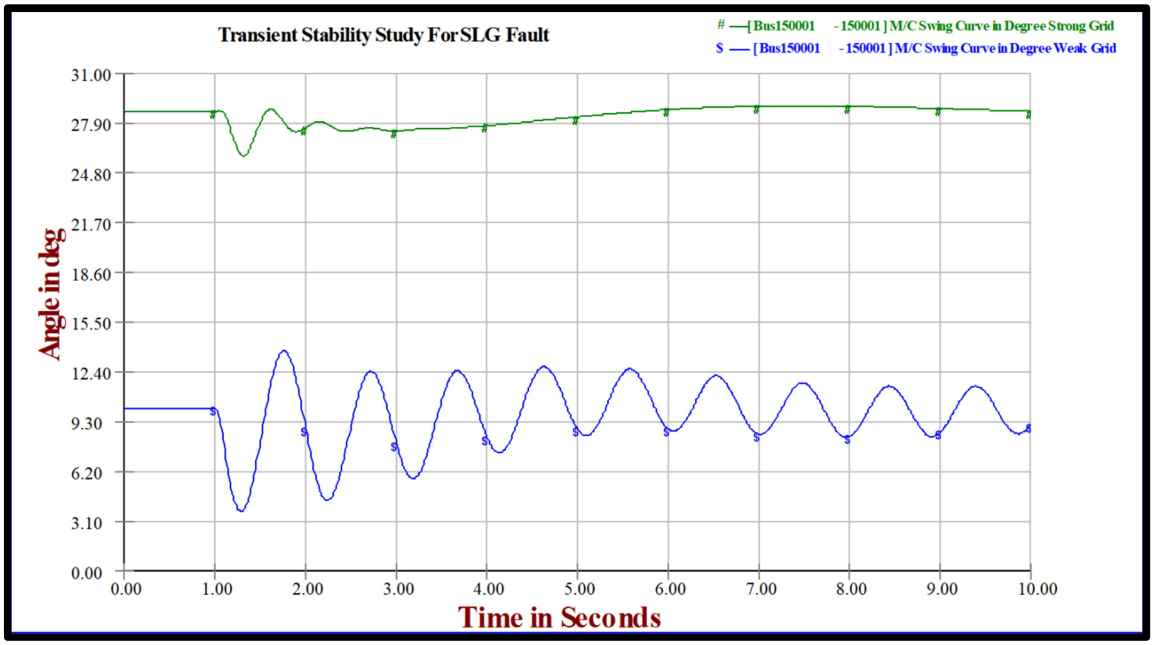

Figure 6-60 Swing curve plot for sudden increase in load inside the plant during import mode of operation of plant

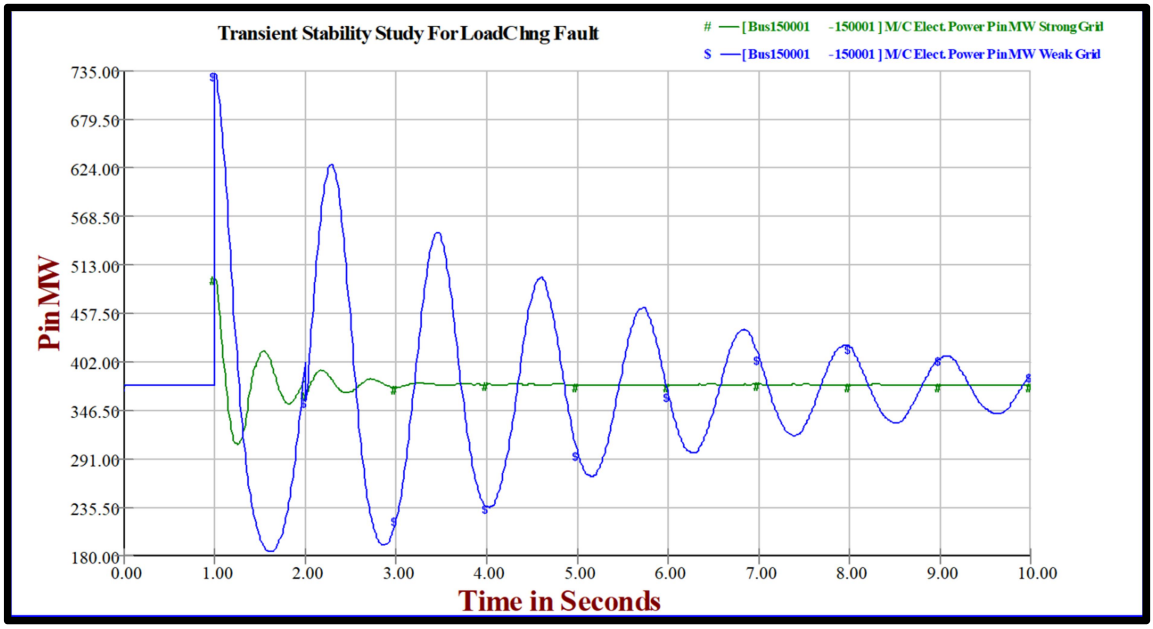

Figure 6-61 Active power plot for sudden increase in load inside the plant during import mode of operation of plant

Export mode

Case 15: Three Phase to ground fault at the AAL plant for a duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-62 to 6-63 for a three phase to ground fault at the power evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

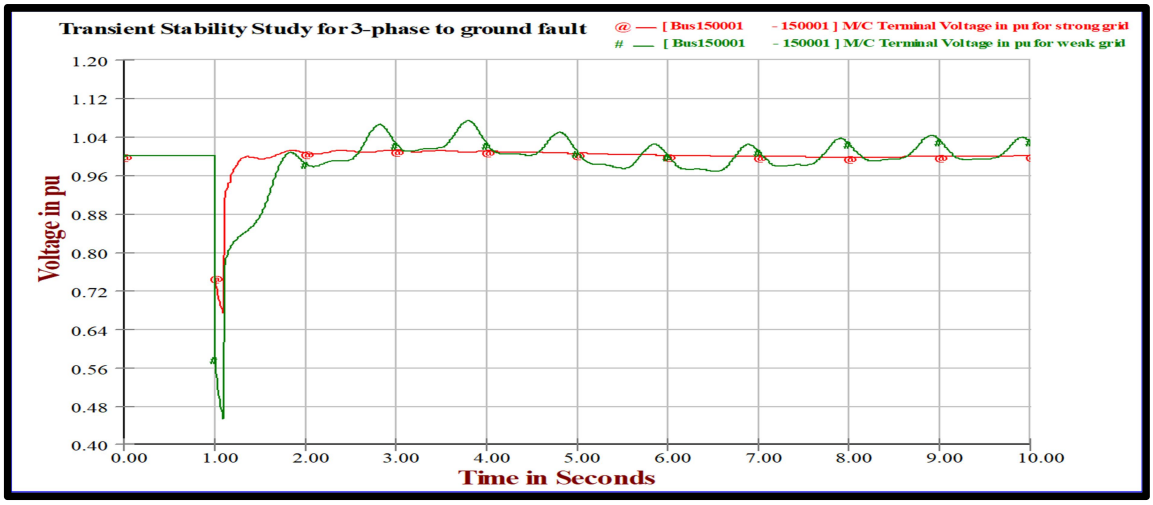

Figure 6-62 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

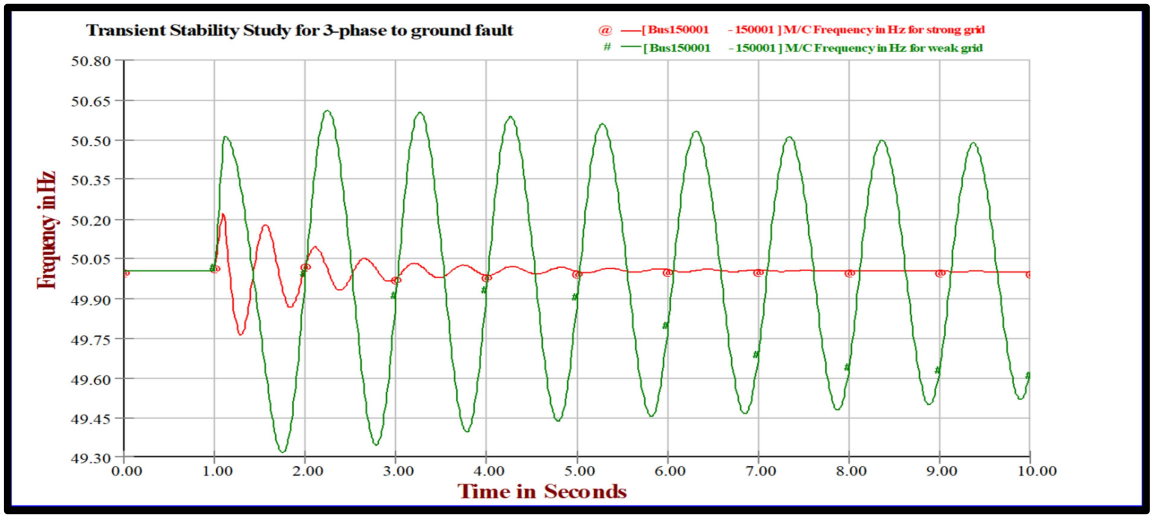

Figure 6-63 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-64 and Figure 6-65. The active power variation indicates, higher swings in case of a weak grid connectivity as compared to the strong grid connectivity.

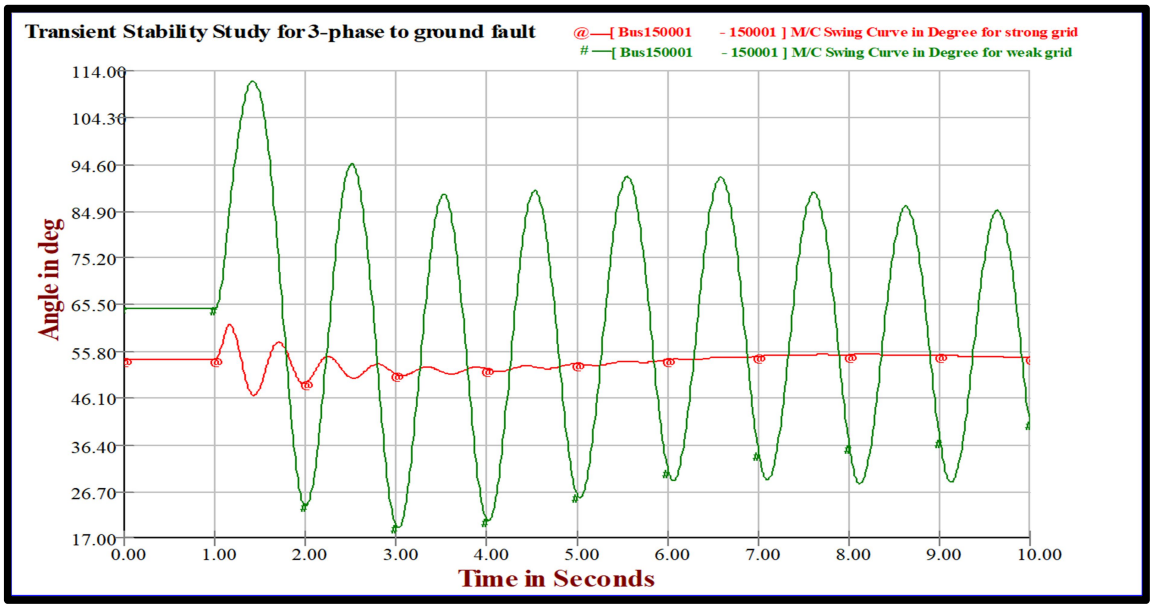

Figure 6-64 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

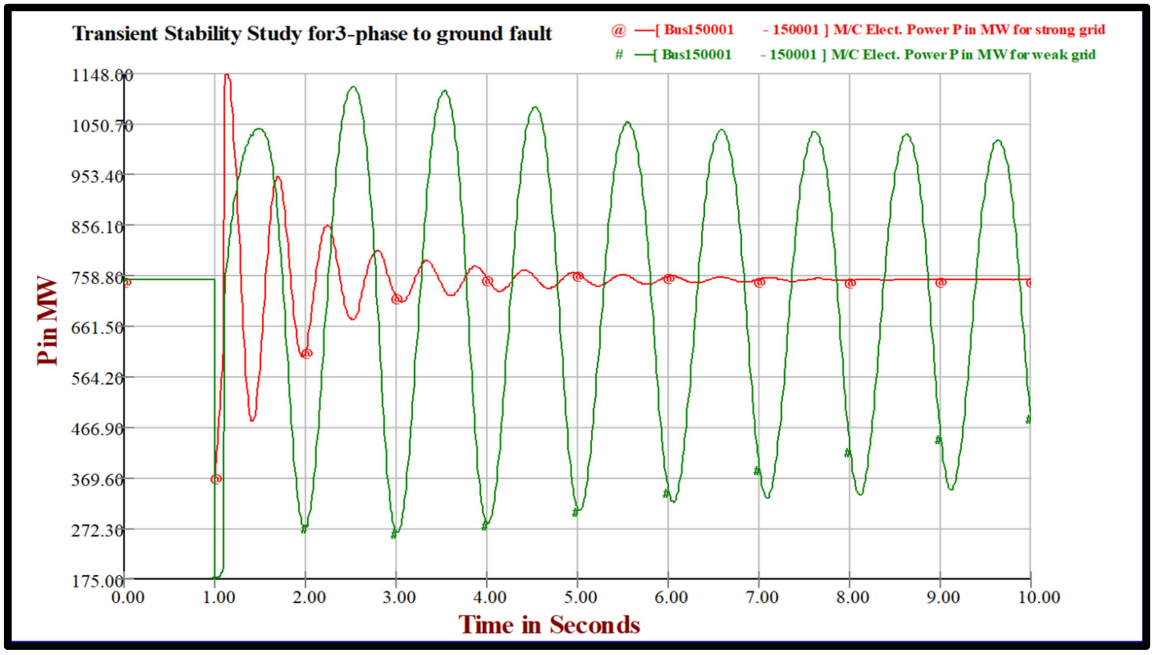

Figure 6-65 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Case 16: Single Line to ground fault at the AAL plant for a duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-66 to 6-67 for a Single line to ground fault at the power evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

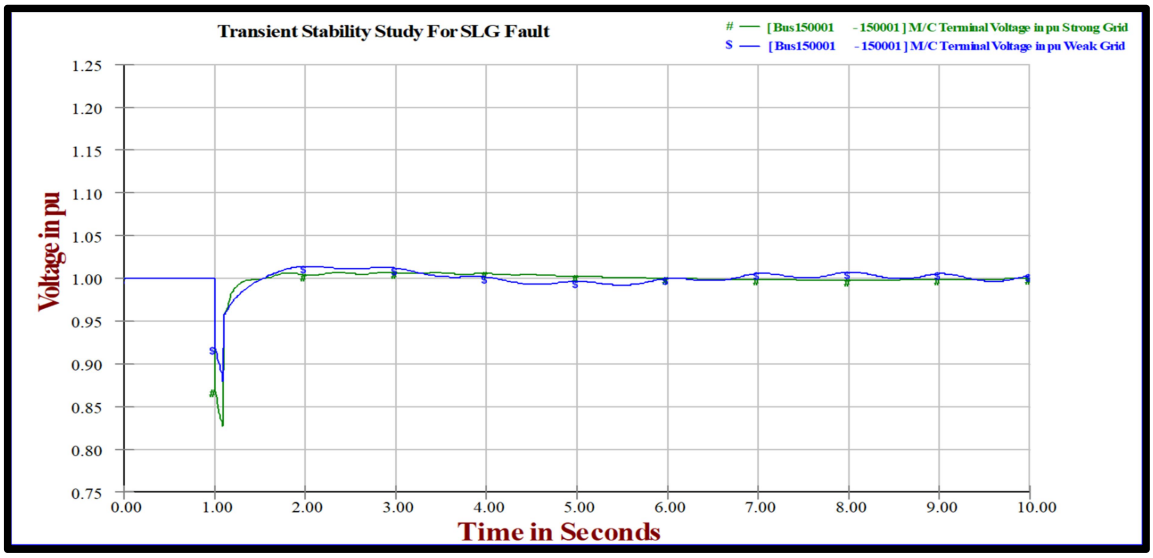

Figure 6-66 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

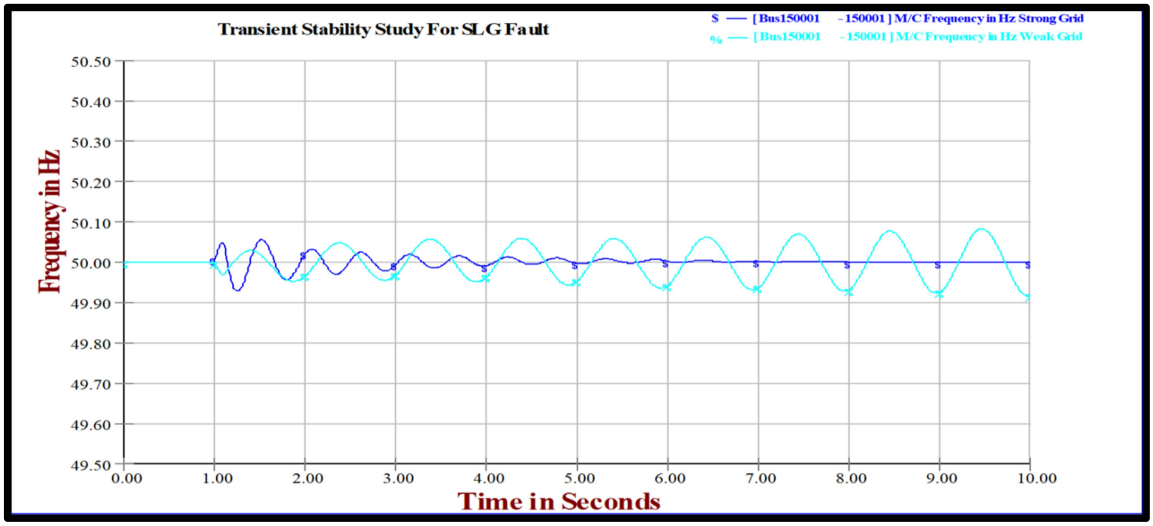

Figure 6-67 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-68 and Figure 6-69.

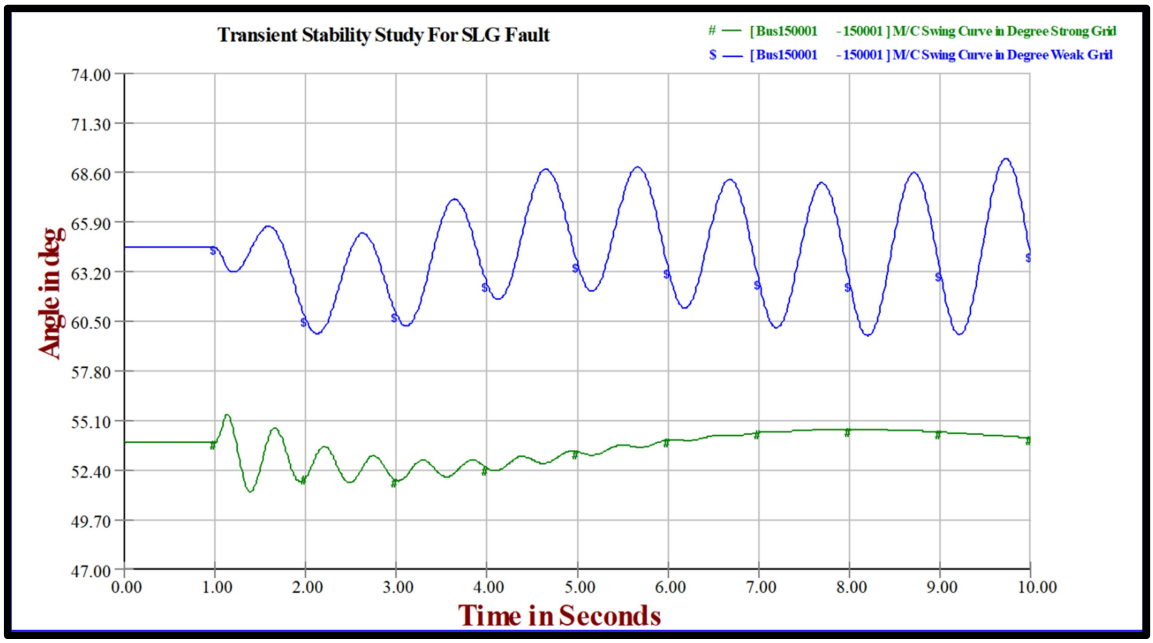

Figure 6-68 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

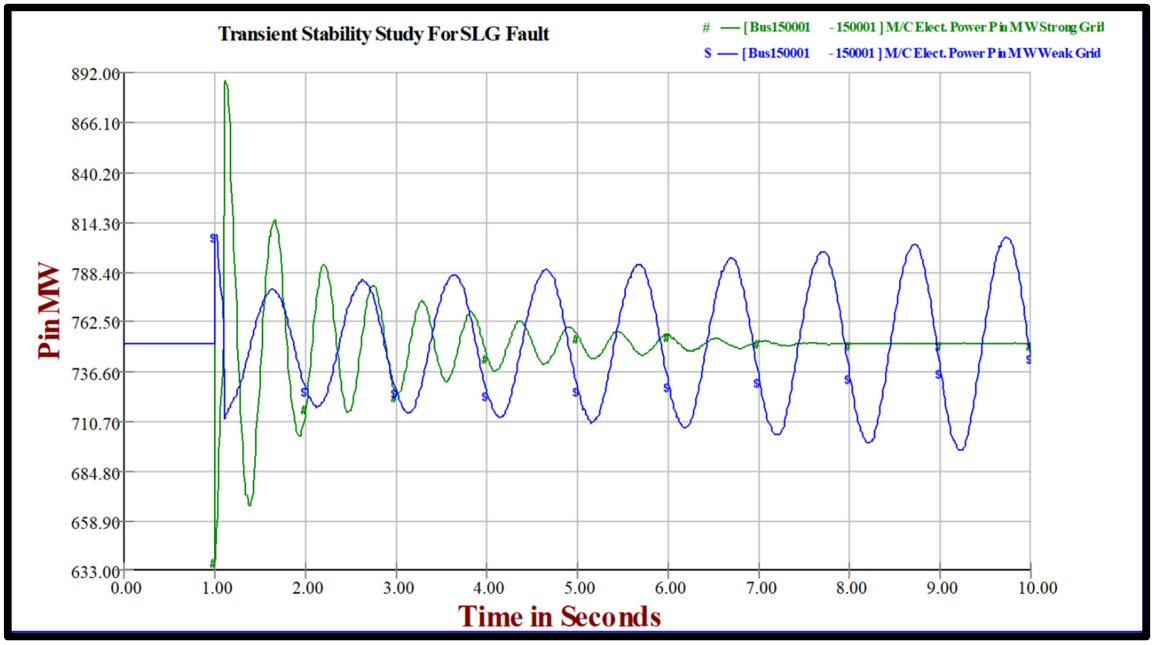

Figure 6-69 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Case 17: Outage of a Generator set at the AAL plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-70 to 6-71 for a disturbance initiated due to generator outage during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

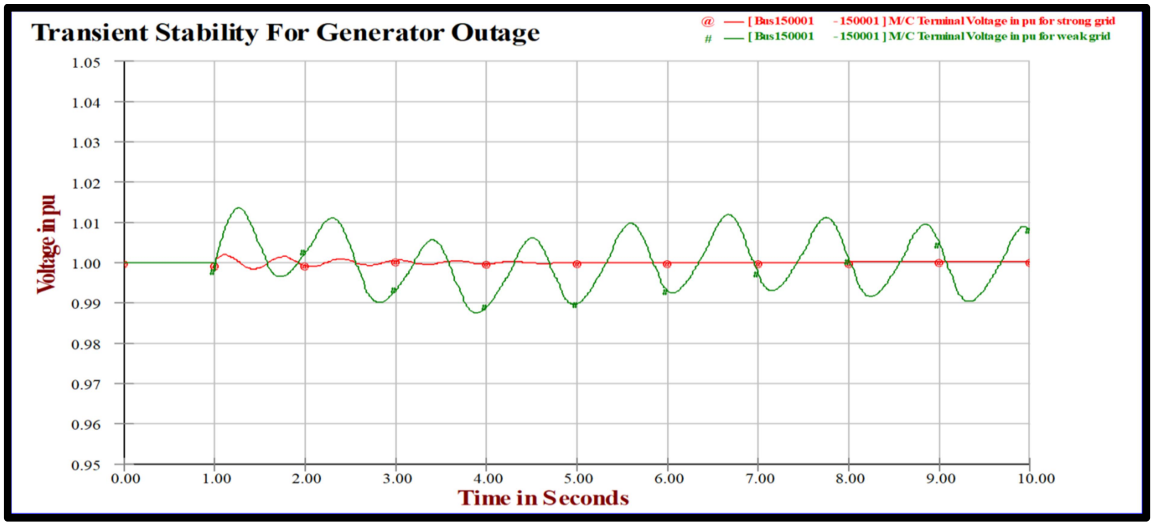

Figure 6-70 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant

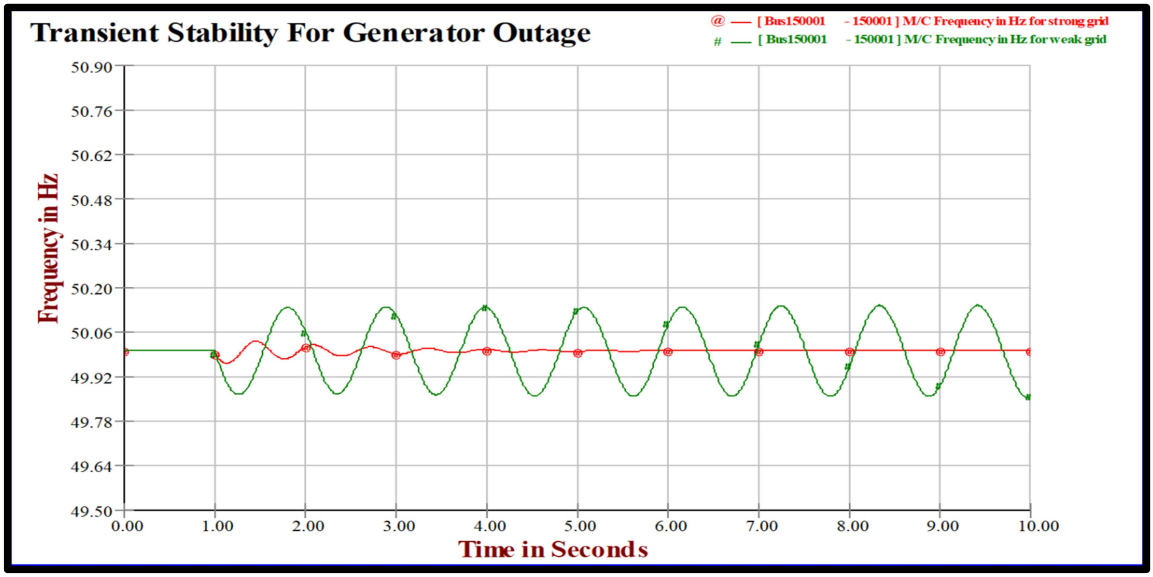

Figure 6-71 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during export mode of operation of plant is presented in Figure 6-72 and Figure 6-73.

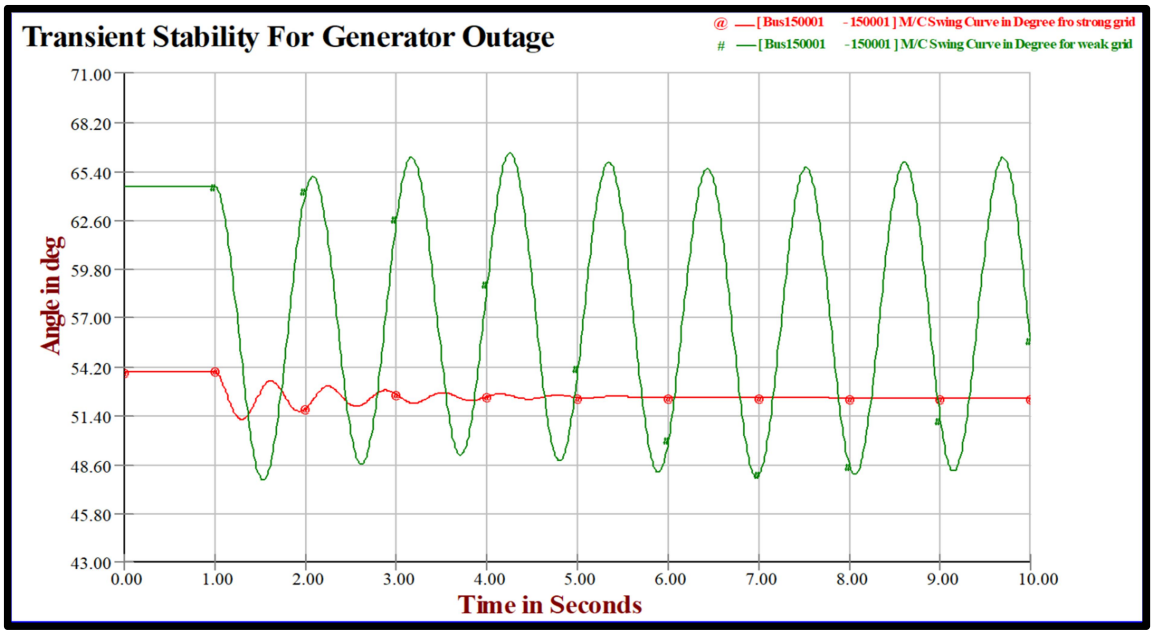

Figure 6-72 Swing curve plot for highest generating unit outage inside the plant during export mode of operation of plant

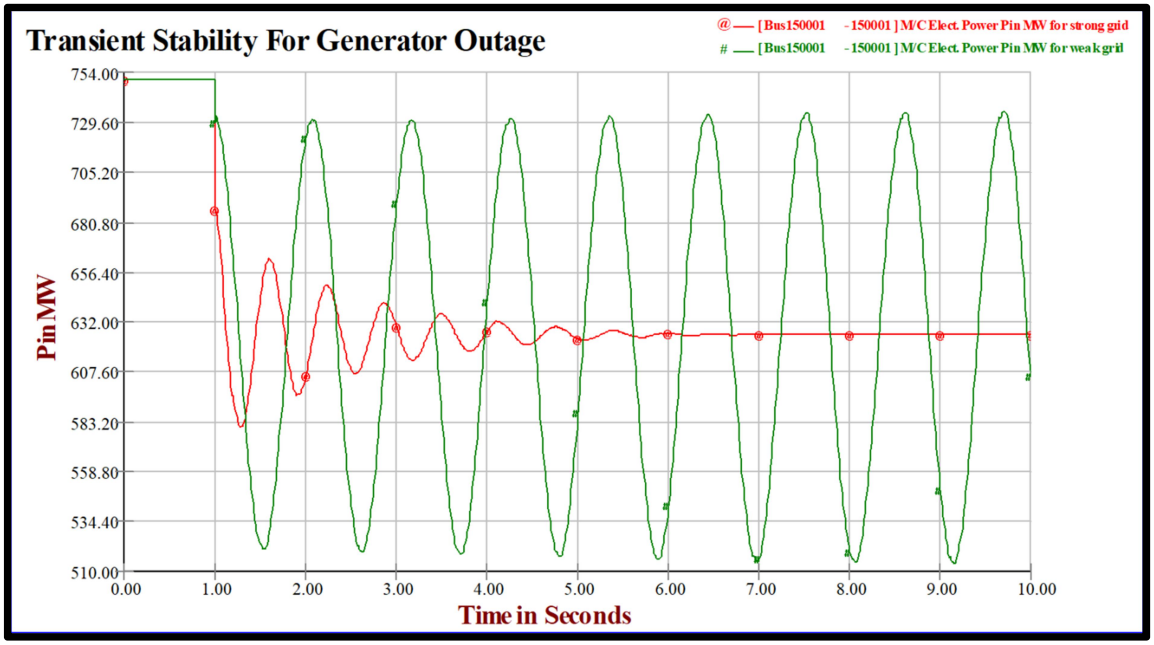

Figure 6-73 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant

Case 18: Load throw off at the AAL plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-74 to 6-75 for a disturbance initiated due to sudden load throw off during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

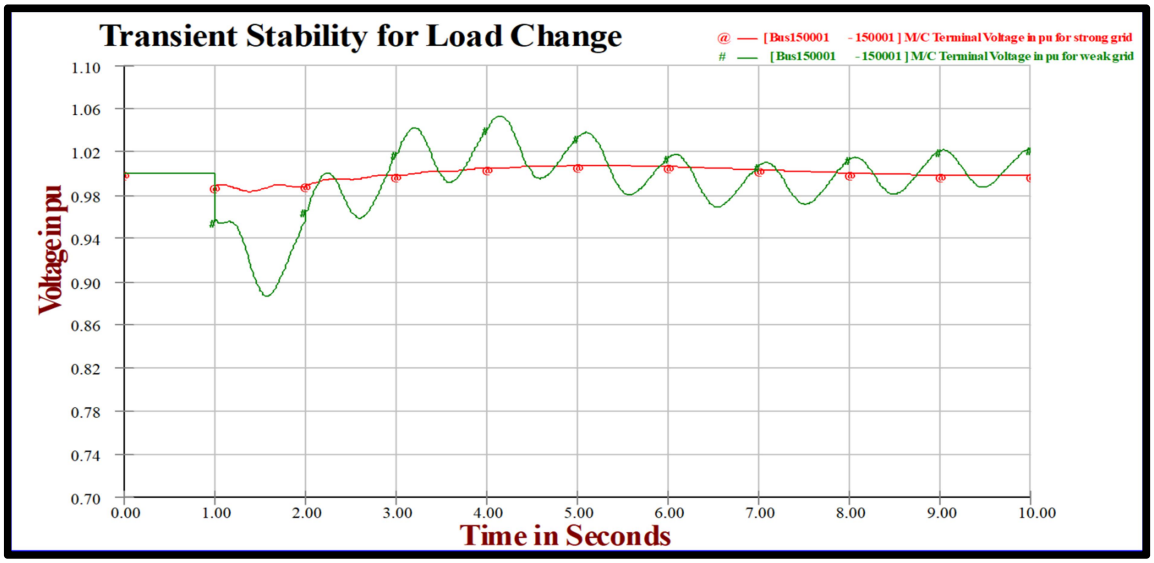

Figure 6-74 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant.

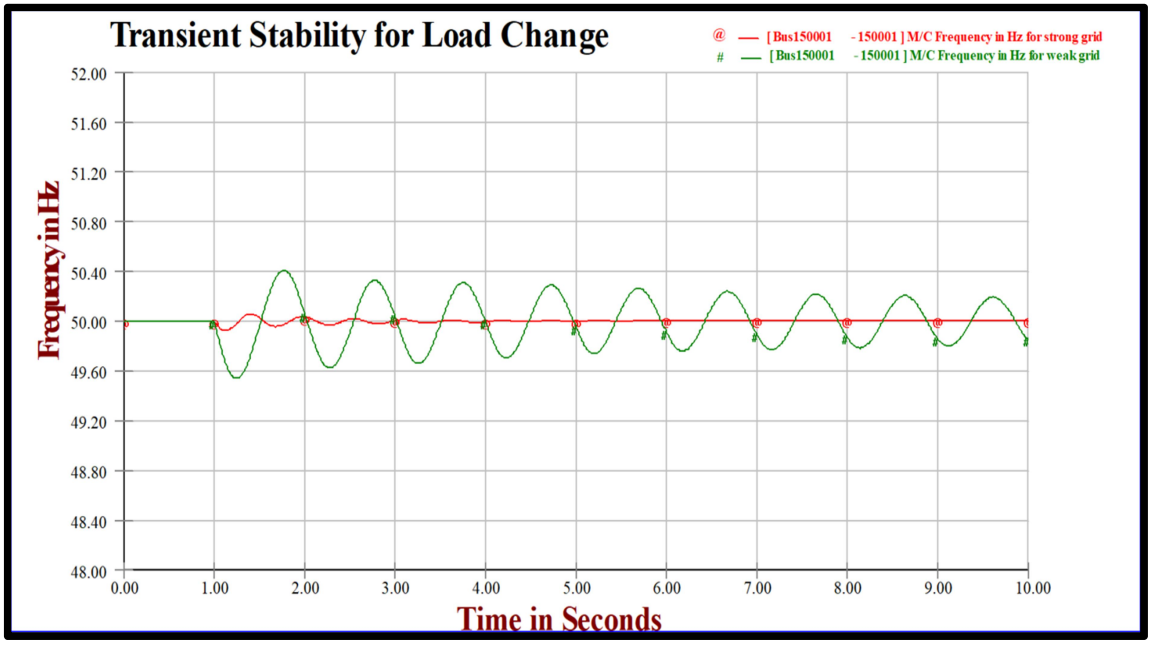

Figure 6-75 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during export mode of plant operation of plant is presented in Figure 6-76 and Figure 6-77.

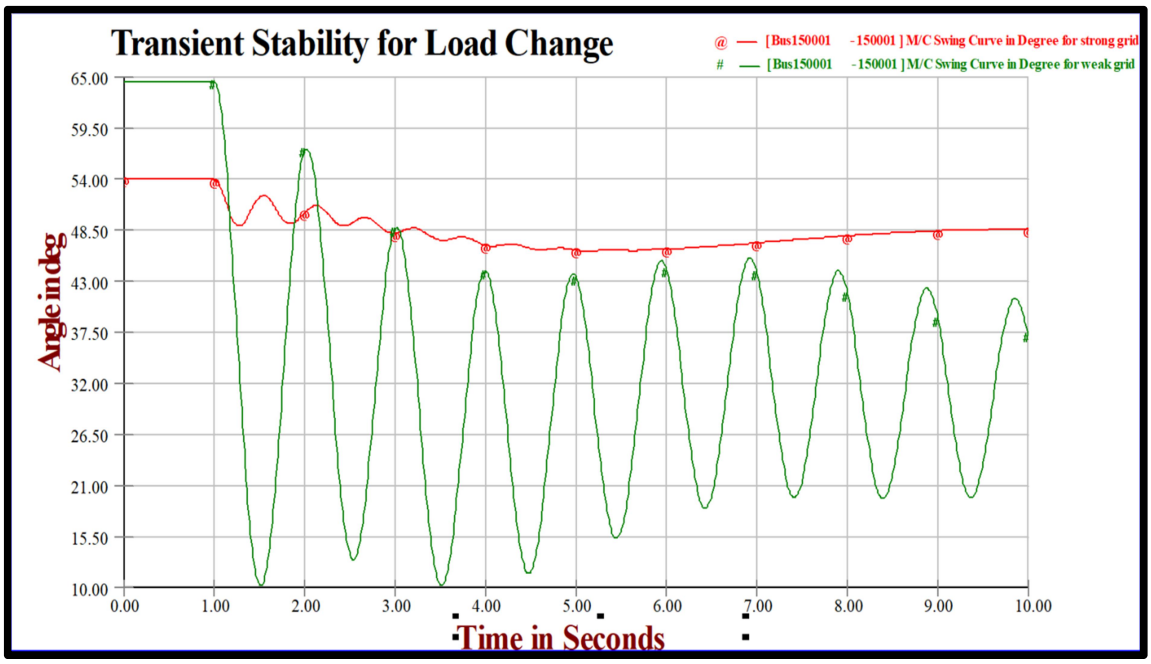

Figure 6-76 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant

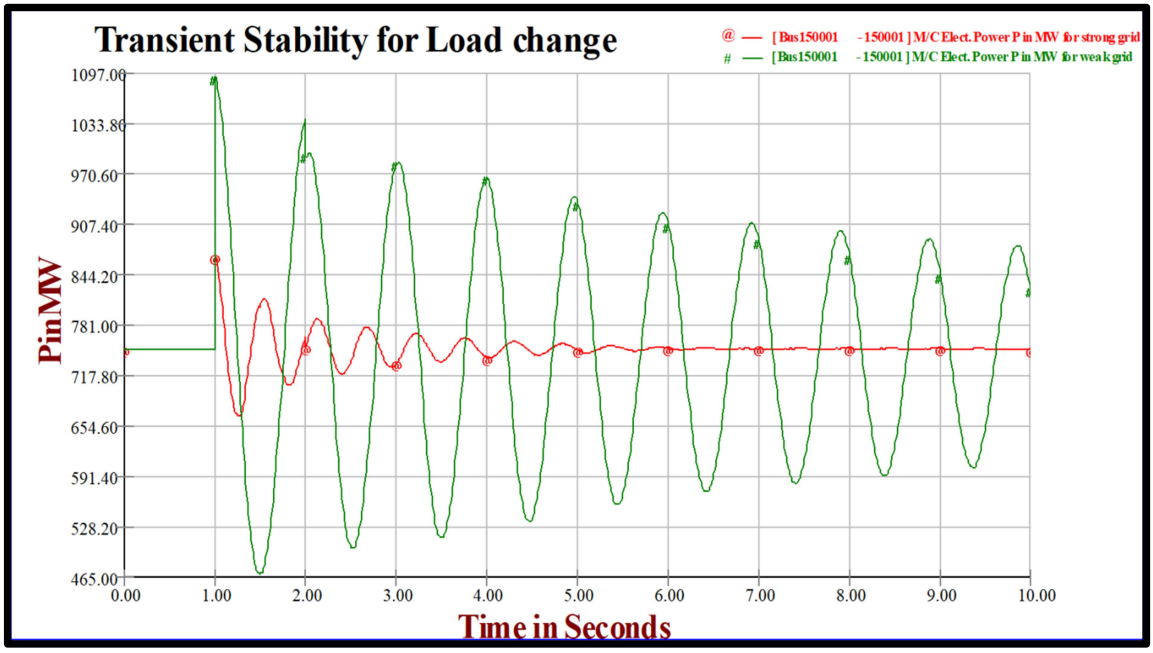

Figure 6-77 Active power plot for sudden increase in load inside the plant during export mode of operation of plant

6.6. Transient Stability study for Jindal Steel Works Bhusan

Jindal Steel Works Bhusan is a Captive generating plant in Jharsuguda area having 1x8+1x40+1x60+3x130 MW generation capacity which is primarily connected to Budhipadar 220kV Bus. In the stability study of JSW plant, three important scenarios are simulated using in MiPSCT. In the first scenario, the Plant is operating in floating mode while assuming the full load operation inside the plant. Similarly, the second and third scenario is simulated by considering the contracted demand of the plant operation. In each of the three scenarios, four different disturbance conditions are simulated to study the transient behaviour of CGP generators.

Floating Mode

Case 19: Three Phase to ground fault at the power evacuation bus inside the JSW plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-78 to 6-79 for a three phase to ground fault at the power evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

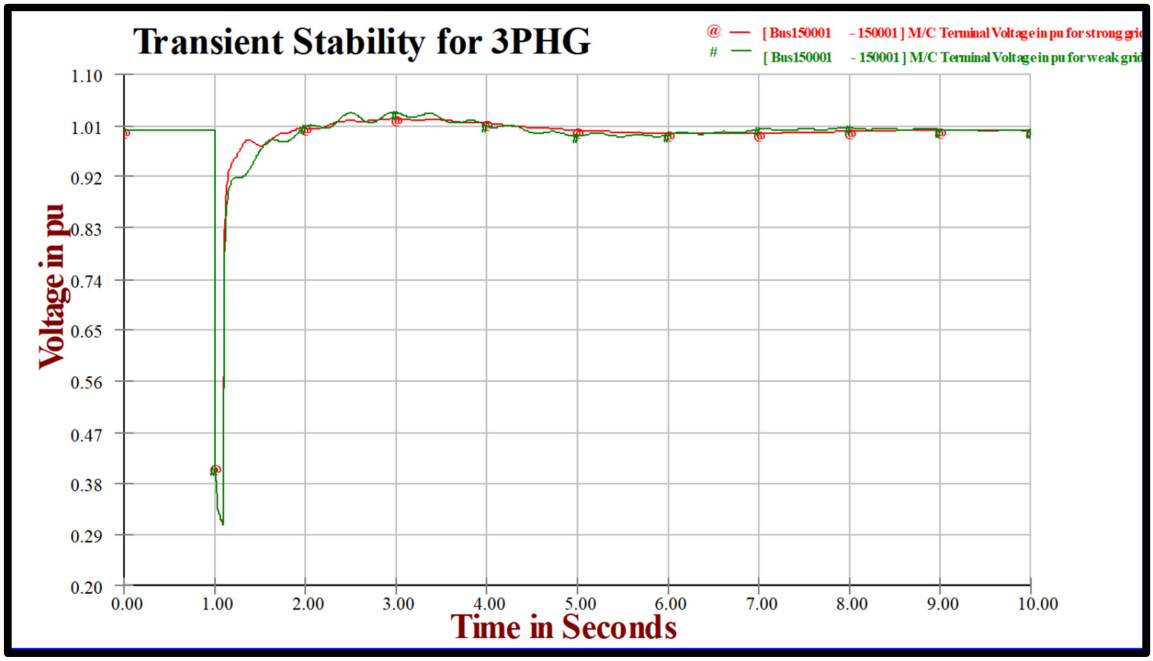

Figure 6-78 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

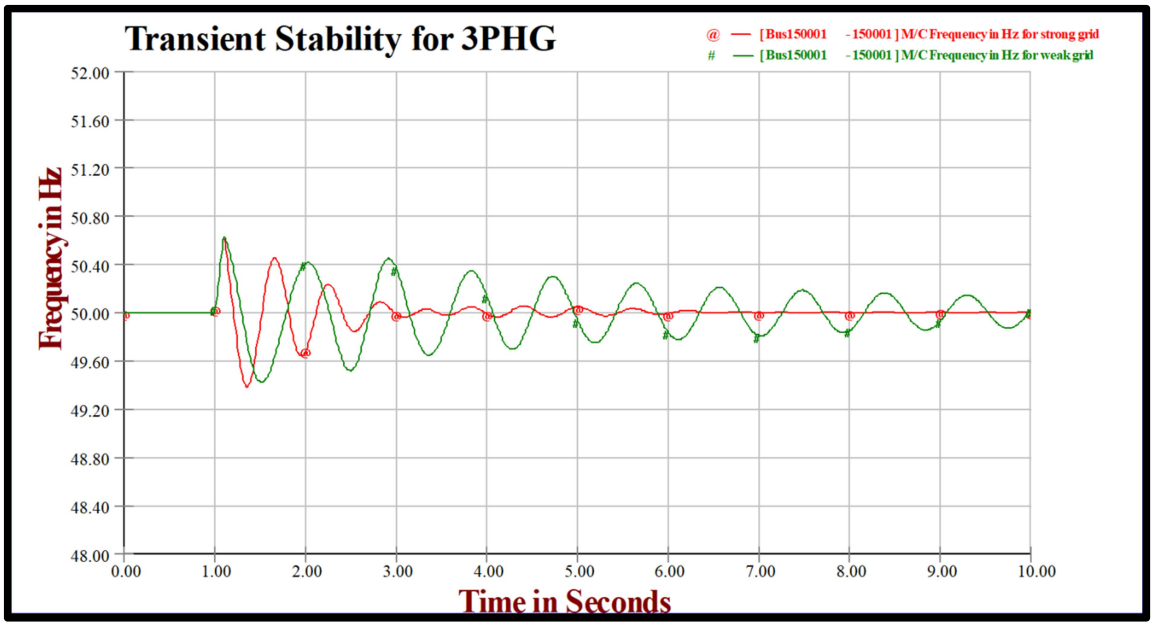

Figure 6-79 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-80 and Figure 6-81.

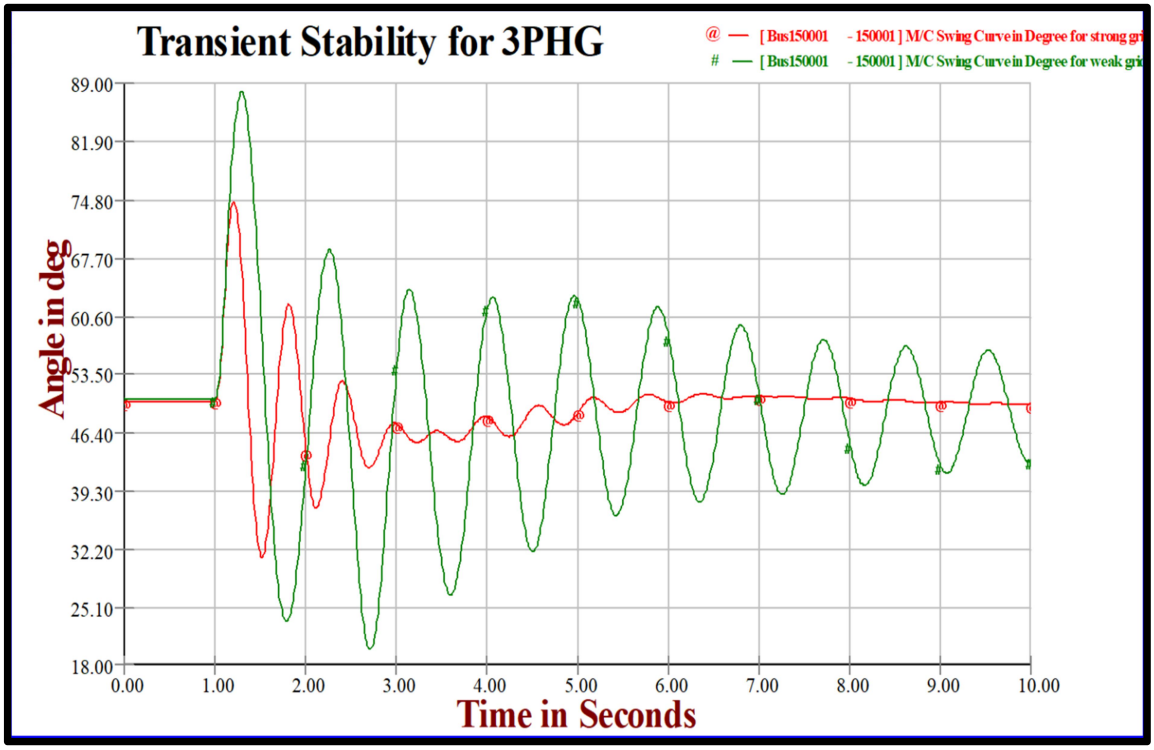

Figure 6-80 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

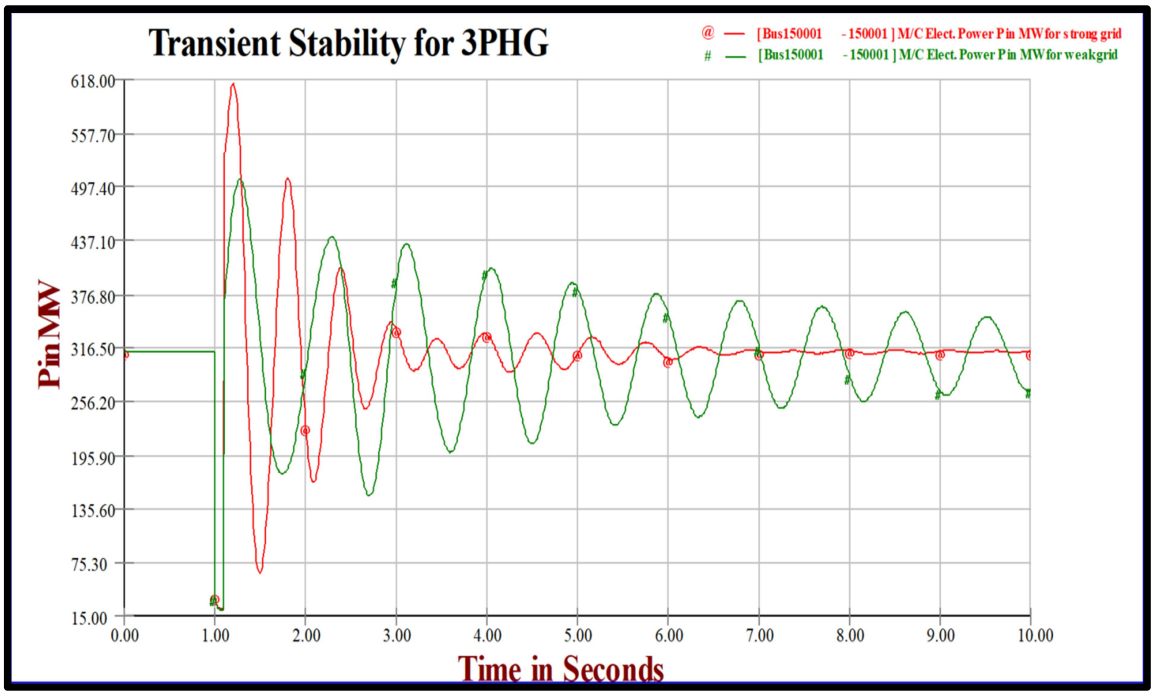

Figure 6-81 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Case 20: Single Line to ground fault at the power evacuation bus inside the JSW plant for duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-82 to 6-83 for a Single line to ground fault at the power evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation. The voltage dip in case of weak grid connectivity is high as compared to the strong grid connectivity.

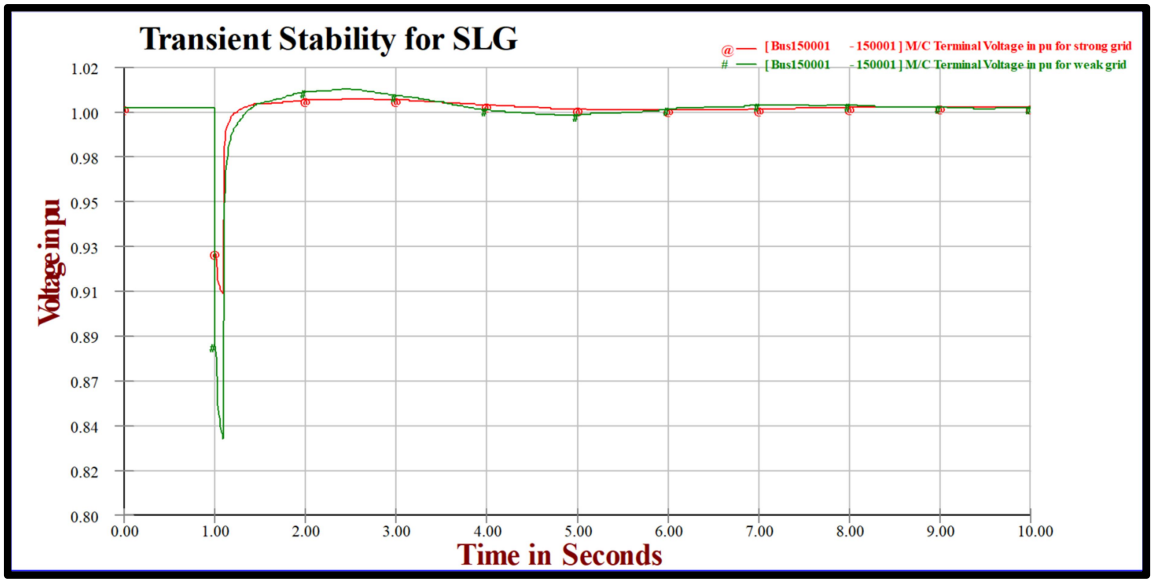

Figure 6-82 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

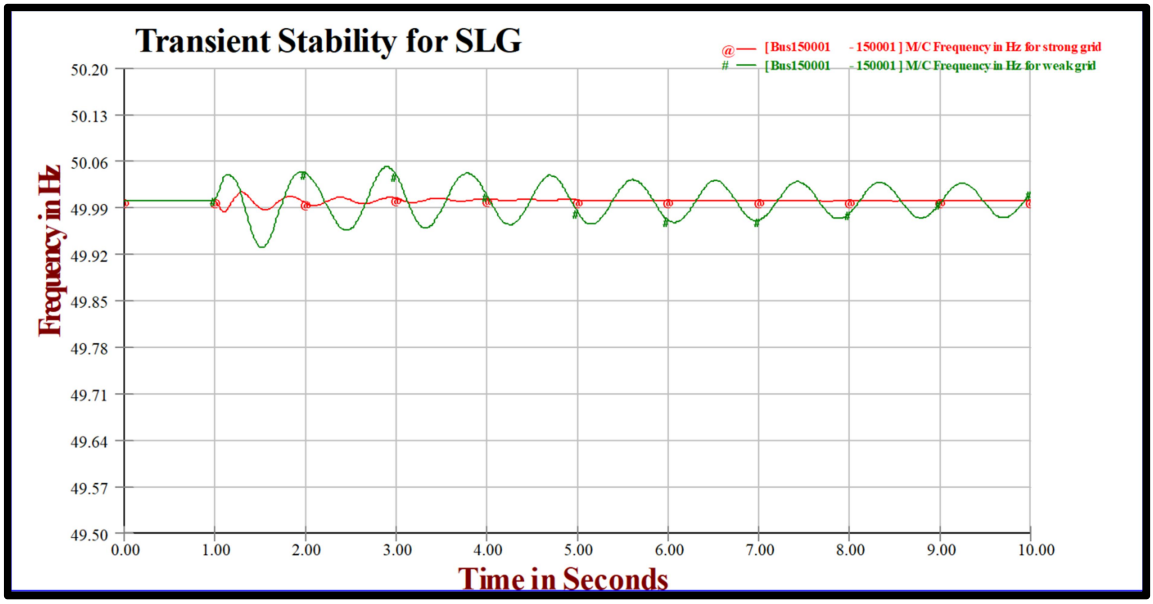

Figure 6-83 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-84 and Figure 6-85.

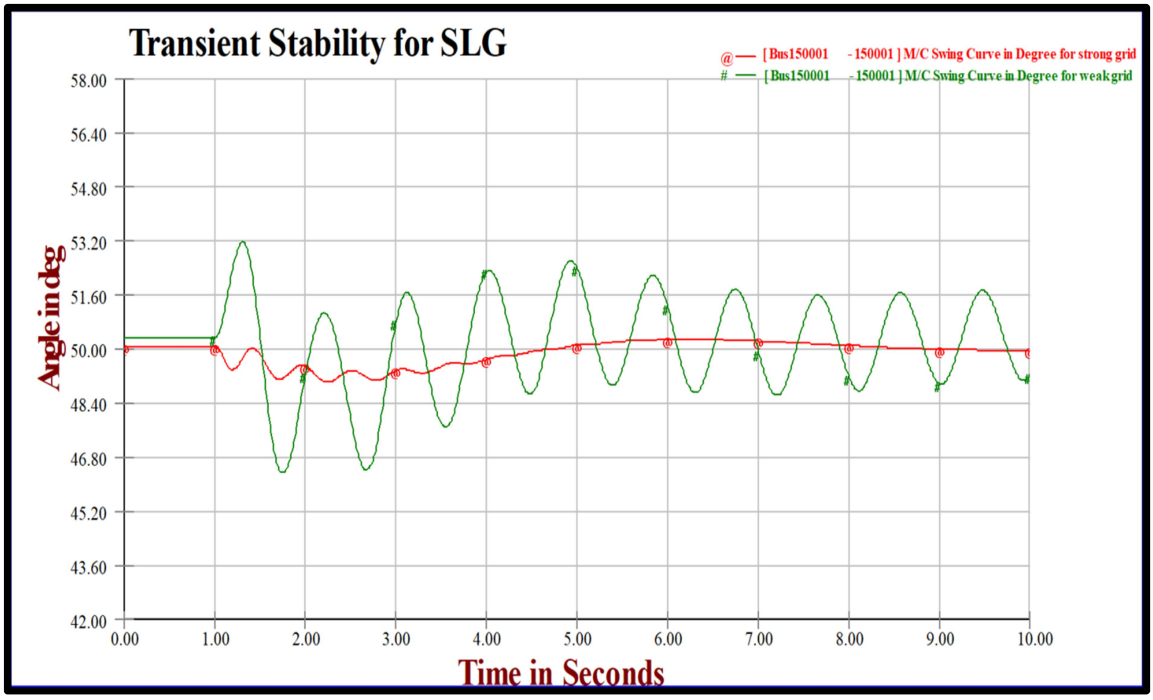

Figure 6-84 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

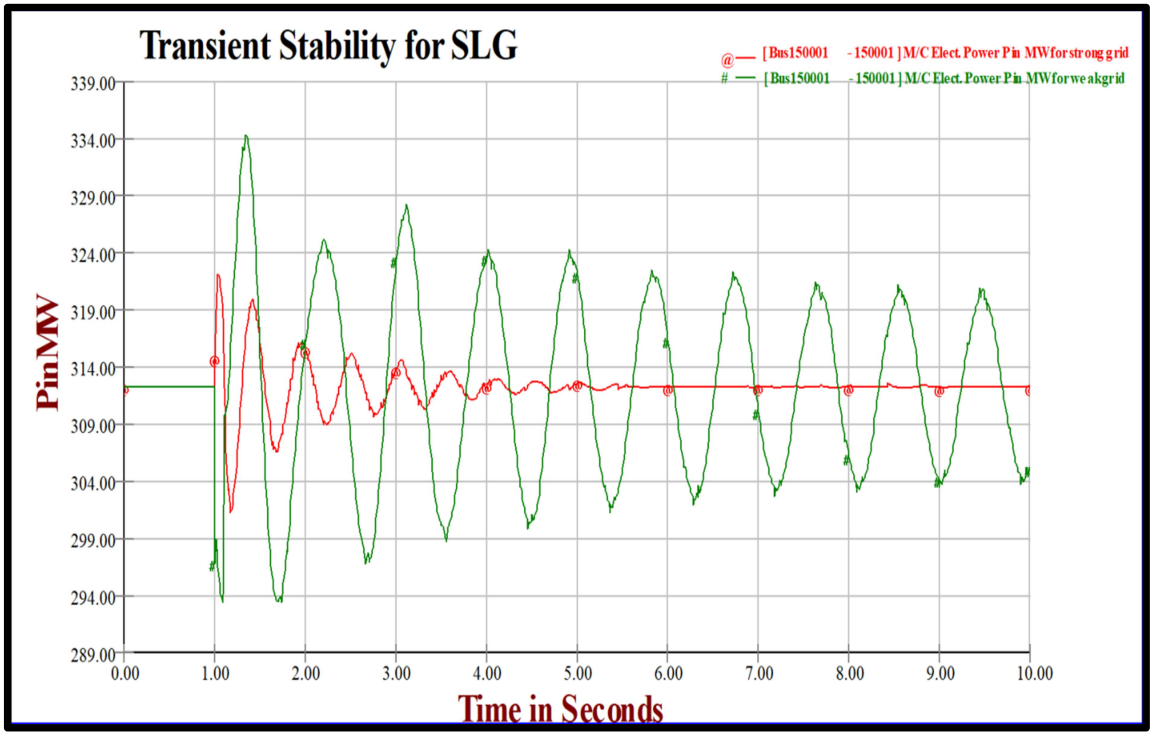

Figure 6-85 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Case 21: Highest Generating unit Outage in the JSW plant for duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-86 to 6-87 for a disturbance initiated due to generator outage during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

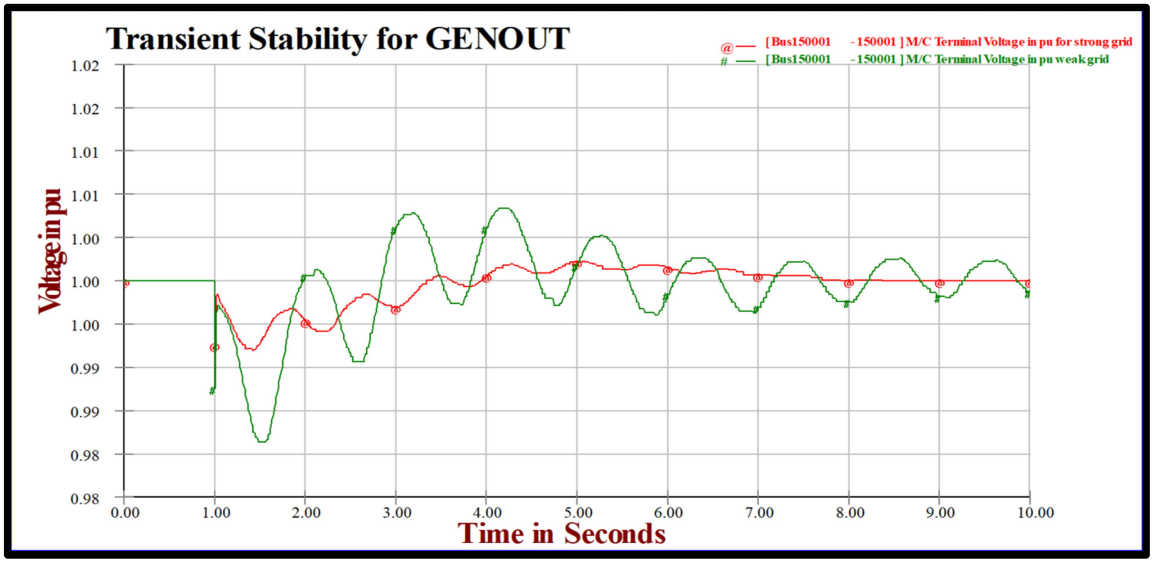

Figure 6-86 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant

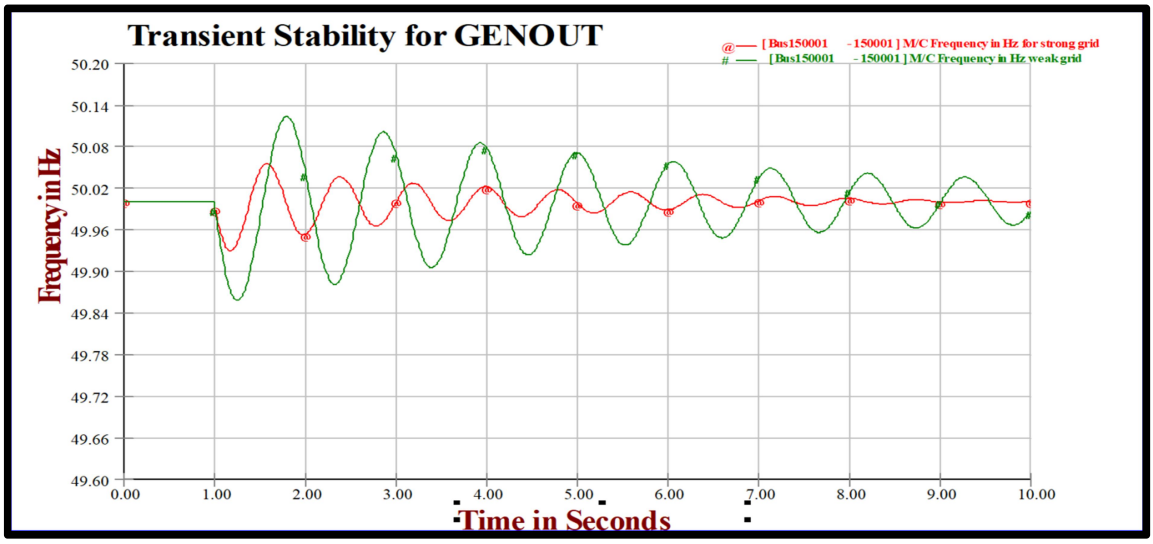

Figure 6-87 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during floating mode of operation of plant is presented in Figure 6-88 and Figure 6-89.

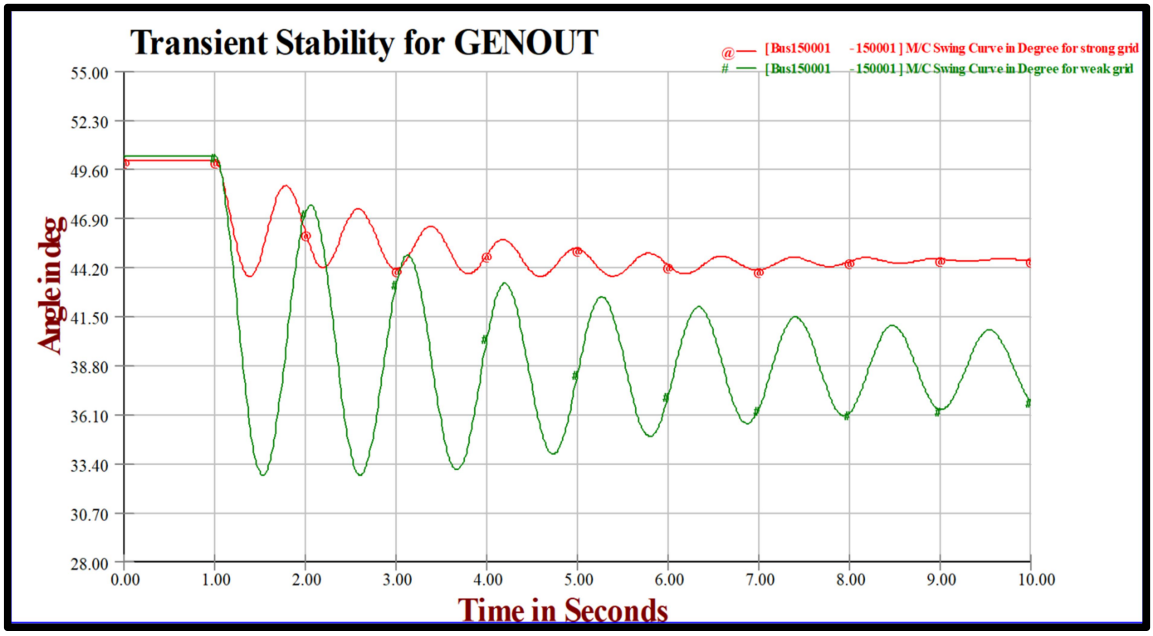

Figure 6-88 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant

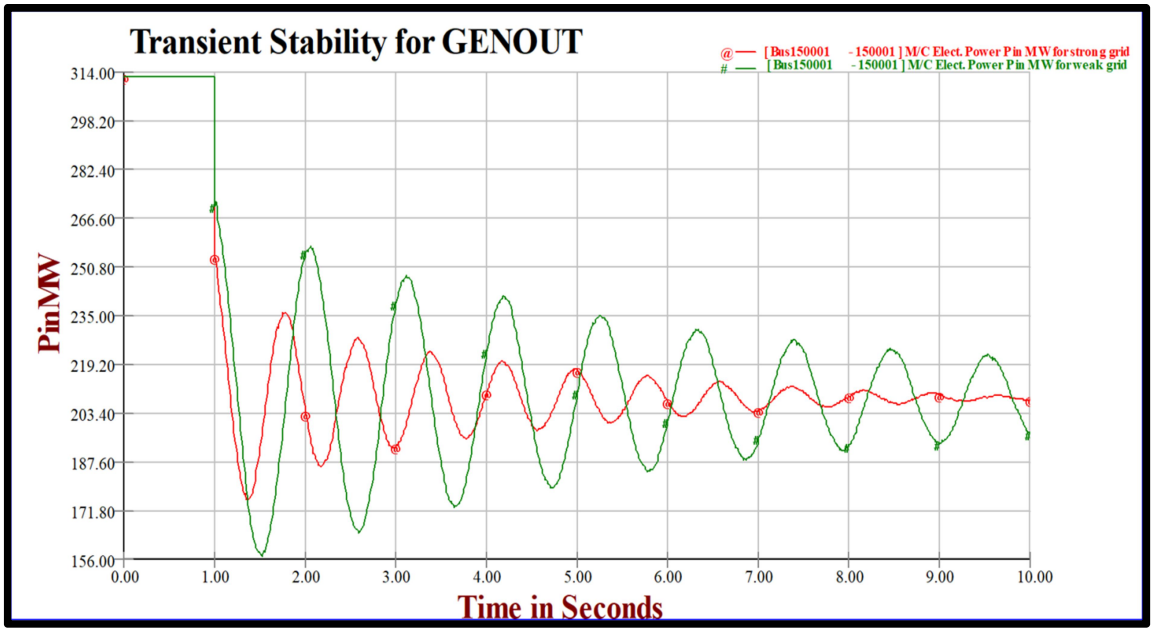

Figure 6-89 Active power for generating bus plot for highest generating unit outage inside the plant during floating mode of operation of plant

Case 22: Load throw off at the JSW plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-90 to 6-91 for a disturbance initiated due to sudden load throw off during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

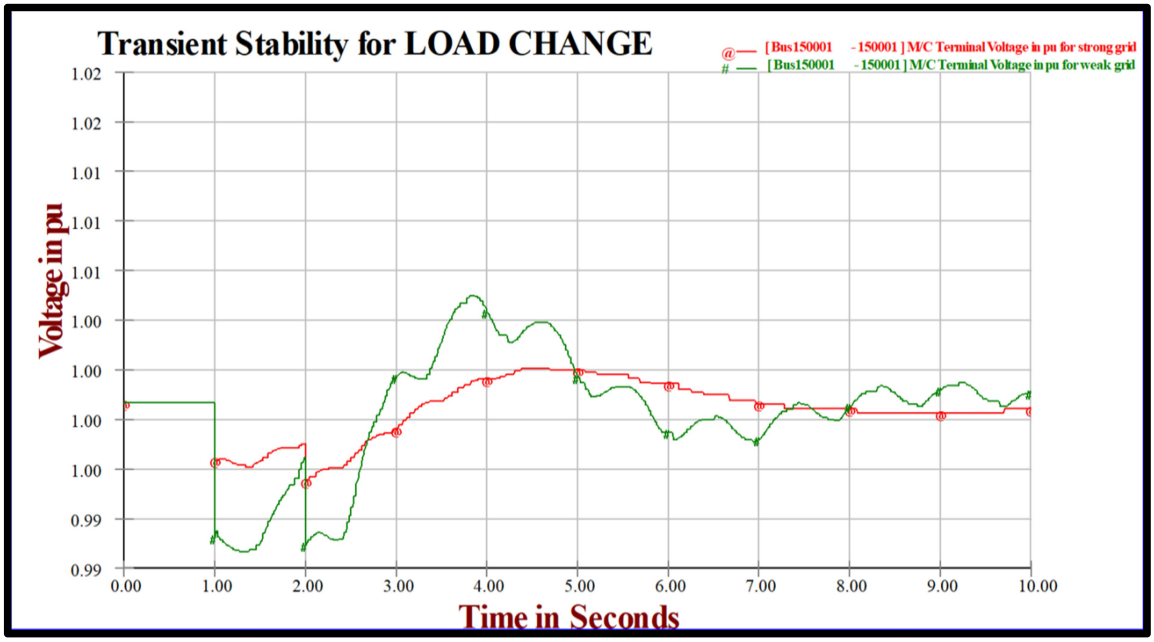

Figure 6-90 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant.

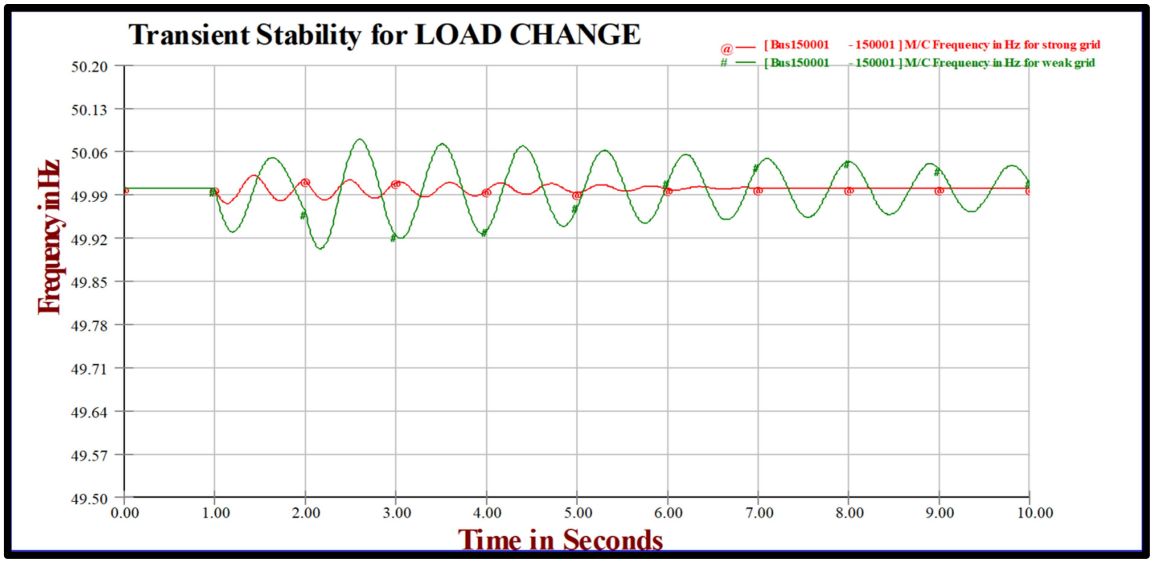

Figure 6-91 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant.

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during floating mode of plant operation of plant is presented in Figure 6-92 and Figure 6-93. Load change in a CGP for a weak grid connectivity leads to higher power swings as compared to a strong grid connectivity.

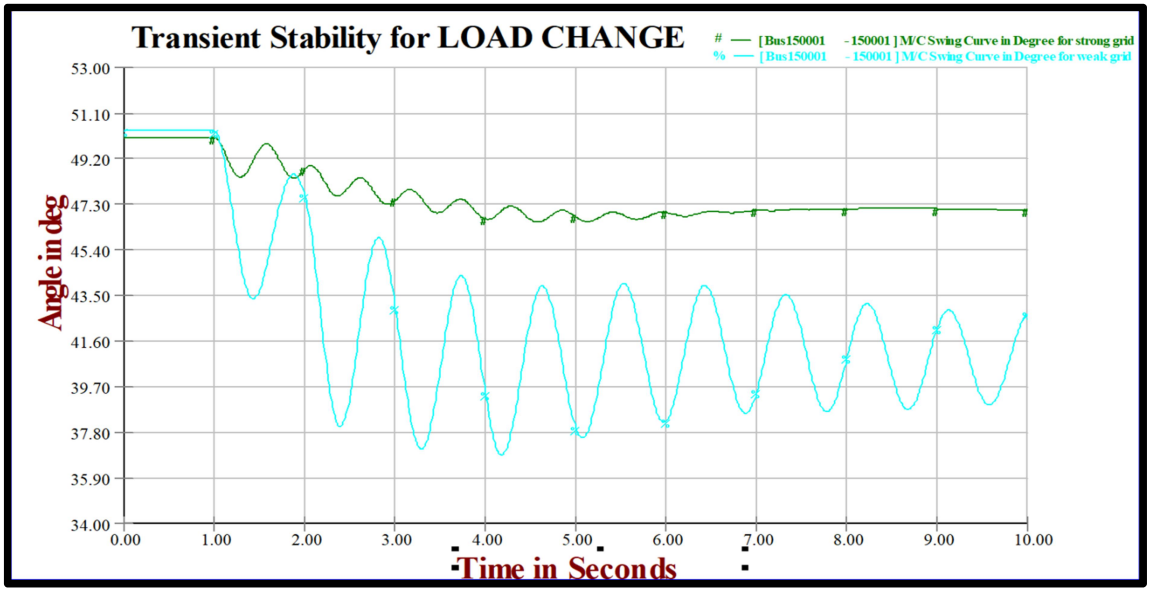

Figure 6-92 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant

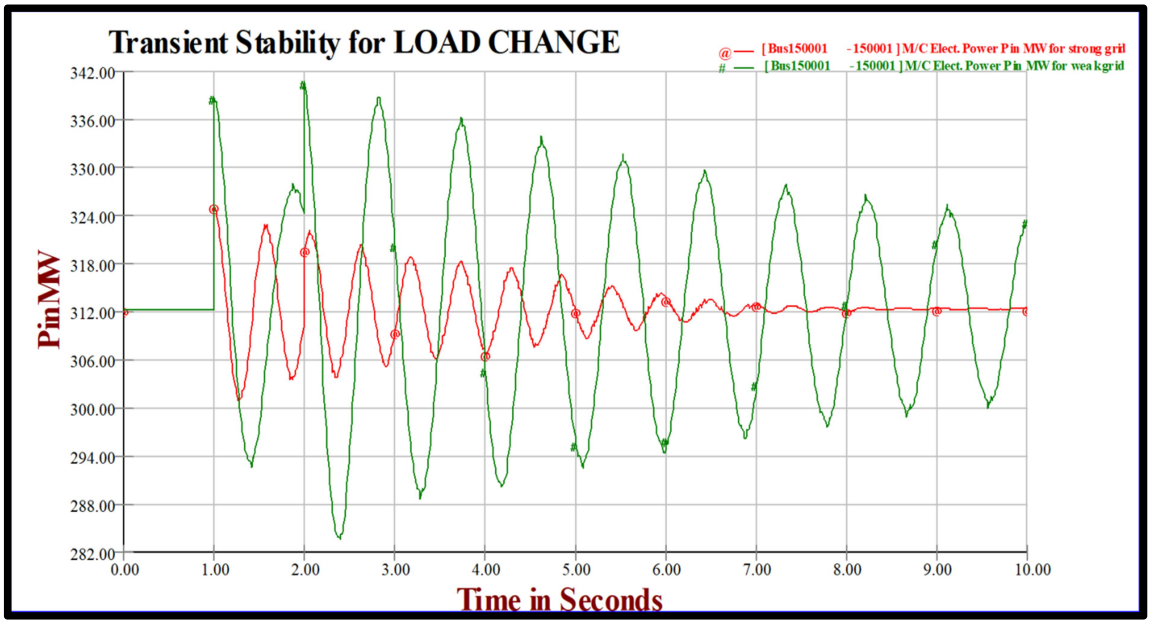

Figure 6-93 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant

Import mode

Case 23: Three Phase to ground fault at the JSW plant for a duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-94 to 6-95 for a three phase to ground fault at the power evacuation

bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

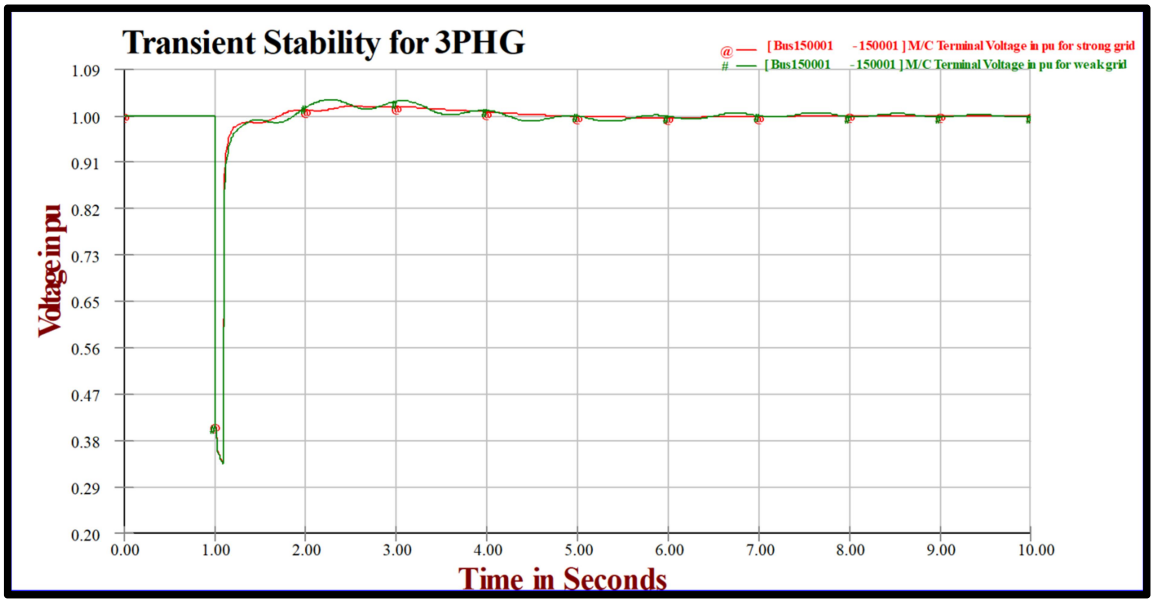

Figure 6-94 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

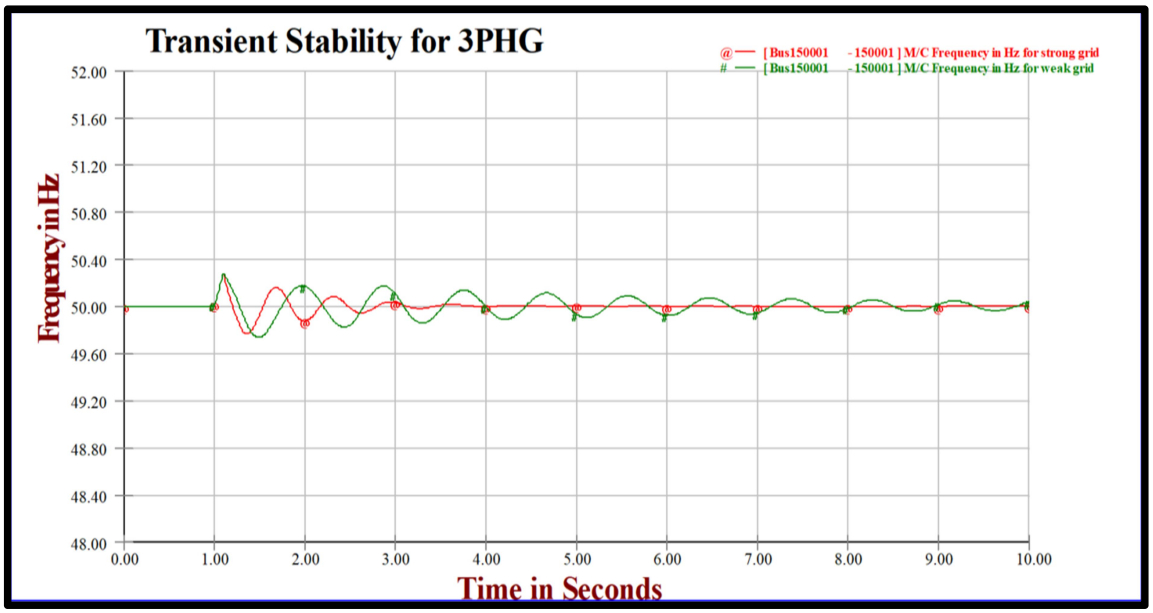

Figure 6-95 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-96 and Figure 6-97. The angle variations in case of weak grid connectivity are damped but with higher swings.

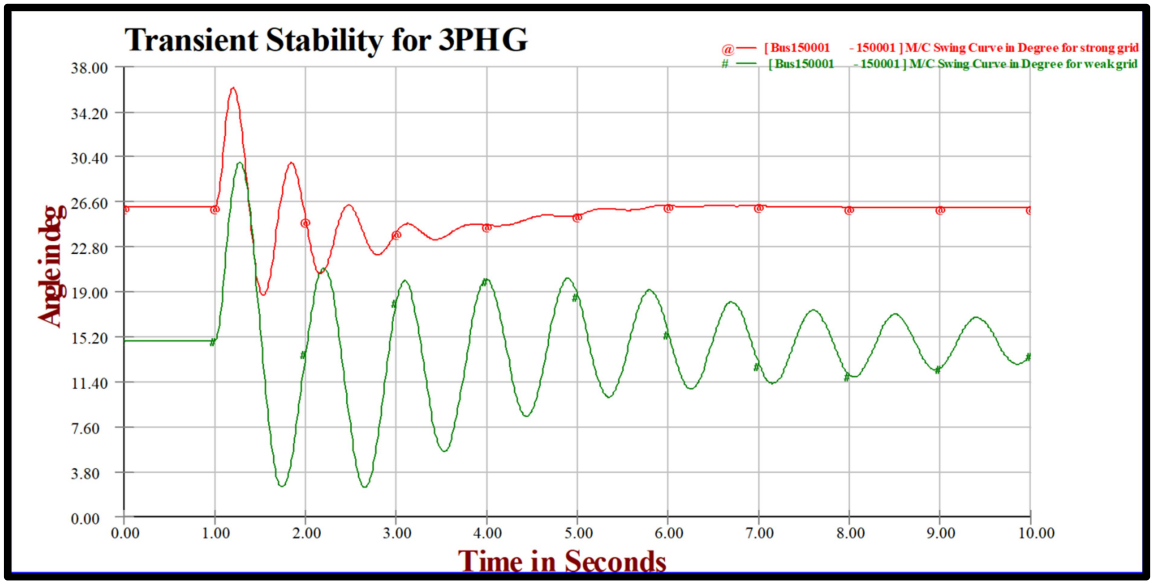

Figure 6-96 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

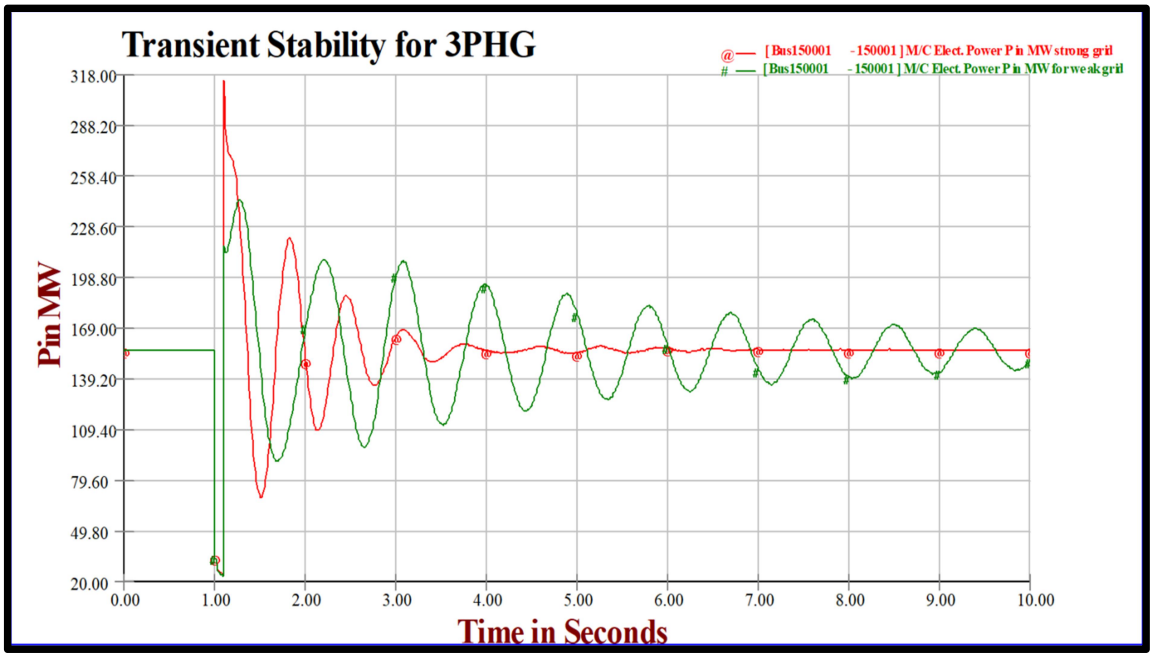

Figure 6-97 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Case 24: Single Line to ground fault at the JSW plant for duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-98 to 6-99 for a Single line to ground fault at the power evacuation bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

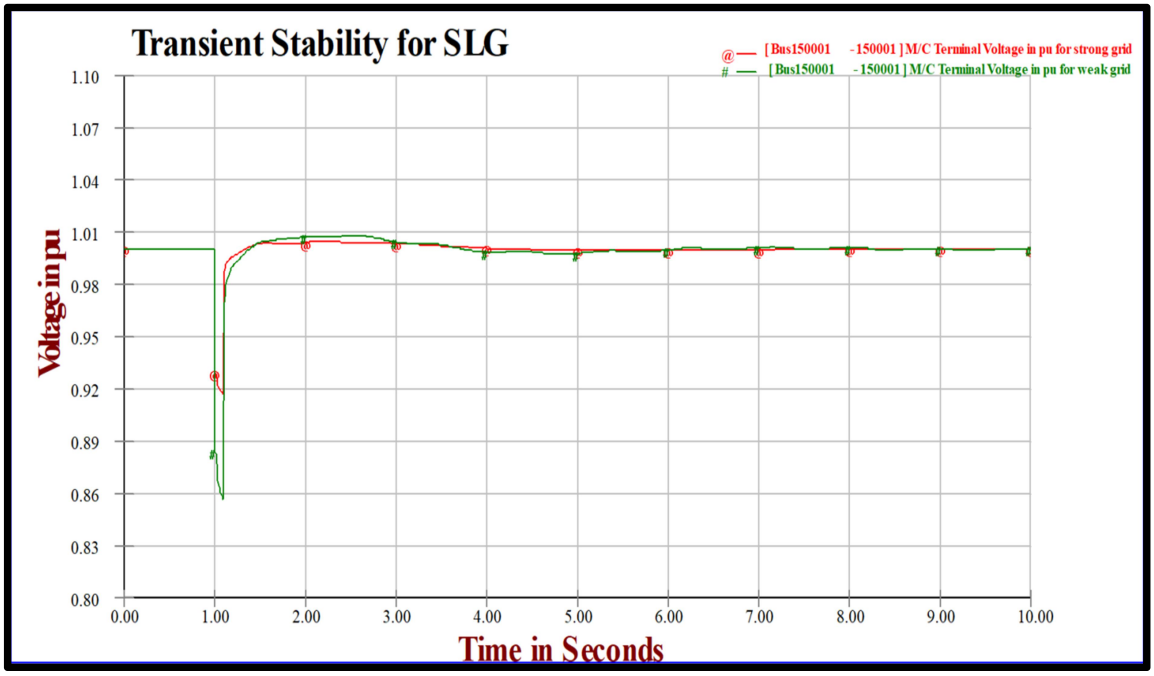

Figure 6-98 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

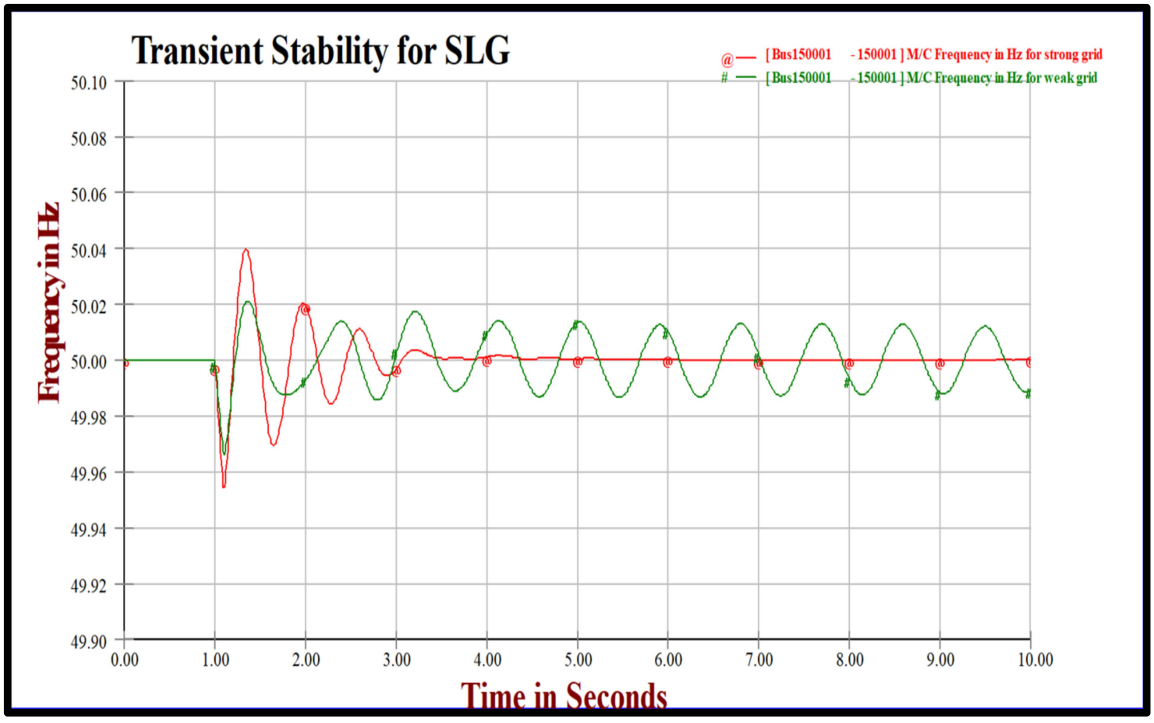

Figure 6-99 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-100 and Figure 6-101.

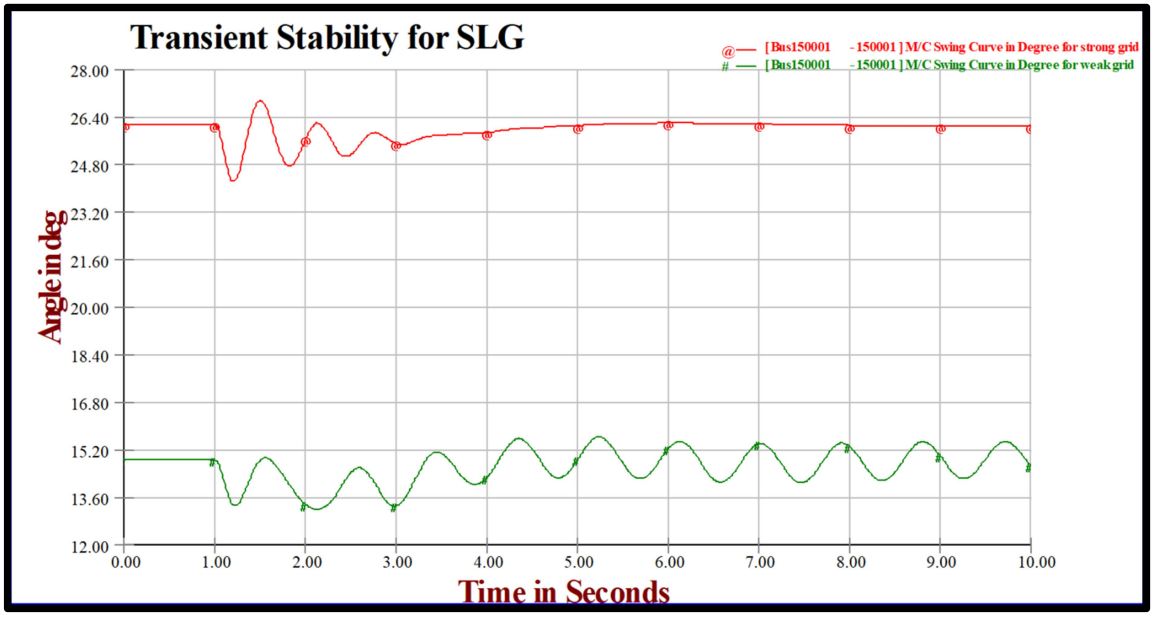

Figure 6-100 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

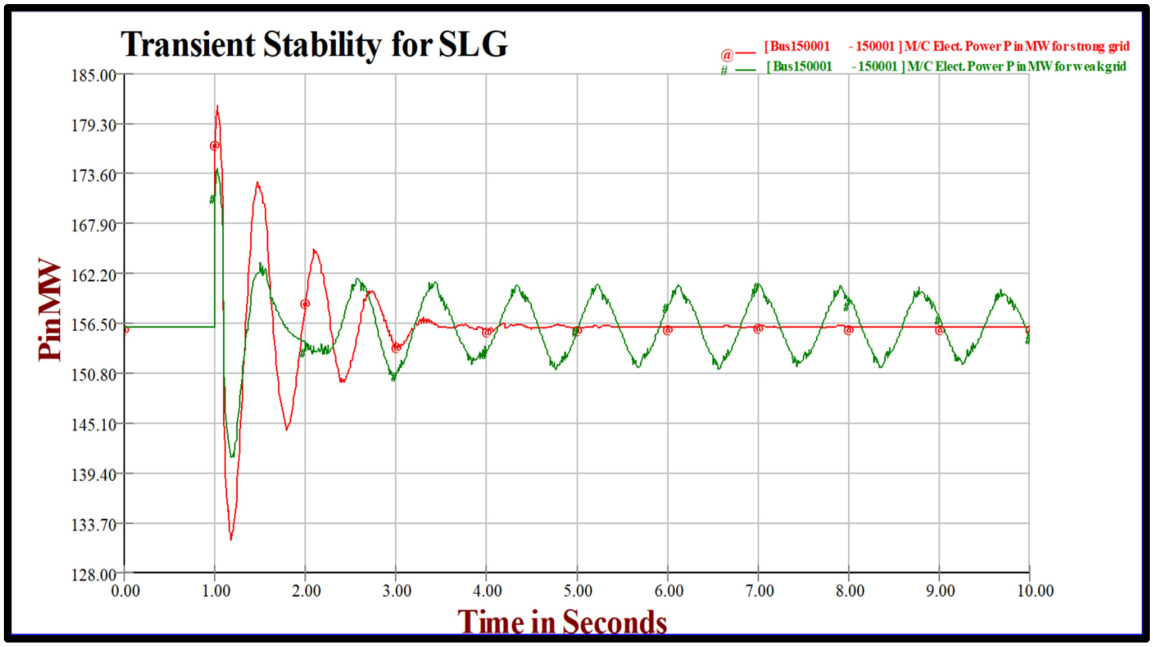

Figure 6-101 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Case 25: Outage of Largest Generator set at the JSW plant with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-102 to 6-103 for a disturbance initiated due to generator outage during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

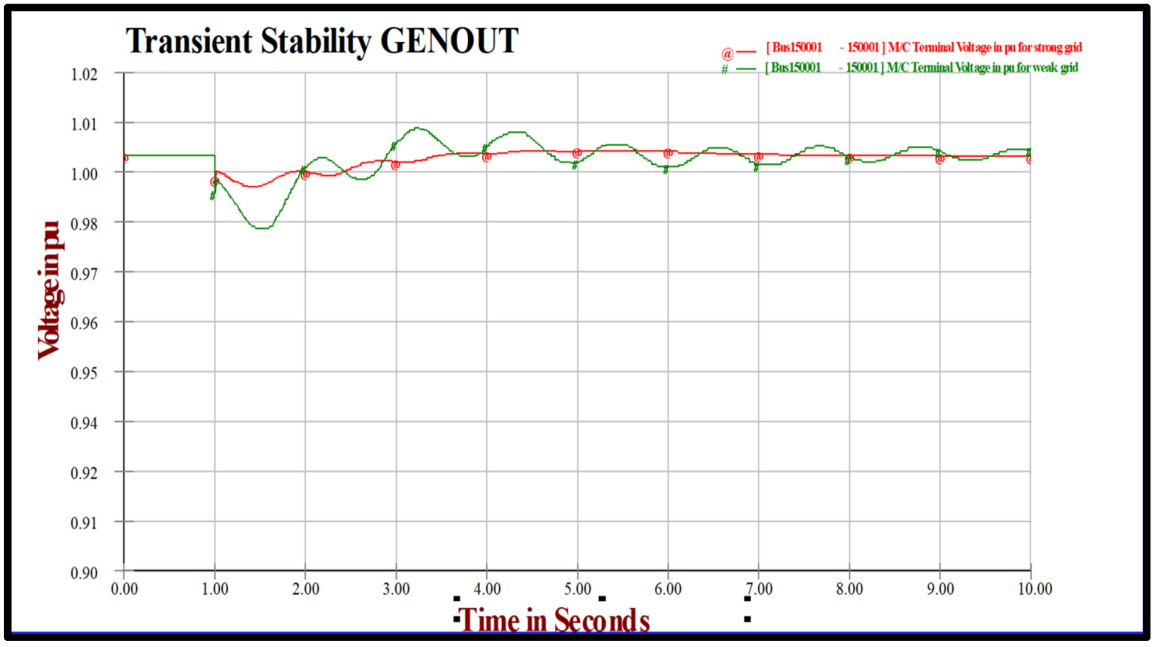

Figure 6-102 Voltage plot for highest generating unit outage inside the plant during import mode of operation of plant

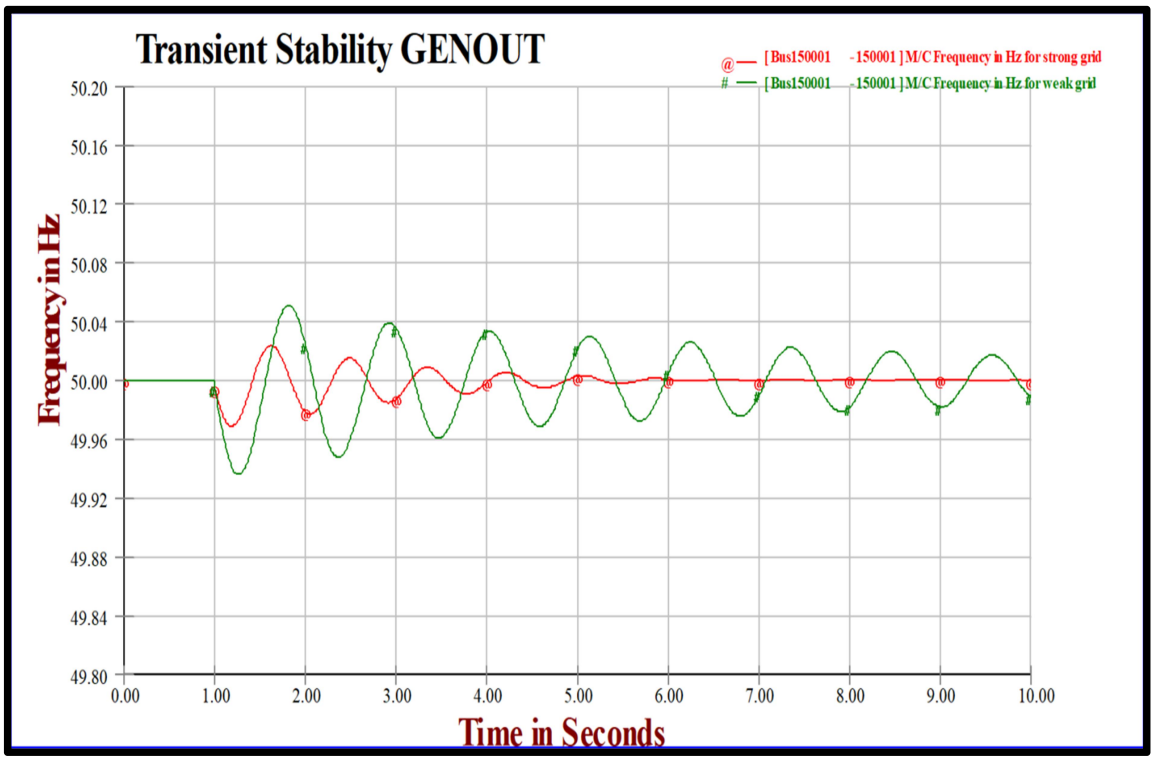

Figure 6-103 Frequency plot for highest generating unit outage inside the plant during import mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during import mode of operation of plant is presented in Figure 6-104 and Figure 6-105.

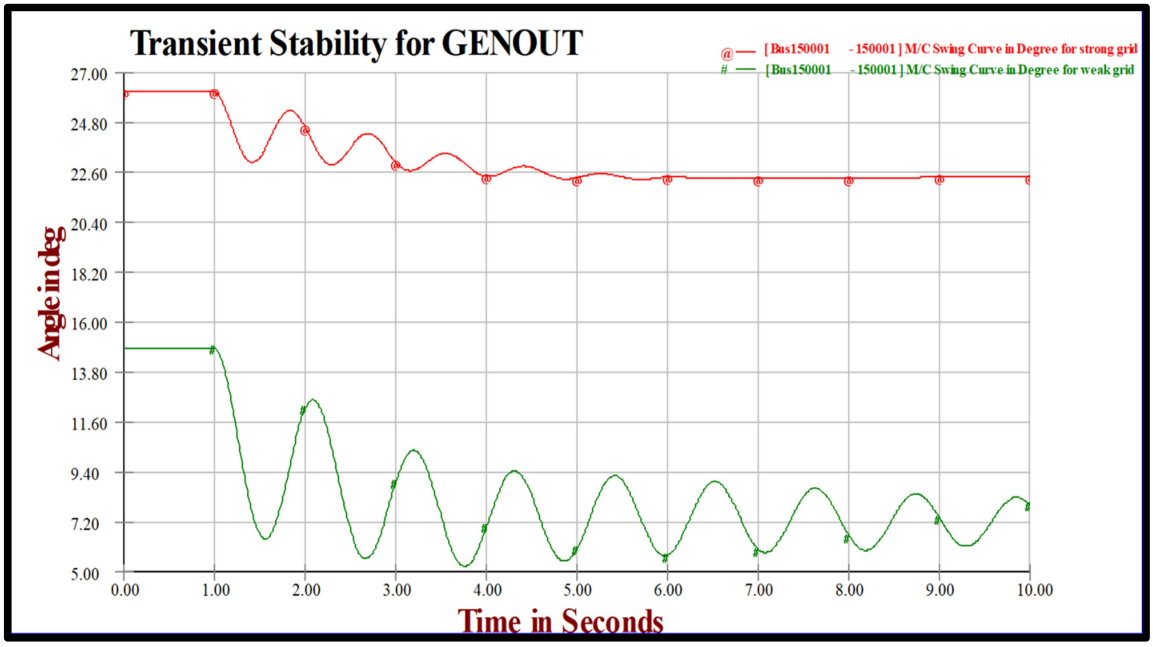

Figure 6-104 Swing curve plot for highest generating unit outage inside the plant during import mode of operation of plant

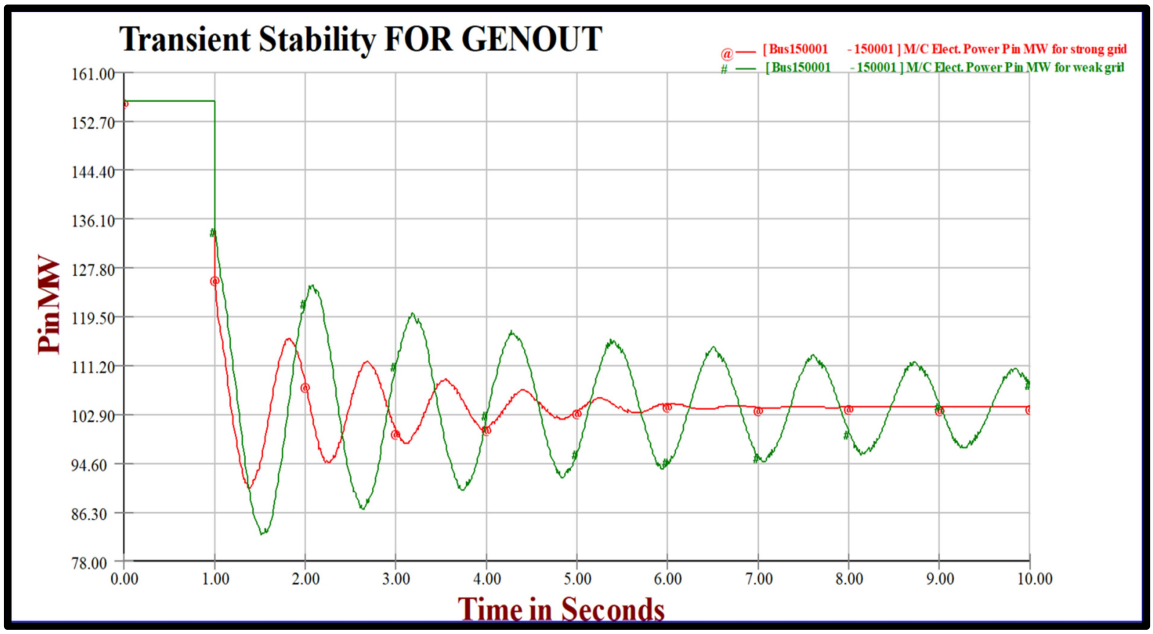

Figure 6-105 Active power plot for highest generating unit outage inside the plant during import mode of operation of plant

Case 26: Load throw off at the JSW plant with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-106 to 6-107 for a disturbance initiated due to sudden load throw off during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

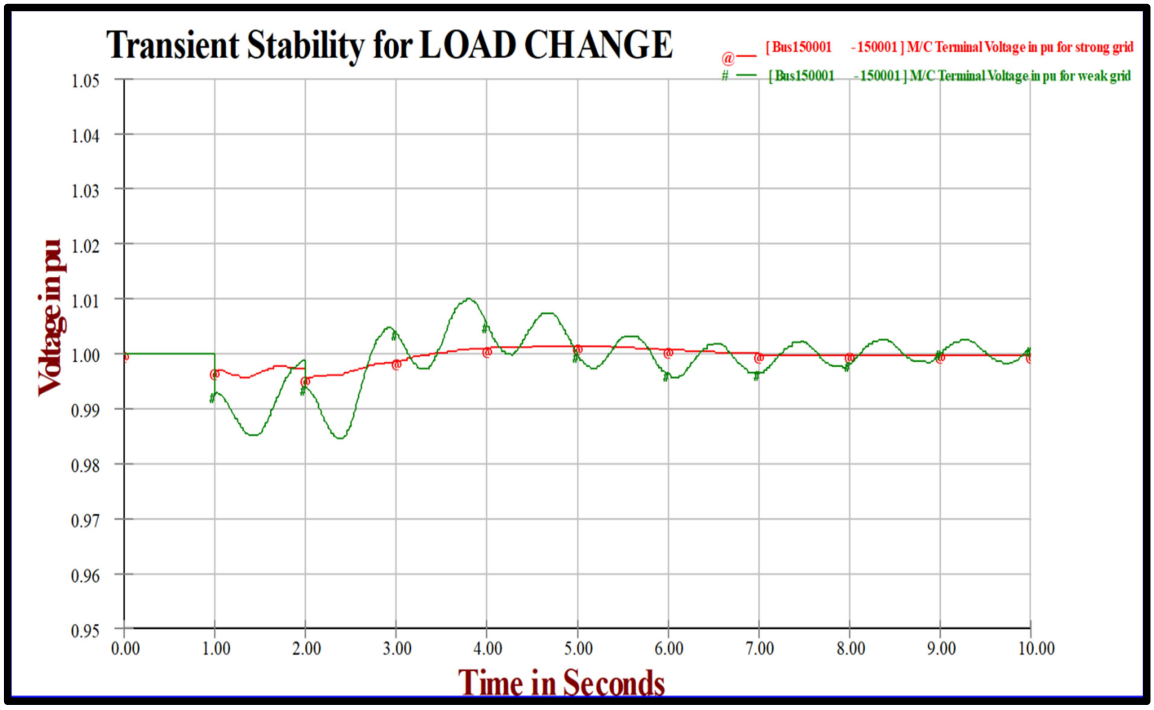

Figure 6-106 Voltage plot for sudden increase in load inside the plant during import mode of operation of plant.

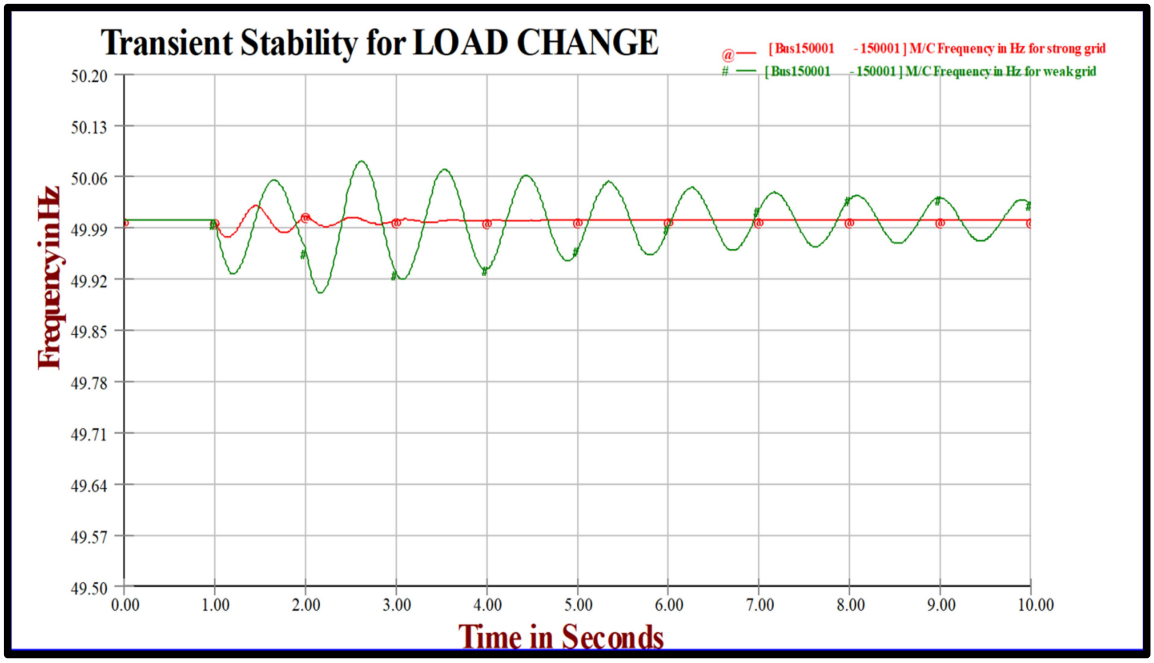

Figure 6-107 Frequency plot for sudden increase in load inside the plant during import mode of operation of plant.

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during import mode of plant operation of plant is presented in Figure 6-108 and Figure 6-109.

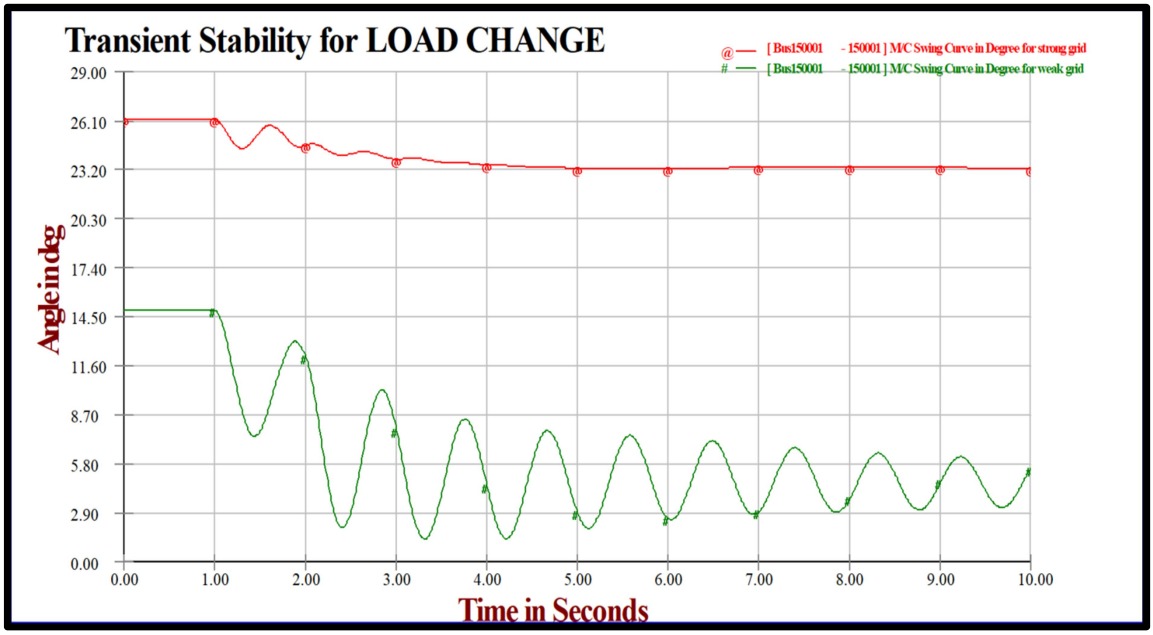

Figure 6-108 Swing curve plot for sudden increase in load inside the plant during import mode of operation of plant

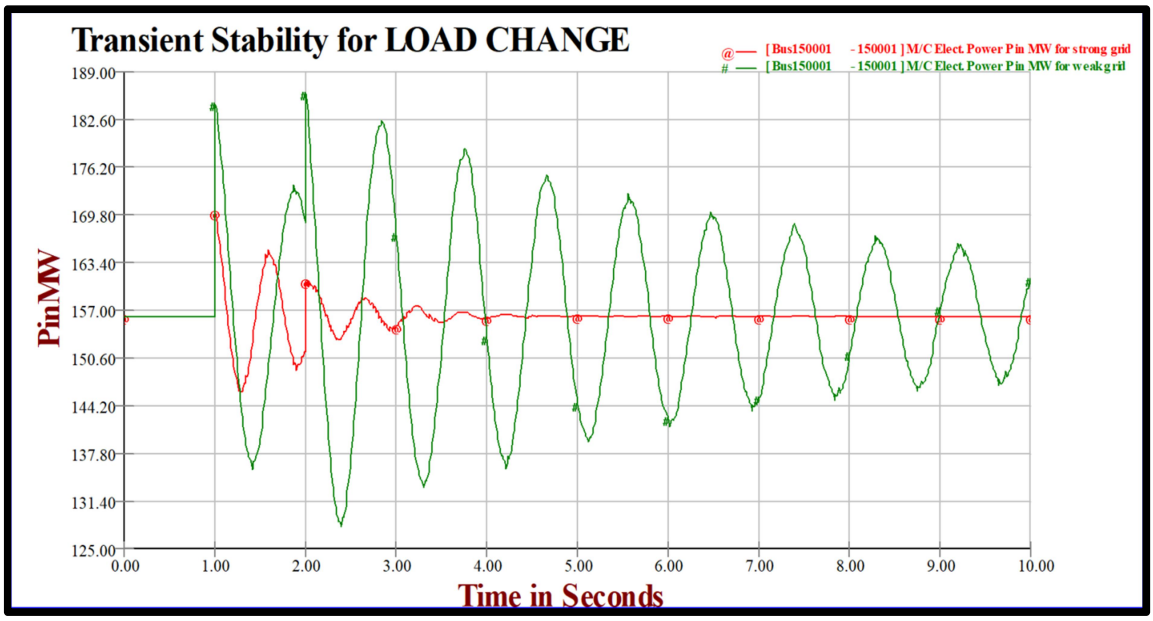

Figure 6-109 Active power plot for sudden increase in load inside the plant during import mode of operation of plant

Export mode

Case 27: Three Phase to ground fault at the JSW plant for a duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-110 to 6-111 for a three phase to ground fault at the power

evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

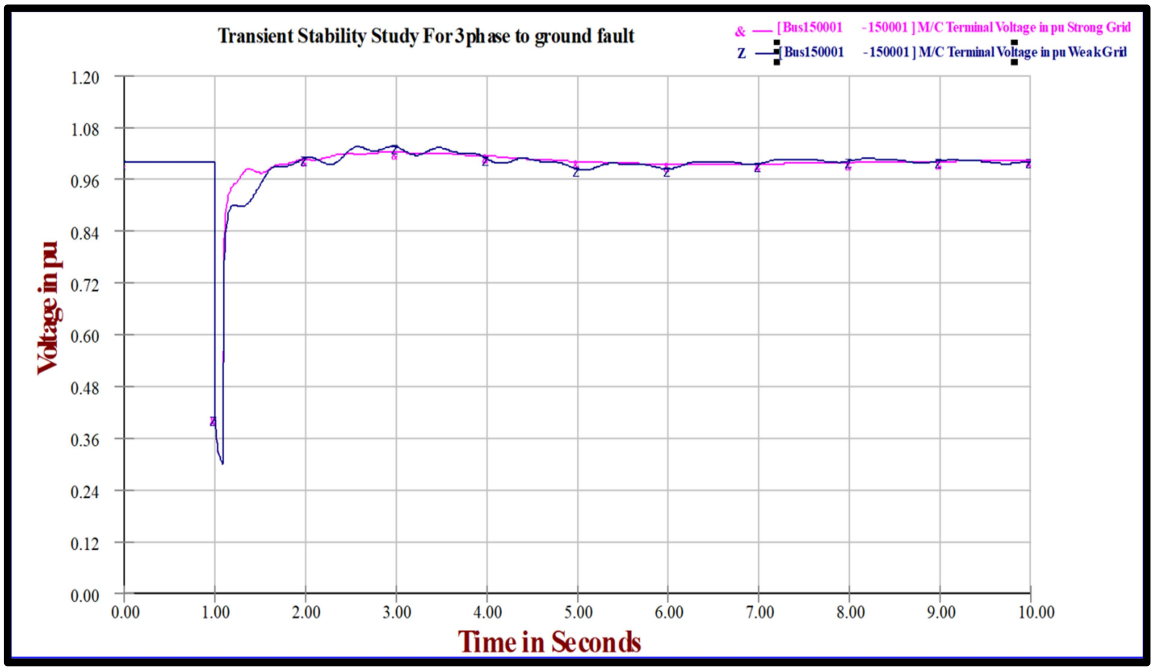

Figure 6-110 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

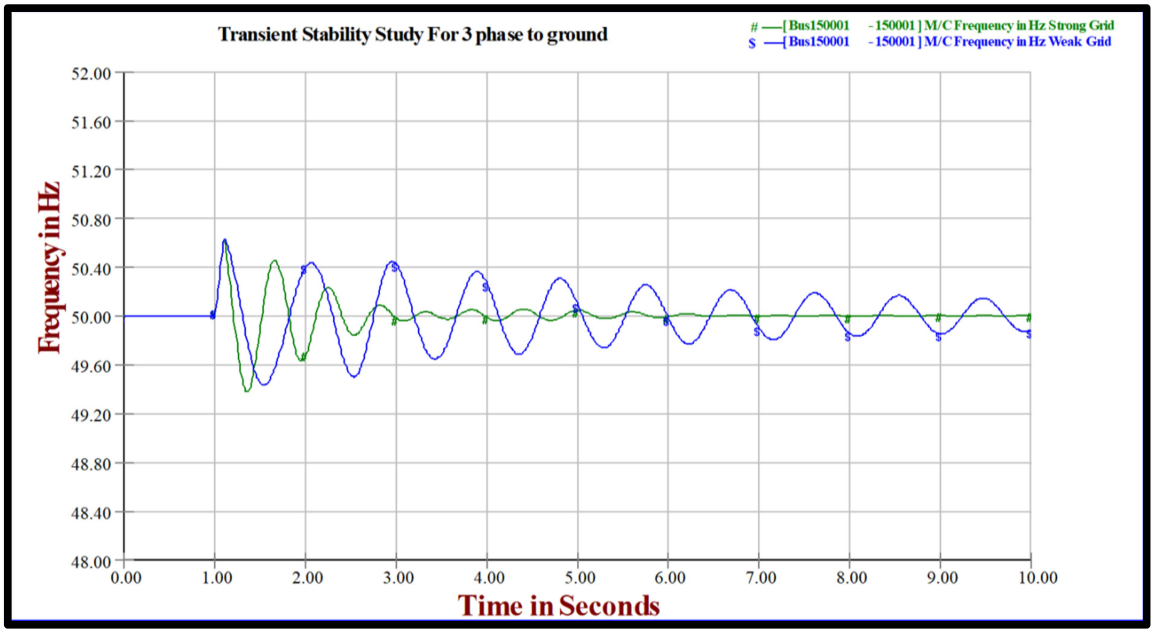

Figure 6-111 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-112 and Figure 6-113.

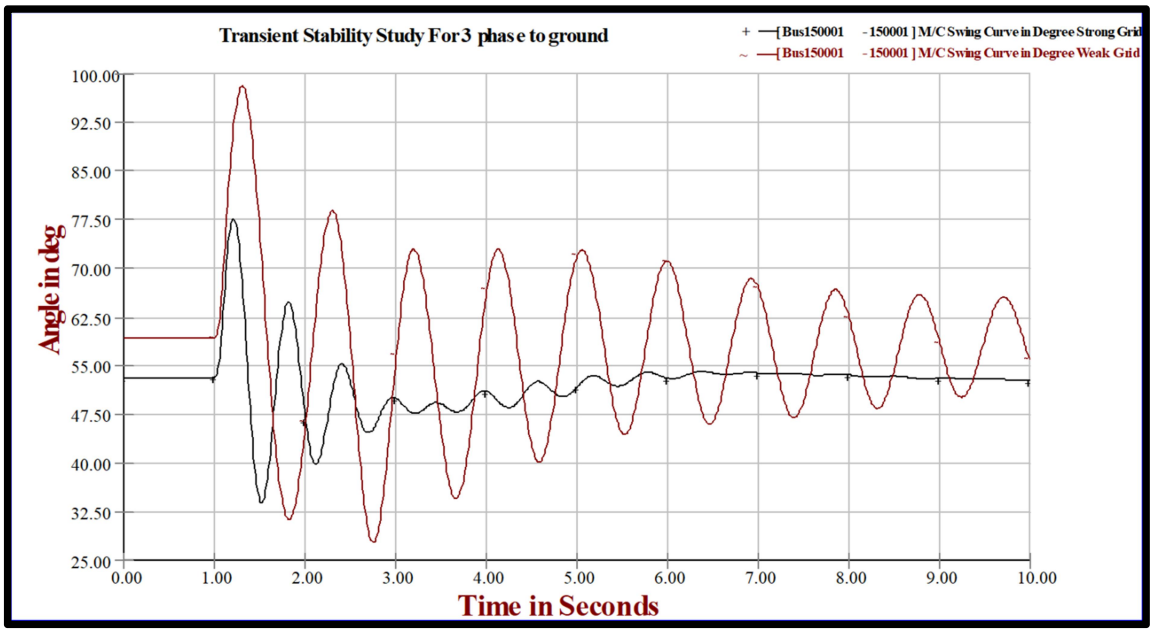

Figure 6-112 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

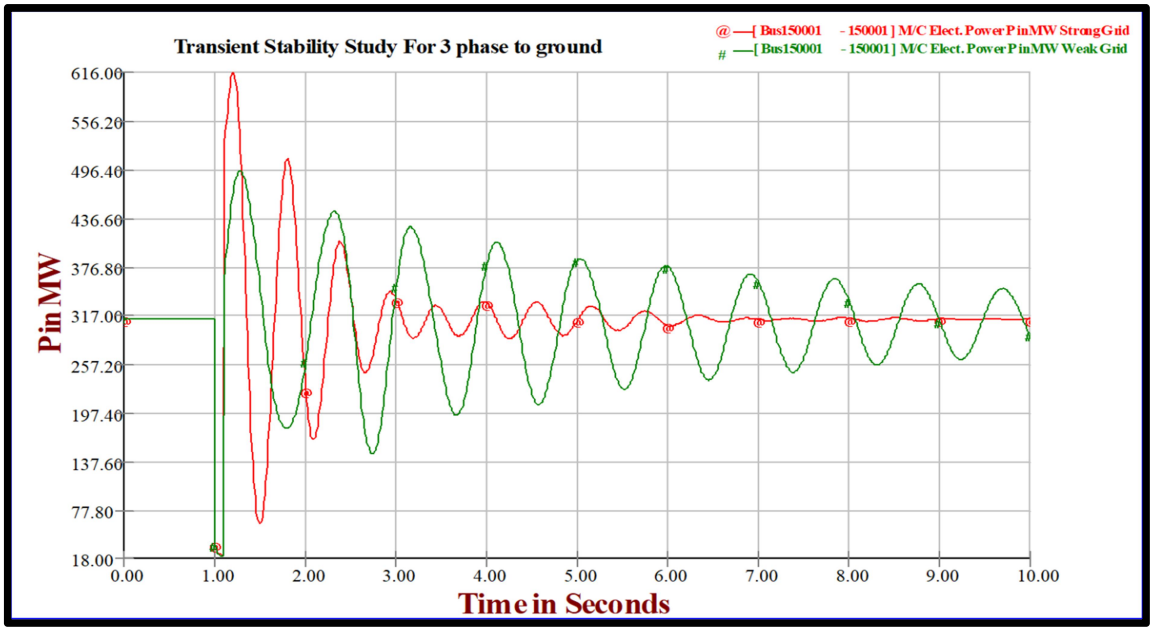

Figure 6-113 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Case 28: Single Line to ground fault at the JSW plant for duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-114 to 6-115 for a Single line to ground fault at the power evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

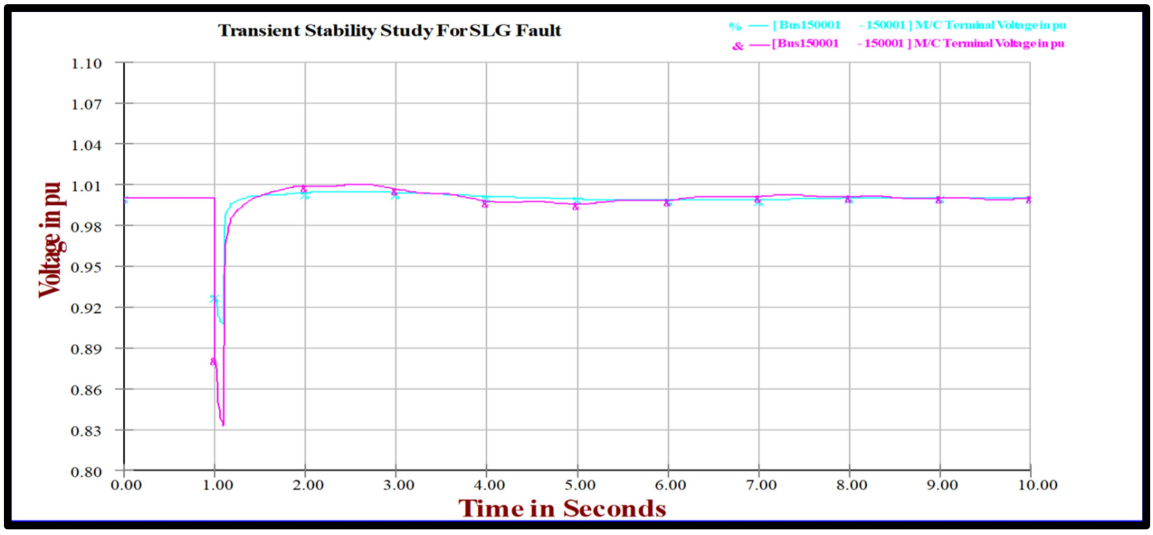

Figure 6-114 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

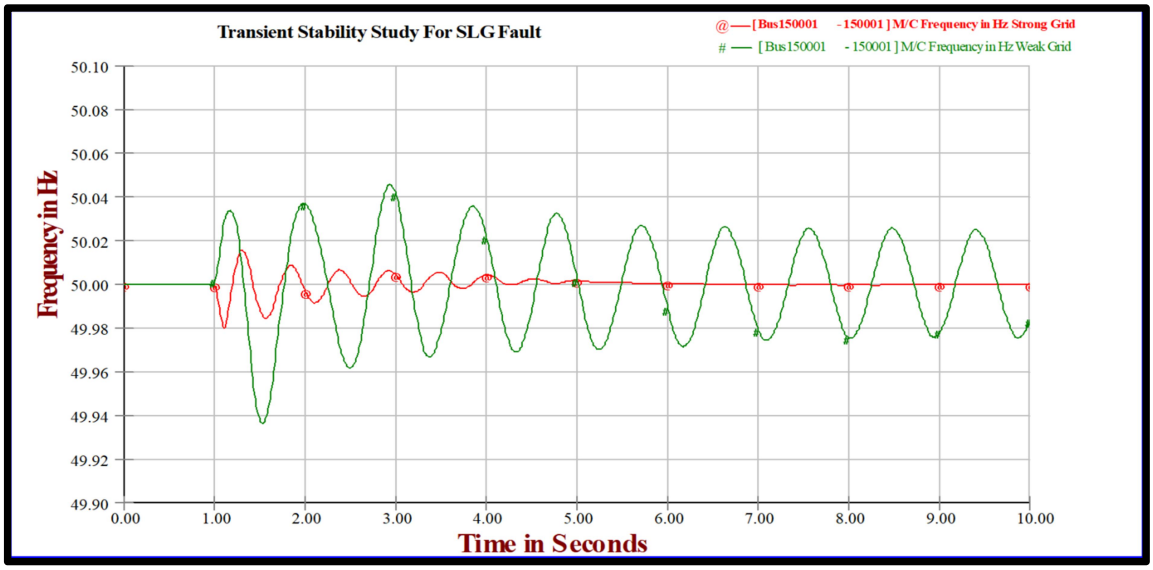

Figure 6-115 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-116 and Figure 6-117.

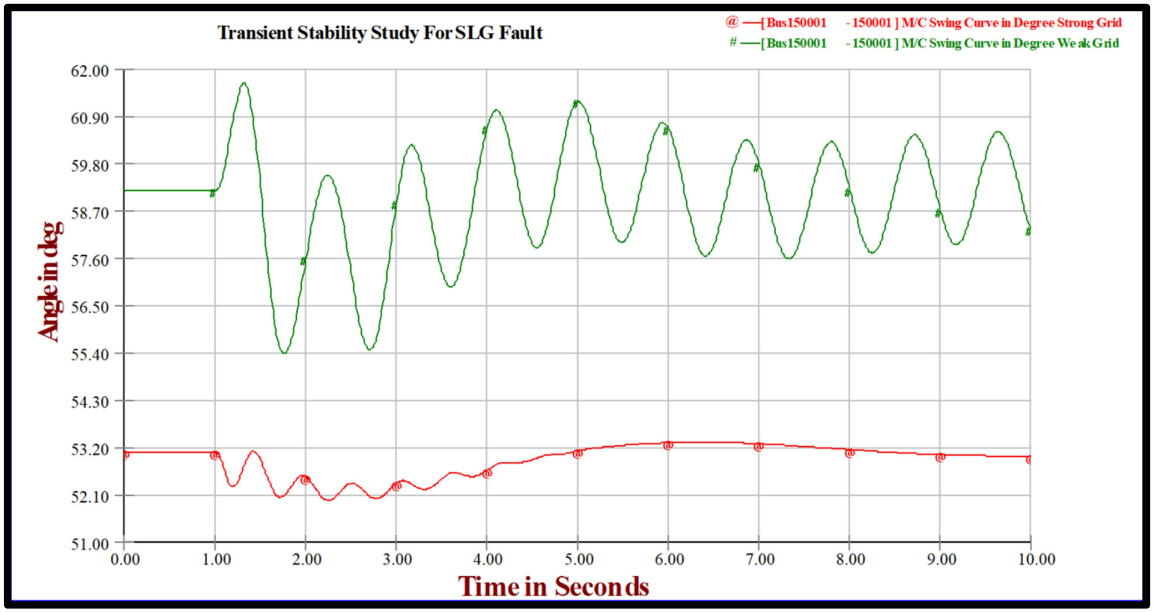

Figure 6-116 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

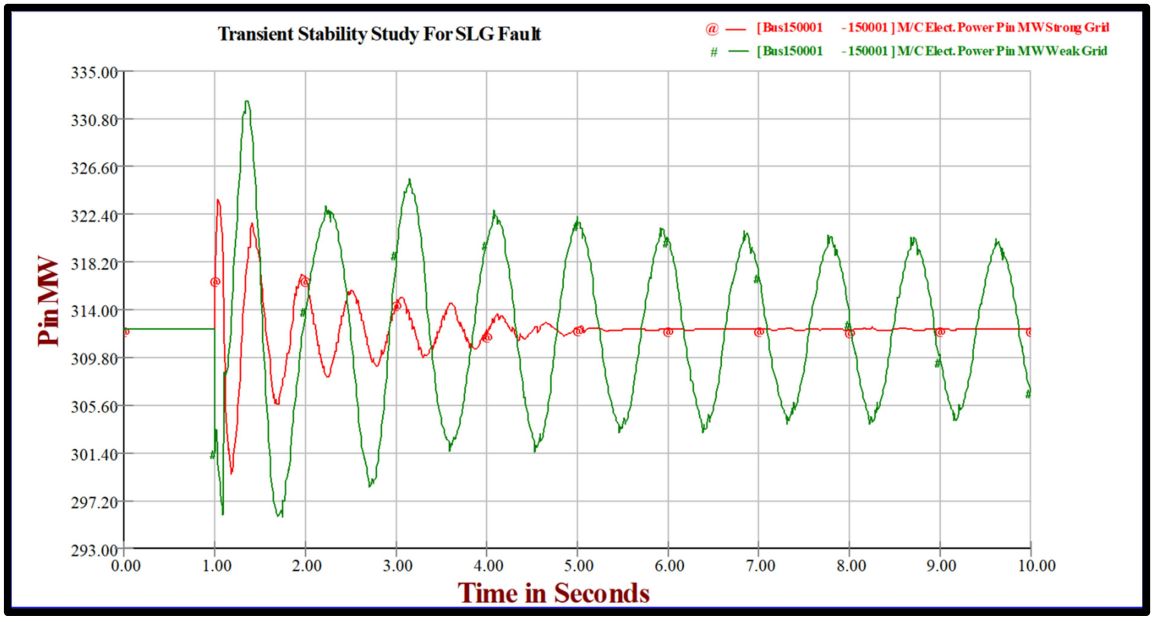

Figure 6-117 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Case 29: Outage of a Generator set at the JSW plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-118 to 6-119 for a disturbance initiated due to generator outage during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

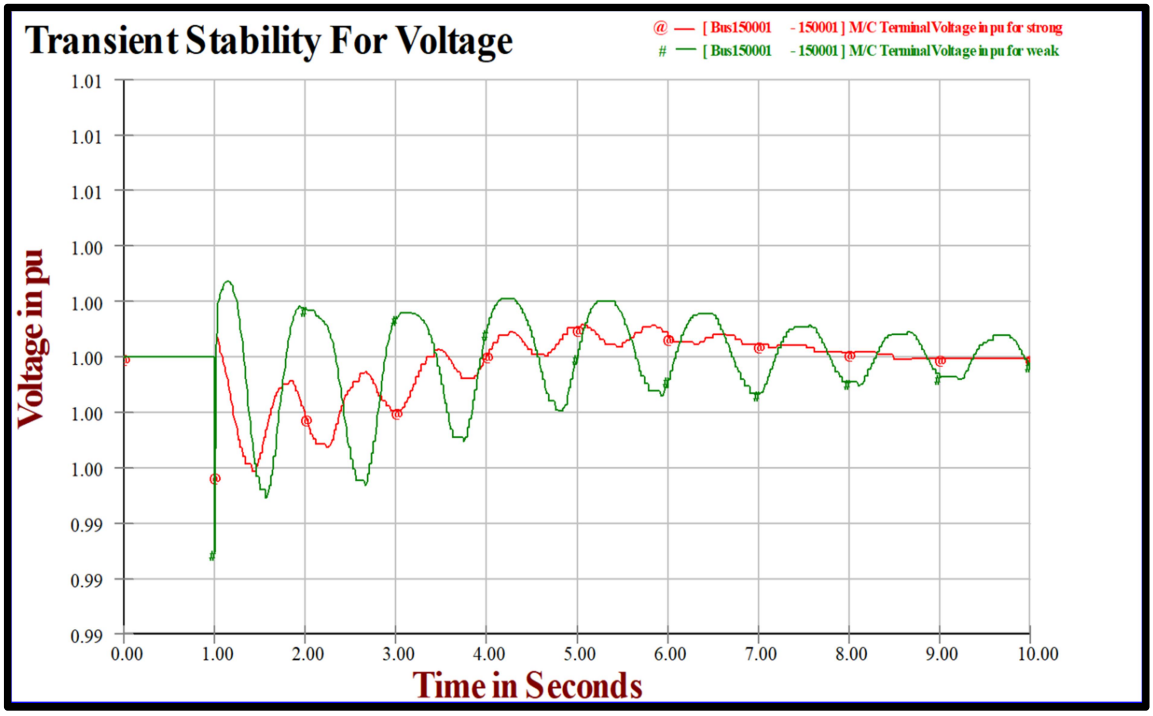

Figure 6-118 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant

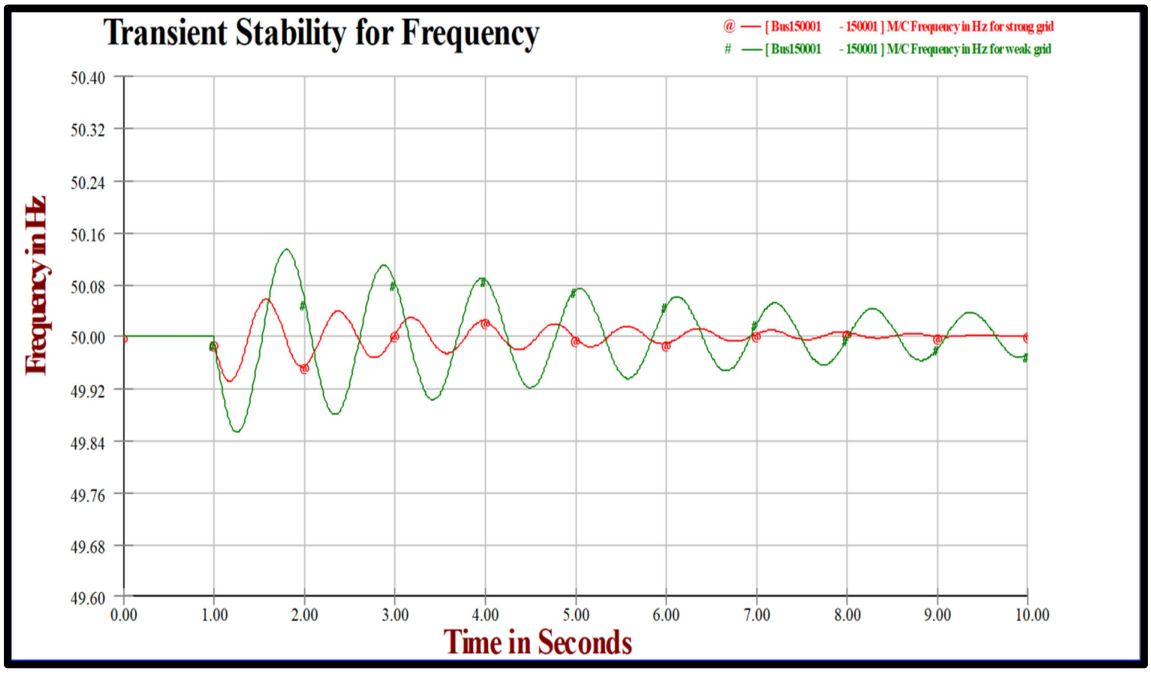

Figure 6-119 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during export mode of operation of plant is presented in Figure 6-120 and Figure 6-121.

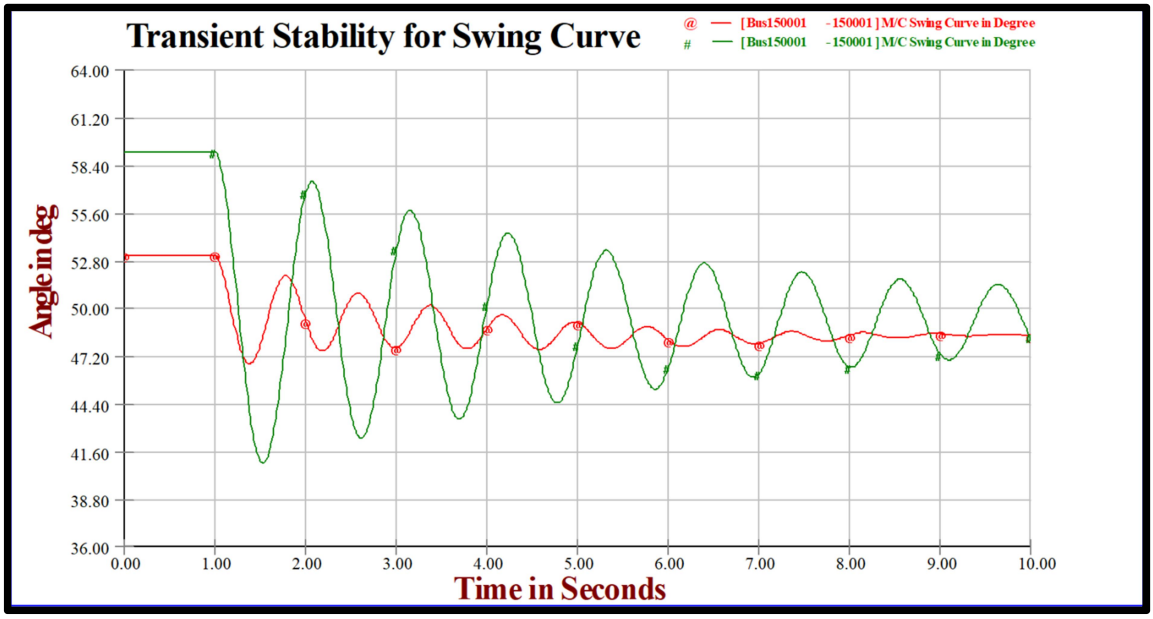

Figure 6-120 Swing curve plot for highest generating unit outage inside the plant during export mode of operation of plant

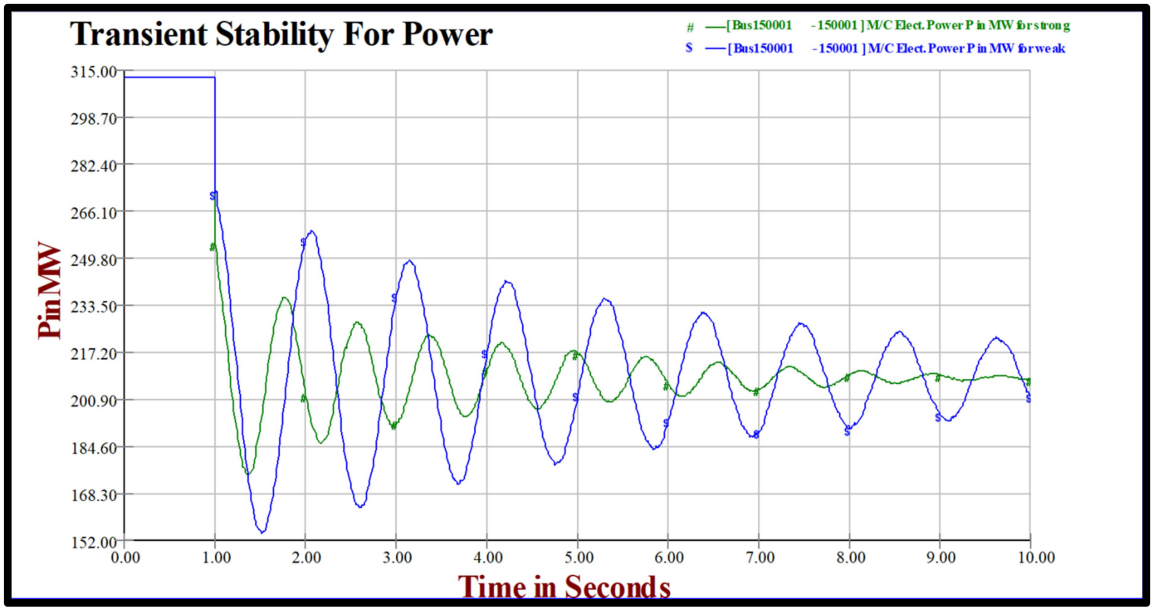

Figure 6-121 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant

Case 30: Load throw off at the JSW plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-122 to 6-123 for a disturbance initiated due to sudden load throw

off during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

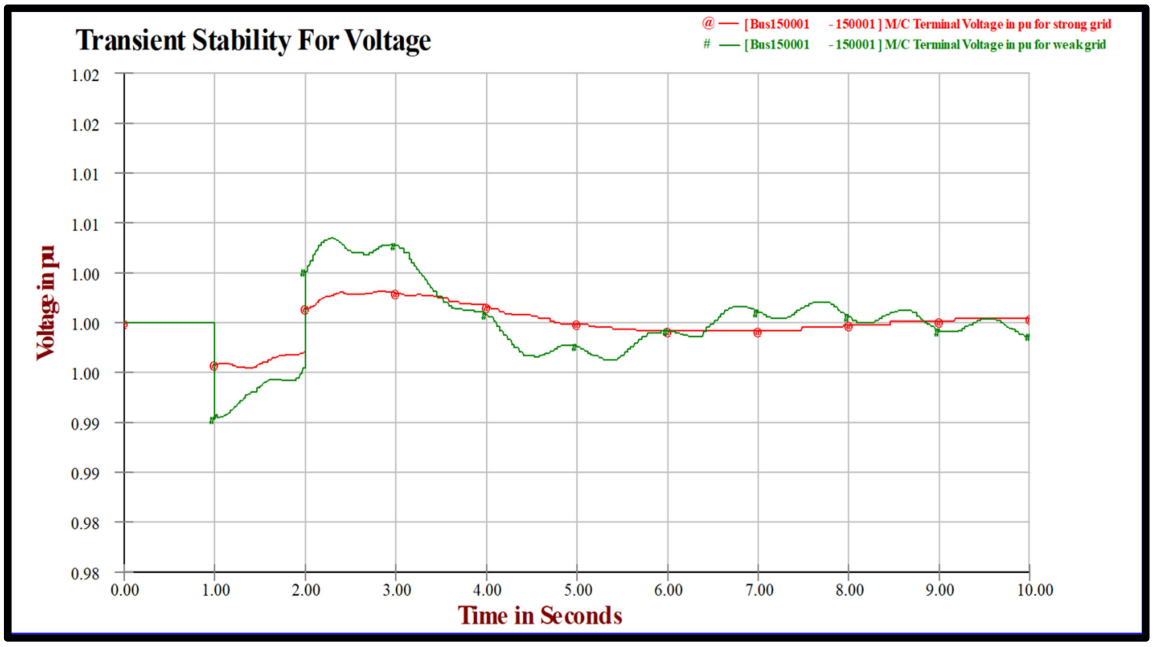

Figure 6-122 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant.

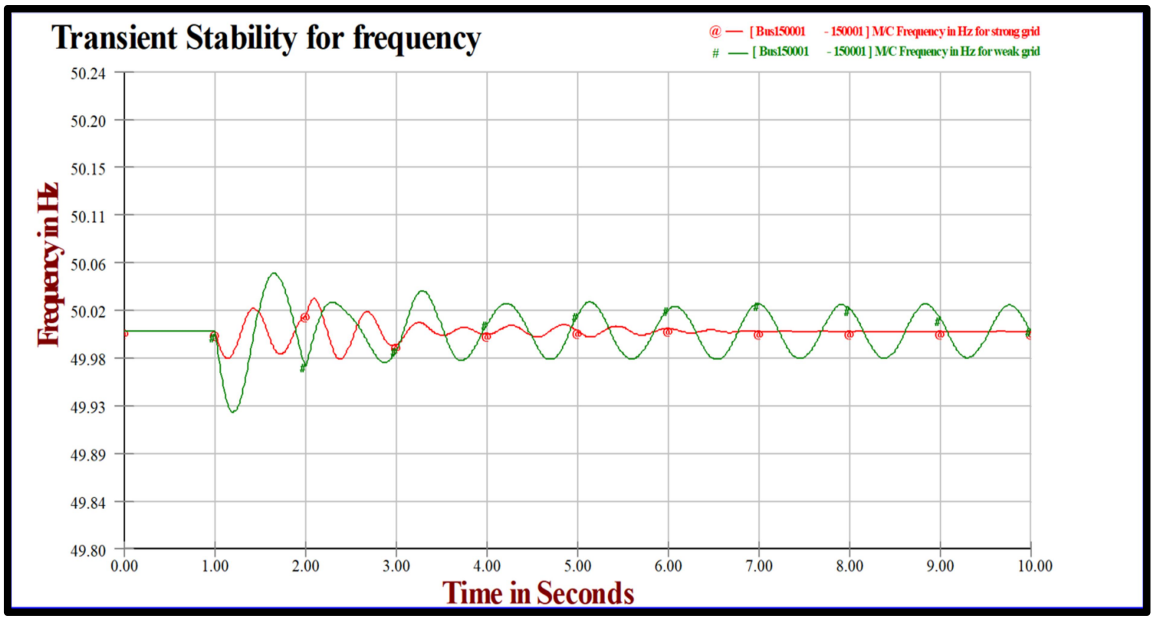

Figure 6-123 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during export mode of plant operation of plant is presented in Figure 6-124 and Figure 6-125.

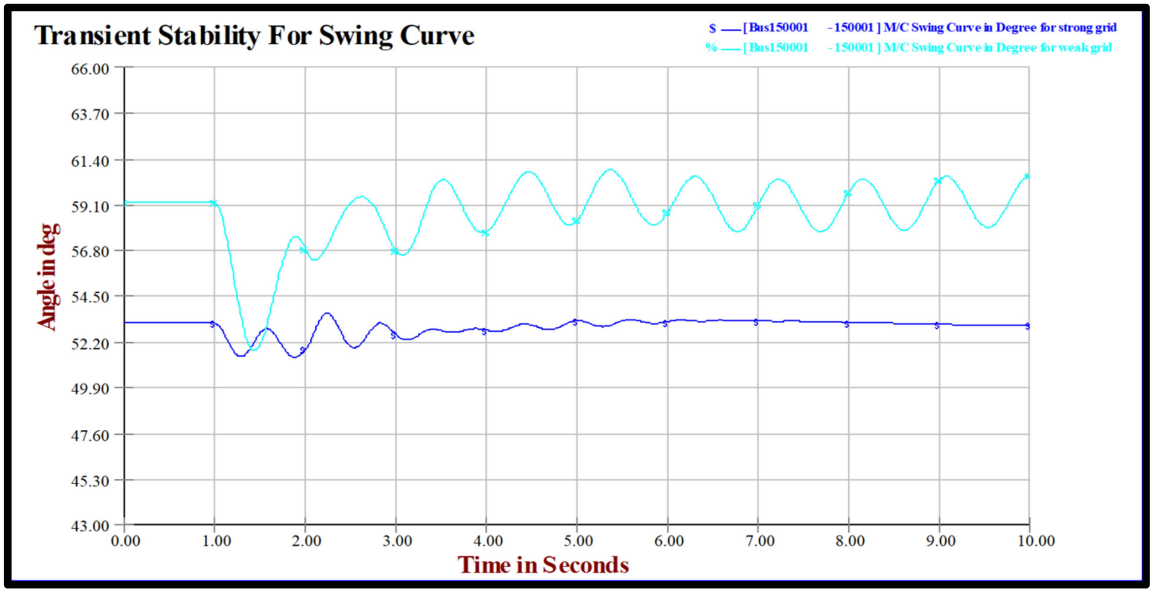

Figure 6-124 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant

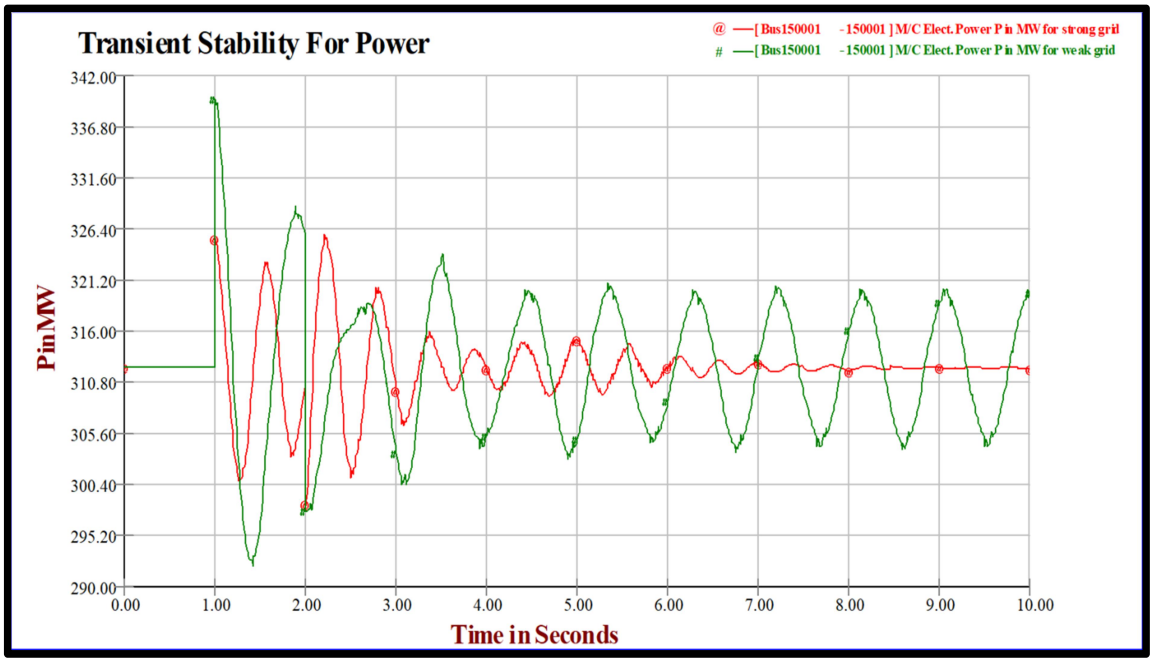

Figure 6-125 Active power plot for sudden increase in load inside the plant during export mode of operation of plant

6.7.Transient Stability of JSW Bhusan under no grid connectivity

The stability of power systems is vital for seamless operations in large-scale industries like Bhushan Steel, where even brief disruptions can have significant impacts on production and safety. This report investigates the transient stability of Bhushan Steel's power system,

analyzing its ability to endure and swiftly recover from sudden disturbances, such as faults or switching events

From Figure 6-126 it can be observed that there is a decrease in frequency after certain interval which indicates that there is a problem with the system. The system might be experiencing a loss of power or a problem with the power generation.

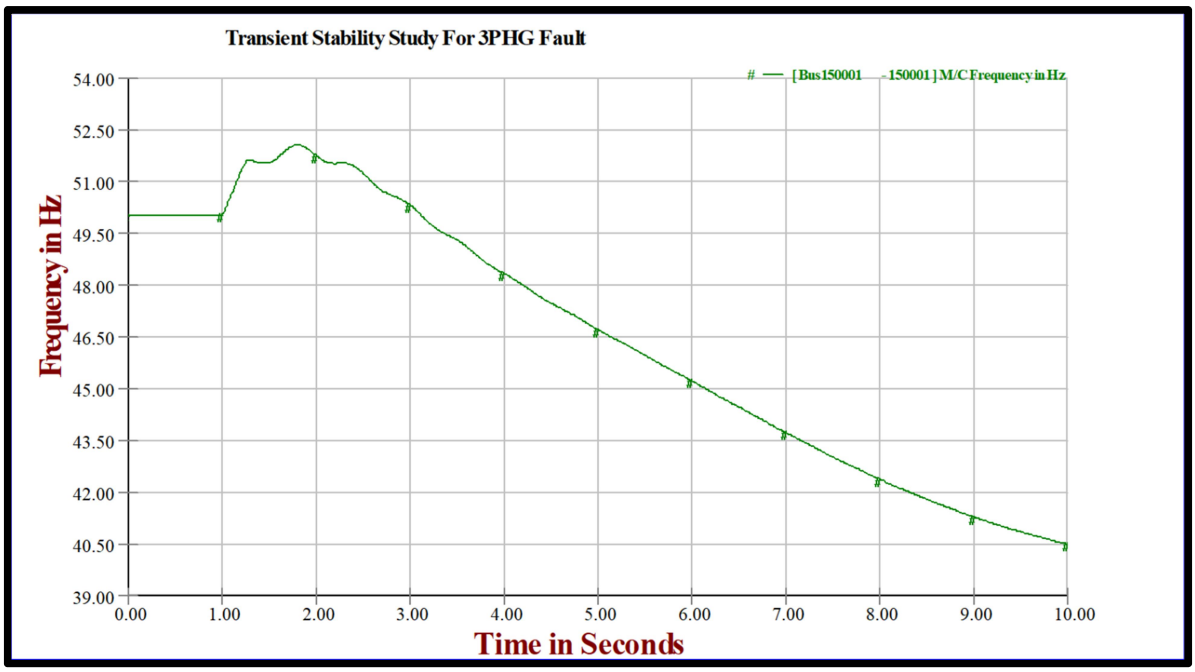

Figure 6-126 Frequency response of Bhusan generator

The voltage stability study for the 3PHG fault shows that the system experienced a significant voltage dip upon the occurrence of the fault. The voltage recovered quickly, but the system voltage settles at a new lower equilibrium state. This suggests that the system is likely not operating at its full capacity which is clearly seen in Figure 6-127.

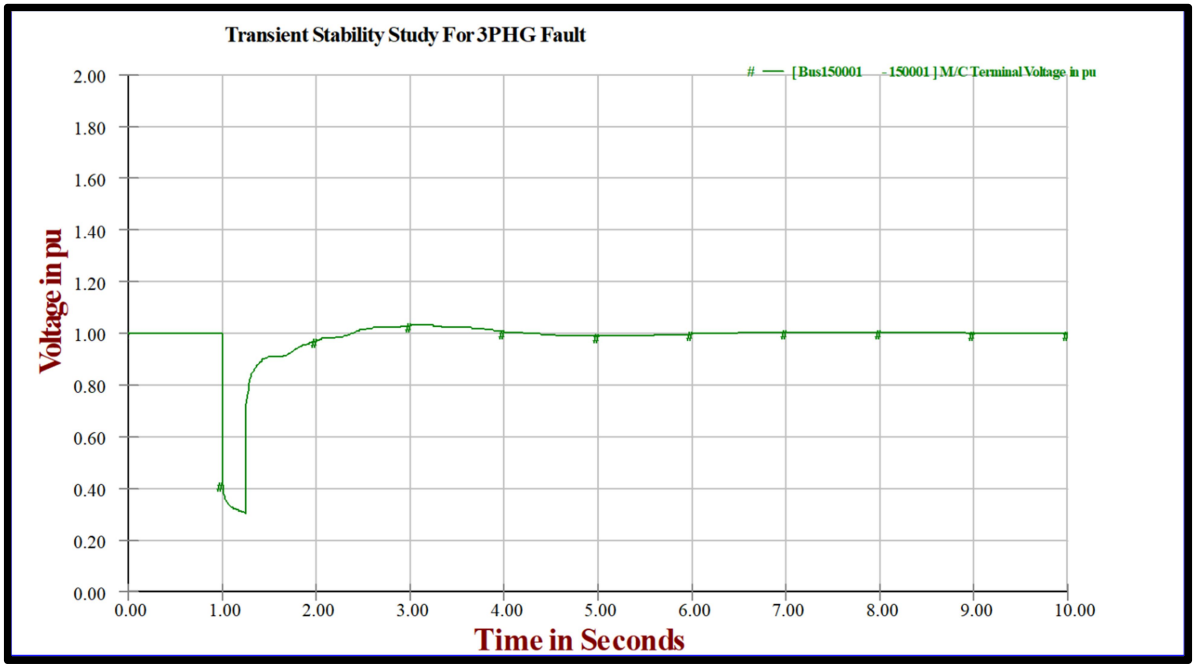

Figure 6-127 Voltage response

The angle curve can be observed from the Figure 6-128. The graph shows that the machine is initially stable, but then becomes unstable after the fault occurs. The machine then oscillates for a while before eventually stabilizing again.

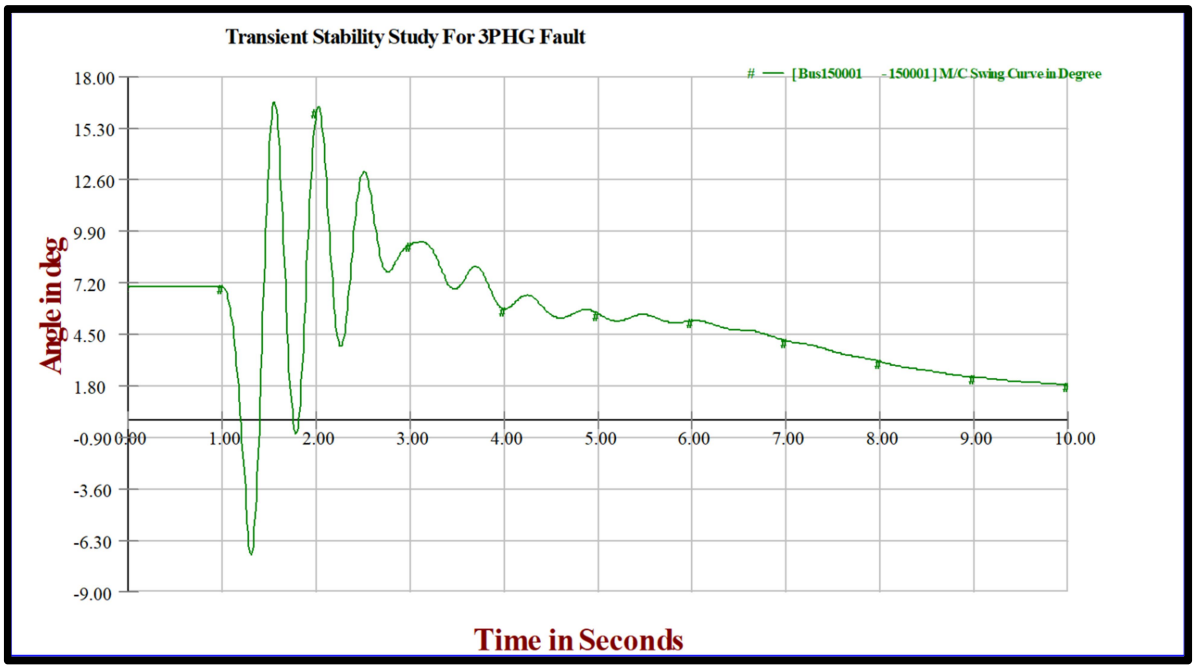

Figure 6-128 Swing curve of Bhusan generator

In Figure 6-129, the power initially drops to a very low value and then oscillates before eventually settling at a new value. This indicates that the system is able to recover from the

fault and maintain stability. The oscillations in the power after the fault are caused by the interaction of the system's components, such as the generators, transmission lines, and loads.

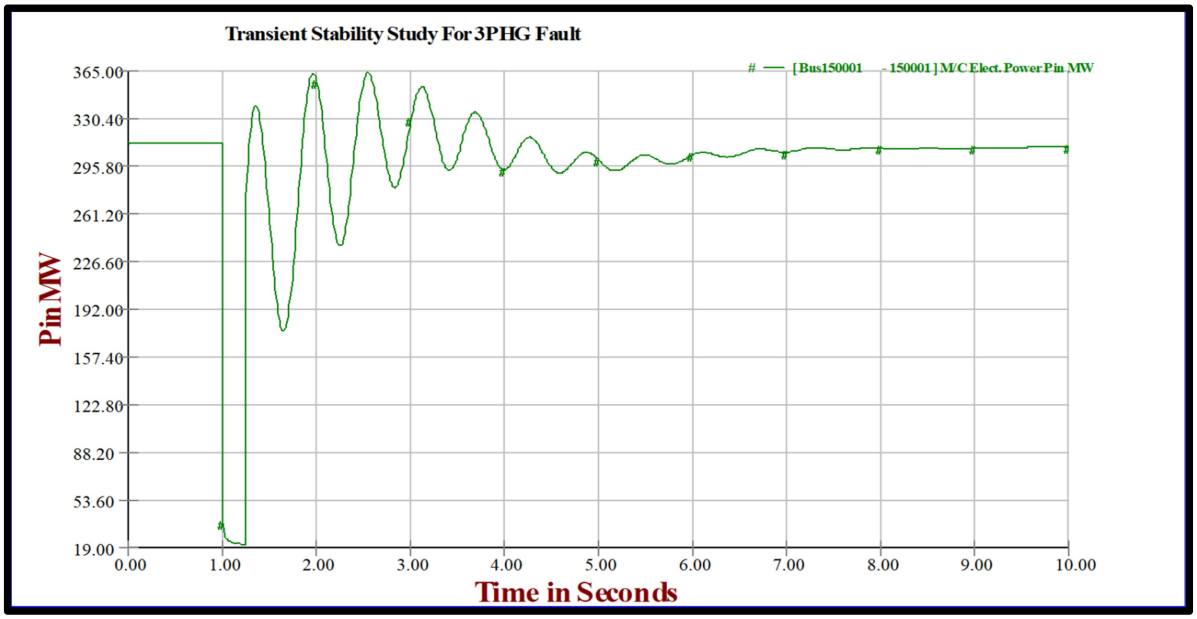

Figure 6-129 Active Power for Bhusan Generator

The Figure 6-129 shows the transient stability study for a 3-phase to ground fault. It appears that the system is stable as the reactive power is settling to a steady value. The initial spike in reactive power is due to the fault, and the subsequent oscillations are due to the system trying to regain its stability. The system recovers quickly within the first few seconds.

6.8. Transient Stability study for JSPL

JSPL is a Captive generating plant in Angul area having 6x135 MW generation capacity which is primarily connected to Meramunduli 400kV Bus. In the stability study of JSW plant, three important scenarios are simulated using in MiPSCT. In the first scenario, the Plant is operating in floating mode while assuming the full load operation inside the plant. Similarly, the second and third scenario is simulated by considering the contracted demand of the plant operation. In each of the three scenarios, four different disturbance conditions are simulated to study the transient behaviour of CGP generators.

Floating Mode

Case 31: Three Phase to ground fault at the power evacuation bus inside the JSPL plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-130 to 6-131 for a three phase to ground fault at the power evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

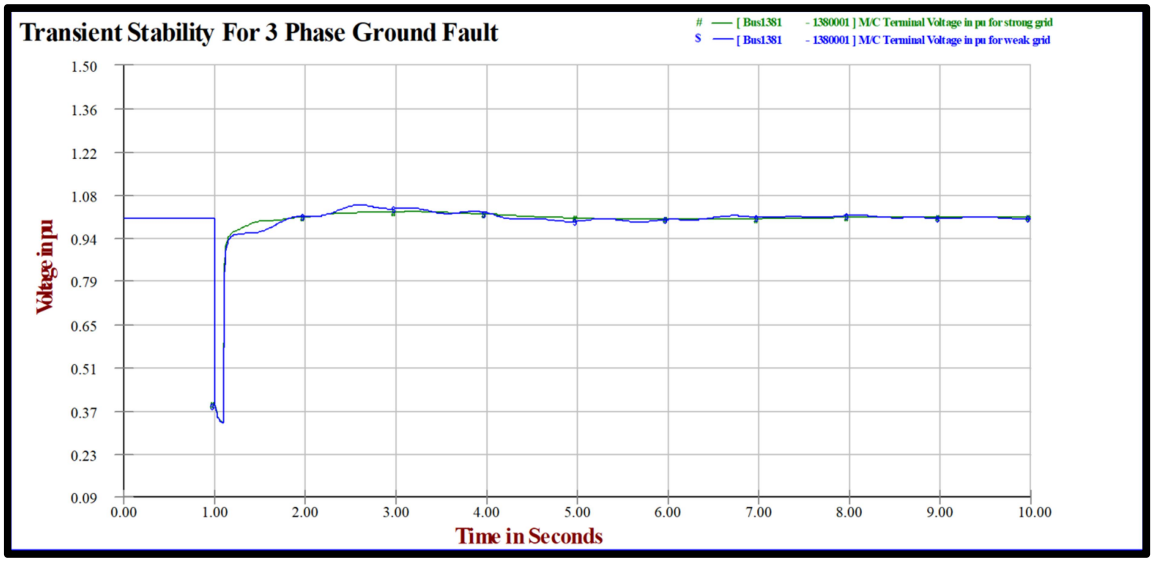

Figure 6-130 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

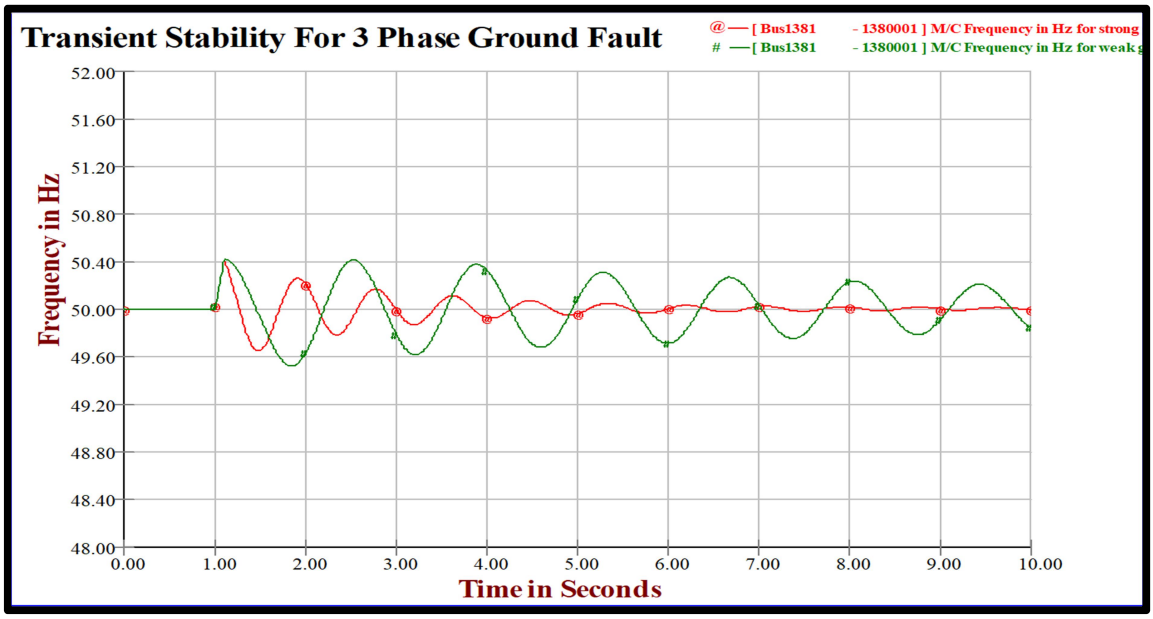

Figure 6-131 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-132 and Figure 6-133.

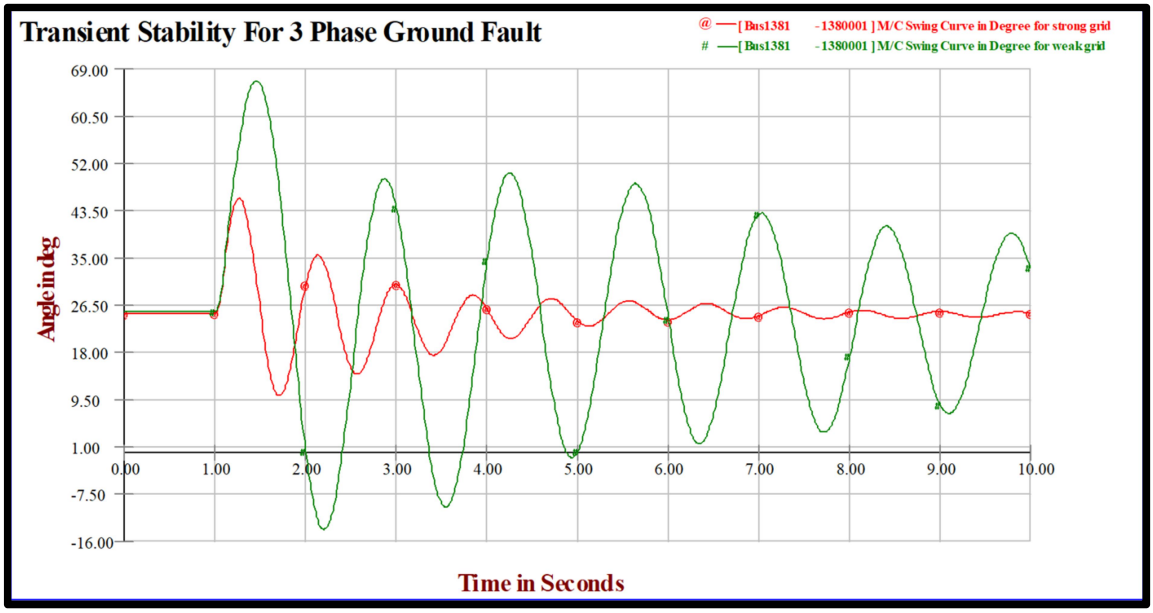

Figure 6-132 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

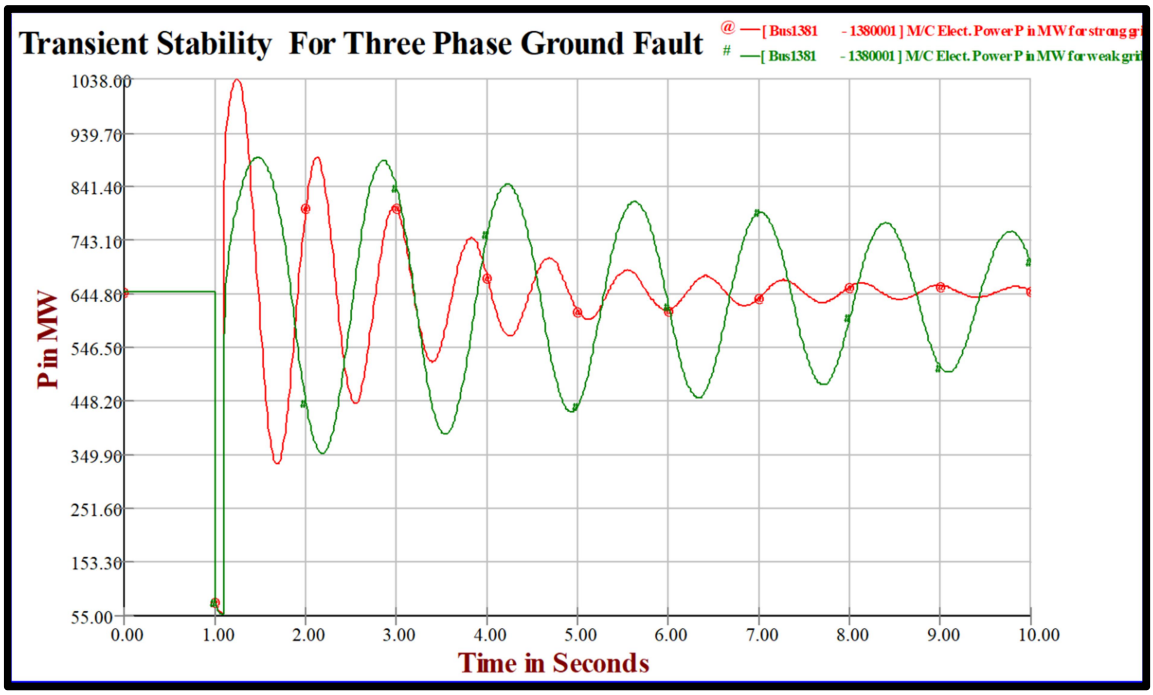

Figure 6-133 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Case 32: Single Line to ground fault at the power evacuation bus inside the JSPL plant for duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-134 to 6-135 for a Single line to ground fault at the power

evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

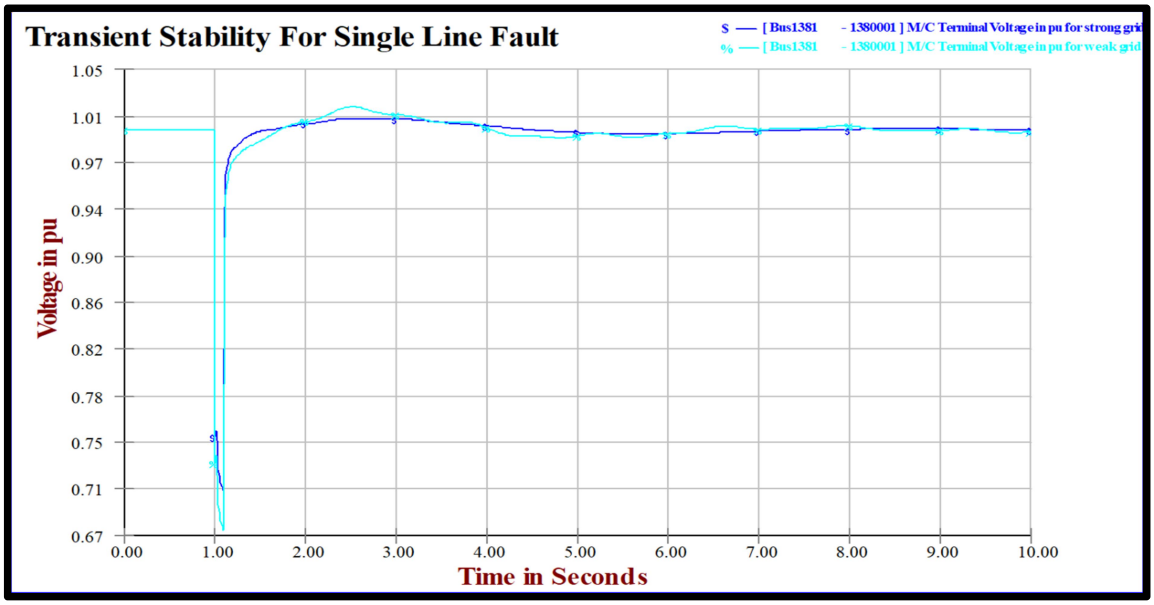

Figure 6-134 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

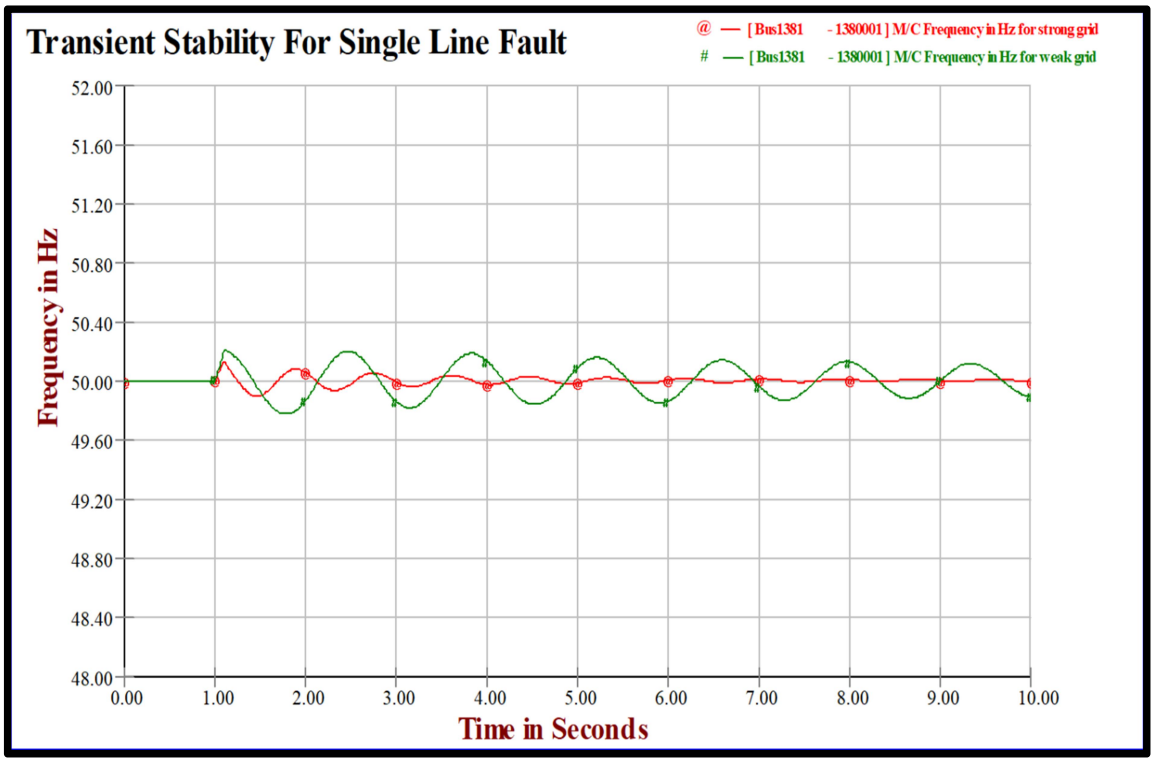

Figure 6-135 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-136 and Figure 6-137.

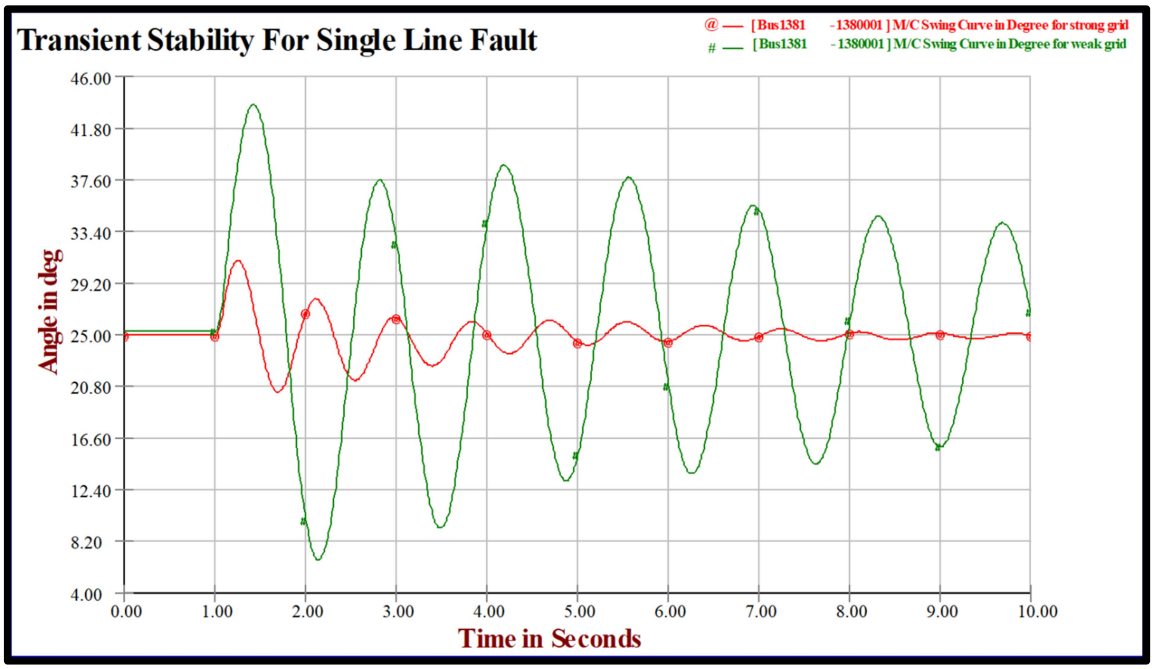

Figure 6-136 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

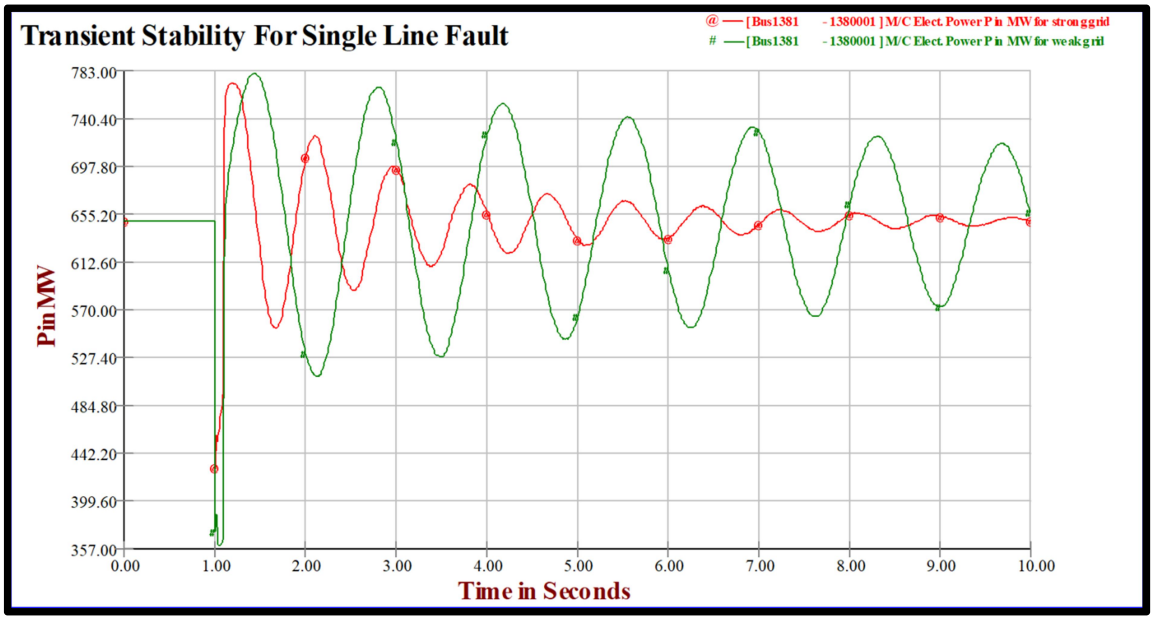

Figure 6-137 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Case 33: Highest Generating unit Outage in the JSPL plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-138 to 6-139 for a disturbance initiated due to generator outage during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

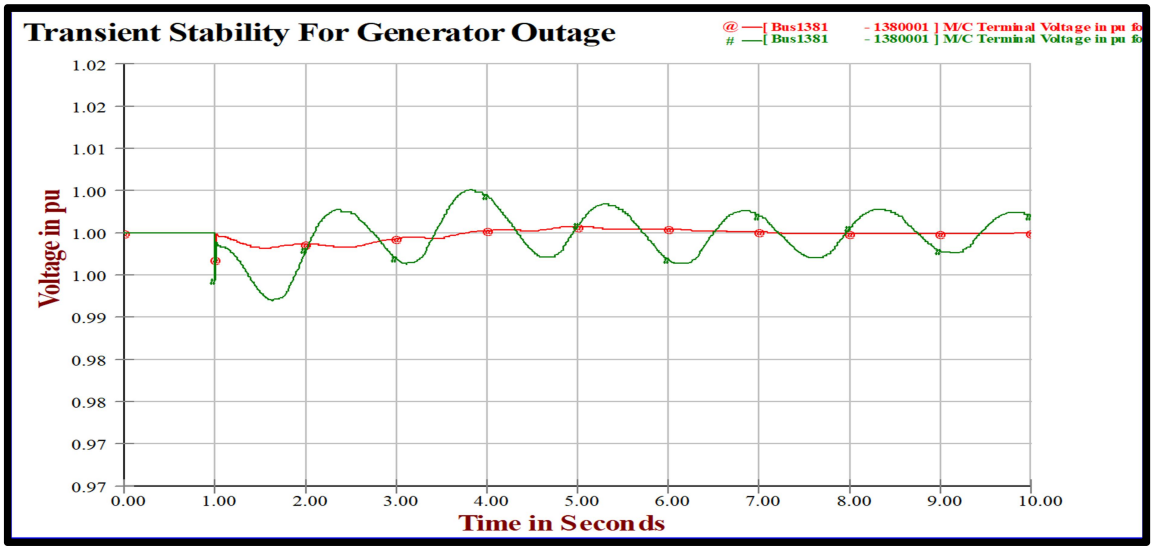

Figure 6-138 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant

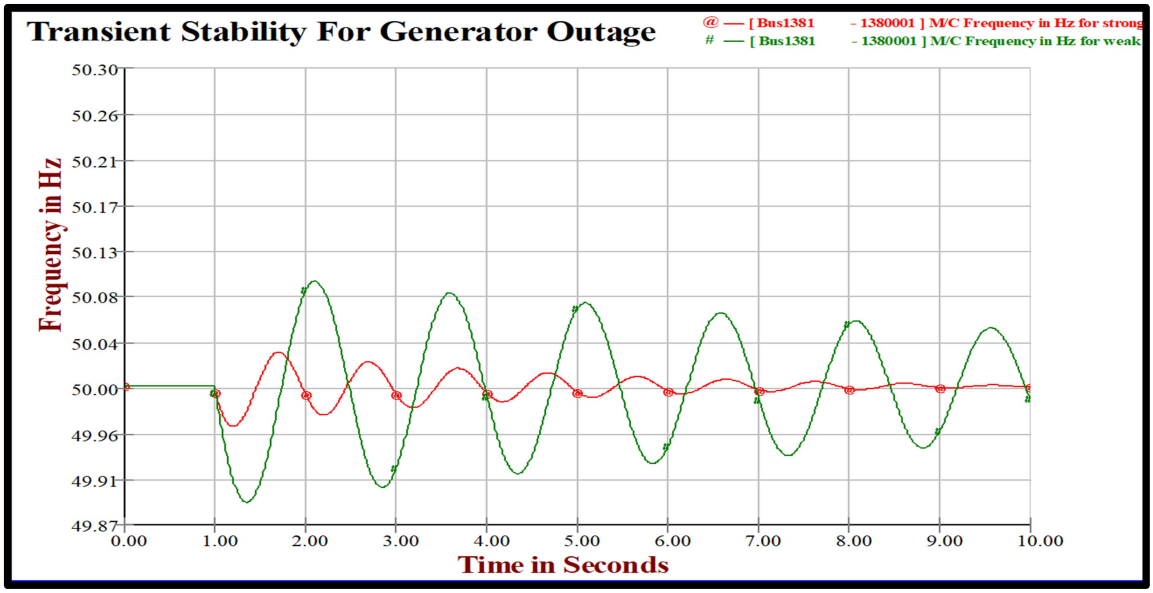

Figure 6-139 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during floating mode of operation of plant is presented in Figure 6-140 and Figure 6-141.

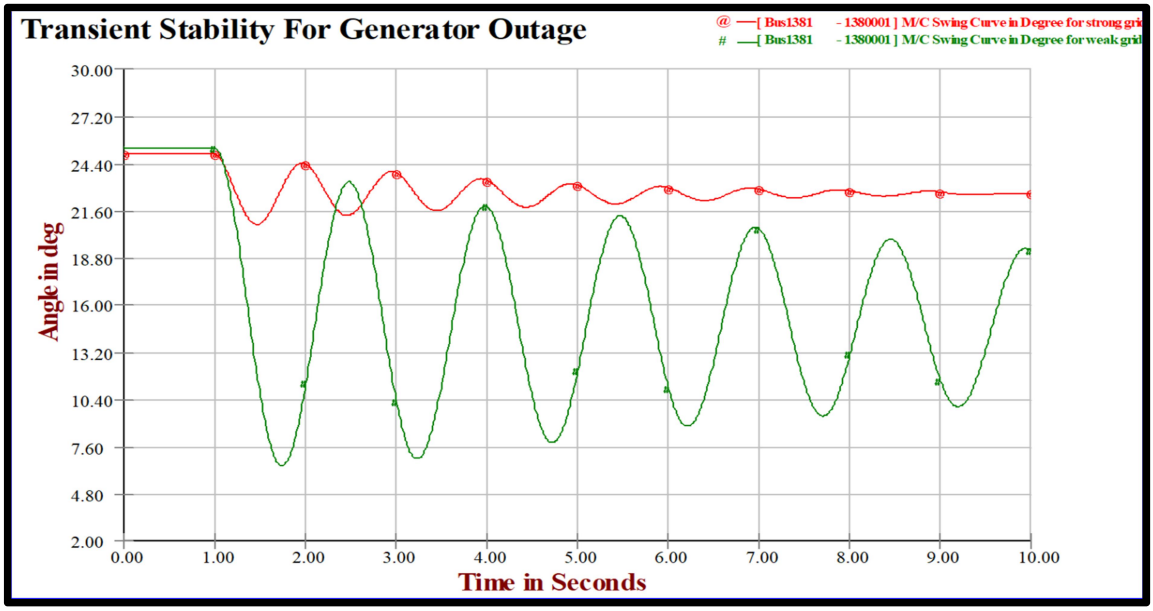

Figure 6-140 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant

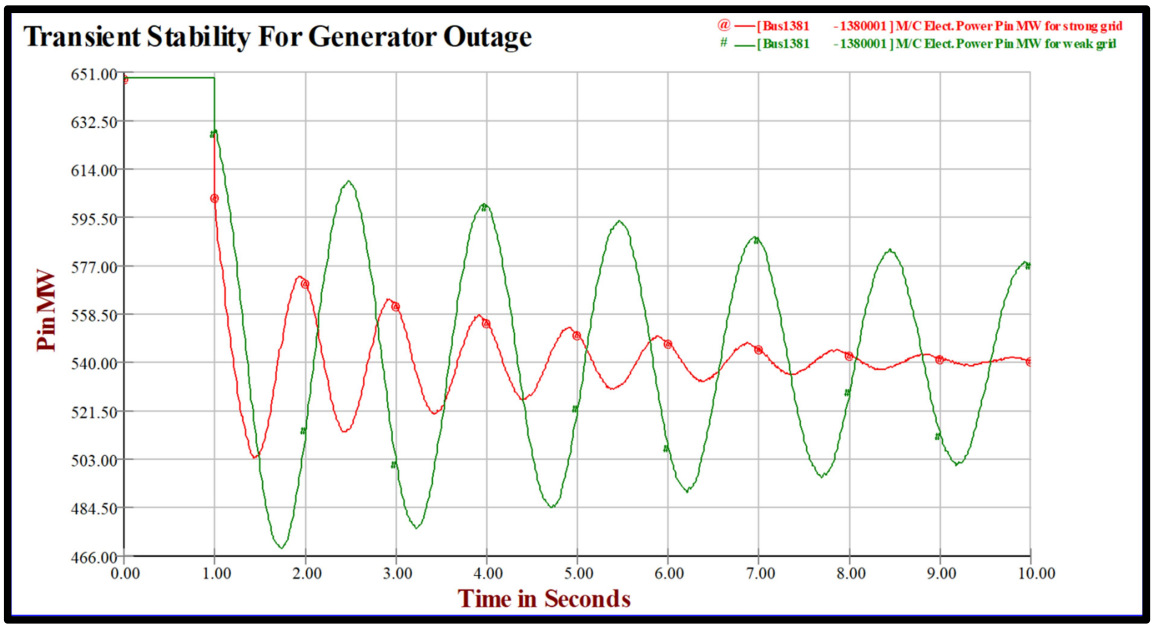

Figure 6-141 Active power for generating bus plot for highest generating unit outage inside the plant during floating mode of operation of plant

Case 34: Load throw off at the AAL plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-142 to 6-143 for a disturbance initiated due to sudden load throw off during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

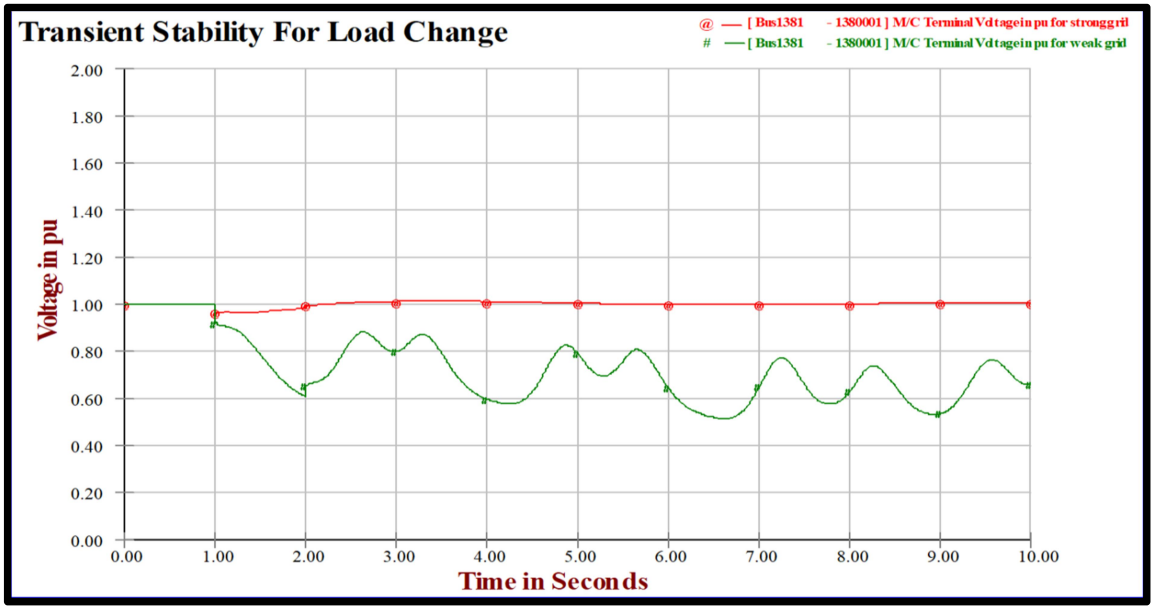

Figure 6-142 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant

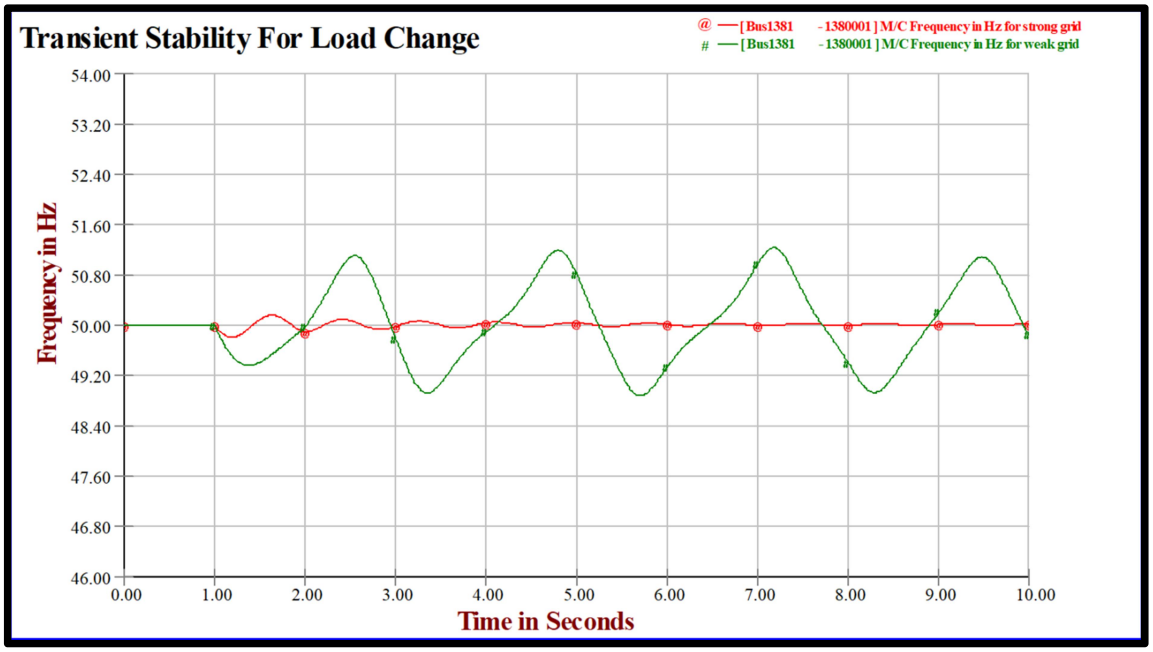

Figure 6-143 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during floating mode of plant operation of plant is presented in Figure 6-144 and Figure 6-145. In case of weak grid connectivity, the frequency variations are undamped subjected to a load throw off disturbance.

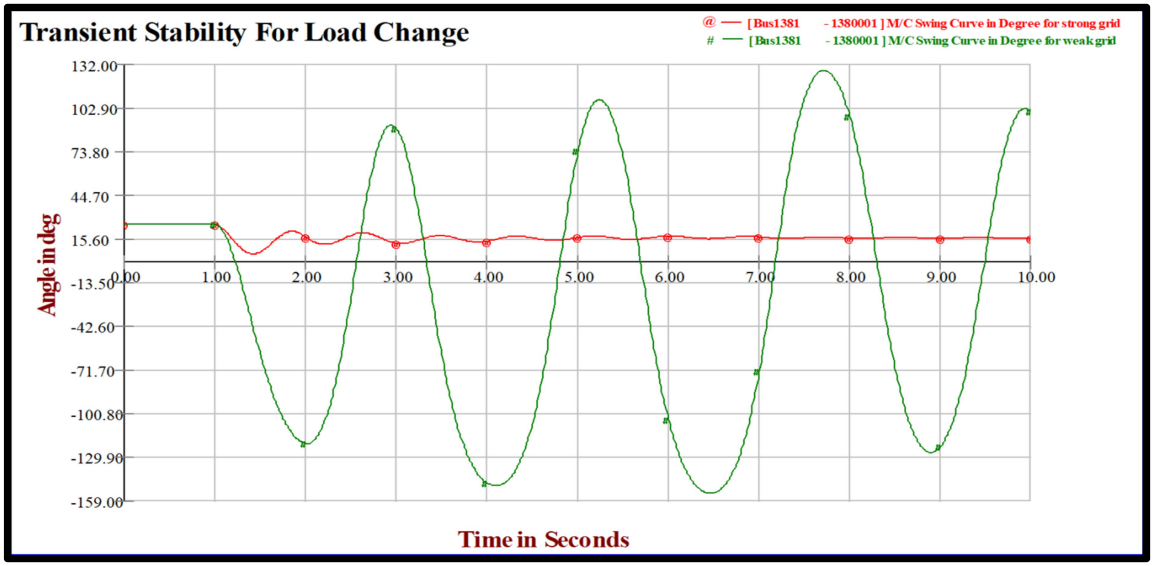

Figure 6-144 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant

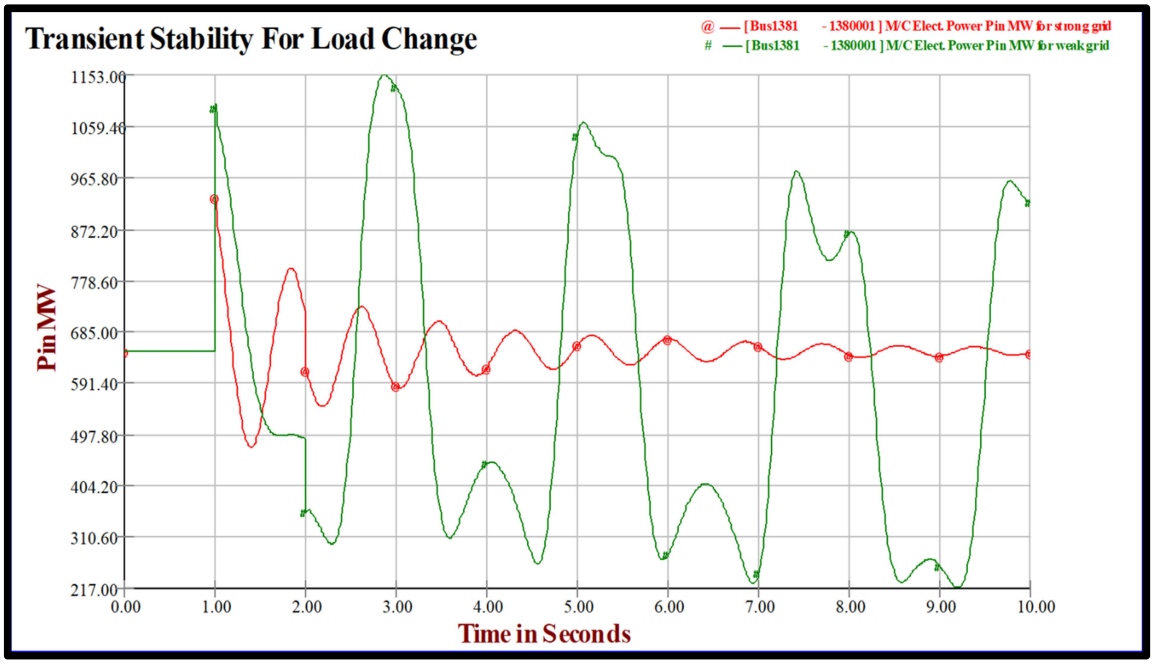

Figure 6-145 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant

Import mode

Case 35: Three Phase to ground fault at the JSPL plant for a duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-146 to 6-147 for a three phase to ground fault at the power

evacuation bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

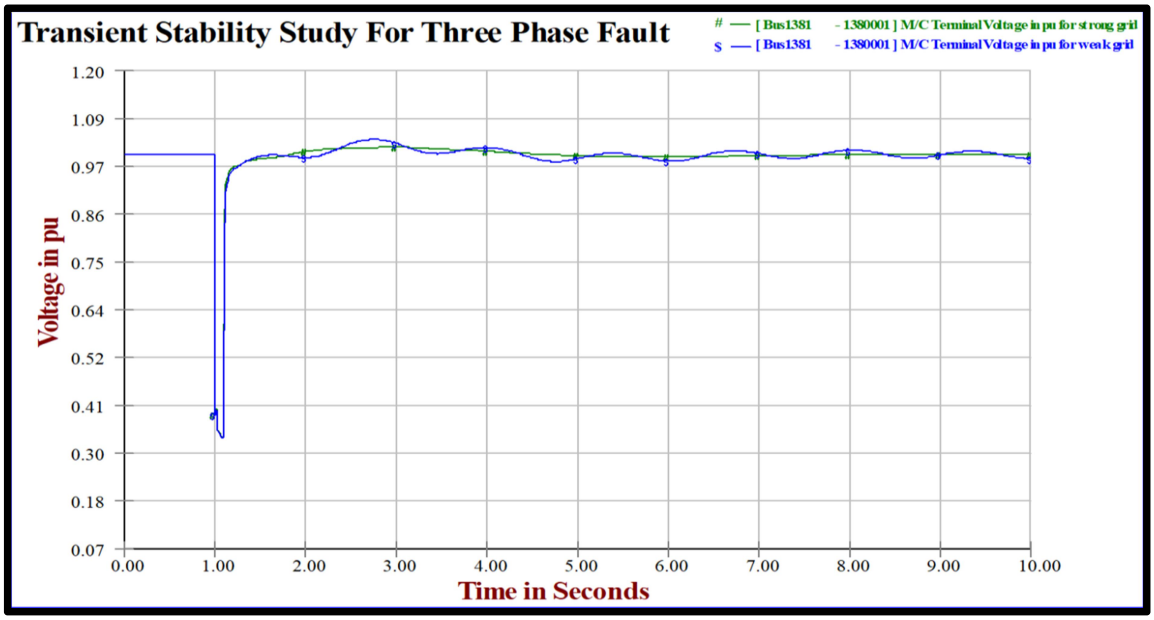

Figure 6-146 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

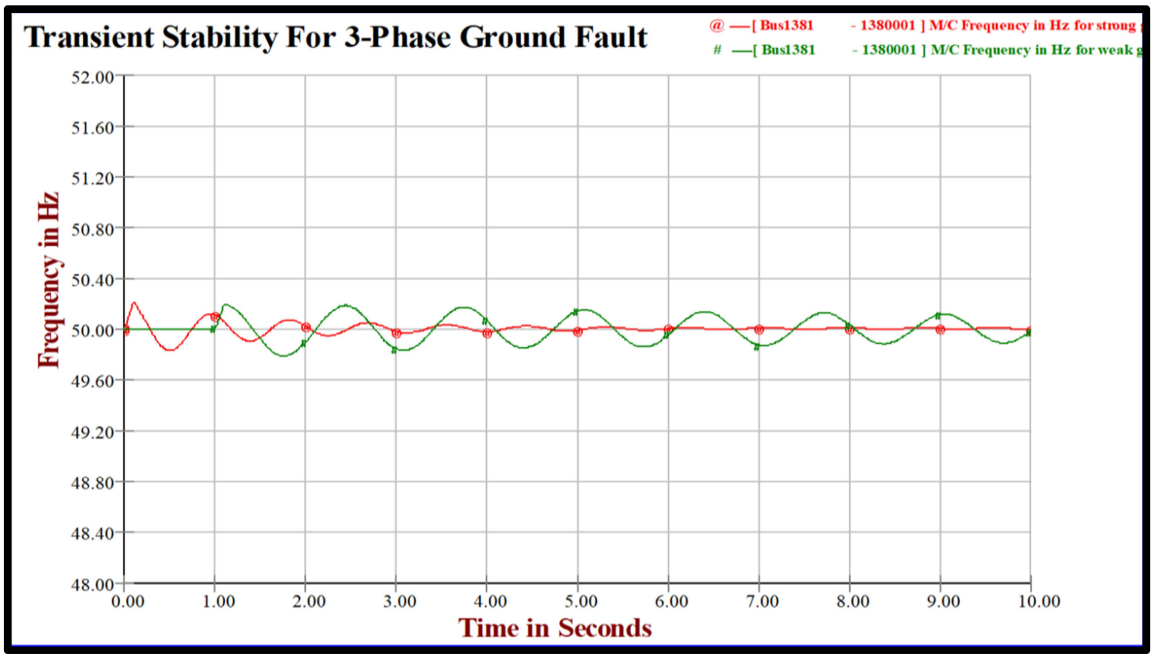

Figure 6-147 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-148 and Figure 6-149.

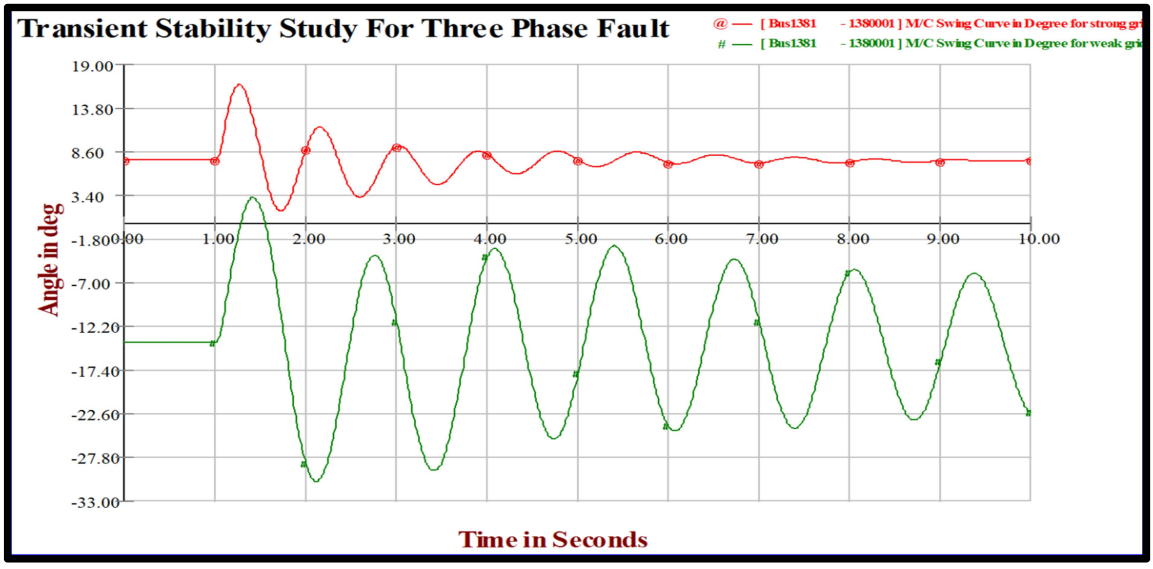

Figure 6-148 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

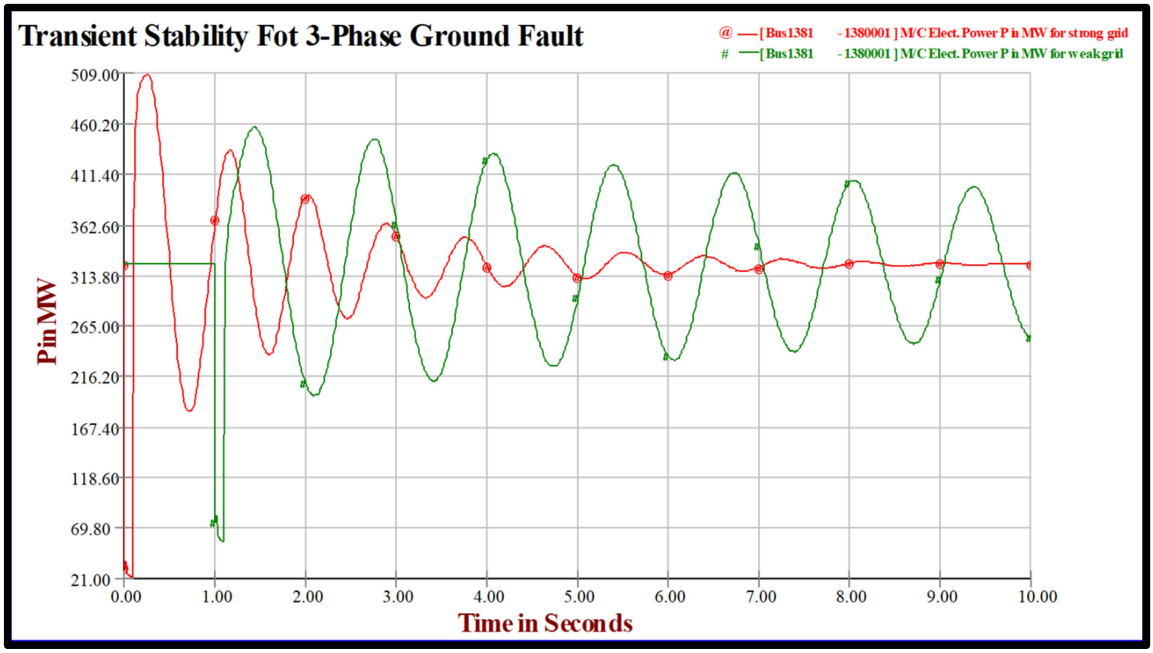

Figure 6-149 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Case 36: Single Line to ground fault at the JSPL plant for a duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-150 to 6-151 for a Single line to ground fault at the power evacuation bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

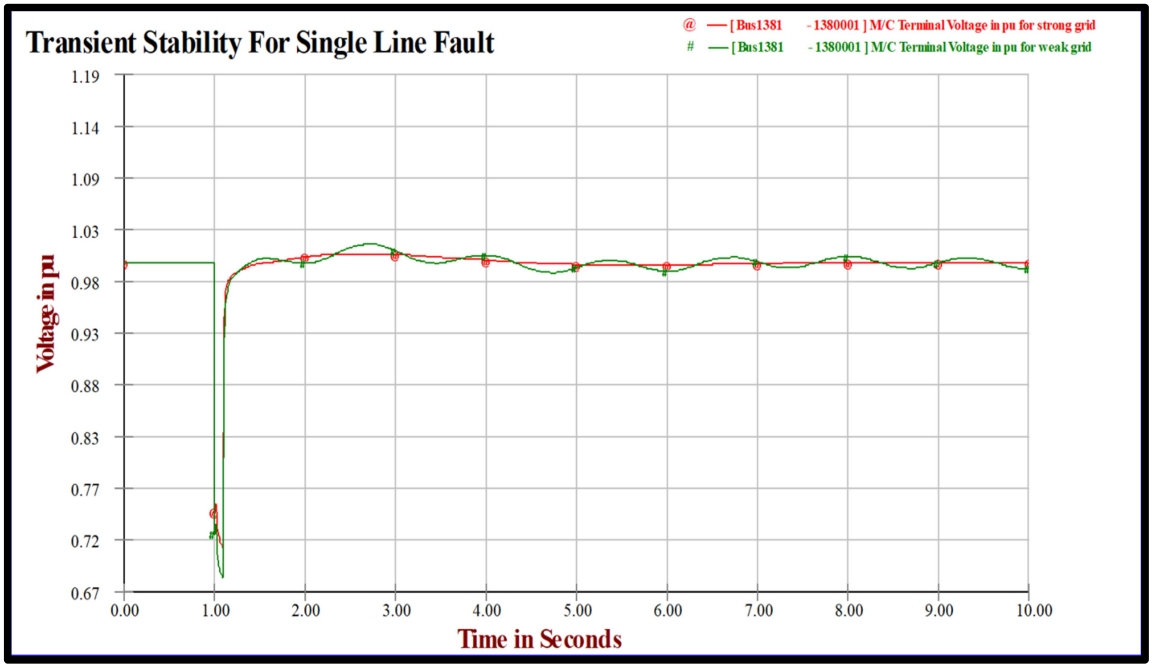

Figure 6-150 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

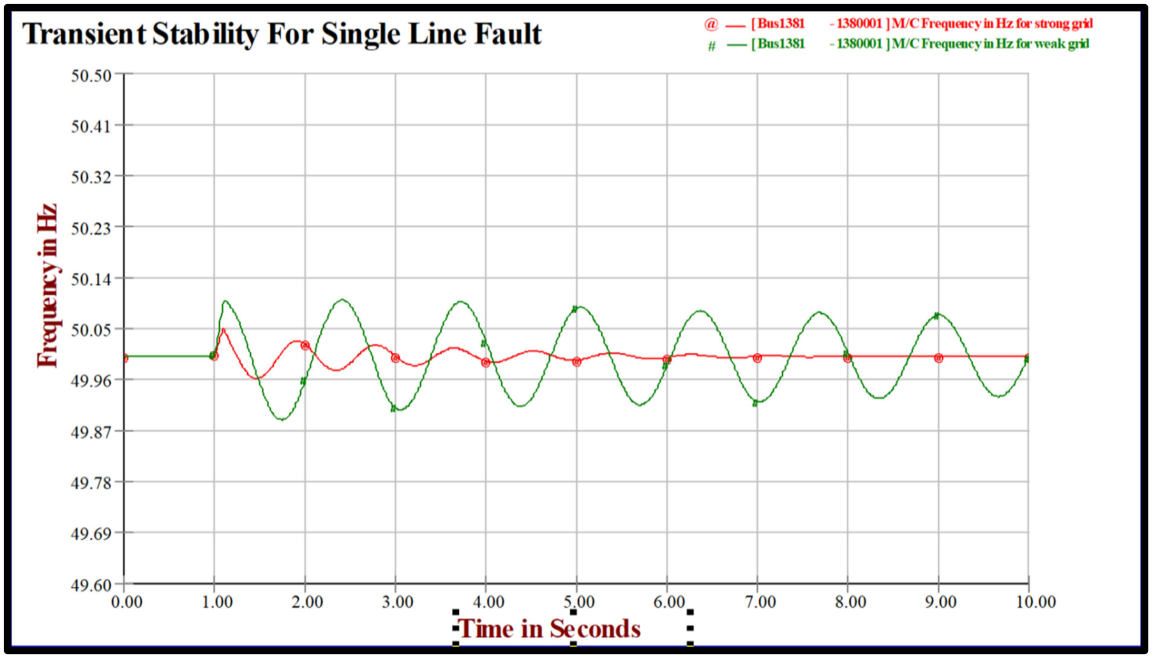

Figure 6-151 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-152 and Figure 6-153.

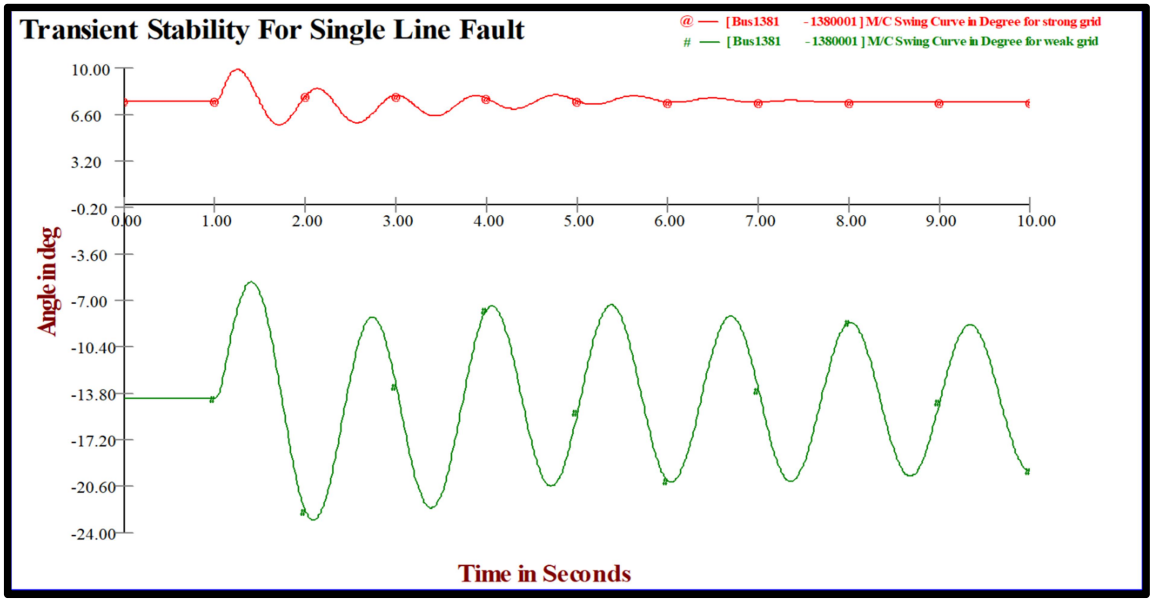

Figure 6-152 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

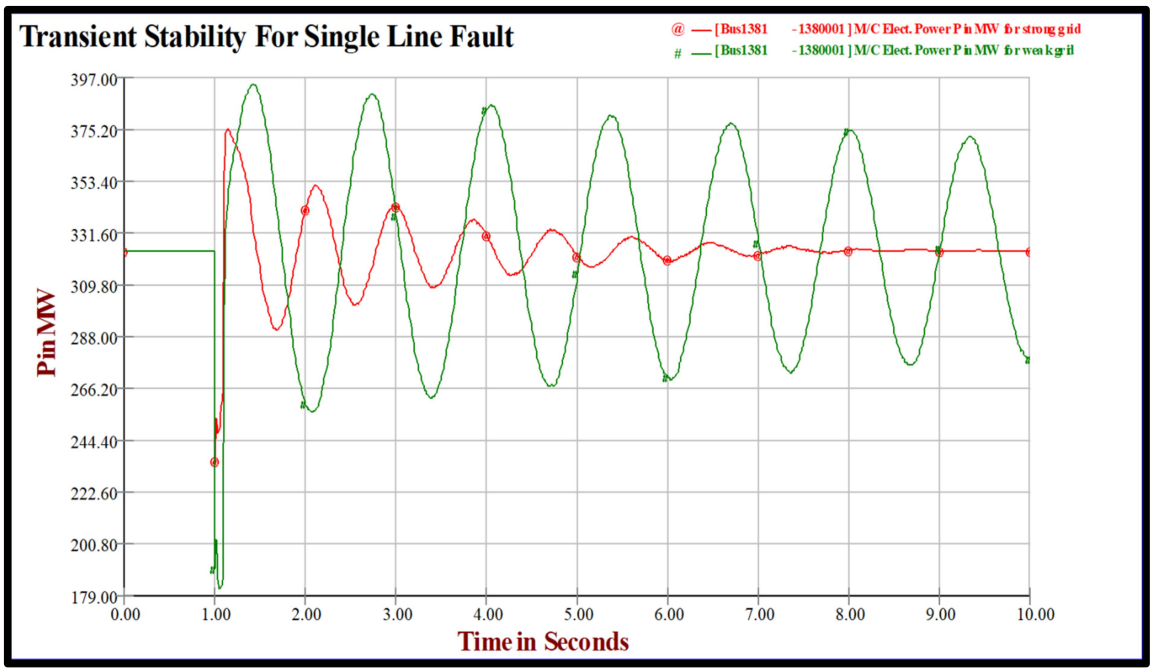

Figure 6-153 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Case 37: Outage of Largest Generator set at the JSPL plant with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-154 to 6-155 for a disturbance initiated due to generator outage

during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

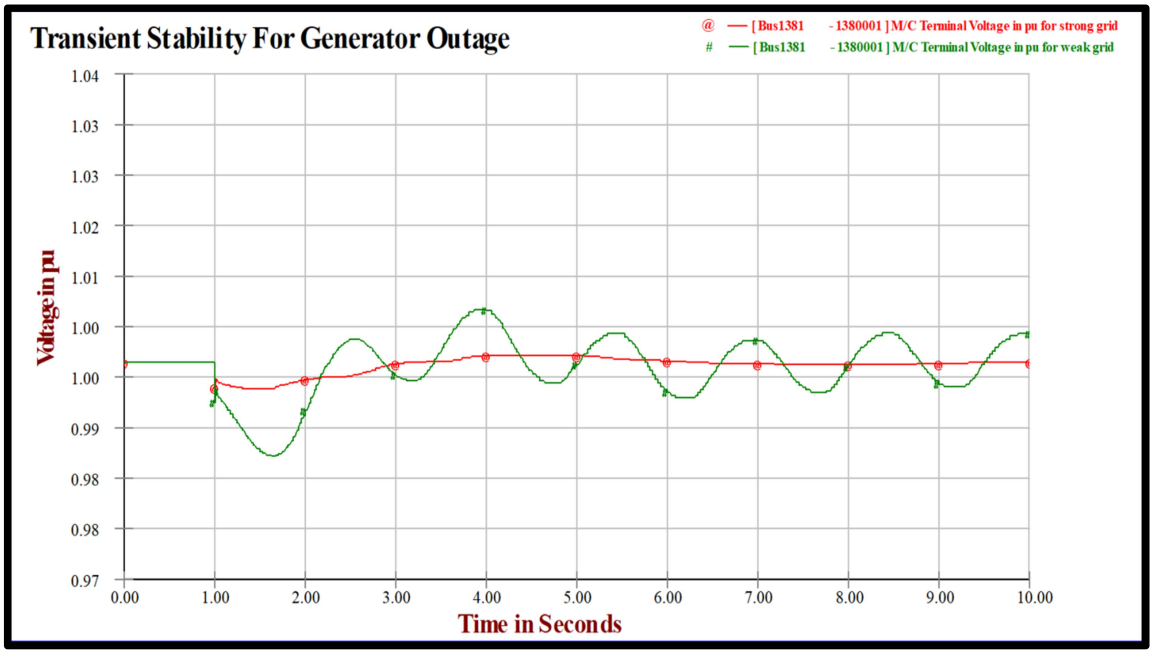

Figure 6-154 Voltage plot for highest generating unit outage inside the plant during import mode of operation of plant

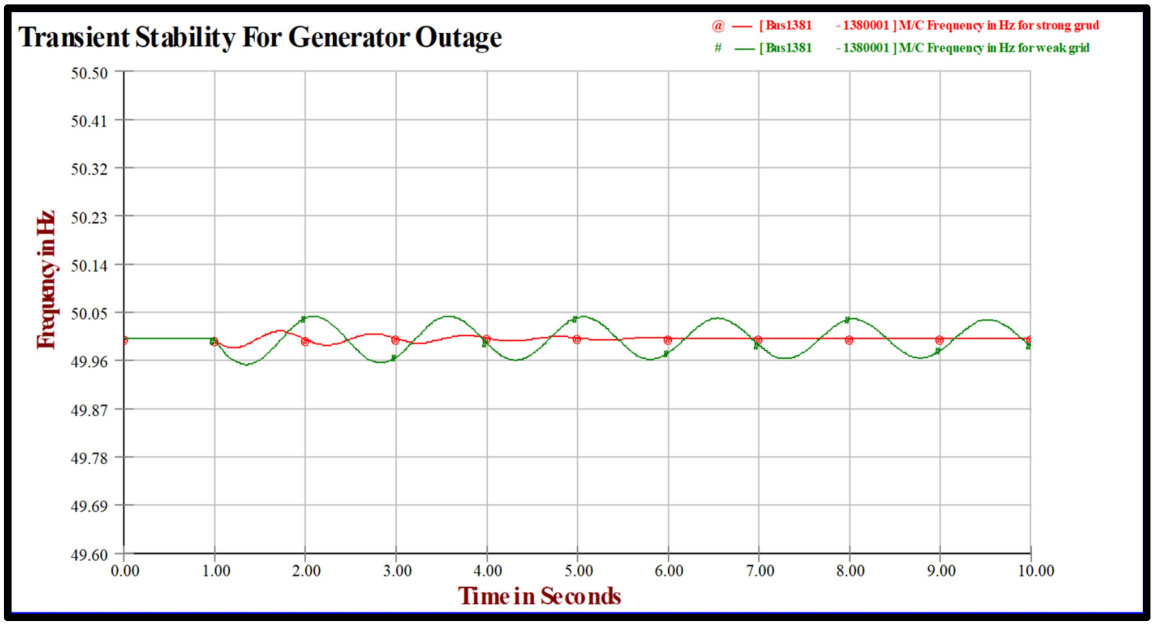

Figure 6-155 Frequency plot for highest generating unit outage inside the plant during import mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during import mode of operation of plant is presented in Figure 6-156 and Figure 6-157.

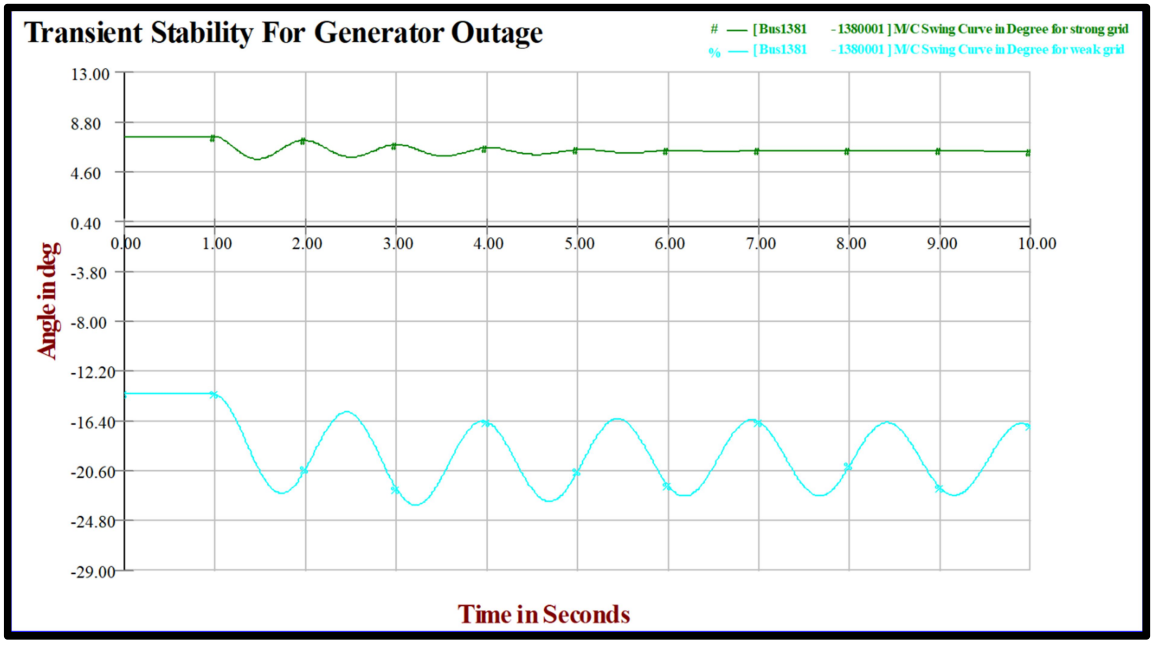

Figure 6-156 Swing curve plot for highest generating unit outage inside the plant during import mode of operation of plant

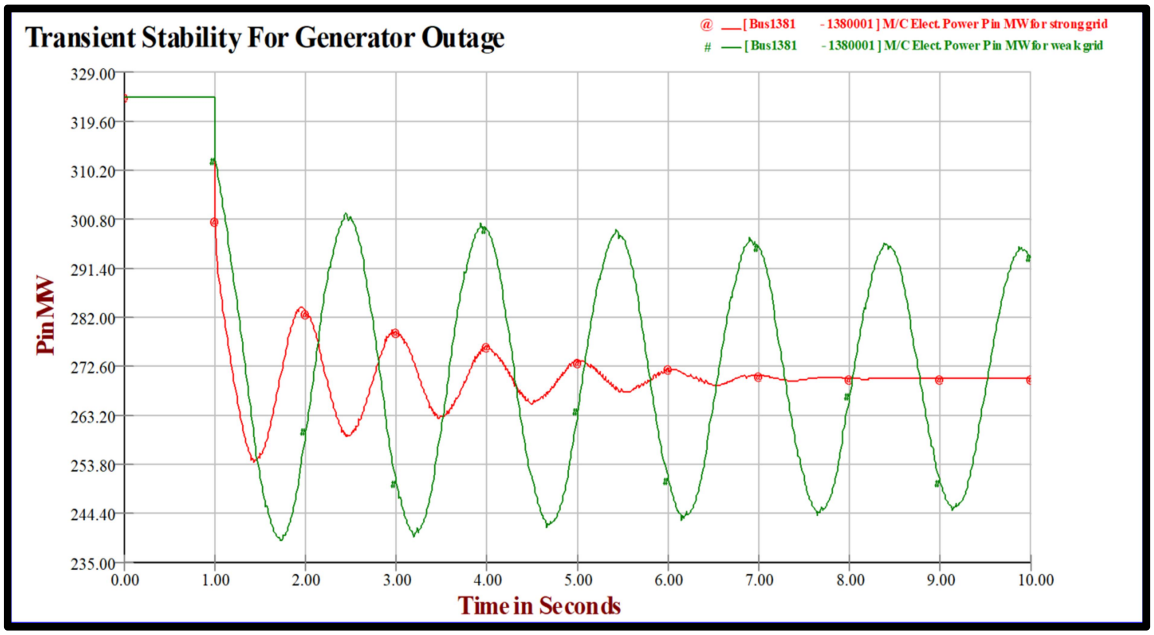

Figure 6-157 Active power plot for highest generating unit outage inside the plant during import mode of operation of plant

Case 38: Load throw off at the JSPL plant with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-158 to 6-159 for a disturbance initiated due to sudden load throw off during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

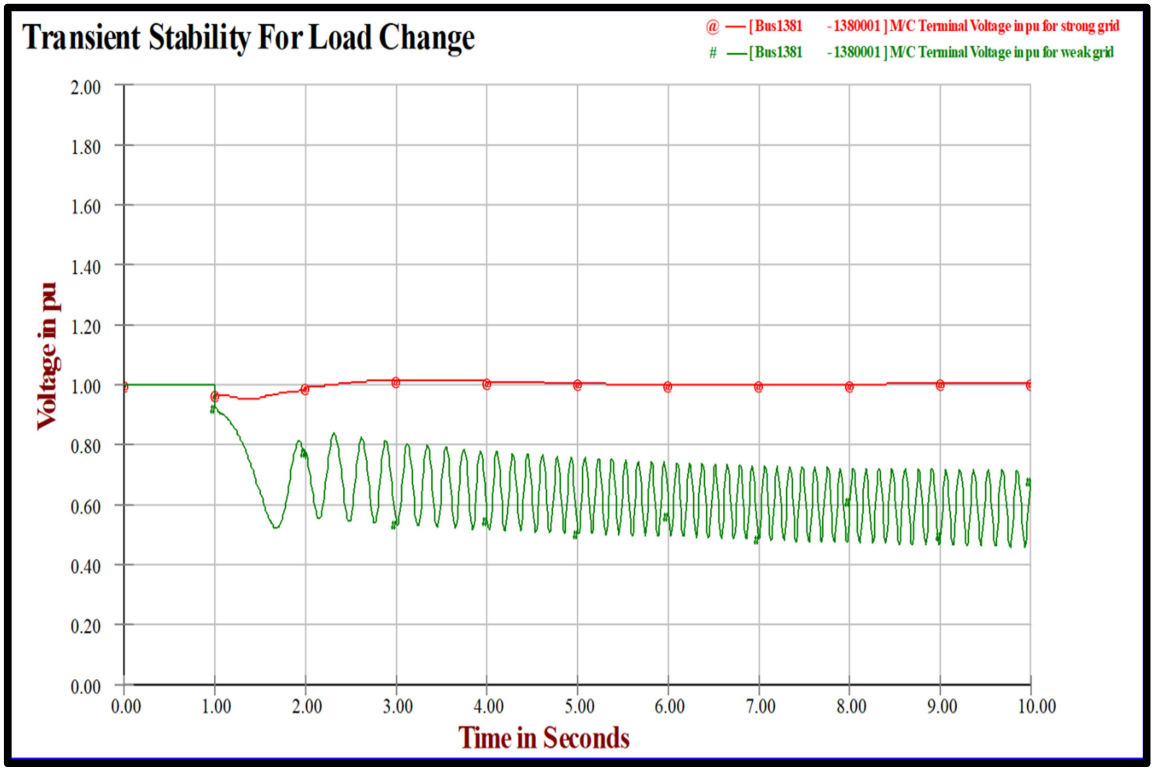

Figure 6-158 Voltage plot for sudden increase in load inside the plant during import mode of operation of plant.

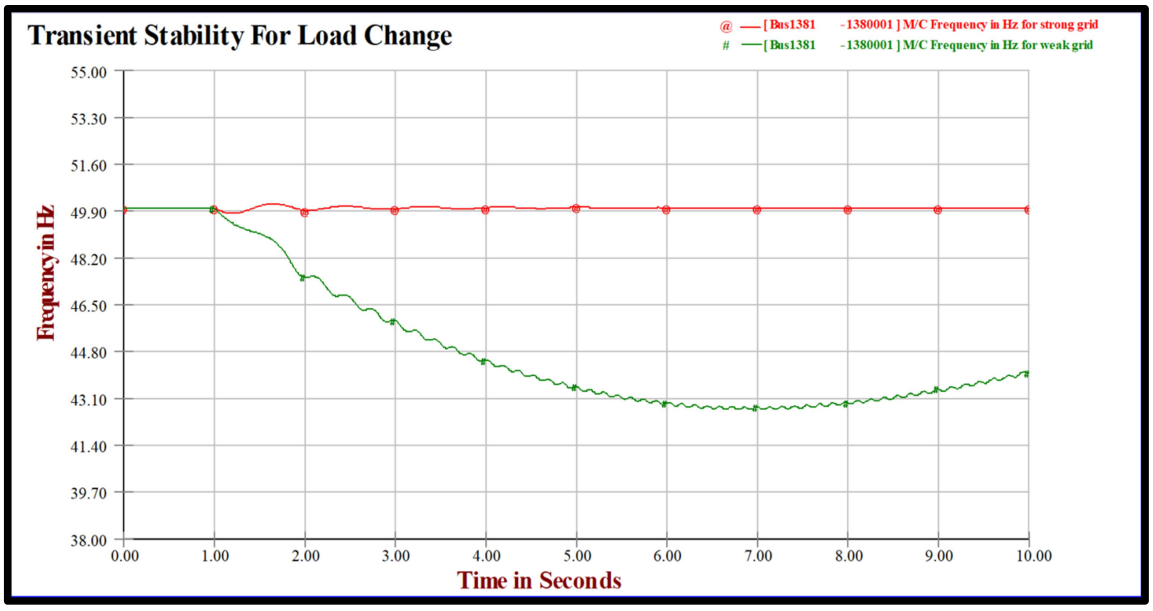

Figure 6-159 Frequency plot for sudden increase in load inside the plant during import mode of operation of plant.

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during import mode of plant operation of plant is presented in Figure 6-160 and Figure 6-161.

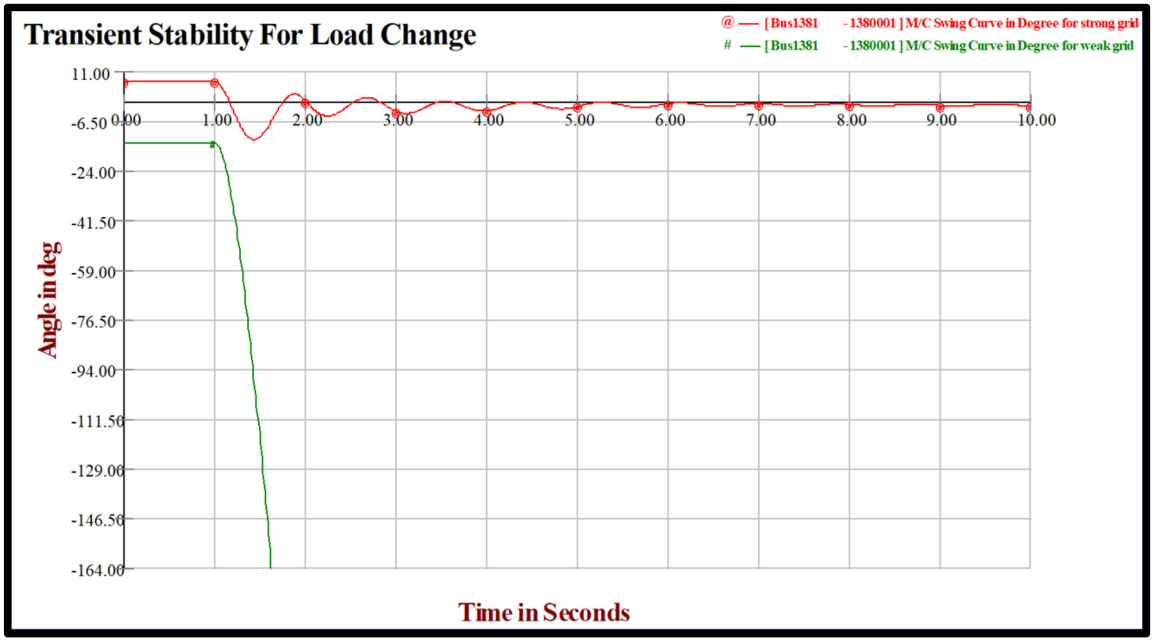

Figure 6-160 Swing curve plot for sudden increase in load inside the plant during import mode of operation of plant

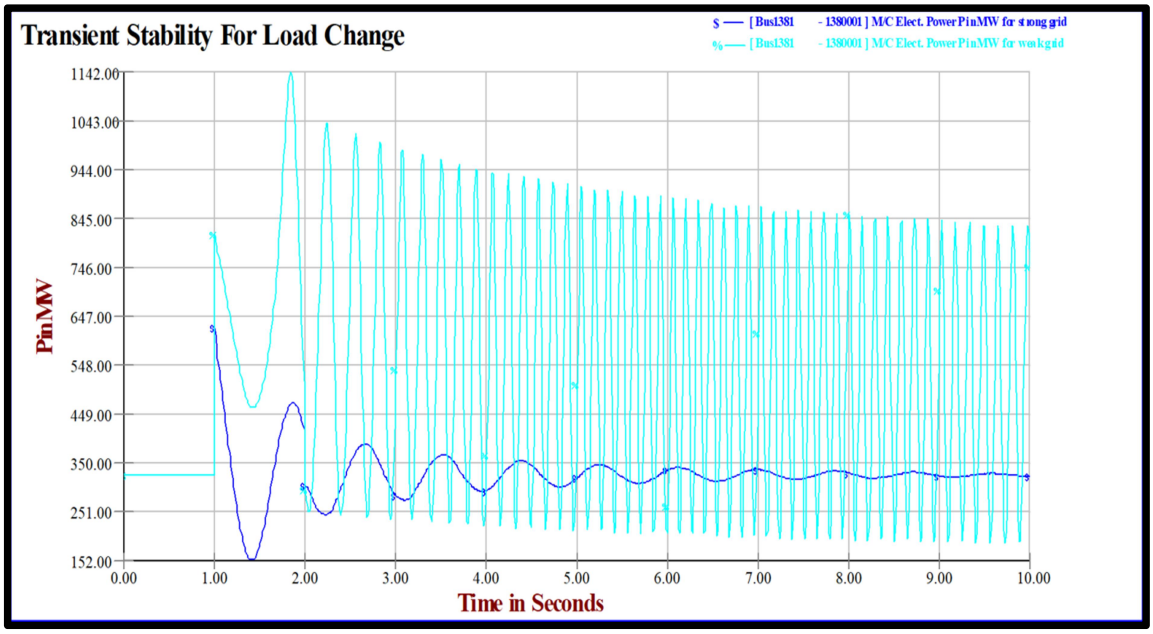

Figure 6-161 Active power plot for sudden increase in load inside the plant during import mode of operation of plant

Export mode

Case 39: Three Phase to ground fault at the JSPL plant for a duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-162 to 6-163 for a three phase to ground fault at the power

evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

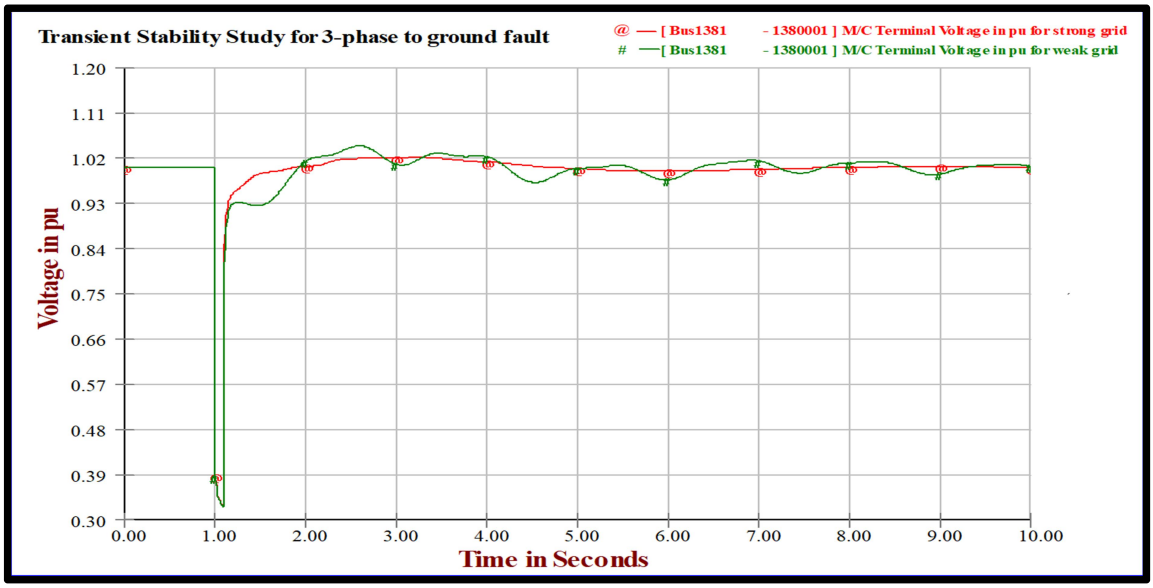

Figure 6-162 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

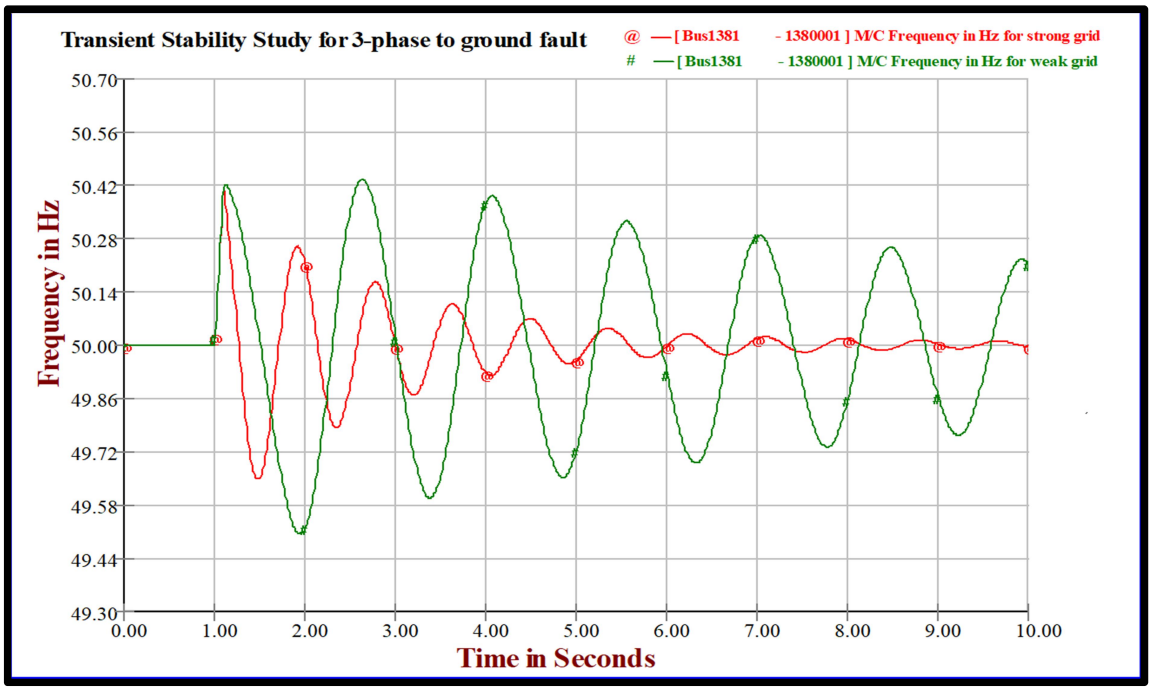

Figure 6-163 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-164 and Figure 6-165.

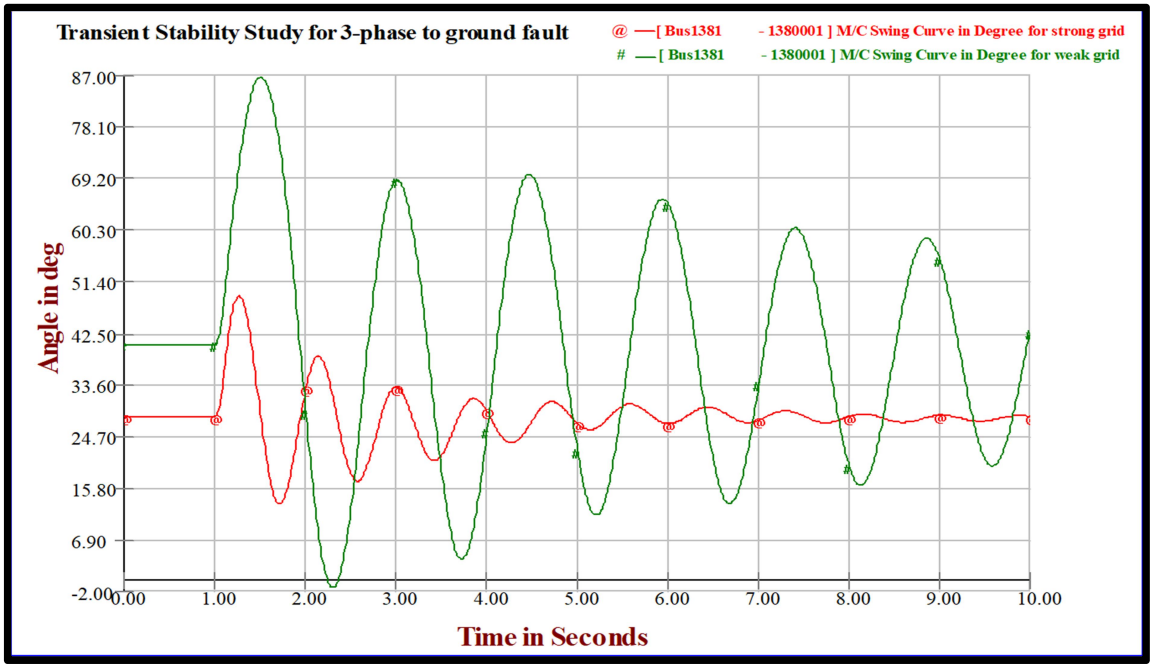

Figure 6-164 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

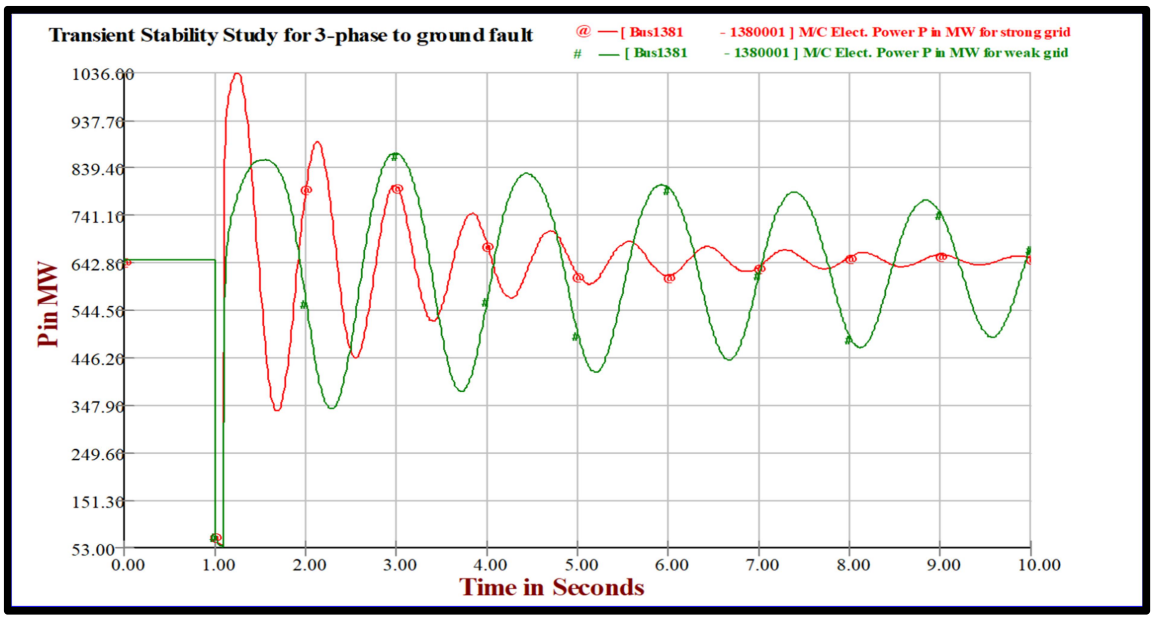

Figure 6-165 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Case 40: Single Line to ground fault at the JSPL plant for duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-166 to 6-167 for a Single line to ground fault at the power

evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

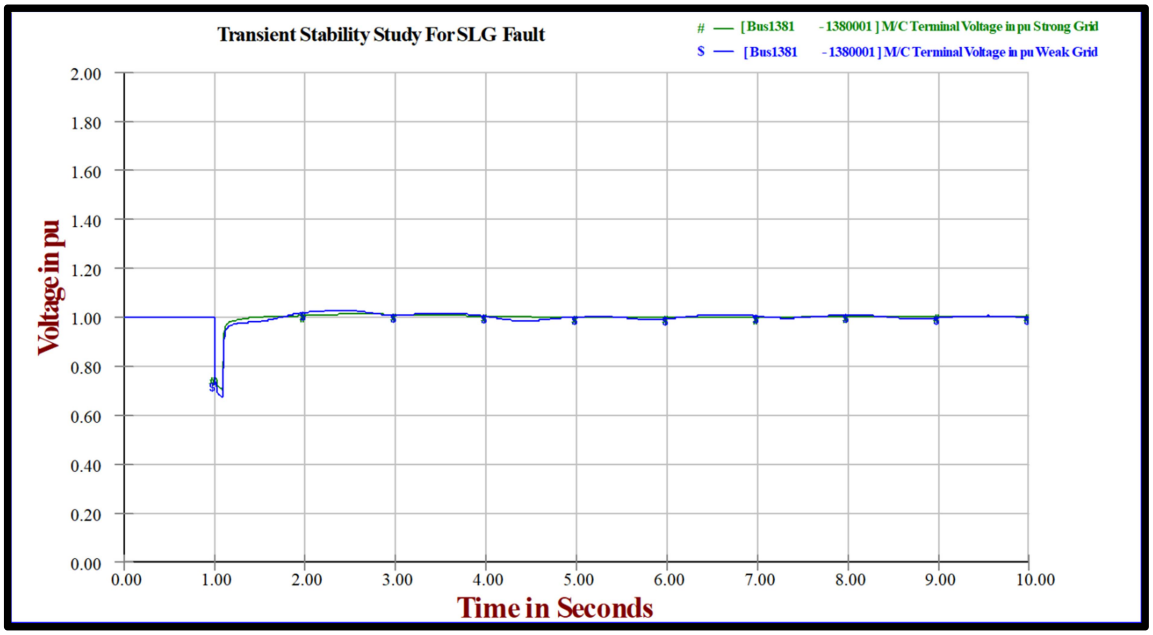

Figure 6-166 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

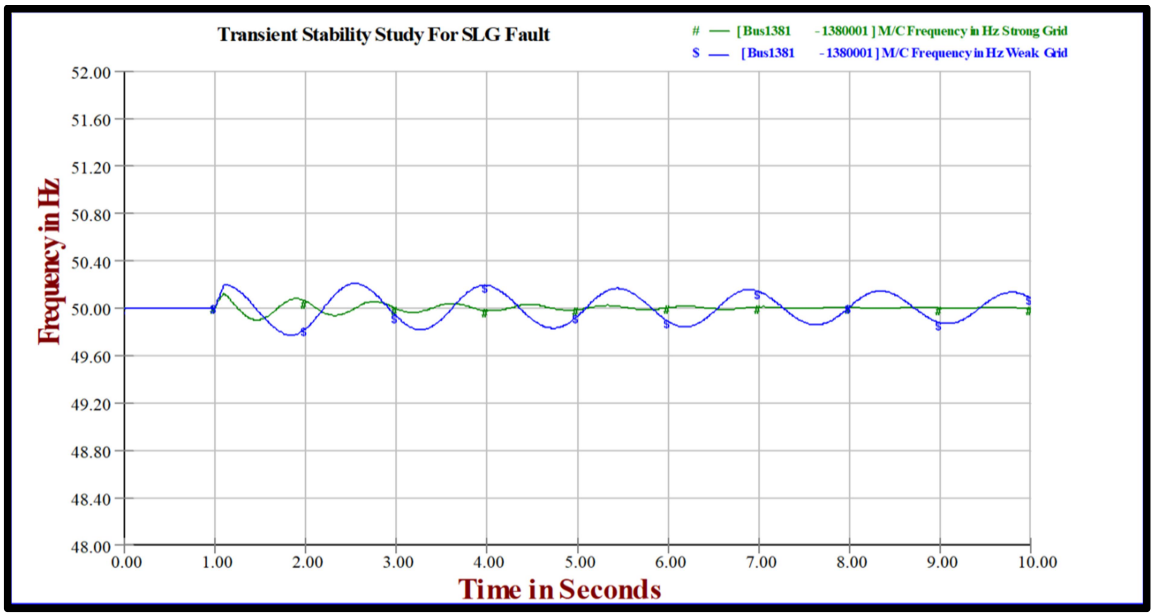

Figure 6-167 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-168 and Figure 6-169.

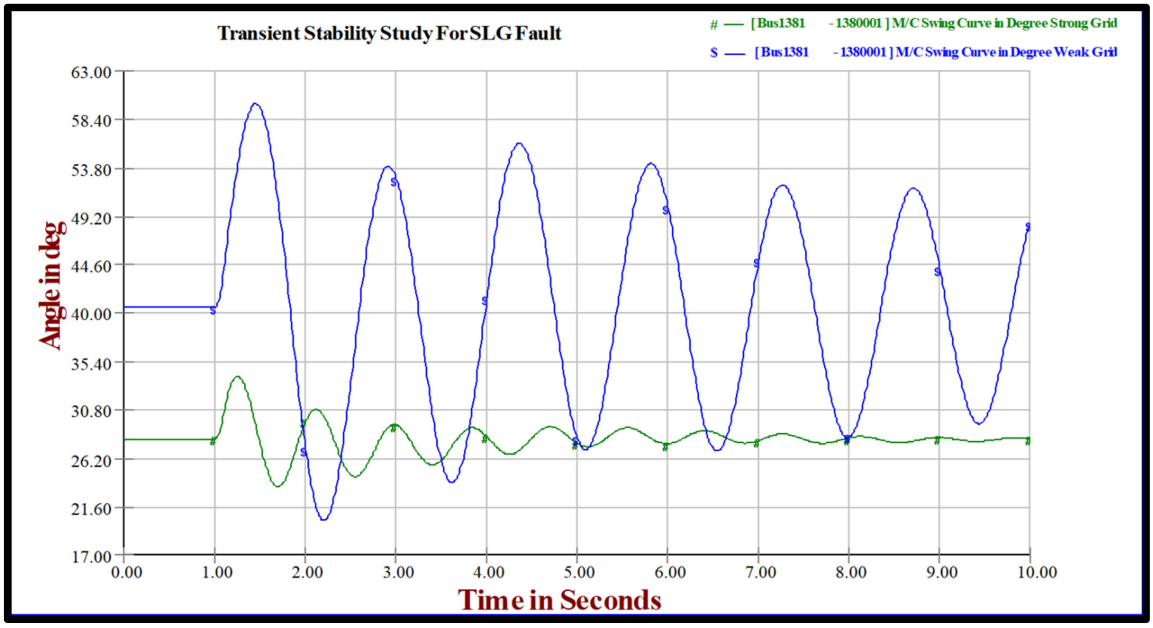

Figure 6-168 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

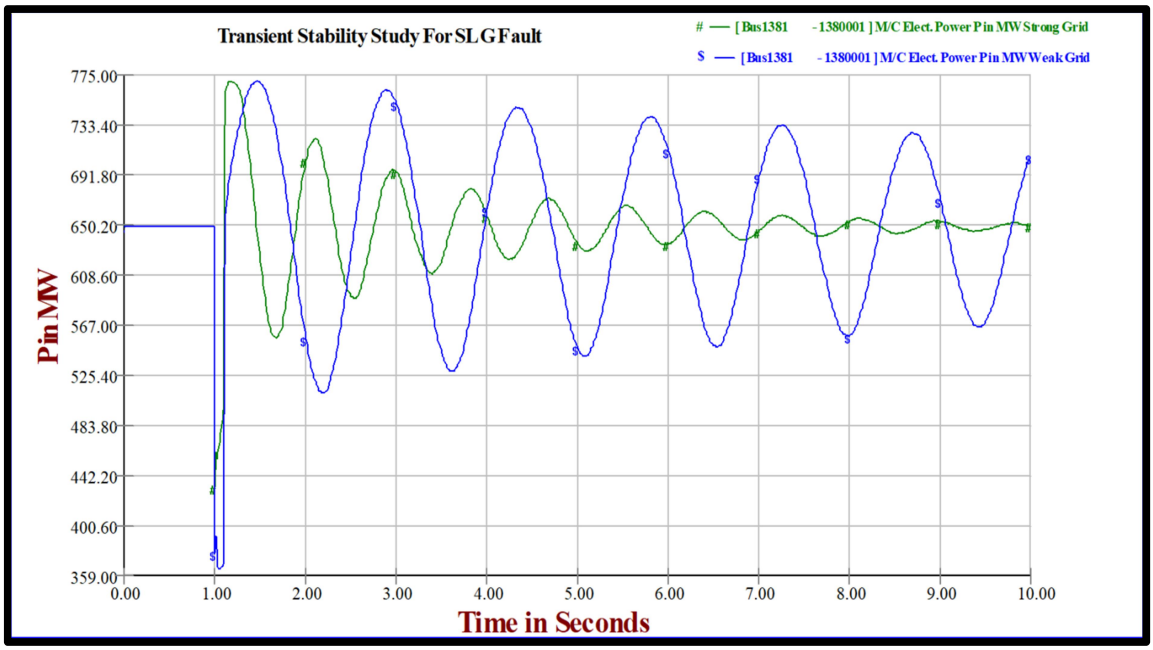

Figure 6-169 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Case 41: Outage of a Generator set at the JSPL plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-170 to 6-171 for a disturbance initiated due to generator outage

during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

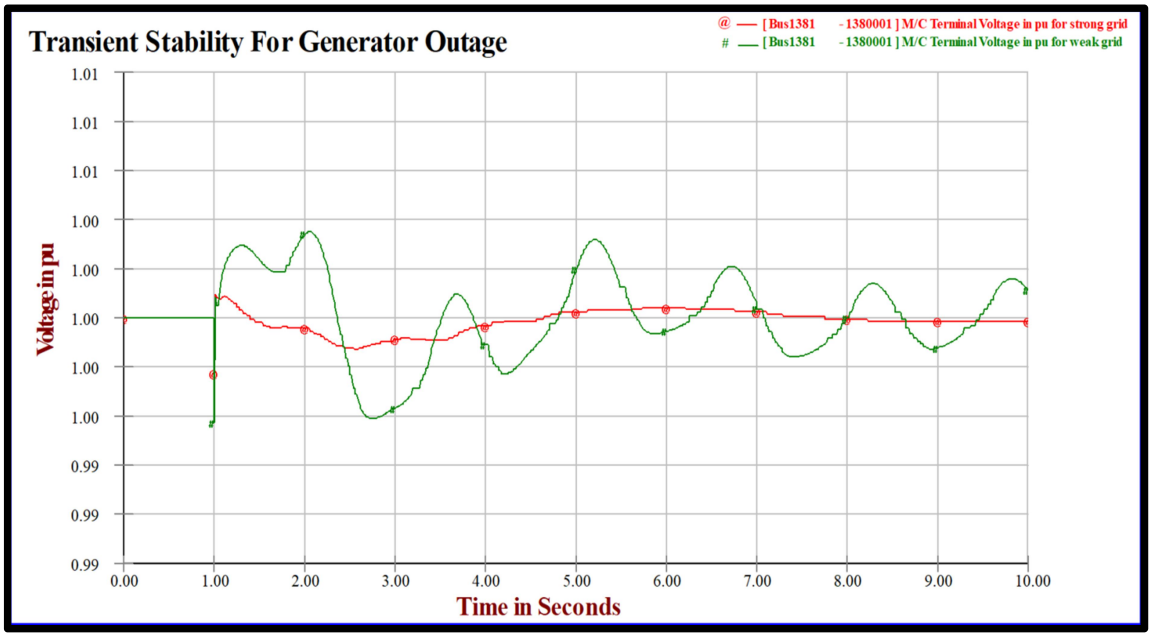

Figure 6-170 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant

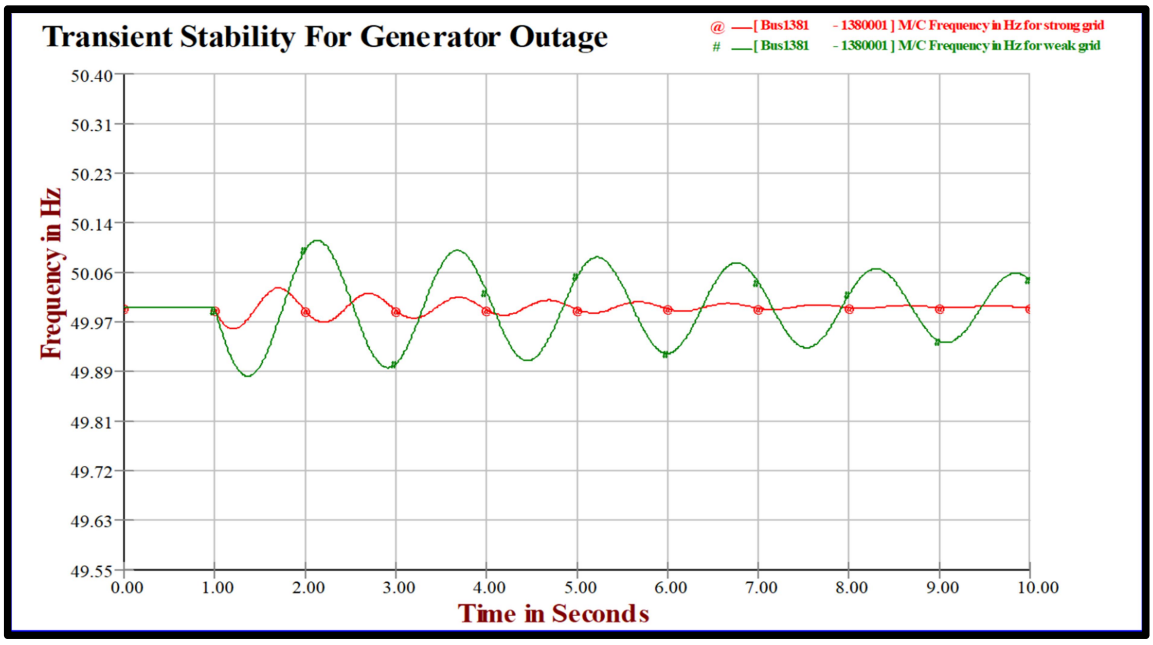

Figure 6-171 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during export mode of operation of plant is presented in Figure 6-172 and Figure 6-173.

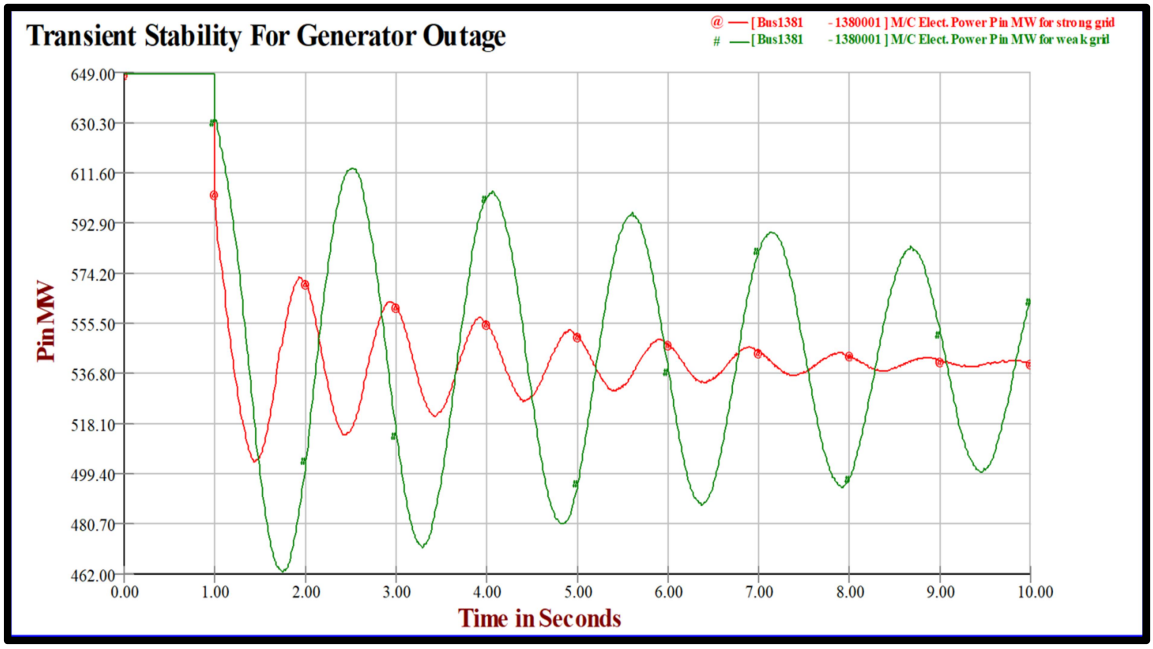

Figure 6-172 Swing curve plot for highest generating unit outage inside the plant during export mode of operation of plant

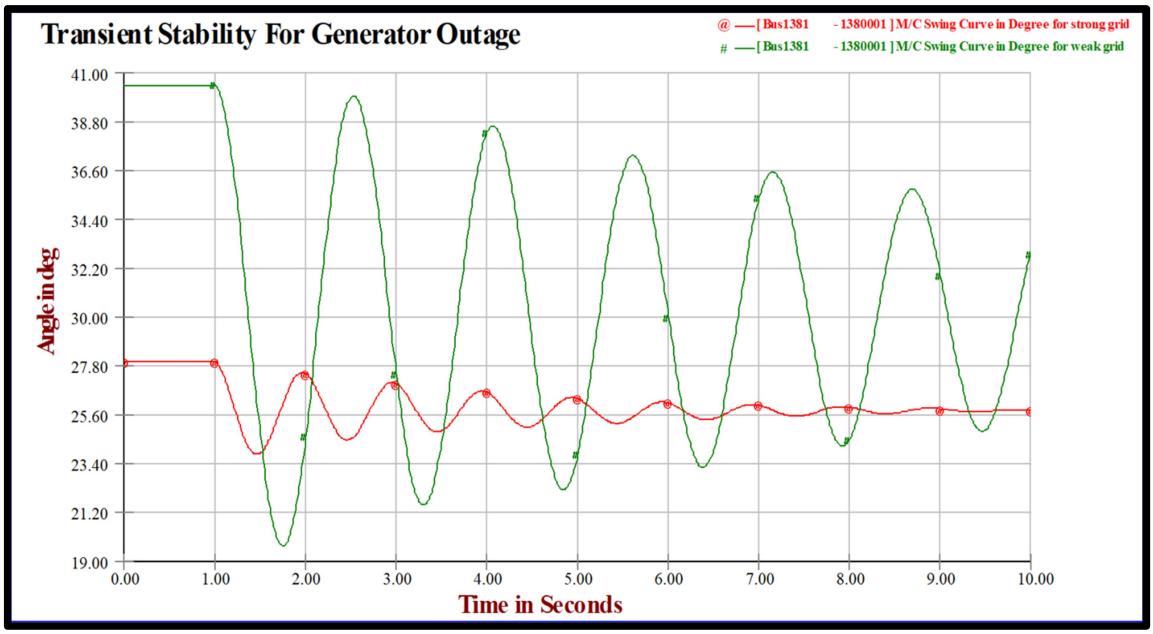

Figure 6-173 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant

Case 42: Load throw off at the JSPL plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-174 to 6-175 for a disturbance initiated due to sudden load throw

off during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

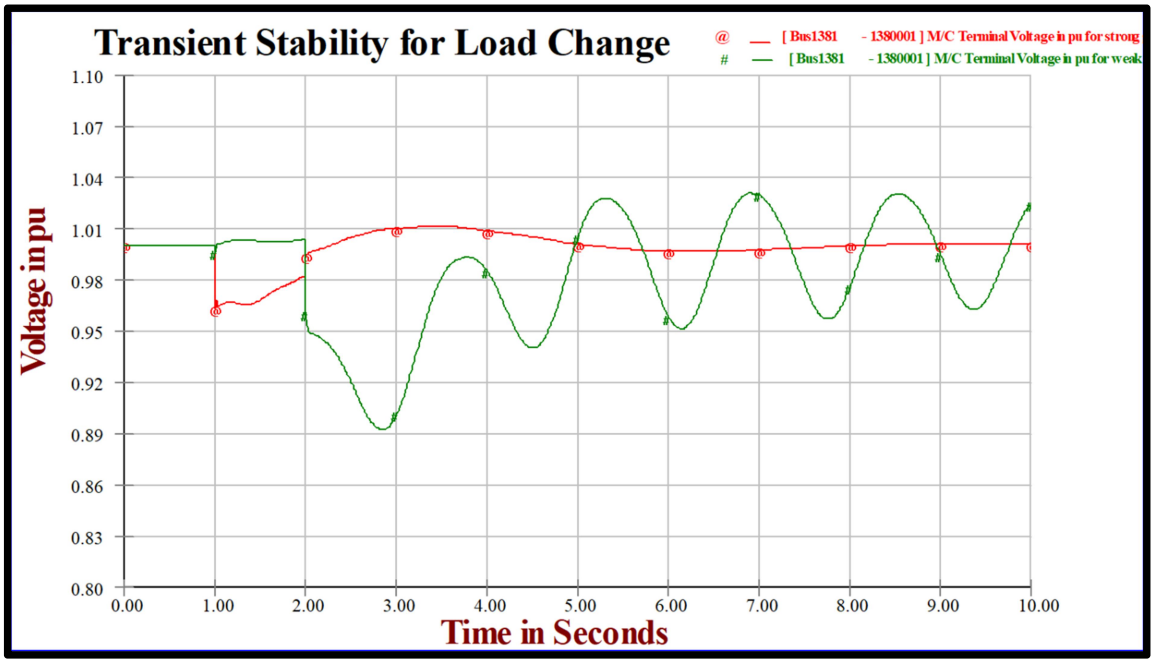

Figure 6-174 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant.

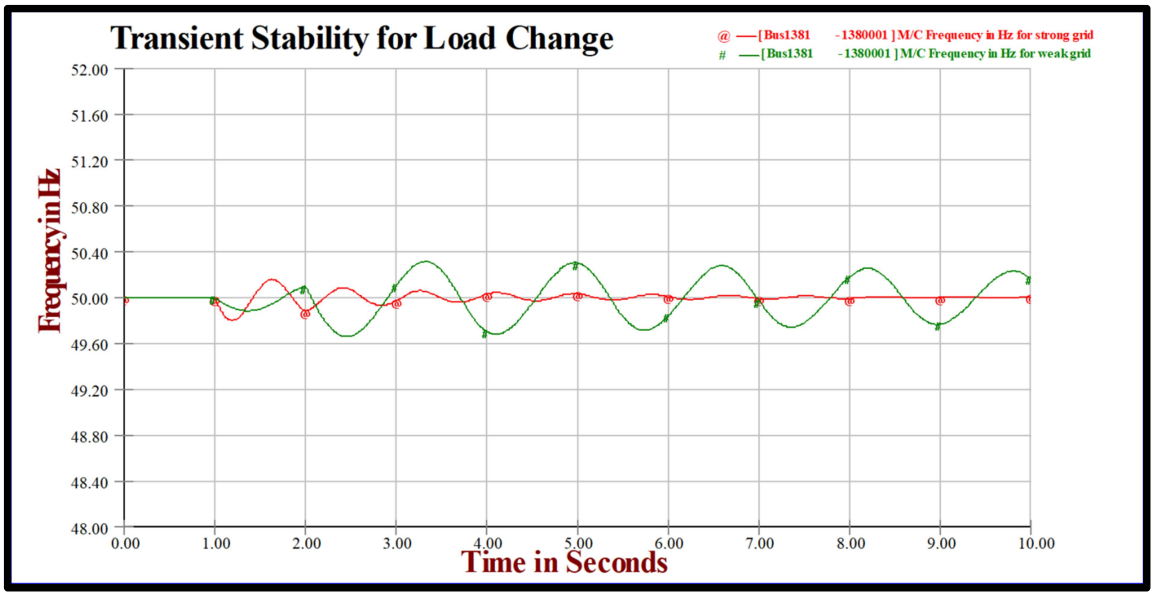

Figure 6-175 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during export mode of plant operation of plant is presented in Figure 6-176 and Figure 6-177.

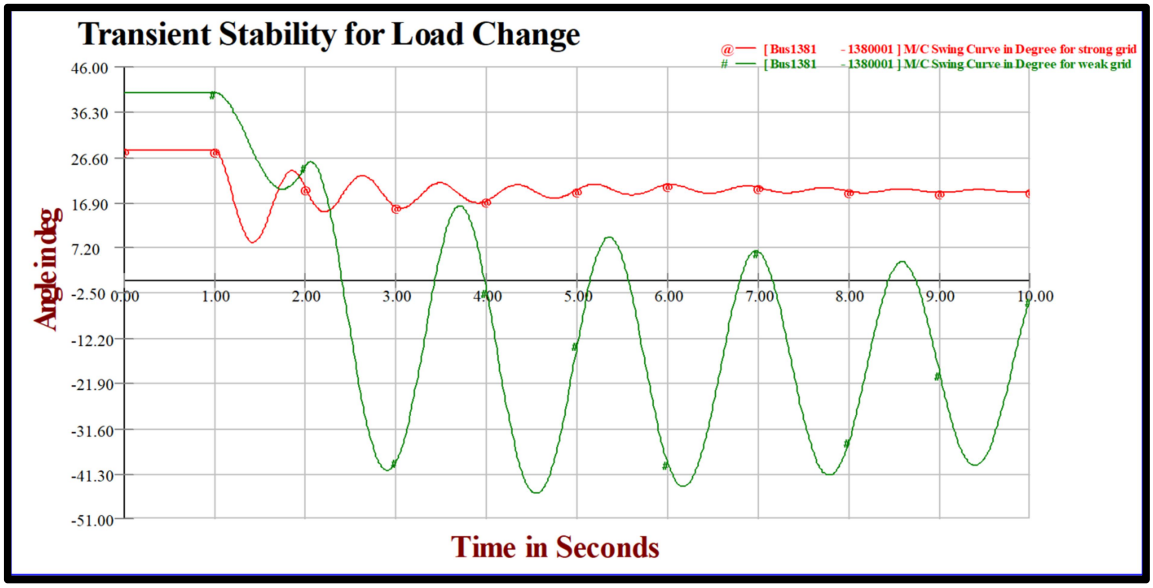

Figure 6-176 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant

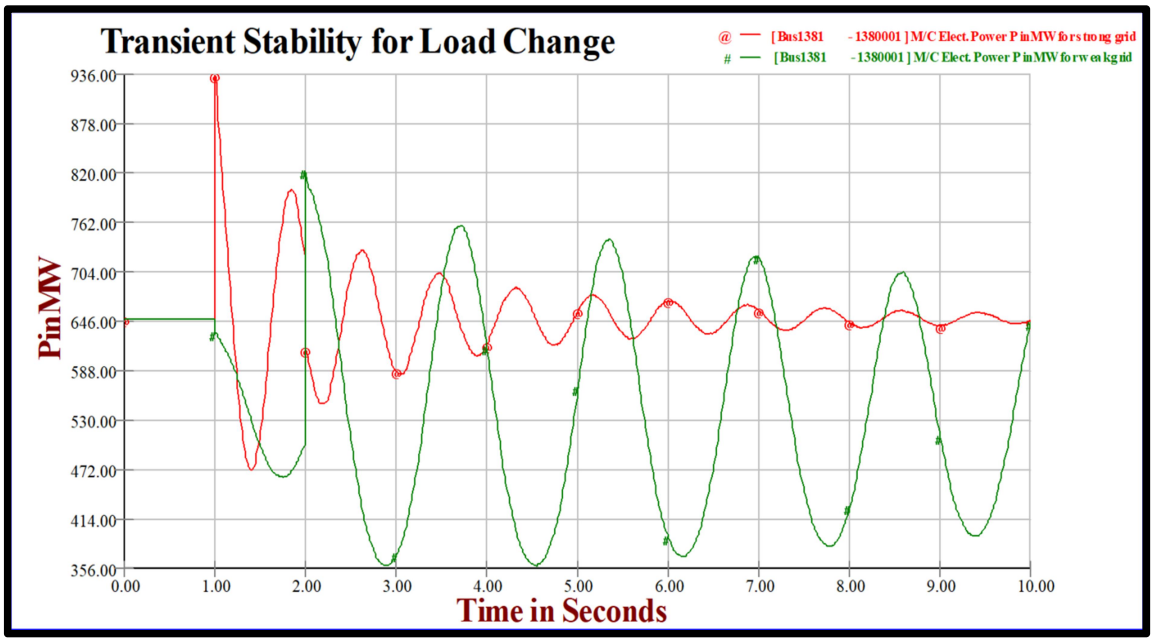

Figure 6-177 Active power plot for sudden increase in load inside the plant during export mode of operation of plant

6.9. Transient Stability study for Vedanta Jharsuguda

Vedanta is a Captive generating plant in Jharsuguda area having 9x135 MW generation capacities which is primarily connected to Budhipdar 220kV Bus. In the stability study of Vedanta plant, three important scenarios are simulated using in MiPSCT. In the first scenario, the Plant is operating in floating mode while assuming the full load operation inside the plant. Similarly, the second and third scenario is simulated by considering the contracted demand of

the plant operation. In each of the three scenarios, four different disturbance conditions are simulated to study the transient behaviour of CGP generators.

Floating Mode

Case 43: Three Phase to ground fault at the power evacuation bus inside the Vedanta plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-178 to 6-179 for a three phase to ground fault at the power evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

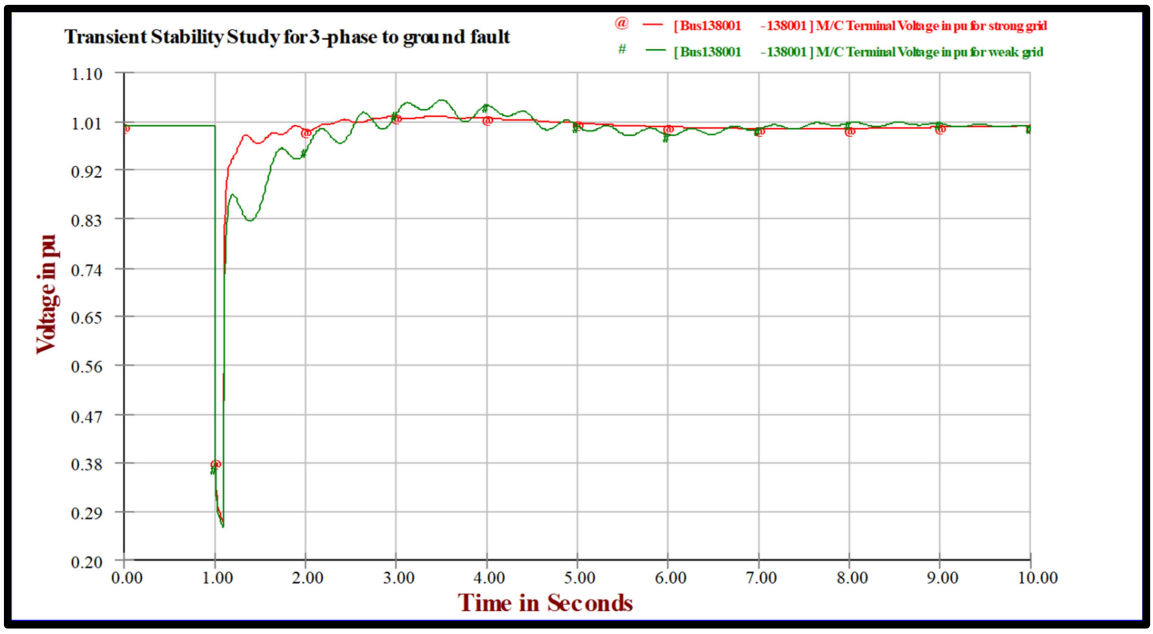

Figure 6-178 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

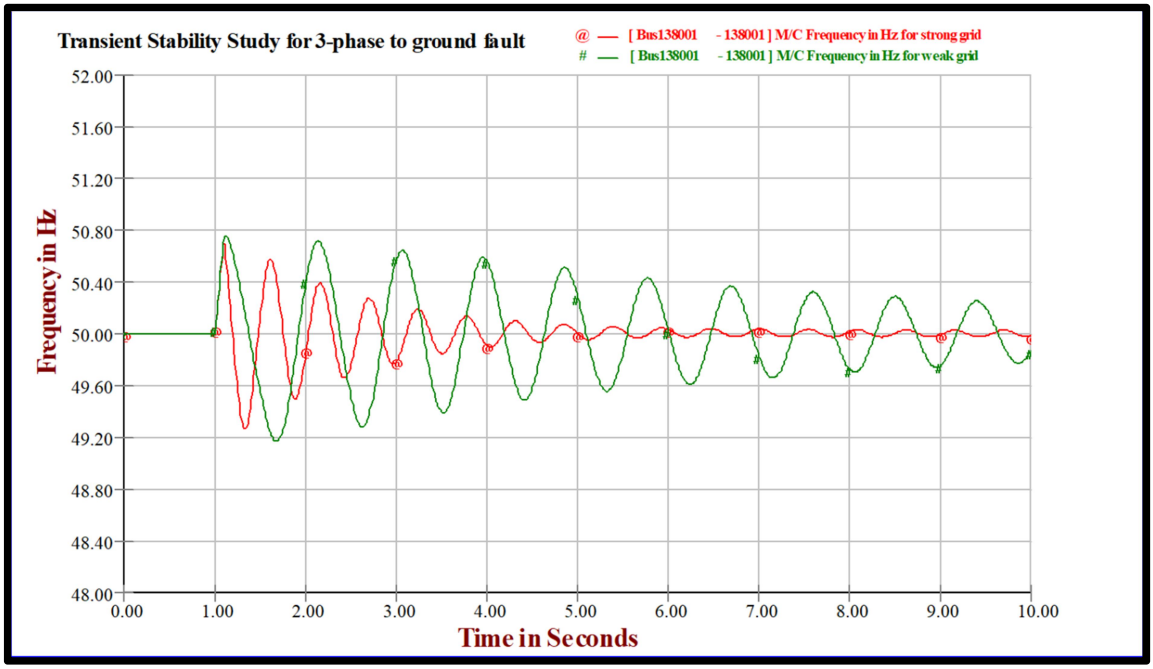

Figure 6-179 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-180 and Figure 6-181.

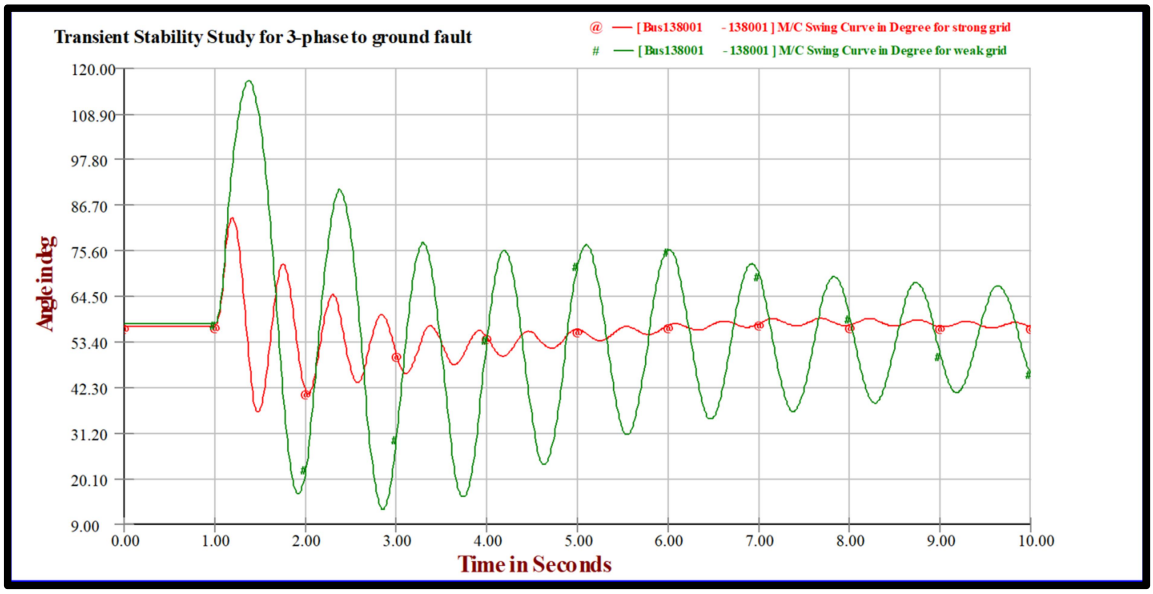

Figure 6-180 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

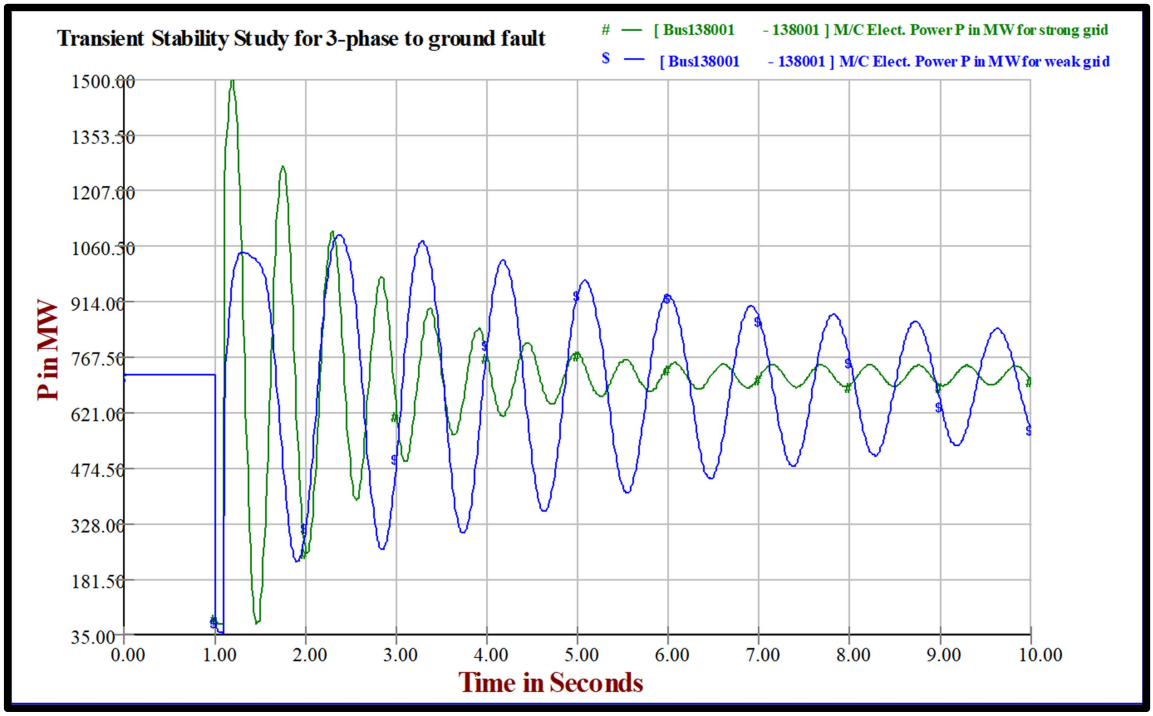

Figure 6-181 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Case 44: Single Line to ground fault at the power evacuation bus inside the Vedanta plant for duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-182 to 6-183 for a Single line to ground fault at the power evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

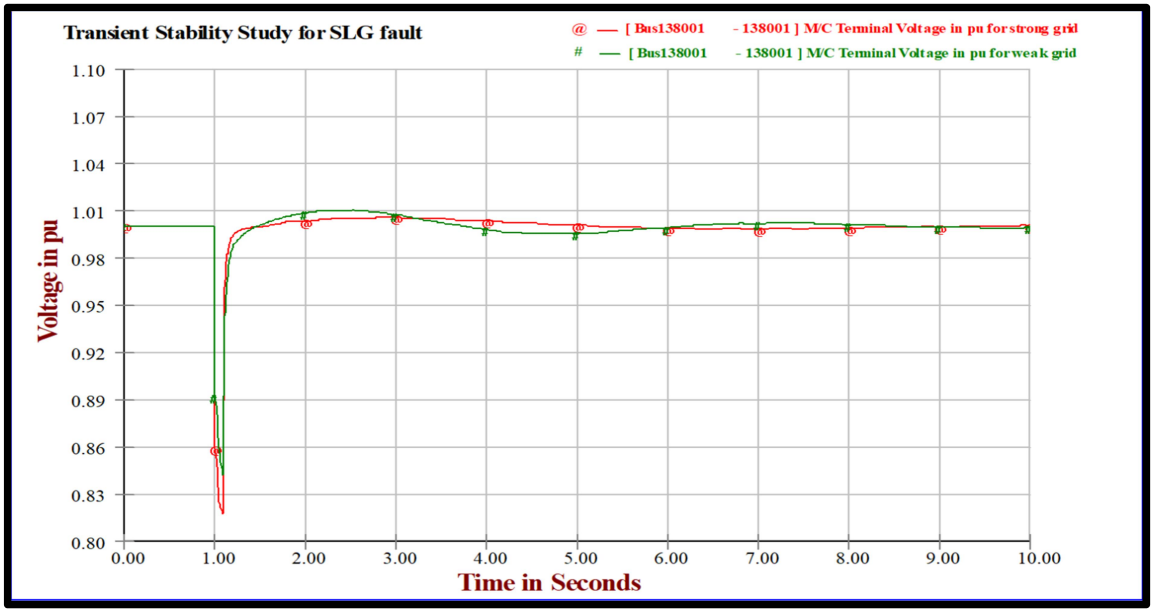

Figure 6-182 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

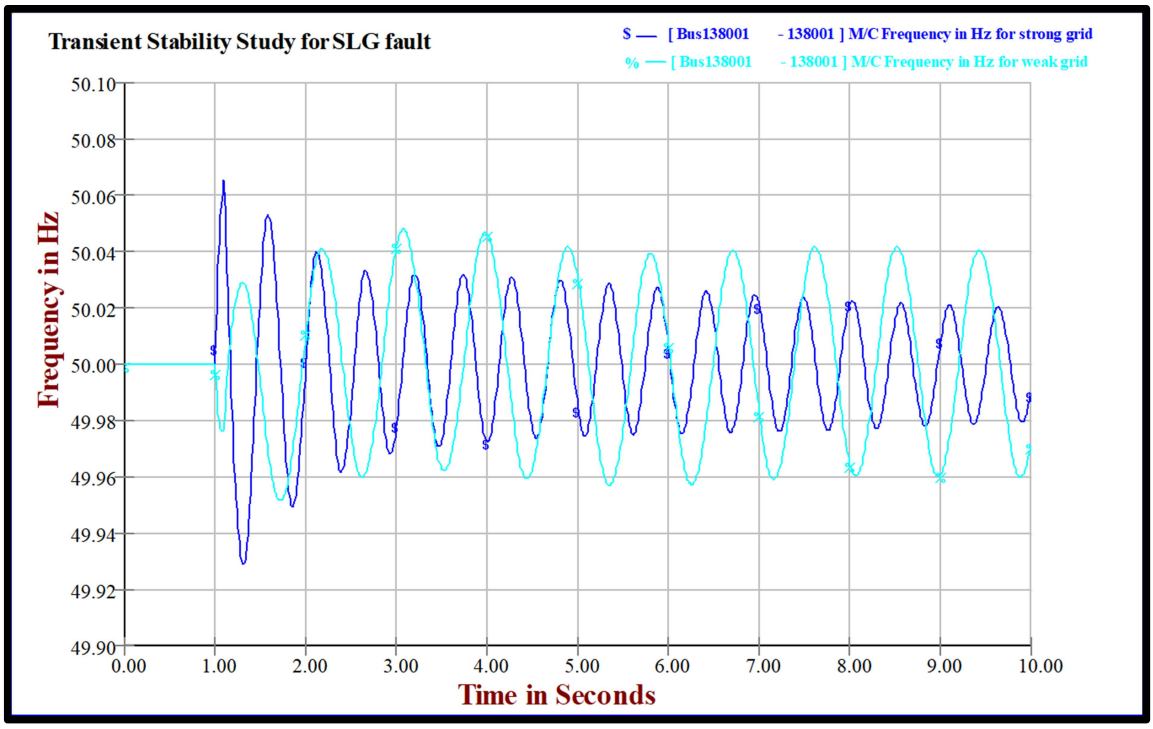

Figure 6-183 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-184 and Figure 6-185.

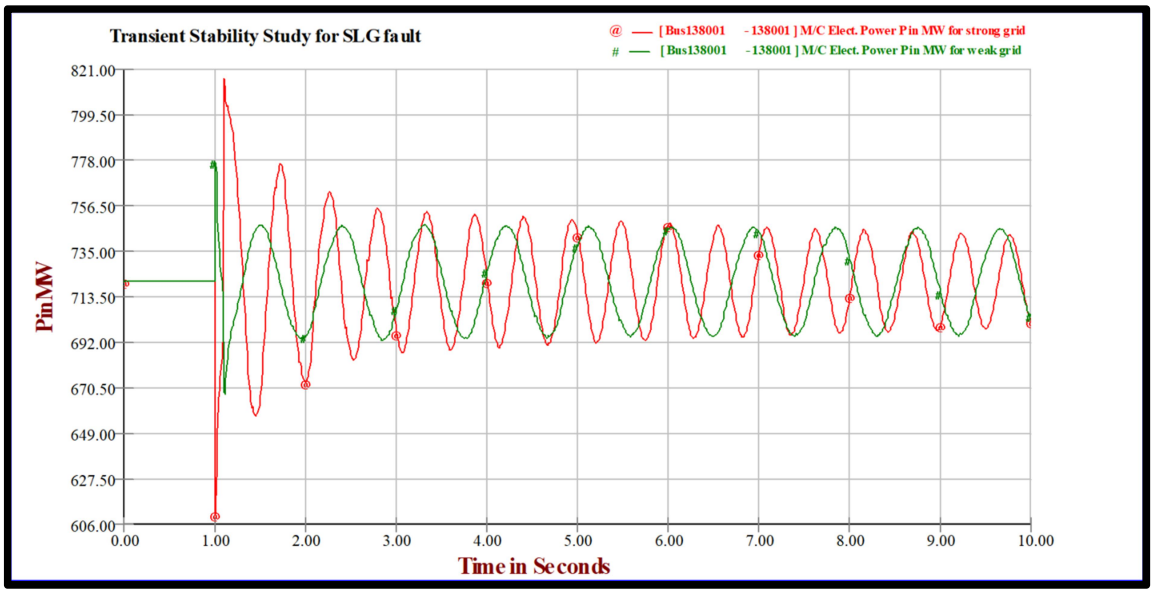

Figure 6-184 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

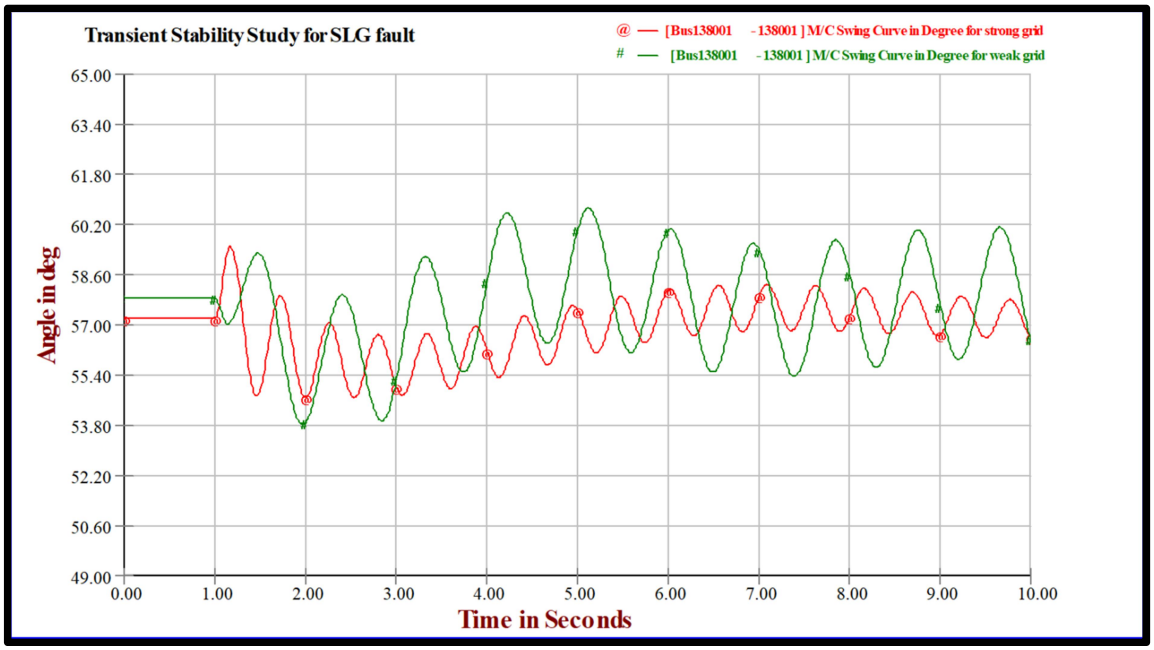

Figure 6-185 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Case 45: Highest Generating unit Outage in the Vedanta plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-186 to 6-187 for a disturbance initiated due to generator outage during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

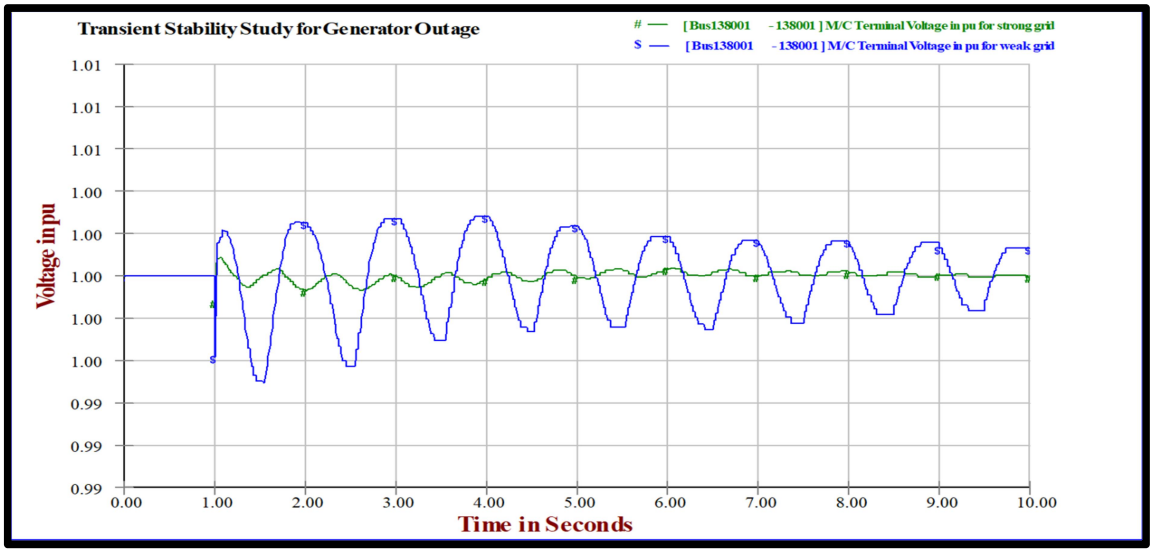

Figure 6-186 Voltage plot for highest generating unit outage inside the plant during floating mode of operation of plant

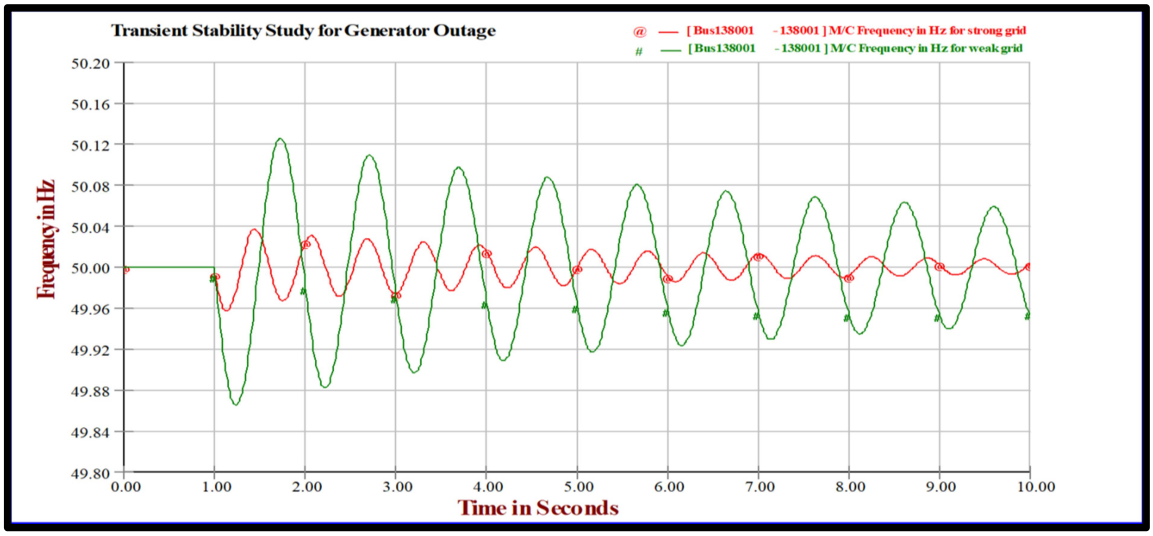

Figure 6-187 Frequency plot for highest generating unit outage inside the plant during floating mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during floating mode of operation of plant is presented in Figure 6-188 and Figure 6-189.

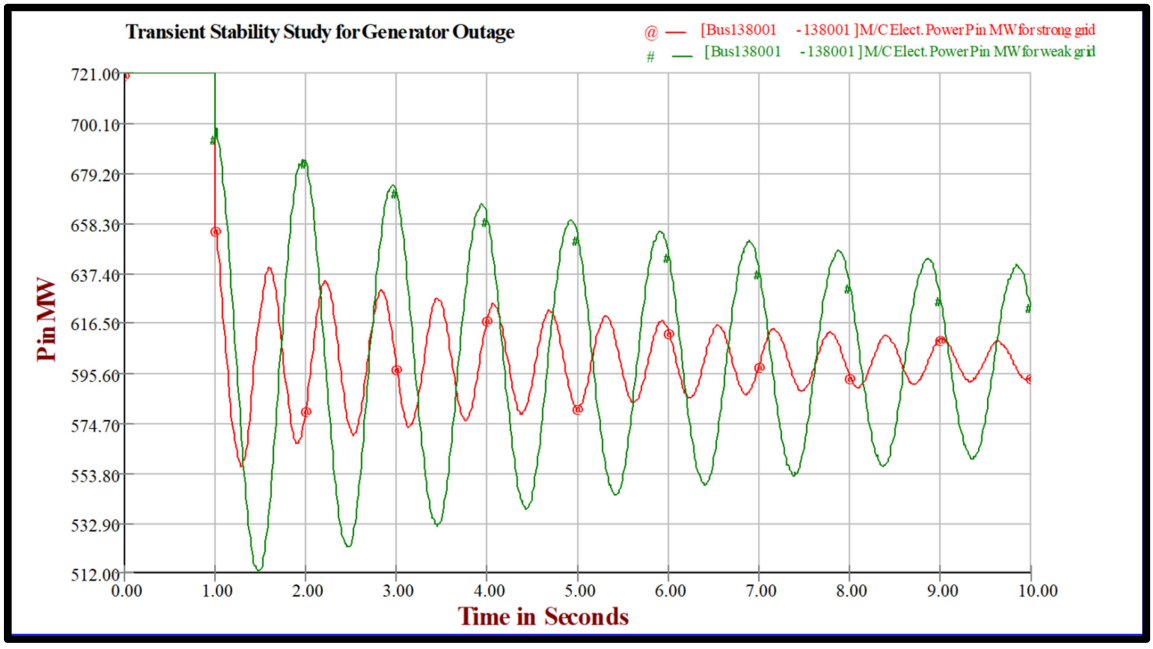

Figure 6-188 Active power for generating bus plot for highest generating unit outage inside the plant during floating mode of operation of plant

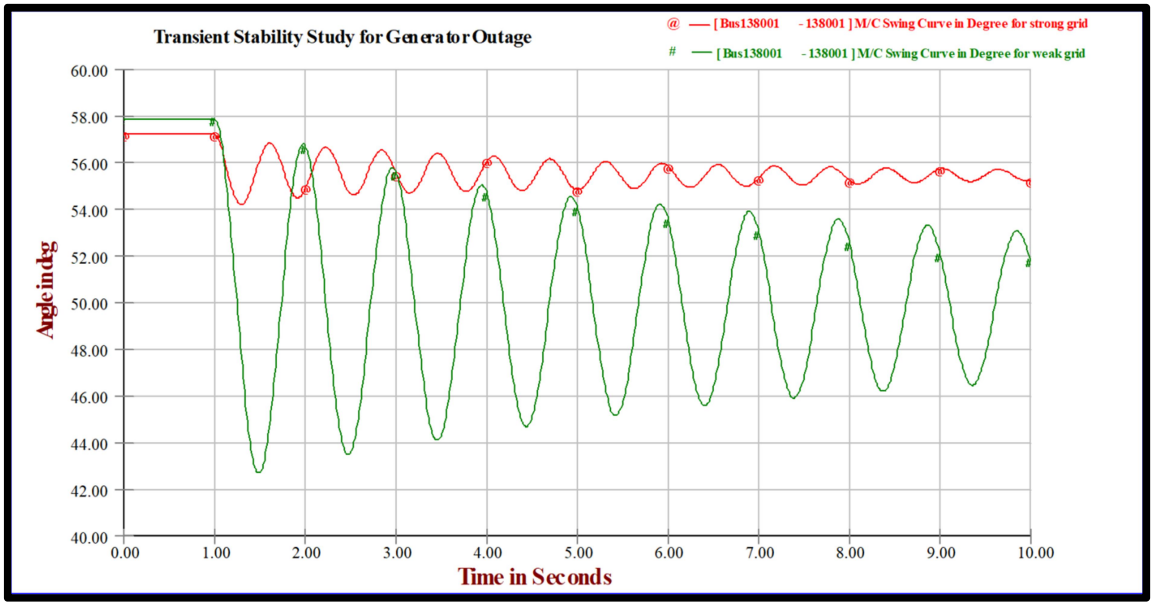

Figure 6-189 Swing curve plot for highest generating unit outage inside the plant during floating mode of operation of plant

Case 46: Load throw off at the Vedanta plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-190 to 6-191 for a disturbance initiated due to sudden load throw off during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

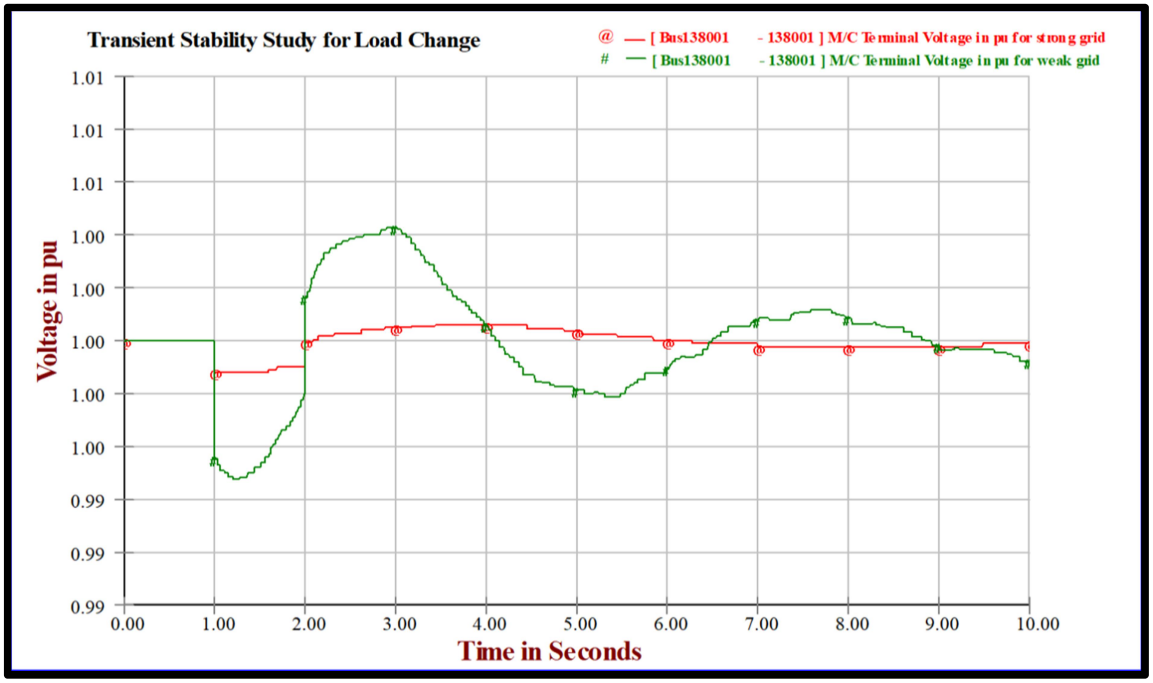

Figure 6-190 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant.

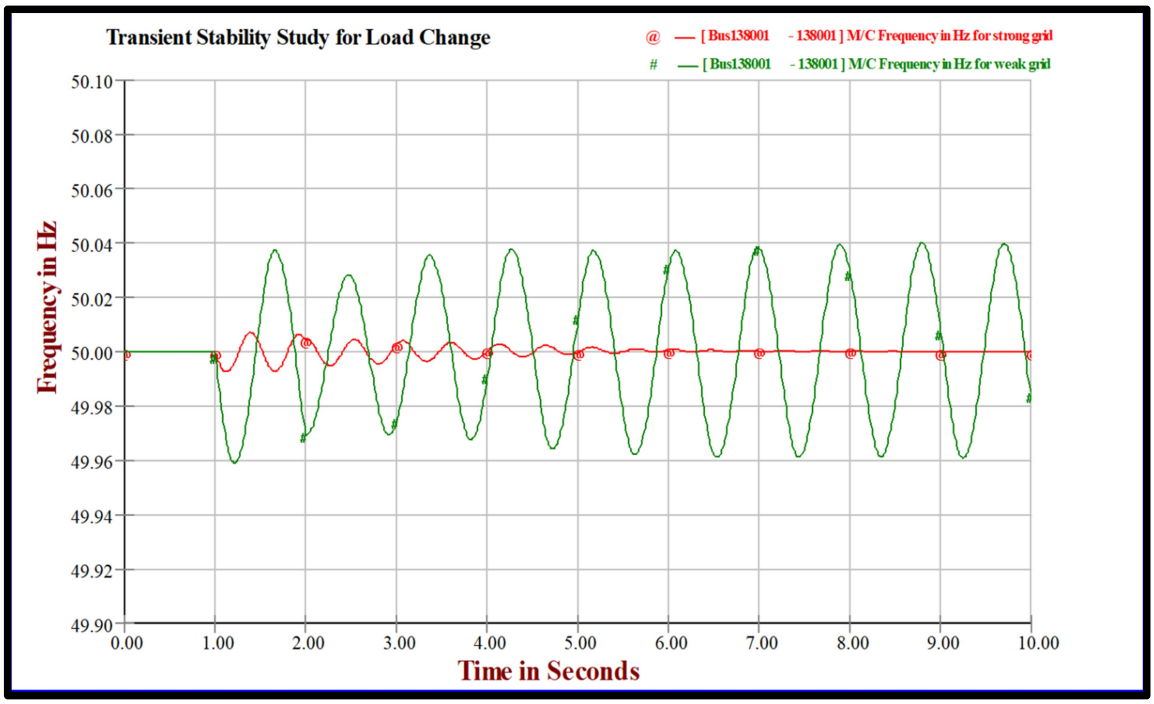

Figure 6-191 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant.

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during floating mode of plant operation of plant is presented in Figure 6-192 and Figure 6-193.

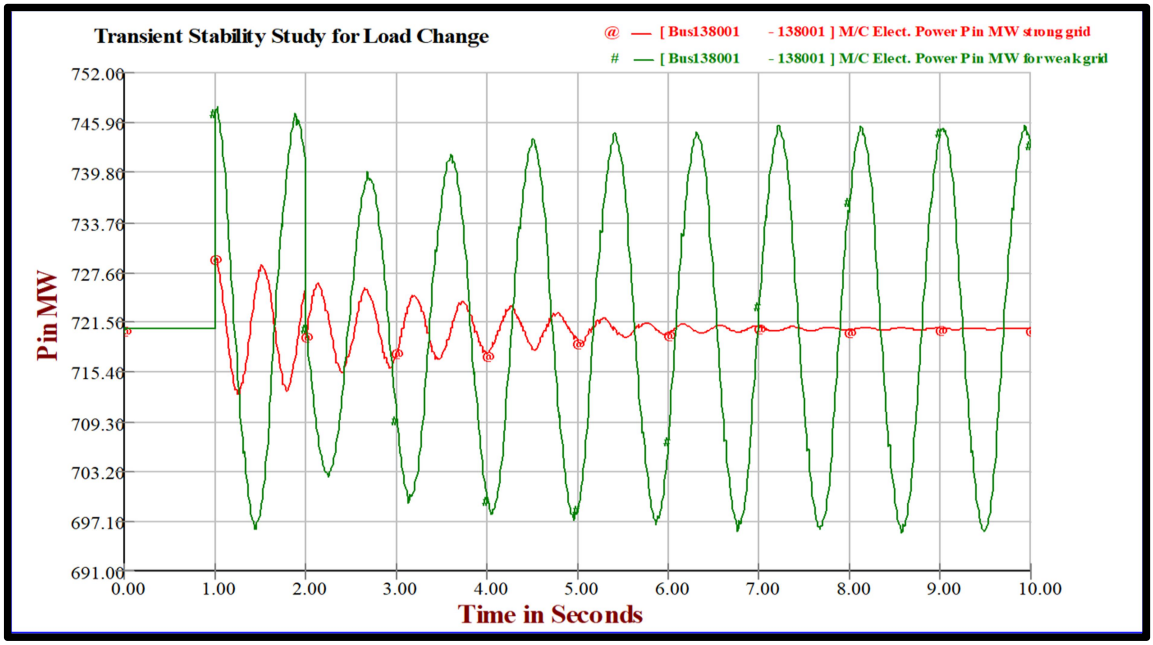

Figure 6-192 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant

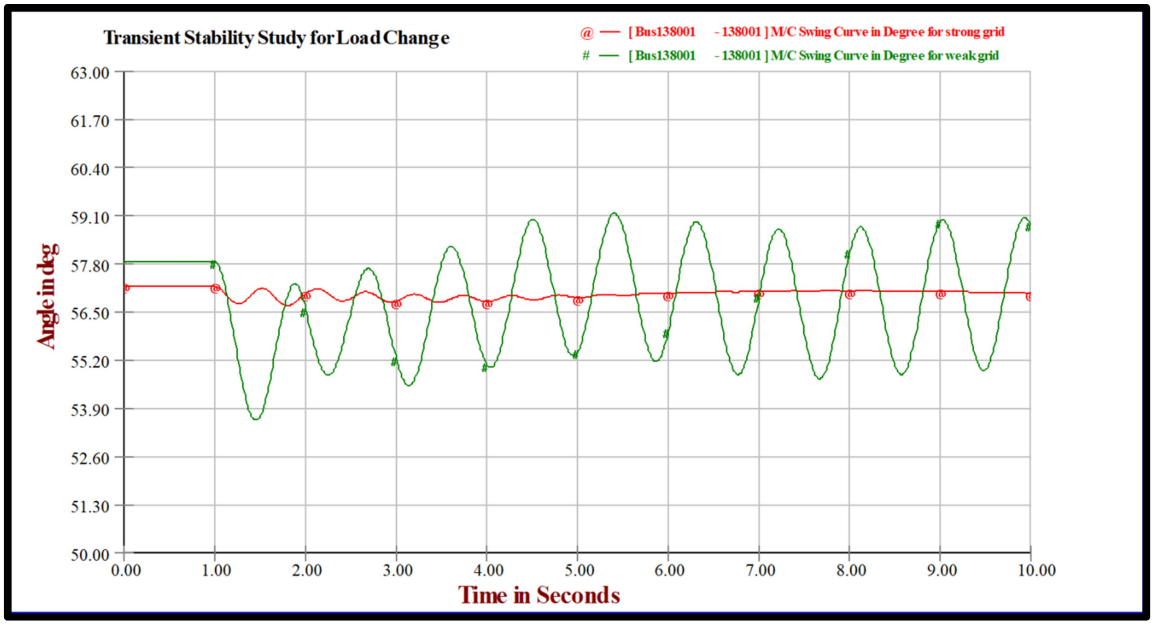

Figure 6-193 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant

Import mode

Case 47: Three Phase to ground fault at the Vedanta plant for a duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-194 to 6-195 for a three phase to ground fault at the power evacuation bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

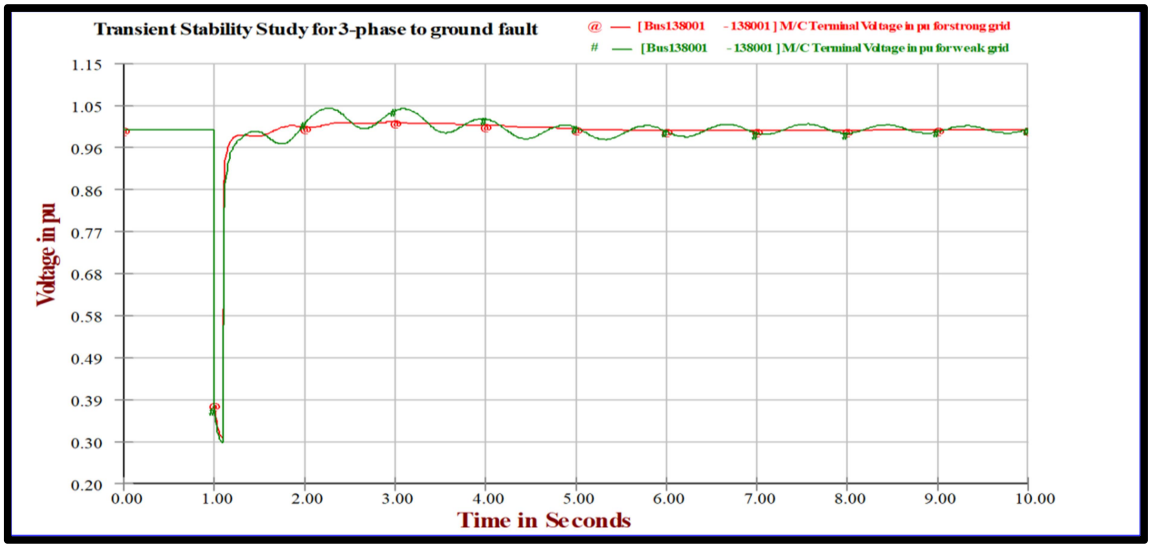

Figure 6-194 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

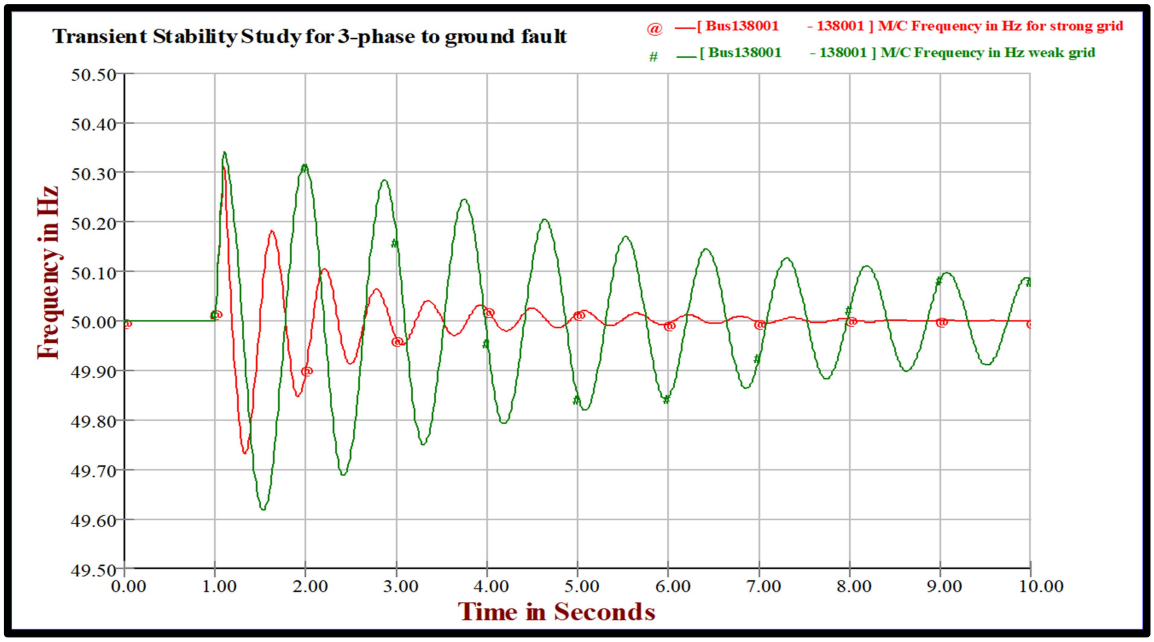

Figure 6-195 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-196 and Figure 6-197.

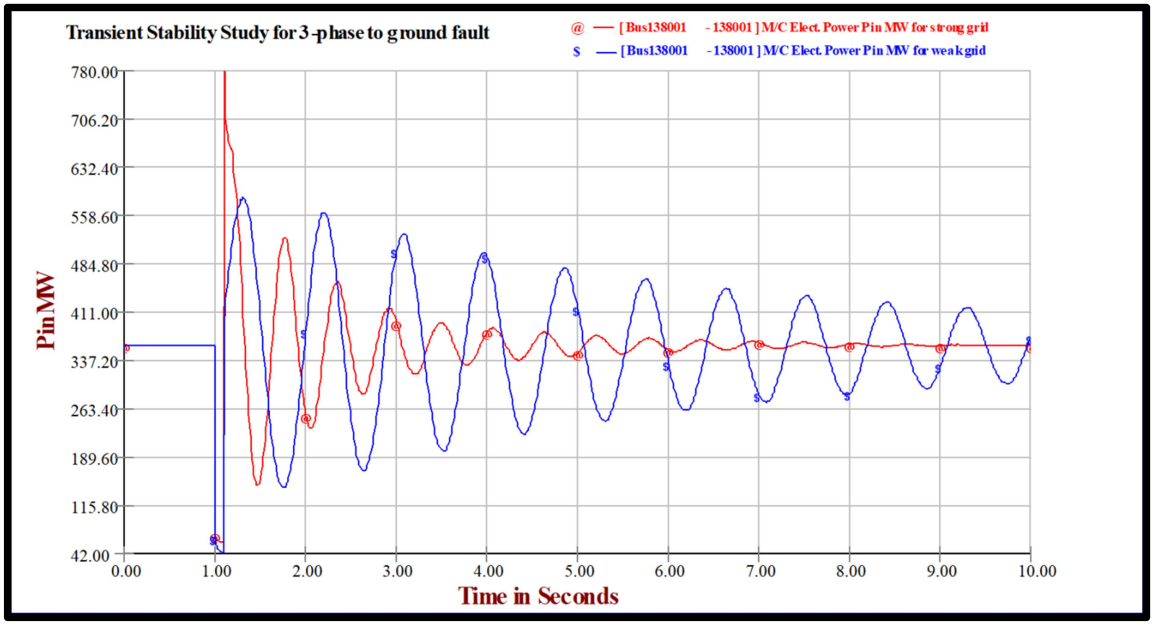

Figure 6-196 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

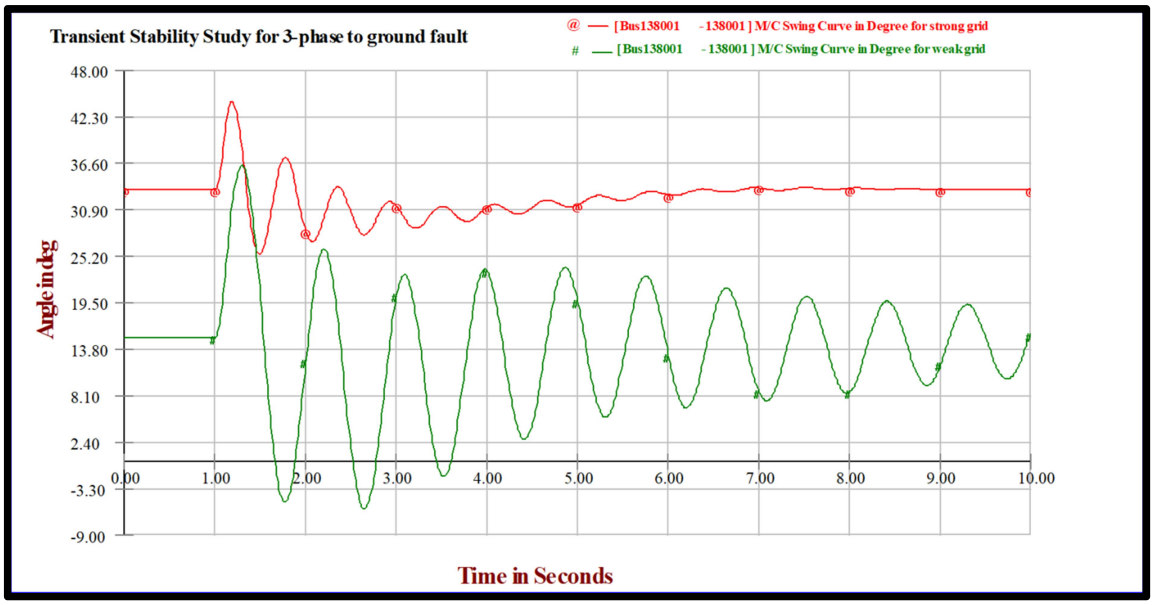

Figure 6-197 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Case 48: Single Line to ground fault at the Vedanta plant for a duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-198 to 6-199 for a Single line to ground fault at the power evacuation bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

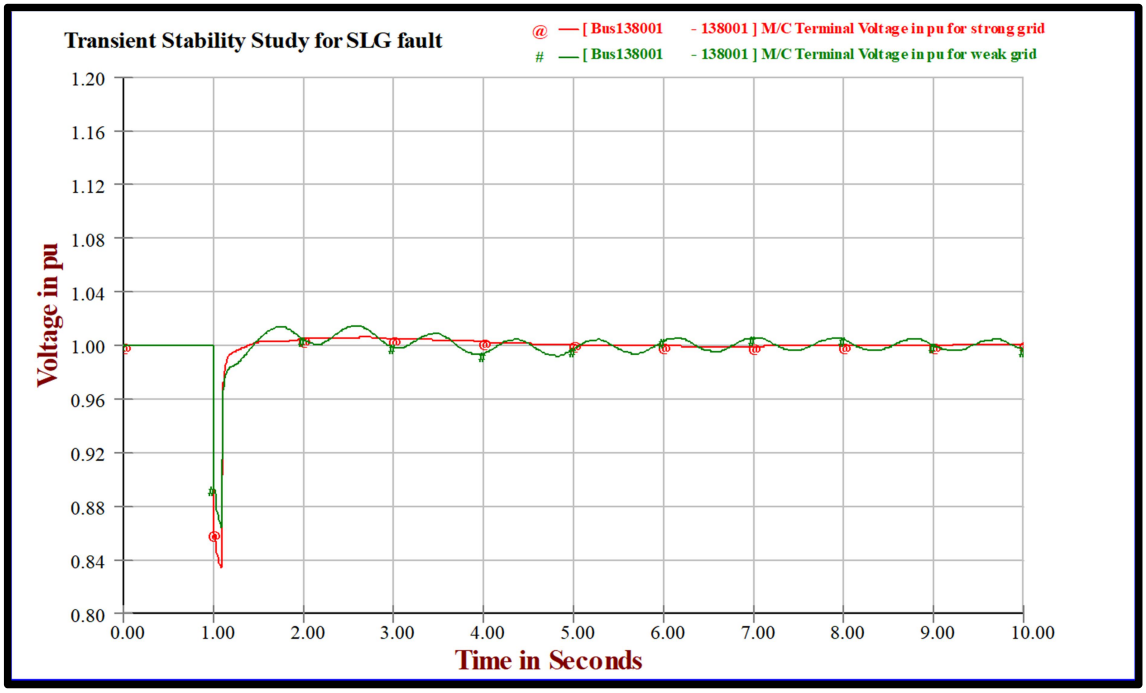

Figure 6-198 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

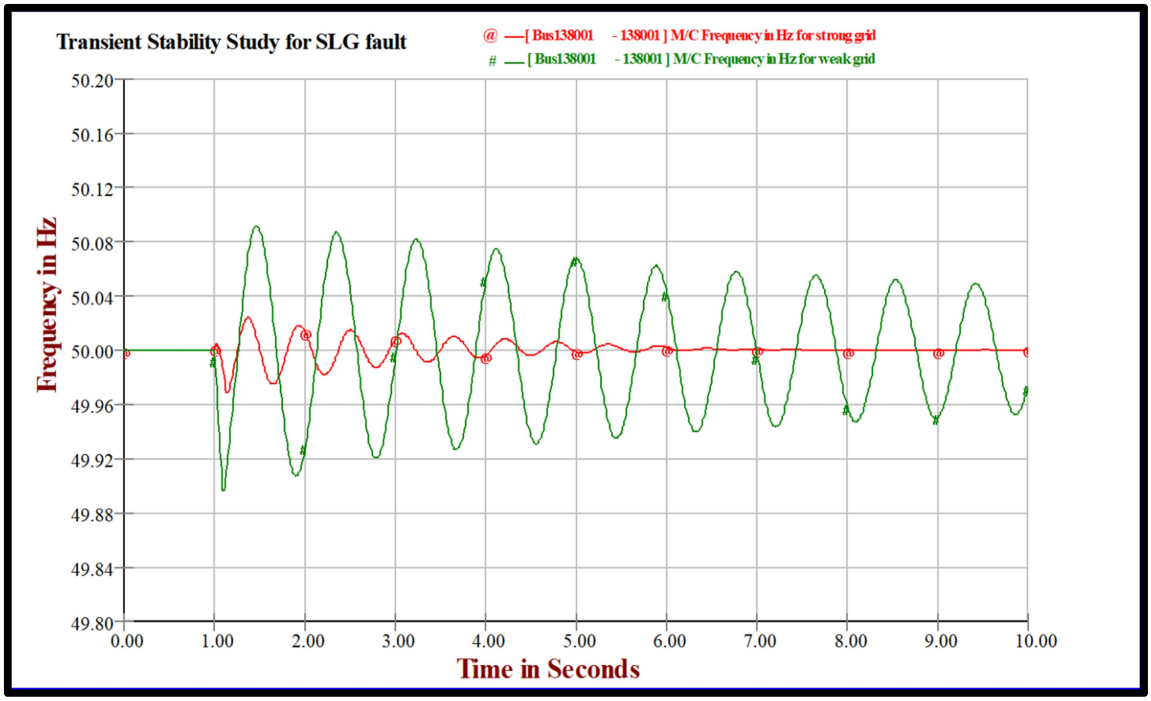

Figure 6-199 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-200 and Figure 6-201.

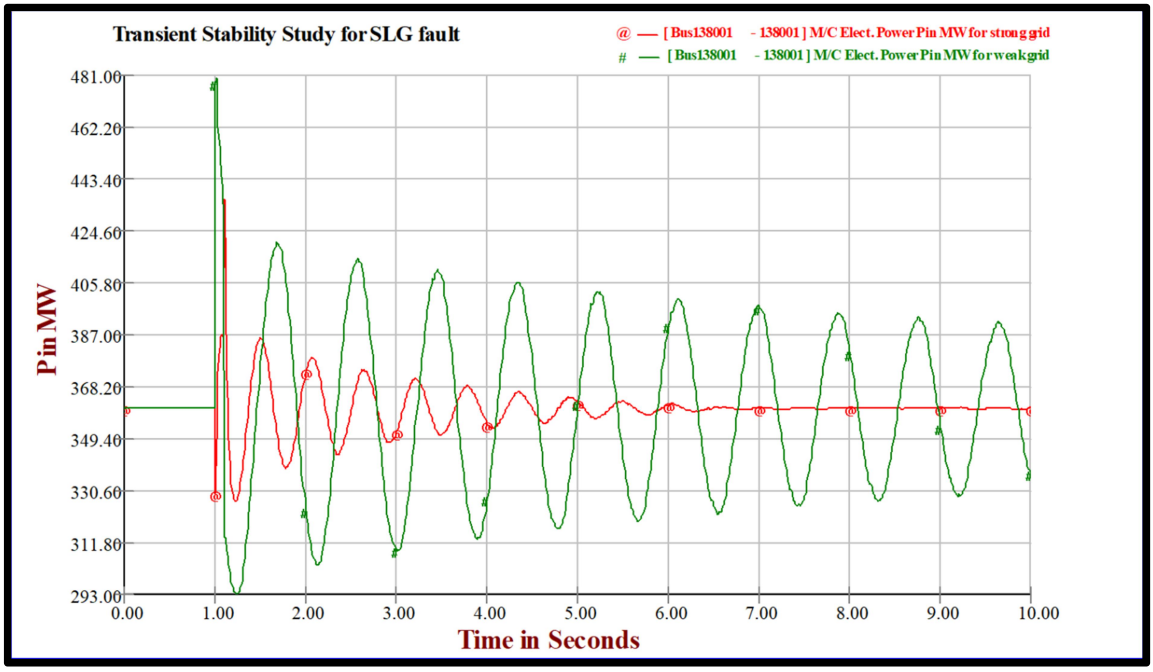

Figure 6-200 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

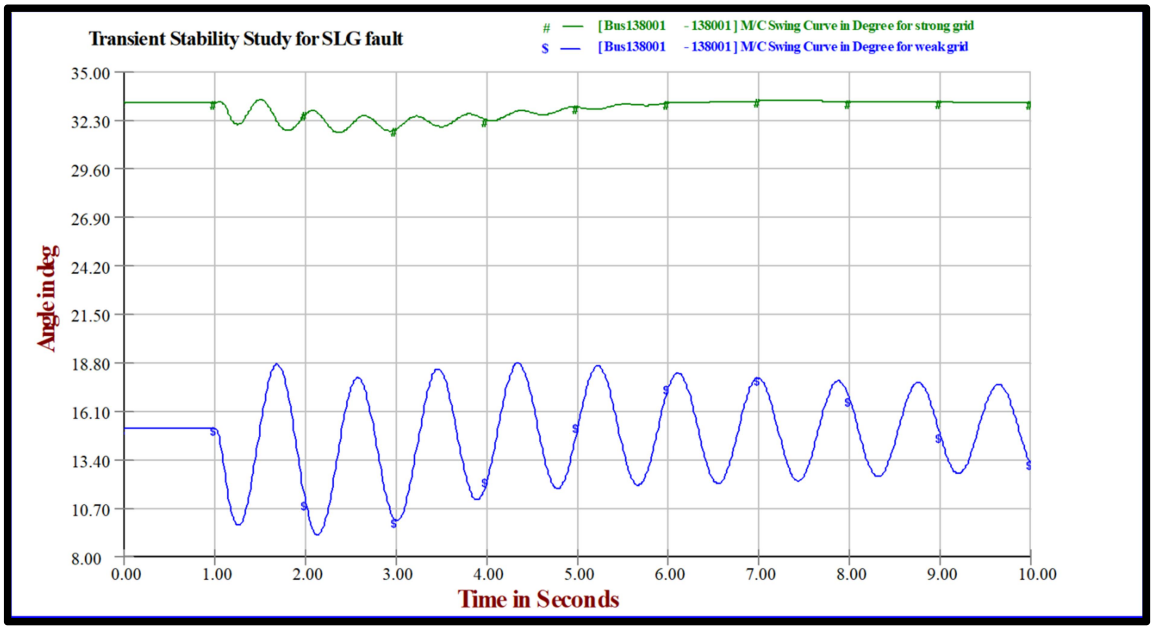

Figure 6-201 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Case 49: Outage of Largest Generator set at the Vedanta plant with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-202 to 6-203 for a disturbance initiated due to generator outage

during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

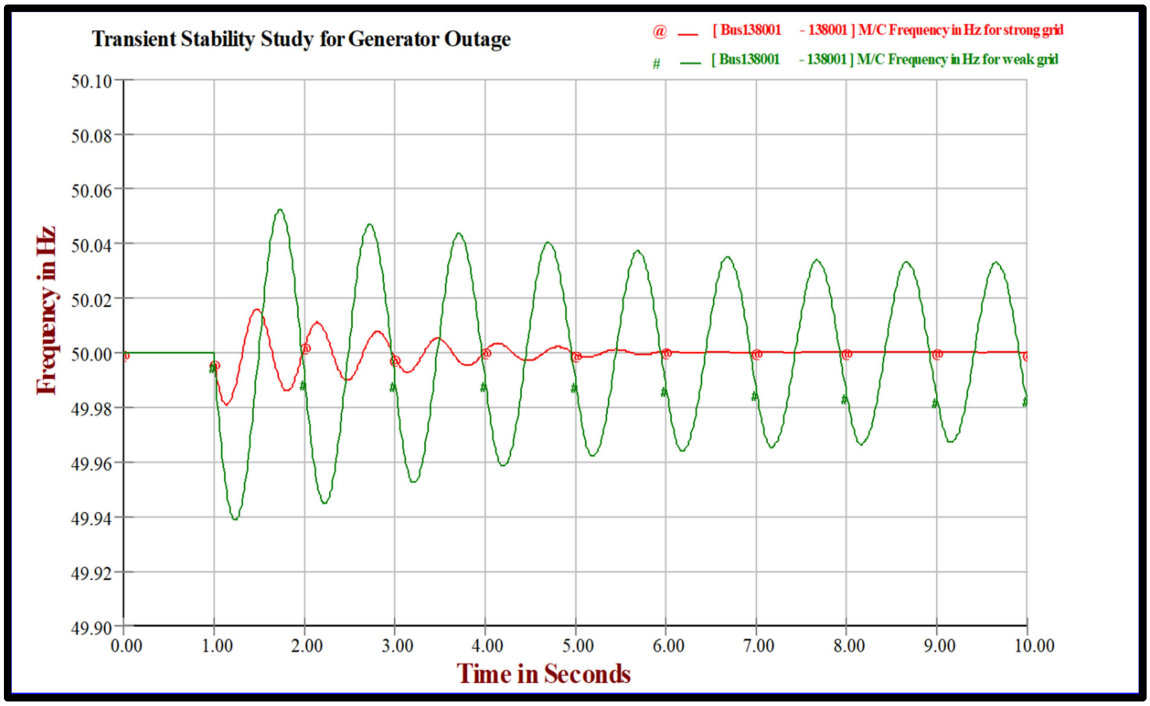

Figure 6-202 Frequency plot for highest generating unit outage inside the plant during import mode of operation of plant

Similarly, the swing curve angle in degree for a disturbance initiated due to generator during import mode of operation of plant is presented in Figure 6-204.

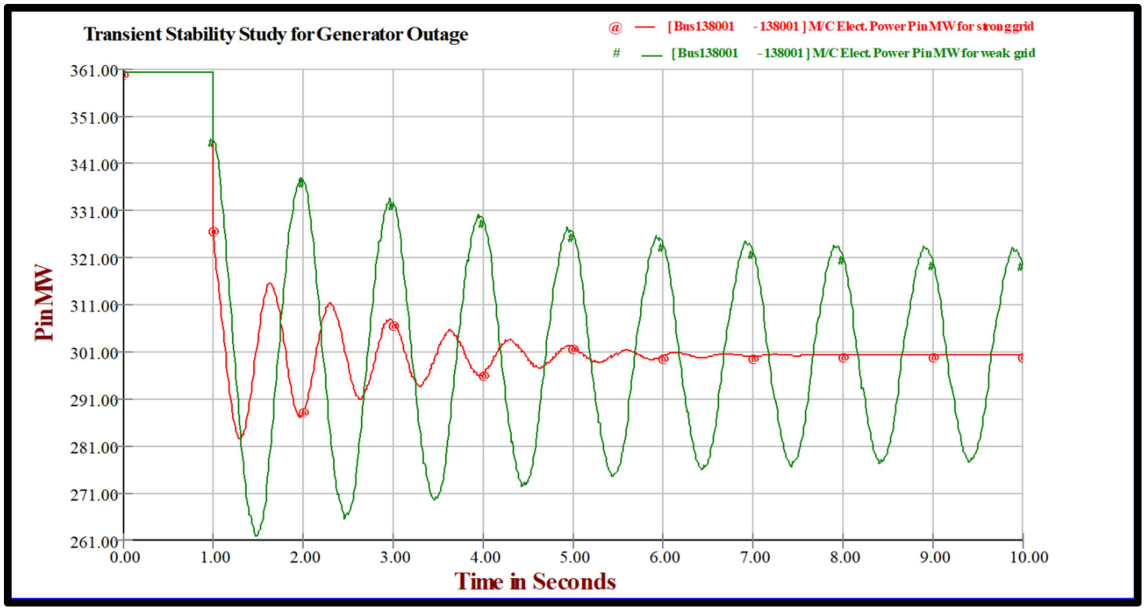

Figure 6-203 Active power plot for highest generating unit outage inside the plant during import mode of operation of plant

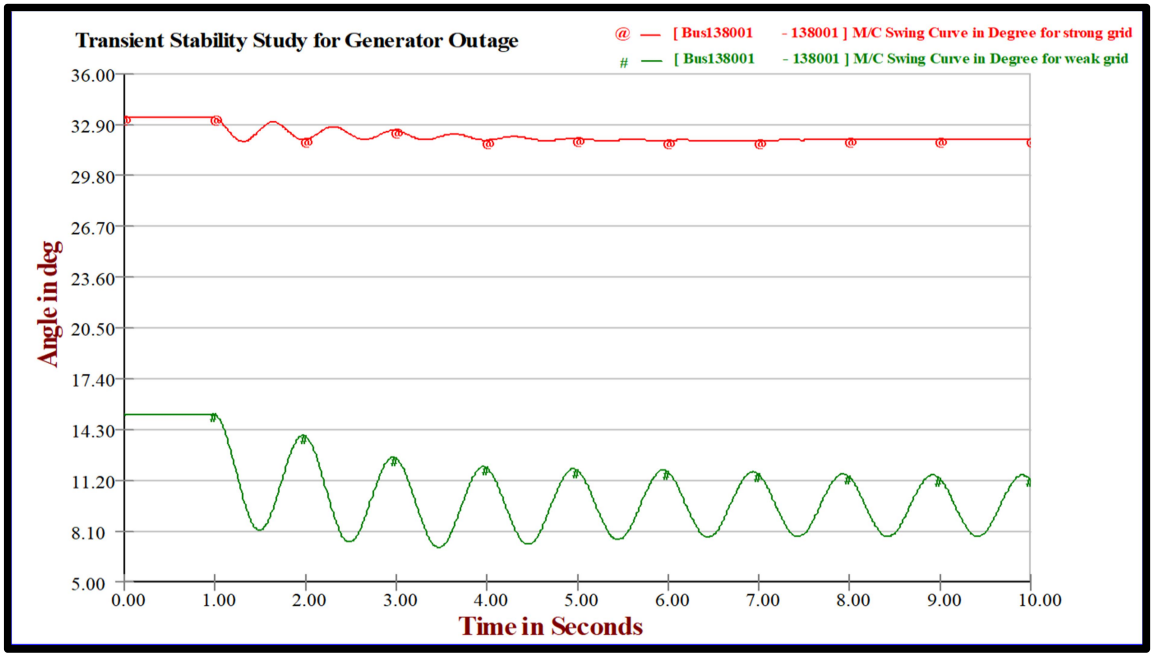

Figure 6-204 Swing curve plot for highest generating unit outage inside the plant during import mode of operation of plant

Case 50: Load throw off at the Vedanta plant with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-205 to 6-206 for a disturbance initiated due to sudden load throw off during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

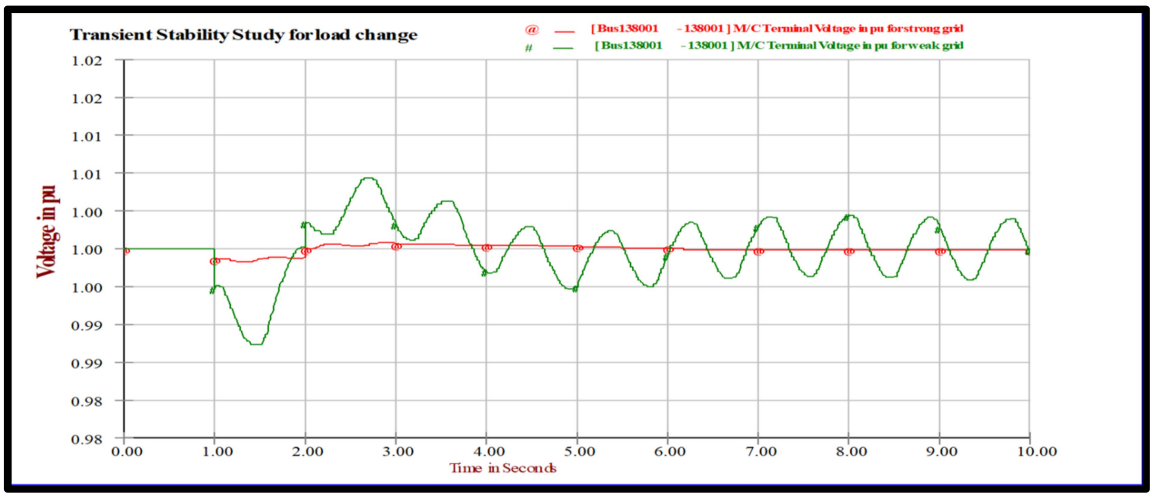

Figure 6-205 Voltage plot for sudden increase in load inside the plant during import mode of operation of plant.

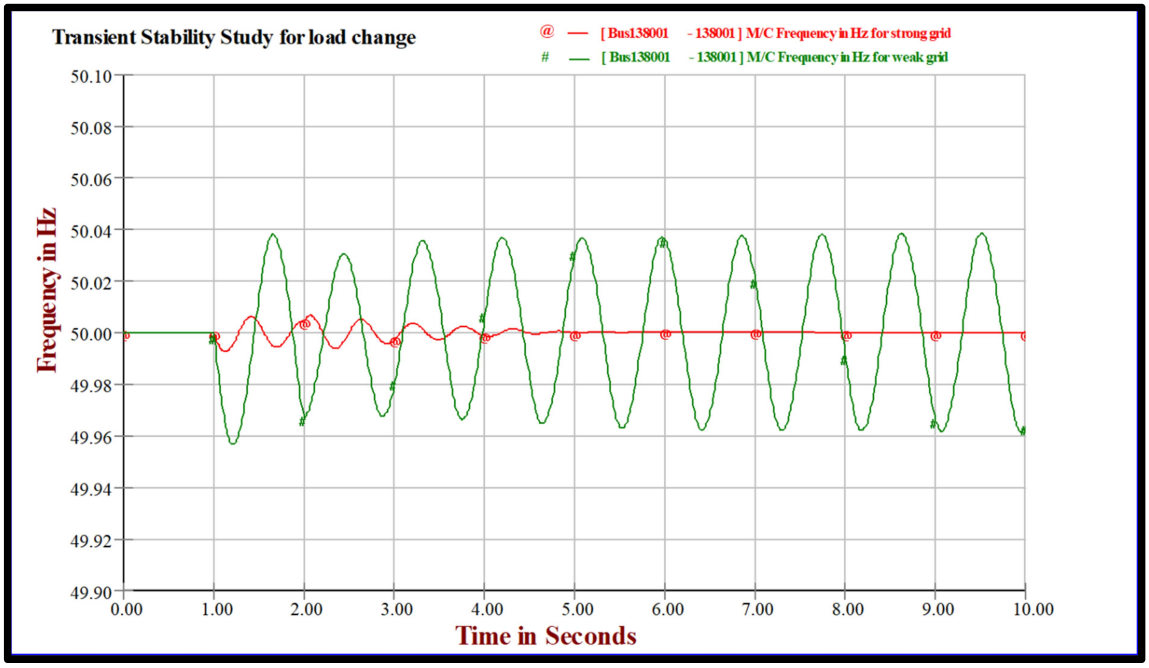

Figure 6-206 Frequency plot for sudden increase in load inside the plant during import mode of operation of plant.

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during import mode of plant operation of plant is presented in Figure 6-207 and Figure 6-208.

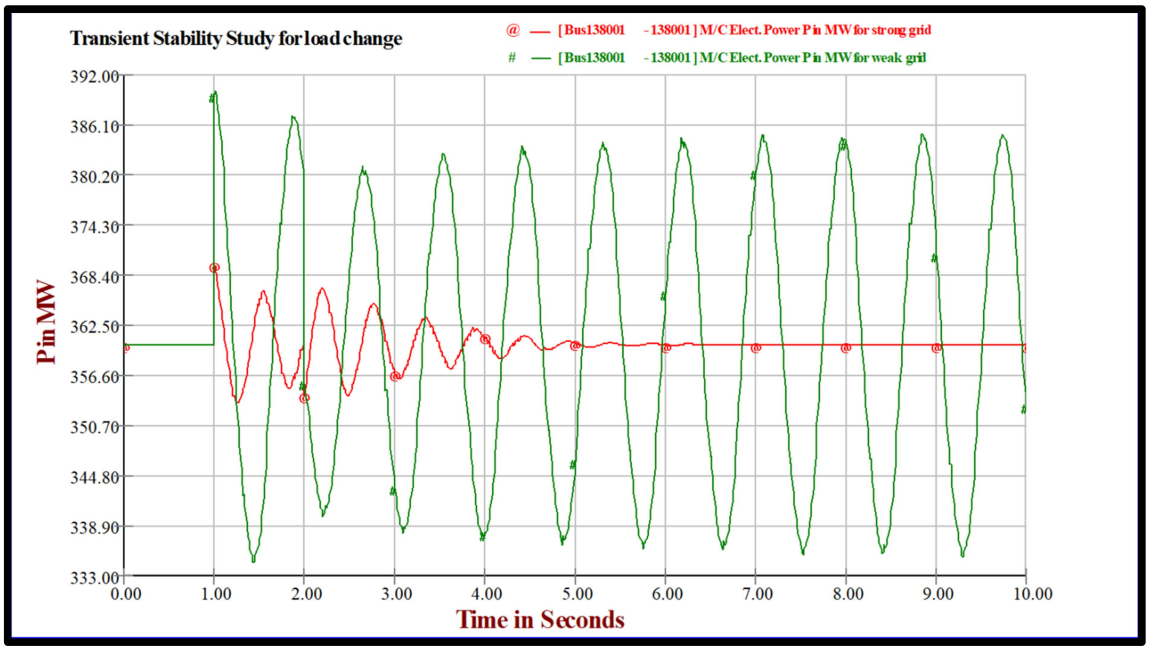

Figure 6-207 Active power plot for sudden increase in load inside the plant during import mode of operation of plant

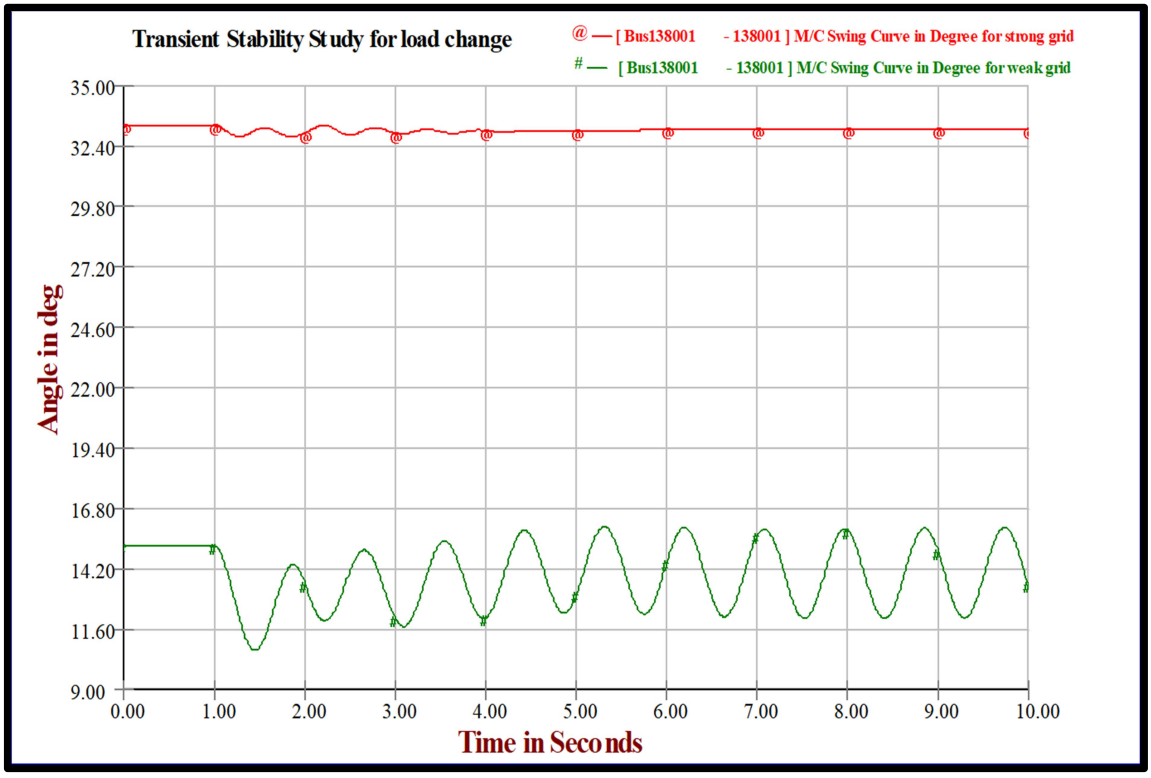

Figure 6-208 Swing curve plot for sudden increase in load inside the plant during import mode of operation of plant

Export mode

Case 51: Three Phase to ground fault at the Vedanta plant for a duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-209 to 6-210 for a three phase to ground fault at the power evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

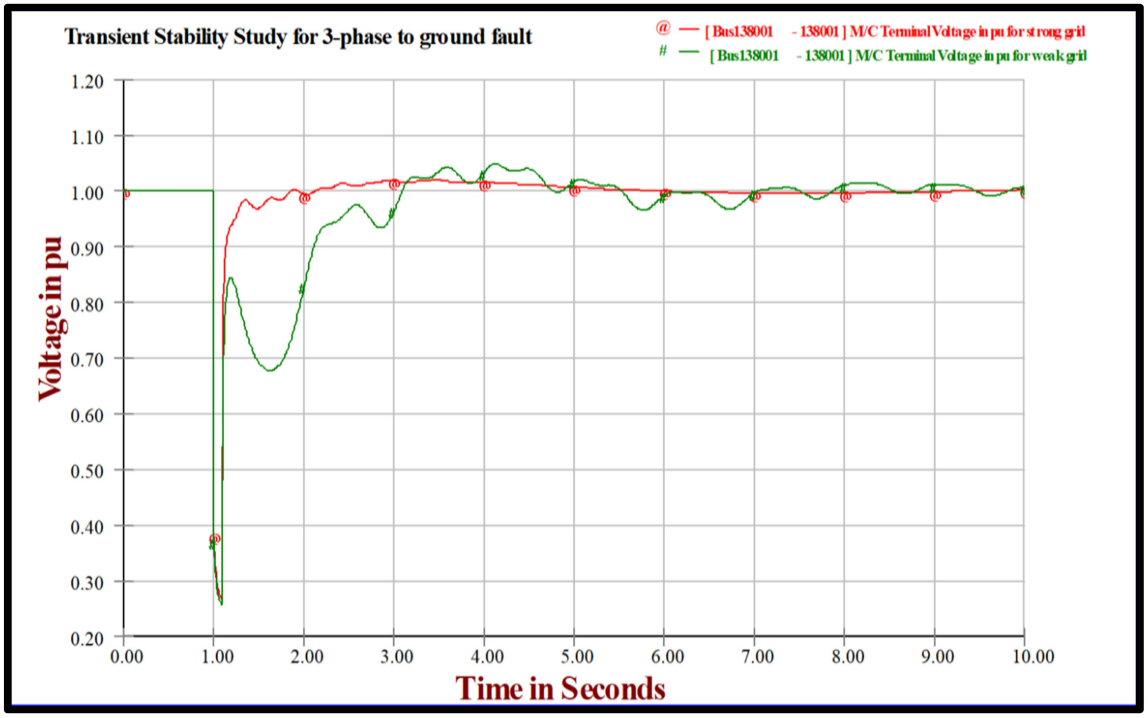

Figure 6-209 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

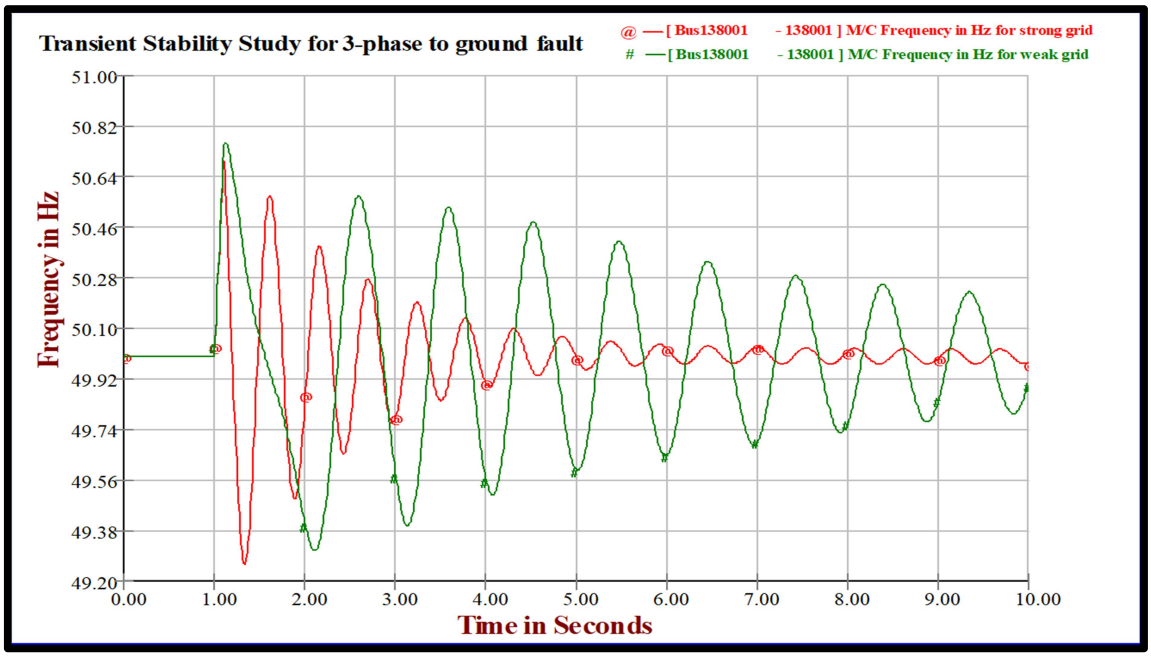

Figure 6-210 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-211 and Figure 6-212.

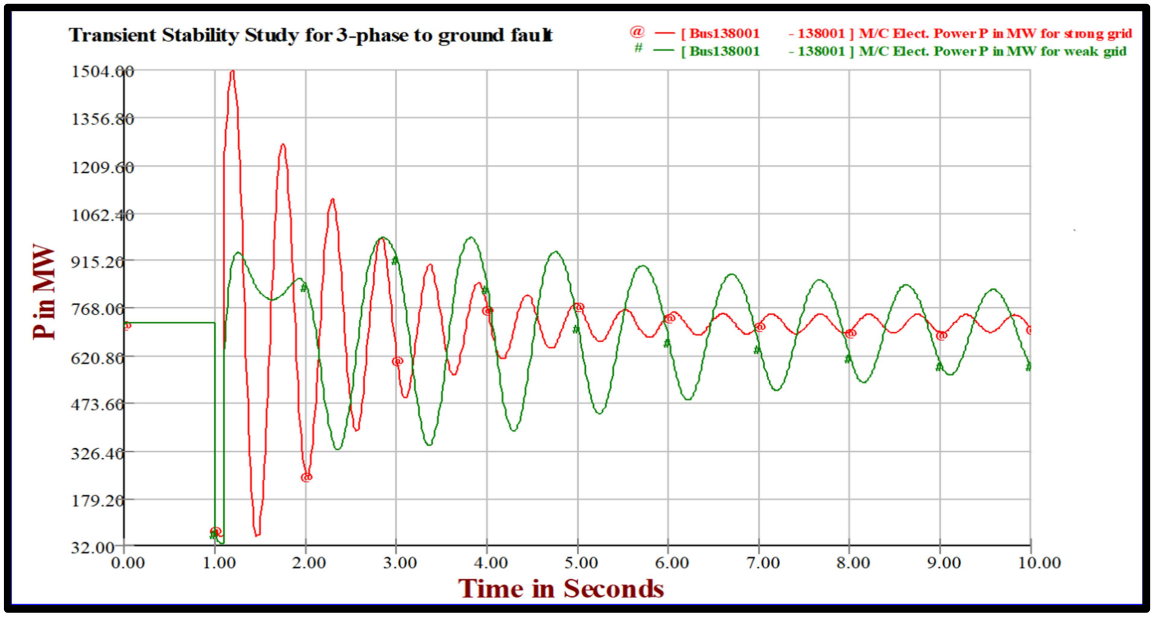

Figure 6-211 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

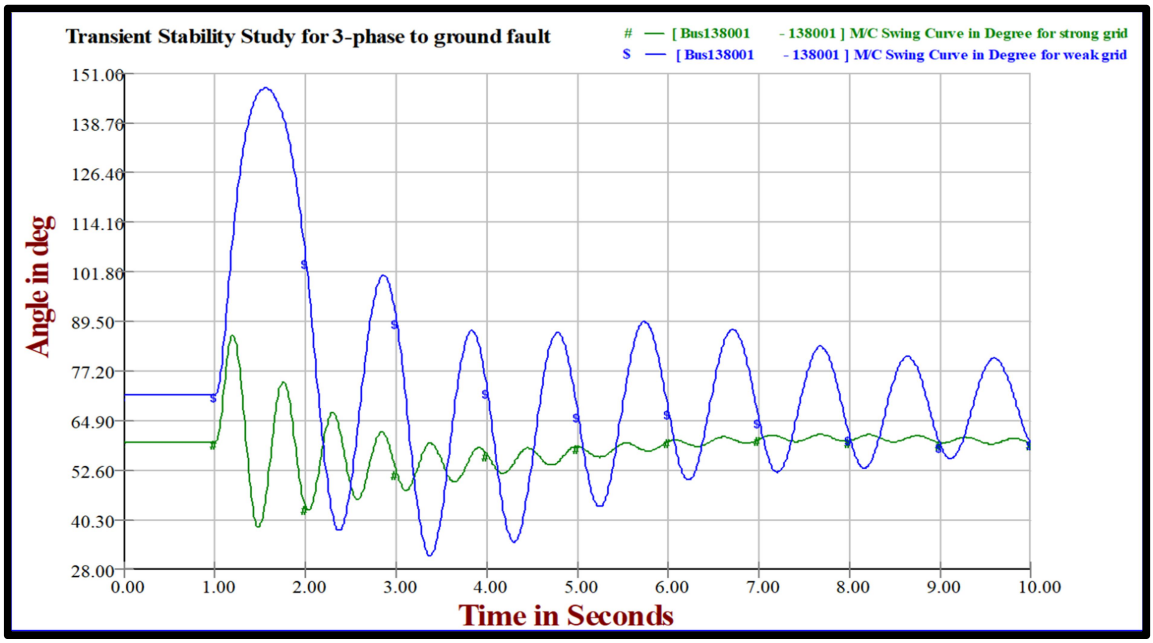

Figure 6-212 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Case 52: Single Line to ground fault at the Vedanta plant for a duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-213 to 6-214 for a Single line to ground fault at the power evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

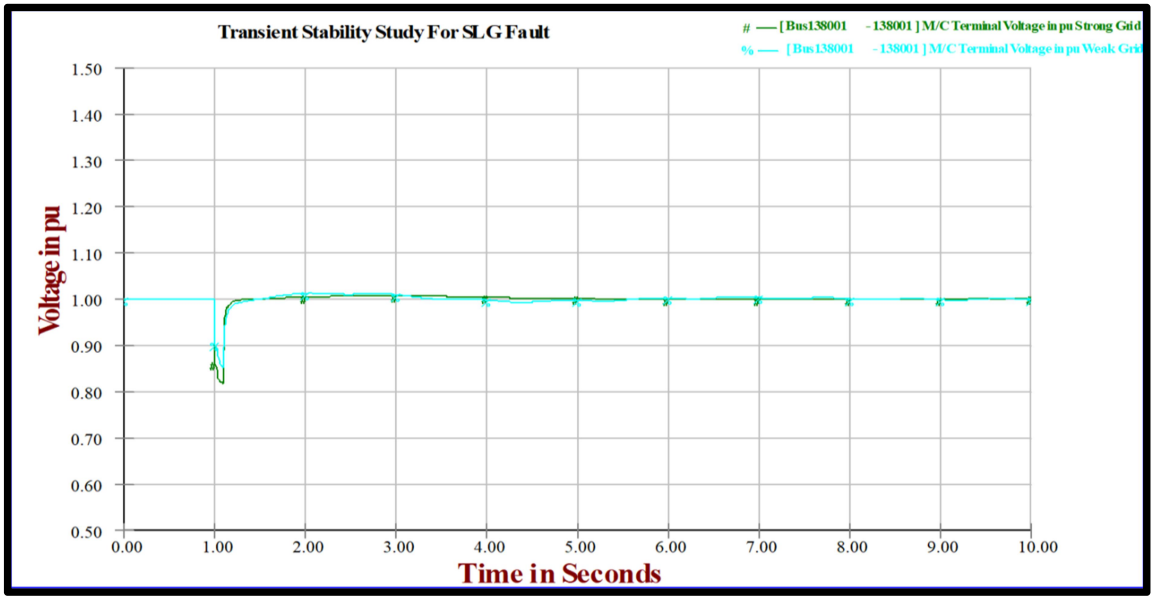

Figure 6-213 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

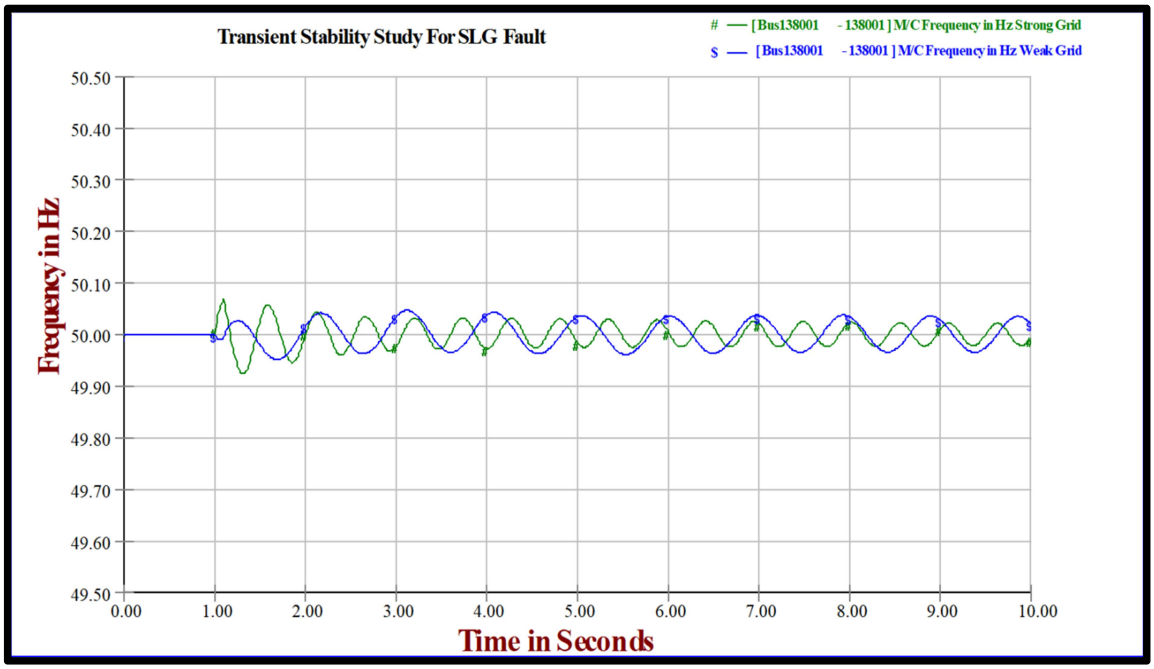

Figure 6-214 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-215 and Figure 6-216.

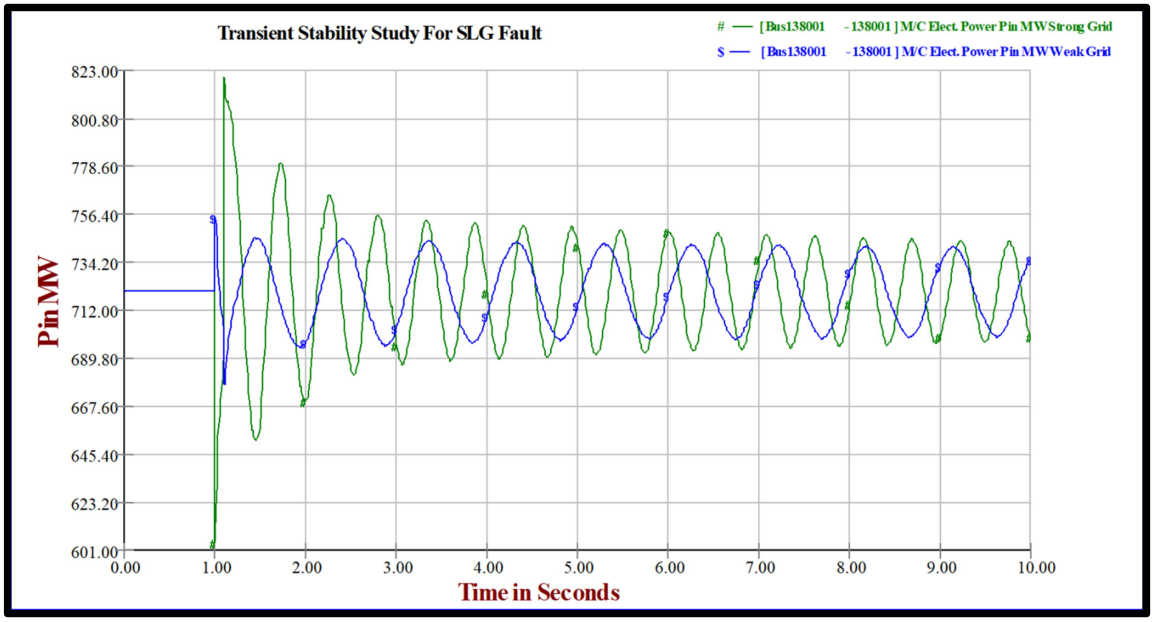

Figure 6-215 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

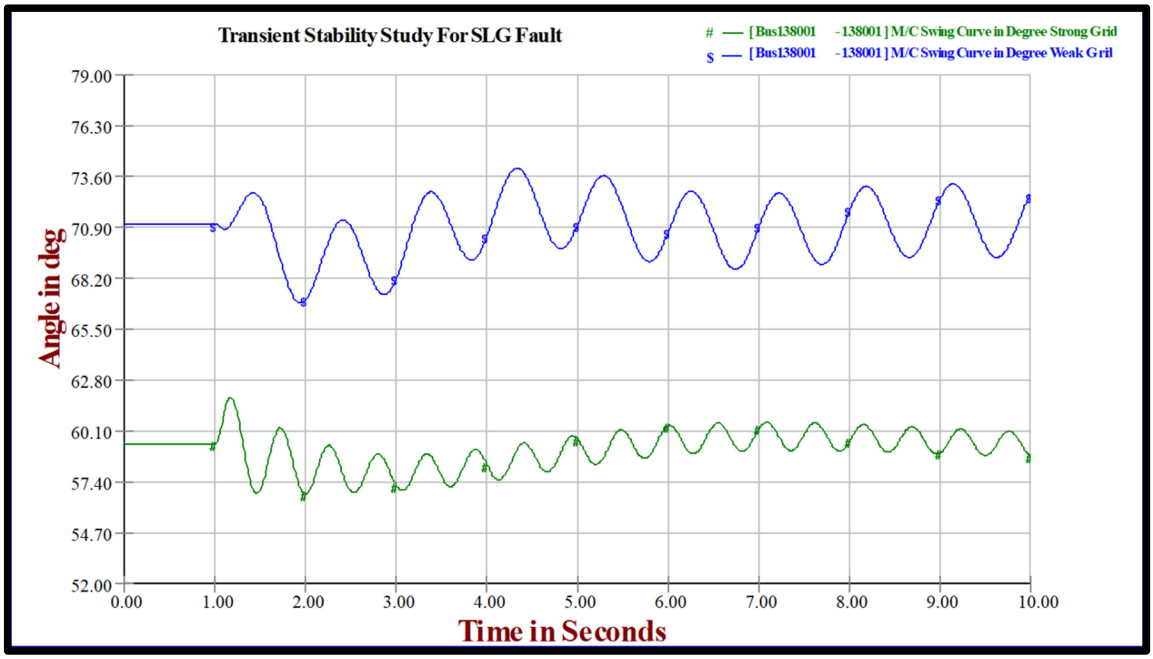

Figure 6-216 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Case 53: Outage of a Generator set at the Vedanta plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-217 to 6-218 for a disturbance initiated due to generator outage

during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

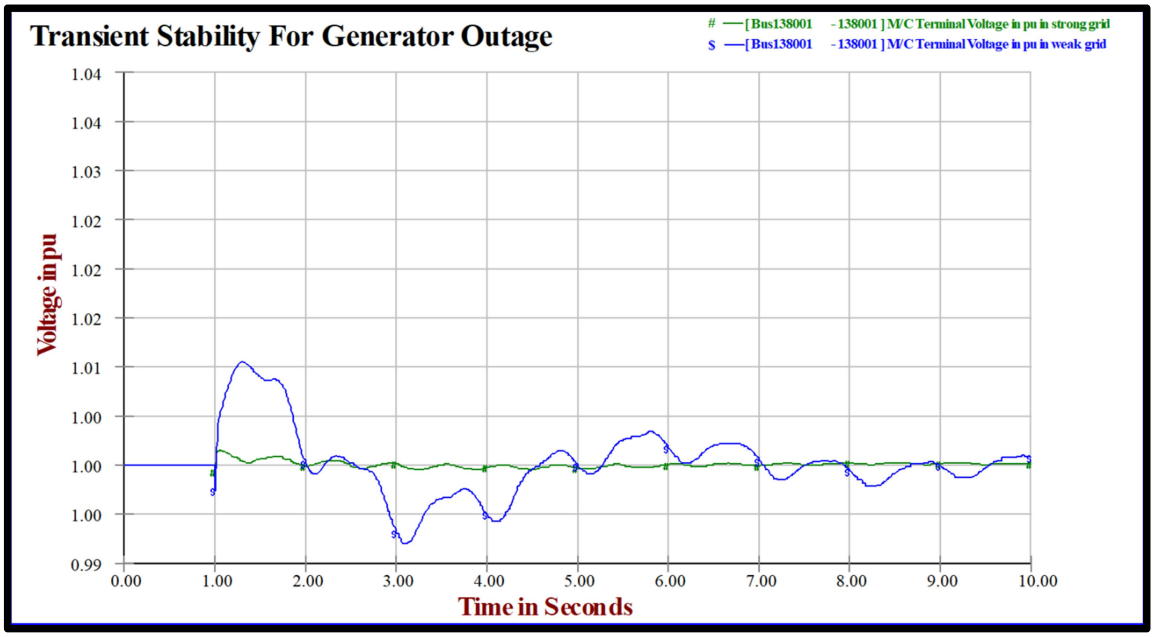

Figure 6-217 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant

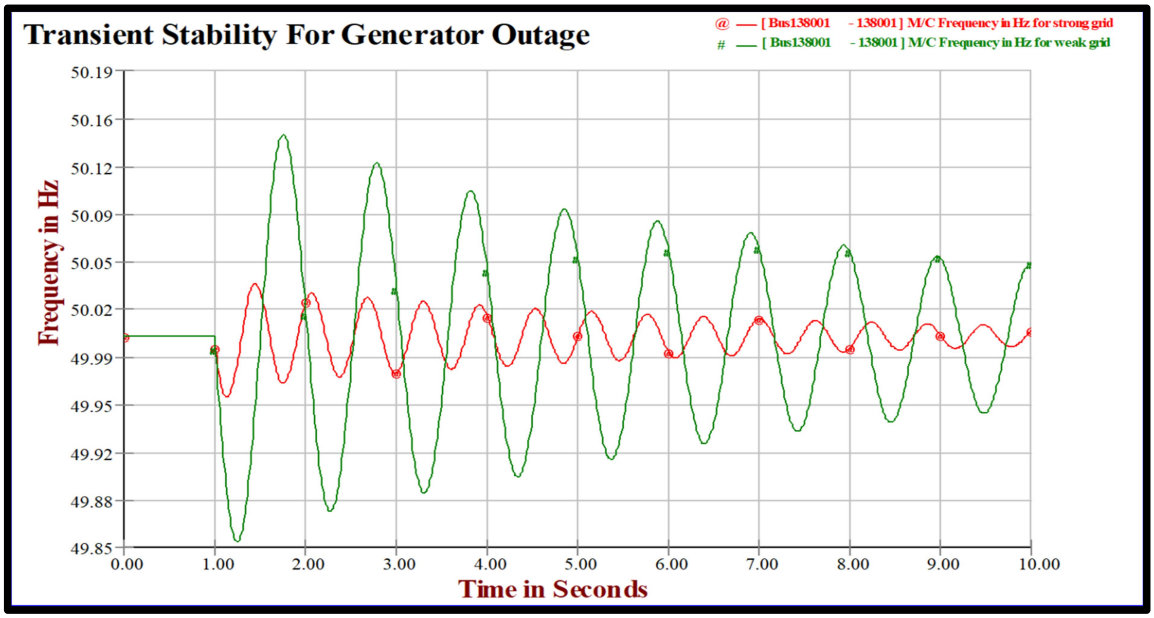

Figure 6-218 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during export mode of operation of plant is presented in Figure 6-219 and Figure 6-220.

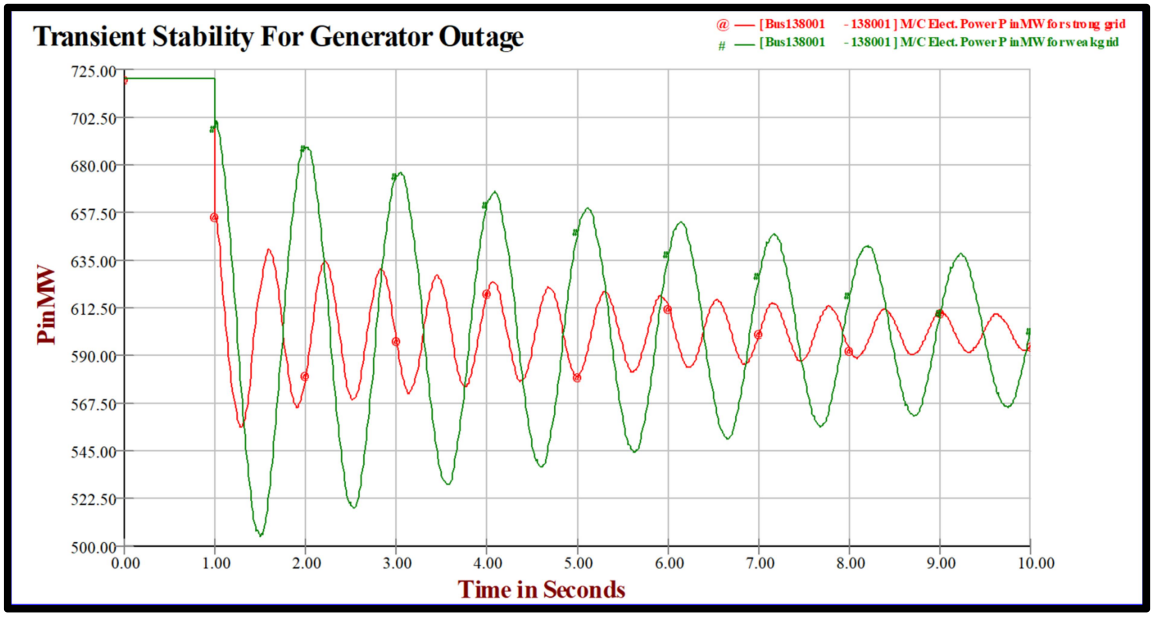

Figure 6-219 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant

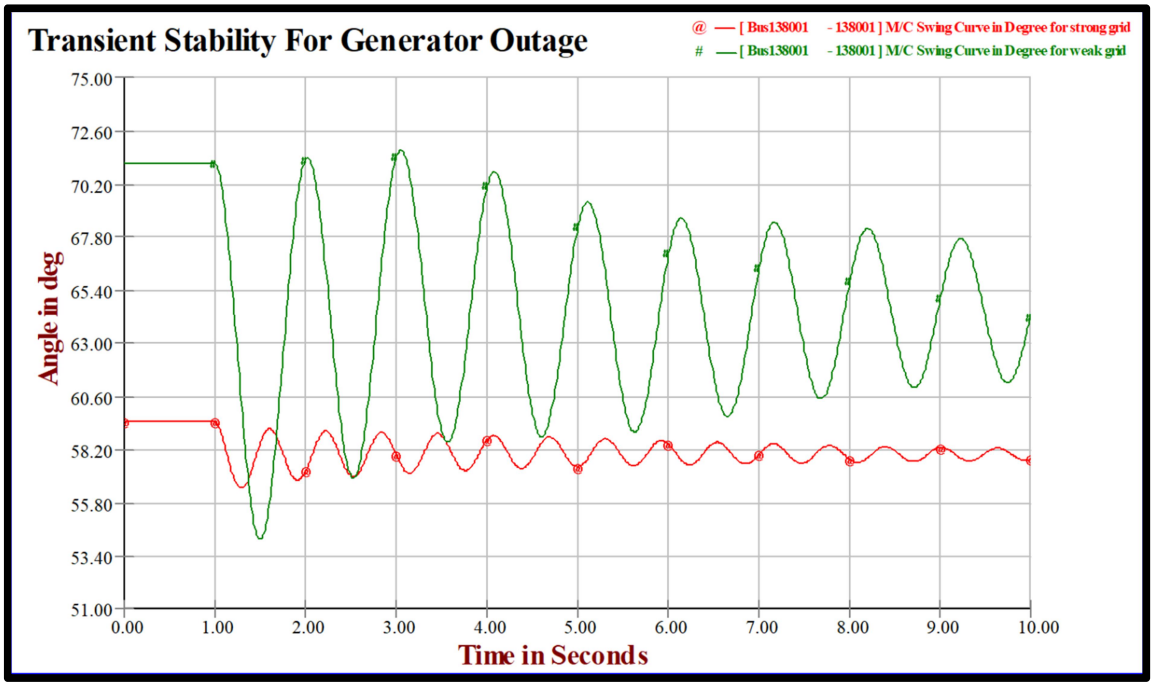

Figure 6-220 Swing curve plot for highest generating unit outage inside the plant during export mode of operation of plant

Case 54: Load throw off at the Vedanta plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-221 to 6-222 for a disturbance initiated due to sudden load throw

off during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

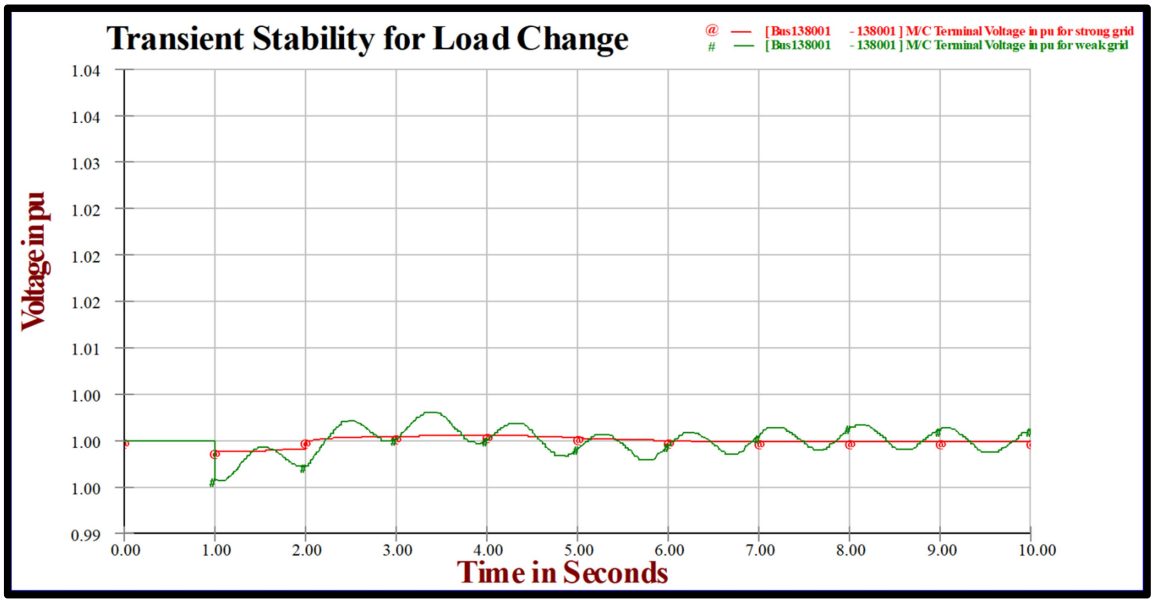

Figure 6-221 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant.

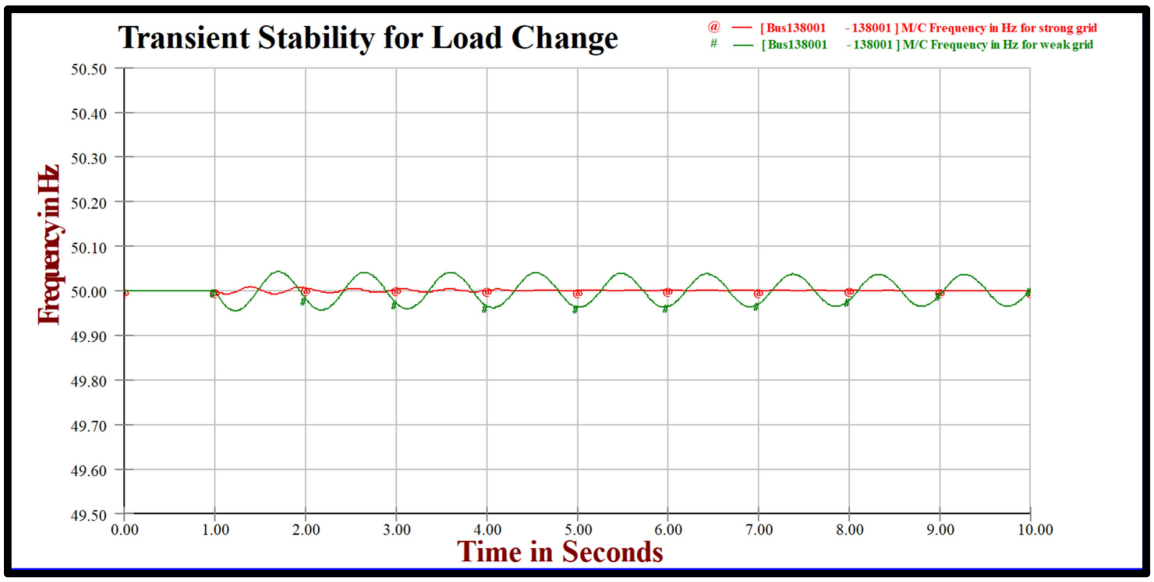

Figure 6-222 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during export mode of plant operation of plant is presented in Figure 6-223 and Figure 6-224.

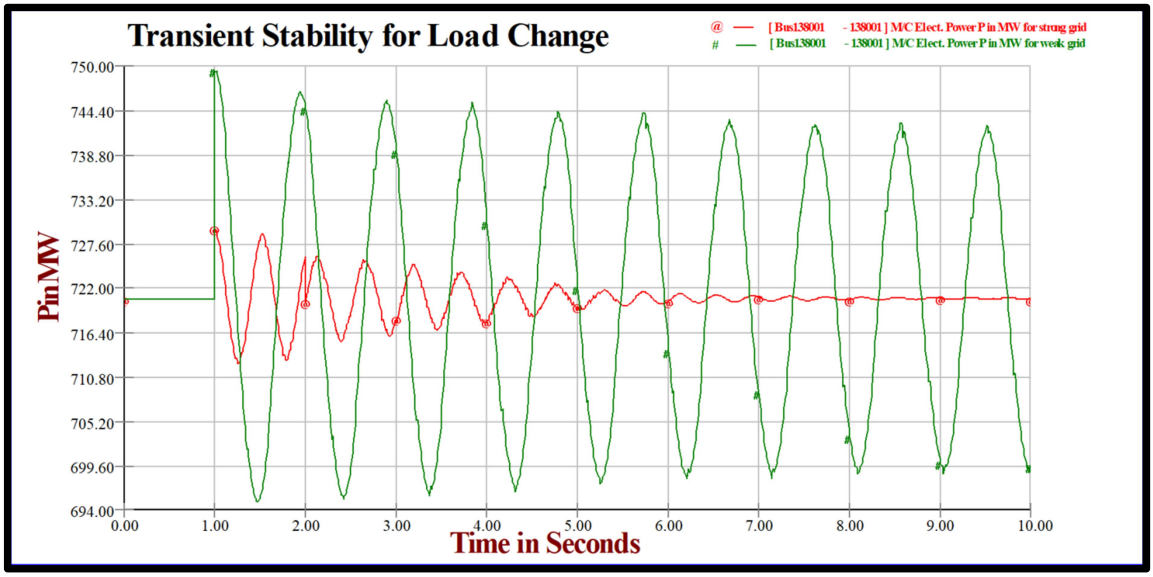

Figure 6-223 Active power plot for sudden increase in load inside the plant during export mode of operation of plant

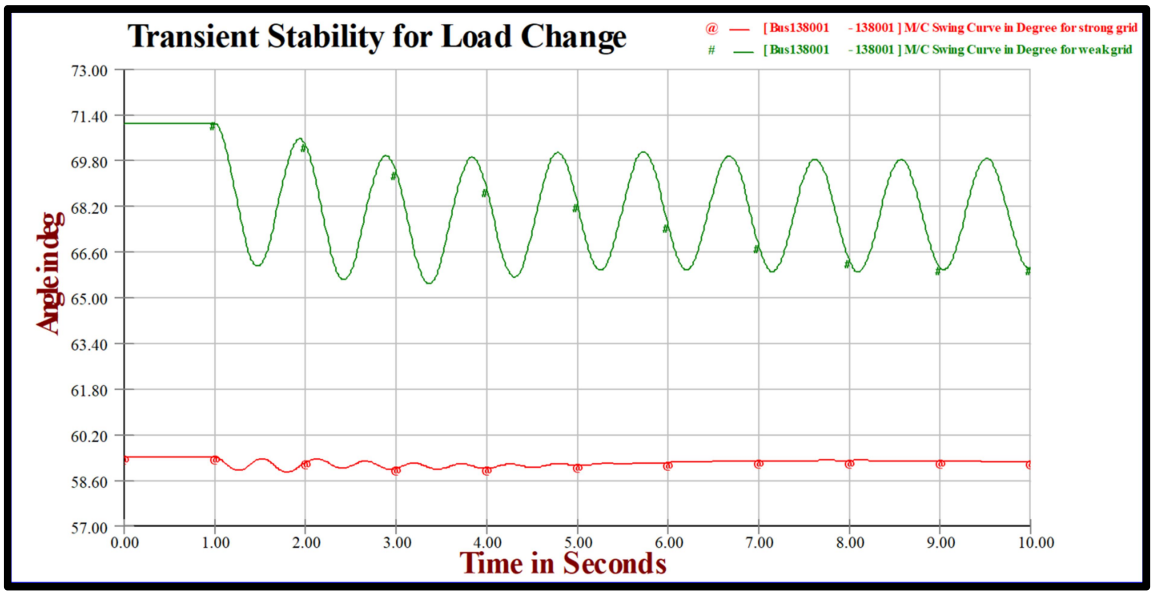

Figure 6-224 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant

6.10. Transient Stability study for Rourkela Steel Plant

Rourkela Steel Plant is a Captive generating plant in Rourkela area having 1x250+2x60+4x25+2x18+1x6.5+1x20MW generation capacities which is primarily connected to Tarkera 220kV Bus. In the stability study of RSP plant, three important scenarios are simulated using in MiPSCT. In the first scenario, the Plant is operating in floating mode while assuming the full load operation inside the plant. Similarly, the second

and third scenario is simulated by considering the contracted demand of the plant operation. In each of the three scenarios, four different disturbance conditions are simulated to study the transient behaviour of CGP generators.

Floating Mode

Case 55: Three Phase to ground fault at the power evacuation bus inside the RSP plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-225 to 6-226 for a three phase to ground fault at the power evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

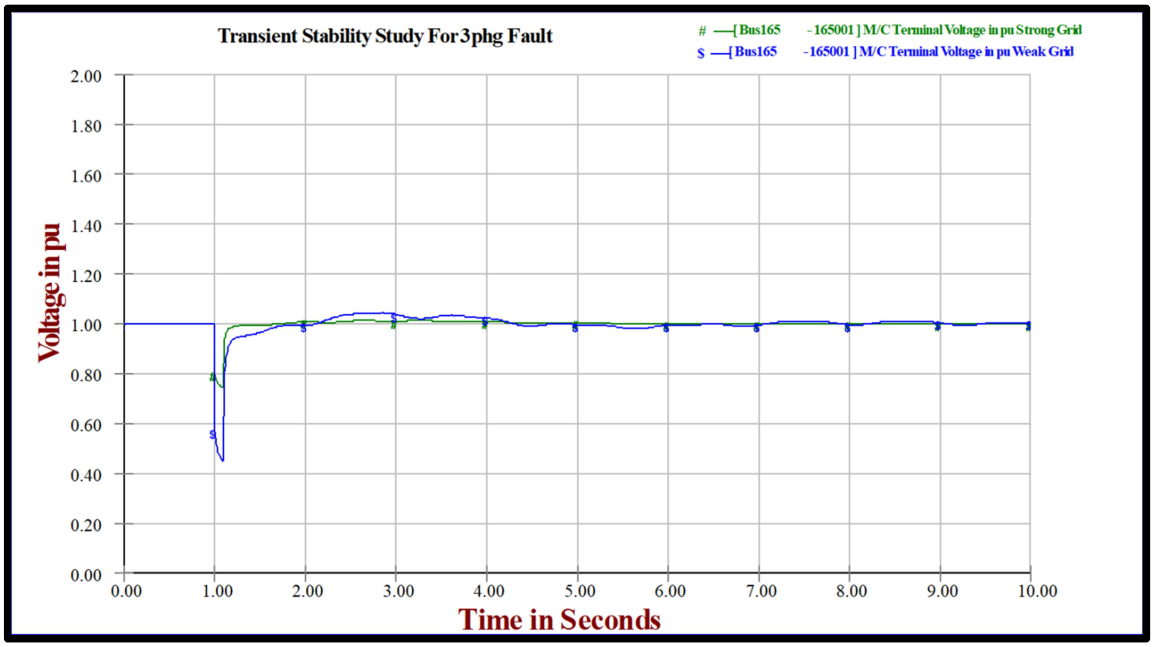

Figure 6-225 Voltage plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

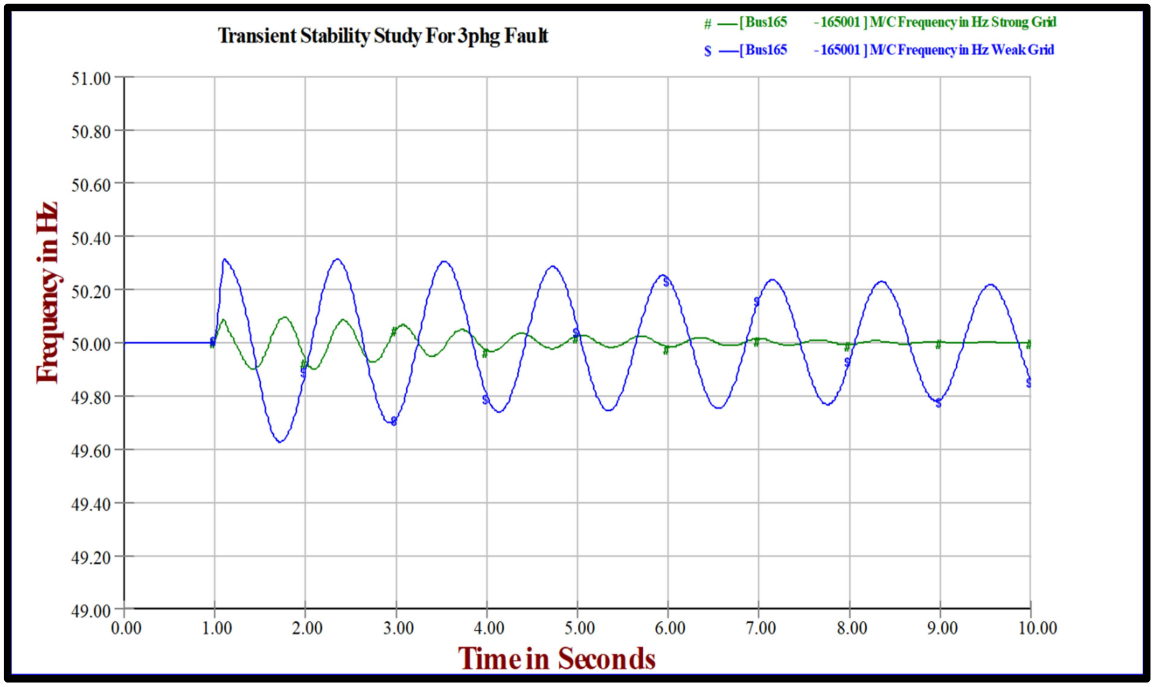

Figure 6-226 Frequency plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-227 and Figure 6-228.

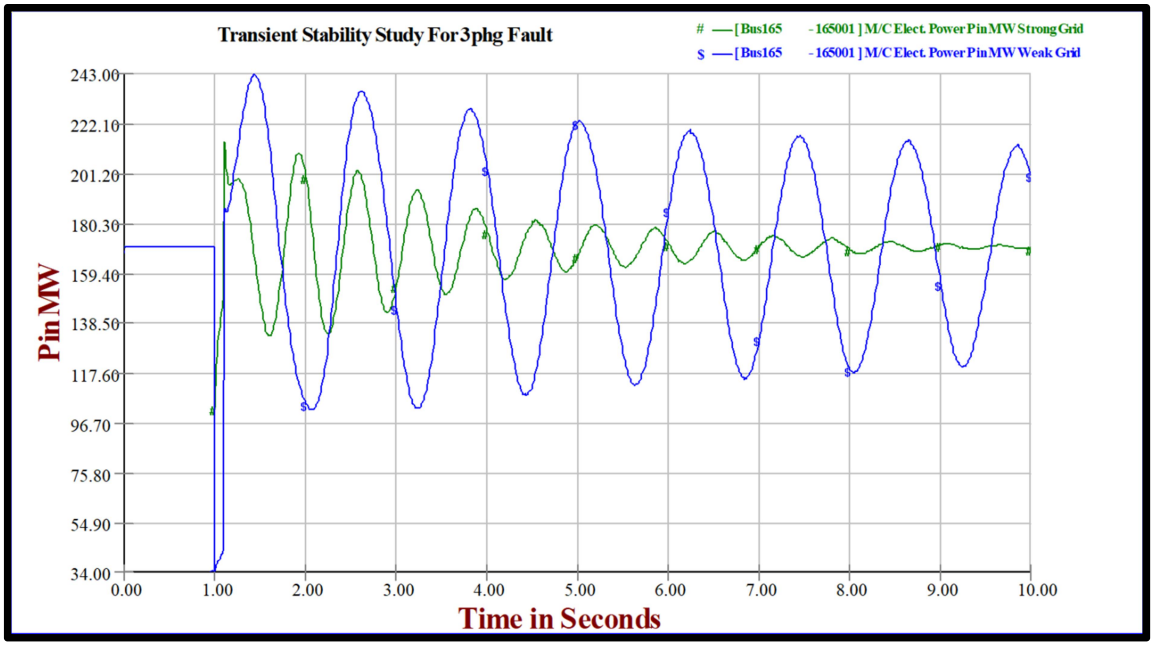

Figure 6-227 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

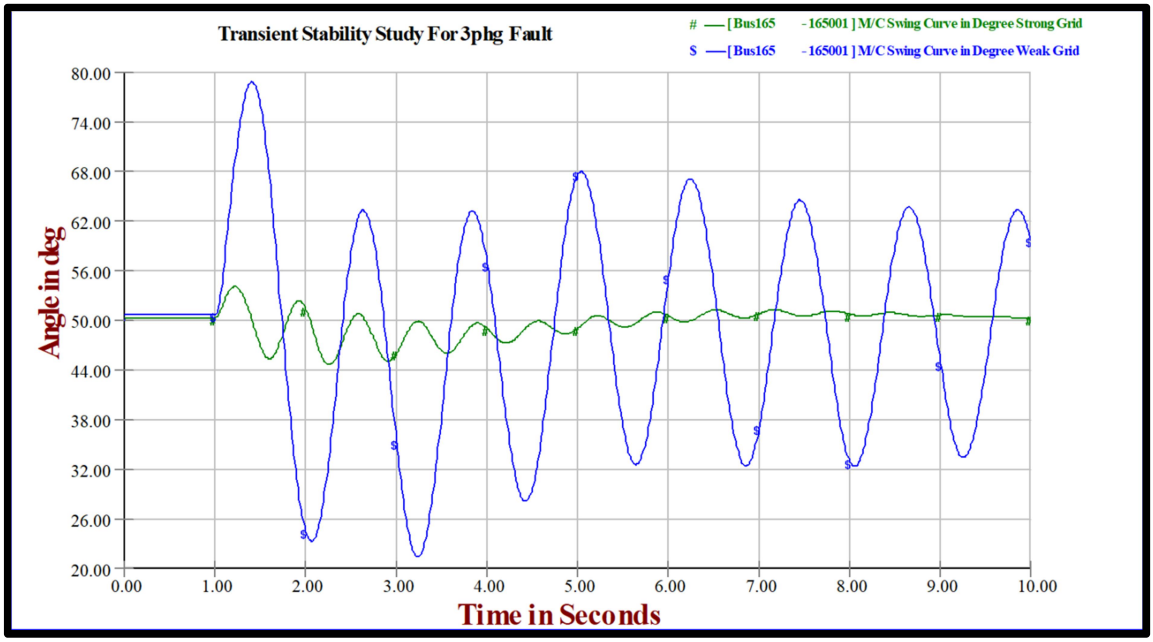

Figure 6-228 Swing curve plot for three phase to ground fault at the power evacuation bus during floating mode of plant operation

Case 56: Single Line to ground fault at the power evacuation bus inside the RSP plant for duration of 160ms with strong and weak grid connectivity operating in floating mode.

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-229 to 6-230 for a Single line to ground fault at the power evacuation bus during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

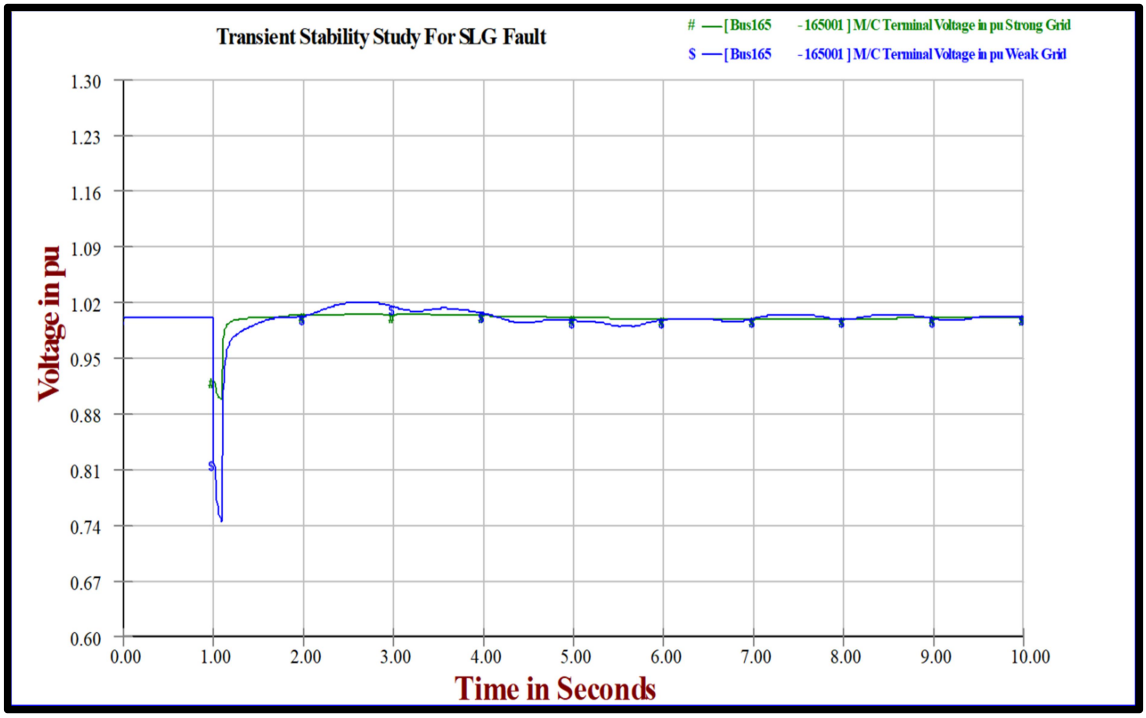

Figure 6-229 Voltage plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

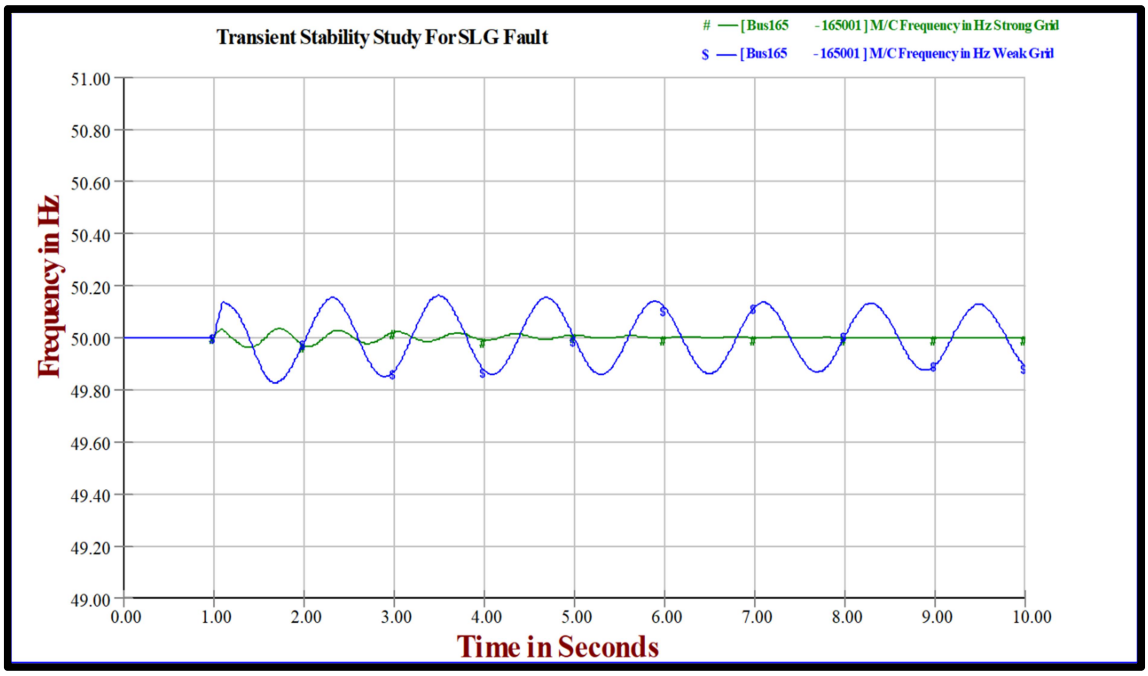

Figure 6-230 Frequency plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during floating mode of operation of plant are presented in Figure 6-231 and Figure 6-232.

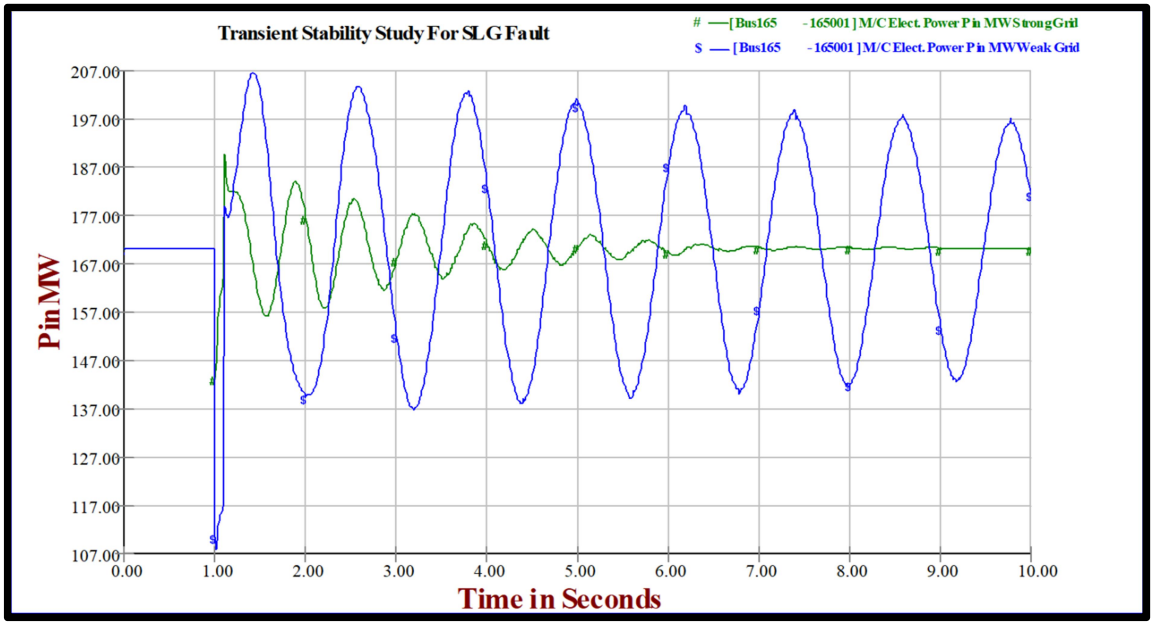

Figure 6-231 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

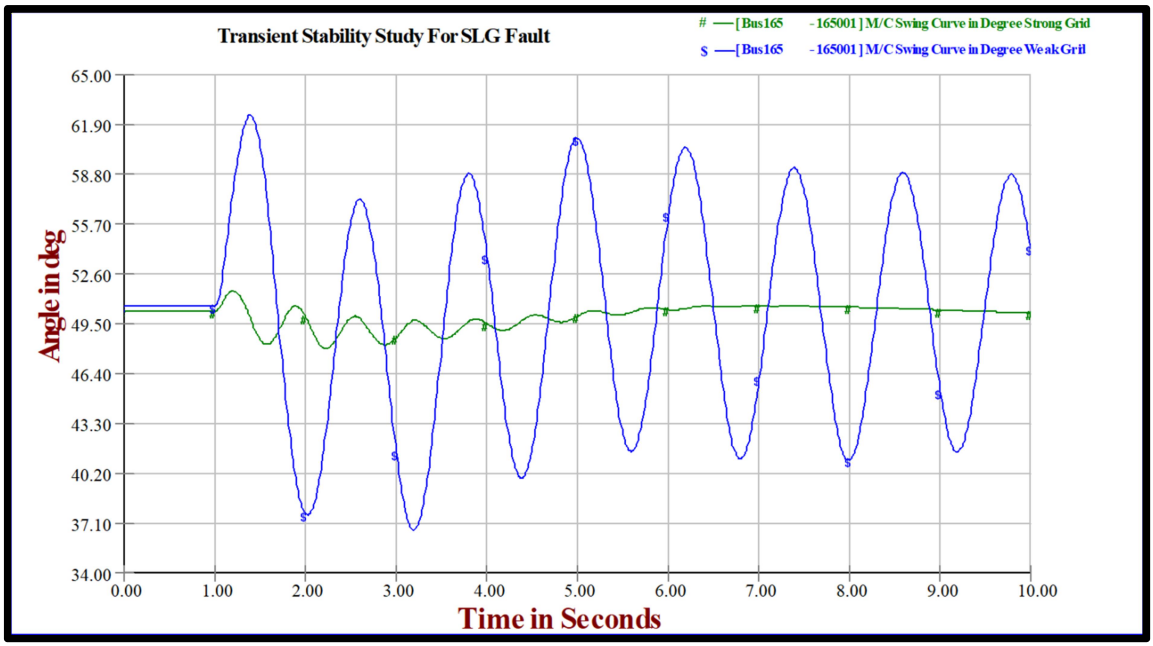

Figure 6-232 Swing curve plot for Single line to ground fault at the power evacuation bus during floating mode of plant operation

Case 57: Load throw off at the RSP plant for a duration of 160ms with strong and weak grid connectivity operating in floating mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-233 to 6-234 for a disturbance initiated due to sudden load throw off during floating mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

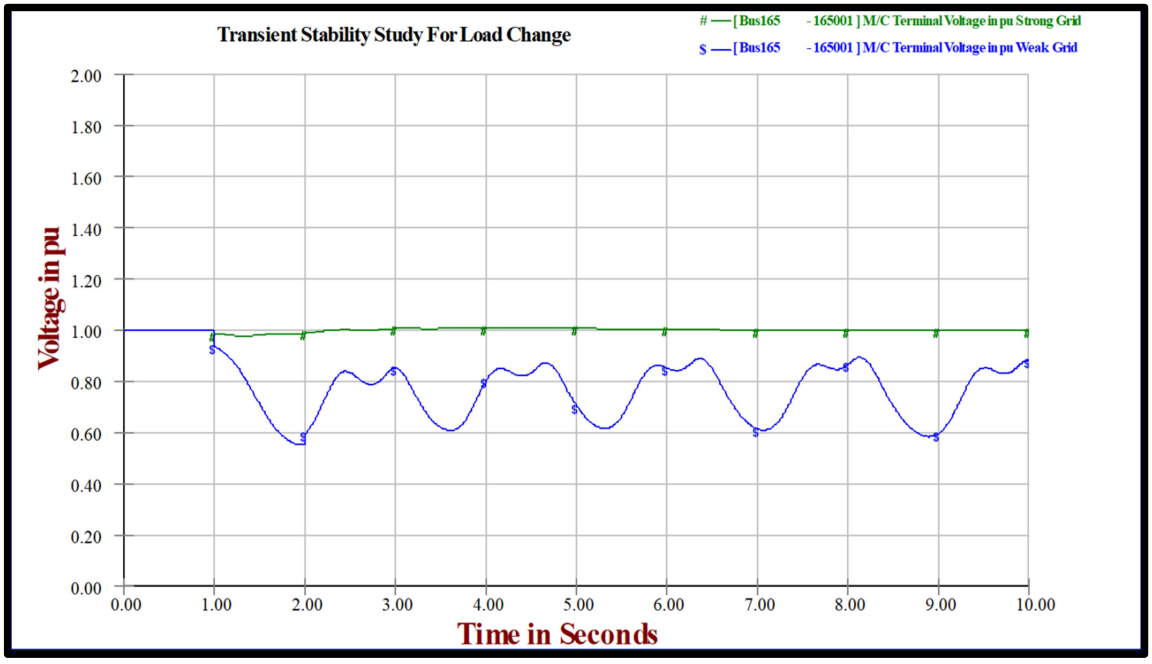

Figure 6-233 Voltage plot for sudden increase in load inside the plant during floating mode of operation of plant.

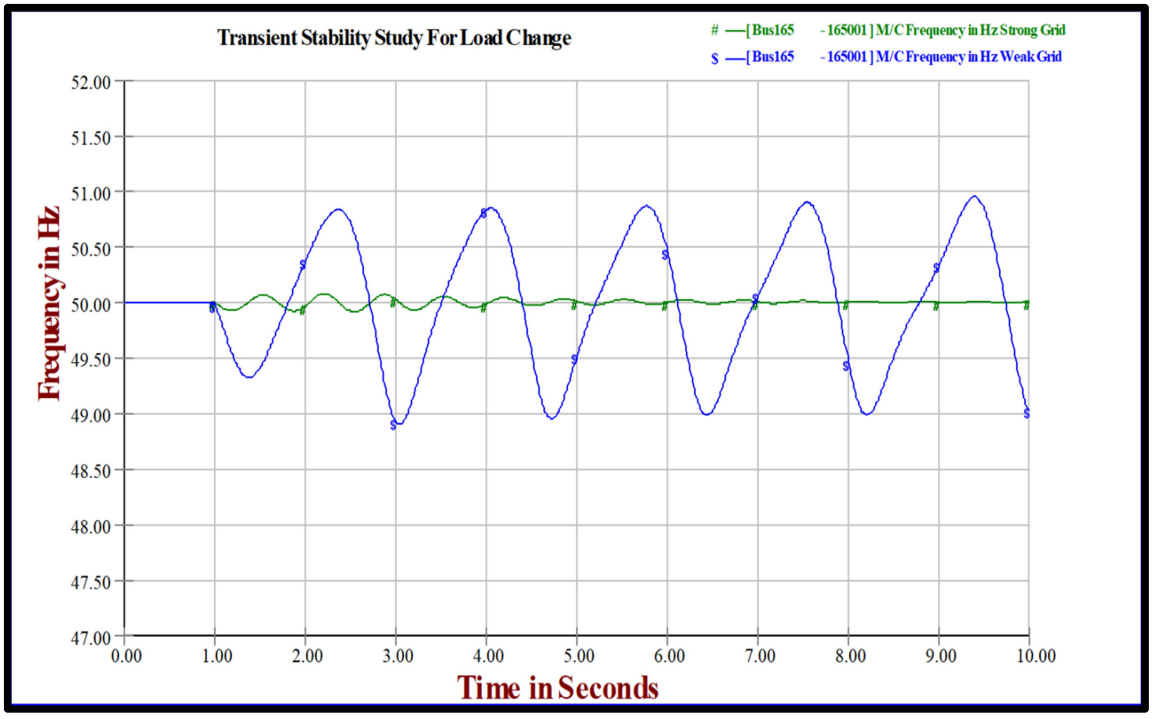

Figure 6-234 Frequency plot for sudden increase in load inside the plant during floating mode of operation of plant.

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during floating mode of plant operation of plant is presented in Figure 6-235 and Figure 6-236.

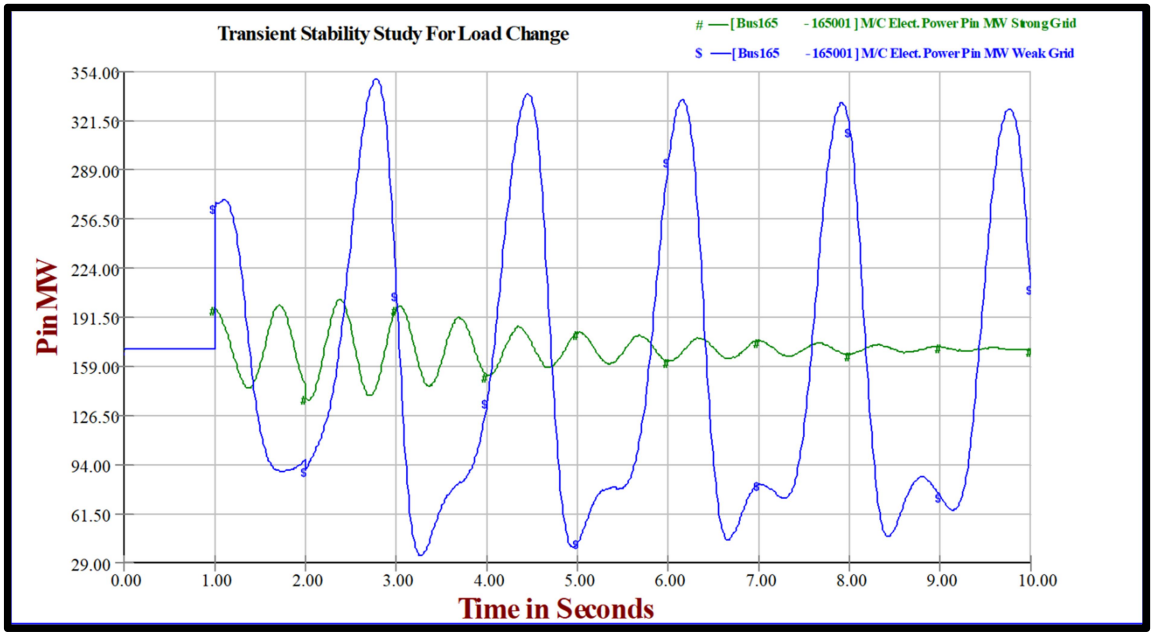

Figure 6-235 Active power plot for sudden increase in load inside the plant during floating mode of operation of plant

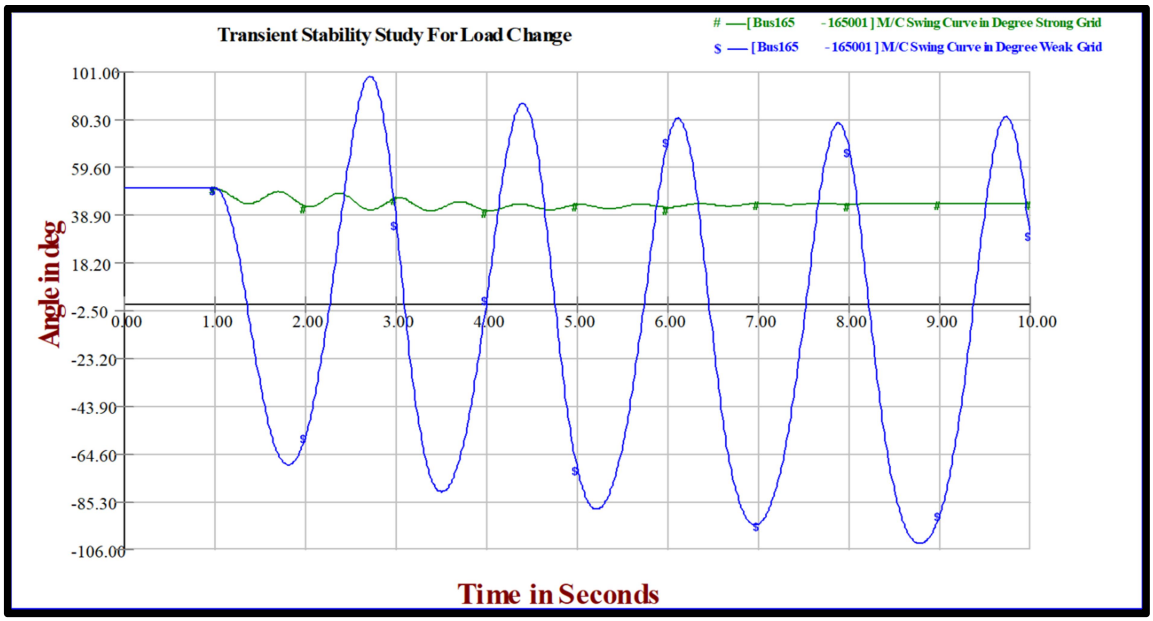

Figure 6-236 Swing curve plot for sudden increase in load inside the plant during floating mode of operation of plant

Import mode

Case 58: Three Phase to ground fault at the RSP plant for a duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-237 to 6-238 for a three phase to ground fault at the power

evacuation bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

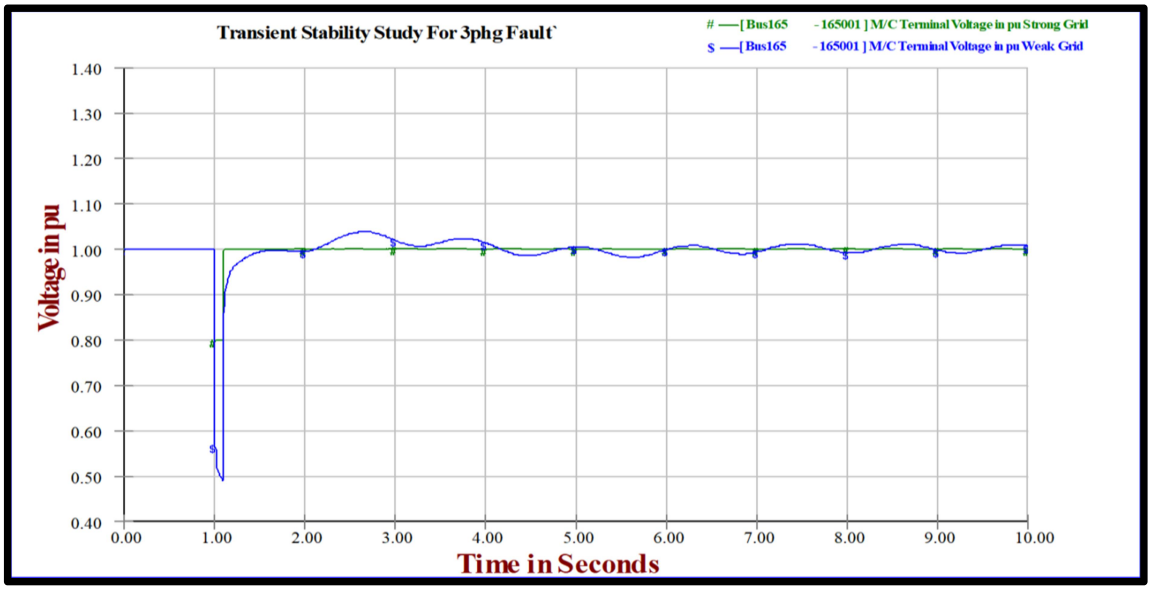

Figure 6-237 Voltage plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

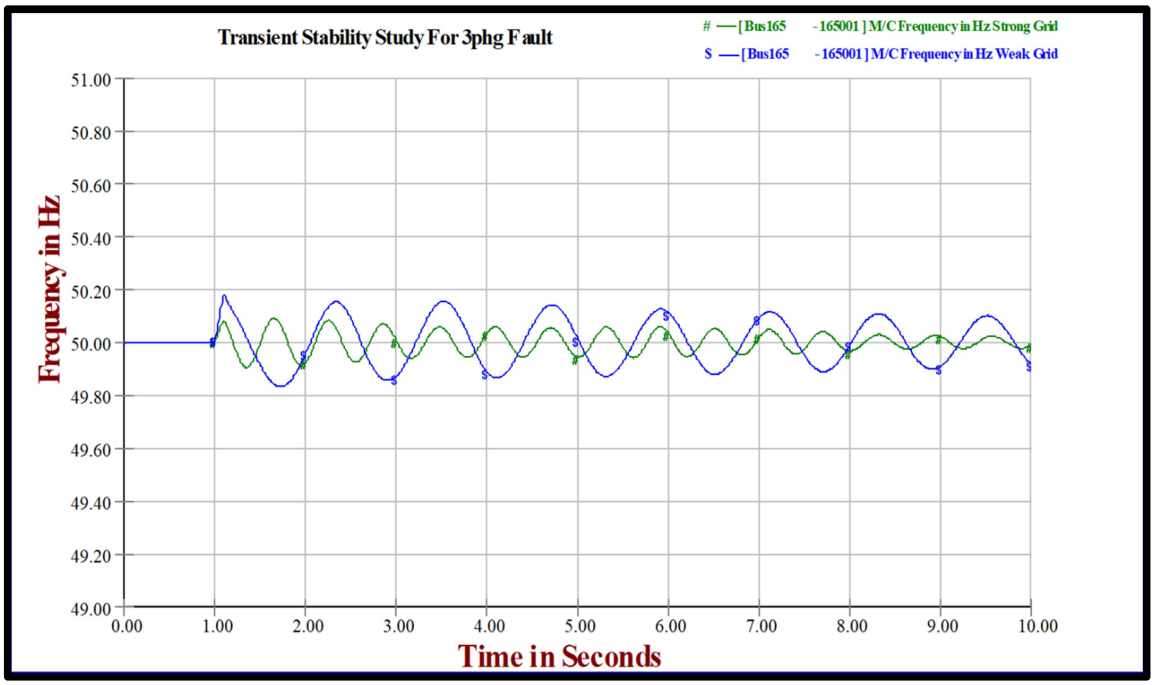

Figure 6-238 Frequency plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-239 and Figure 6-240.

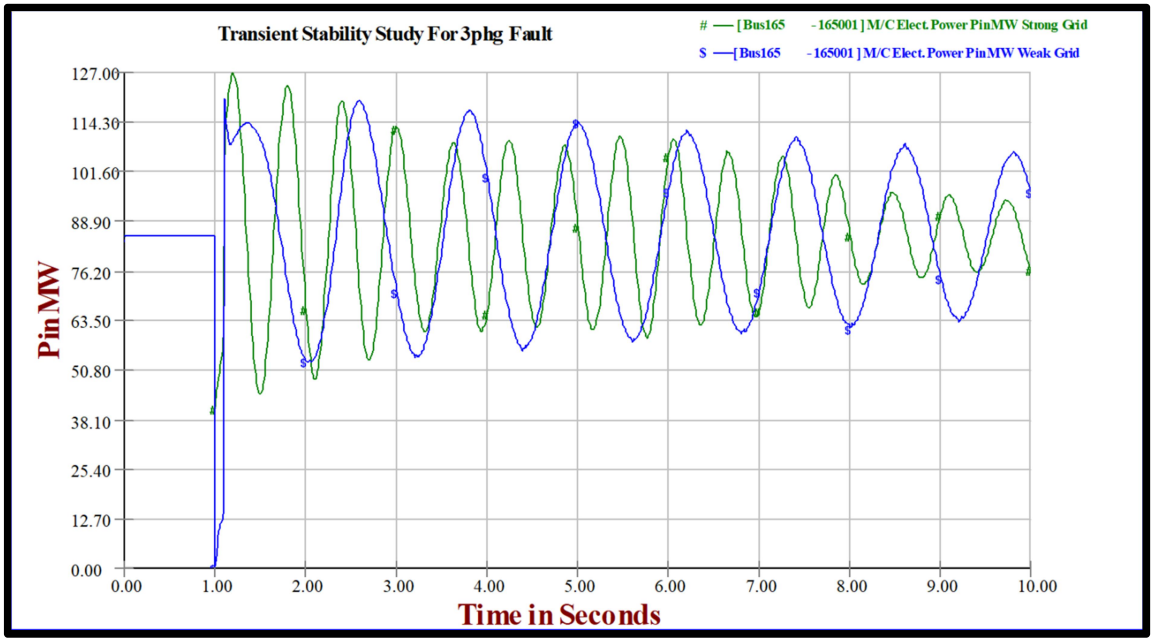

Figure 6-239 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

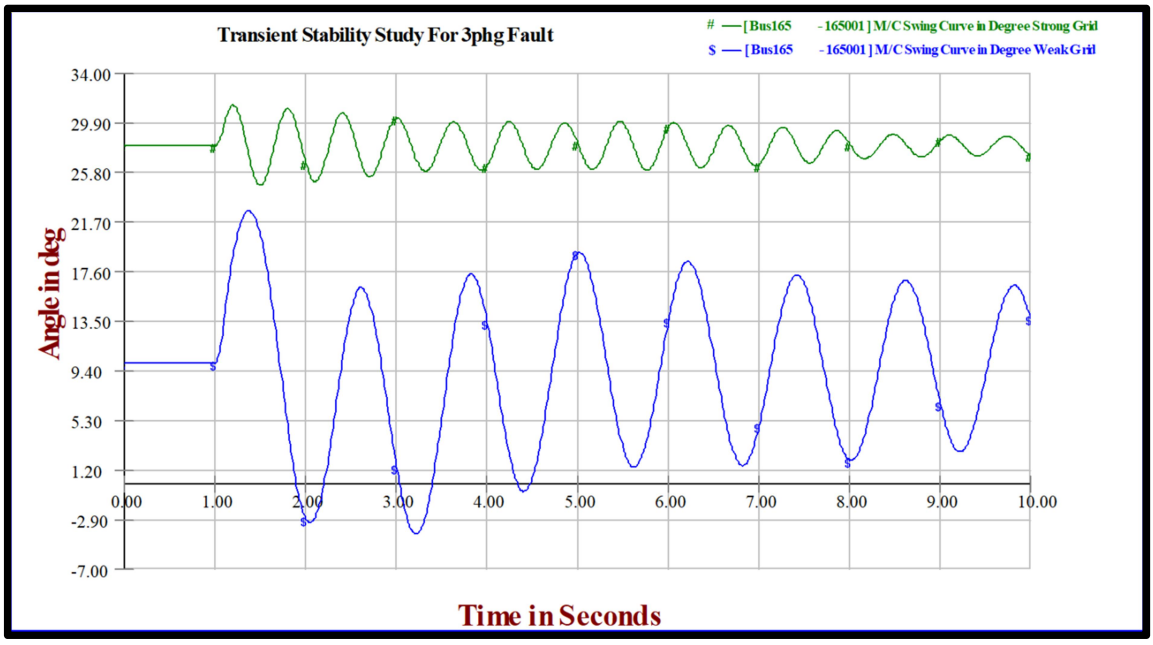

Figure 6-240 Swing curve plot for three phase to ground fault at the power evacuation bus during import mode of plant operation

Case 59: Single Line to ground fault at the RSP plant for a duration of 160ms with strong and weak grid connectivity operating in import mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-241 to 6-242 for a Single line to ground fault at the power

evacuation bus during import mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

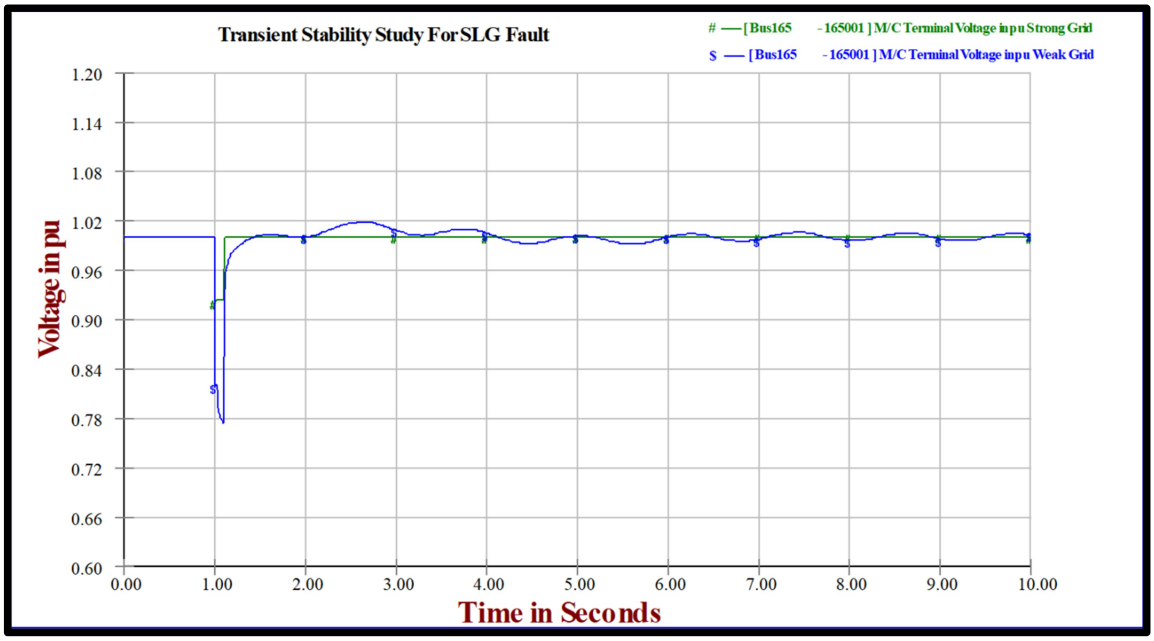

Figure 6-241 Voltage plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

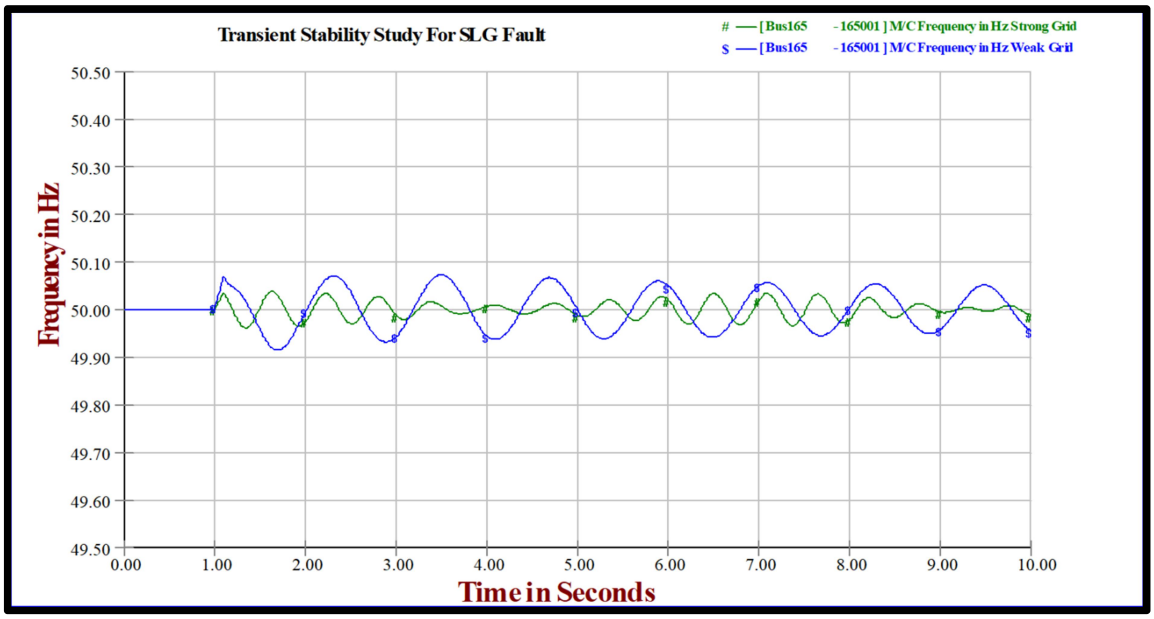

Figure 6-242 Frequency plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during import mode of operation of plant are presented in Figure 6-243 and Figure 6-244.

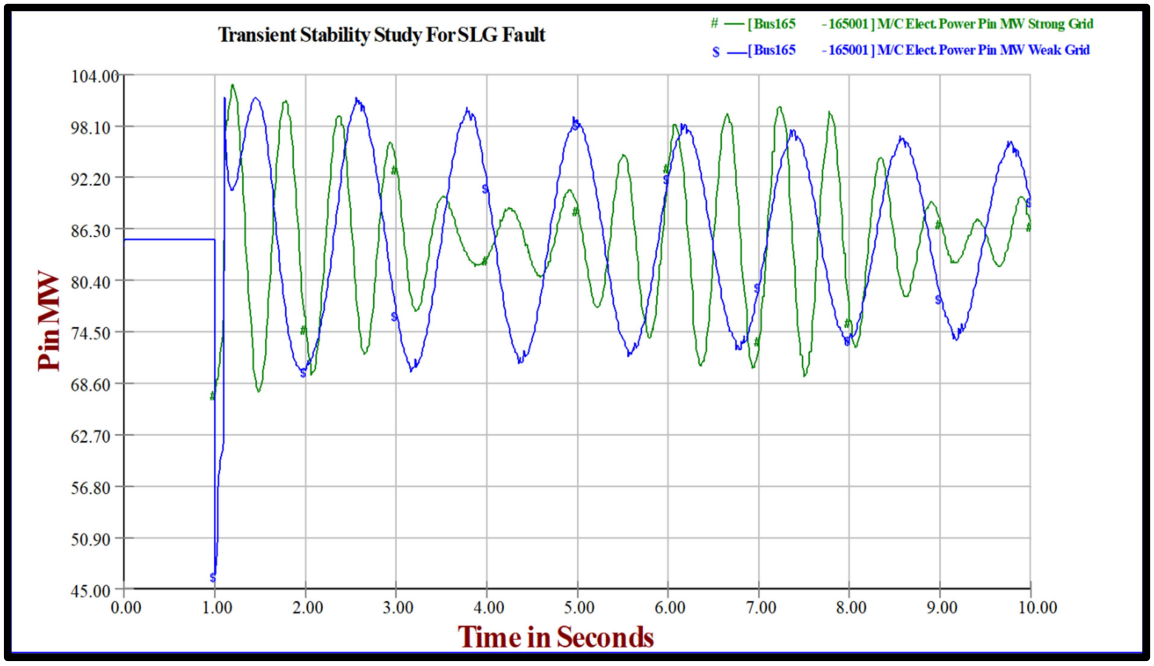

Figure 6-243 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

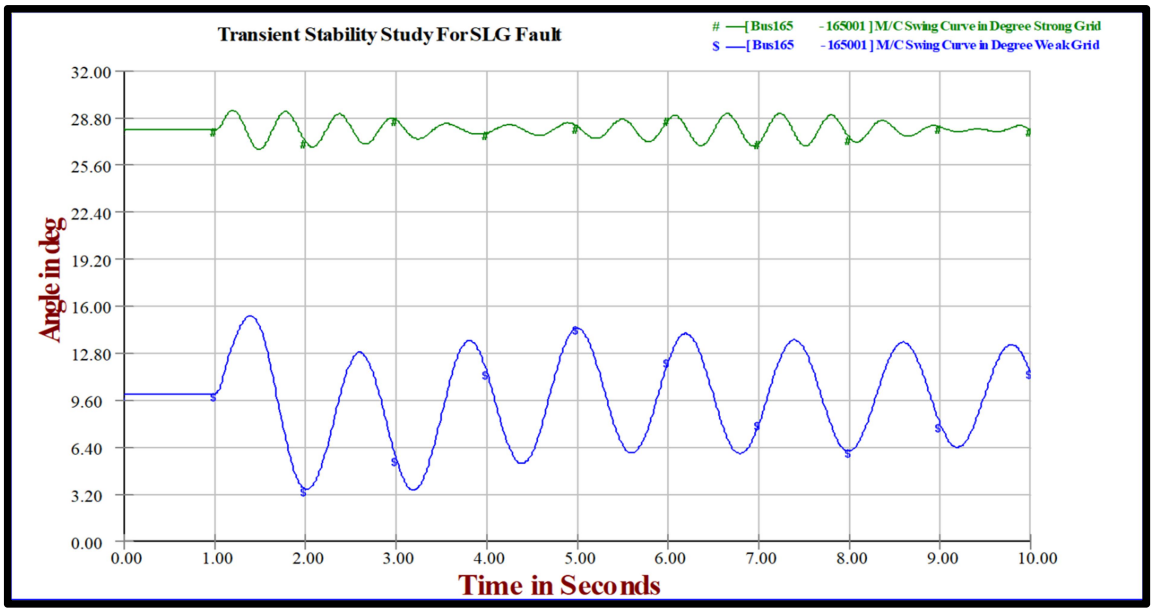

Figure 6-244 Swing curve plot for Single line to ground fault at the power evacuation bus during import mode of plant operation

Export mode

Case 60: Three Phase to ground fault at the RSP plant for a duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-245 to 6-246 for a three phase to ground fault at the power

evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

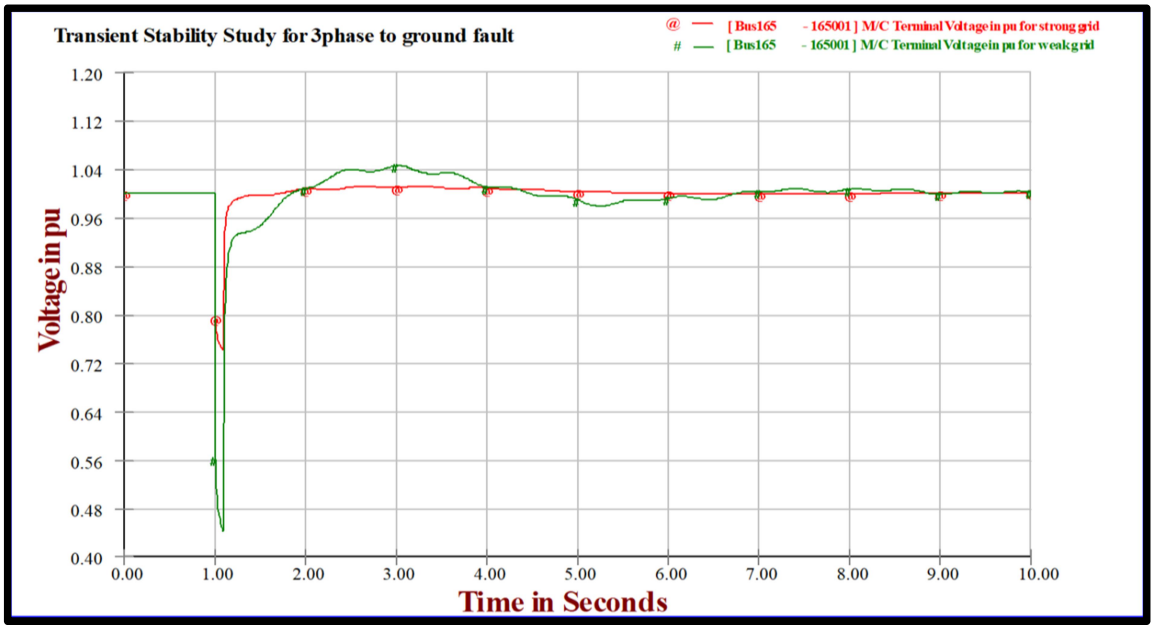

Figure 6-245 Voltage plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

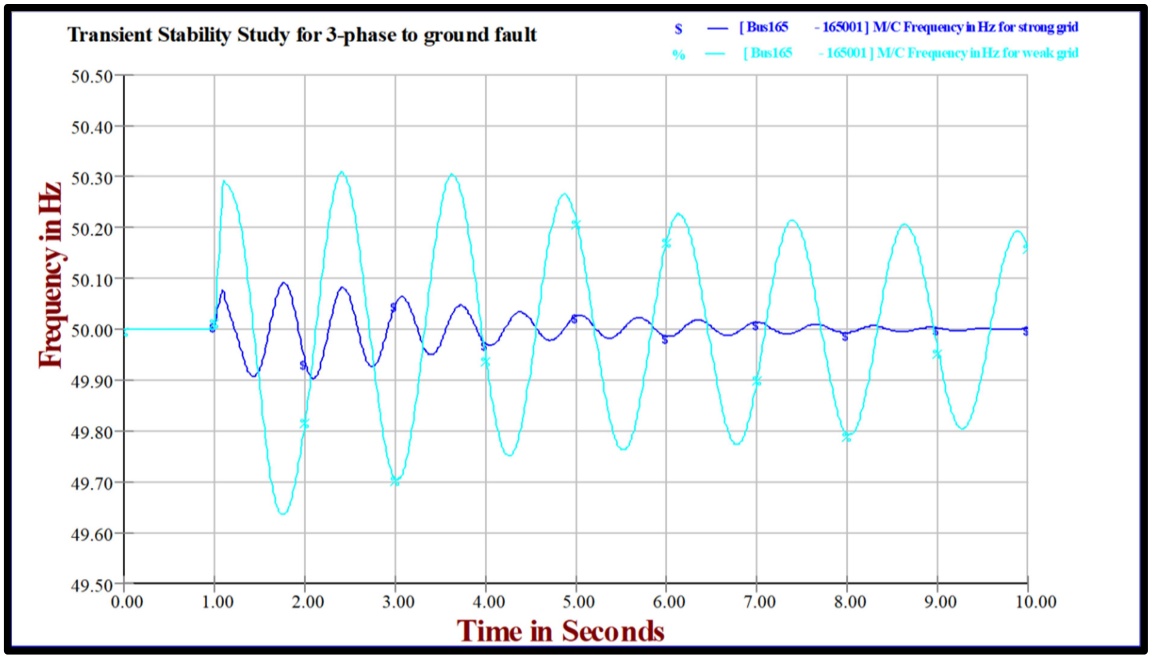

Figure 6-246 Frequency plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the three phase to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-247 and Figure 6-248.

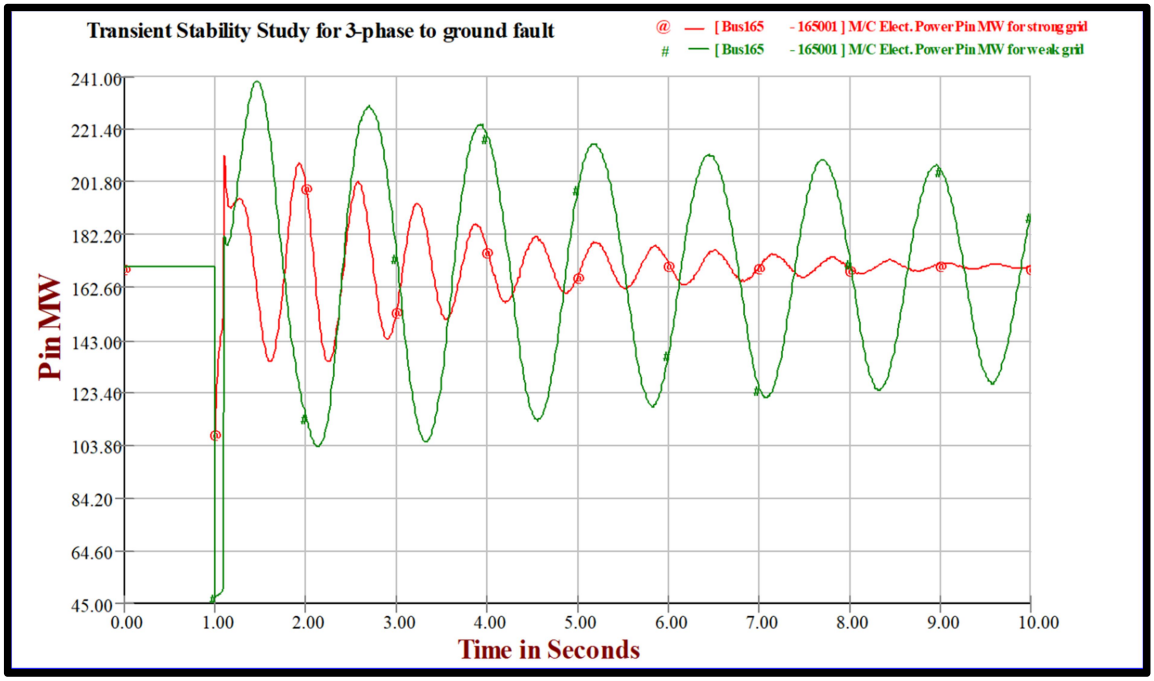

Figure 6-247 Active power of generating bus plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

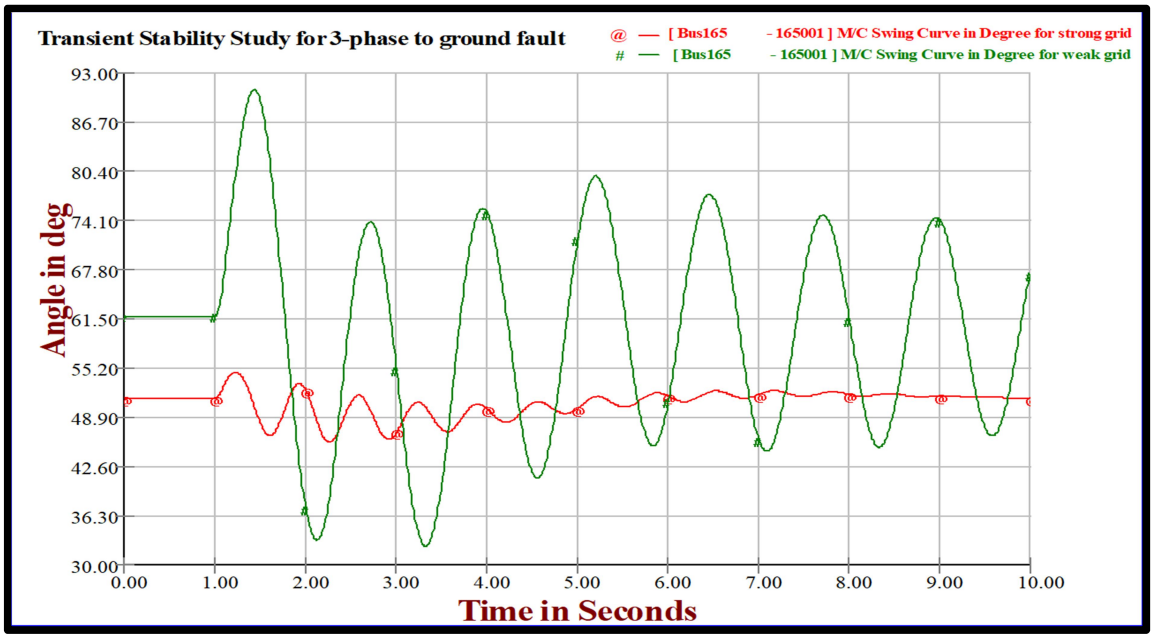

Figure 6-248 Swing curve plot for three phase to ground fault at the power evacuation bus during export mode of plant operation

Case 61: Single Line to ground fault at the RSP plant for a duration of 160ms with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-249 to 6-250 for a Single line to ground fault at the power

evacuation bus during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

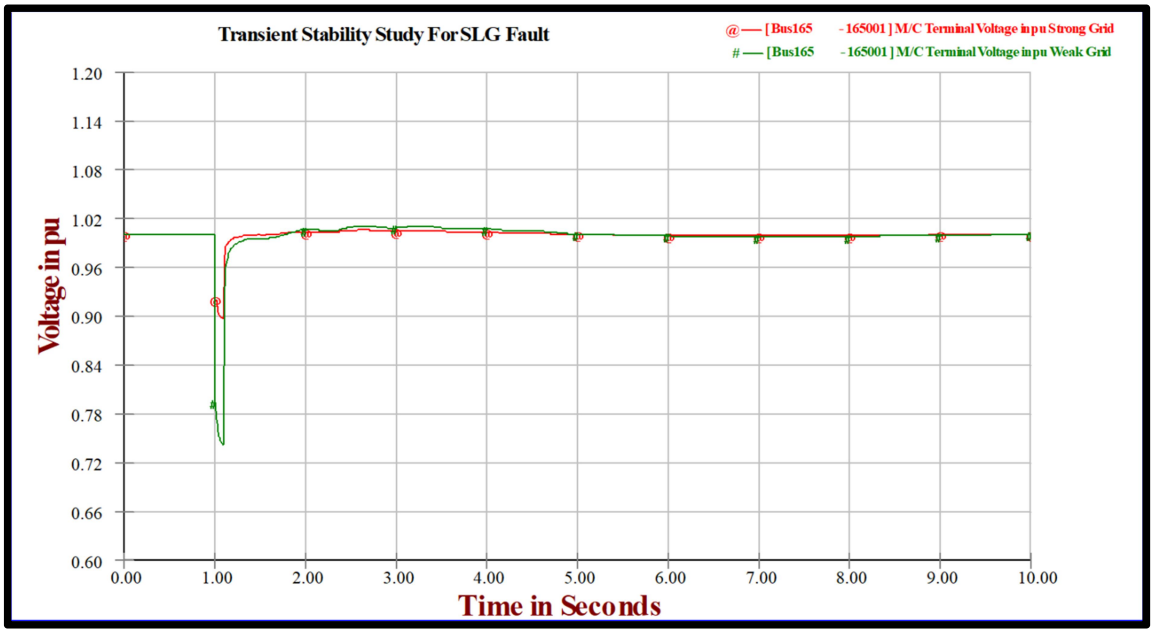

Figure 6-249 Voltage plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

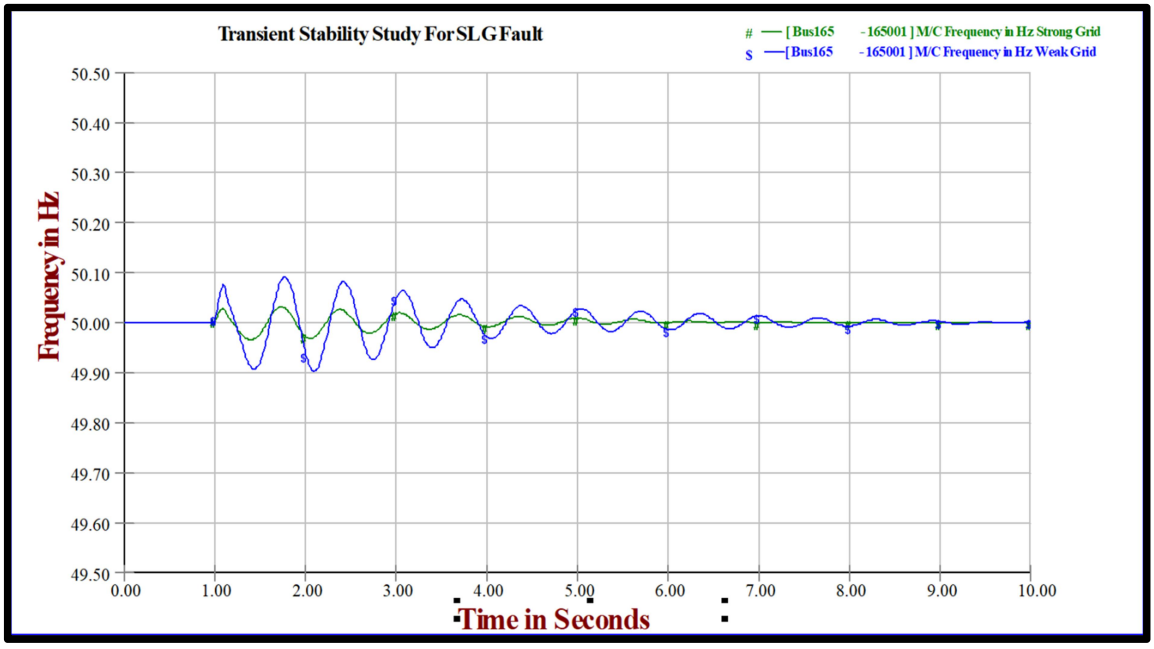

Figure 6-250 Frequency plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Similarly, the swing curve angle in degree and active power flow from the generating bus for the Single line to ground fault at the power evacuation bus during export mode of operation of plant are presented in Figure 6-251 and Figure 6-252.

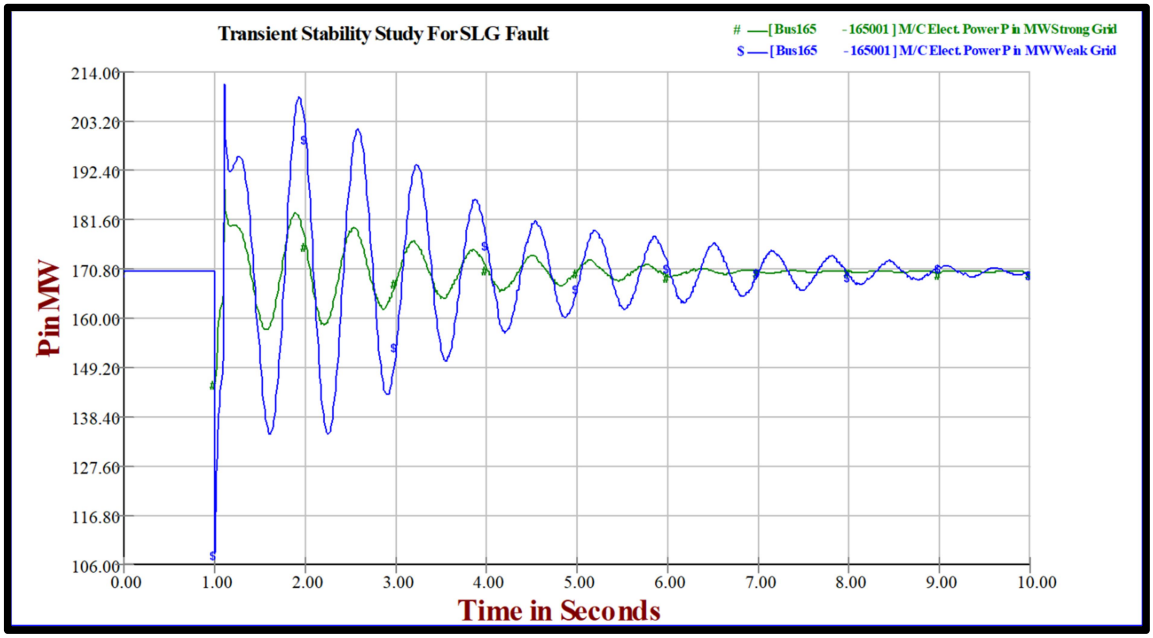

Figure 6-251 Active power of generating bus plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

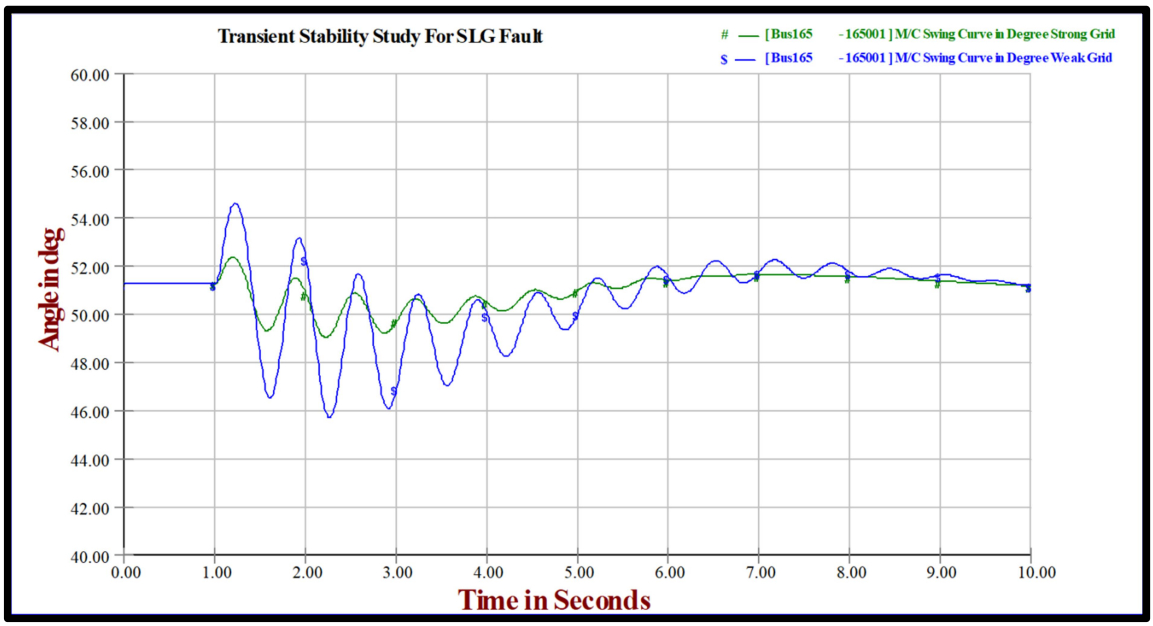

Figure 6-252 Swing curve plot for Single line to ground fault at the power evacuation bus during export mode of plant operation

Case 62: Outage of a Generator set at the RSP plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-253 to 6-254 for a disturbance initiated due to generator outage

during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

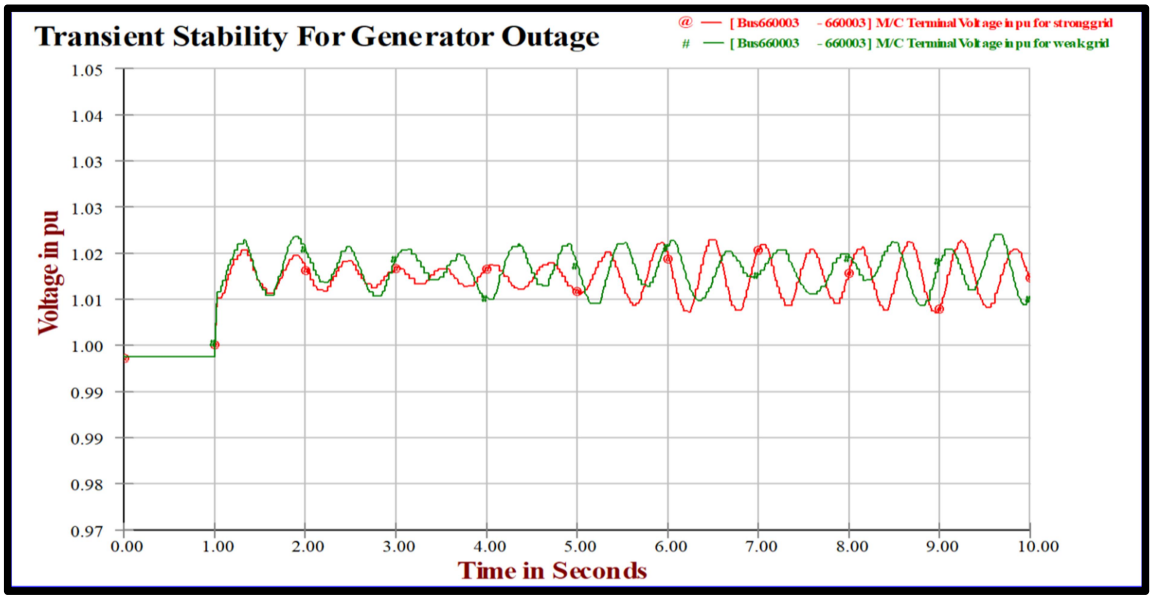

Figure 6-253 Voltage plot for highest generating unit outage inside the plant during export mode of operation of plant

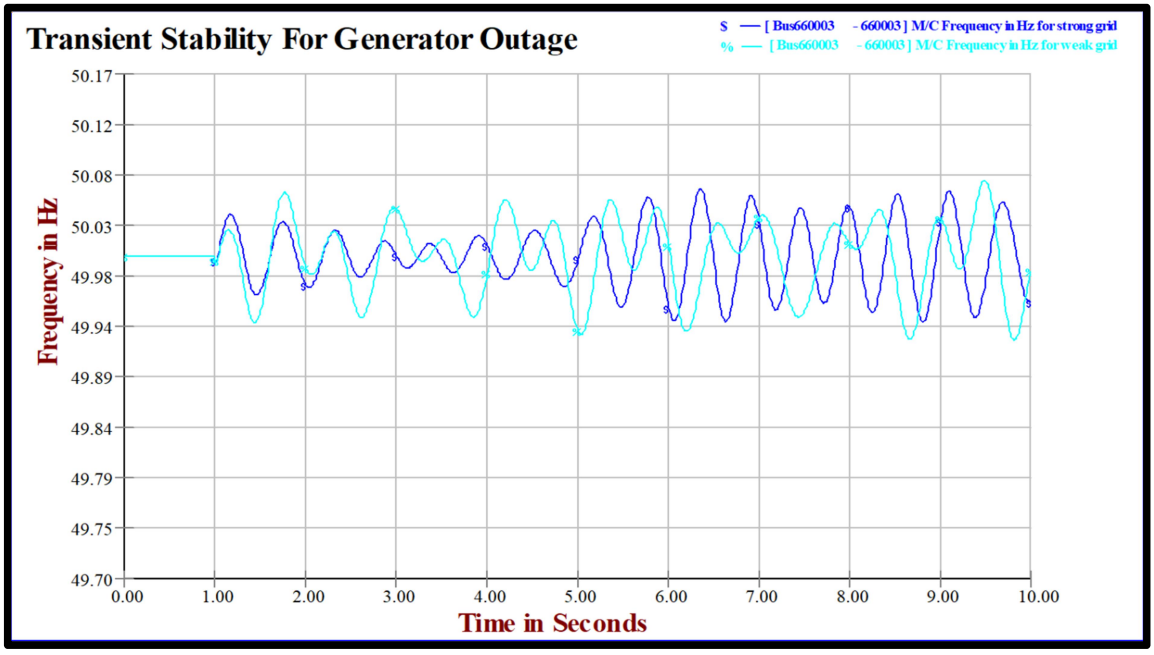

Figure 6-254 Frequency plot for highest generating unit outage inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to generator during export mode of operation of plant is presented in Figure 6-255 and Figure 6-256.

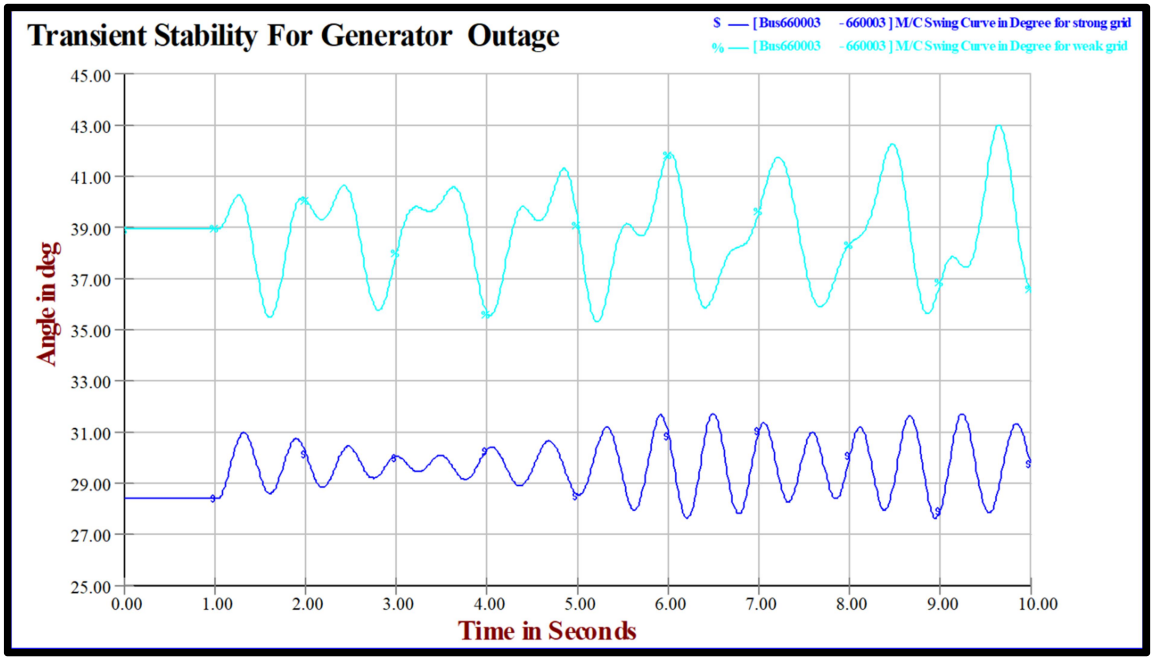

Figure 6-255 Swing curve plot for highest generating unit outage inside the plant during export mod e of operation of plant

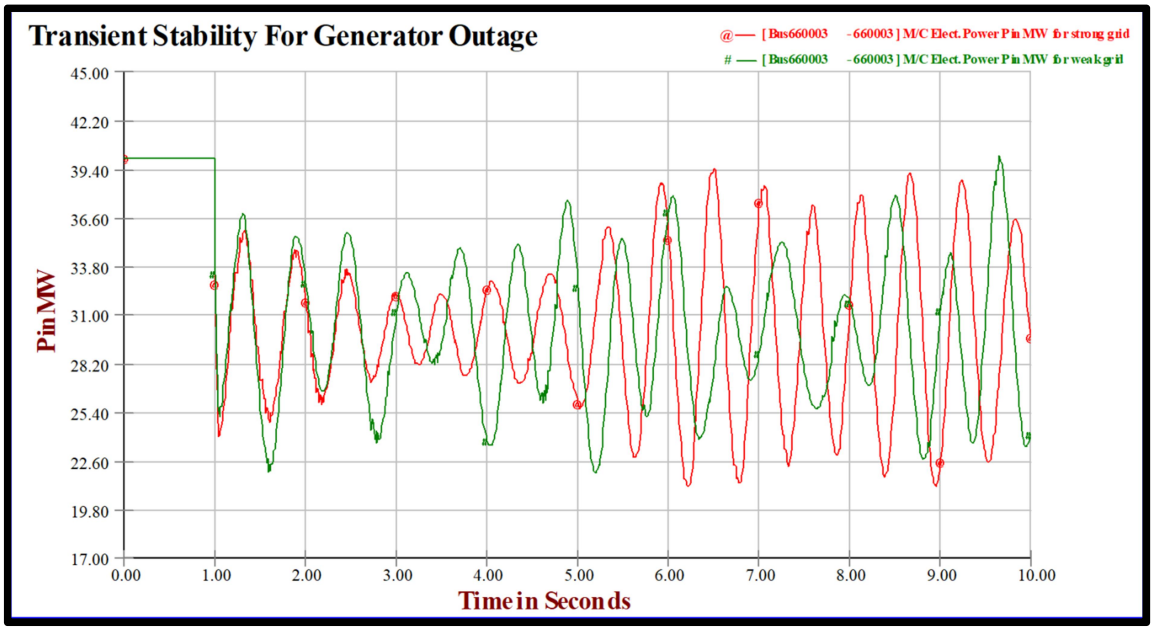

Figure 6-256 Active power for generating bus plot for highest generating unit outage inside the plant during export mode of operation of plant

Case 63: Load throw off at the RSP plant with strong and weak grid connectivity operating in export mode

The simulation results representing the voltage and frequency plot of power evacuation bus are presented in Figure 6-257 to 6-258 for a disturbance initiated due to sudden load throw

off during export mode of plant operation. In the absence of the normal grid connectivity, weak grid connectivity leads to unstable plant operation.

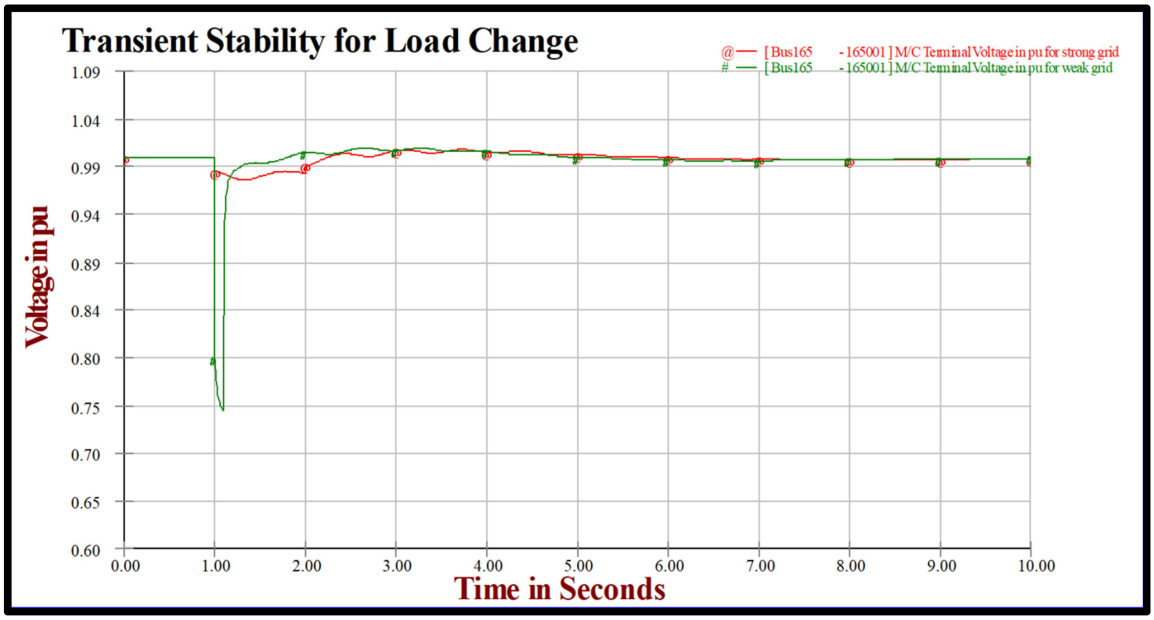

Figure 6-257 Voltage plot for sudden increase in load inside the plant during export mode of operation of plant

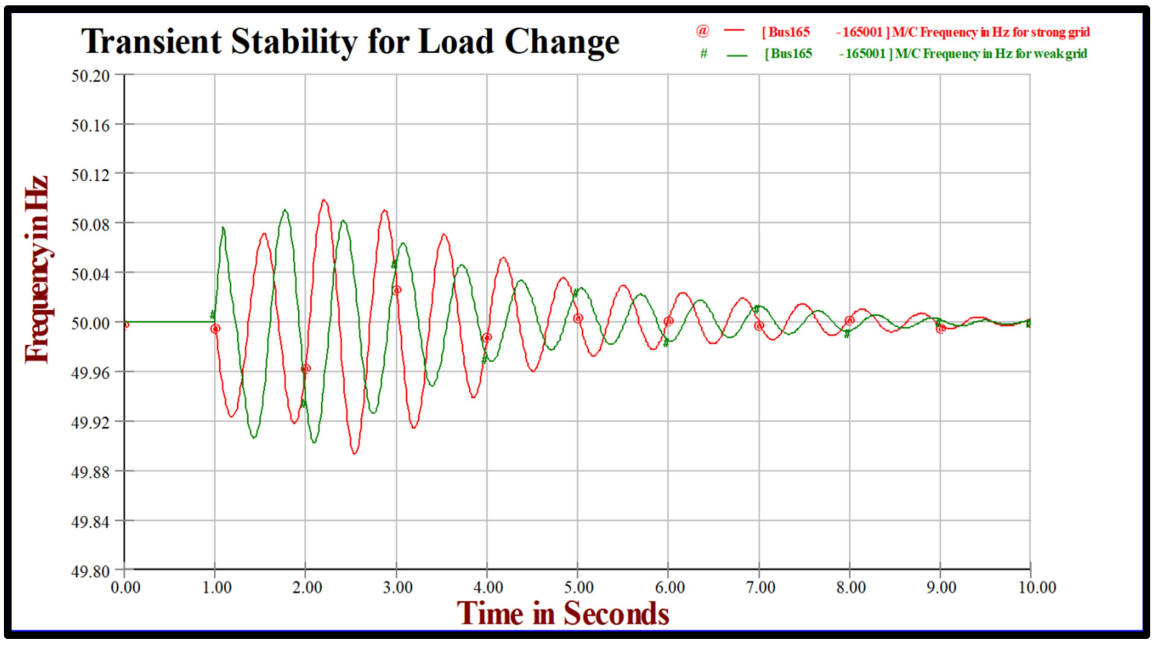

Figure 6-258 Frequency plot for sudden increase in load inside the plant during export mode of operation of plant

Similarly, the swing curve angle in degree and active power flow from the generating bus for a disturbance initiated due to sudden load throw off during export mode of plant operation of plant is presented in Figure 6-259 and Figure 6-260.

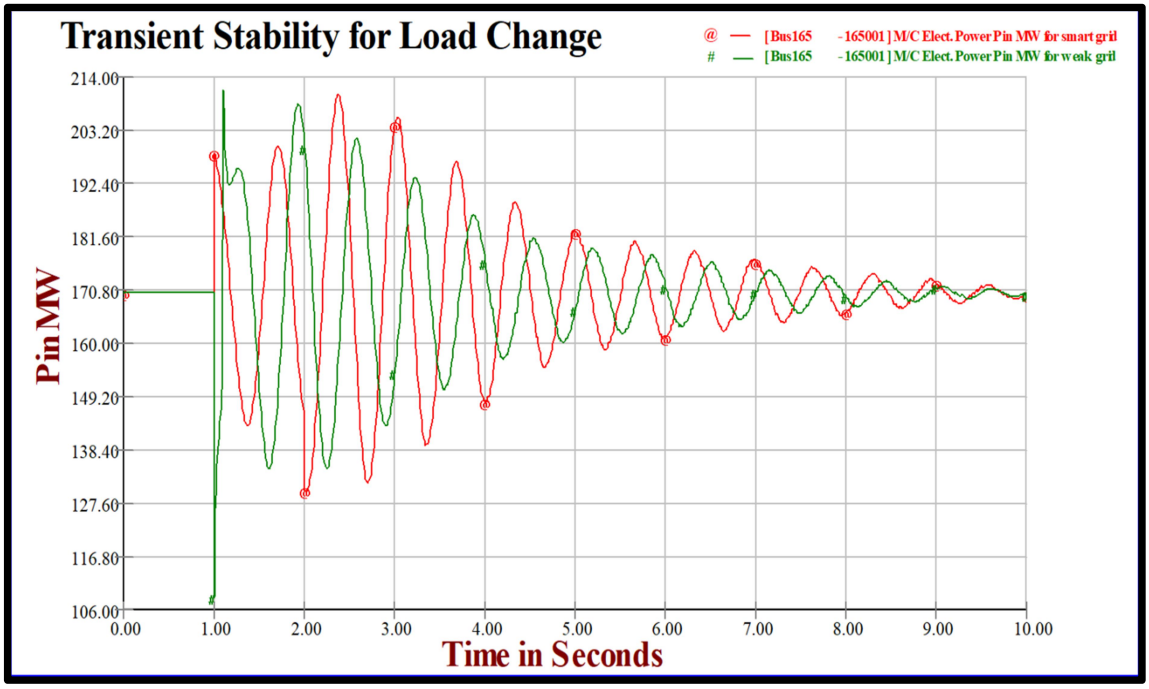

Figure 6-259 Active power plot for sudden increase in load inside the plant during export mode of operation of plant

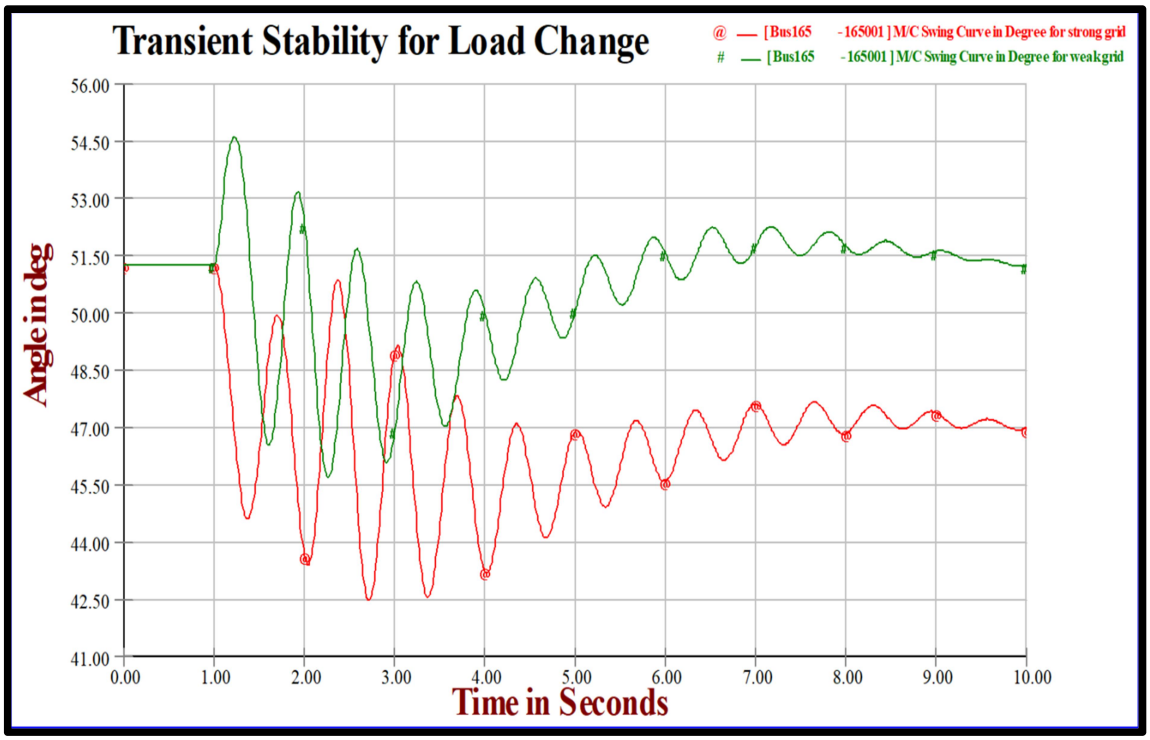

Figure 6-260 Swing curve plot for sudden increase in load inside the plant during export mode of operation of plant

6.11. Transient Stability of RSP under no grid connectivity

This part of the report evaluates the transient stability of Rourkela Steel Plant's electrical network, focusing on its voltage, frequency, reactive power, active power, and swing curve stability under various operational conditions. Ensuring stable operation in these parameters is crucial for uninterrupted plant processes and safety.

In the voltage response graph, a steady or swiftly recovering line after a disturbance indicates effective voltage control. RSP's system ideally maintains voltage levels close to nominal values to avoid equipment stress and ensure process continuity.

Figure 6-261 Voltage response of Generator terminal bus during 3-Phase to ground fault

In Figure 6-262, frequency stability is depicted as the return to the nominal frequency following disturbances. At RSP, the reduced frequency ensures that the under frequency relay might operate, which leads to unstable operation.

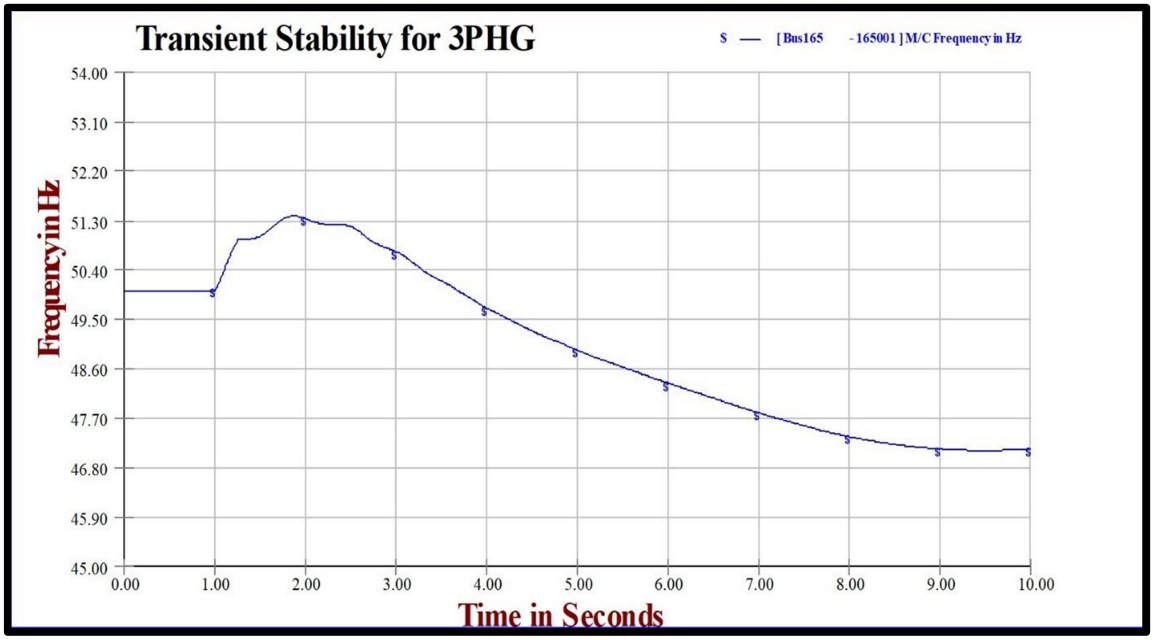

Figure 6-262 Frequency response of Generator terminal bus during 3-Phase to ground fault

Reactive power stability is observed in the system's response to regulate voltage under load variations or faults. RSP's electrical system should display reactive power that stabilizes quickly after transients.

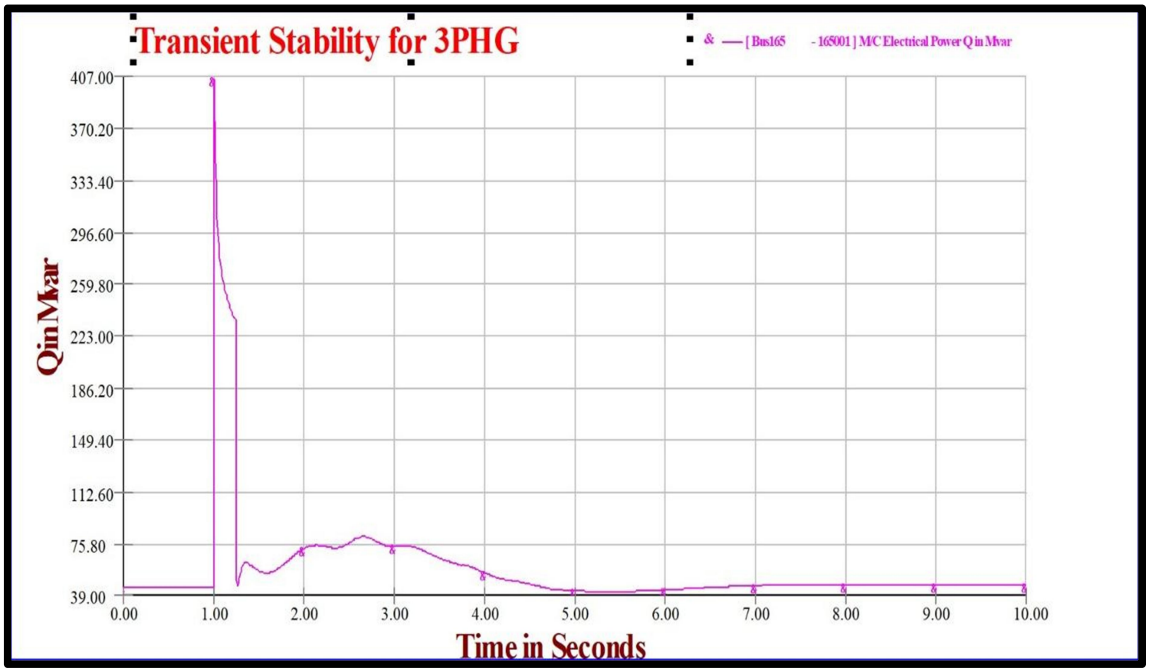

Figure 6-263 Reactive power of Generator terminal bus during 3-Phase to ground fault

In Figure 6-264, Active power stability graphs will show momentary variations as the system compensates for disturbances, returning quickly to a steady state. Consistent active power at RSP helps avoid interruptions in production processes and ensures continuous machinery operation.

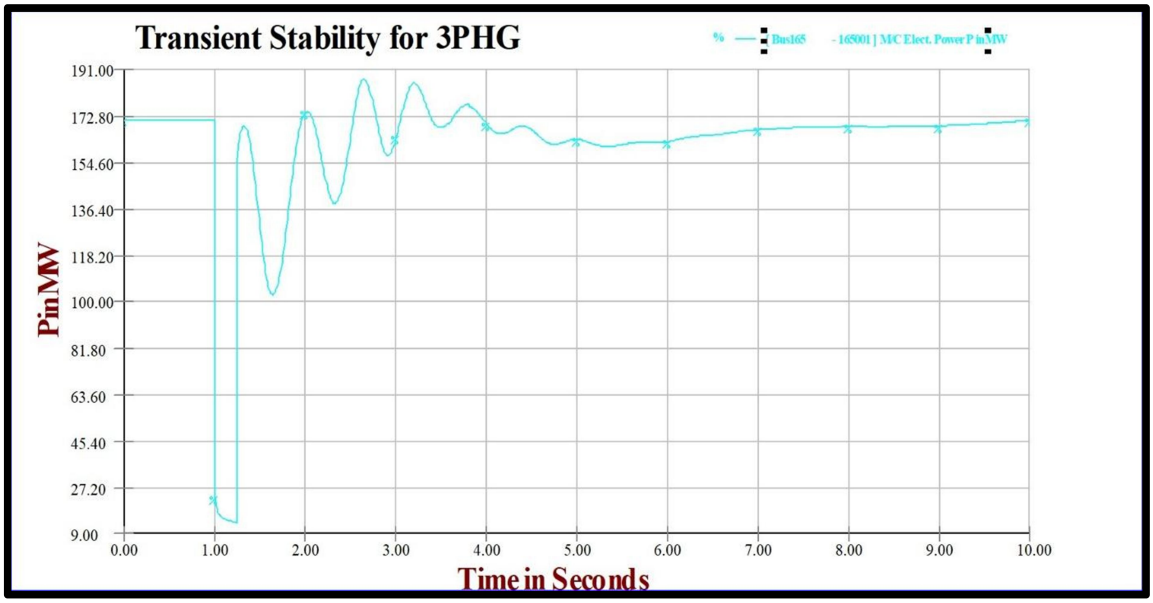

Figure 6-264 Reactive power of Generator terminal bus during 3-Phase to ground fault

In Figure 6-265, Swing curves indicate how generator rotor angles respond and stabilize after a disturbance. In RSP's case, maintaining synchronization between generators is crucial to prevent phase differences that could destabilize the entire network.

Figure 6-265 Swing curve in degree Generator terminal bus during 3-Phase to ground fault

6.12. General inferences from studies

- Load flow studies show that the grid is strong and it gives much higher or at least similar short ckt support to the CGPs.
- The connectivity to CGP is strong for supplying emergency power both during steady state and transient.
- It meets the N-1 reliability criteria.
- The short ckt levels are within the capacity of the switchgears.
- Strong short ckt support provides good damping during recovery from transients where as with weak grid support or no support the transient recovery is oscillatory and slow
- A slow voltage /active power and frequency recovery could cause tripping in the relays either cutting off the auxiliary supply or the CGP generator.

7. HARMONIC ANALYSIS (ON-SITE)

The major sources of harmonics in any CGP are Rolling Mills, Ladle heat furnaces (LHF) and Drive driven machines. The above mentioned loads are nonlinear in nature and tends to inject the harmonics in to the CGP electrical network. In order to verify the harmonic distortion levels caused by these loads, harmonic measurement and analysis has been carried out and results are compared with IEEE 519 permissible limits. The harmonic measurement is taken at two outgoing CGP feeders of OPTCL network.

The IEEE Std. 519 "*IEEE recommended practices and requirements for harmonic control in electrical power systems*" specifies the harmonic distortion limits. As per IEEE Std. 519, voltage distortion and current distortion limits for different voltage levels are presented in Table 7-1 to Table 7-4.

Table 7-1 IEEE STD. 519 VOLTAGE DISTORTION LIMITS

BUS VOLTAGE AT PCC	INDIVIDUAL VOLTAGE DISTORTION (%)	TOTAL VOLTAGE DISTORTION THD (%)
69 kV and below	3	5
69.001kV through 161kV	1.5	2.5
Above 161 kV	1	1.5

Table 7-2 IEEE STD. 519 CURRENT DISTORTION LIMITS 120V TO 69kV

MAXMIMUM HARMONIC CURRENT DISTORTION IN PERCENTAGE OF I_L						
INDIVIDUAL HARMONIC ORDER (ODD HARMONIC)						
I_{SC} / I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≥h	TDD
<20*	4	2	1.5	0.6	0.3	5
20<50	7	3.5	2.5	1	0.5	8
50<100	10	4.5	4	1.5	0.7	12
100<1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20
EVEN HARMONICS ARE LIMITED TO 25% OF THE ODD HARMONIC LIMITS ABOVE.						
CURRENT DISTORTIONS THE RESULT IN A DC OFFSET, e.g., HALF-WAVE CONVERTERS, ARE NOT ALLOWED						
*ALL POWER GENERATION EQUIPMENT IS LIMITED TO THESE VALUES OF CURRENT DISTORTION, REGARDLESS OF ACTUAL I_{SC} /I_L						
WHERE, I_{SC} = MAXIMUM SHORT-CIRCUIT CURRENT AT PCC. I_L = MAXIMUM DEMAND LOAD CURRENT (FUNDAMENTAL FREQUENCY COMPONENT) AT PCC						

Table 7-3 IEEE STD.519 CURRENT DISTORTION LIMITS 69kV TO 161 kV

MAXMIMUM HARMONIC CURRENT DISTORTION IN PERCENTAGE OF I_L						
INDIVIDUAL HARMONIC ORDER (ODD HARMONIC)						
I_{SC} / I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≥h	TDD
<20*	2	1	0.75	0.3	0.15	2.5
20<50	3.5	1.75	1.25	0.5	0.25	4
50<100	5	2.25	2	0.75	0.35	6
100<1000	6	2.75	2.5	1	0.50	7.5
>1000	7.5	3.50	3	1.25	0.70	10
EVEN HARMONICS ARE LIMITED TO 25% OF THE ODD HARMONIC LIMITS ABOVE.						
CURRENT DISTORTIONS THE RESULT IN A DC OFFSET, e.g., HALF-WAVE CONVERTERS, ARE NOT ALLOWED						
*ALL POWER GENERATION EQUIPMENT IS LIMITED TO THESE VALUES OF CURRENT DISTORTION, REGARDLESS OF ACTUAL ISC /IL						
WHERE, I_{SC} = MAXIMUM SHORT-CIRCUIT CURRENT AT PCC. I_L = MAXIMUM DEMAND LOAD CURRENT (FUNDAMENTAL FREQUENCY COMPONENT) AT PCC						

Table 7-4 IEEE Std.519 Current distortion limits > 161 V

Maximum harmonic current distortion in percentage of I_L						
Individual harmonic order (odd harmonic)						
I_{SC}/I_L	<11	11h<17	17≤h<23	23≤h<35	35≥h	TDD
<50*	2	1	0.75	0.3	0.15	2.5
≥50	3	1.5	1.15	0.45	0.22	3.75
Even harmonics are limited to 25% of the odd harmonic limits above.						
Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.						
All power generation equipment is limited to these values of current distortion, regardless of actual ISC/IL.						
Where, I_{SC} =maximum short-circuit at PCC I_L=maximum demand load current (fundamental frequency component) at PCC.						

Harmonics/ inter harmonics always create a negative impact on the power system equipment. In recent times, the increase in the switch based devices lead to injection of more amounts of harmonics into the system. The main tendency is for the harmonic currents to flow from the harmonic-producing load to the power system source [30]. Due to the presence of harmonic components in the load current, the waveform is distorted from its original form. Waveforms of harmonic sources have somewhat arbitrary wave shapes depending on the distorting phenomena, but they contain several harmonics in significant quantities [30]. These currents when added with the source current, leads to distortion of the original current waveform shape.

The impact of these distorted waveforms is significant in power system equipment. The test results in [31] show that the voltage regulation of a synchronous generator under various load conditions is related to the different level of harmonic distortion produced by the load. Similarly, it is found that the impact of residential load harmonics on transformers is approximately proportional to the square of current THD [32]. In transformers, the harmonic injection leads to over-heating and over-loading which ultimately affects the equipment life. In industries, the investigation results in [33], show that traction load harmonic emissions can have a significant impact. A one point measurement approach will not always provide an adequate harmonic assessment on a network with multiple harmonic sources [33].

The Standard Oil filled transformers are derated according to the following formula:

$$F_K = \sqrt{1 + \frac{e}{e+1}\left(\frac{I_1}{I}\right)^2 \sum_{h=2}^{h=h_{max}} h^q \left(\frac{I_h}{I_1}\right)^2}$$

e is the eddy current loss due to sinusoidal current at the fundamental frequency, divided by the loss due to DC current equal to the RMS current of the sinusoidal current value, both at reference temperature. The exponent q is dependent on the type of windings and on the frequency. The variable $I_h$defines the current component of h order harmonics. The derating factor is given by $1/F_K$. This indicates that, with increase in the harmonic indices, the derating increases.

7.1.Vedanta 400kV Feeder in Lapanga 400/220/132kV GSS

The harmonic measurement for the Vedanta (Sterlite) 400kV outgoing feeder is taken at Lapanga 400/220/132 kV Sub-station. The voltage, current, and frequency variation corresponding to the time recorded from the Vedanta (Sterlite) 400kV feeder are presented in Figure 7-1 to Figure 7-3. The harmonic measurement at this point is recorded for a period of 4 hours with a sampling time of 1 second.

The total harmonic distortion and the harmonic order are presented in Figure 7-4 and Figure 7-5, respectively. The voltage THD varies in the range of 1.8%, while the current THD varies in the range of 1-3%. The voltage is slightly above the acceptable limits.

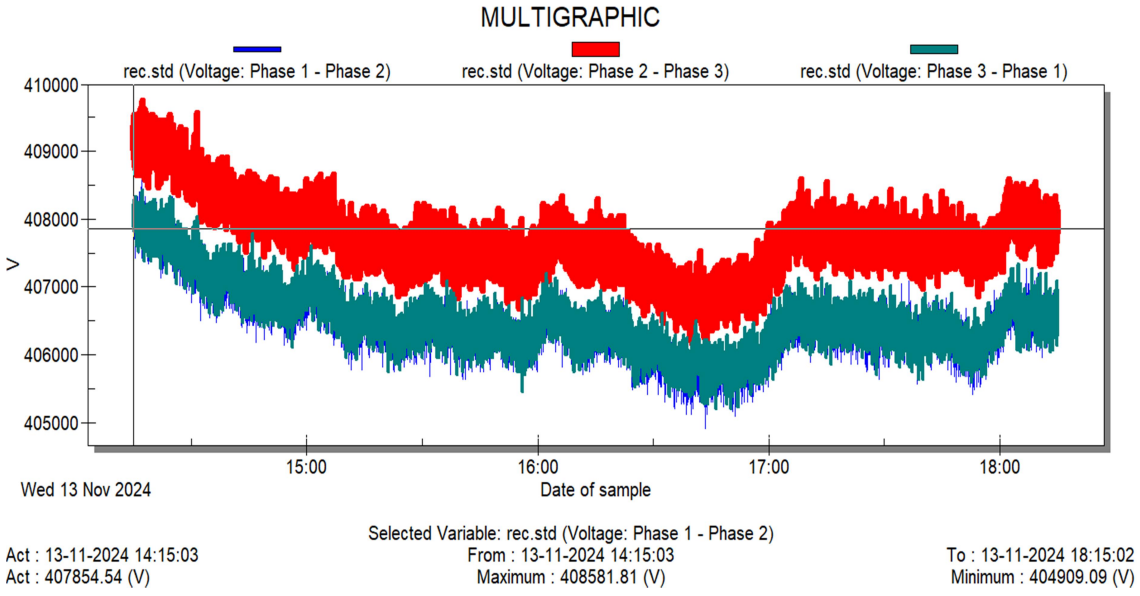

Figure 7-1 Voltage response

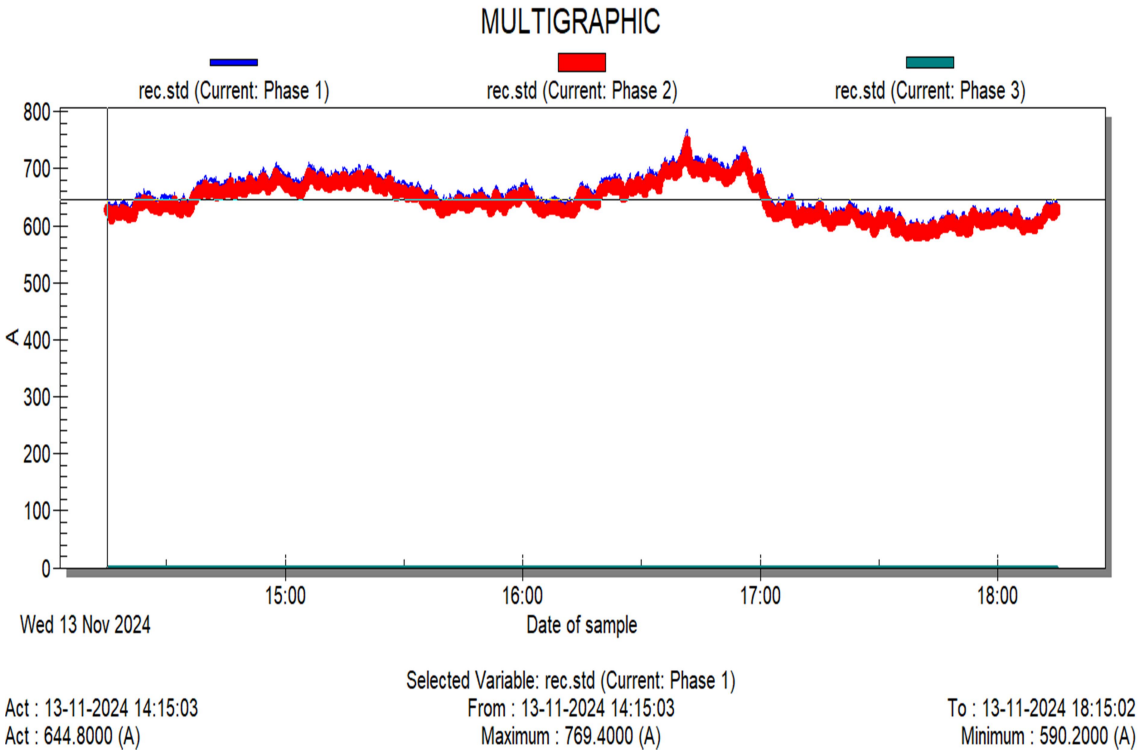

Figure 7-2 Current in Ampere

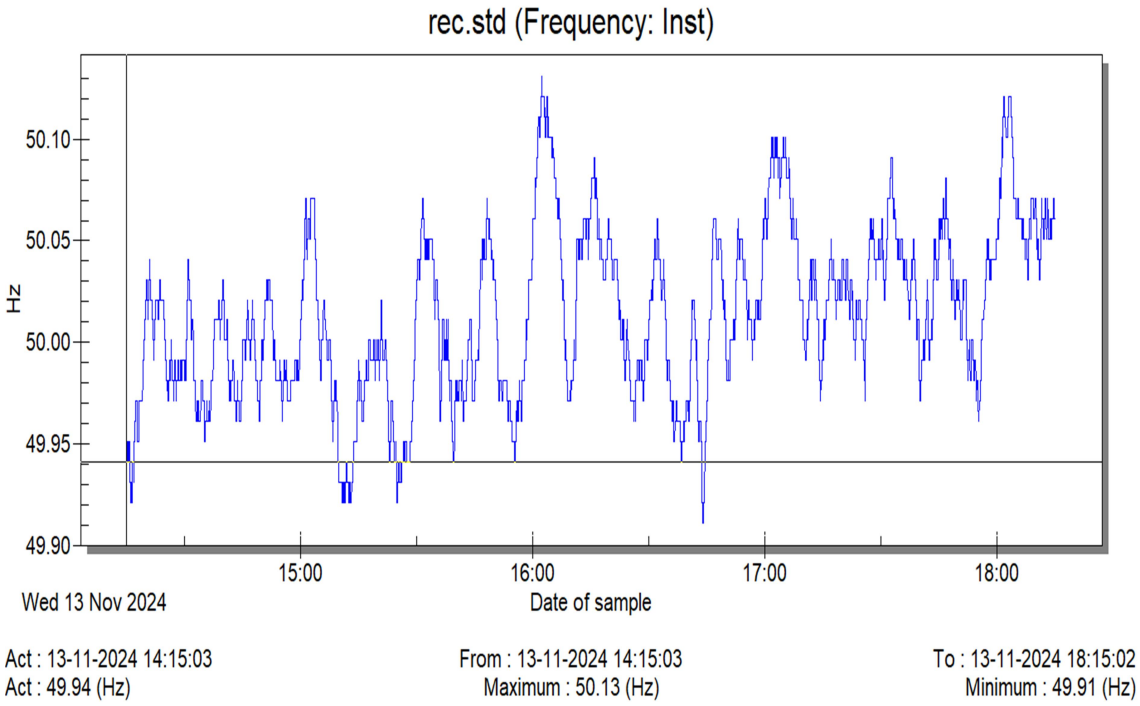

Figure 7-3 Frequency response in Hz

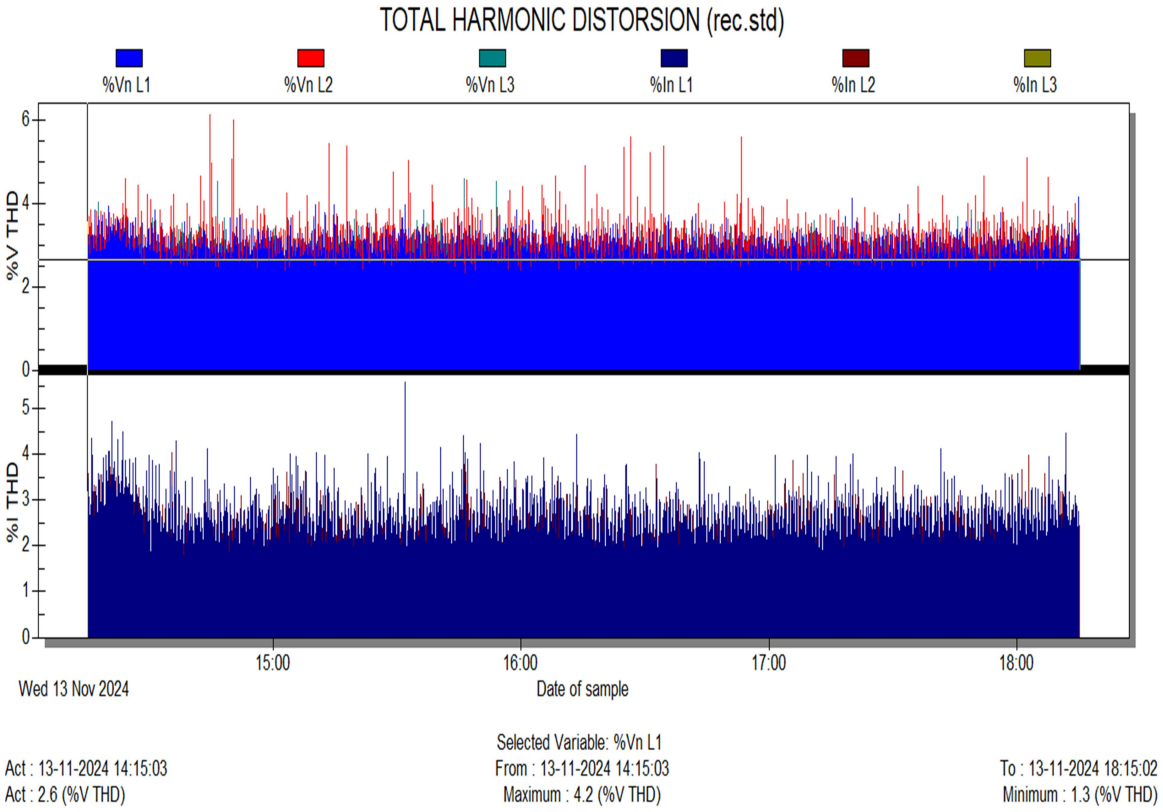

Figure 7-4 Total Harmonic distortion in percentage

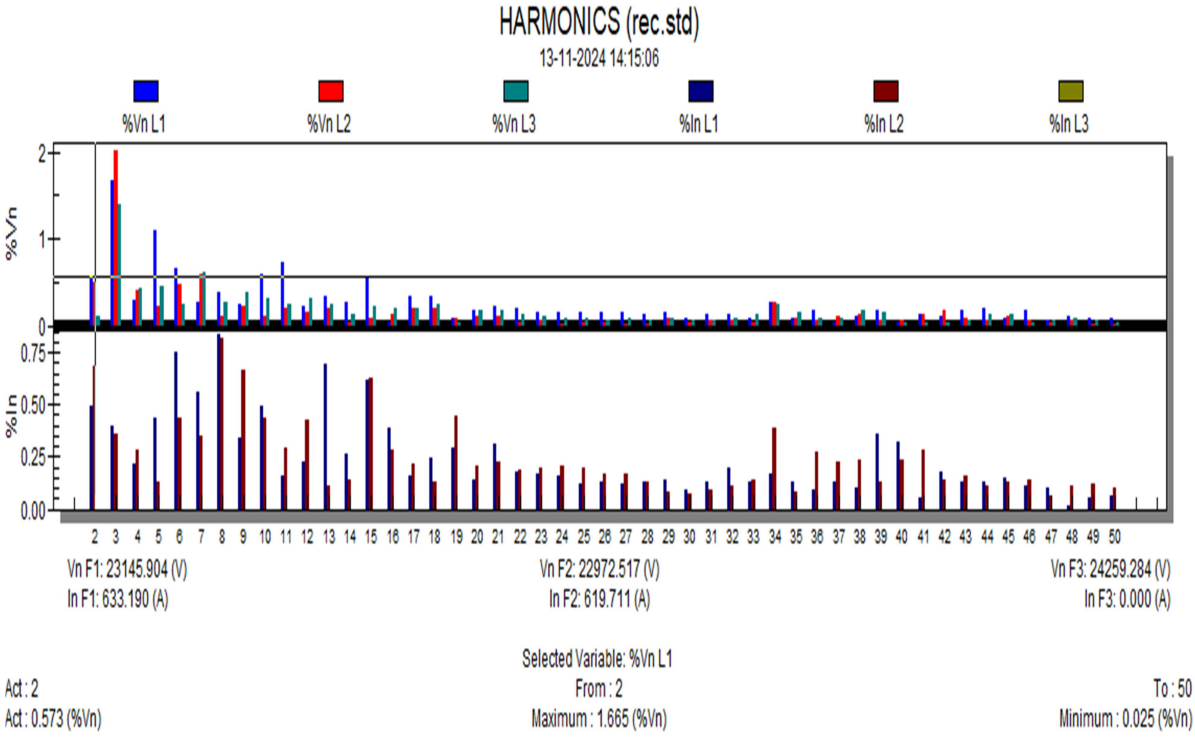

Figure 7-5 Harmonic components (upto 50th order of fundamental) at a sample time

7.2.JSW Bhusan 220kV feeder from Budhipadar 220/132/33kV GSS

The harmonic measurement for the JSW Bhusan 220kV outgoing feeder is taken at Budhipadar 220/132 kV Sub-station. The voltage, current, and frequency variation corresponding to the time recorded from the JSW Bhusan 220kV feeder are presented in Figure 7-6 to Figure 7-8. The harmonic measurement at this point is recorded for a period of 4 hours with a sampling time of 1 second.

The total harmonic distortion and the harmonic order are presented in Figure 7-9 and Figure 7-10, respectively. The voltage THD varies in the range of 1.7%, while the current THD varies in the range of 1-3%. The voltage and current THD are slightly above the acceptable limits.

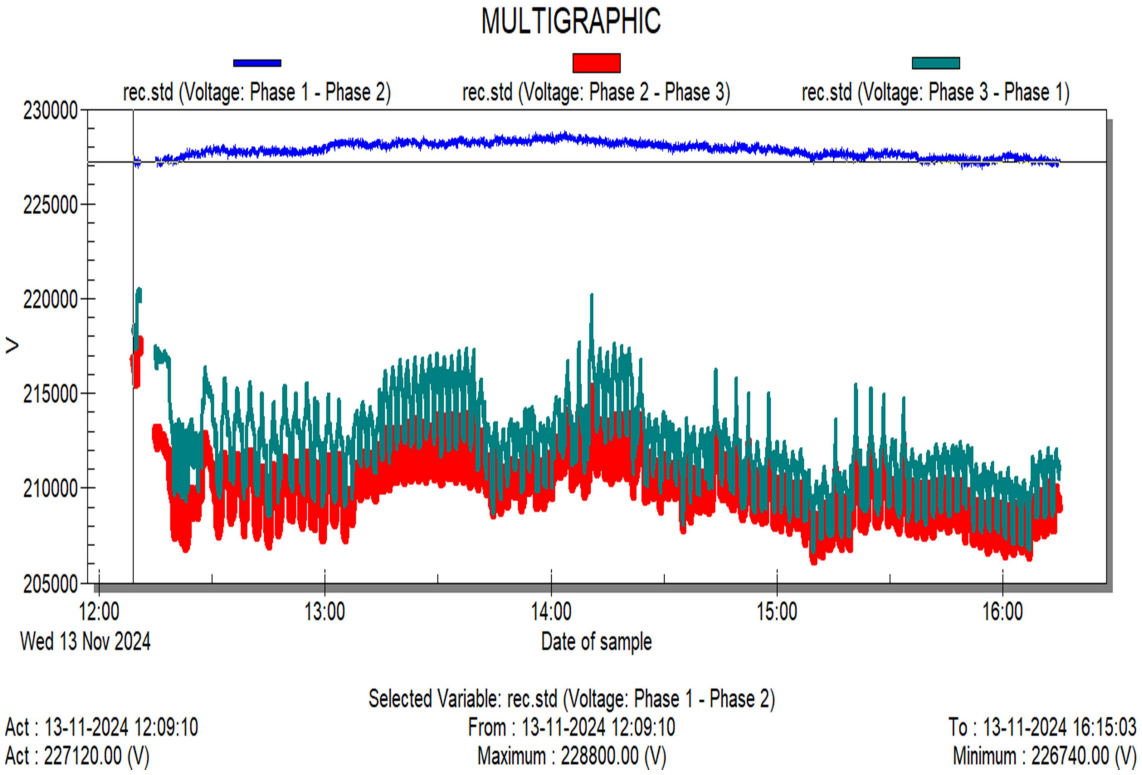

Figure 7-6 Voltage response

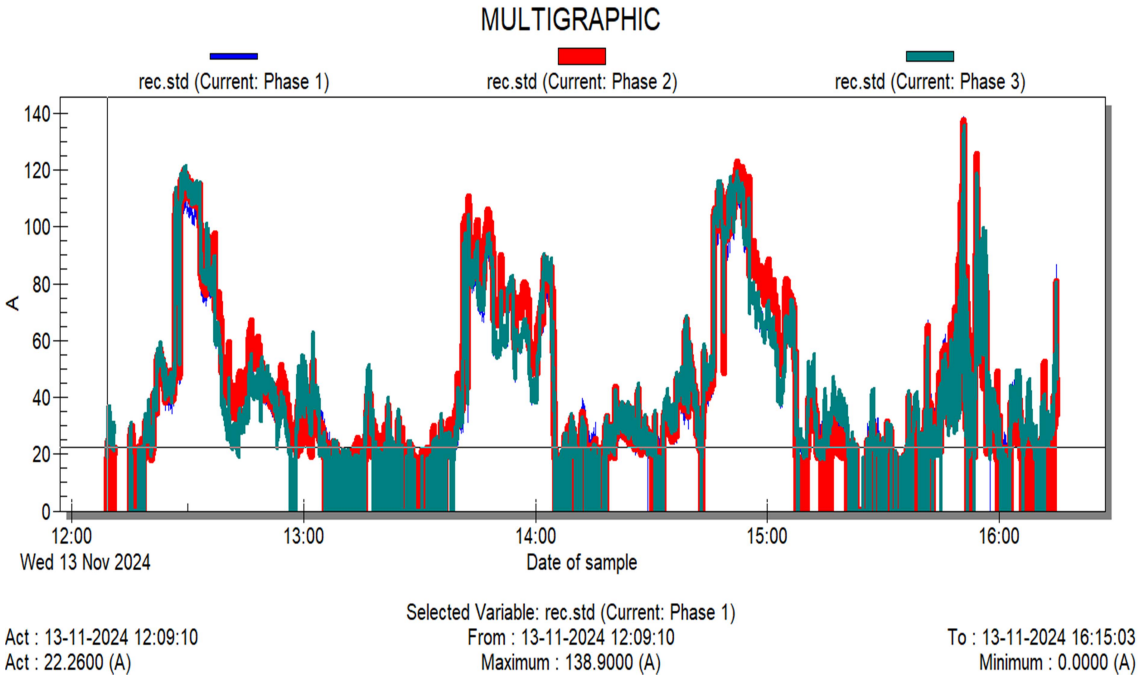

Figure 7-7 Current in Ampere

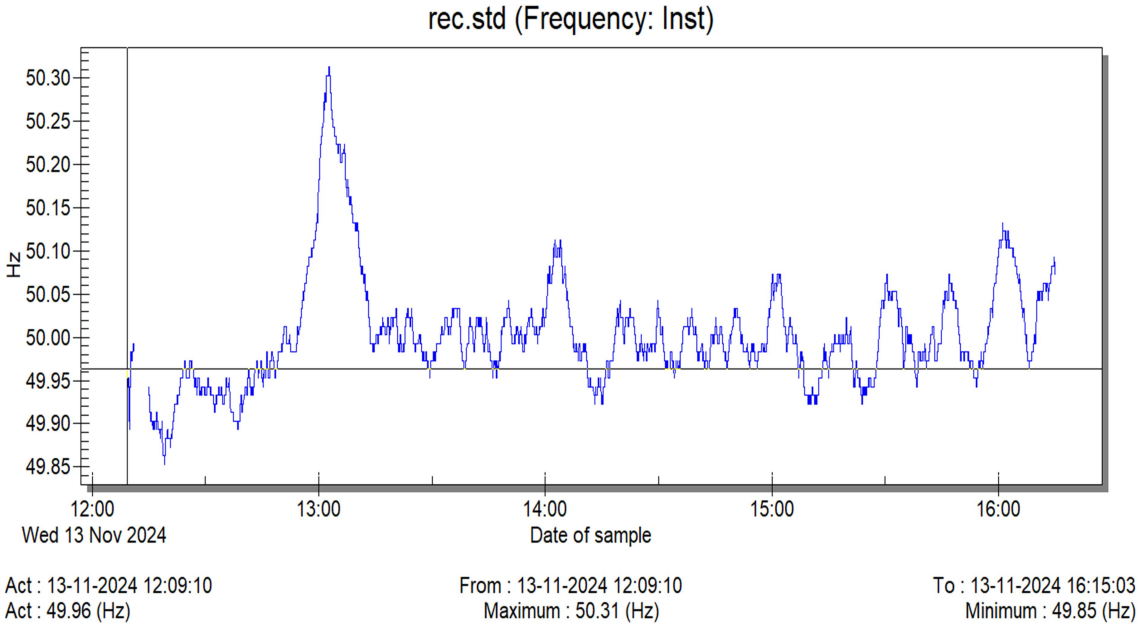

Figure 7-8 Frequency response in Hz

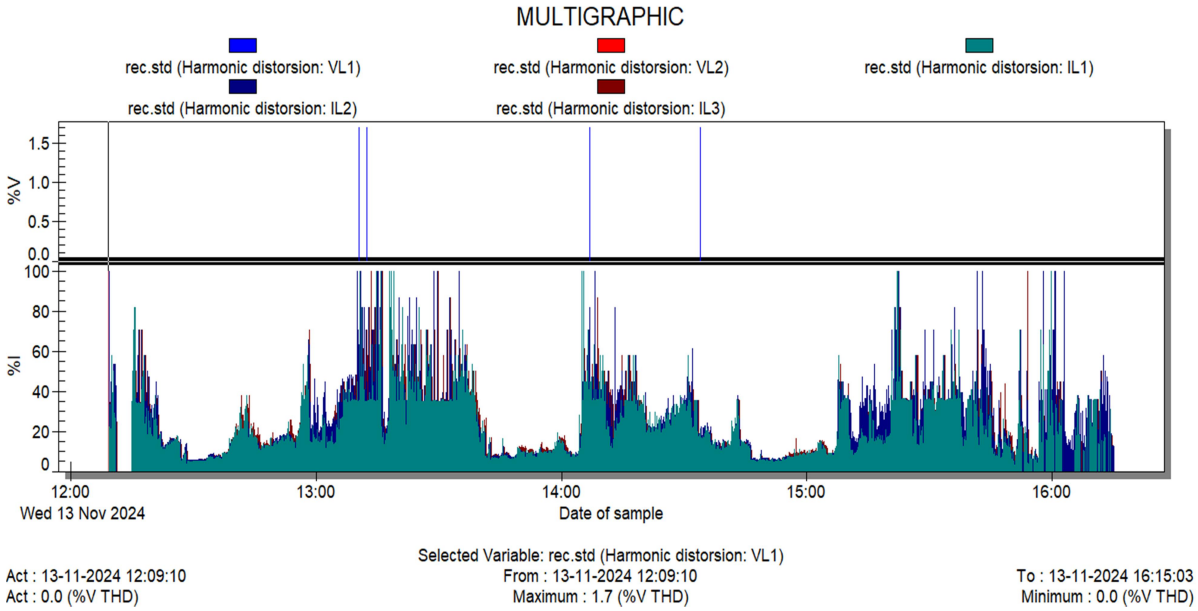

Figure 7-9 Total Harmonic distortion in percentage

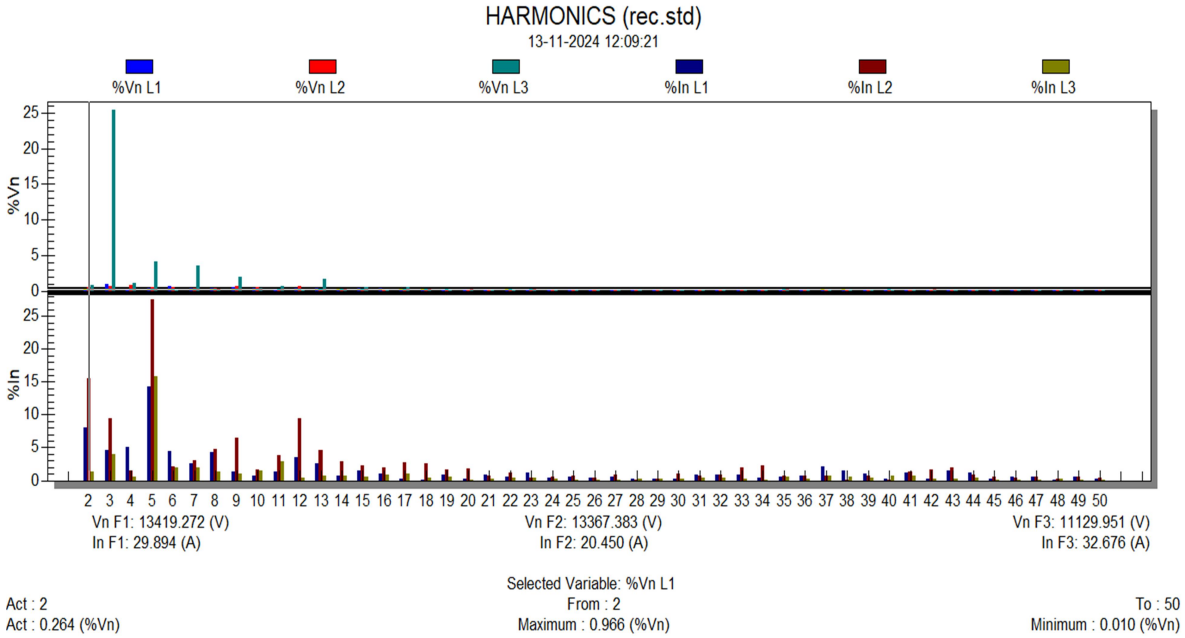

Figure 7-10 Harmonic components (upto 50th order of fundamental) at a sample time

7.3. Bhubaneswar Power 132kV feeder at Chandaka 220/132/33kV feeder

The harmonic measurement for the Bhubaneswar Power 132kV outgoing feeder is taken at Chandaka 220/132/33 kV Sub-station. The voltage, current, and frequency variation corresponding to the time recorded from Chandaka 220/132/33 kV feeder are presented in

Figure 7-11 to Figure 7-13. The harmonic measurement at this point is recorded for a period of 4 hours with a sampling time of 1 second.

The total harmonic distortion and the harmonic order are presented in Figure 7-14 and Figure 7-15, respectively. The voltage THD varies in the range of 2.6%, while the current THD varies more than 5%. The voltage and current THD are slightly above the acceptable limits.

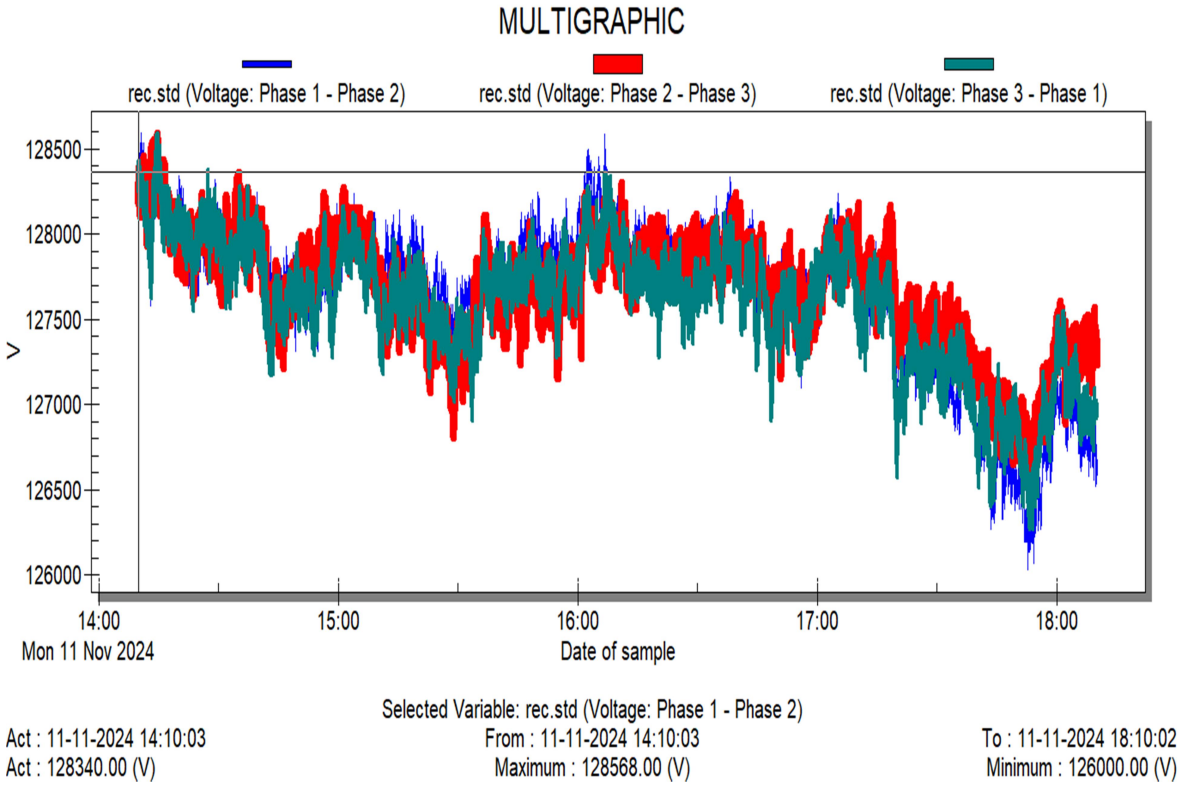

Figure 7-11 Voltage response

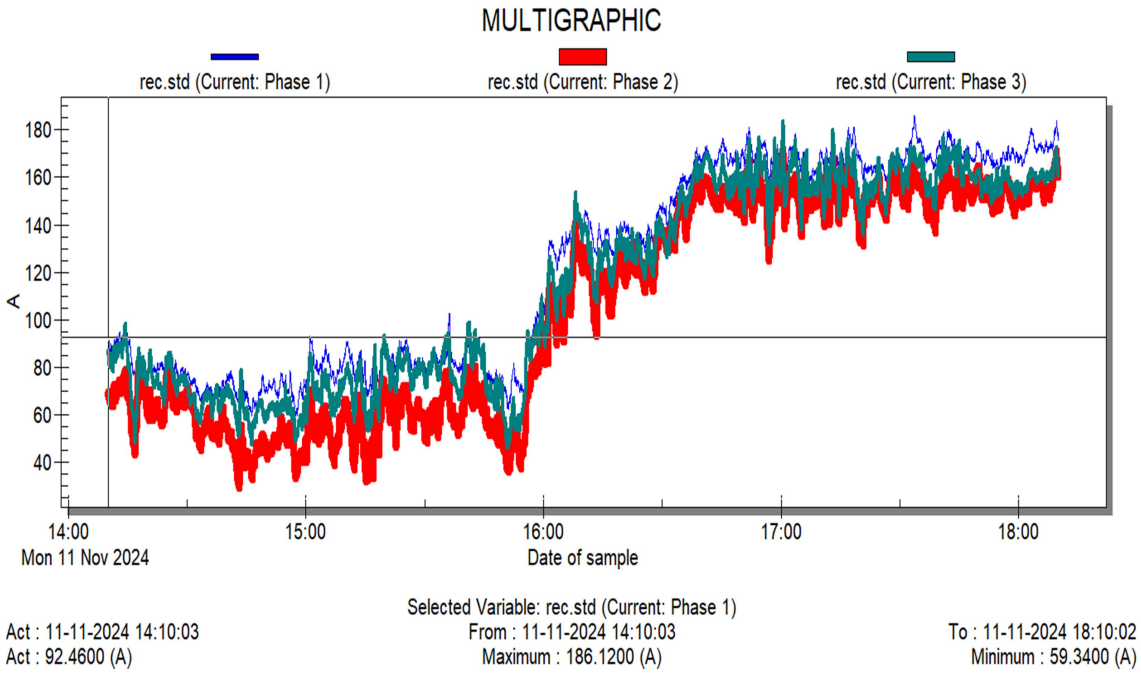

Figure 7-12 Current in Ampere

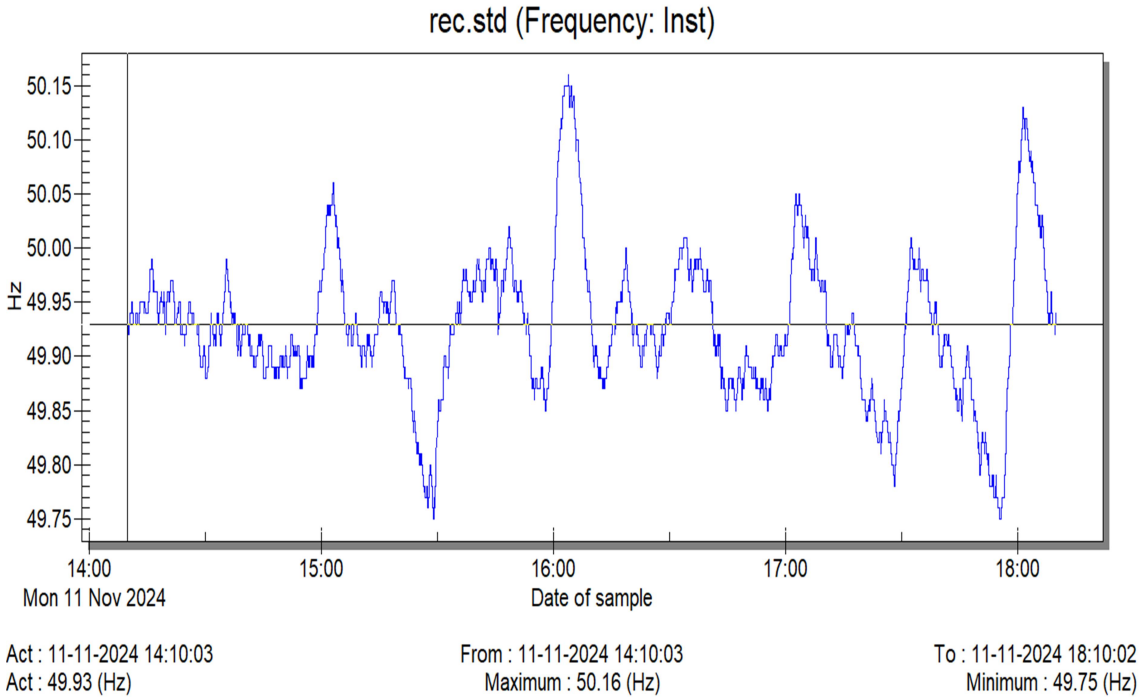

Figure 7-13 Frequency response in Hz

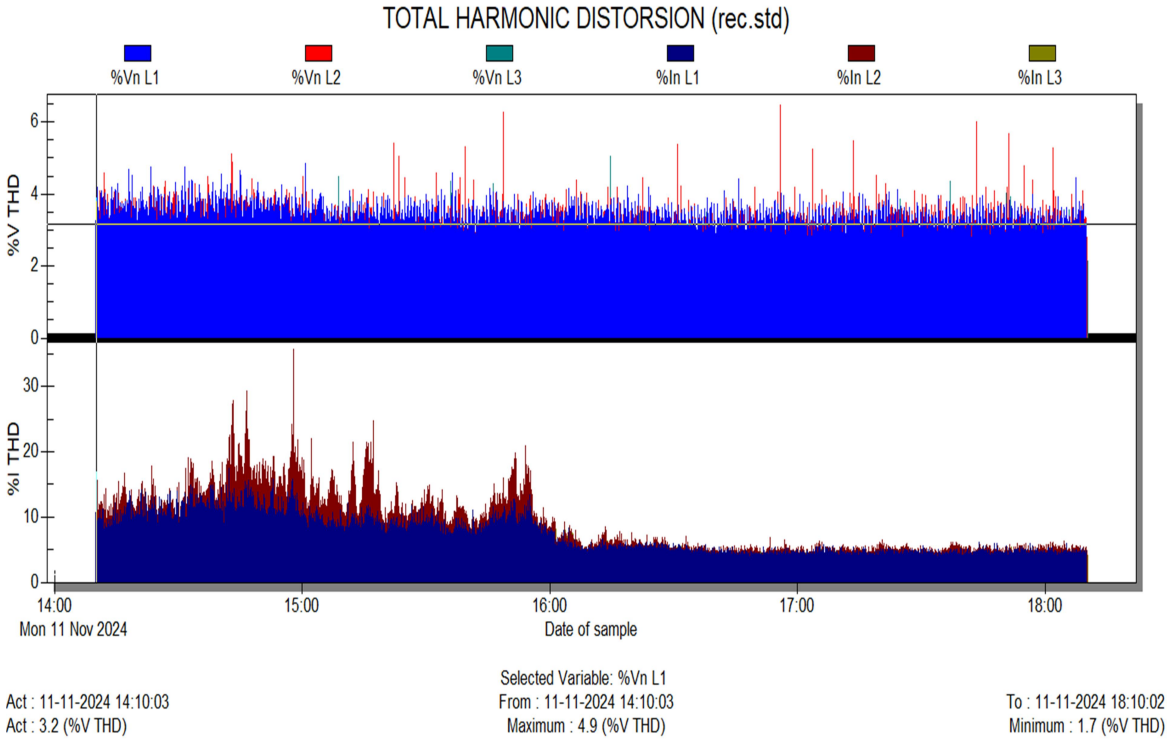

Figure 7-14 Total Harmonic distortion in percentage

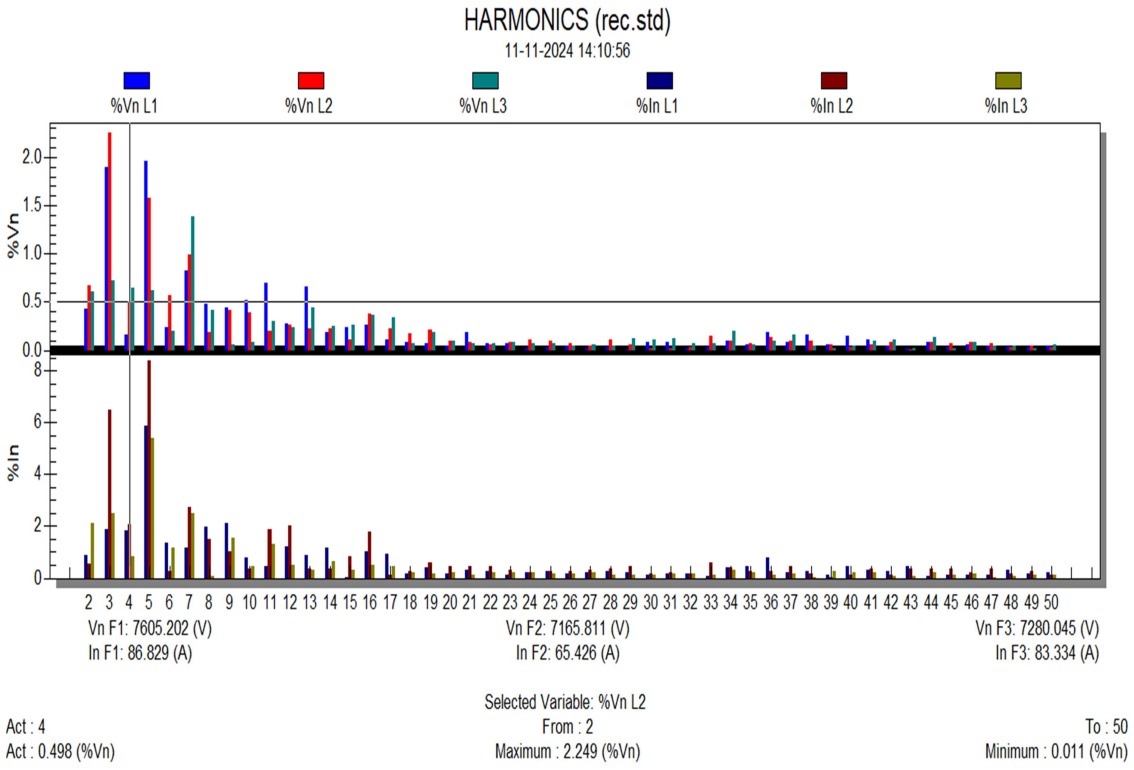

Figure 7-15 Harmonic components (upto 50th order of fundamental) at a sample time

7.4.IMFA 132kV feeder at ICCL Switching Station

The harmonic measurement for the IMFA 132kV outgoing feeder is taken at ICCL switching station. The voltage, current, and frequency variation corresponding to the time recorded from IMFA 132 kV feeder are presented in Figure 7-16 to Figure 7-18. The harmonic measurement at this point is recorded for a period of 24 hours with a sampling time of 2 minutes 30 second.

The total harmonic distortion and the harmonic order are presented in Figure 7-19 and Figure 7-20, respectively. The voltage THD varies within 1.9%, while the current THD varies in the range of 3-5%. The voltage and current THD are within the acceptable limits.

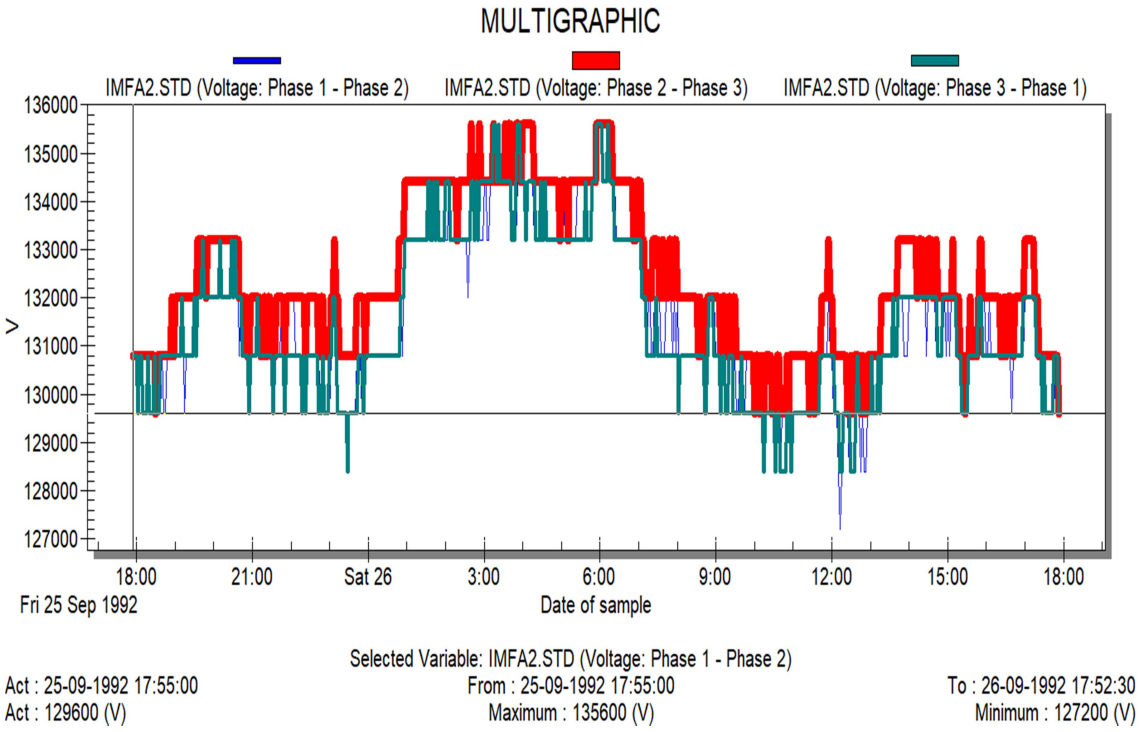

Figure 7-16 Voltage response

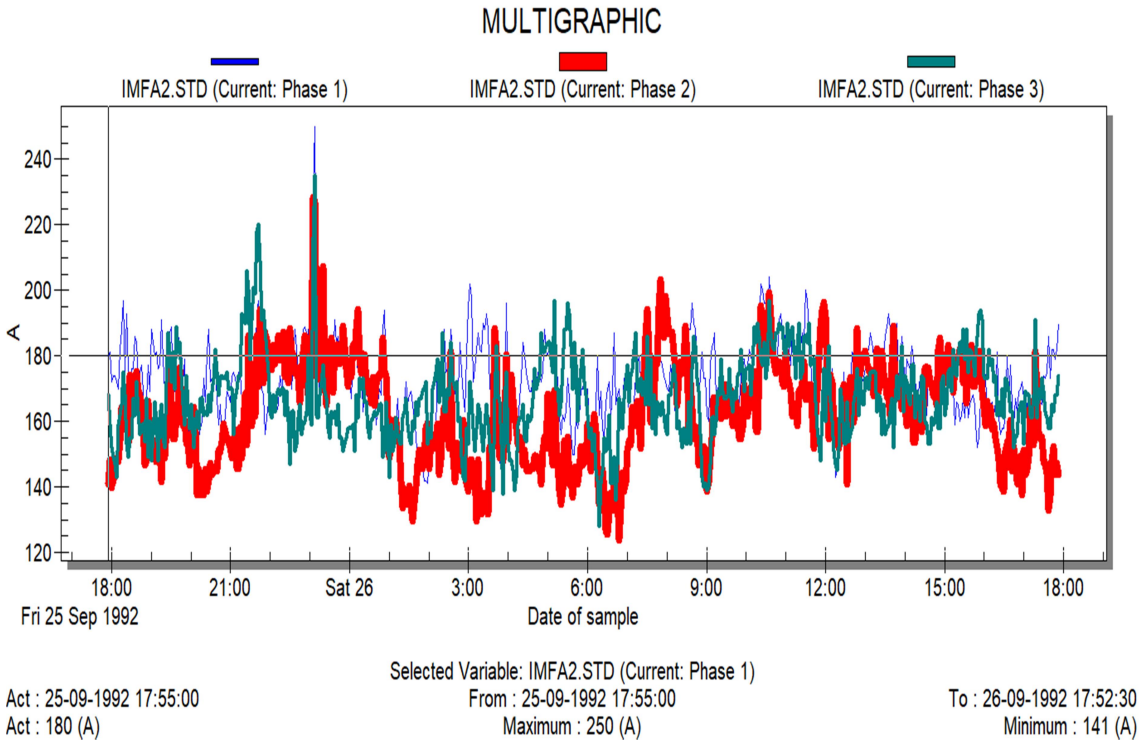

Figure 7-17 Current in Ampere

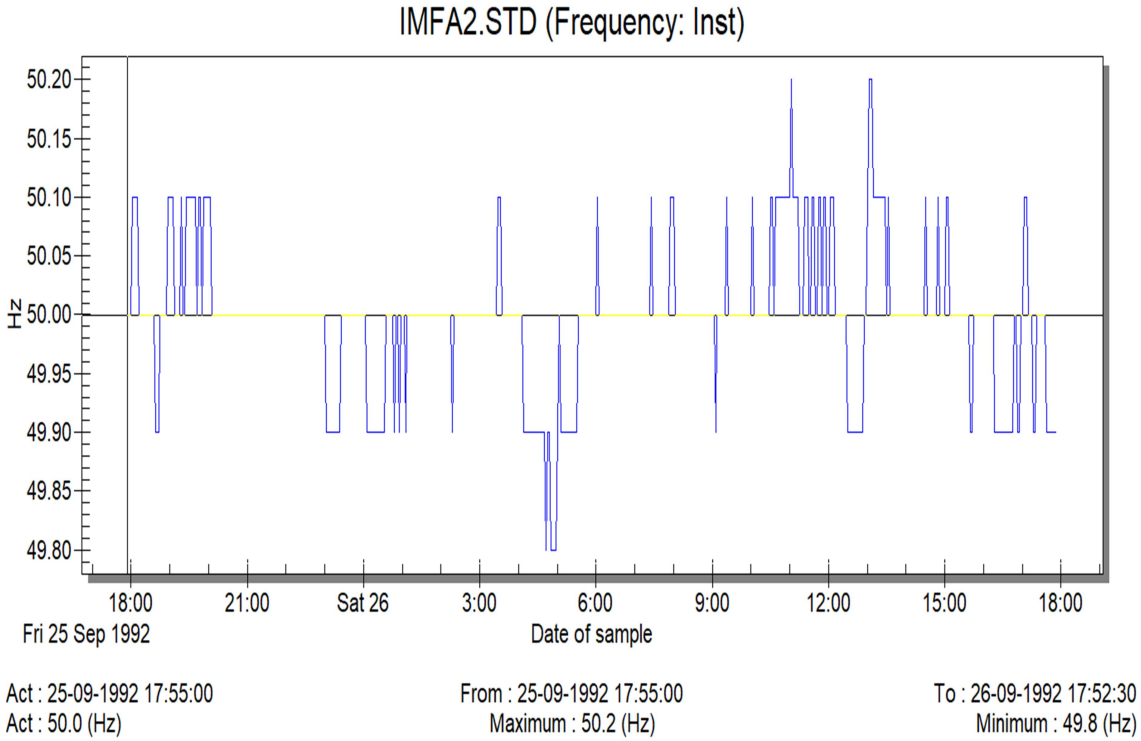

Figure 7-18 Frequency response in Hz

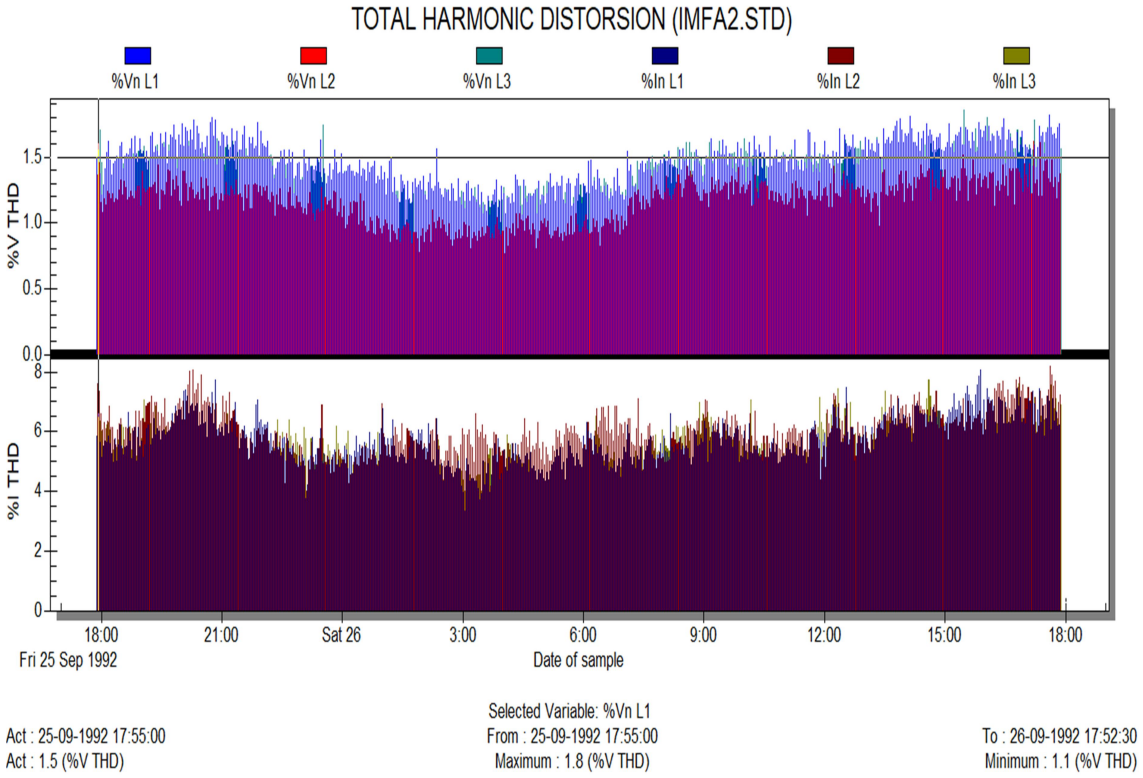

Figure 7-19 Total Harmonic distortion in percentage

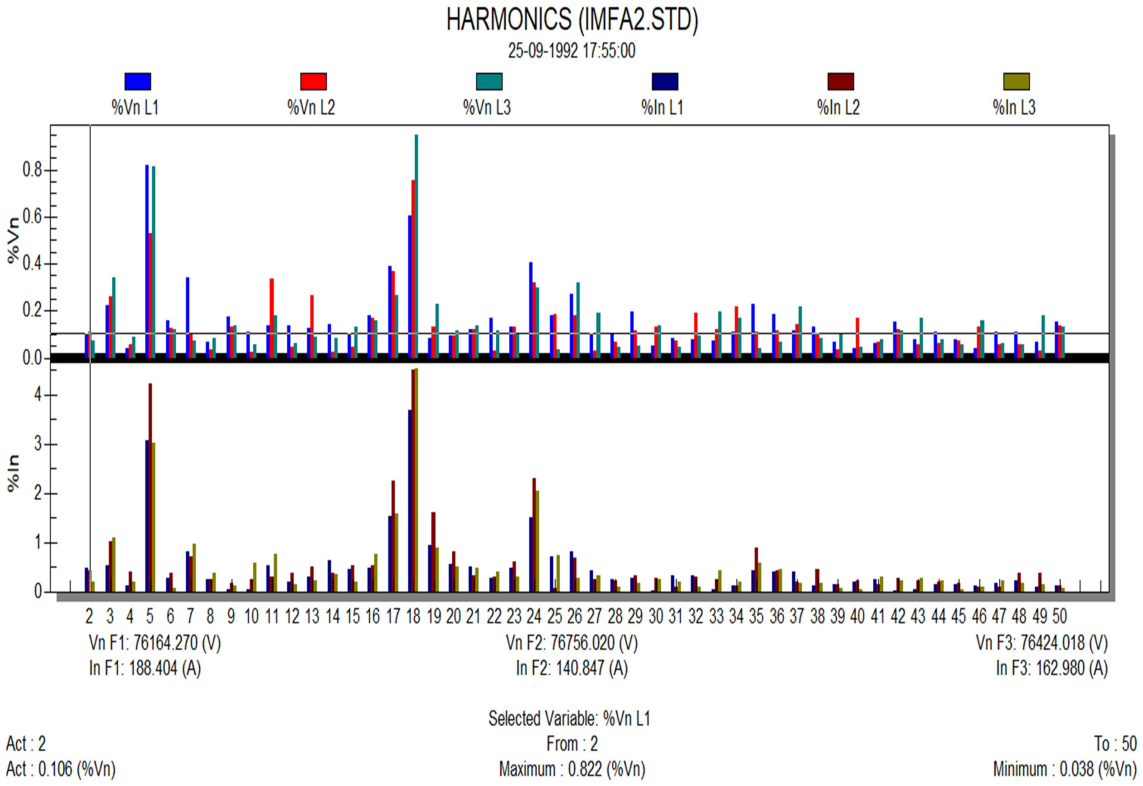

Figure 7-20 Harmonic components (upto 50th order of fundamental) at a sample time

7.5.Jindal 220kV Feeder from Duburi New 400/220kV GSS

The harmonic measurement for the Jindal 220kV outgoing feeder is taken at Duburi New 400/220 station. The voltage, current, and frequency variation corresponding to the time recorded from Jindal 220 kV feeder are presented in Figure 7-16 to Figure 7-18. The harmonic measurement at this point is recorded for a period of 24 hours with a sampling time of 2 minutes 30 second.

The total harmonic distortion and the harmonic order are presented in Figure 7-24 and Figure 7-25, respectively. The voltage THD varies within 2.1%, while the current THD varies in the range of 11-15%. The voltage and current THD are slightly above the acceptable limits.

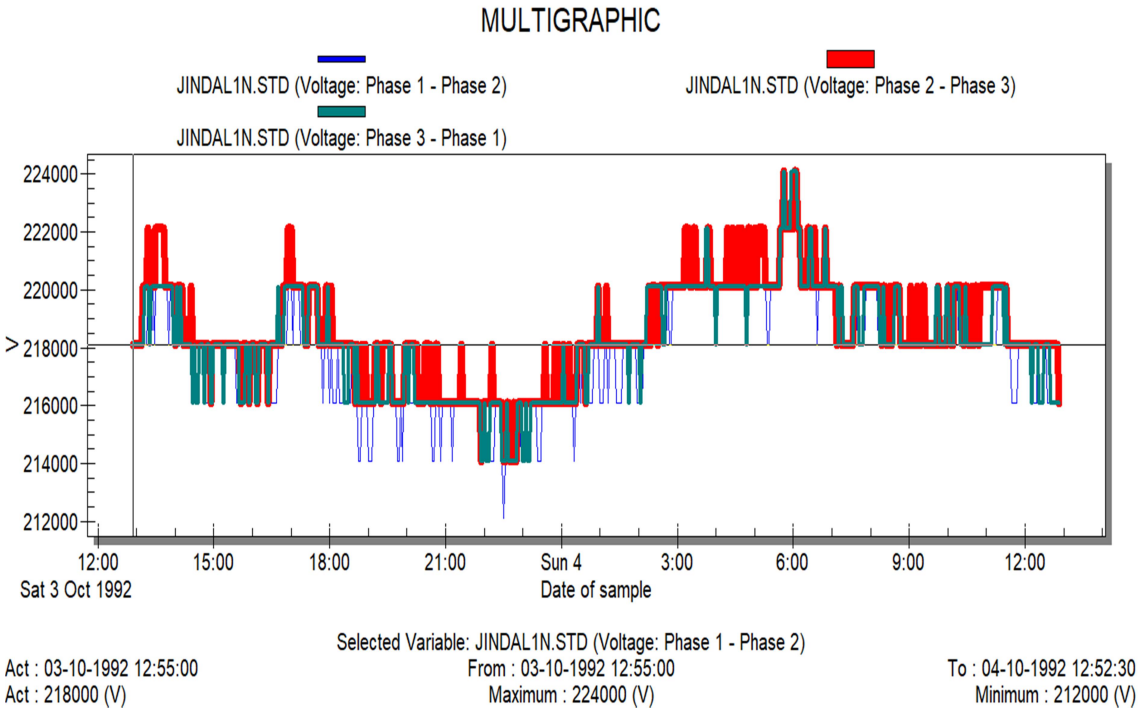

Figure 7-21 Voltage response

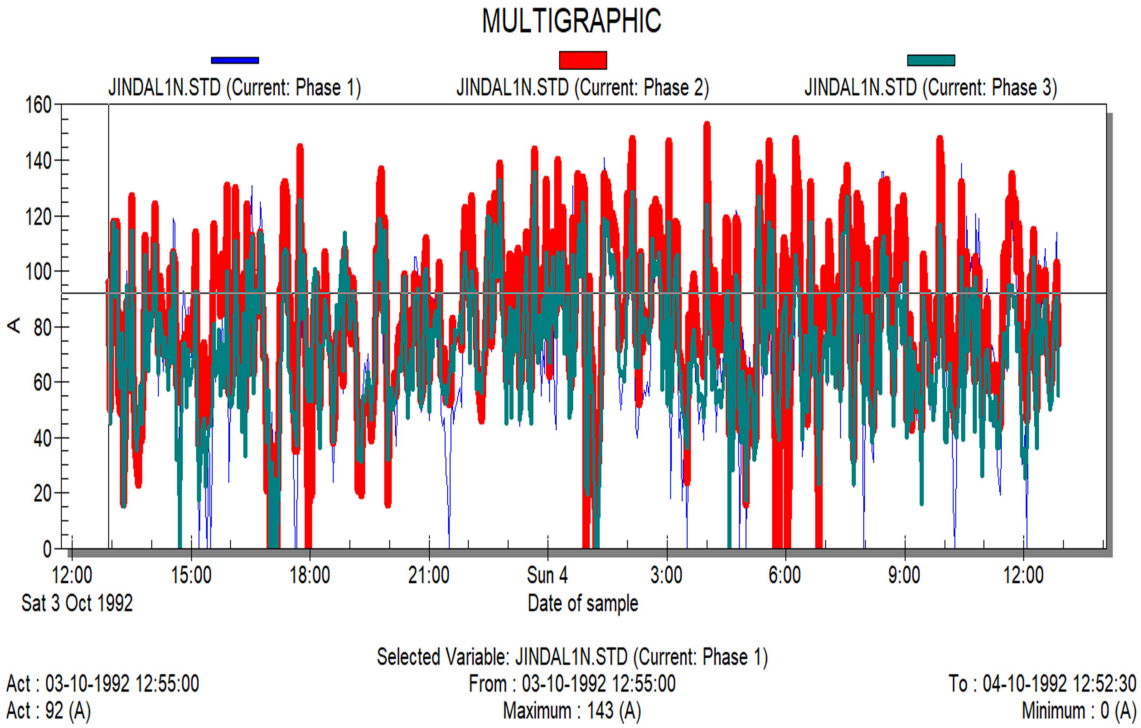

Figure 7-22 Current in Ampere

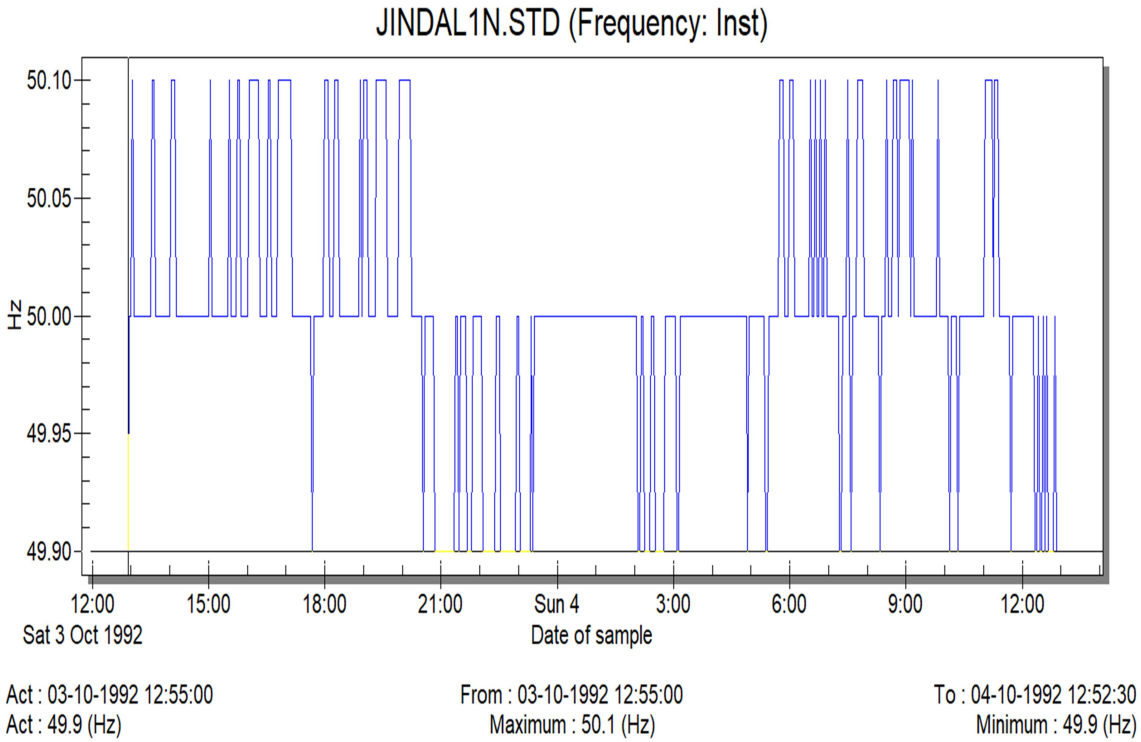

Figure 7-23 Frequency response in Hz

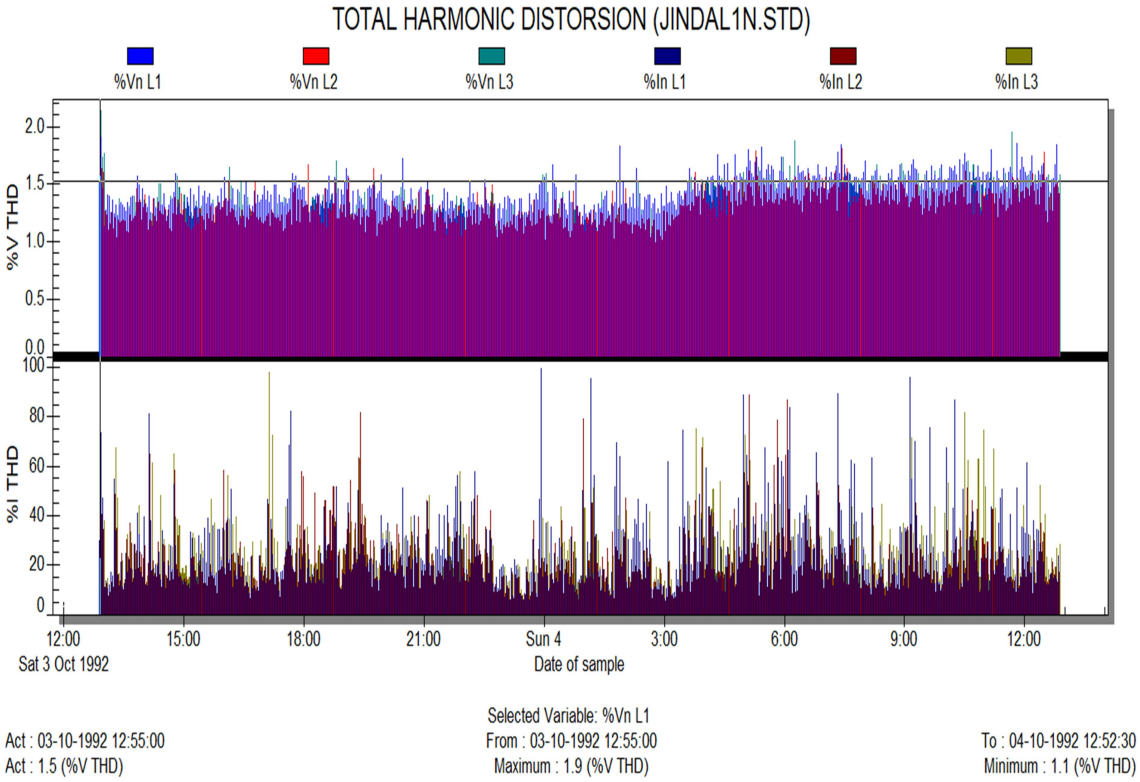

Figure 7-24 Total Harmonic distortion in percentage

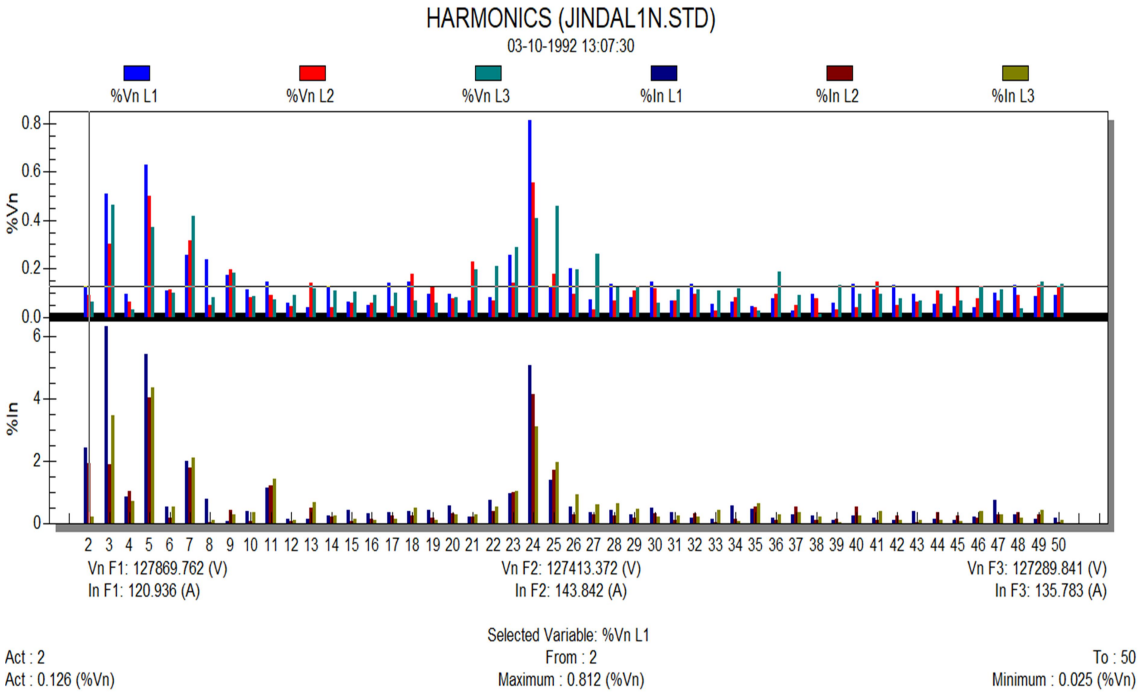

Figure 7-25 Harmonic components (upto 50th order of fundamental) at a sample time

7.6.NBVL 132kV feeder from Kharagprasad Switching Station

The harmonic measurement for the NBVL 132 kV outgoing feeder is taken at Kharagprasad switching station. The voltage, current, and frequency variation corresponding to the time recorded from Kharagprasad switching station are presented in Figure 7-26 to Figure 7-28. The harmonic measurement at this point is recorded for a period of 4 hours with a sampling time of 1 second.

The total harmonic distortion and the harmonic order are presented in Figure 7-29 and Figure 7-30, respectively. The voltage THD varies within 1.8%, while the current THD varies in the range of 5-8%. The voltage and current THD are within the acceptable limits.

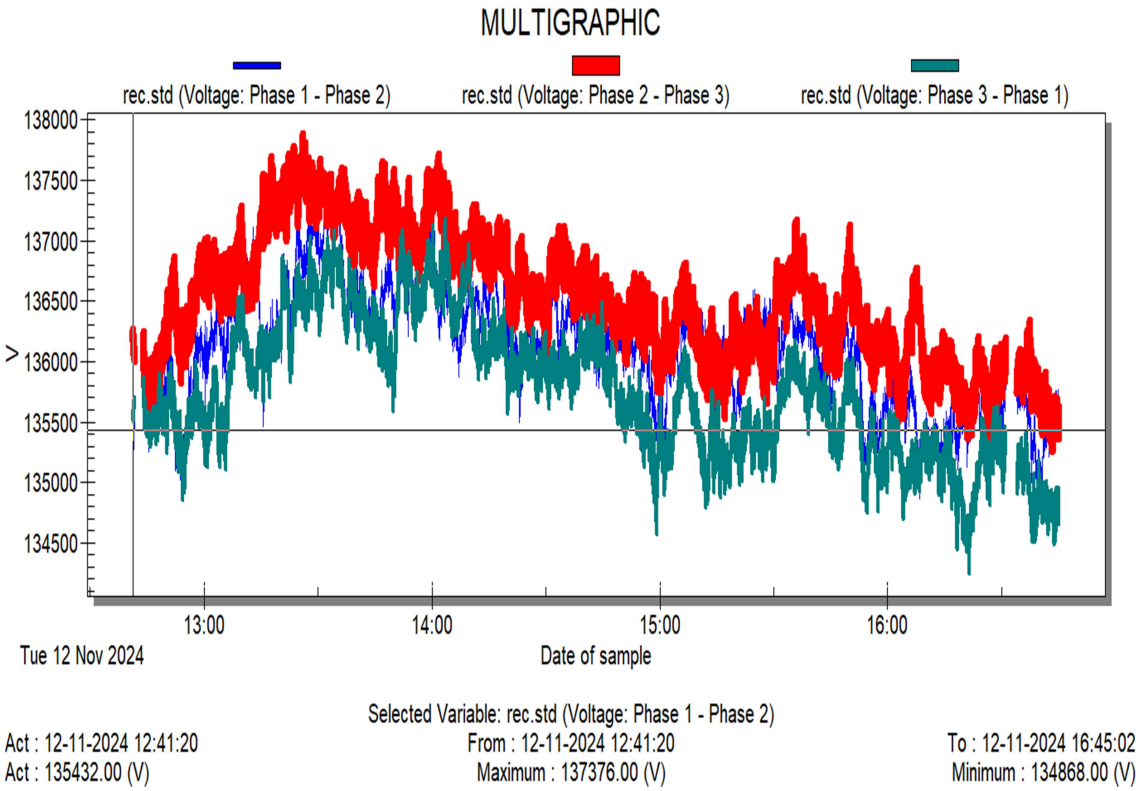

Figure 7-26 Voltage response

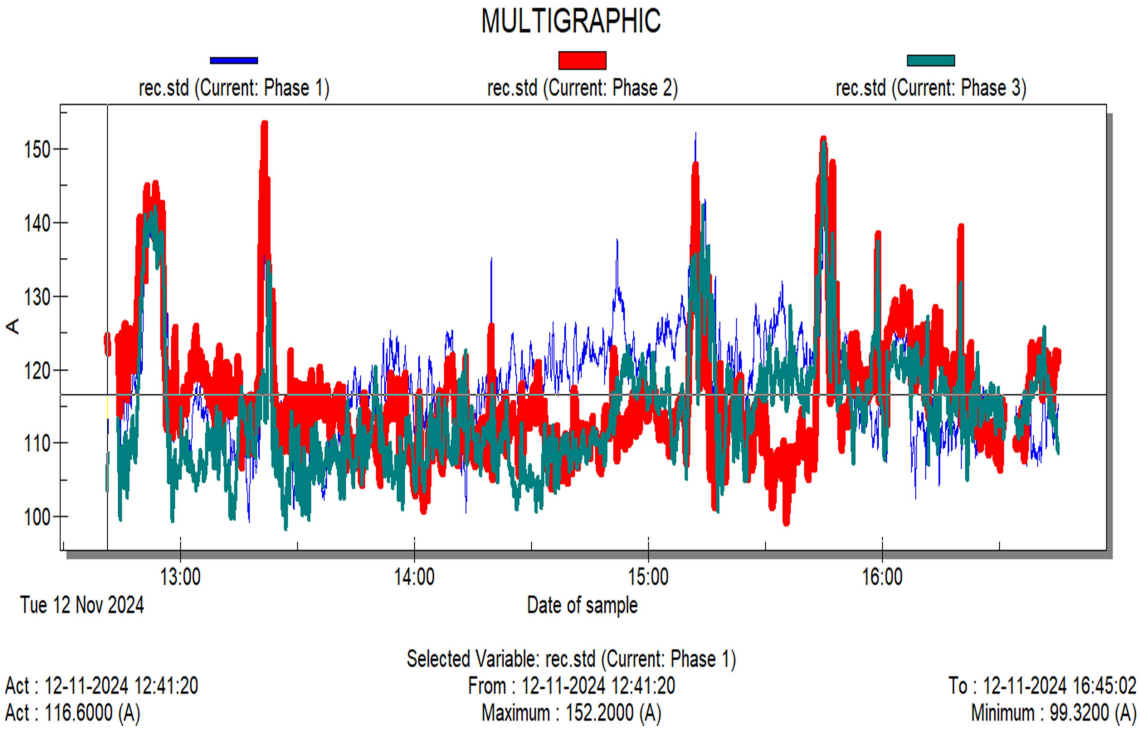

Figure 7-27 Current in Ampere

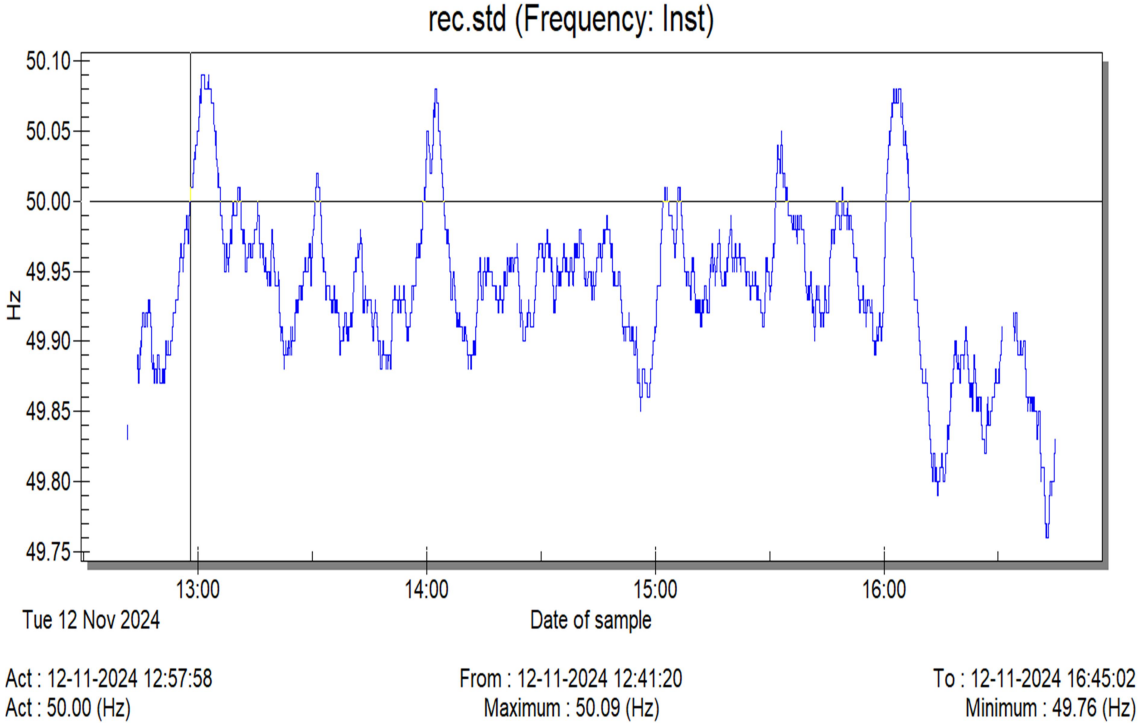

Figure 7-28 Frequency response in Hz

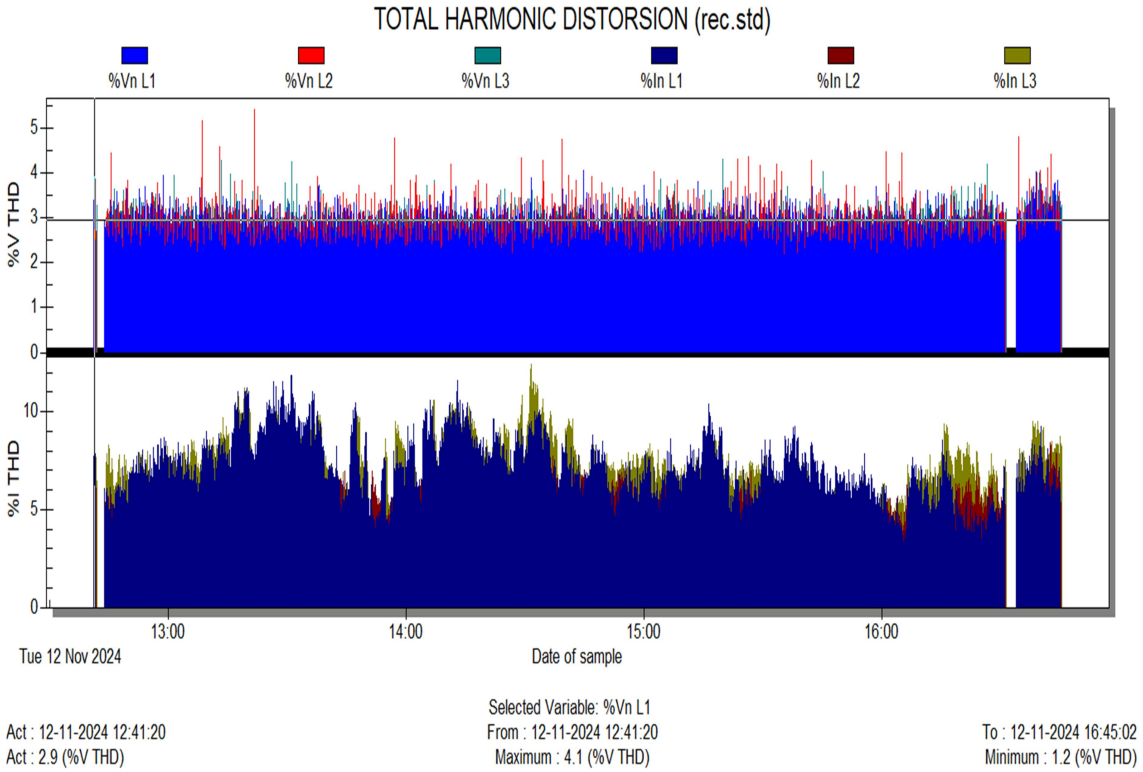

Figure 7-29 Total Harmonic distortion in percentage

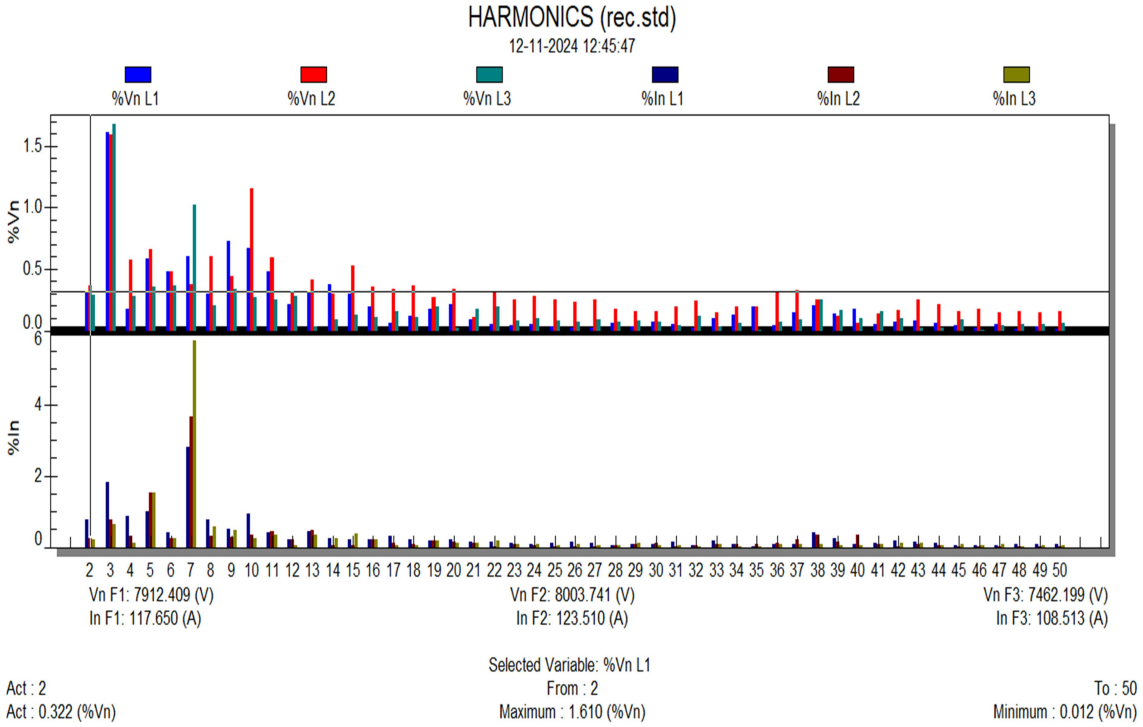

Figure 7-30 Harmonic components (upto 50th order of fundamental) at a sample time

7.7. Tata Steel Bhusan 220kV feeder from Meramunduli 400/220/132kV GSS

The harmonic measurement for the Tata Steel Bhusan 220 kV outgoing feeder is taken at Meramundululi 400/220/132 kV Sub-station. The voltage, current, and frequency variation corresponding to the time recorded from Meramundululi 400/220/132 kV Sub-station are presented in Figure 7-26 to Figure 7-28. The harmonic measurement at this point is recorded for a period of 4 hours with a sampling time of 1 second.

The total harmonic distortion and the harmonic order are presented in Figure 7-34 and Figure 7-35, respectively. The voltage THD varies within 1.8%, while the current THD varies in the range of 8-10%. The voltage and current THD are slightly above the acceptable limits.

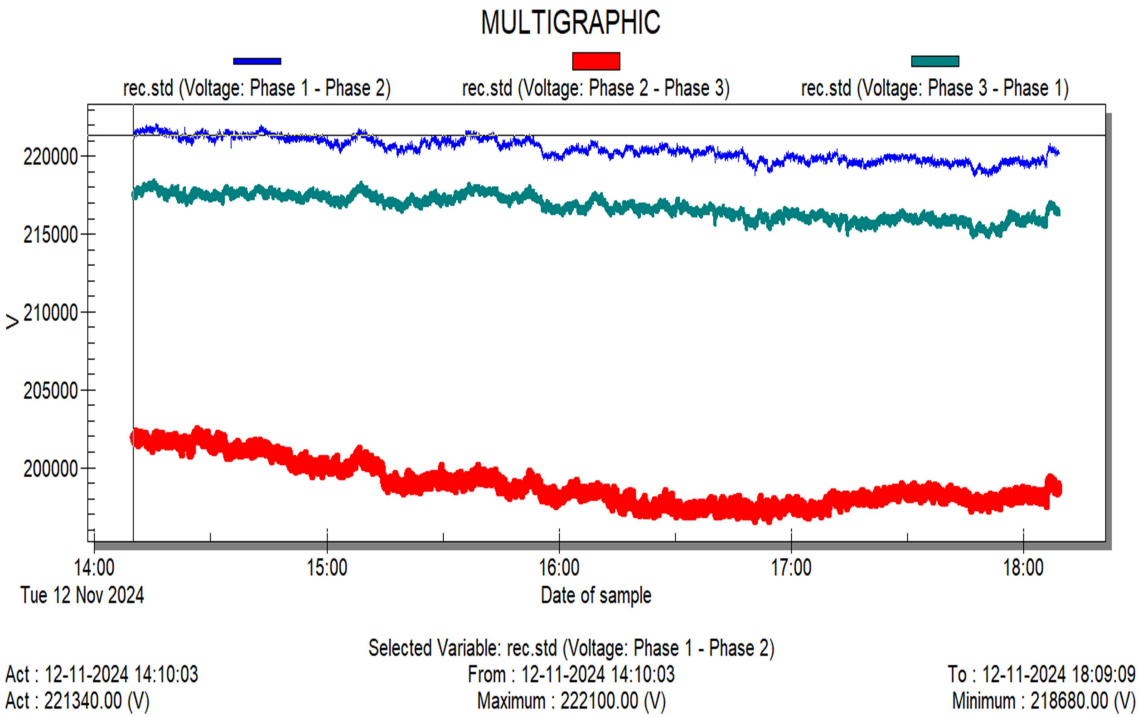

Figure 7-31 Voltage response

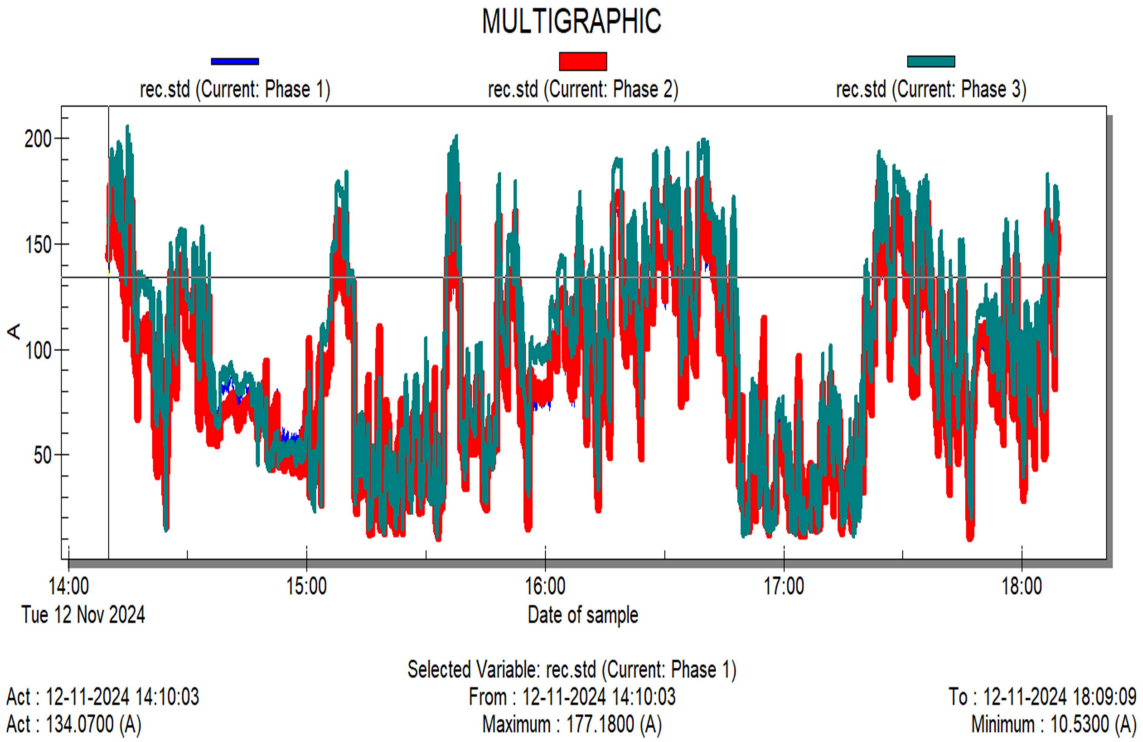

Figure 7-32 Current in Ampere

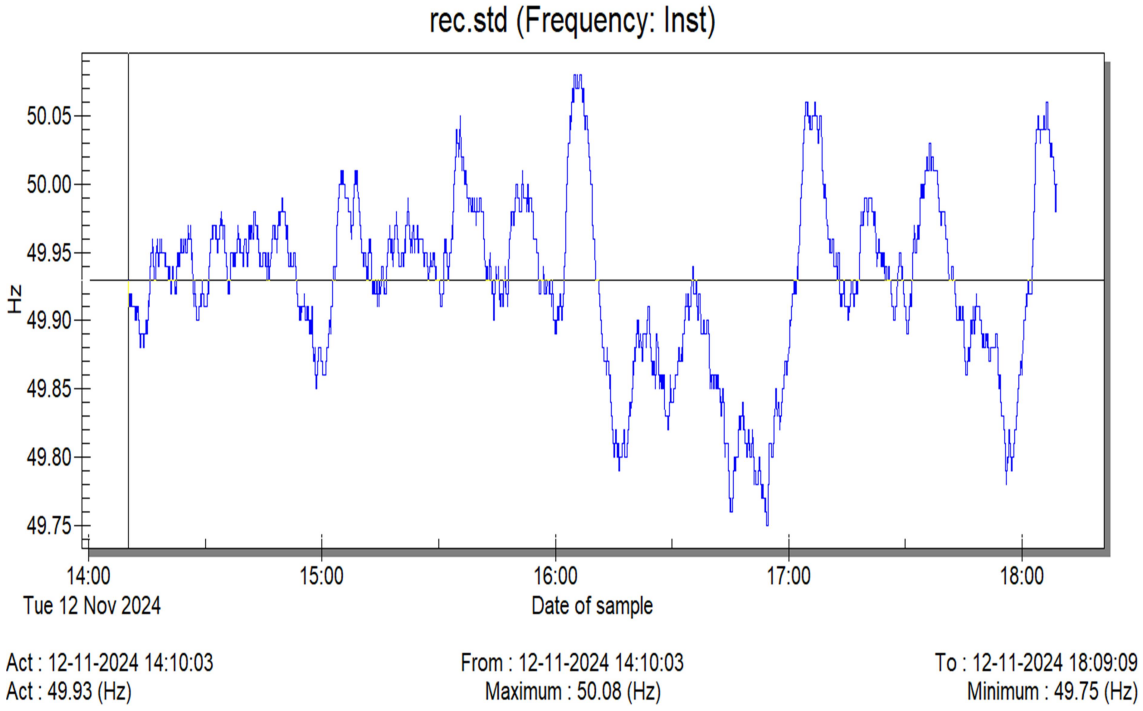

Figure 7-33 Frequency response in Hz

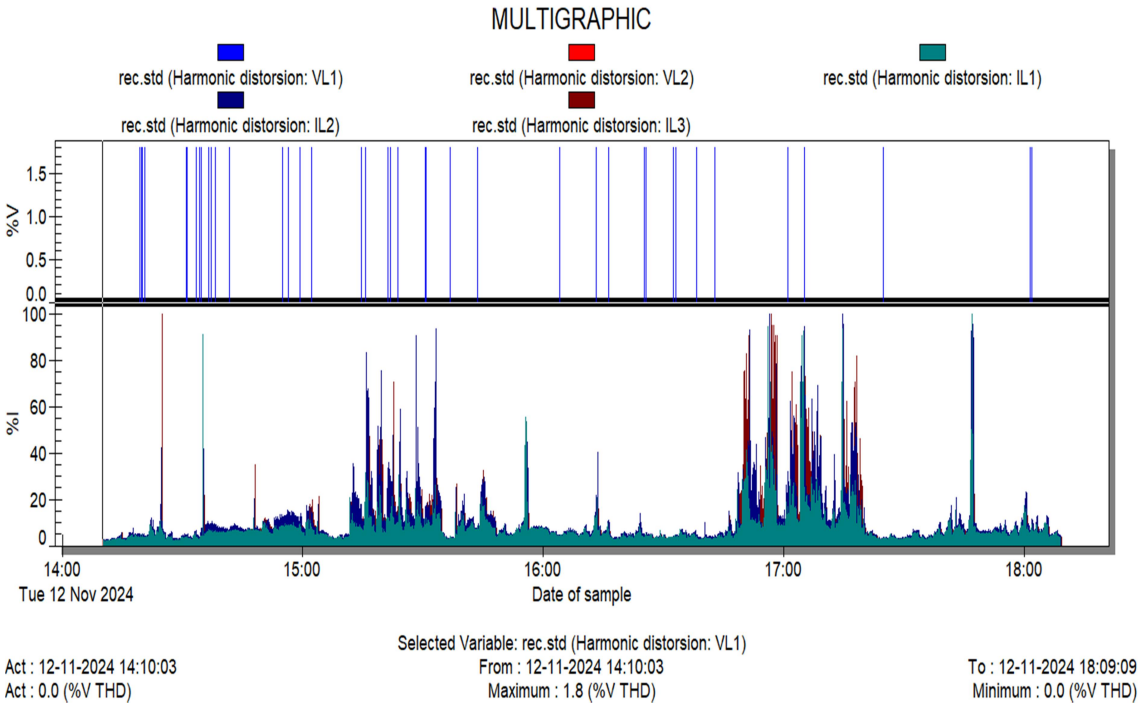

Figure 7-34 Total Harmonic distortion in percentage

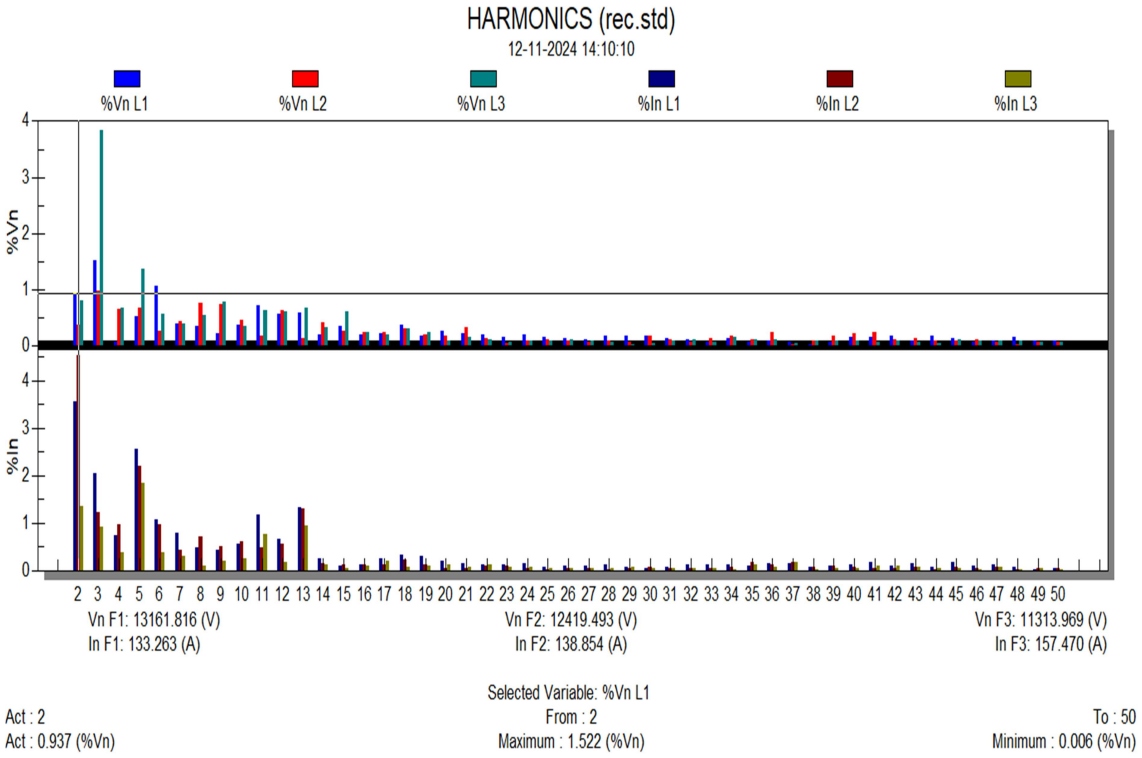

Figure 7-35 Harmonic components (upto 50th order of fundamental) at a sample time

7.8. Utkala Alumina 220kV feeder from Laxmipur GSS

The harmonic measurement for the Utkala Alumina 220 kV outgoing feeder is taken at Laxmipur 220/132 kV Sub-station. The voltage, current, and frequency variation corresponding to the time recorded from Laxmipur 220/132 kV Sub-station are presented in Figure 7-36 to Figure 7-38. The harmonic measurement at this point is recorded for a period of 12 hours with a sampling time of 10 second.

The total harmonic distortion and the harmonic order are presented in Figure 7-39 and Figure 7-40, respectively. The voltage THD varies within 1.5%, while the current THD varies in the range of 3-4%. The voltage and current THD are slightly above the acceptable limits.

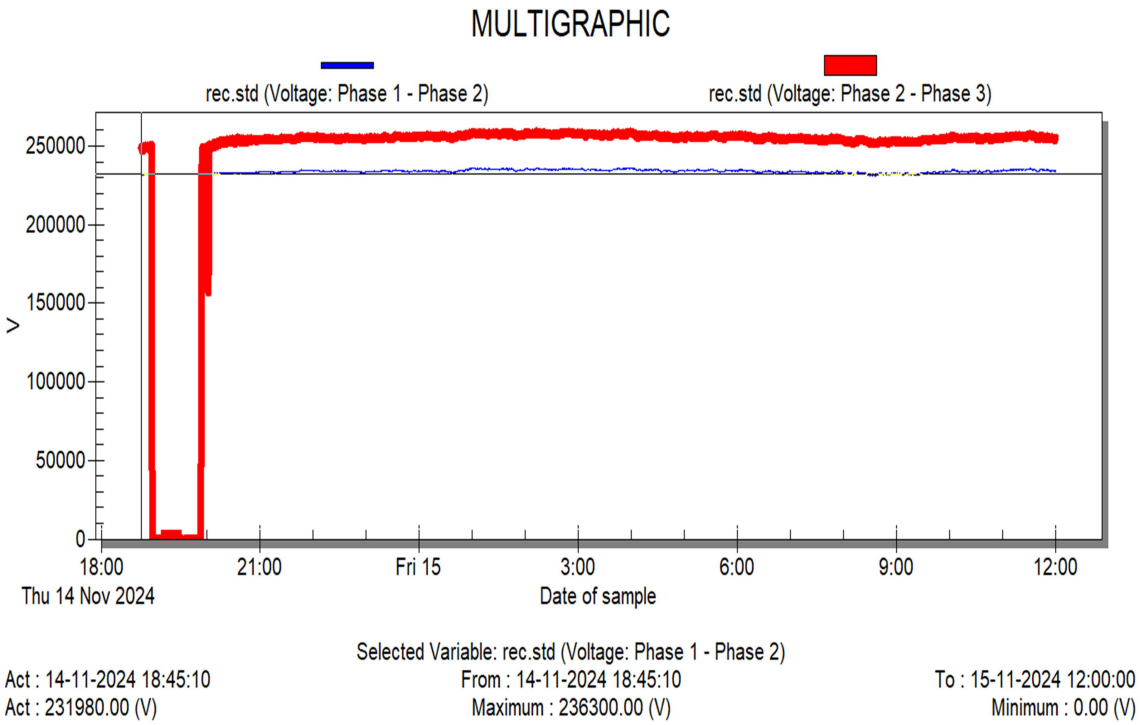

Figure 7-36 Voltage response

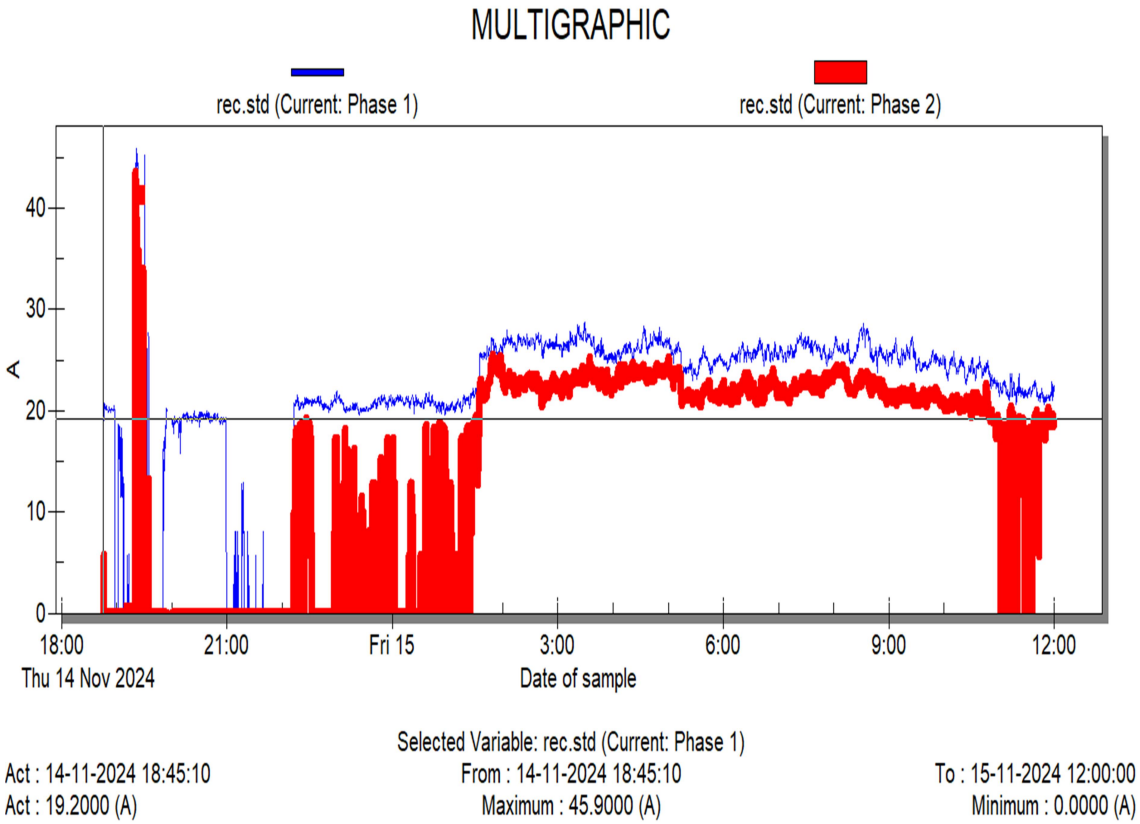

Figure 7-37 Current in Ampere

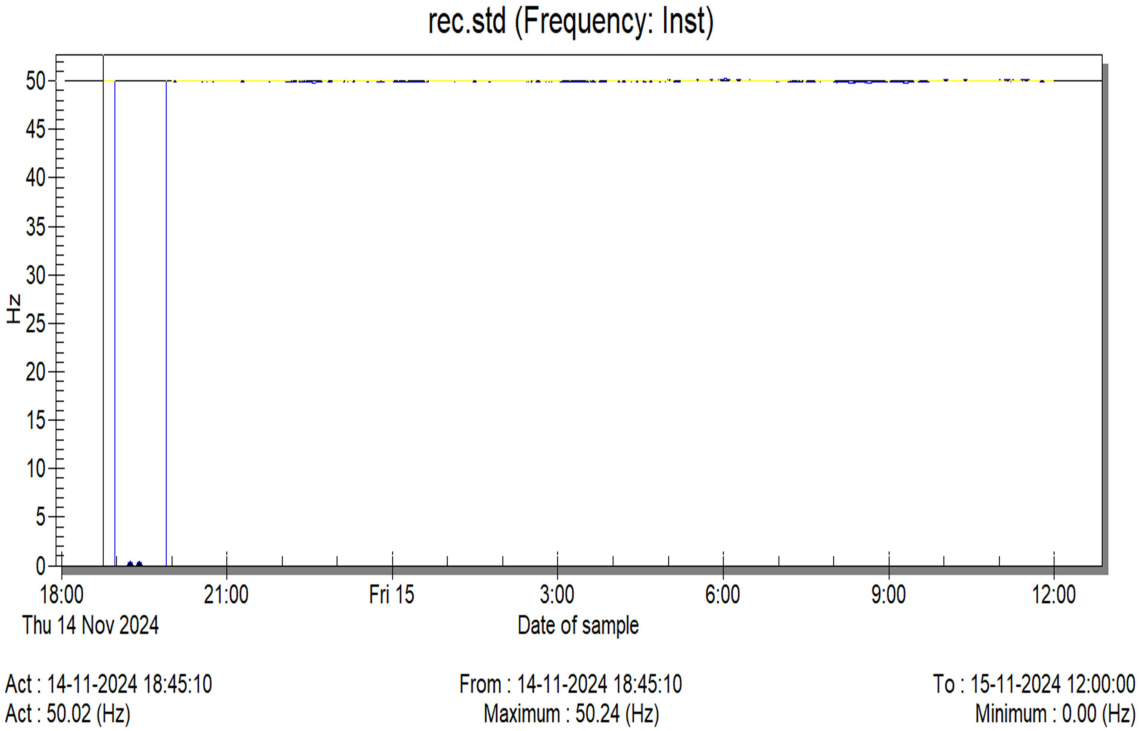

Figure 7-38 Frequency response in Hz

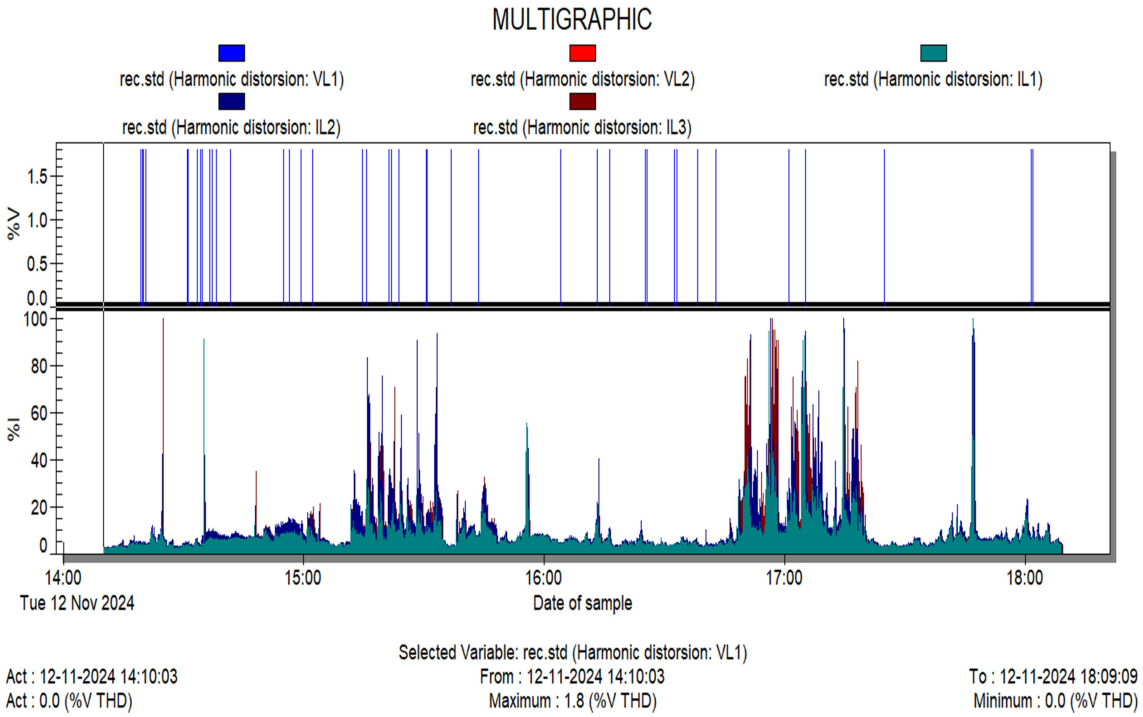

Figure 7-39 Total Harmonic distortion in percentage

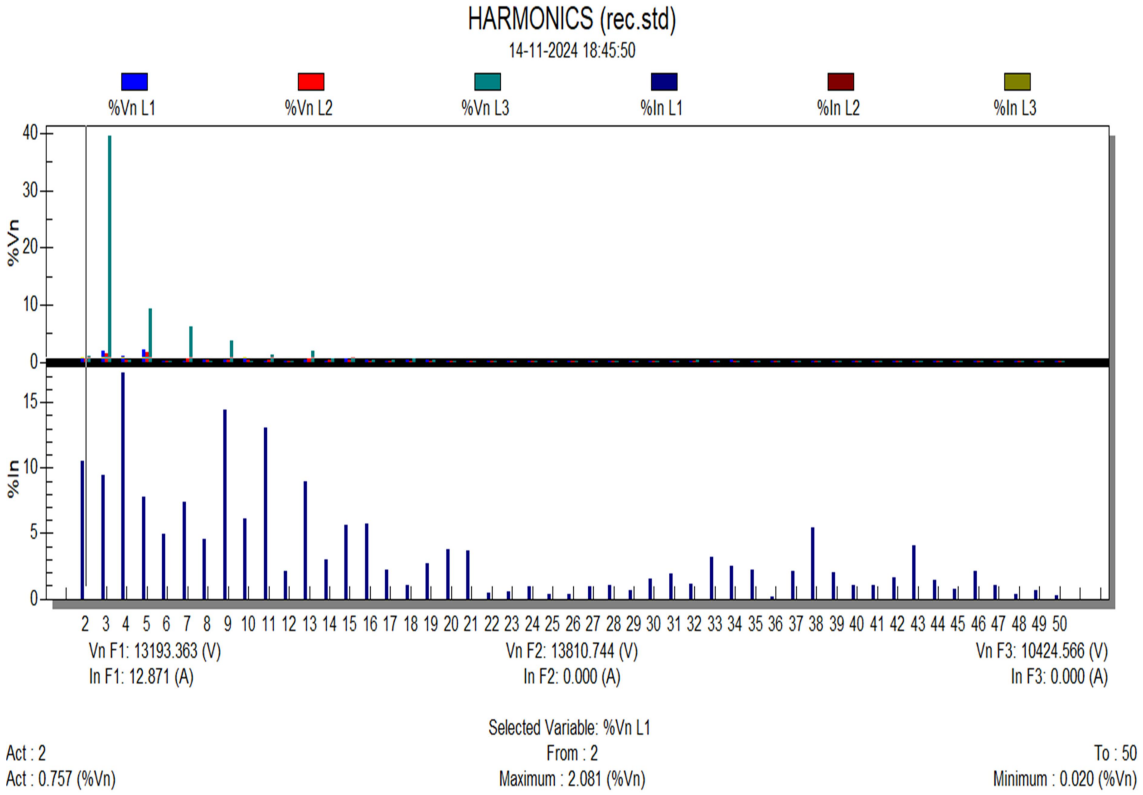

Figure 7-40 Harmonic components (upto 50th order of fundamental) at a sample time

The THD values for voltage and current are measured from the grid side are withing limit. The actual release of harmonics from Captive power plant could be higher which can be explored by taking adequate measurements on the CGP side.

7.9. Arcelor Mittal 220kV feeder from Paradeep GSS

The harmonic measurement for the Arcelor Mittal 220 kV outgoing feeder is taken at Paradeep 220/132 kV Sub-station. The voltage, current, and frequency variation corresponding to the time recorded from Paradeep 220/132 kV Sub-station are presented in Figure 7-41 to Figure 7-43. The harmonic measurement at this point is recorded for a period of 4 hours with a sampling time of 1 second.

The total harmonic distortion and the harmonic order are presented in Figure 7-44 and Figure 7-45, respectively. The voltage THD varies within 1.9%, while the current THD varies in the range of 11-15%. The voltage and current THD are slightly above the acceptable limits.

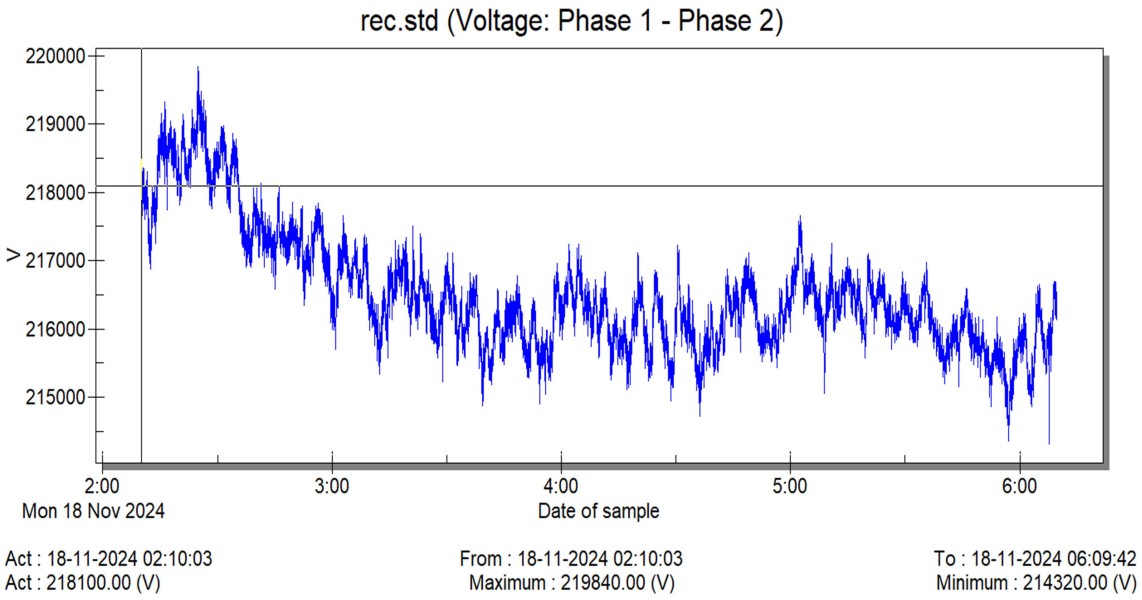

Figure 7-41 Voltage response

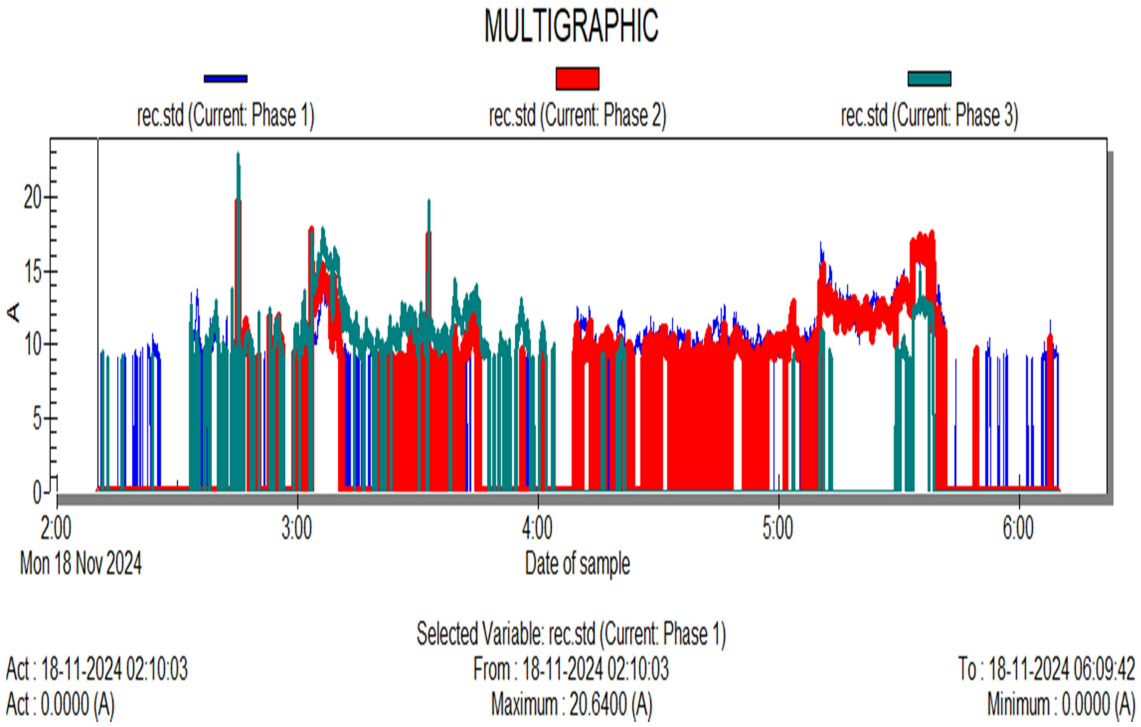

Figure 7-42 Current in Ampere

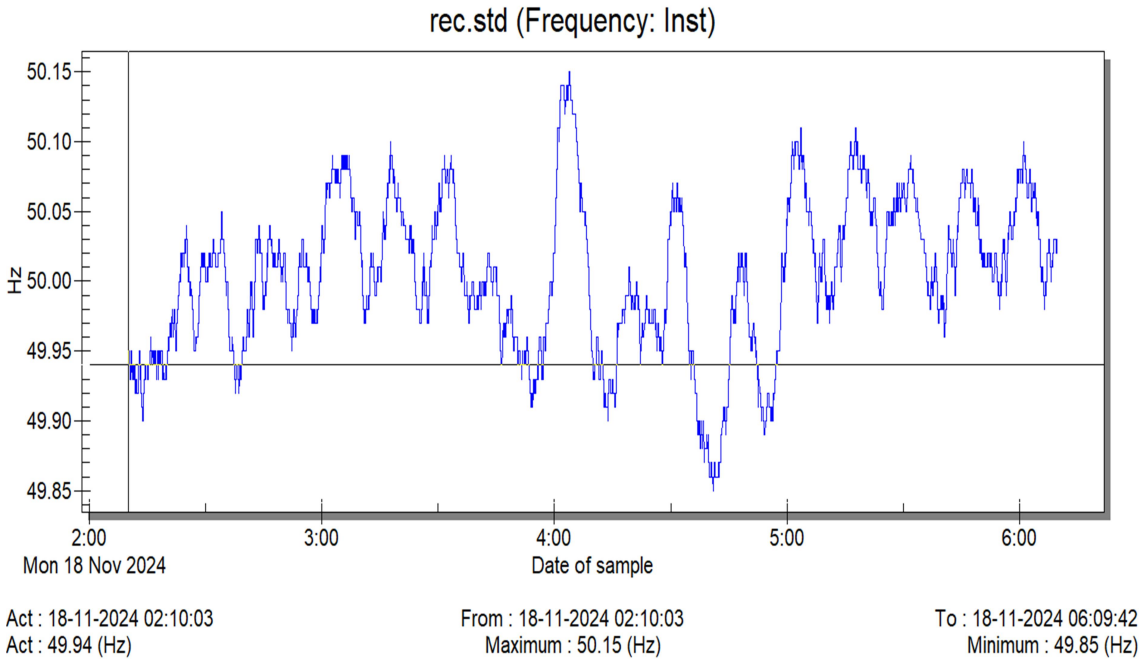

Figure 7-43 Frequency response in Hz

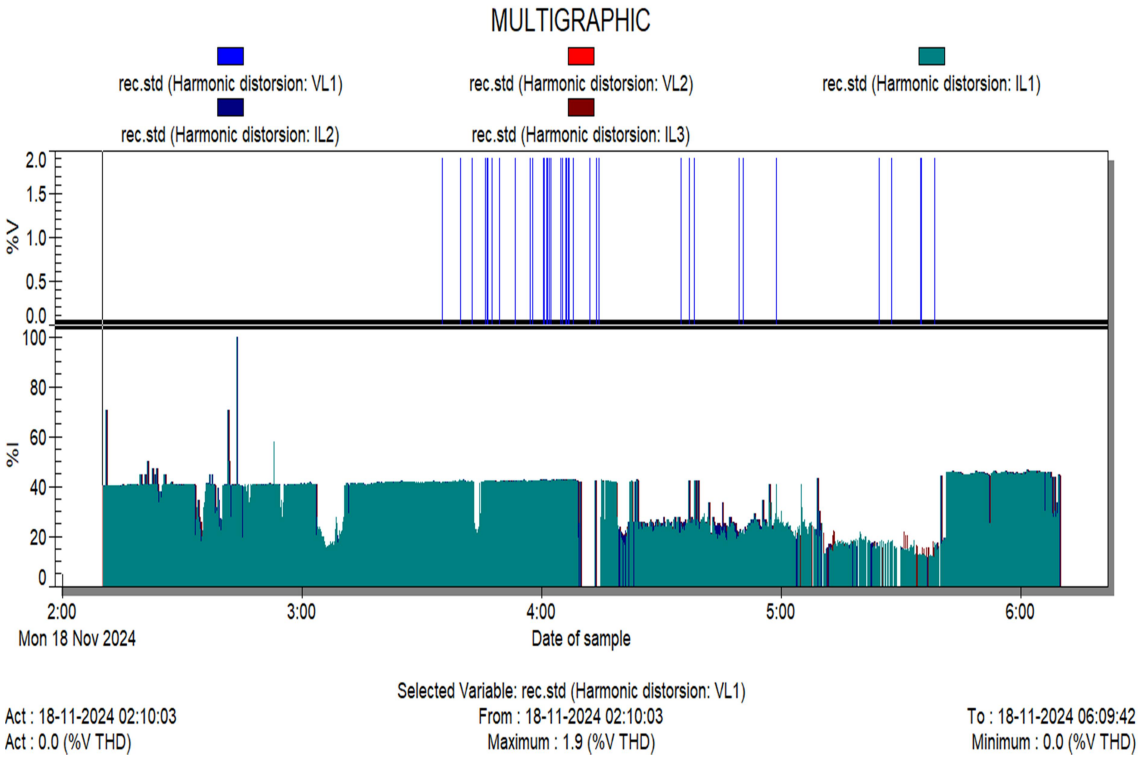

Figure 7-44 Total Harmonic distortion in percentage

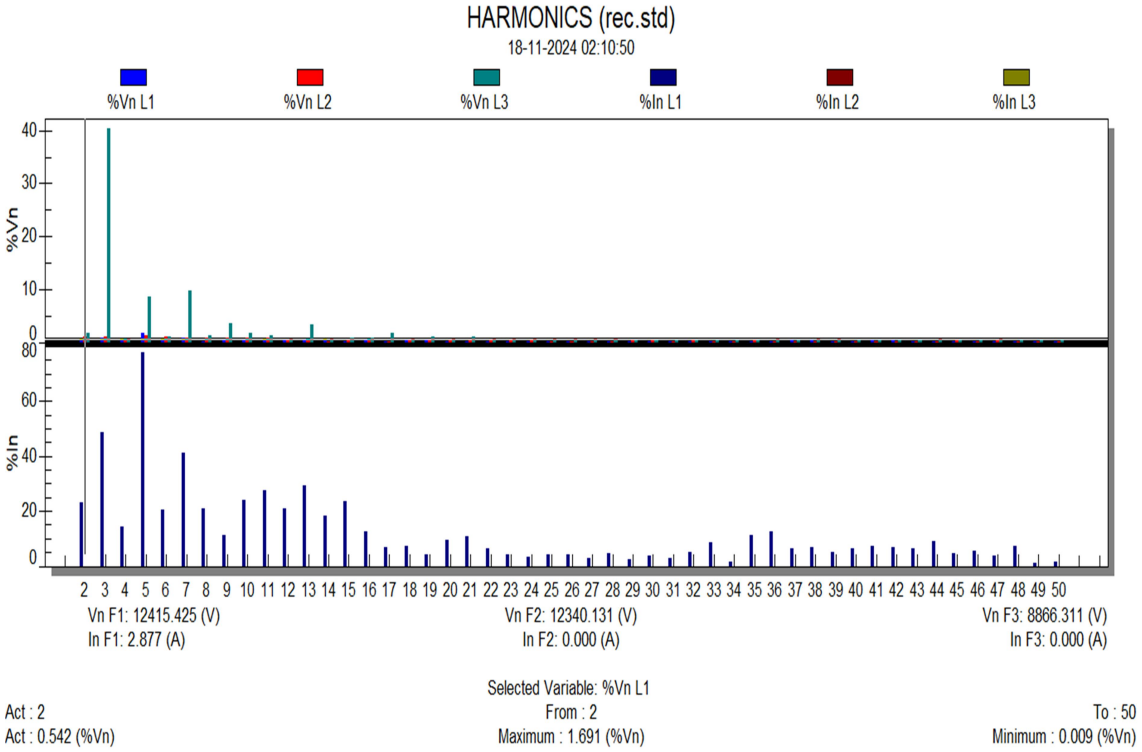

Figure 7-45 Harmonic components (upto 50th order of fundamental) at a sample time

7.10. Summary of Harmonic measurement results

The summary of results associated to Harmonic measurement in different CGP feeders are presented in the following table. The limits for the THD value or individual harmonic order are also mentioned in the table.

Table 7-5 Summary of Harmonic measurement results

Parameter	Voltage		Current harmonic order for Isc/IL > 1000				
	THD (maximum value is considered for the duration where accurate reading was taken)	Individual harmonics	Harmonic order below 11	Harmonic order 11 to 17	Harmonic order 17 to 23	Harmonic order 23 to 35	Harmonic order 35 to 50
Limits	**1.5**	**1**	**7.5**	**3.5**	**3**	**1.25**	**0.7**
JSW Budhipadar	1.7	1.3	15.1	2.1	1.0	0.7	0.7
Jindal Duburi	2.1	0.6	11.2	3.5	2.6	3.3	1.2
Utkala Alumina Laxmipur	1.5	2.3	3.6	2.3	1.3	1.1	1.0
NINL Duburi	1.25	0.5	2.9	1.1	1.1	1.1	0.3
Paradeep Duburi	1.9	1.6	11.3	2.0	1.1	0.8	0.8
Sterlite Vedanta	1.8	1.6	0.8	0.3	0.2	0.1	0.1

Parameter	Voltage		Current harmonic order for Isc/IL > 1000				
	THD (maximum value is considered for the duration where accurate reading was taken)	**Individual harmonics**	**Harmonic order below 11**	**Harmonic order 11 to 17**	**Harmonic order 17 to 23**	**Harmonic order 23 to 35**	**Harmonic order 35 to 50**
Lapanga							
TATA Steel Meramundulli	1.8	1.5	8.4	1.8	0.4	0.3	0.3
Limits	**2.5**	**1.5**	**7.5**	**3.5**	**3**	**1.25**	**0.7**
BPPL Chandaka	2.6	1.6	6.2	0.8	0.4	0.2	0.2
NBVL, Kharagrasad	1.8	1.4	6.1	0.5	0.3	0.1	0.1
IMFA, Choudwar	1.9	0.8	3.9	0.7	0.7	0.7	0.2

8. CASE NO-52 OF 2020

8.1.Case Summary

OPTCL had filed an application before commission on 23/09/2020 registered as Case No 52 /2020 for determination and approval for levy of Grid Support Charges (GSC) for industries having CGPs and running in parallel with OPTCL Grids. M/s. Vedanta Limited and Others filed a batch of Writ Petitions in W. P. (C) No.2220 of 2021, W. P. (C) No.16513 of 2021 &

W. P. (C) No.38361 of 2021 before the Hon'ble High Court of Orissa challenging the order dated 17.11.2020 and the other orders passed by this Commission on the ground of res judicata.

Hon'ble High Court of Orissa ordered on 06/07/2023 in the following language:

"As the cumulative effect of all these observations as made above, we set aside the proceeding being the OERC Case No.52 of 2020 by declaring that the orders passed in that proceeding as ultra vires, void ab initio an without any effect whatsoever on the charge. It is our duty to observe that if the Opposite Party No-2 filed a separate application urging the Opposite Party No-1 for examining whether the levy of GSC/POC is justifiable and if found justifiable, to frame the appropriate regulation in exercise of the powers conferred upon the Opposite Party No-1 in that event, the Opposite Party No-1 shall examine the matter, not initiating a proceeding, but by invoking its powers as provided under section 181 of the Electricity Act."

Inference: Petitioner OPTCL needs to file a separate application urging the commission for examining whether the levy of GSC/POC is justifiable and if found justifiable, to frame the appropriate regulation in exercise of the powers conferred upon the Commission, that Commission shall do so not by initiating a proceeding but by invoking it's powers under section 181 of the electricity act, 2003.

In view of the above, OERC has asked petitioner- OPTCL (Case no 44/2024 dated 9/7/2024):

a) To furnish a consolidated study report that includes an analysis of impact of Inertia, Harmonics, Reactive Power, Power factor at PCC & Generator output terminals both in isolated and grid connection mode.
b) To clarify that levying GSC/POC will not contradict the existing provisions of Charges/Payment under Odisha Grid Code Regulations, 2015 particularly regulation 1.7.
c) To study / identify if harmonics and other grid pollutants are attributable to industries without CGP.
d) To justify the GSC/POC methodology for different Capacity, Contract Demand, Power exports to Grid.
e) To apportion GSC/POC between DISSCOM & OPTCL, since it's an integrated network.
f) To give views on GSC/POC of RE based CGP, of CGP becoming IPP.
g) To study impact GSC on Transmission Tariff & Retail Tariff
h) To suggest a methodology for recovery of GSC in case of default.(Section 56 of EA 2003)

8.2. PRDC's Views on the Case

PRDC's views of CASE 52/2020 and similar cases/petition filed before and after by OPTCL to justify GSC/POC are given as follows:

5.2(a) Petitioner –M/s. OPTCL had filed similar petition before this Commission in Case No. 46 of 2012. Respondent Industries challenged the validity of the proceeding on the ground that there was no provision to impose and recover the Grid Support Charges under the frame work of the Electricity Act, 2003 and the Rules & Regulations made thereunder. By the order dated 31.03.2014 in Case No. 46 of 2012, this Commission had rejected the petition filed by the Petitioner-M/s. OPTCL.

PRDC's view:

The following sections of EA 2003 [17] may justify the above petition filed by OPTCL and defy the objections raised by the respondents. Although, GSC may not have a direct mention, the Act framework does support such a charge.

Section 36 of EA. (Charges for intervening transmission facilities): --- (1) Every licensee shall, on an order made under section 35, provide his intervening transmission facilities at rates, charges and terms and conditions as may be mutually agreed upon: Provided that the Appropriate Commission may specify rates, charges and terms and conditions if these cannot be mutually agreed upon by the licensees.

Section 40 of EA (Duties of transmission licensees): It shall be the duty of a transmission licensee - to build, maintain and operate an efficient, coordinated and economical inter-State transmission system or intra-State transmission system.

Section 41 of EA. (Other business of transmission licensee): A transmission licensee may, with prior intimation to the Appropriate Commission, engage in any business for optimum utilization of its assets.

Section 62. (Determination of tariff): --- (1) The Appropriate Commission shall determine the tariff in accordance with the provisions of this Act for: (5) The Commission may require a licensee or a generating company to comply with such procedures as may be specified for calculating the expected revenues from the tariff and charges which he or it is permitted to recover.

Section 178 of EA. (Powers of Central Commission to make regulations): The Central Commission may, by notification make regulations consistent with this Act and the rules generally to carry out the provisions of this Act in the matter of :

(i) Rates, charges and terms and conditions in respect of intervening transmission facilities under proviso to section 36.

(n) Proportion of revenues from other business to be utilized for reducing the transmission and wheeling charges under proviso to section 41

(u) The procedures for calculating the expected revenue from tariff and charges under sub-section (5) of section 62

Section 181. (Powers of State Commissions to make regulations): (1) The State Commissions may, by notification, make regulations consistent with this Act and the rules generally to carry out the provisions of this Act

(zf) the methodologies and procedures for calculating the expected revenue from tariff and charges under sub-section (5) of section 62

5.2(b) *Installed capacity of the CGPs in the State as submitted by OPTCL is 5173 MW which is more than or equal to the capacity of other generators connected to Odisha Grid including Odisha share of power from Central Generation Stations. Holding industry having CGPs only responsible for grid pollutants like harmonics is not correct.*

PRDC's view

Based on the nature of the load, any industry connected to the transmission system can inject grid pollutants like harmonics if not mitigated locally .CGPs also need to follow the grid discipline to maintain grid health, non-compliance of which will be penalized as per regulation.

5.2 (c) There are ample provisions in the Odisha Grid Code to regulate the behaviour of entities connected to the OPTCL system. Hence, a generic method of calculation of Grid Support Charges for all industries may not be proper. The Petitioner has failed to submit a State-wide study before us basing on which a decision could have been taken. One solution fits all can't be applicable here.

PRDC's view

Based on the following section of EA 2003 ,

Section 62 subsection 3 of EA: The Appropriate Commission shall not, while determining the tariff under this Act, show undue preference to any consumer of electricity but may differentiate according to the consumer's load factor, power factor, voltage, total consumption of electricity during any specified period or the time at which the supply is required or the geographical position of any area, the nature of supply and the purpose for which the supply is required.

it is suggested the POC/GSC be calculated based on factors mentioned above.

5.2 (d) There are enough provisions in Odisha Grid Code, 2006 to maintain qualitative supply in the grid system. Regulation 4.7 of Odisha Grid Code discuss elaborately the ideal behaviour of constituent of the Grid. OPTCL should play the role of watchdog and analyse the pollutant injected by various constituents of the grid system. The non-compliance by any industry or industry having CGP of the Grid Code should be dealt as per Regulation 1.18 of OGC, 2006.

PRDC's view

All non-compliances need to be recorded and dealt accordingly.

5.2(e) *"As the cumulative effect of all these observations as made above, we set aside the proceeding being the OERC Case No.52 of 2020 by declaring that the orders passed in that proceeding as ultra vires, void ab initio an without any effect whatsoever on the charge. It is our duty to observe that if the Opposite Party No-2 filed a separate application urging the Opposite Party No-1 for examining whether the levy of GSC/POC is justifiable and if found justifiable, to frame the appropriate regulation in exercise of the powers conferred upon the Opposite Party No-1 in that event, the Opposite Party No-1 shall examine the matter, not initiating a proceeding, but by invoking its powers as provided under section 181 of the Electricity Act."*

PRDC's view

Justification for the levying GSC/POC can be found in the chapters of this report .The chapters gives details of nature of load of CGP industries, nature of their electricity consumption, transient behavior of industries associated with CGPs, reliability support given by grid to the CGPs because of connectivity, CGPs contributing to grid stability, transmission system availability and charges or payments approved by the commission.

The reply to the comments received by the honorable commission in Para 10 vide Case No 44/2024 are included in Annexure 6 of the report.

9. GRID SUPPORT CHARGES

9.1. Survey of GSC/POC in different states

Grid support charges have been proposed over years by various STU's/Discoms & petitions have been filed to corresponding regulatory commissions by industries & utilities. The following paragraphs will mention about Grid Support charges or Parallel Operation Charges surveyed in proposals, petitions and orders to or by the commission.

9.2. Andhra Pradesh Electricity Regulatory Commission (APERC)

The DISCOMs have proposed to collect grid support charges as described below [18]:

"Persons operating Captive Power Plants (CPPs)/Co-Generation Plants in parallel with A.P. Grid have to pay 'Grid Support Charges' on the difference between the capacity of CPP/Co-Generation Plant in kVA and the contracted Maximum Demand in kVA with Licensee and all other sources of supply, at a rate equal to 50% of the prevailing demand charge for HT

Consumers. In case of CPPs/Co-Generation Plants exporting firm power to APTransco, the capacity, which is dedicated to such export, will also be additionally subtracted from the CPP/Co-Generation Plant capacity."

"The DISCOMs utilize the transmission network owned by State Transmission Utility/Transmission Licensee (APTransco), for power evacuation/flow from generating stations to the distribution network for which they need to pay the transmission charges at the rates/charges determined by the Commission in the Transmission Tariff Orders."

Based on the total generation capacity connected to AP state grid as of 31.12.2021 and R&M charges of APTransco and the DISCOMs, the Commission has determined the Grid support charges/parallel operation charges as shown below:

Table 9-1 Grid support charges/parallel operation charges

FY2022-23		Yearly charges	Monthly charges
Total installed capacity (MW)	16854		
DISCOM's R&M (Cr.)	830	492.46	41.04
Transco R&M (Cr.)	224.39	133.14	11.09
Total monthly charges Rs. per kW per month			52.13

As can be seen from the above table, the Commission has computed charges @Rs.52.13 per kW per month.

9.3.Gujarat Electricity Regulatory Commission (GERC)

The Commission decided the petition No.256/2003 and No.867/2006 to the effect that the parallel operation charges is leviable on the captive generating plants, which are operating the CGP in parallel with the grid. The Commission order dated 1.6.2011 passed in Petition No.256/2003 and No. 867/2006 and decided levy of POC at the rate of 26.50 per KVA per month. The Commission order dated 25th June 2004 has stated/quoted the following [19]:

"We have already examined above the nature of parallel operation charges. These charges should not be confused with the demand charges as has been done in many submissions of CPPs. Demand charges are charged for the demand of electricity supply contracted and can also be charged from those CPPs who have not opted for parallel operation. Therefore, those

wanting to operate parallels must be necessarily distinguished from those who have not opted for the same. As mentioned earlier, CPPs opt for parallel operation to seek safety, security and comfort of a larger Gujarat Electricity Board (GEB) system and the system has to make investment to provide on a portion of infrastructure of generation, transmission and distribution created by the GEB. The Commission is of the view that for such a claim the GEB is well within its rights to charge parallel operation charges."

"The Commission would like to observe that the open access right given to CPPs (subject to availabilities of spare capacities in the transmission and distribution systems), which is subject to payment of wheeling charges, would not automatically exclude POC. In respect of open access, CPPs are given better terms than other consumers who besides wheeling charges will have to pay for surcharge and additional surcharge. As we saw, surcharge covers the component of cross-subsidy existing in the current tariff structure. The additional surcharge applicable (to consumers in distribution open access) is designed to meet the fixed cost of such distribution licensee arising out of his obligation to supply."

"The Commission is of the view that POC have to be seen in the context of grid connectivity in a wider sense than merely in terms of wheeling of power."

" It is a source of stand-by power available 'on-tap' to meet the contingencies that may arise in industrial units operating CPPs."

"The levy of the parallel operation charges is not inconsistent with any of the provisions of the Central Act. "

"Parallel Operation Charge or Grid Support Charge is an expenditure incurred by the Board on account of CPPs synchronized with the grid. The classification of such costs –- either as fixed or variable or under appropriate tariff categories or other income -- is really an accounting issue. "

The possible nature of the grid support to CPPs and the likely attributable cost on the following lines:

i. Annual Recurring Cost (both fixed and variable) of the grid network. (Under recovery reasonably attributable to CPPs).
ii. Cost of No-Load Losses being incurred for keeping the grid energized (portion reasonably attributable to these customers.)
iii. Cost of keeping sufficient spinning reserve in the grid or drawing this power from the regional grid to meet sudden load requirement of the CPPs exceeding their contract demand. Alternatively, such excess demand has to be met through under frequency relay operation or load shedding.

iv. Cost attributable to the transient surges from CPPs.

9.4. Madhya Pradesh Electricity Regulatory Commission (MPREC)

Madhya Pradesh Power Transmission Co Limited (MPPTCL), herein filed a petition, filed petition no. 50 / 2010, for determination of parallel operation charges (POC) on intra-state power generating plants in the state of Madhya Pradesh. The commission's order, dated 31.12.2012, decided the Parallel Operation Charges (POC) be levied on all the Captive Power Plants (CPPs) in Madhya Pradesh connected to the utility grid. The technical considerations to levy charges were as under [20]:

(i) Absorption of harmonics and negative phase sequence current

(ii) Improvement in power factor

(iii) Meeting fluctuations

(iv) Providing reactive power support

(v) The electrical pollutant has been the major consideration for imposing parallel operation charges. The injection of such pollutant is feasible provided the CPP and bulk load have common point of interconnection.

(vi) that the basic condition for levy of Parallel Operation Charges is that the Captive Power Plant as well as the consuming units as co-located in the same place and the person derives grid support for constant running of his co-located facilities to protect from sudden variations in generation from the captive power plant.

(vii) The methodology for computation of parallel operation charges suggested by the ERDA (consultant) which is the Base MVA Method where,
Base MVA = Installed Capacity – Contract Demand – Power Export to Grid.

As per order in Suo Motu Petition 73/2012 passed by this Commission (MPERC) vide order dated 31.12.2012 wherein Commission determined Parallel operation charges to be levied at Rs. 20/- per KVA per month on the capacity of CPP (after deducting load pertaining to auxiliary consumption) connected to the Grid.

9.5. Chhattisgarh State Electricity Regulatory commission (CSERC)

On 06.02.2006, an order was passed in petition No. 17 of 2005 wherein the Commission reviewed the rate of POC fixed by the Commission. The following justification for levying POC was given [21]:

"7.4 ---------- The Board has given the following reasoning in justification of parallel operation charges:

1) Synchronization with the grid maintains the continuity of supply, even in cases one of the systems fails in a two/multiple supply system. In a continuous process industry uninterrupted power supply is a critical requirement.

2) By parallel operation a CPP is benefited by way of improvement in plant load factor. A consumer will generally install a CPP which would generate the required base power while he meets the fluctuating demand of the load through the supply system of the licensee. This is generally the case with electric arc furnace, rolling mills and similar industries. Thus by paralleling captive power plant with supply system the consumer is not required to make investment for his maximum load. Secondly, PLF is higher if a CPP is synchronized with grid as compared to the CPP running in an isolated mode. By paralleling the captive generation with the supply system the CPP-holder is able to make optimum use of his generator.

3) By paralleling the supply system the CPP-holder is able to divert the reactive power requirement on the supply system and use the captive power generators for generation of active power. Hence the generator efficiency in such cases is generally very high; i.e. of the order of 100% of even more.

4) By paralleling with the supply system, the capacity to sustain the fault level of the CPP is enhanced which helps in controlling the voltage dips due to arcing and drawal of heavy instantaneous load which is generally encountered in electric arc furnace operation. While the support which the consumer gets from the supply system is very vital for its load, the supply system hardly gets anything because the duration of such instantaneous load is very short and is not reflected in the energy consumption or in the load recorded by the meter.

5) Electric arc furnace, rolling mills, mini steel plants, induction furnace etc. generate lot of harmonics which are diverted / absorbed by the grid. This amounts to pollution by such industries in the supply system. Such pollution results in higher losses and may result in failure of certain equipment's. If the captive generators run in isolation, it will be virtually impossible to run their system because of such heavy pollution due to harmonics, voltage dips and due to negative phase sequence current and voltage. Generally, consumers do not install the required equipment for controlling such pollution in the supply system such as harmonic filters, static var compensator.

6) The direction of harmonic power flow is from load to supply system while fundamental power flows from the supply system to load. This effects the metering and meter may record less. ….."

Parallel Operation Charges shall be payable by CPP to CSPDCL for its captive and non-captive load at the rate of 13 paise /kWh according to Tariff Schedule FY23-24.

9.6.GSC/POC Calculation Methodology

Grid support charges to be levied upon must have a basis based on which a certain methodology needs to be formulated. The methodology to be adopted should ensure fair pricing in terms of grid support, return of revenue as well as customer's fair share of transacted benefits. Any pricing related to electrical power will be either beneficiary based or societal based. Beneficiary based pricing will depend upon the exact volume of benefits/services taken. Societal based pricing will be shared among all stake holders with constraint margins or weighed margins. Difficulty arises with measurement or knowledge of exact benefits, constraints, weights with dynamic load variation, intermittency in generation & diversified electricity consumer base. In the present study of grid support charges or parallel operation charges, an analytical and system study approach is adopted to justify the requirement of such pricing. Formulation of GSC can be done in the following ways:

i. Base MVA method (proposed in previous literature)
ii. Spinning reserve method (proposed in previous literature)
iii. Peak Instantaneous Demand based methods (proposed by PRDC)
iv. Specific Energy Consumption based method (proposed by PRDC)
v. An 'adaption' of reliability model from CERC's point of connection framework * (proposed by PRDC)

*Point of connection framework is proposed by Task Force to Review Framework of Point of Connection (2019), CERC

9.6.1. Base MVA method

OPTCL in it's earlier petition to OERC No.46/2012 has prayed to adopt Base MVA method for GSC levied upon CGPs. This method is based on the fault level support available at point of common coupling i.e. the point at which the CGP is connected with the grid. Basically the fault level has the significance of service provided by utility to CGPs in terms of voltage regulation, stability, reliability and absorbing the load variation / fluctuation, etc. OPTCL has calculated Grid Support Charges in line with the recommendation of ERDA, a power system consultant as delineated in the following steps.

Base MVA (A) = fault level support at PCC x Transient Reactance

Where, fault level support at PCC is equal to the difference between the fault level in MVA with grid interconnection and fault level contributed by CGP. This is the support available at PCC.CGP is supplying surplus power to the utility grid and for this export of power; CGPs are required to regulate their system. Hence, the power export to grid has been given due

weightage while arriving at GSC. The bulk consumers with CGPs pay demand charges on the contract demand. The contract demand has also been given due weightage.

MVA support required by CGP from grid is equal to the installed capacity (B) of the CGP. It may happen that support available at the point of common coupling is higher than what CGP needs. Hence OPTCL has considered the minimum of support available and support required by CGP(C).

C= (A) or (B), whichever is minimum

9.6.2. Spinning reserve method

The basis of this method is the need for creating a spinning reserve for the CPPs running in parallel to the grid for reliable operation of the industrial unit. Also on the concept of reserve requirement of the industrial consumers who run their captive units on constant power mode. Spinning reserve is the system's unused capacity which will respond voluntarily to contingencies within a given time frame. Though this method captures the major issue of reliability requirement of the CPP consumers yet it does not differentiate the MW & MVAR drawal from transient supports availed from the Grid. Quantifying the reliability support in context on the basis of spinning reserve may not be accurate.

9.6.3. Basis of methods proposed by PRDC

Reliability to be an economic measure requires understanding and assessment of the components of reliability in the power system. Since the study in context involves industries with CGP and their grid connectivity, reliability assessment of the interconnection is of utmost importance to quantify the benefits and put a price against it. In the preceding chapters, industries have been studied based on their nature of load, energy consumption & system analysis of interconnection. In practice, reliability can be understood as adequacy and security of the system and it's assessment for relationship to pricing requires a set of performance measures as follows:

a. System availability
b. Estimated unsupplied /unutilized energy
c. No of events/incidents
d. Number of hours of interruption
e. Violations of set voltage limit
f. d) Violations of set frequency limit
g. Violation of stability margin
h. Violation of damping margin

i. Violation of relay margin

System Adequacy Support: It is the support incurred by the industries in cases when adequacy of generation or system is not maintained in the CGP due to several reasons such as maintenance of units, non-sufficiency of equipment rating to withstand harmonics (grid absorbs harmonics), forced outages.

Also grid system's dedicated availability in terms of generation capacity, operating capacity and network capacity gives system adequacy support to the CGPs [23].

System Security Support: It is support for enhancement of ability of the industries with CGP to respond to disturbances within the system. These disturbances can have local and wide spread impact leading to economic losses for both transmission licensee and industries. Security is related to the dynamic processes where system needs to be restored within a time frame to achieve steady and stable operation. Interconnection to grid helps industries to settle the dynamic needs within the performance time of production. This also helps industries to maintain their own power system's & grid's health as per compliance with non-violation of set margins.

The connection with the grid helps CPP's connected to steel mills and arc furnaces i.e., the system with fluctuating loads in stabilizing their units. Thus the grid acts as the supporting system for the CPPs for its successful operation in terms of electrical performances. Initially the CPPs were having contract demand roughly equivalent to their peak demand so that the utility was getting the fixed charges. The cost of providing infrastructure to maintain reliability and stability is not fully recovered due to non-accounting of reliability and stability cost which are not forming part of the tariff. The actual demand is also not reflected in the installed meters if the usage of grid supply is for less than 30 minutes. In real time operation of the grid, the generation must balance the load. In case of sudden spikes in load caused by the CPPs, variation in the system frequency and voltage is observed. The dip in the voltage and frequency at the time of starting large motors is minimized as the grid supply acts as an infinite bus. In some cases, the slow responses of the CPP's governors and excitation system will make the plant sluggish without the support of the grid. The shocks created by sudden load throw off's and consequent tripping of CPP's generator on over speeding is avoided with the grid taking care of the shocks. These issues form the basis of peak instantaneous demand based GSC whose calculation is based on:

a. Based on the highest instantaneous demand recorded in the system connected to the CPPs

b. Based on the size of the largest motor connected to the CPP or size of the interconnecting transformer between the grid and the CPP

Energy intensive industries such as aluminum refinery, sponge iron, cement industry, paper mills etc. have CGPs & grid import – export to meet and balance their electrical power requirement (deficit & surplus) . CGPs are commissioned to support the industries for their production and profitability. Each process in the industries consumes specific amount of energy (thermal, mechanical, chemical, electrical etc) for producing an unit of product. Consumption of electrical energy used for producing an unit of product can be quantified in terms of Specific Electrical Energy Consumption (MWh / ton). Grid connectivity ensures reliability in plant operation by "adequate and secured" energy supply. This forms the basis for specific energy consumption based GSC.

CERC engaged a task force in 2019 to review point of connection methodology [22] which decides how transmission charges are shared among the stake holders. The framework for the monthly transmission charges has three components [22]:

a) "Point of connection portion" which deals with transmission charges for connected customers with contract demands, open access customers under LTOA, MTOA and STOA. This portion is shared among the designated customers based on actual utilization in each time block.
b) "Reliability portion" which deals with N-1 contingency reliability calculated as a priori on the current year transmission planning (all peak scenario).This portion is shared among designated customers in terms of ratio of non-coincident peak to sum of actual peaks of all lines.
c) "Residual portion" which deals which is the balance of charge of each line after deducting point of connection charge and reliability portion. This portion is shared among the designated customers in terms of ratio of LTOA/MTOA to total LTOA/MTOA. These accounts for the unused portion of the transaction agreement which are available.

In the present study, PRDC has proposed to adapt the above framework for levying GSC whose basis is instantaneous reliability support.

9.6.4. Peak Instantaneous Demand based GSC

The Grid support charges based on the highest instantaneous demand recorded by the CPP are possible based on measurement. This methodology is most suitable for the CPP's who have large inductive machines.

Grid support charges

= Grid support charges per MVA x (Highest plant demand recorded in MVA - Maximum plant demand in MVA) or

Grid support charges = Grid Support Charges per MVA x RMS deviation of the demand spikes with respect to maximum demand

The starting current of the induction motors in industrial units of CPPs is about 5 times the rated current. These large motors usually take about 7 seconds to start at ideal conditions. Studies have proved without grid support the motor rating has to be much higher for successful starting of the motor. The interconnecting transformer size is decided based on the grid import /export requirement. Grid provides the instantaneous demand support for motor starting.

9.6.5. Specific energy consumption based GSC

Most of the CGPs are thermal power plant in captivity whose generation ramp rate is around 5% per min which is by nature incapable of meeting the ramping of industry's daily peaks and variability which are due to arc furnace loading, smelter plant loading, variable speed etc. These are supplied by the grid by laws of physics because of connectivity. Industries opt to operate at constant scheduled power mode because of many operational advantages. The instantaneous peak or variable power requirements minus the constant scheduled power in a day are the power deficit/surplus which grid is supporting for reliable production.

In terms of Specific Energy Consumption (electrical) known as specific electrical consumption (SEC_e), this support can be quantified at plant level as well as plant process level. Different process in the industries have different specific electrical consumption. An example for different sections of forming and press process of paper industry in the following figure[24].

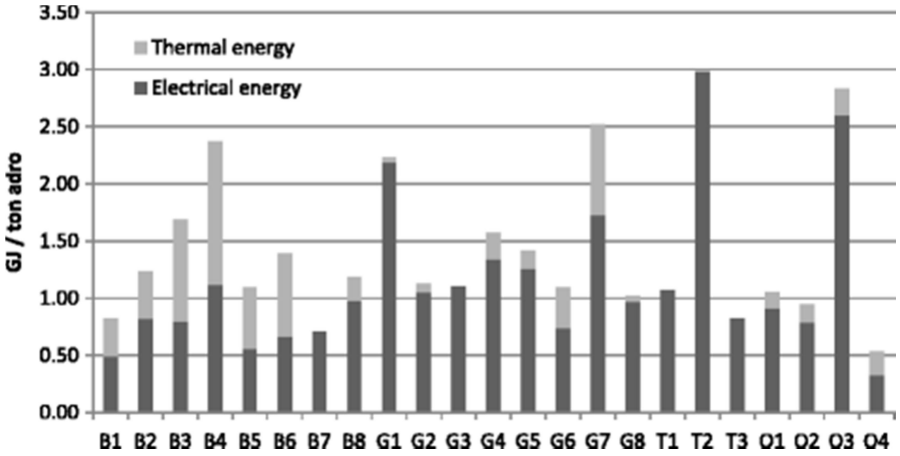

Figure 9-1 An example of Specific Thermal & Electrical Energy Consumption in a forming & press process of Paper industry (source: Ref [24])

Annual Specific Electrical consumption

= Total annual electrical energy consumption / Annual average production (MWh /tons)

= (Captive generation+ Grid import) in MW * 8760 / Annual average production in tons
Grid import recorded = Contracted demand + unscheduled interchange (if any)

Actual Grid support = Contracted demand + unscheduled inter change (if any) + instantaneous support

A constant power mode specific electrical consumption can be calculated as:

On daily basis

SEC_{ed} (constant power mode) =
Constant daily scheduled generated power in MWh / daily average production in tons

On monthly basis,

SEC_{em} (constant power mode) =
Monthly average of scheduled generated power in MWh / monthly average production in tons

At plant process level (100 % utilization)

Quantified SEC support required = sum of (SEC_e of each process - SEC_{ed} |) in MWh / tons

OR = sum of (| SEC_e of each process - SEC_{em} |) in MWh / tons

Actual SEC_e reliability support = [Contract Demand SEC_e+ unscheduled interchange SEC_e (if any) - Quantified SEC_e support] in MWh / tons

As per Odisha Grid code 2015 definitions section 1.19, "Time block is the block of 15 minutes/ 5 minutes for which special energy meters record specified electrical parameters and quantities with first time block starting at 0.00 hrs." Unscheduled interchange is defined as "in a time block for generating station or a seller means its total actual generation minus it's total scheduled generation and for a beneficiary or buyer means its total actual drawal minus

it's total scheduled drawal." Actual SEC_e reliability support takes into account the instantaneous support given by the grid to CGPs which may not recorded in a time block. Amount of instantaneous energy transfer from the grid can be calculated from the instantaneous power measurement at the PCC or can be directly measured using smart energy metering.

Grid support charges =

Grid support charges per MWh / ton X Actual SEC_e reliability support in MWh/ton

9.6.6. GSC based on adaption of point of connection framework

There is an intangible reliability component in "unused capacity". This capacity can be in terms of generation capacity, operating capacity & network capacity. To understand this reliability in steady state contingency studies are carried out during transmission planning. In the point of connection framework, N-1 contingency studies are used to identify the reliability model. These studies are done to identify the maximum loading on transmission lines. Excess flow multiplied with line cost rate on capacity base represents the allocation of reliability cost. As an example, it was proposed "if usage of line is 17%, then 83 % cost is recovered through postage stamp basis. Then in line usage percentage, 17 % will be reliability cost, 34 % usage cost and rest residual of 66% will be postage stamp basis." Transmission charges under this framework can be determined on MW per circuit kilometer basis, zonal postage stamp basis or some other pragmatic variant. The ultimate objective is to get transmission system users to share the total transmission cost based on their respective utilization in terms of usage, reliability & residual.

Adapting the same framework, CGPs connected to grid has connection agreements of demand (analogous to usage), reliability during transients (analogous to reliability portion) and non-utilization of dedicated infrastructure (analogous to residual).

A methodology to determine reliability benefit has been given by the CERC taskforce. It has been mentioned, Embedded Cost = Capacity Use + Reliability Charge. Question for reflection: "What is each transmission element's contribution in 'system adequacy' and 'system security?." Reliability charge is proposed by finding reliability indices from contingency studies [22].

A security assessment refers to the analysis whether of or not system meets the specified reliability and security criteria during steady state and transients. Depending on system operating condition and contingency probability of disturbances, robustness of the system to respond and the degree of risk that can be taken without interrupting the services can be assessed. Security of a system during and after a transient process is ensured if stable operation leads to maintenance of synchronism, acceptable voltage and frequency levels. Transient conditions with reasonable probability of occurrences and fault conditions which may have worst impacts are used for security monitoring, analysis and security margin determination. Under transmission open access environment, it is important that security margin is defined using selected variables and the network should be assessed under pre-assigned set of contingencies. Static security assessment relies on methodologies which verify bus voltage and line power flow limits for post contingency operating state. Dynamic security assessment relies on methodologies for evaluating the damping and stability margin of the system after the contingency or transient conditions have occurred [23].

The operating conditions and contingencies that may cause transient angle instabilities, voltage and frequency excursions, relay margin violations etc. which need to be assessed and reliability needs to be quantified in terms of indices. These indices help evaluating the stability and quality of transient processes and levy charges.

When a transient disturbance occurs, it causes the affected component /zone to diverge from the system equilibrium. Even when the disturbance is removed, energy causing acceleration or deceleration may cause the affected zone / component move away from a stable operating state. The ability of the system to absorb the energy which causes instability can be decided by calculating the accumulated potential energy index under post disturbance conditions [25]. Another transient stability index which can give a measure to quantify the distance between pre-fault equilibrium point and the critical operating point is rotor angle difference index. This index gives an account of stability margin. Post disturbance stability can be quantified in terms of system oscillations damping index which is calculated from oscillations during transients [26, 27].

ΔP_g $Power\ deviation\ from\ steady-state$

Δf_g $Frequency\ deviation\ from\ steady\ state$

t_{clear} $time\ of\ fault\ clearing$

t_0 $Short\ time\ after\ fault\ clearing$

t_{fault} $Time\ at\ which\ fault\ occured$

δ_{max} $Maximum\ angle$

δ_{min} $Minimum\ angle$

M_{ti} $Peak\ value\ of\ quantity\ at\ time\ t_i$

$$Transient\ Potential\ energy\ index\ (TPEI) = \sum_{t_{clear}}^{t_0} \Delta P_g * \Delta f_g$$

$$First\ Cycle\ Damping\ Index\ (FCDI) = \frac{ln\left(\frac{M_{t1}}{M_{t2}}\right)}{\sqrt{1+\left(\frac{2\pi}{ln\left(\frac{M_{t1}}{M_{t2}}\right)}\right)^2}}$$

$$N\ Cycle\ Damping\ Index\ (NCDI) = \frac{ln\left(\frac{M_{t1}}{M_{tn}}\right)}{\sqrt{1+\left(\frac{2n\pi}{ln\left(\frac{M_{t1}}{M_{tn}}\right)}\right)^2}}$$

Sample Calculation of Grid Support charge based on adaption of point of connection framework

TPEI calculation of Vedanta

Table 9-2 Sample calculation of TPEI for different modes of operation using strong and weak inertia support from Grid

TPEI for Different operating modes	Export	Floating	Import
For strong inertia grid connectivity	4310.23	4311.34	939.519
For weak inertia grid connectivity	2786.37	2848.78	685.212

NCDI calculation sample

Table 9-3 NCDI calculation for a floating mode 3 Phase to ground fault case for strong grid connectivity

No of Cycle	1	2	3	4	5
Time stamp	1.11	1.62	2.17	3.25	3.78
Frequency	50.6948	50.391	50.2701	50.1878	50.1331
NCDI		8.63034E-12	5.92E-12	4.48E-12	3.44E-12

Table 9-4 NCDI calculation for a floating mode 3 Phase to ground fault case for weak grid connectivity

No of Cycle	1	2	3	4	5
Time stamp	1.12	2.14	3.07	3.97	4.86

Frequency	50.7539	50.7118	50.6447	50.5857	50.5096
NCDI		2.27101E-14	9.93E-14	1.62E-13	2.79E-13

Table 9-5 NCDI calculation for export mode 3 Phase to ground fault case for strong grid connectivity

No of Cycle	1	2	3	4	5
Time stamp	1.09	1.62	2.17	2.71	3.24
Frequency	50.6159	50.573	50.3945	50.2732	50.1909
NCDI		2.42273E-14	8.37E-13	1.38E-12	1.49E-12

Table 9-6 NCDI calculation for export mode 3 Phase to ground fault case for weak grid connectivity

No of Cycle	1	2	3	4	5
Time stamp	1.13	2.6	3.54	4.53	5.48
Frequency	50.7594	50.5708	50.4922	50.48	50.4099
NCDI		2.04994E-12	1.46E-12	7.43E-13	8.19E-13

Table 9-7 NCDI calculation for import mode 3 Phase to ground fault case for strong grid connectivity

No of Cycle	1	2	3	4	5
Time stamp	1.1	1.64	2.21	2.79	3.36
Frequency	50.3132	50.2802	50.1051	50.063	50.0401
NCDI		1.12244E-14	7.07E-13	5.47E-13	4E-13

Table 9-8 NCDI calculation for import mode 3 Phase to ground fault case for weak grid connectivity

No of Cycle	1	2	3	4	5
Time stamp	1.11	1.99	2.87	3.76	4.64
Frequency	50.3415	50.3135	50.2836	50.2448	50.2036
NCDI		6.84383E-15	1.51E-14	3.14E-14	5.13E-14

10. IMPACT OF REACTIVE POWER, INERTIA, AND SOLAR PENETRATION IN CGP

10.1. Reactive Power Analysis

The reactive power support provided by the grid is analyzed by simulating the CGP model which are both importing and exporting reactive power. In both the import and export model, a three phase to ground fault disturbance is simulated at the power evacuation bus inside the plant.

The electrical parameters associated to the simulation study are presented in Figure 10-1 to 10-5 for the scenario where the CGP is importing reactive power from the grid.

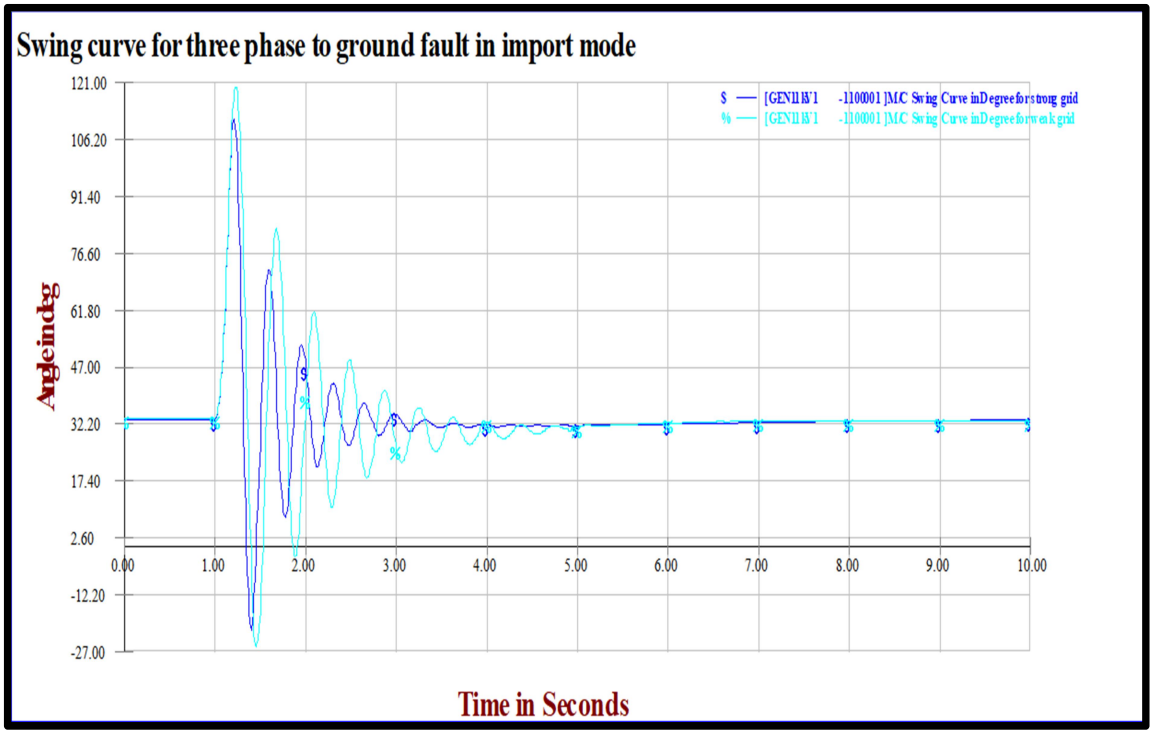

Figure 10-1 Swing curve for three phase to ground fault in import mode

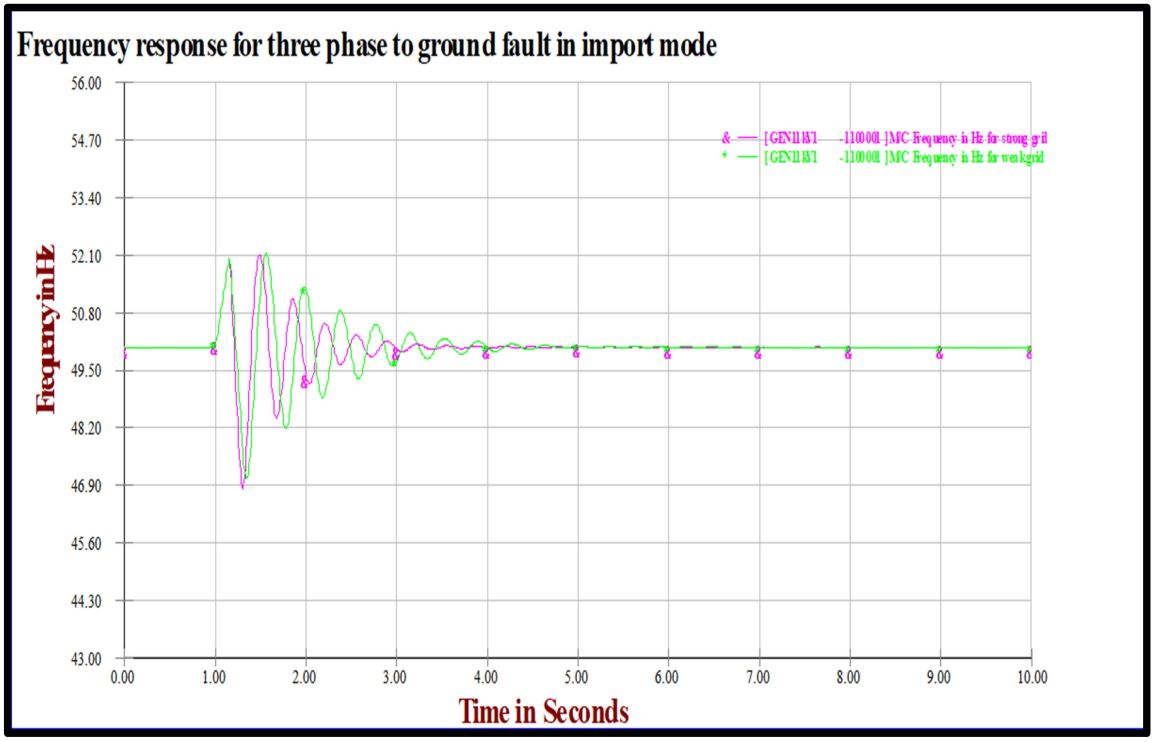

Figure 10-2 Frequency response for three phase to ground fault in import mode

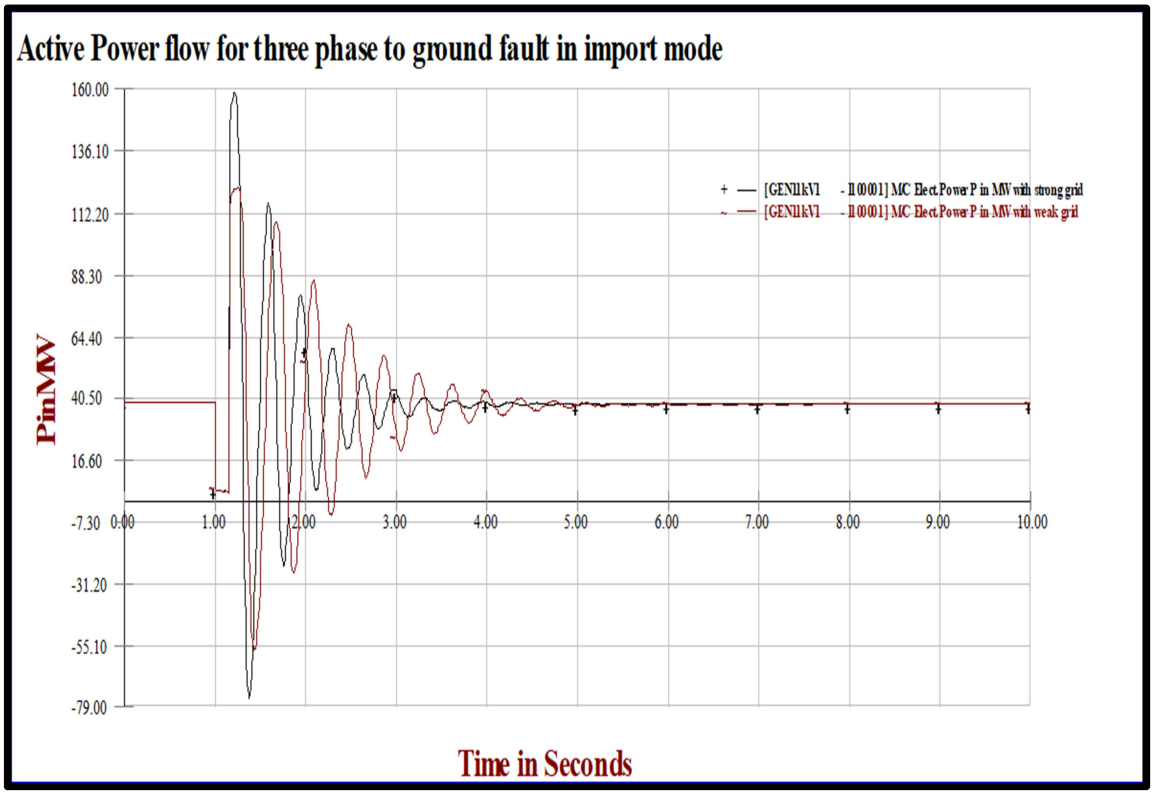

Figure 10-3 Active power for three phase to ground fault in import mode

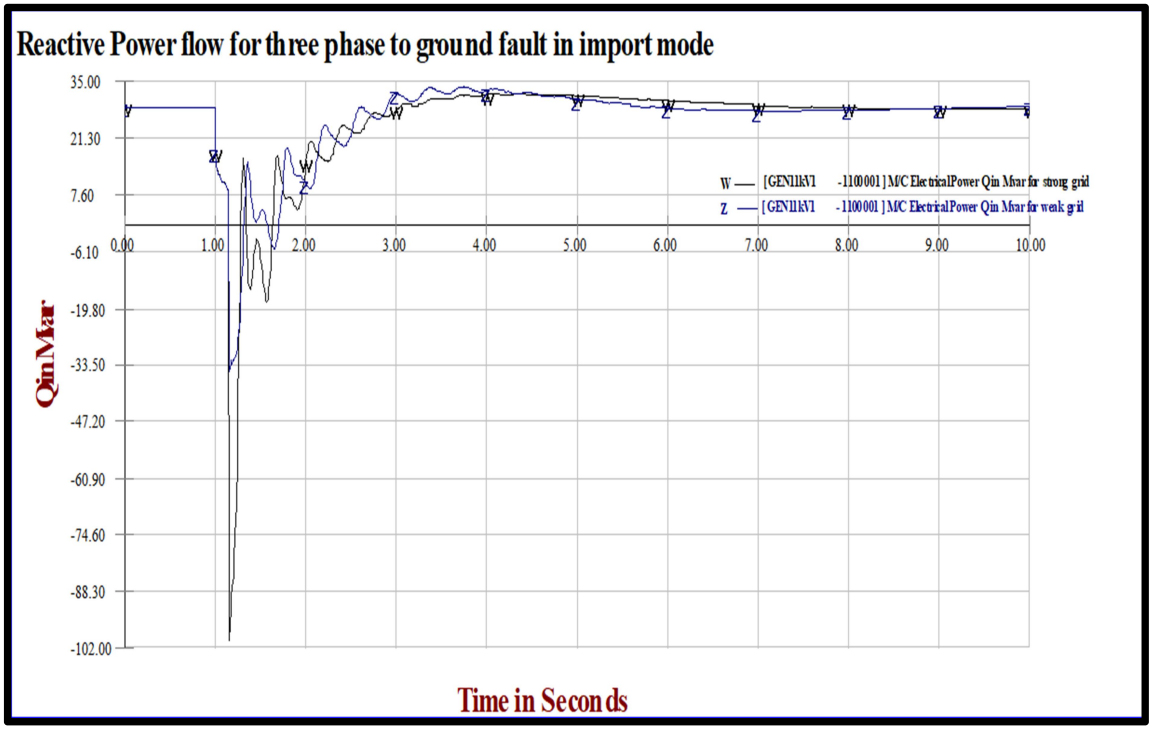

Figure 10-4 Reactive power for three phase to ground fault in import mode

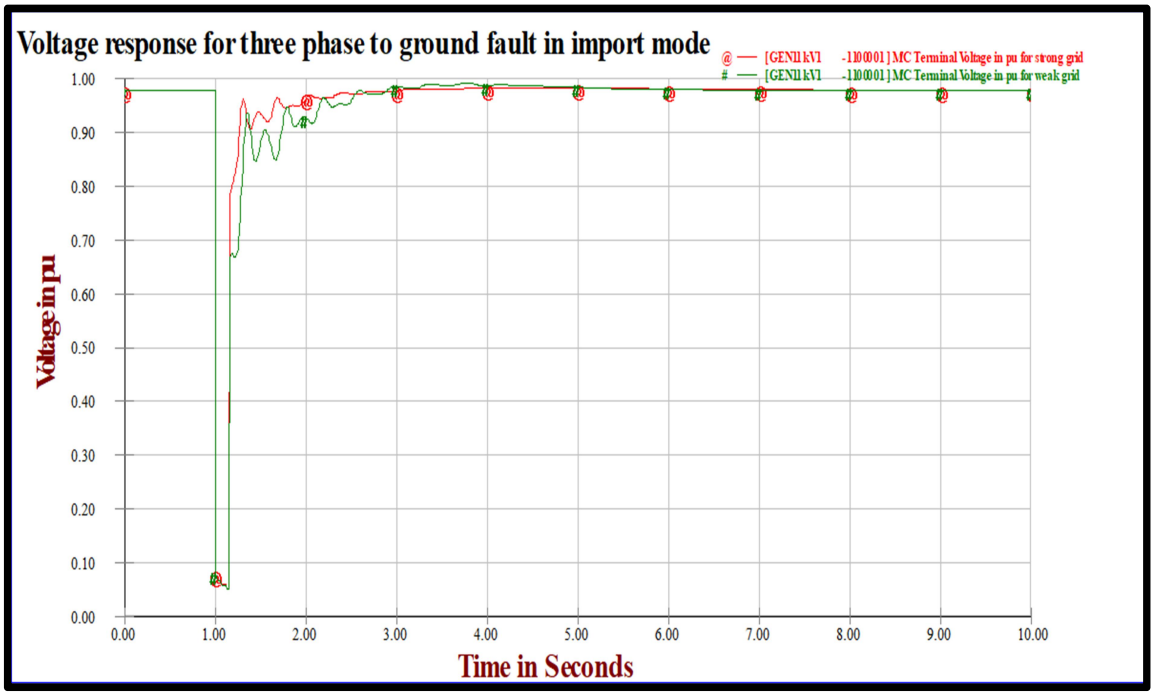

Figure 10-5 Voltage response for three phase to ground fault in import mode

Similarly, the electrical parameters associated to the simulation study are presented in Figure 10-6 to 10-10 for the scenario where the CGP is exporting reactive power to the grid.

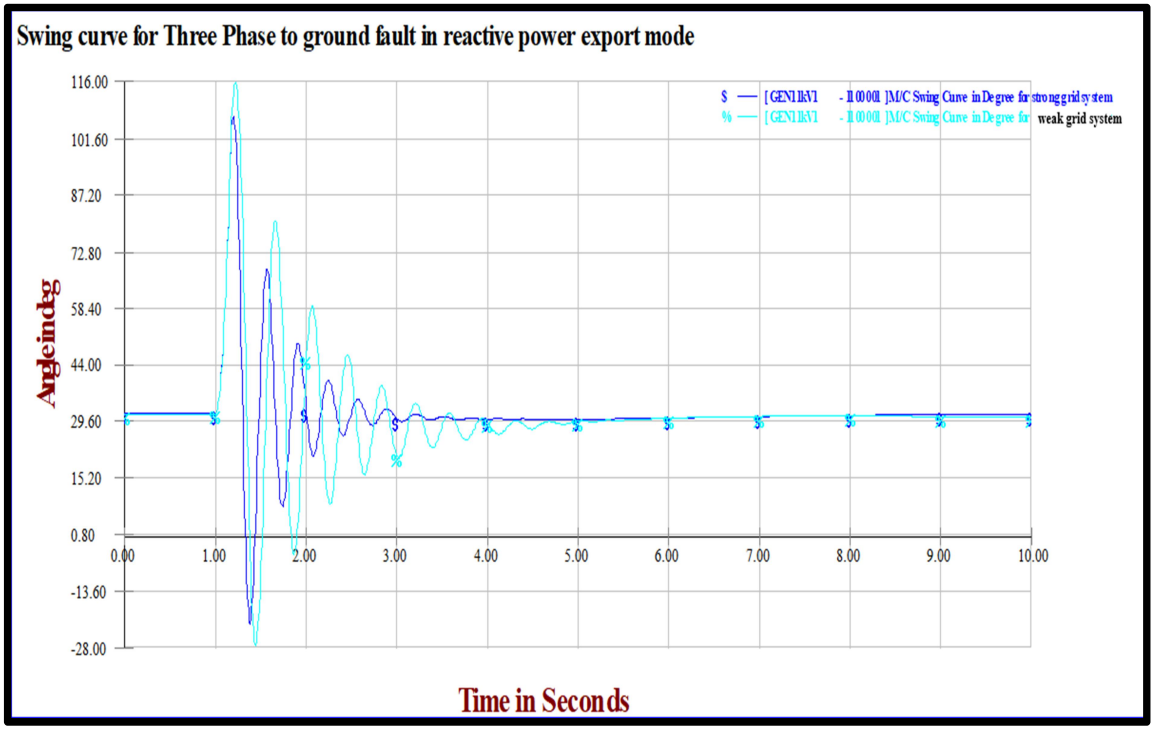

Figure 10-6 Swing curve for three phase to ground fault in export mode

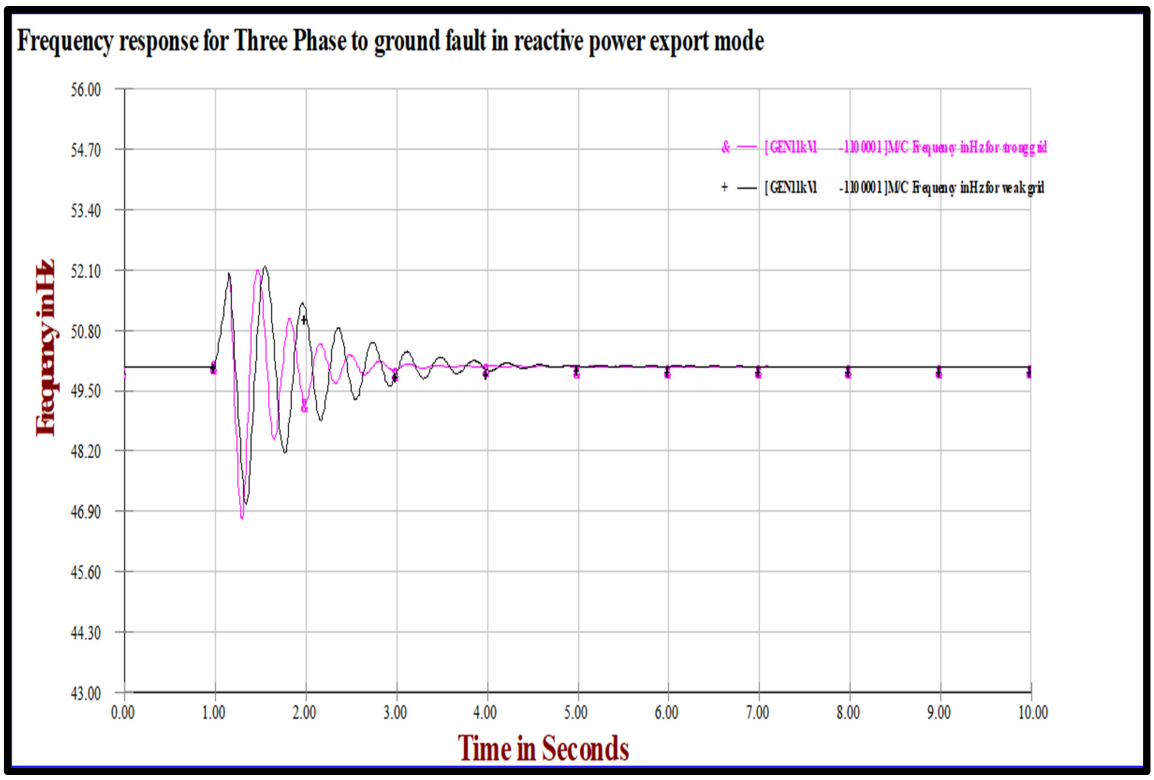

Figure 10-7 Frequency response for three phase to ground fault in export mode

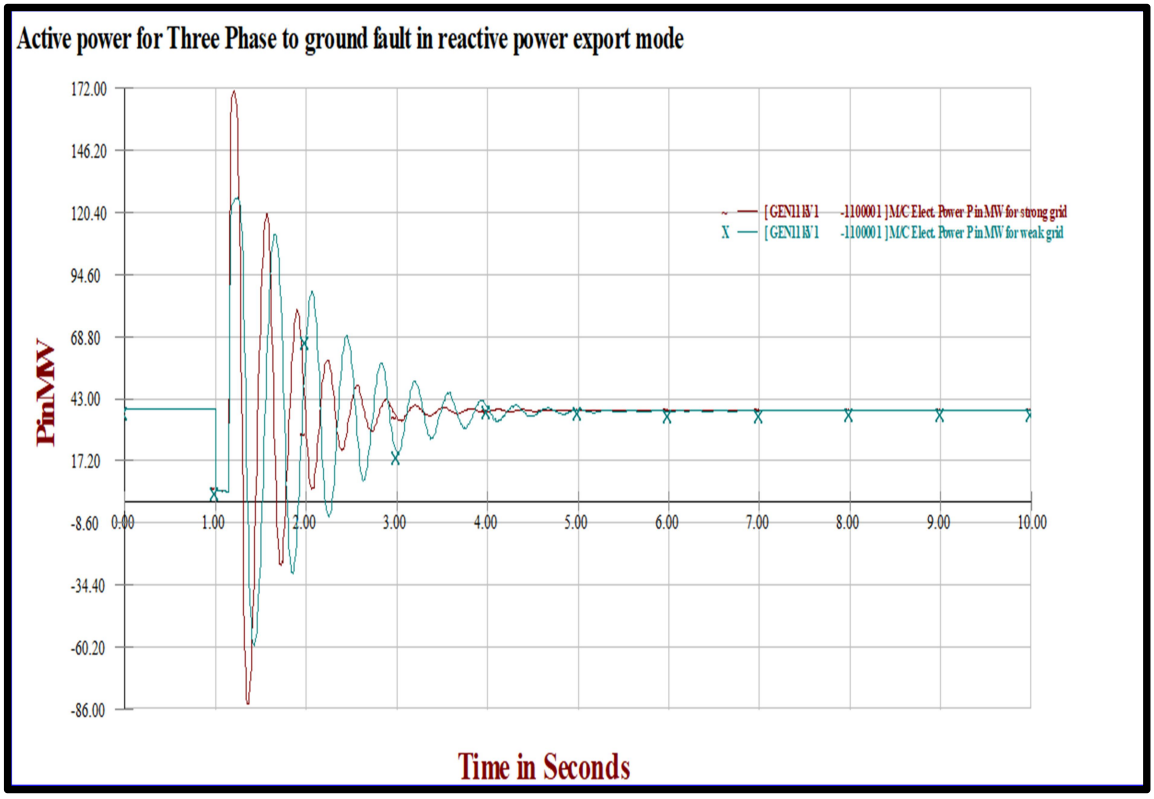

Figure 10-8 Active power for three phase to ground fault in export mode

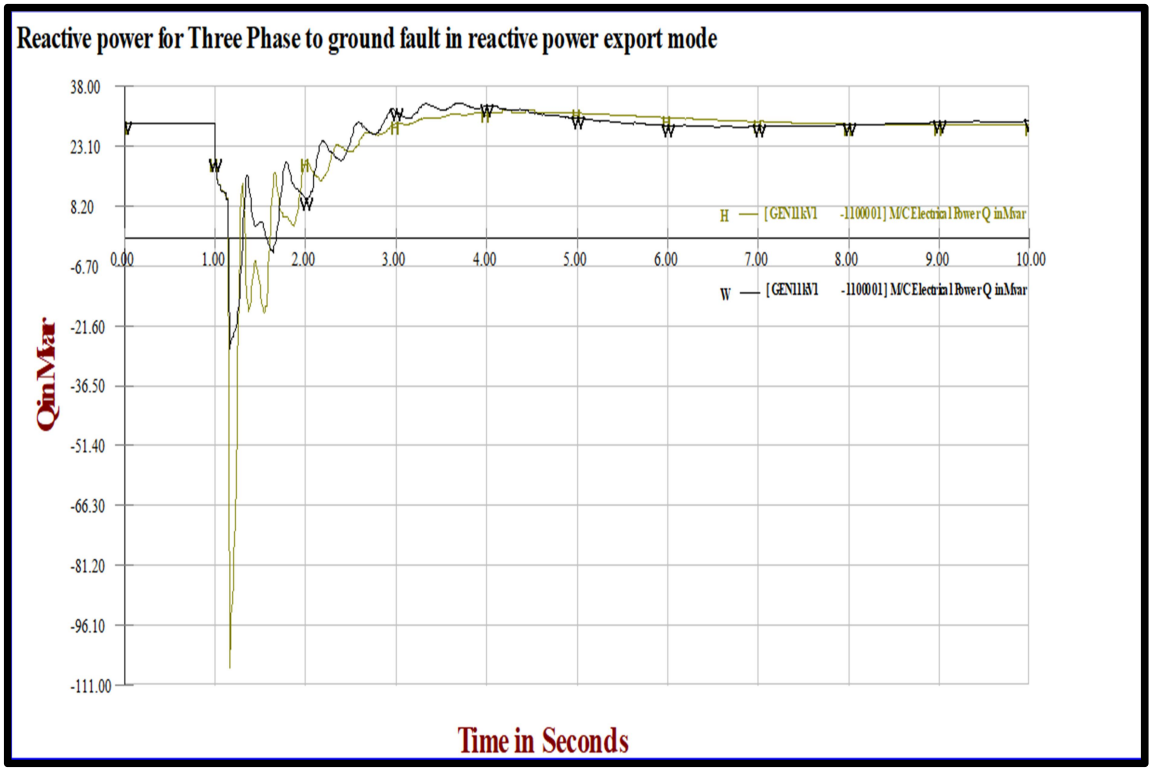

Figure 10-9 Reactive power for three phase to ground fault in export mode

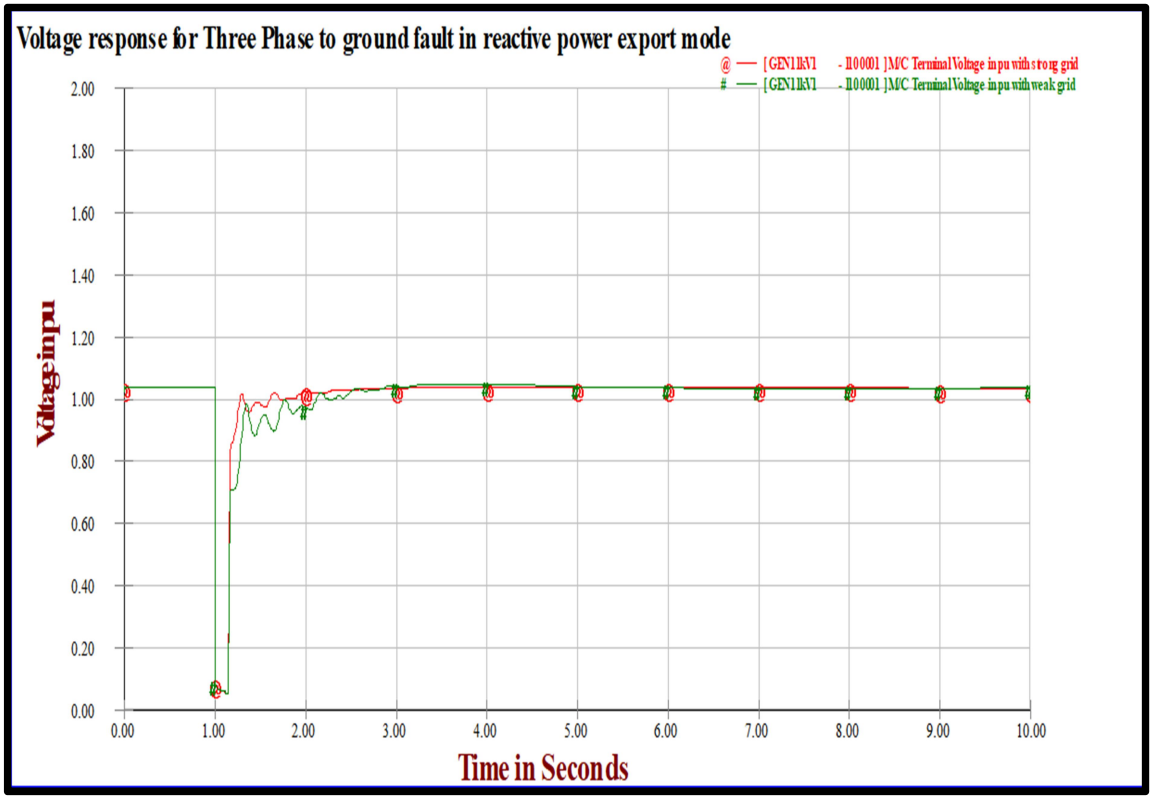

Figure 10-10 Voltage response for three phase to ground fault in export mode

A general conclusion from this study concludes that, the CGP and grid perform better during post fault recovery period because of dynamic grid support from grid. This help in avoiding inadvertent tripping.

10.2. Inertia support analysis for NINL CGP

The inertia support received by NINL from the Duburi Old Grid Sub Station is analyzed in this section in details.

A comparison of technical parameters associated to the strong and weak grid inertia support is presented as follows. In the following analysis a disturbance of three phase to ground fault is created at the power evacuation bus at NINL.

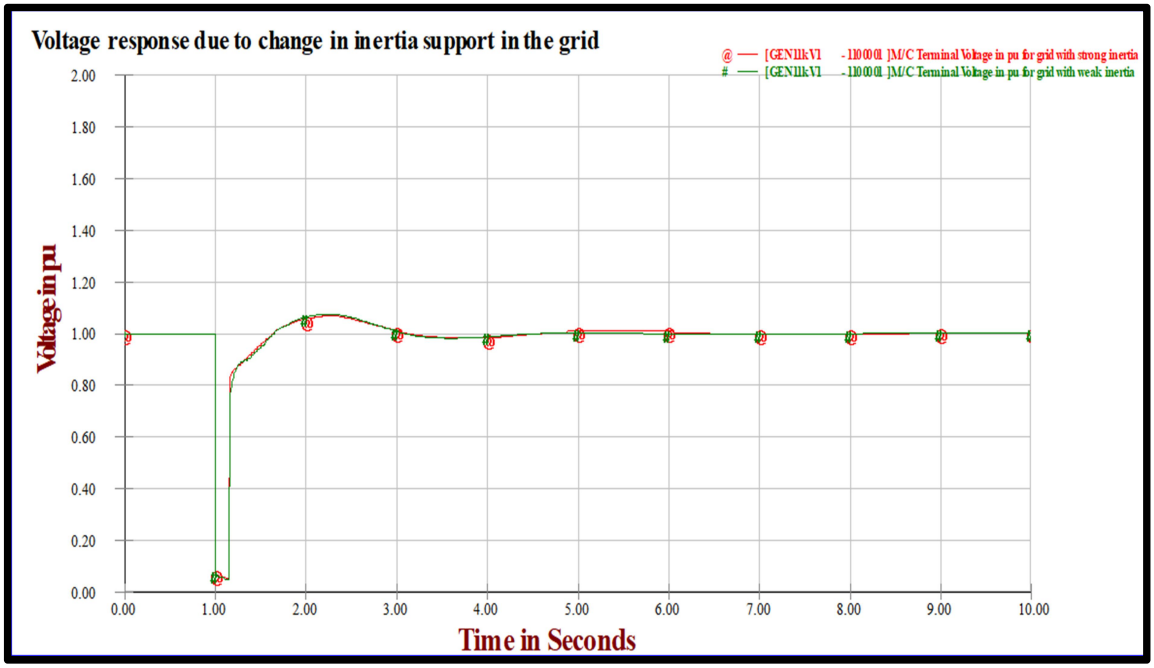

Figure 10-11 Voltage response due to change in inertia support in the grid

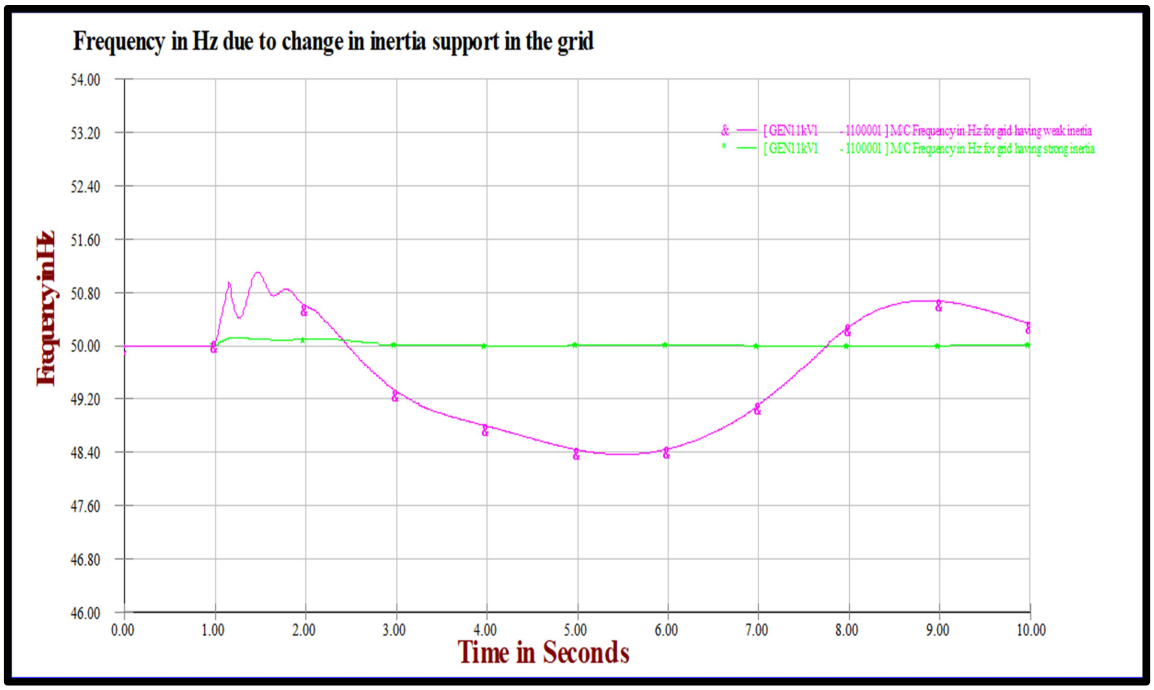

Figure 10-12 Frequency response due to change in inertia support in the grid

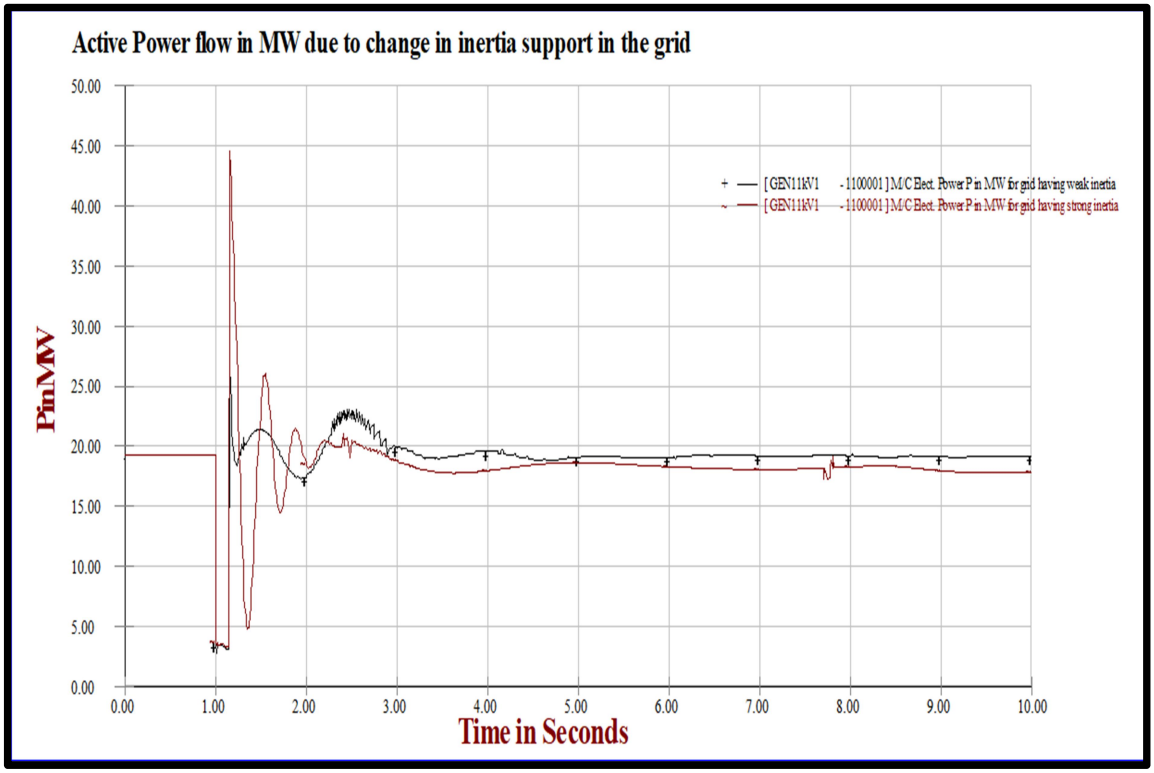

Figure 10-13 Active Power due to change in inertia support in the grid

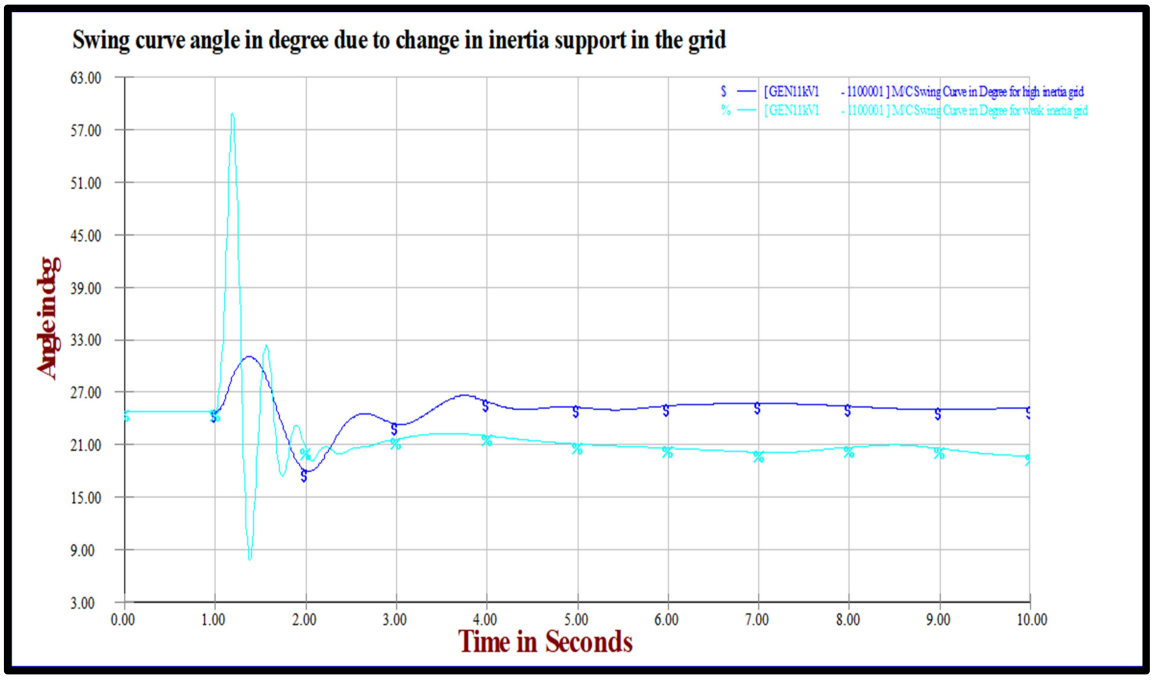

Figure 10-14 Swing curve in degree due to change in inertia support in the grid

A comparison of technical parameters associated to the strong and weak grid inertia support is presented as follows. In the following analysis a disturbance of single line to ground fault is created at the power evacuation bus at NINL.

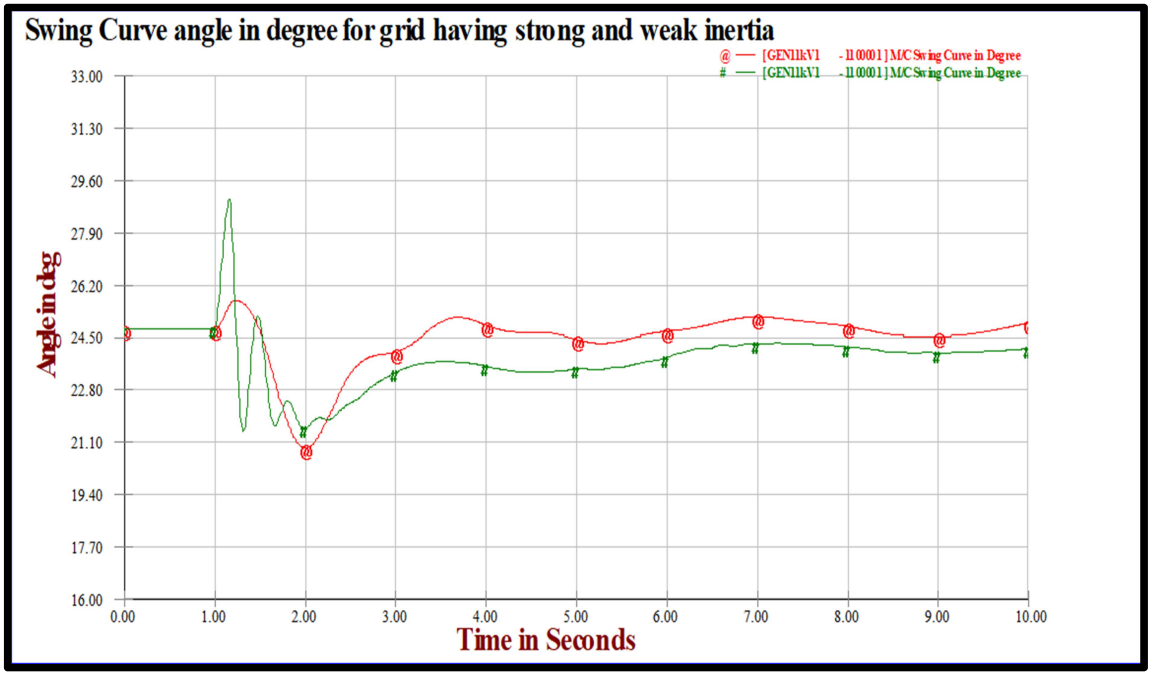

Figure 10-15 Swing curve in degree for SLG fault with strong and weak inertia grid

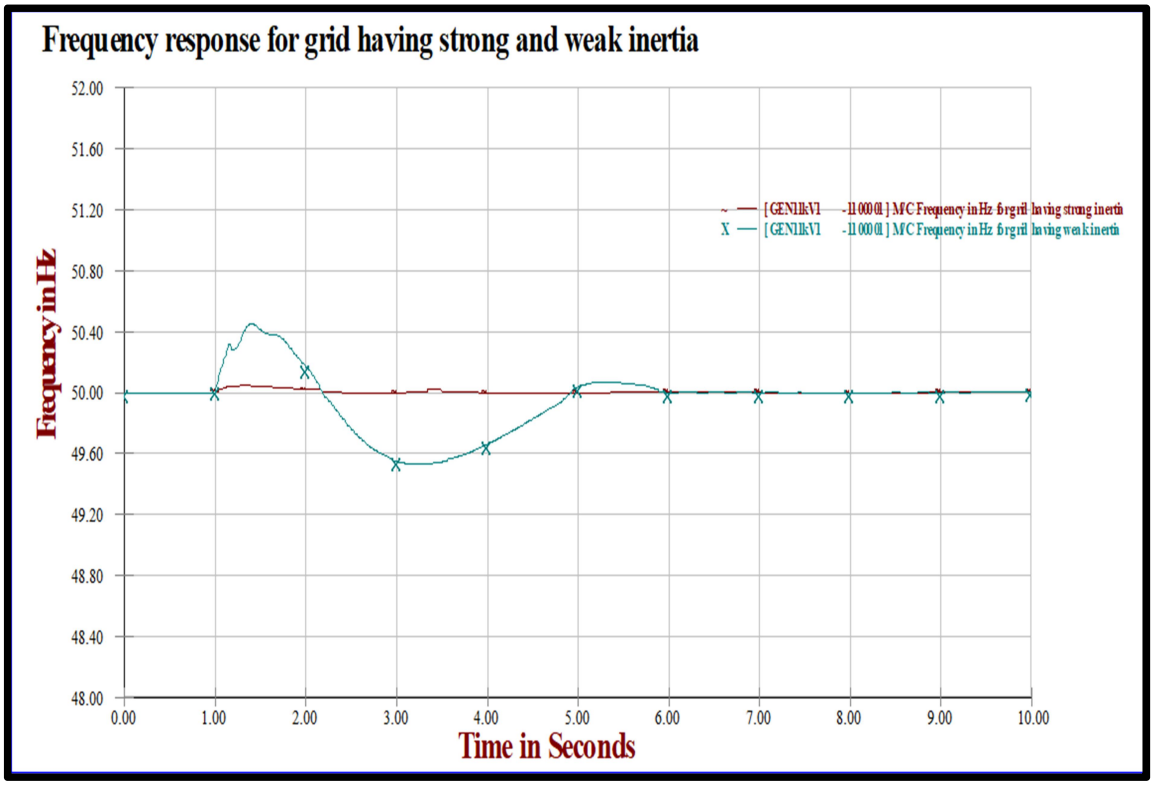

Figure 10-16 Frequency response for SLG fault with strong and weak inertia grid

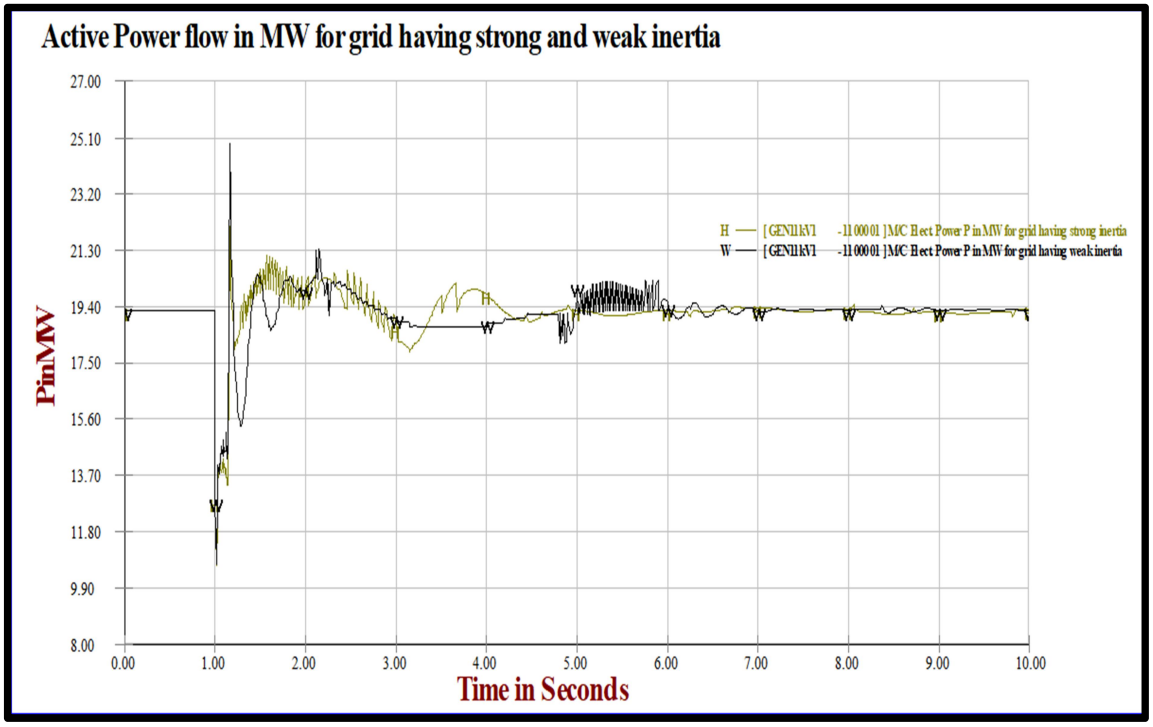

Figure 10-17 Active power flow for grid having strong and weak inertia during SLG fault

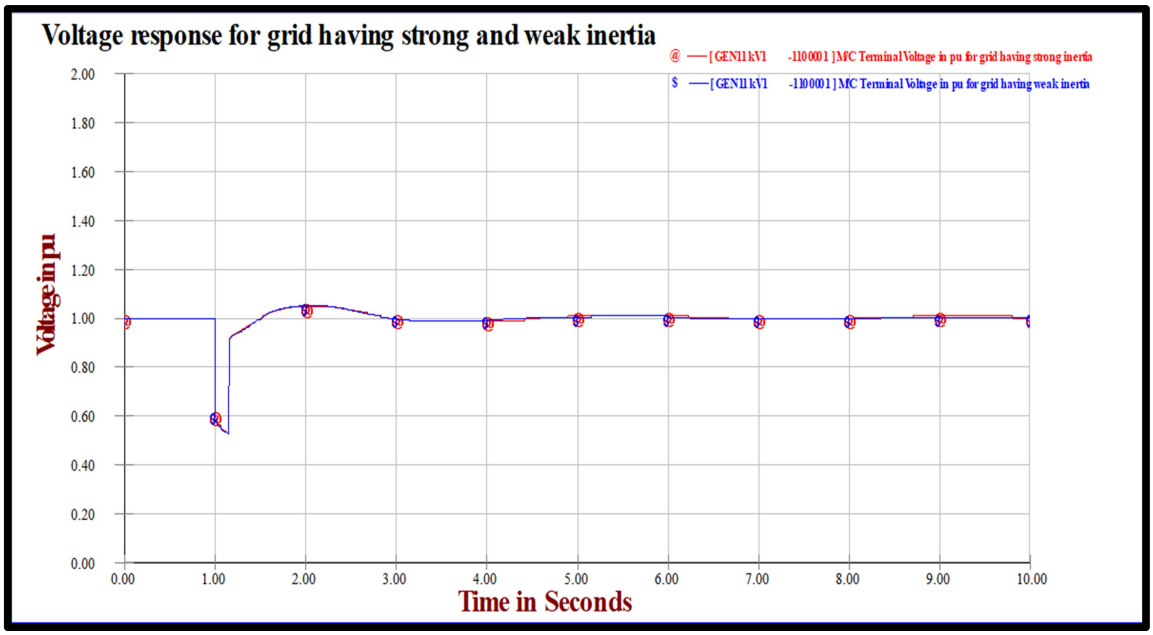

Figure 10-18 Active power flow for grid having strong and weak inertia during SLG fault

10.3. Inertia support analysis for Vedanta CGP

The inertia support received by Vedanta from the Budhipadar Grid Sub Station is analyzed in this section in details.

A comparison of technical parameters associated to the strong and weak grid inertia support is presented as follows. In the following analysis a disturbance of Three Phase to ground fault is created at the power evacuation bus at Vedanta.

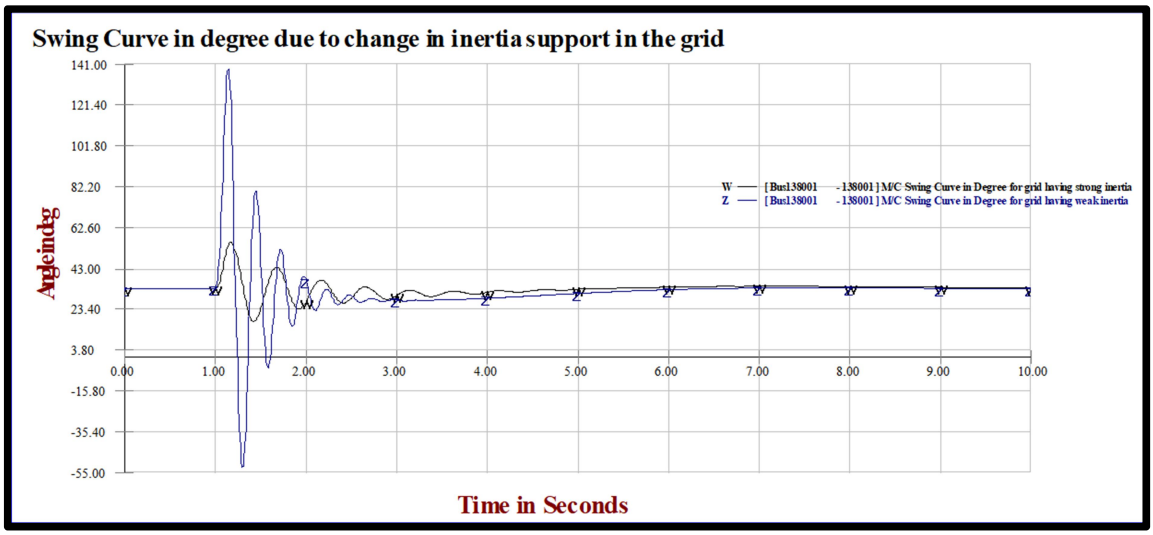

Figure 10-19 Swing curve in degree due to change in inertia support in grid during three phase to ground fault condition

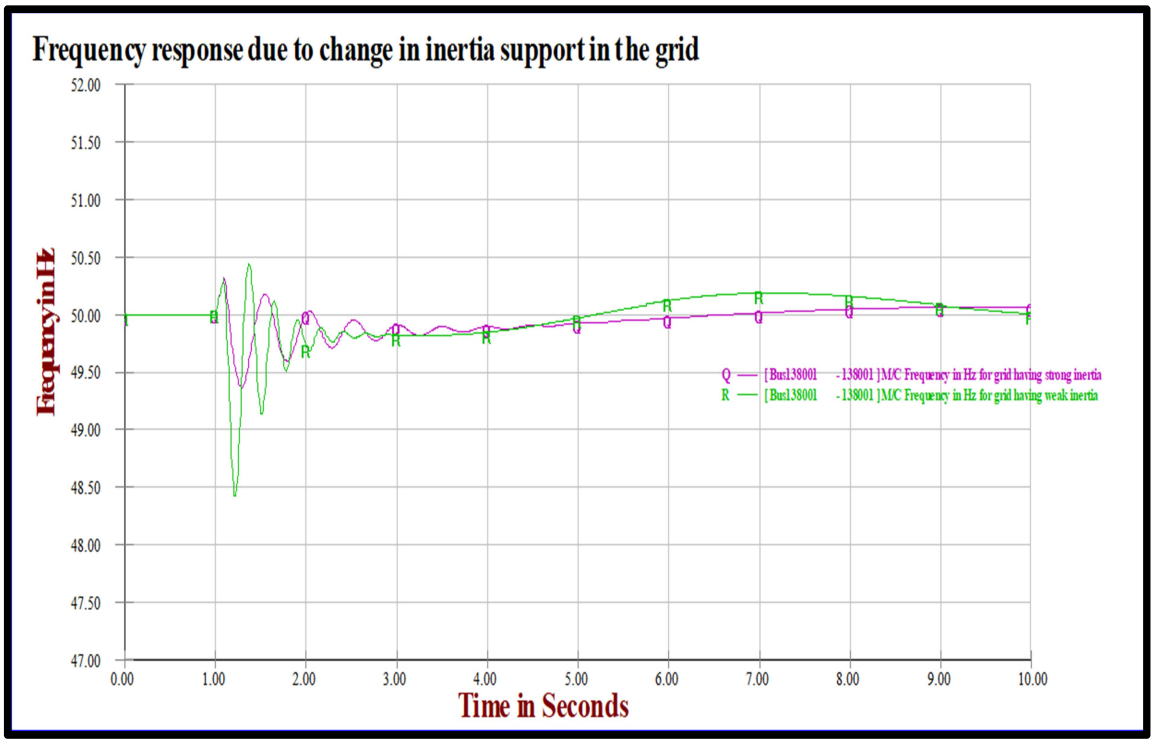

Figure 10-20 Frequency response due to change in inertia support in grid during three phase to ground fault condition

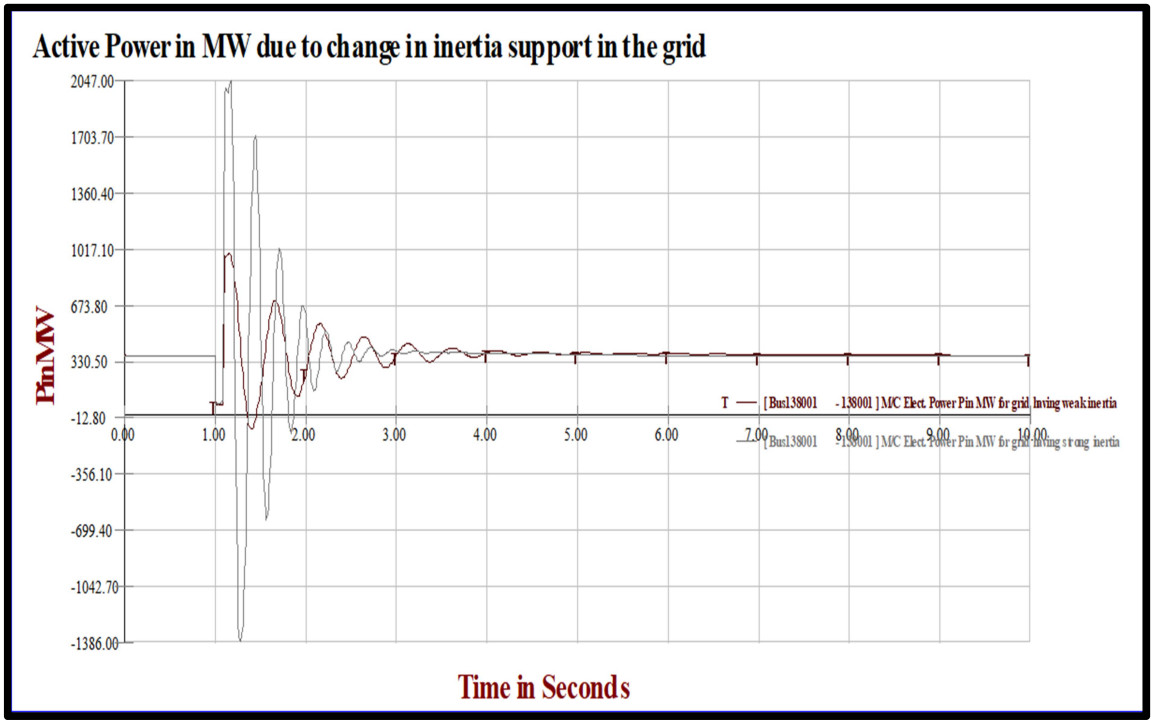

Figure 10-21 Active power due to change in inertia support in grid during three phase to ground fault condition

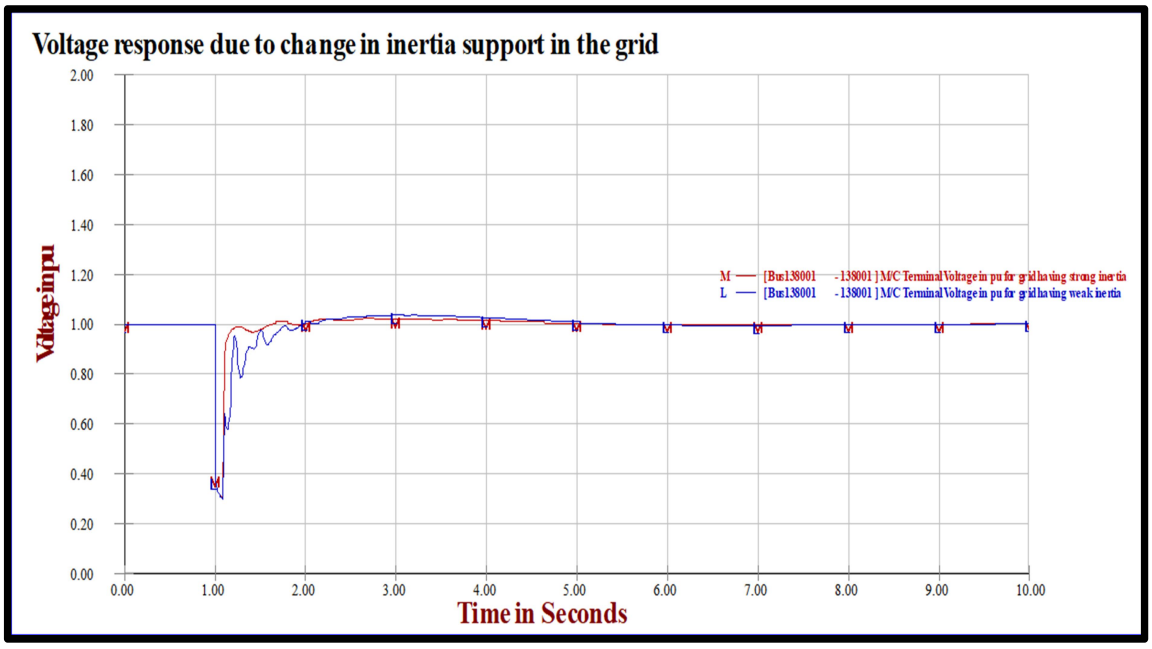

Figure 10-22 Voltage response due to change in inertia support in grid during three phase to ground fault condition

A comparison of technical parameters associated to the strong and weak grid inertia support is presented as follows. In the following analysis a disturbance of Single Line to ground fault is created at the power evacuation bus at Vedanta.

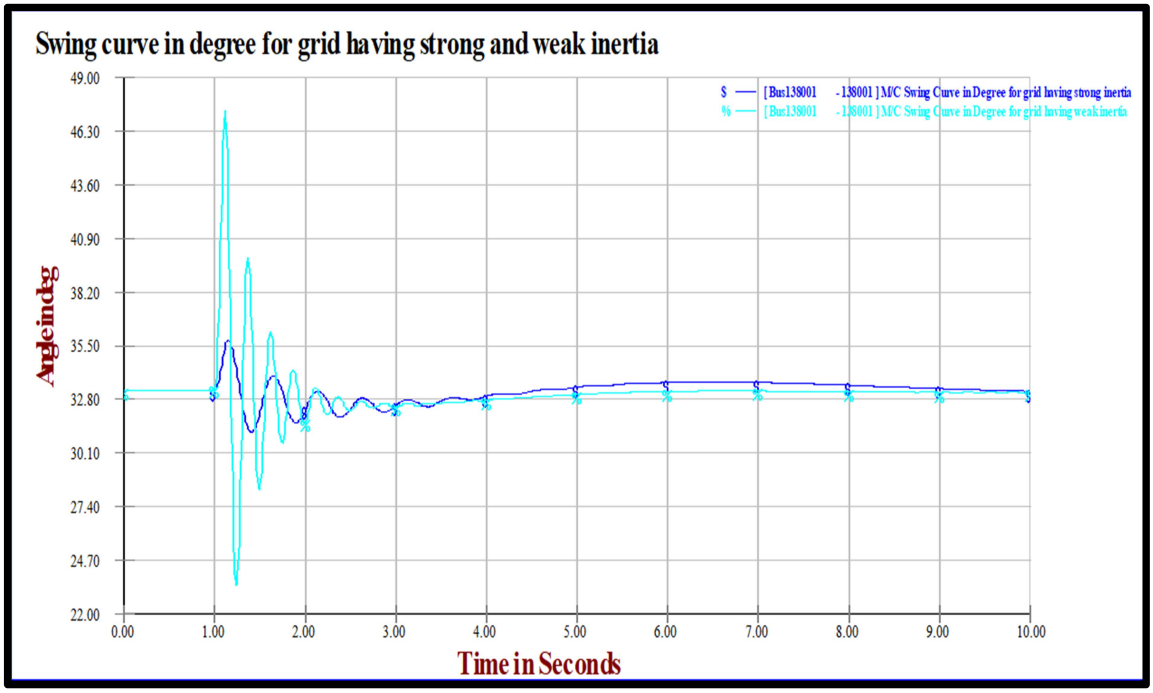

Figure 10-23 Swing curve due to change in inertia support in grid during Single line to ground fault condition

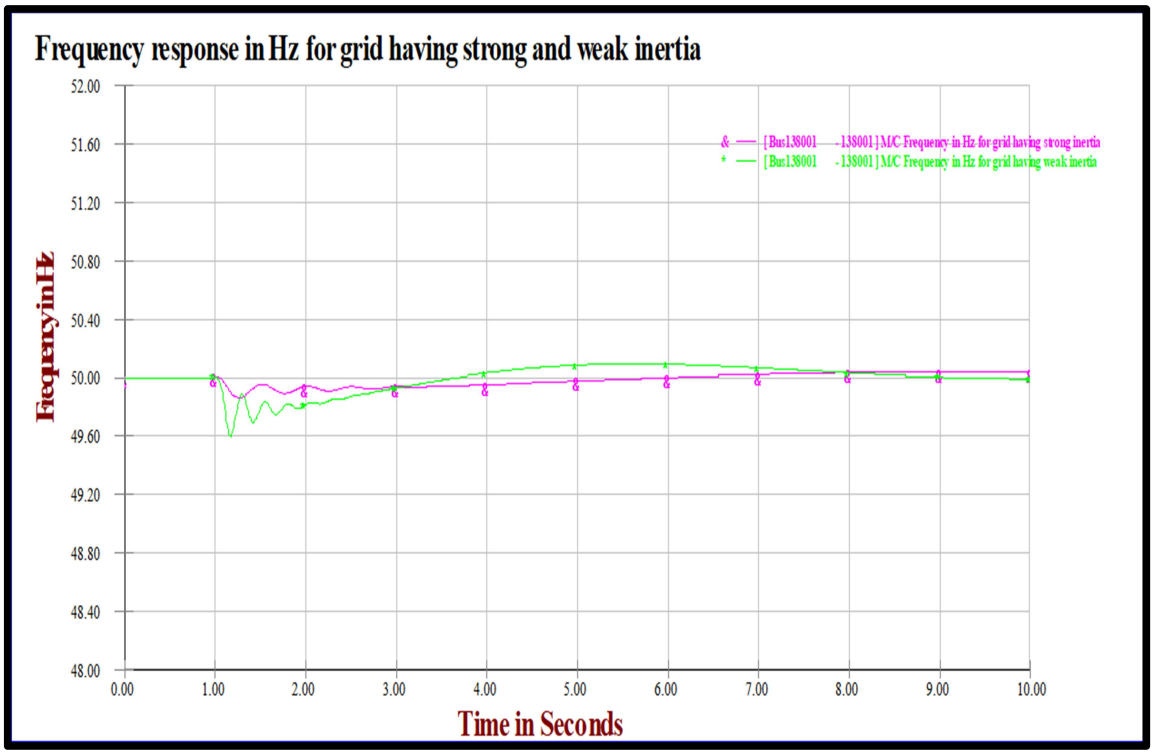

Figure 10-24 Swing curve due to change in inertia support in grid during Single line to ground fault condition

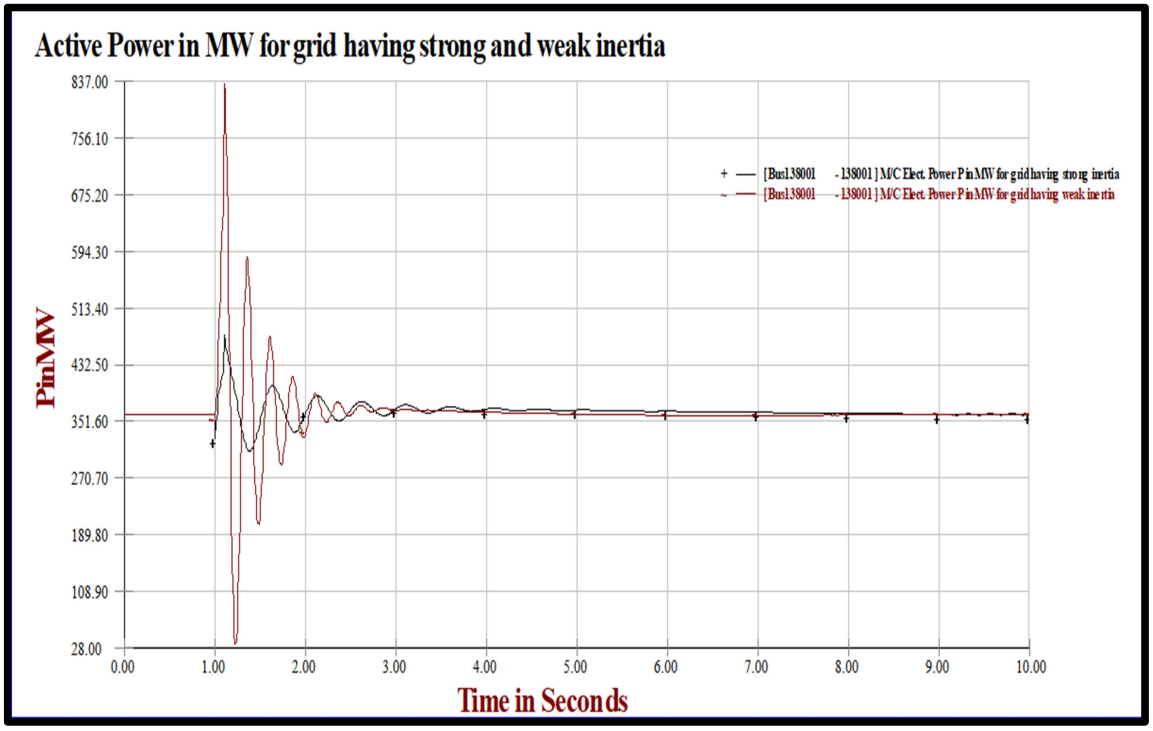

Figure 10-25 Swing curve due to change in inertia support in grid during Single line to ground fault condition

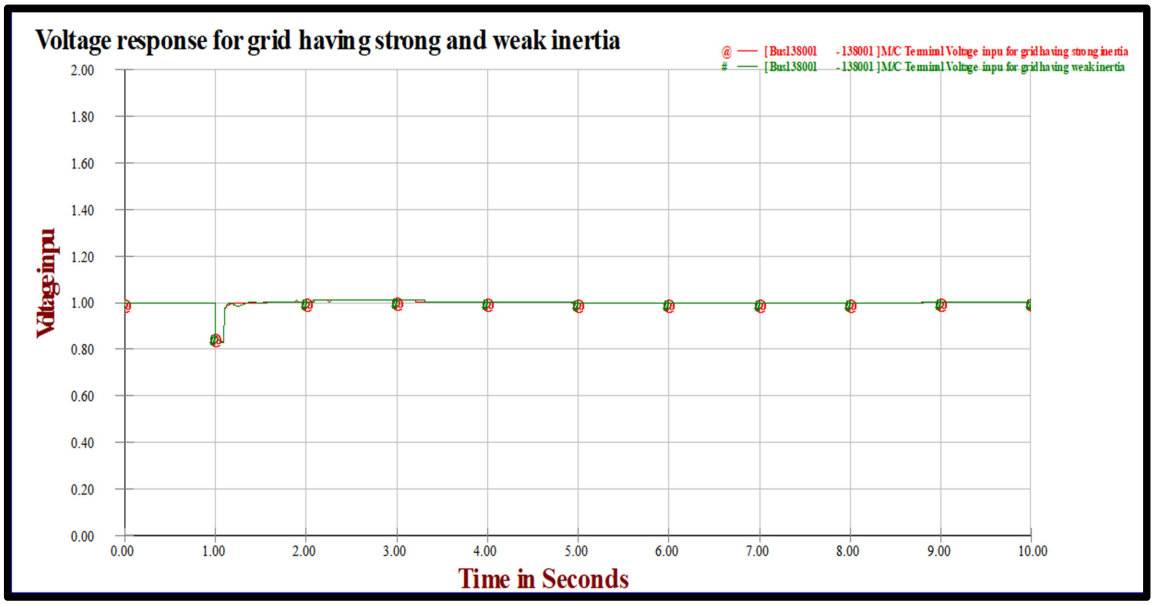

Figure 10-26 Swing curve due to change in inertia support in grid during Single line to ground fault condition

General conclusion is that, strong grid support CGP to different degrees based on the sizes of CGP and inertia support diminish the rate of change in frequency and voltage.

10.4. Impact of Solar contribution in CGP

In recent times, many Captive generating plants are adopting integration of Solar plant into their system to achieve more reliable operation other than their conventional synchronous generators.

The voltage response from the synchronous generator of the Captive Generating plants is presented in Figure 10-27.

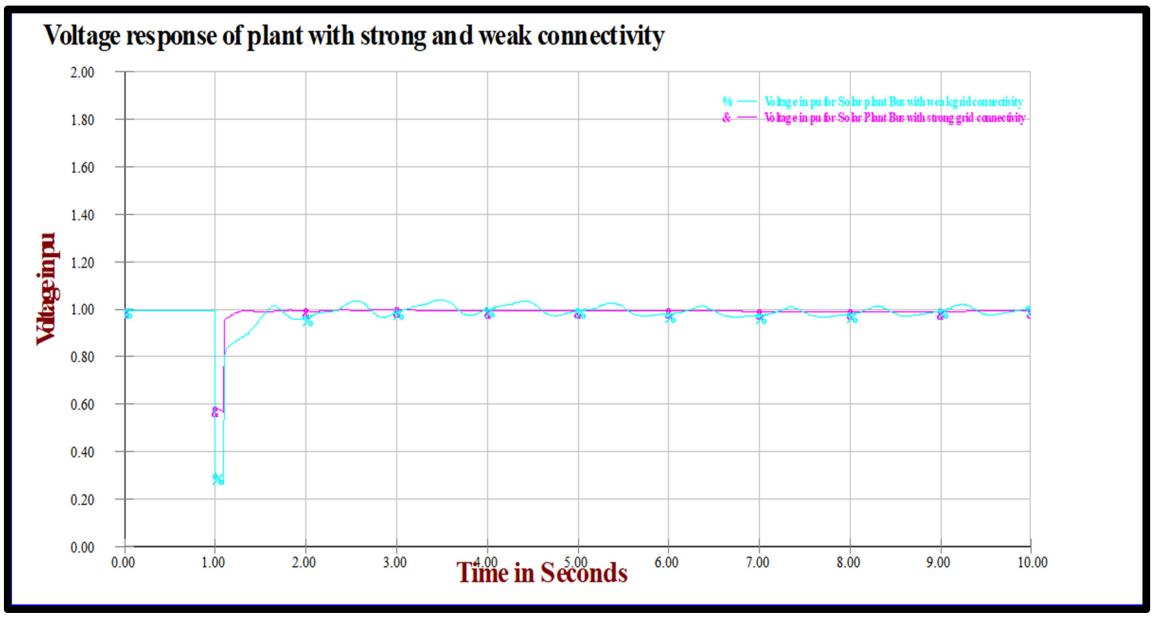

Figure 10-27 Voltage response of CGP generator having solar penetration with strong and weak grid connectivity

The reactive power drawls from the solar plant due to the use of nonlinear devices with strong and weak grid connectivity are presented in Figure 10-28. From Figure 10-28, it is clear that the reactive power deviation for the solar plant is more in case of weak grid connectivity as compared to the strong grid connectivity.

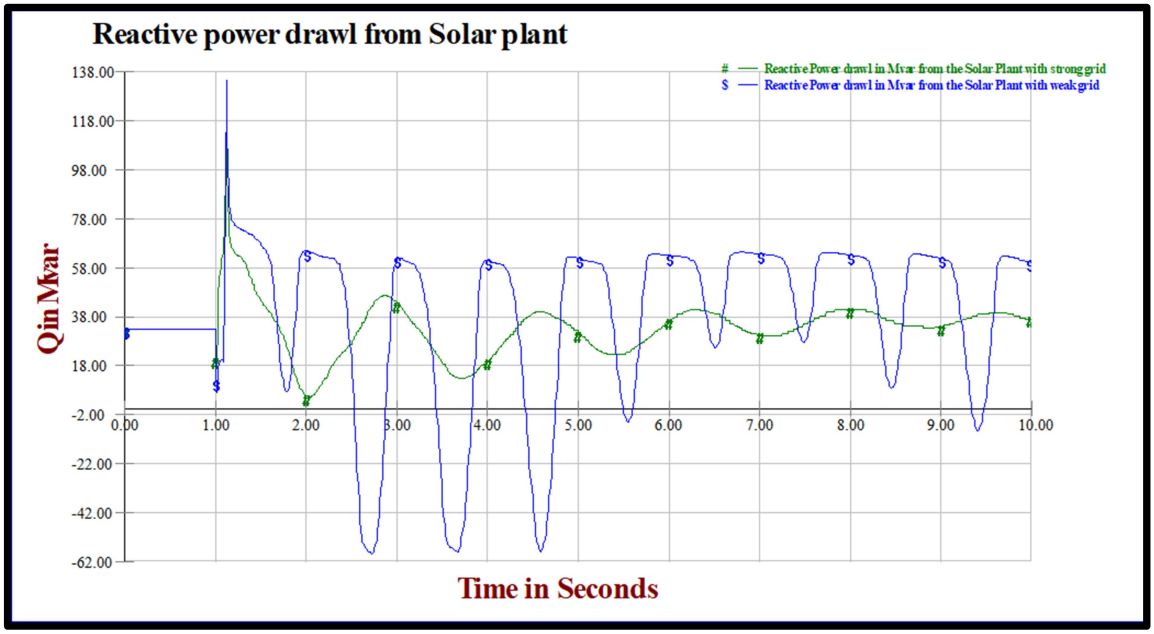

Figure 10-28 Reactive power response of CGP generator having solar penetration with strong and weak grid connectivity

Reliability support received by CGPs containing the Solar power production capacity

Solar power plants are not similar to the synchronous machine based generation units. Increasing penetrations of non-synchronous generation in transmission network could cause the system inertia to fall to dangerously low levels without additional stability support [28]. The recent study in this report is carried out using different scenarios of a typical CGP, which is operating in different levels of solar penetration. The CGP contain no solar generation with only synchronous generating units and the CGP containing similar quantity of solar generation are analyzed comparatively using the N cycle damping index (NCDI). The results in recent research works [29] show that solar photovoltaic injection and reactive power compensation positively and negatively impact the prosumer grid.

Reliability Support received by Solar Plant and the calculation of associated Grid Support charge for strong and weak grid connectivity are compared for a three phase to ground fault scenario inside the CGP bus. Reactive power support received by Solar system for a plant having 0% solar contribution is presented in Figure 10-29.

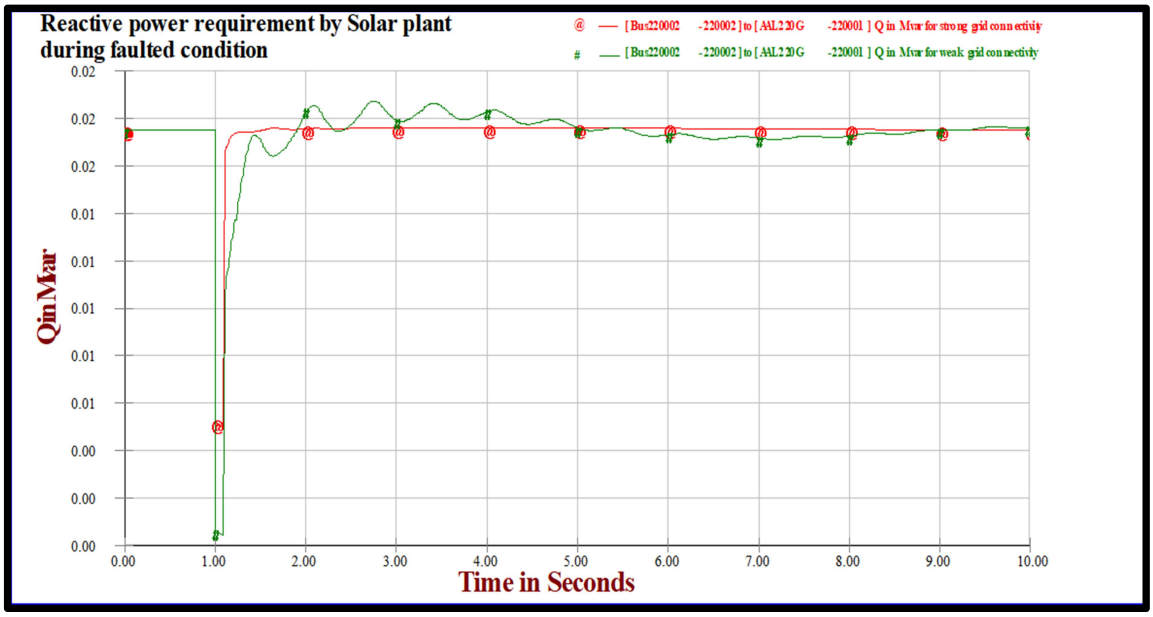

Figure 10-29 Reactive power requirement by plant having 0% solar contribution with strong and weak grid connectivity during three phase to ground fault

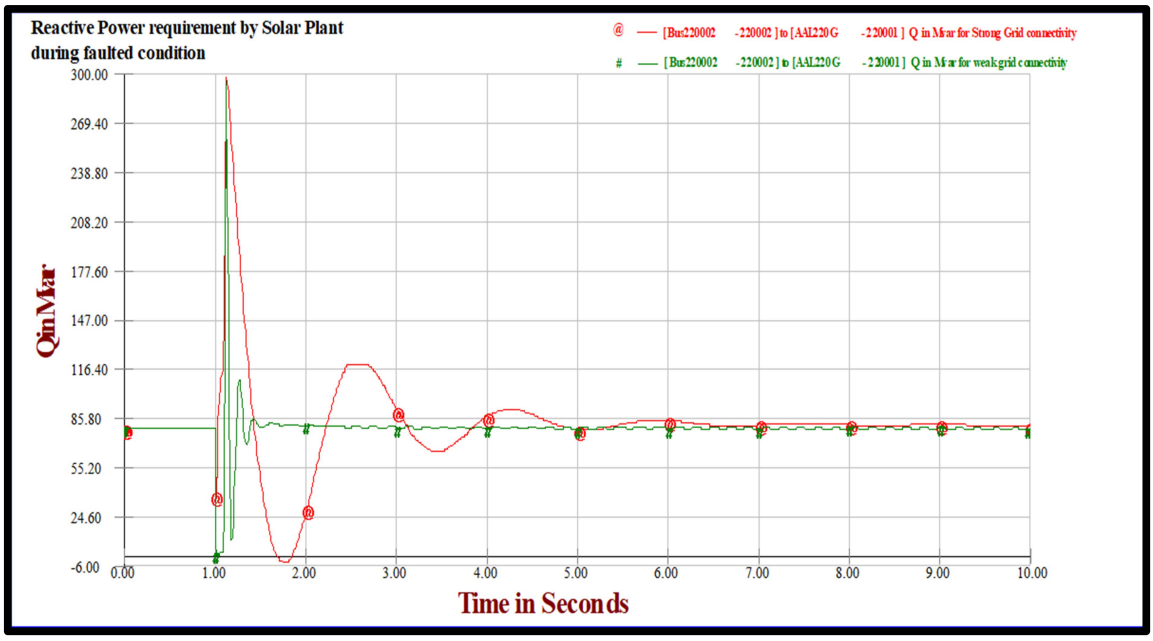

Figure 10-30 Reactive power requirement by solar plant having 100% solar contribution with strong and weak grid connectivity during three phase to ground fault

Reactive power support received by Solar system for a plant having 100% solar contribution is presented in Figure 10-30.

Table 10-1 NCDI for 3PHG strong grid connectivity

Zero percentage Solar penetration	3- Phase to Ground Fault for Strong grid connectivity			
No of Cycle	1	2	3	4
Time stamp	1.06	1.62	2.07	2.78
Reactive power	0.005	0.0175	0.0175	0.0175
NCDI		-7.81242E-05	-1.95332E-05	-8.7E-06

Table 10-2 NCDI for 3PHG weak grid connectivity

Zero percentage Solar penetration	3- Phase to Ground Fault for Weak grid connectivity			
No of Cycle	1	2	3	4
Time stamp	1.09	1.62	2.07	2.78
Reactive power	0.0004	0.0164	0.0185	0.0187
NCDI		-0.00203268	-0.000559774	-0.00025

Table 10-3 NCDI for 3PHG weak grid connectivity

100% percentage Solar penetration	3- Phase to Ground Fault for Weak grid connectivity			
No of Cycle	1	2	3	4
Time stamp	1.13	1.29	1.42	1.64
Reactive power	297.3	175.69	90.06	7.78
NCDI		-0.045121171	-0.00932709	-0.00175

Table 10-4 NCDI for 3PHG strong grid connectivity

100% percentage Solar penetration	3- Phase to Ground Fault for strong grid connectivity			
No of Cycle	1	2	3	4
Time stamp	1.12	2.55	4.27	5.92
Reactive power	295.63	80.417	80.117	79.58
NCDI		-0.071390093	-0.018013039	-0.00801

The corresponding NCDI indices for the reactive power response are presented in following table. This reliability index, gives a comparative result which decide how the CGP is receiving reliability support from the Grid.

According to the exponential relationship, the reduction in grid short circuit level can be attributed to the reduction in the NCDI indices. If, S1 and S2 are the two short circuit fault levels of Grid and N1 and N2 are the corresponding NCDI indices associated to the CGP connected to that grid then the nonlinear exponential equation can be expressed as follows.

$$e^{-p\frac{S1}{S2}} = \frac{N1}{N2}$$

Where, p is the required reliability index

Table 10-5 Summary of NCDI indices

	Average NCDI Indices	Reliability index
0% Solar penetration	0.035975	-0.90099
100% Solar penetration	2.694453	3.022343
Reliability improvement for scenario having 0% and 100% solar penetration		0.22965

Based on the analysis, it can be clearly observed that, for a CGP having 100% solar penetration is receiving 22% reactive support as compared to the reactive support received by a CGP having 0% solar penetration. Therefore, the grid support charge applied on the CGPs having solar generation should be at maximum 22% of the proposed charge by neglecting the transient active power support received during disturbances.

It is to be noted that, the grid support received by a CGP having solar penetration receives full active power support similar to a conventional CGP. In return, the Solar based CGPs are not able to contribute to the fault level of the Grid connection. Apart from this, it is estimated that a solar plant is by virtue of its capacity, is dependent on the grid support for a duration of 4 hours in a day (i.e. 24 hours). Similar assumption is applicable for the Wind Turbine based CGPs with different effective production hours. Beyond that period of time, the CGP will act

like a HT industry only, which is connected to the grid. Therefore, it is appropriate to charge the solar based CGPs with one sixth of the proposed grid support charge.

10.5. Transient support calculation using damping index

$$N\ Cycle\ Damping\ Index\ (NCDI) = \frac{ln\left(\frac{M_{t1}}{M_{tn}}\right)}{\sqrt{1+\left(\frac{2n}{ln\ \frac{M_{t1}}{M_{tn}}}\right)^2}}$$

It is estimated that the short circuit MVA in the grid at the point of common coupling is exponentially related to the damping indices in a particular range where the CGP and grid are operating in stable and floating mode.

The damping index discussed in above equation can be treated as a relative parameter to compare the support received by the CGP from the grid. This gives a measure of how the CGP are responding to the grid during transient disturbances by the help of an index. The responses of the NCD indices for different values of n are presented in Figure 10-31. In Figure 10-31, the x-axis is considered by the ratio of 1st peak magnitude to the Nth peak magnitude.

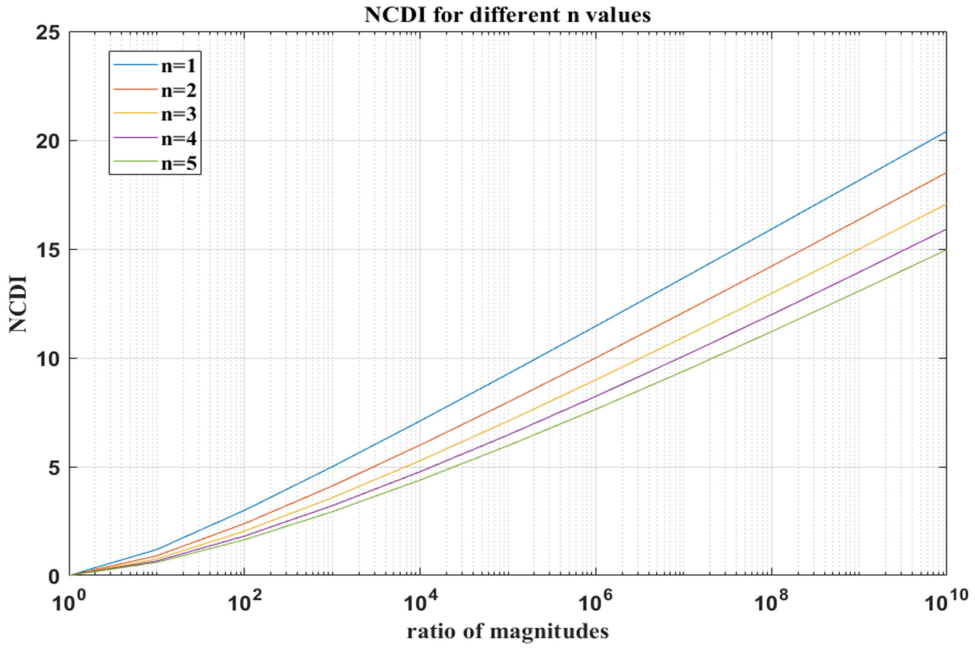

Figure 10-31 Variation of NCDI based on the ratio

A comparative study of this damping indices are presented for three phase to ground fault at Vedanta plant in different power exchange scenarios. Table 10-6 represents the N cycle damping index calculation for a three phase to ground fault scenario for Vedant plant operating in floating mode with strong grid connectivity. Table 10-7 represents the N cycle damping index calculation for a three phase to ground fault scenario for Vedant plant operating in floating mode with weak grid connectivity.

Table 10-6 NCDI for strong grid and floating mode

	Three Phase to Ground fault in strong grid condition for Vedanta operating in floating mode				
No of Cycle	1	2	3	4	5
Time stamp	1.11	1.62	2.17	3.25	3.78
Frequency	50.6948	50.391	50.2701	50.1878	50.1331
NCDI		8.6E-12	5.9E-12	4.5E-12	3.4E-12

Table 10-7 NCDI for weak grid and floating mode

	Three Phase to Ground fault in weak grid condition for Vedanta operating in floating mode				
No of Cycle	1	2	3	4	5
Time stamp	1.12	2.14	3.07	3.97	4.86
Frequency	50.7539	50.7118	50.6447	50.5857	50.5096
NCDI		2.3E-14	9.9E-14	1.6E-13	2.8E-13

Table 10-8 represents the N cycle damping index calculation for a three phase to ground fault scenario for Vedant plant operating in export mode with strong grid connectivity. Table 10-9 represents the N cycle damping index calculation for a three phase to ground fault scenario for Vedant plant operating in export mode with weak grid connectivity.

Table 10-8 NCDI for strong grid and export mode

	Three Phase to Ground fault in strong grid condition for Vedanta operating in export mode				
No of Cycle	1	2	3	4	5
Time stamp	1.09	1.62	2.17	2.71	3.24
Frequency	50.6159	50.573	50.3945	50.2732	50.1909
NCDI		2.4E-14	8.4E-13	1.4E-12	1.5E-12

Table 10-9 NCDI for weak grid and export mode

	Three Phase to Ground fault in weak grid condition for Vedanta operating in export mode				
No of Cycle	1	2	3	4	5
Time stamp	1.13	2.6	3.54	4.53	5.48

	Three Phase to Ground fault in weak grid condition for Vedanta operating in export mode				
No of Cycle	1	2	3	4	5
Frequency	50.7594	50.5708	50.4922	50.48	50.4099
NCDI		2E-12	1.5E-12	7.4E-13	8.2E-13

Table 10-10 represents the N cycle damping index calculation for a three phase to ground fault scenario for Vedant plant operating in import mode with strong grid connectivity. Table 10-11 represents the N cycle damping index calculation for a three phase to ground fault scenario for Vedant plant operating in import mode with weak grid connectivity.

Table 10-10 NCDI for strong grid and import mode

	Three Phase to Ground fault in strong grid condition for Vedanta operating in import mode				
No of Cycle	1	2	3	4	5
Time stamp	1.1	1.64	2.21	2.79	3.36
Frequency	50.3132	50.2802	50.1051	50.063	50.0401
NCDI		1.1E-14	7.1E-13	5.5E-13	4E-13

Table 10-11 NCDI for weak grid and import mode

	Three Phase to Ground fault in weak grid condition for Vedanta operating in import mode				
No of Cycle	1	2	3	4	5
Time stamp	1.11	1.99	2.87	3.76	4.64
Frequency	50.3415	50.3135	50.2836	50.2448	50.2036
NCDI		6.8E-15	1.5E-14	3.1E-14	5.1E-14

Based on the indices, calculated from different transient stability study during a floating mode of plant operation, it is estimated that the damping index improves by a factor of 100 to 100000. As discussed in the previous section, the reliability index (p) can be presented in the following equation.

$$e^{-p\frac{S1}{S2}} = \frac{N1}{N2}$$

This improvement in the damping index, when applied in the above equation, the corresponding reliability index varies in the range of 0.27 to 0.65.

10.6. Waveform Distortion from PCC for CGPs

Due to the presence of nonlinear loads and captive generation, the sinusoidal waveforms associated to the voltage and current parameters deviate from the conventional sinusoidal nature. The sample waveforms with transient distortions measured at PCC for BPPL CGP is presented in Figure 10-32 to 10-37.

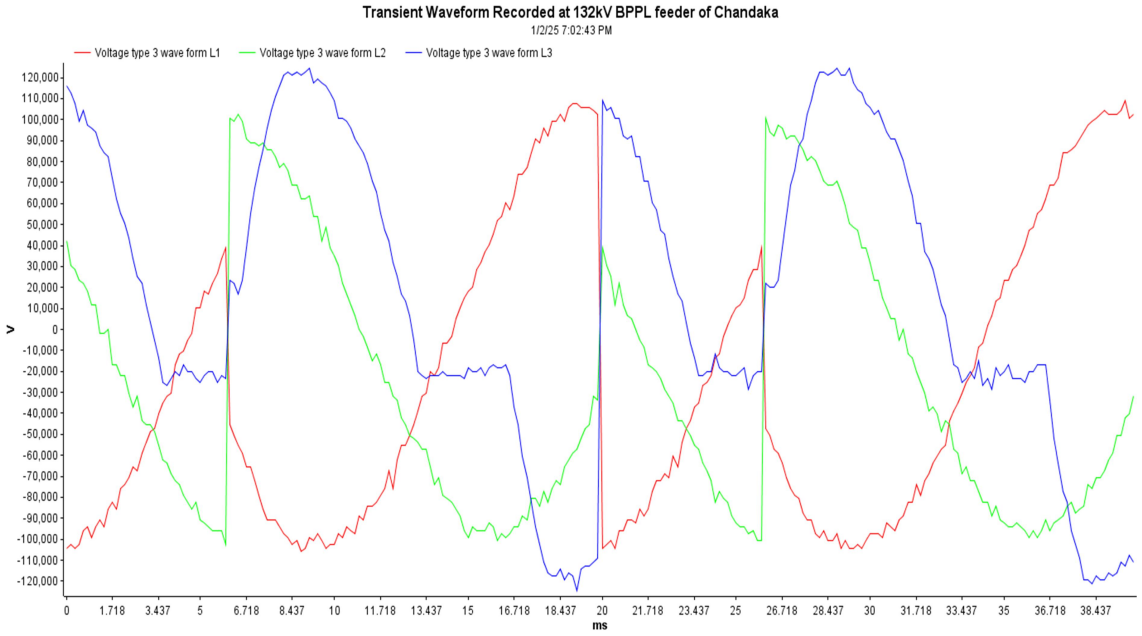

Figure 10-32 Distorted waveform measured at PCC

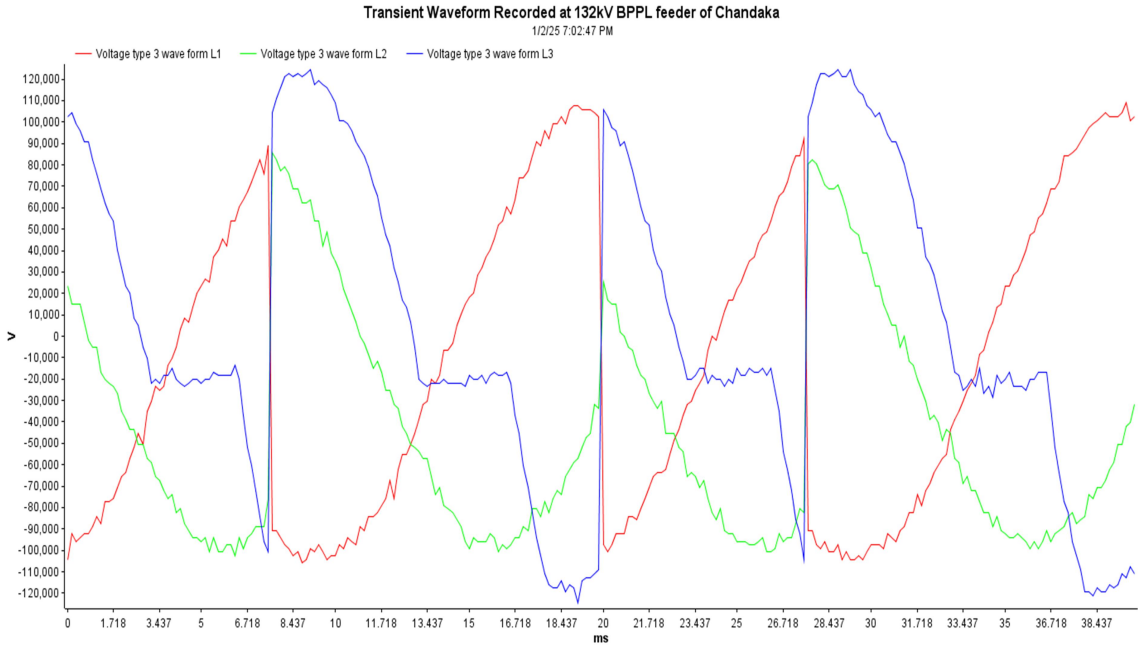

Figure 10-33 Distorted waveform measured at PCC

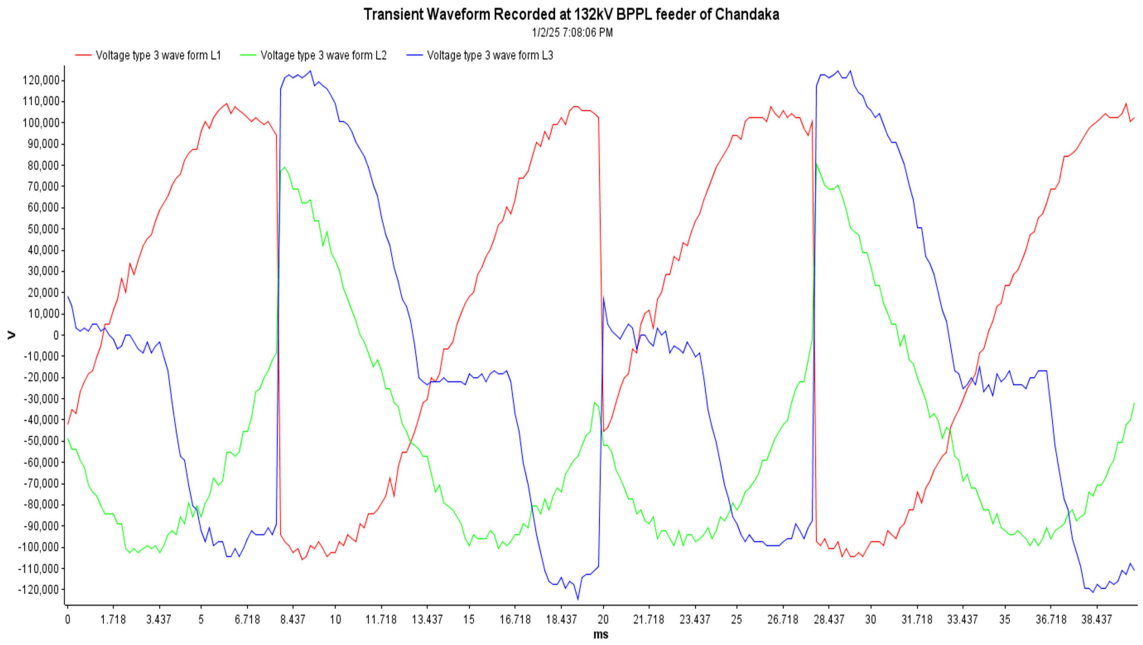

Figure 10-34 Distorted waveform measured at PCC

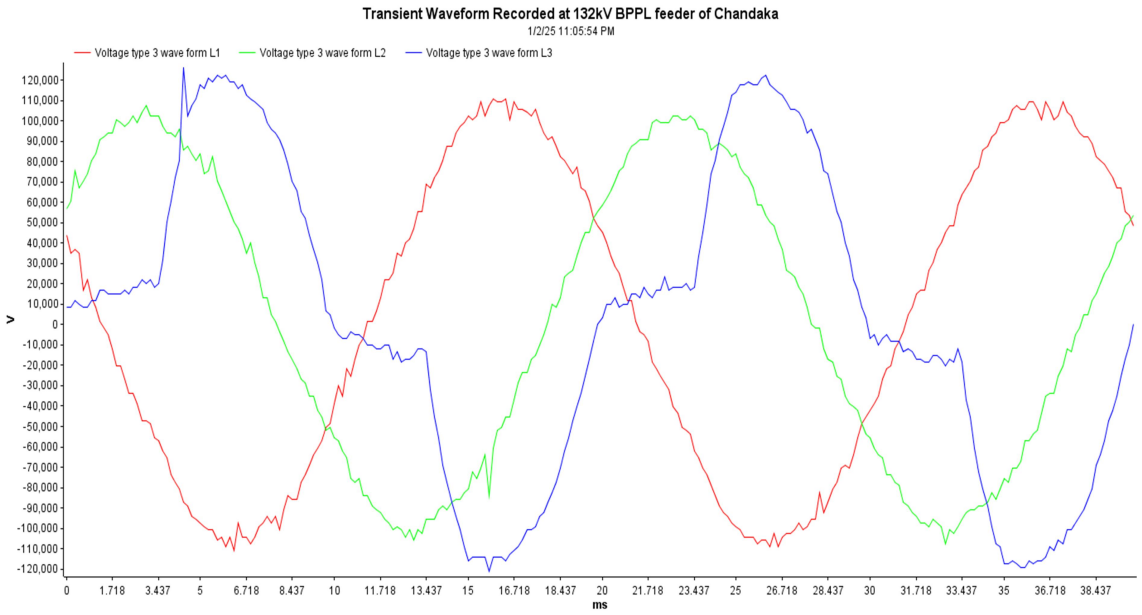

Figure 10-35 Distorted waveform measured at PCC

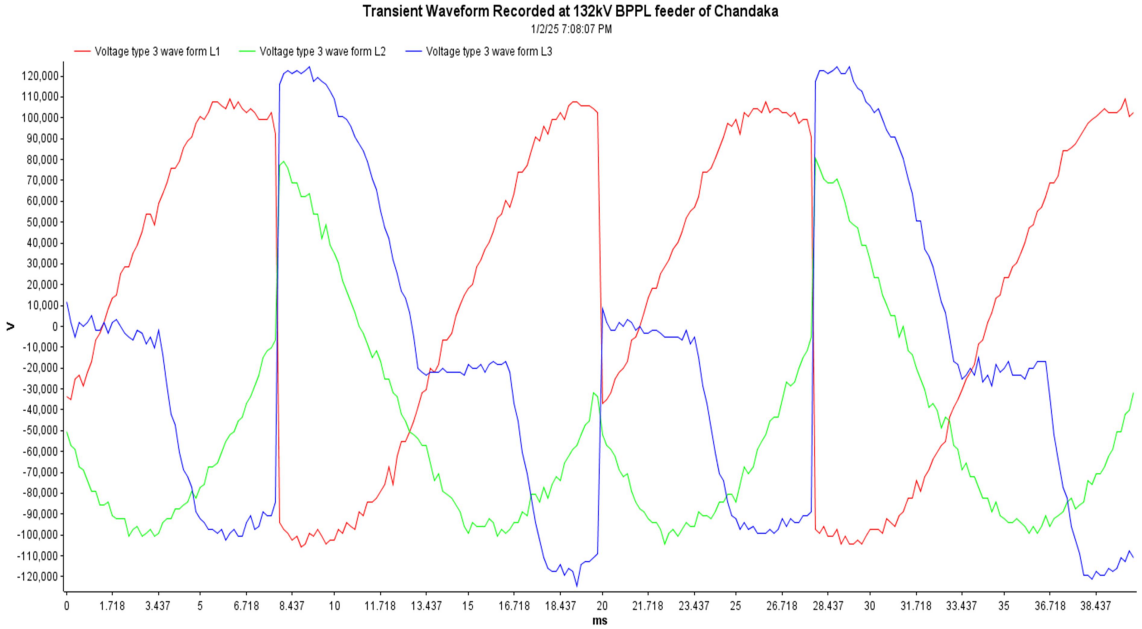

Figure 10-36 Distorted waveform measured at PCC

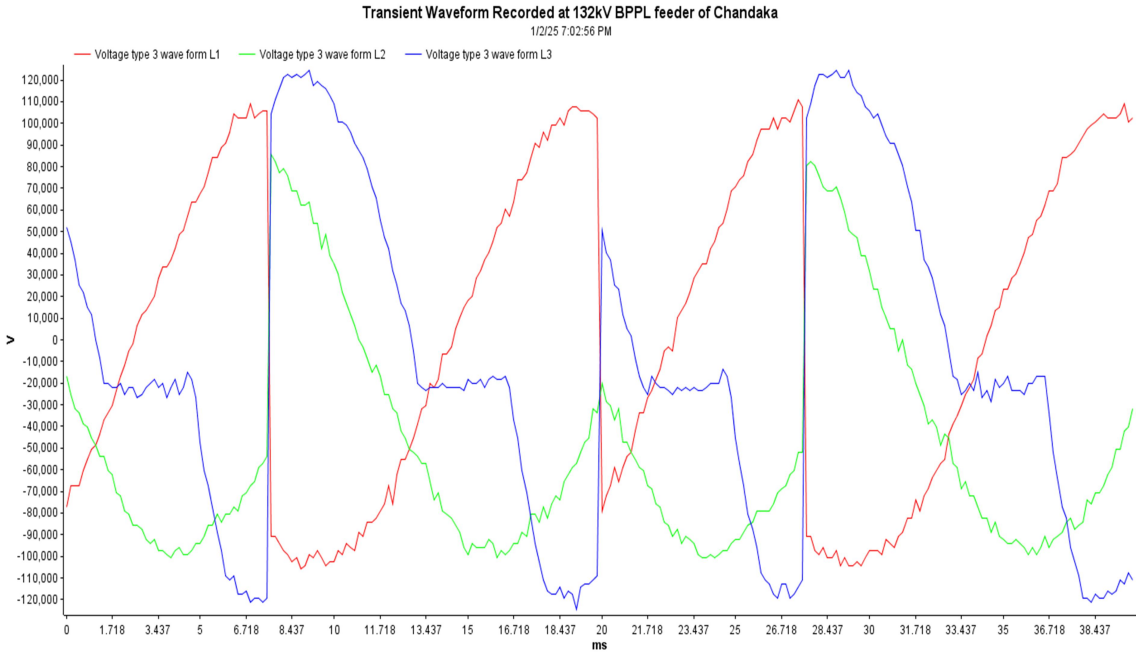

Figure 10-37 Distorted waveform measured at PCC

10.7. Power factor measurement of CGP at the PCC

The sample power factor data recorded at the PCC for the CGP are presented in Figure 10-38 to 10-41.

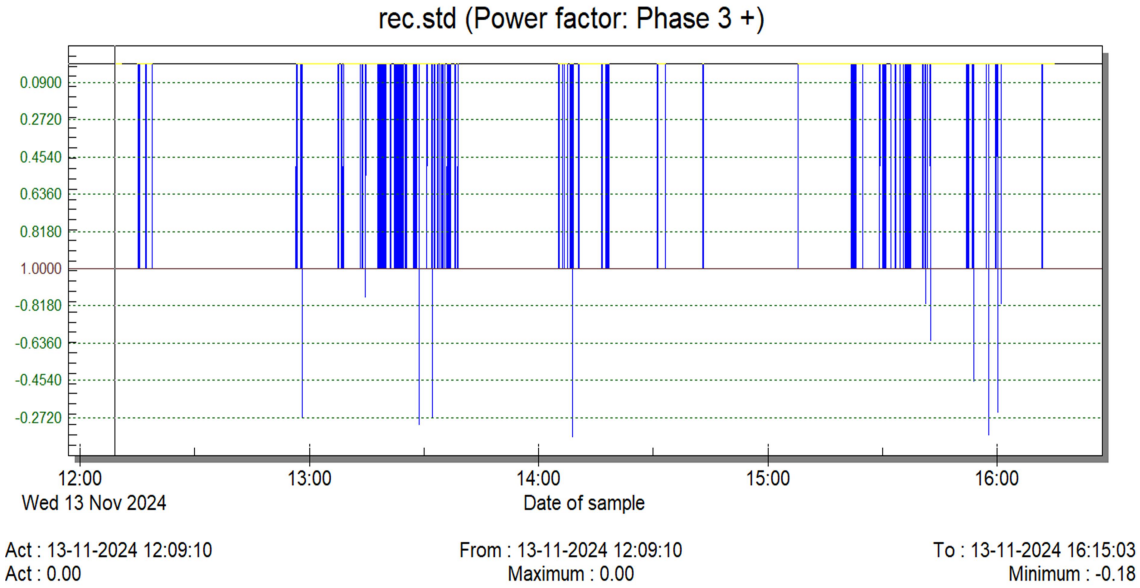

Figure 10-38 Power factor of JSW

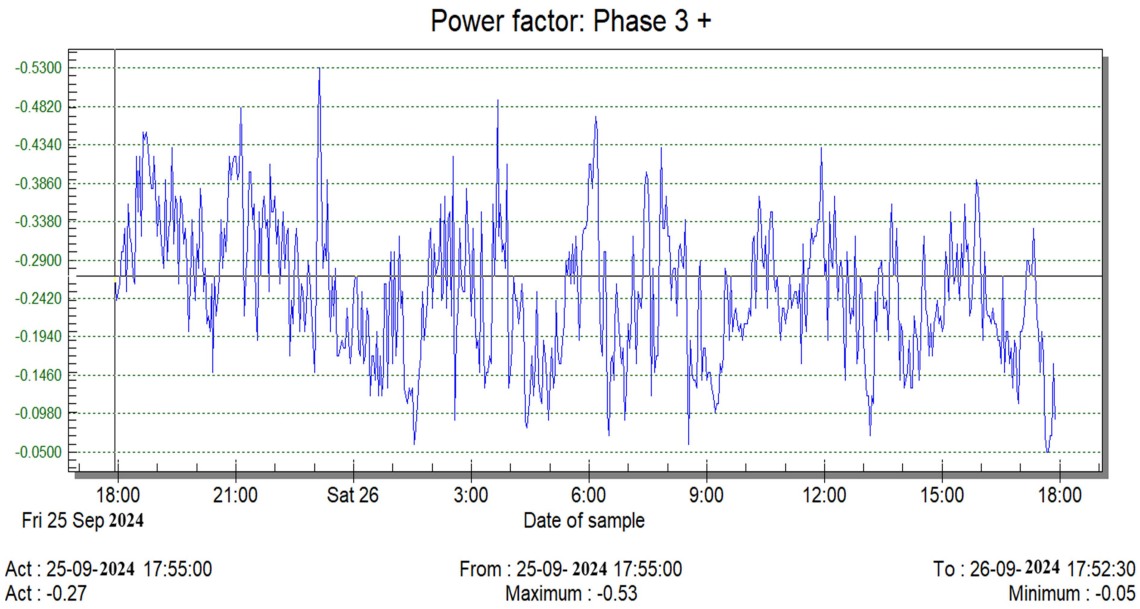

Figure 10-39 Power factor of IMFA

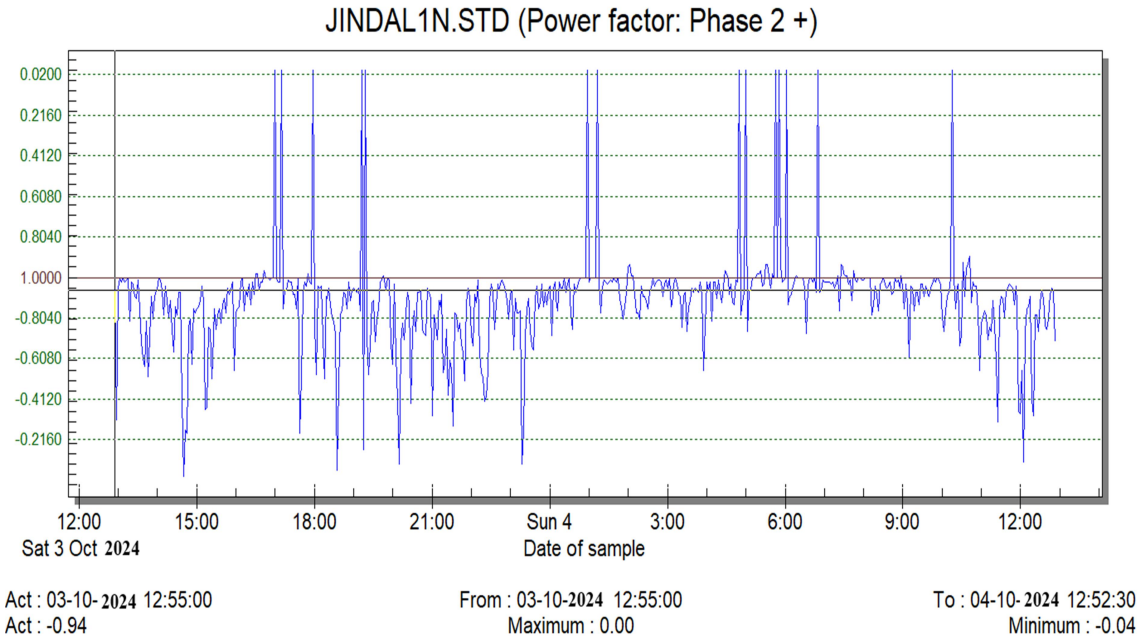

Figure 10-40 Power factor of Jindal

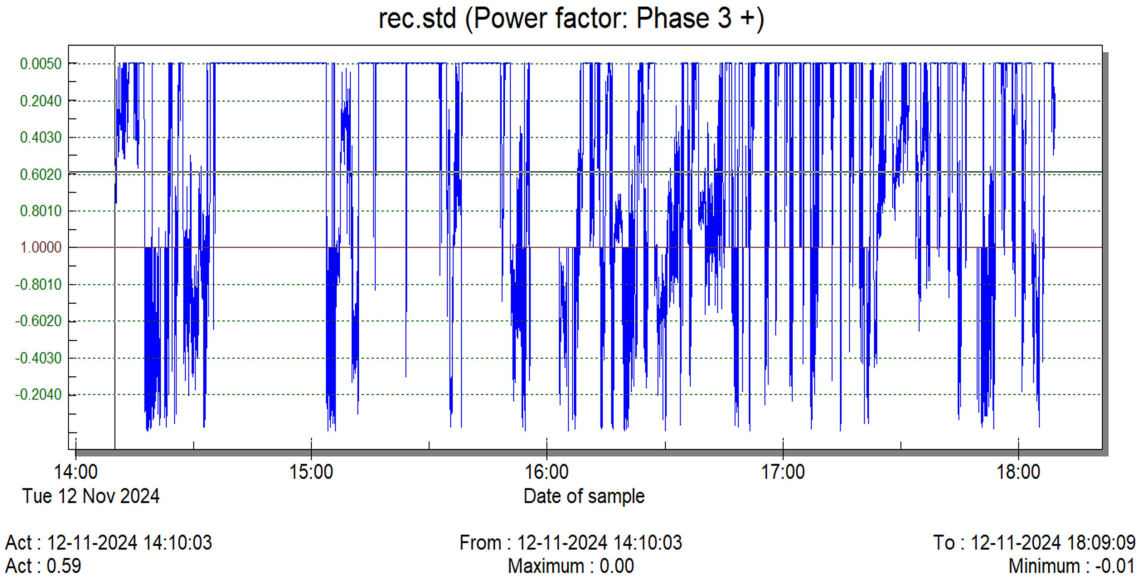

Figure 10-41 Power factor of Tata Steel Bhusan

10.8. Reactive power measurement at PCC

The sample reactive power data recorded at the PCC for the CGP are presented in Figure 10-42 to 10-47.

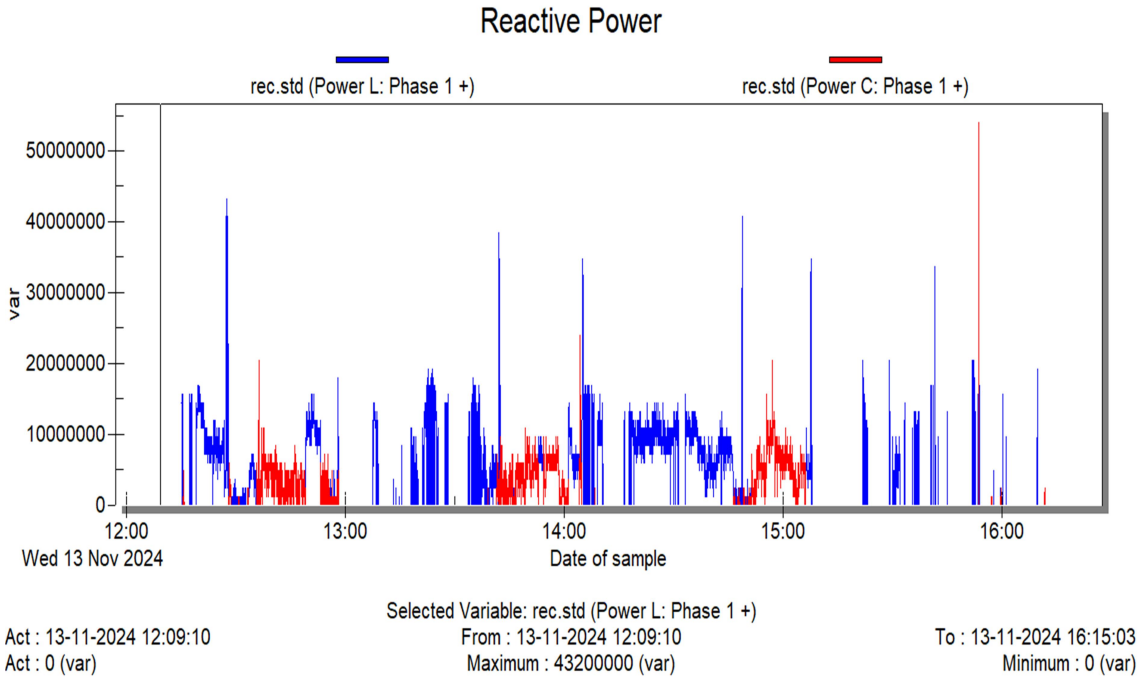

Figure 10-42 Reactive Power of JSW

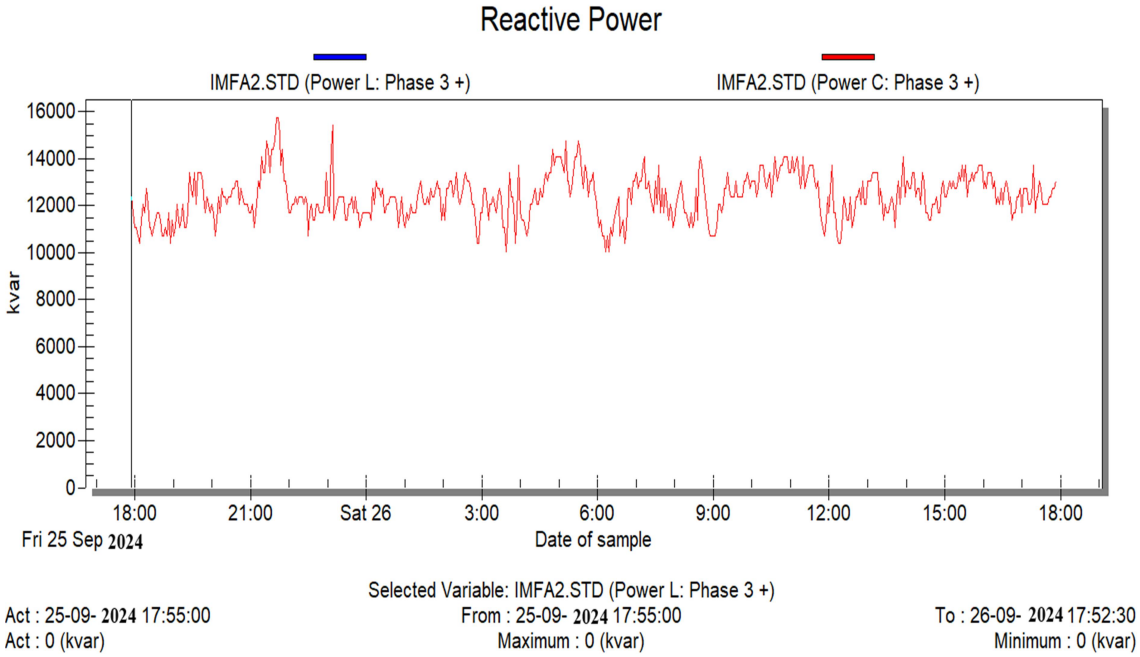

Figure 10-43 Reactive Power of IMFA

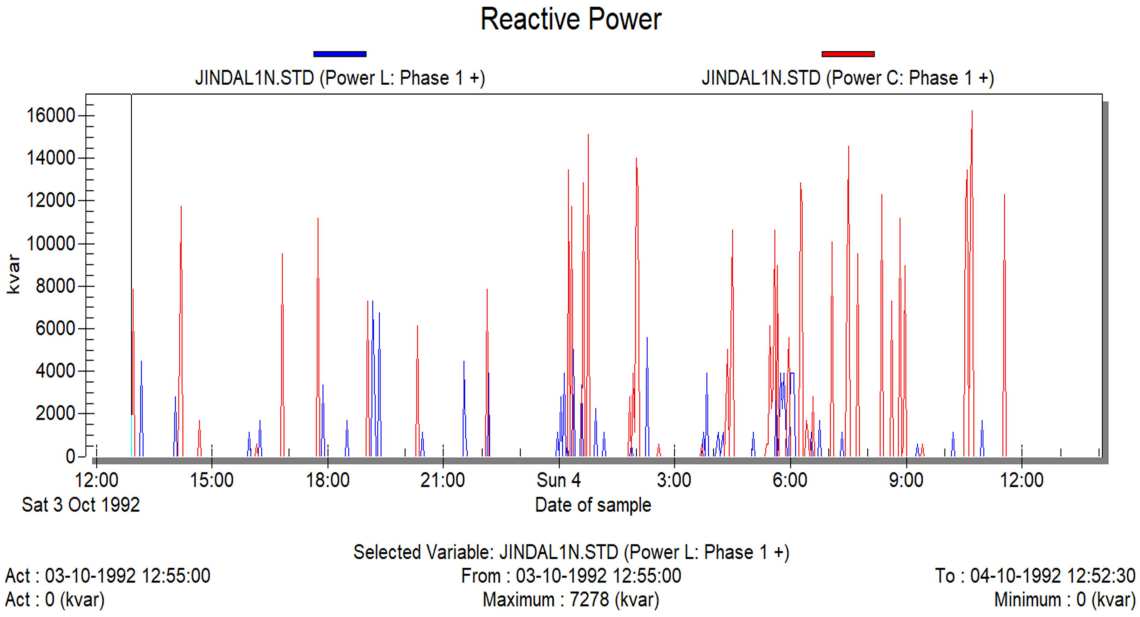

Figure 10-44 Reactive Power of Jindal

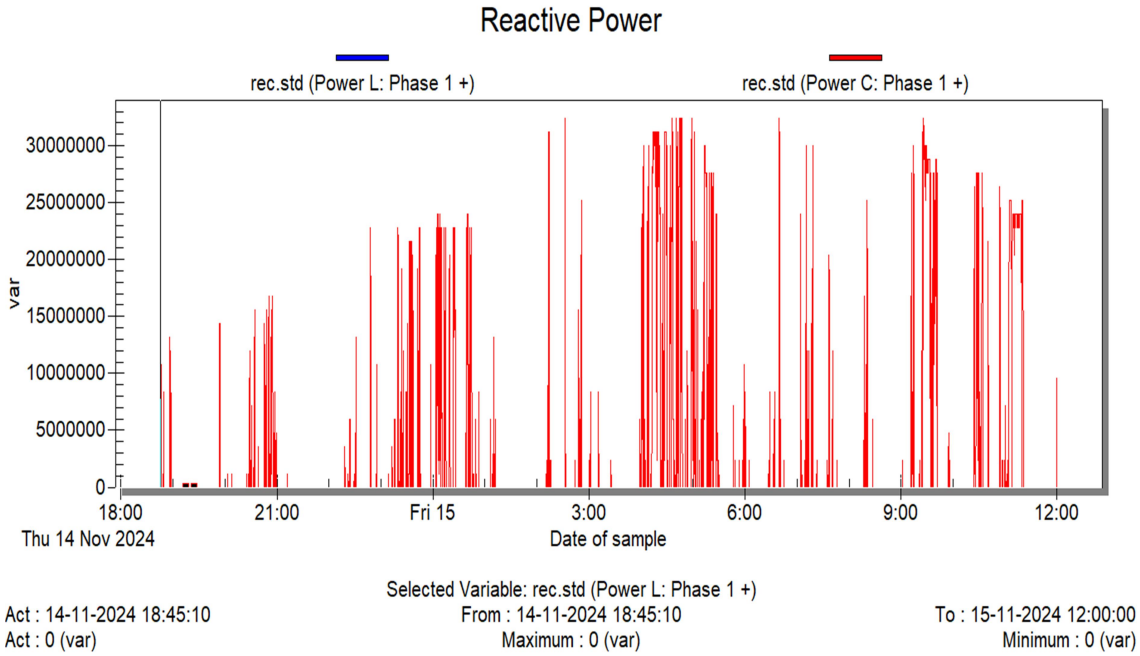

Figure 10-45 Reactive Power of Utkal Alumina

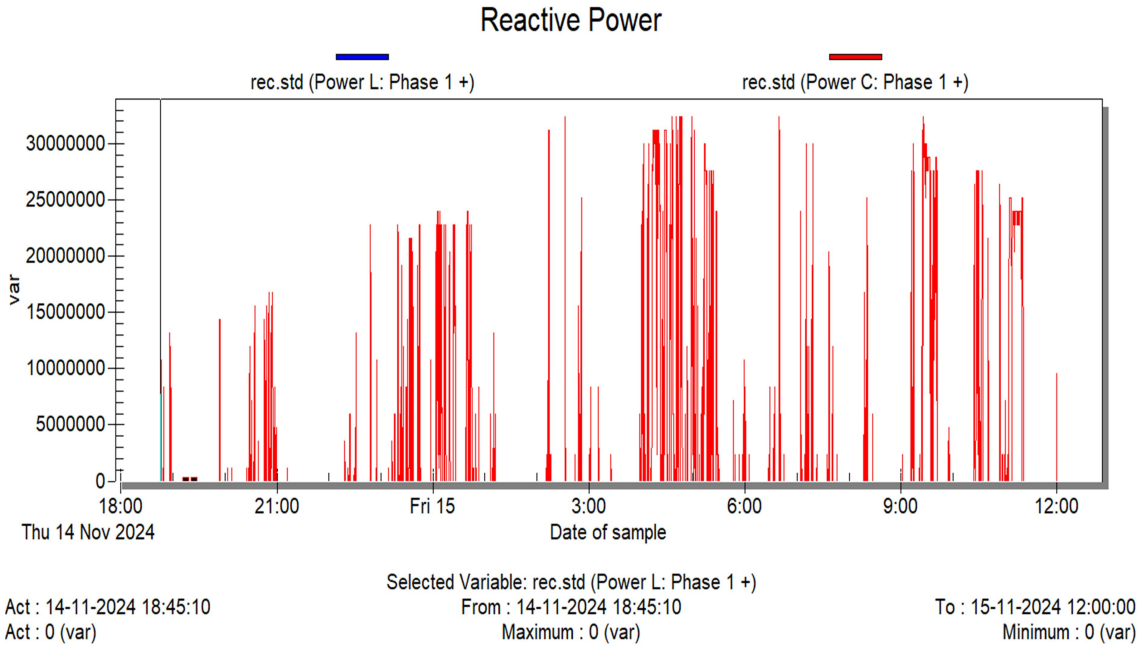

Figure 10-46 Reactive Power of Arcelor Mittal

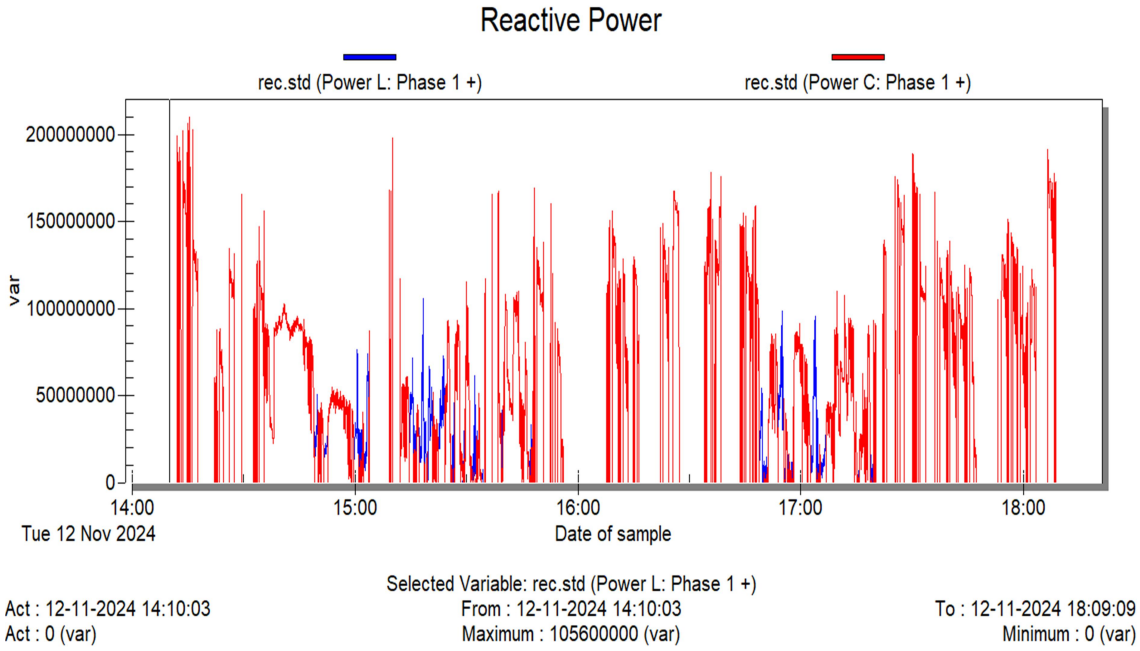

Figure 10-47 Reactive Power of Tata Steel Bhusan

11. PROPOSED GSC CALCULATION

11.1.Comparison of methods for the calculation of GSC

Comparison of the methods discussed in the previous section for calculating the Grid Support charge is presented in the table 11-1 below.

Table 11-1 Comparison of GSC calculation methods

Methods for calculating the Grid Support charge	Merits	Demerits
Spinning reserve approach	• It determines the reserve requirement of industrial consumers who run their captive units on constant power mode. • It takes care of the unused capacity of STU which will respond voluntarily during contingencies within a given time frame.	• Does not quantify the reliability support. • The calculation depends on installed capacity.
Peak Instantaneous Demand based GSC	• Takes care of instantaneous demand support received by CGPs. • Suitable for large CGPs having large inductive machines exhibiting extreme transient behavior.	• Requires measurement with high sampling rates.

Methods for calculating the Grid Support charge	Merits	Demerits
Specific Energy Consumption based GSC	• It takes care of generator ramp rate in CGPs. • It takes care of instantaneous peak or variable power requirements minus the constant scheduled power in a day. • Specific energy consumption in an industry is quantified at plant level as well as plant process level. • It takes into account the instantaneous support given by grid CGPs which may not be recorded in a time block.	• Requires measurement of instantaneous power at the PCC using smart measuring meter. • Calculation of Specific Energy Consumption is a conflicting matter for the utility and CGP.
GSC based on adaption of POC framework	• N-1 contingency studies are used to identify the reliability model. • It takes into account the system operating conditions and contingency probability of disturbances. • That dynamic security assessment relies on methodologies for evaluating the damping and stability margin of the system after transient conditions. • Calculation of accumulated potential energy index.	• It depends on the simulation studies that take care of probable transient situations. • Exact network modeling of the plant is necessary to arrive at a composite reliability index (with suitable weights).
Base MVA method	• Considers the fault level at the PCC with the OPTCL grid. • The fault level contribution takes into account the reliability associated to absorbing load variations / fluctuations. • The reliability support received is calculated based on the minimum support availed. • It takes care of installed capacity, contracted demand, and average scheduled power export. • No real time measurement required.	

11.2. Empirical formula for Grid Support charge based on Base MVA method (proposed in previous report)

Grid Support charge per KVA per month to be charged on the CGPs will be determined based on the following empirical formula. This formula is used in consequent tables for evaluating the individual grid support charge of CGPs.

$$\frac{\left(\left(\frac{GH}{12\,I}\,\frac{min(C,A)\,-D}{A}\right)+E\right)(A-B-F)}{A}$$

Where, A is the installed capacity of the concerned CGP in KVA

B is the Contracted demand in KVA

C is the equivalent generator from grid side at PCC = Grid side fault contribution (at PCC) x Transient reactance

D is the Support provided by CGP to Utility (Calculated based on fault MVA)

E is no load loss cost

F is the average export

G is the charge to be levied from CGP

H is the percentage of CGP installed capacity out of net Odisha generation

I is the net installed capacity of all CGPs in Odisha

After determining the individual GSC for all CGPs, the proposed GSC is estimated by averaging the GSC of individual CGPs.

11.3. Calculation of unit transmission charge

The proposed grid support charge is calculated based on the Base MVA method which is evaluated from the short circuit contribution. In the Base MVA method of grid support charge calculation, unit transmission charge and cost of no-load loss are some of the important components. The unit transmission charge in Rs/KVA/month is calculated from the total generation installed capacity of state and net transmission cost as mentioned in following tables. Table 11-2 represents the net installed capacity of the state that is handled by the State Transmission Utility.

Table 11-2 Generation of State

Component	Installed Capacity in MW
State Sector Installed Capacity	6240
Central Sector Installed Capacity	5920
IPP	4937
CGP	11604.17
TOTAL	28701.17

According to the net generation of Odisha network, CGP installed capacity accounts for the 40.43 % of the net generation installed capacity of Odisha system. The calculation of Transmission charge is adopted from the ARR submitted by OPTCL to OERC. According to the submitted ARR, Total Transmission Cost is 1434.95 Crore rupees However, in practice, the Charge per month per KVA to be levied from CGP is only a portion of Rs. 37.5/KVA/month (approx.).

Table 11-3 Transmission charge calculation

Variables	Cost in Crore
Total Transmission Cost	1435.0
Charge to be levied from CGPs (40 % of net transmission cost)	580.2
Charge per month to be levied from CGP	48.3
CGP Installed capacity in KVA	12893522
Charge Per Month per KVA to be Levied from CGP	37.50

Similar to the transmission charge calculation in rupees per KVA per month, the cost of no-load loss per KVA per month is calculated as follows in Table 11-4. Assuming, no load power factor and corresponding no load loss percentage of transformer to be 0.1 and 0.3%, the cost of no-load cost per KVA per month is estimated to be Rs 1.11/KVA/month.

Table 11-4 Calculation of No-Load Loss

Net Transformation capacity of OPTCL in MVA	32765
No Load Power factor	0.1
No Load Transformation in MW	3276.5
Loss percentage for Transformer	0.3
Transformer Loss	9.8295
Loss per month in Units	7077240
Unit Cost	5
Cost of No load loss per month	35386200
Cost of No-load loss per KVA per month	1.11

11.4.Proposed Grid Support Charge

The reliability support received by each CGP is calculated from the short circuit sharing by the CGP and Grid at the point of common coupling as shown in Table 11-5. Although, Odisha contains, 59 CGPs, but due to various reasons, only 53 are considered in the calculation. However, all 59 CGPs are considered for the study. ABRL Solar Saintala, ABRL

Solar Khajuriakata, and BEL Saintala, are included in the study but due to non-co-located loads, these are not included in the calculation of GSC. Shree Cement is considered in the study, but are not included in the calculation due to solar contribution. Similarly, SIVA cement and Thakur Prasad are also included in the study but due to unavailability of data related to contracted demand, these are removed from the calculation of GSC.

Table 11-5 Table for calculation of reliability support

SL No	Name of the CGP	Grid Side Fault Contribution (Point of Common Contact) (MVA)	Fault level at PCC (MVA)	Fault Contribution by CGP side (MVA)	Transient Reactance (PU)	Equivalent Generation from Grid Side (MVA)	Total Installed Capacity in MW	Total installed Capacity in MVA	CD(MVA)	Export (MVA)*	Base MVA (MVA)	Additional Support (MVA)**	CGP to UTILITY (MVA)	Reliability Support (MVA)
		1	2	3=2-1	4	5=1*4	6	7	8	9	10= 7-8-9	11=Min(5, 7)	12=(7x3)/2	13=10*(11-12)/7
1	AARTI STEEL LIMITED,Ghantikhal	2059.8	3076.0	1016.2	0.23	473.8	90.0	100.0	11.1	0.0	88.9	100.0	33.0	59.5
2	ACC, BARGARH	2196.8	2301.9	105.0	0.34	746.9	30.0	33.3	5.0	0.0	28.3	33.3	1.5	27.0
3	ADHUNIK METALLIKS LTD,Jharsuguda	1792.6	1890.8	98.2	0.20	358.5	22.5	25.0	3.5	0.0	21.5	25.0	1.3	20.4
4	ACTION ISPAT & POWER PVT.LTD,Jharsuguda	5996.7	6229.7	232.9	0.20	1199.3	80.0	88.9	9.0	0.0	79.9	88.9	3.3	76.9
5	ARYAN ISPAT & POWER PVT.LTD,Sambalpur	4884.6	4969.1	84.5	0.20	976.9	18.0	20.0	5.0	0.0	15.0	20.0	0.3	14.7
6	ADITYA ALUMINIUM LTD,Rengali	15726.4	18809.3	3082.9	0.23	3617.1	900.0	1000.0	55.6	0.0	944.4	1000.0	163.9	789.6
7	AM NIPPON STEEL INDIA LTD,Paradeep(Earlier ESSAR)	8019.2	8209.5	190.3	0.34	2726.5	60.0	66.7	32.0	0.0	34.7	66.7	1.5	33.9
8	BHUBANESWAR POWER PVT.LTD.Athagarh	9065.9	11543.6	2477.7	0.23	2085.2	135.0	150.0	5.6	0.0	144.4	150.0	32.2	113.4
9	TATA STEEL LTD. Meramundali	12575.0	15307.7	2732.7	0.23	2892.3	740.0	822.2	90.0	0.0	732.2	822.2	146.8	601.5

SL No	Name of the CGP	Grid Side Fault Contribution (Point of Common Contact) (MVA)	Fault level at PCC (MVA)	Fault Contribution by CGP side (MVA)	Transient Reactance (PU)	Equivalent Generation from Grid Side (MVA)	Total Installed Capacity in MW	Total installed Capacity in MVA	CD(MVA)	Export (MVA)*	Base MVA (MVA)	Additional Support (MVA)**	CGP to UTILITY (MVA)	Reliability Support (MVA)
		1	2	3=2-1	4	5=1*4	6	7	8	9	10= 7-8-9	11=Min(5, 7)	12=(7x3)/2	13=10*(11-12)/7
10	BHUSHAN POWER &STEEL LTD.Jharsuguda	16875.8	18809.3	1933.4	0.24	4050.2	513.0	570.0	200.0	0.0	370.0	570.0	58.6	332.0
11	EMAMI PAPER MILLS , Baleswar	1831.4	1963.9	132.4	0.20	366.3	33.5	37.2	13.0	0.0	24.2	37.2	2.5	22.6
12	FACOR POWER LTD. Bhadrak	3233.6	3461.9	228.4	0.20	646.7	45.0	50.0	5.5	0.0	44.5	50.0	3.3	41.6
13	HINDALCO INDUSTRIES LTD. Hirakud	6188.6	7330.4	1141.8	0.19	1175.8	467.5	519.4	40.0	0.0	479.4	519.4	80.9	404.8
14	IMFA, Choudwar	2562.2	3692.6	1130.4	0.20	512.4	258.0	286.7	0.0	0.0	286.7	286.7	87.8	198.9
15	INDIA OIL CORPORATION LTD. , Paradeep	6641.5	8209.5	1568.1	0.20	1328.3	366.0	406.7	52.0	0.0	354.7	406.7	77.7	286.9
16	IFFCO LIMITED ,Paradeep	4133.3	4398.2	264.9	0.31	1281.3	110.0	122.2	11.0	0.0	111.2	122.2	7.4	104.5
17	JINDAL STAINLESS LTD.Duburi	9157.2	10340.9	1183.7	0.23	2106.2	263.0	292.2	72.0	0.0	220.2	292.2	33.4	195.0
18	JINDAL STEEL & POWER LTD. Anugul	26669.7	29700.6	3031.0	0.22	5867.3	810.0	900.0	90.0	0.0	810.0	900.0	91.8	727.3
19	KJS AHLUWALIA STEEL, Barbil	727.9	848.9	121.0	0.20	145.6	28.0	31.1	8.0	0.0	23.1	31.1	4.4	19.8
20	NINL,Duburi	8434.1	8635.8	201.7	0.20	1686.8	62.5	69.4	50.0	0.0	19.4	69.4	1.6	19.0
21	MAHAVIR FERRO ALLOYS PVT. LTD.	787.8	828.9	41.1	0.20	157.6	15.0	16.7	3.0	0.0	13.7	16.7	0.8	13.0

SL No	Name of the CGP	Grid Side Fault Contribution (Point of Common Contact) (MVA)	Fault level at PCC (MVA)	Fault Contribution by CGP side (MVA)	Transient Reactance (PU)	Equivalent Generation from Grid Side (MVA)	Total Installed Capacity in MW	Total installed Capacity in MVA	CD(MVA)	Export (MVA)*	Base MVA (MVA)	Additional Support (MVA)**	CGP to UTILITY (MVA)	Reliability Support (MVA)
		1	2	3=2-1	4	5=1*4	6	7	8	9	10= 7-8-9	11=Min(5, 7)	12=(7x3)/2	13=10*(11-12)/7
	Rourkela													
22	MAITHAN ISPAT NIGAM LTD.Jajpur	10234.3	10340.9	106.6	0.34	3479.7	30.0	33.3	10.0	0.0	23.3	33.3	0.3	23.1
23	MSP METALICS LTD, Jharsuguda	6775.4	6923.9	148.4	0.20	1355.1	25.0	27.8	9.5	0.0	18.3	27.8	0.6	17.9
24	MGM MINERALS LIMITED	4471.3	4539.8	68.5	0.20	894.3	8.0	8.9	2.8	0.0	6.1	8.9	0.1	6.0
25	NALCO, Angul	13214.4	15307.7	2093.3	0.20	2642.9	1200.0	1333.3	0.0	0.0	1333.3	1333.3	182.3	1151.0
26	NALCO, Damanjodi	4662.4	4970.6	308.3	0.20	932.5	74.0	82.2	0.0	0.0	82.2	82.2	5.1	77.1
27	NARBHERAM POWER & STEEL PVT. Dhenkanal	3005.2	3073.7	68.5	0.20	601.0	8.0	8.9	3.0	0.0	5.9	8.9	0.2	5.8
28	NBVL, MERAMUNDULI	4142.5	4539.8	397.3	0.19	787.1	90.0	100.0	3.0	0.0	97.0	100.0	8.8	88.5
29	OCL INDIA LTD., RAJGANGPUR	3219.9	3402.6	182.7	0.28	901.6	54.0	60.0	13.0	0.0	47.0	60.0	3.2	44.5
30	OISL, Rajgangapur	3288.4	3402.6	114.2	0.34	1118.1	35.0	38.9	5.5	0.0	33.4	38.9	1.3	32.3
31	ORISSA SPONGE IRON & STEEL LTD,Barbil	1404.4	1541.4	137.0	0.20	280.9	36.0	40.0	4.0	0.0	36.0	40.0	3.6	32.8
32	PARADEEP PHOSPHATES LTD,Paradeep	6858.4	7330.4	471.9	0.20	1371.7	55.0	61.1	23.0	0.0	38.1	61.1	3.9	35.7

SL No	Name of the CGP	Grid Side Fault Contribution (Point of Common Contact) (MVA)	Fault level at PCC (MVA)	Fault Contribution by CGP side (MVA)	Transient Reactance (PU)	Equivalent Generation from Grid Side (MVA)	Total Installed Capacity in MW	Total installed Capacity in MVA	CD(MVA)	Export (MVA)*	Base MVA (MVA)	Additional Support (MVA)**	CGP to UTILITY (MVA)	Reliability Support (MVA)
		1	2	3=2-1	4	5=1*4	6	7	8	9	10= 7-8-9	11=Min(5, 7)	12=(7x3)/2	13=10*(11-12)/7
33	MGM Minerals Ltd,Keonjhar(Earlier Patnaik Steel)	2098.6	2253.9	155.3	0.20	419.7	8.0	8.9	1.5	0.0	7.4	8.9	0.6	6.9
34	RATHI STEEL & POWER LTD,Sambalpur	713.6	789.6	75.9	0.20	142.7	20.0	22.2	4.5	0.0	17.7	22.2	2.1	16.0
35	RSP ROURKELA	7604.4	8205.7	601.3	0.16	1216.7	656.0	728.9	232.0	0.0	496.9	728.9	53.4	460.5
36	RUNGTA MINES-Dhenkanal or RML DSP	2712.9	3073.7	360.8	0.20	542.6	100.0	111.1	34.0	0.0	77.1	111.1	13.0	68.1
37	RUNGTA MINES-Barbil RML Karakhendra	1349.6	2409.2	1059.6	0.20	269.9	22.0	24.4	4.4	0.0	20.0	24.4	10.8	11.2
38	RUNGTA MINES - Kamanda Steel Plant	1890.8	2164.9	274.0	0.20	378.2	60.0	66.7	11.8	0.0	54.8	66.7	8.4	47.9
39	SEVEN STAR STEELS LTD, Jharsuguda	327.7	339.7	12.0	0.20	65.5	1.5	1.7	0.8	0.0	0.9	1.7	0.1	0.8
40	SHYAM METALICS LTD,Sambalpur	7147.7	8963.1	1815.5	0.20	1429.5	90.0	100.0	20.0	0.0	80.0	100.0	20.3	63.8
41	SMC POWER GENERATION LTD,Hirma	7309.8	8289.5	979.7	0.20	1462.0	37.6	41.8	4.0	0.0	37.8	41.8	4.9	33.3
42	SMC POWER GENERATION LTD-II,Badmal	11153.1	11285.6	132.4	0.20	2230.6	70.0	77.8	7.5	0.0	70.3	77.8	0.9	69.5
43	SHREE GANESH	3245.0	4615.2	1370.2	0.20	649.0	32.0	35.6	6.0	0.0	29.6	35.6	10.6	20.8

SL No	Name of the CGP	Grid Side Fault Contribution (Point of Common Contact) (MVA)	Fault level at PCC (MVA)	Fault Contribution by CGP side (MVA)	Transient Reactance (PU)	Equivalent Generation from Grid Side (MVA)	Total Installed Capacity in MW	Total installed Capacity in MVA	CD(MVA)	Export (MVA)*	Base MVA (MVA)	Additional Support (MVA)**	CGP to UTILITY (MVA)	Reliability Support (MVA)
		1	2	3=2-1	4	5=1*4	6	7	8	9	10= 7-8-9	11=Min(5, 7)	12=(7x3)/2	13=10*(11-12)/7
	METALICS LTD,Rourkela													
44	SHREE JAGANNATH STEEL & POWER, Barbil or Beekay Steel	1116.7	1242.3	125.6	0.20	223.3	30.0	33.3	0.8	0.0	32.5	33.3	3.4	29.2
45	TATA STEEL LONG PRODUCT LTD, Joda	4053.4	4163.8	110.4	0.20	810.7	26.0	28.9	7.8	0.0	21.1	28.9	0.8	20.5
46	TATA STEEL LTD,Kalinga Nagar	15597.7	16787.9	1190.2	0.20	3119.5	398.0	442.2	110.0	0.0	332.2	442.2	31.4	308.7
47	UTKAL ALLUMINA,Laxmipur	4681.4	4970.6	289.3	0.20	936.3	90.0	100.0	33.3	0.0	66.7	100.0	5.8	62.8
48	VEDANTA LTD(SEZ),Jharsuguda	19590.5	32835.4	13244.9	0.20	3918.1	1800.0	2000.0	300.0	0.0	1700.0	2000.0	806.7	1014.3
49	VEDANTA LTD, Jharsuguda	15475.2	18809.3	3334.1	0.23	3559.3	1215.0	1350.0	66.7	0.0	1283.3	1350.0	239.3	1055.8
50	VEDANTA LTD,Langigarh	2203.7	3174.2	970.5	0.20	440.7	90.0	100.0	15.0	0.0	85.0	100.0	30.6	59.0
51	VISA STEEL LTD, New Duburi	9899.4	10340.9	441.5	0.20	1979.9	75.0	83.3	18.0	0.0	65.3	83.3	3.6	62.5
52	VIRAJ STEEL & ENERGY PVT LTD, Sambalpur	4873.2	4969.1	95.9	0.20	974.6	28.0	31.1	6.0	0.0	25.1	31.1	0.6	24.6
53	YAZDANI STEEL & POWER LTD, Jajpur	762.7	794.7	32.0	0.20	152.5	10.0	11.1	2.0	0.0	9.1	11.1	0.4	8.7

***Average scheduled power export to grid**

**** Additional Support Available Over and above CD(MVA)**

***** Support Provided by CGP to UTILITY (MVA)**

11.5.Calculation of Support MVA Using Rs.37 as unit Transmission Charge

Based on the reliability support in MVA calculated in Table 11-5 for all CGPs the Grid support charge per month per KVA is calculated in Table 11-6. The average of the Grid Support charge per KVA per month is estimated to be Rs 27.5 / KVA/month.

Table 11-6 Table for calculation of Grid Support charge based on reliability support

Sl No	CGP Name	Total installed Capacity (MVA)	Reliability Support from previous table (MVA)	Base MVA (MVA)	Transmission Charge (Rs/KVA)	Cost of No Load Loss(Rs/KVA)	GSC (Rs/month)	GSC per Rs/KVA/month
		1	2	3	4	5	6=4*2+5*3	7=6/1
1	AARTI STEEL LIMITED,Ghantikhal	100.0	59.5	88.9	37.5	1.11	2331078.8	23.3
2	ACC, BARGARH	33.3	27.0	28.3	37.5	1.11	1045462.9	31.4
3	ADHUNIK METALLIKS LTD,Jharsuguda	25.0	20.4	21.5	37.5	1.11	788244.5	31.5
4	ACTION ISPAT & POWER PVT.LTD,Jharsuguda	88.9	76.9	79.9	37.5	1.11	2972495.7	33.4
5	ARYAN ISPAT & POWER PVT.LTD,Sambalpur	20.0	14.7	15.0	37.5	1.11	569585.4	28.5
6	ADITYA ALUMINIUM LTD,Rengali	1000.0	789.6	944.4	37.5	1.11	30658721.1	30.7
7	AM NIPPON STEEL INDIA LTD,Paradeep(Earlier ESSAR)	66.7	33.9	34.7	37.5	1.11	1308345.6	19.6
8	BHUBANESWAR POWER PVT.LTD.Athagarh	150.0	113.4	144.4	37.5	1.11	4413014.0	29.4
9	TATA STEEL LTD. Meramundali	822.2	601.5	732.2	37.5	1.11	23369289.1	28.4

Sl No	CGP Name	Total installed Capacity (MVA)	Reliability Support from previous table (MVA)	Base MVA (MVA)	Transmission Charge (Rs/KVA)	Cost of No Load Loss(Rs/KVA)	GSC (Rs/month)	GSC per Rs/KVA/month
		1	2	3	4	5	6=4*2+5*3	7=6/1
10	BHUSHAN POWER &STEEL LTD.Jharsuguda	570.0	332.0	370.0	37.5	1.11	12859455.6	22.6
11	EMAMI PAPER MILLS , Baleswar	37.2	22.6	24.2	37.5	1.11	873960.3	23.5
12	FACOR POWER LTD. Bhadrak	50.0	41.6	44.5	37.5	1.11	1608069.1	32.2
13	HINDALCO INDUSTRIES LTD. Hirakud	519.4	404.8	479.4	37.5	1.11	15710856.7	30.2
14	IMFA, Choudwar	286.7	198.9	286.7	37.5	1.11	7777383.7	27.1
15	INDIA OIL CORPORATION LTD. , Paradeep	406.7	286.9	354.7	37.5	1.11	11153299.8	27.4
16	IFFCO LIMITED ,Paradeep	122.2	104.5	111.2	37.5	1.11	4043087.2	33.1
17	JINDAL STAINLESS LTD.Duburi	292.2	195.0	220.2	37.5	1.11	7557494.1	25.9
18	JINDAL STEEL & POWER LTD. Anugul	900.0	727.3	810.0	37.5	1.11	28174321.3	31.3
19	KJS AHLUWALIA STEEL, Barbil	31.1	19.8	23.1	37.5	1.11	768760.3	24.7
20	NINL,Duburi	69.4	19.0	19.4	37.5	1.11	733717.9	10.6
21	MAHAVIR FERRO ALLOYS PVT. LTD. Rourkela	16.7	13.0	13.7	37.5	1.11	502256.8	30.1
22	MAITHAN ISPAT NIGAM LTD.Jajpur	33.3	23.1	23.3	37.5	1.11	891882.7	26.8
23	MSP METALICS LTD, Jharsuguda	27.8	17.9	18.3	37.5	1.11	691011.0	24.9
24	MGM MINERALS LIMITED	8.9	6.0	6.1	37.5	1.11	231646.3	26.1
25	NALCO, Angul	1333.3	1151.0	1333.3	37.5	1.11	44642605.7	33.5

Sl No	CGP Name	Total installed Capacity (MVA)	Reliability Support from previous table (MVA)	Base MVA (MVA)	Transmission Charge (Rs/KVA)	Cost of No Load Loss(Rs/KVA)	GSC (Rs/month)	GSC per Rs/KVA/month
		1	2	3	4	5	6=4*2+5*3	7=6/1
26	NALCO, Damanjodi	82.2	77.1	82.2	37.5	1.11	2983367.2	36.3
27	NARBHERAM POWER & STEEL PVT. Dhenkanal	8.9	5.8	5.9	37.5	1.11	222448.0	25.0
28	NBVL, MERAMUNDULI	100.0	88.5	97.0	37.5	1.11	3426797.3	34.3
29	OCL INDIA LTD., RAJGANGPUR	60.0	44.5	47.0	37.5	1.11	1720039.1	28.7
30	OISL, Rajgangapur	38.9	32.3	33.4	37.5	1.11	1247128.8	32.1
31	ORISSA SPONGE IRON & STEEL LTD,Barbil	40.0	32.8	36.0	37.5	1.11	1269960.0	31.7
32	PARADEEP PHOSPHATES LTD,Paradeep	61.1	35.7	38.1	37.5	1.11	1379457.2	22.6
33	MGM Minerals Ltd,Keonjhar(Earlier Patnaik Steel)	8.9	6.9	7.4	37.5	1.11	266195.2	29.9
34	RATHI STEEL & POWER LTD,Sambalpur	22.2	16.0	17.7	37.5	1.11	620343.5	27.9
35	RSP ROURKELA	728.9	460.5	496.9	37.5	1.11	17819357.4	24.4
36	RUNGTA MINES-Dhenkanal or RML DSP	111.1	68.1	77.1	37.5	1.11	2637822.2	23.7
37	RUNGTA MINES-Barbil RML Karakhendra	24.4	11.2	20.0	37.5	1.11	442329.9	18.1
38	RUNGTA MINES - Kamanda Steel Plant	66.7	47.9	54.8	37.5	1.11	1857281.7	27.9
39	SEVEN STAR STEELS LTD, Jharsuguda	1.7	0.8	0.9	37.5	1.11	32314.9	19.4
40	SHYAM METALICS LTD,Sambalpur	100.0	63.8	80.0	37.5	1.11	2481156.7	24.8
41	SMC POWER GENERATION LTD,Hirma	41.8	33.3	37.8	37.5	1.11	1291175.8	30.9

Sl No	CGP Name	Total installed Capacity (MVA)	Reliability Support from previous table (MVA)	Base MVA (MVA)	Transmission Charge (Rs/KVA)	Cost of No Load Loss(Rs/KVA)	GSC (Rs/month)	GSC per Rs/KVA/month
		1	2	3	4	5	6=4*2+5*3	7=6/1
42	SMC POWER GENERATION LTD-II,Badmal	77.8	69.5	70.3	37.5	1.11	2682495.4	34.5
43	SHREE GANESH METALICS LTD,Rourkela	35.6	20.8	29.6	37.5	1.11	812095.0	22.8
44	SHREE JAGANNATH STEEL & POWER, Barbil or Beekay Steel	33.3	29.2	32.5	37.5	1.11	1132070.0	34.0
45	TATA STEEL LONG PRODUCT LTD, Joda	28.9	20.5	21.1	37.5	1.11	793278.4	27.5
46	TATA STEEL LTD,Kalinga Nagar	442.2	308.7	332.2	37.5	1.11	11943821.6	27.0
47	UTKAL ALLUMINA,Laxmipur	100.0	62.8	66.7	37.5	1.11	2429731.9	24.3
48	VEDANTA LTD(SEZ),Jharsuguda	2000.0	1014.3	1700.0	37.5	1.11	39922036.9	20.0
49	VEDANTA LTD, Jharsuguda	1350.0	1055.8	1283.3	37.5	1.11	41017981.3	30.4
50	VEDANTA LTD,Langigarh	100.0	59.0	85.0	37.5	1.11	2307254.7	23.1
51	VISA STEEL LTD, New Duburi	83.3	62.5	65.3	37.5	1.11	2417919.3	29.0
52	VIRAJ STEEL & ENERGY PVT LTD, Sambalpur	31.1	24.6	25.1	37.5	1.11	951364.4	30.6
53	YAZDANI STEEL & POWER LTD, Jajpur	11.1	8.7	9.1	37.5	1.11	338034.8	30.4
		Average unit cost						27.50

11.6.The basis of imposing the Grid Support Charge

By using the Base MVA method, the grid support charge per KVA per month is also estimated to be Rs.27.5 for the CGPs. Although, the unit charge for each of the CGPs are different but the proposed charge is estimated based on the average of all charges for all the CGPs to accommodate future change in the network conditions. Charging the GSC based on the CGP Base MVA is more logical explanation, because it subtracts the Contracted demand of CGP along with the Average scheduled export to the grid. This method will improve the rational behavior of CGP. This will motivate CGPs to improve their contracted demand and scheduled power export to the STU which will be economical for the end-use-consumers. Cost to OPTCL in the above mentioned method is Rs 366 Cr (approx.). However, by imposing the GSC of Rs.27.5 per KVA per month based on the installed capacity of CGP, financial benefit to OPTCL will be Rs 422 Cr (approx.).

12. CONCLUSIONS

Industries having high energy intensity opt to have CGPs along with a connection agreement for power import-export under LTOA, MTOA or STOA with the utility. These industries being parallelly connected to the grid have reliability support as an advantage upon which charges can be levied. The basis and justification of the same has been provided in this technical study. Quantification of the reliability support is formulated and methodologies have been proposed. Harmonic study of some important CGP is recorded and is reported in the report to estimate the harmonic injection of CGP in to the OPTCL network. Apart from that necessary simulation results using load flow, short circuit, and transient stability study results are also presented in the report to validate the grid support to the CGPs.

This report discusses different methods of calculating the Grid Support charge. A comparative study of different methodologies is also discussed for the five different methods. Base MVA method is adopted to evaluate the grid support charge rate as Rs. 27.5 /KVA/month. It is recommended to charge the CGPs based on their base MVA.

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ANNEXURES

ANNEXURE 1

EXPORT & IMPORT TTC/ATC OF OPTCL SYSTEM FOR THE MONTH MAY-2024(R-0)

EXPORT TTC/ATC

SL. No.	Control Area	Month	Export TTC	Reliability Margin	Counterflow on Surrender of ISGS	Export ATC	Contingency	Assumptions
1	Odisha	May-24	1058	78 MW (2% of load assumed)	0	980	Outage of one 210MW Generator of IBTPS Stage-1	Generation: 5048 MW Load: 3900 MW

IMPORT TTC/ATC

SL. No.	Control Area	Month	Import TTC	Reliability Margin	Approved GNA	Import ATC	Contingency	Assumptions
1	Odisha(excluding Vedanta)	May-24	3106	112 MW (2% of load assumed)	2157 MW	837 MW	Outage of one 220kV Tarkera-Rourkela(PG) Ckt.*	Generation: 2686 MW Load: 5600 MW
2	Vedanta		1600	38 MW (2% of load assumed)	NIL	1562 MW	Outage of one 400kV OPGC-Lapanga ckt	Generation: 300 MW Load: 1900 MW

Total Import TTC for Odisha Control Area = 3106 MW+ 1600 MW = 4706 MW

* **SPS has been designed for 220kV Tarkera-Rourkela PG line. So, this ckt is not a constraint**

Source: https://www.sldcorissa.org.in/

ANNEXURE 2

List of CGPs as on SLDC website (attached)

CGP List

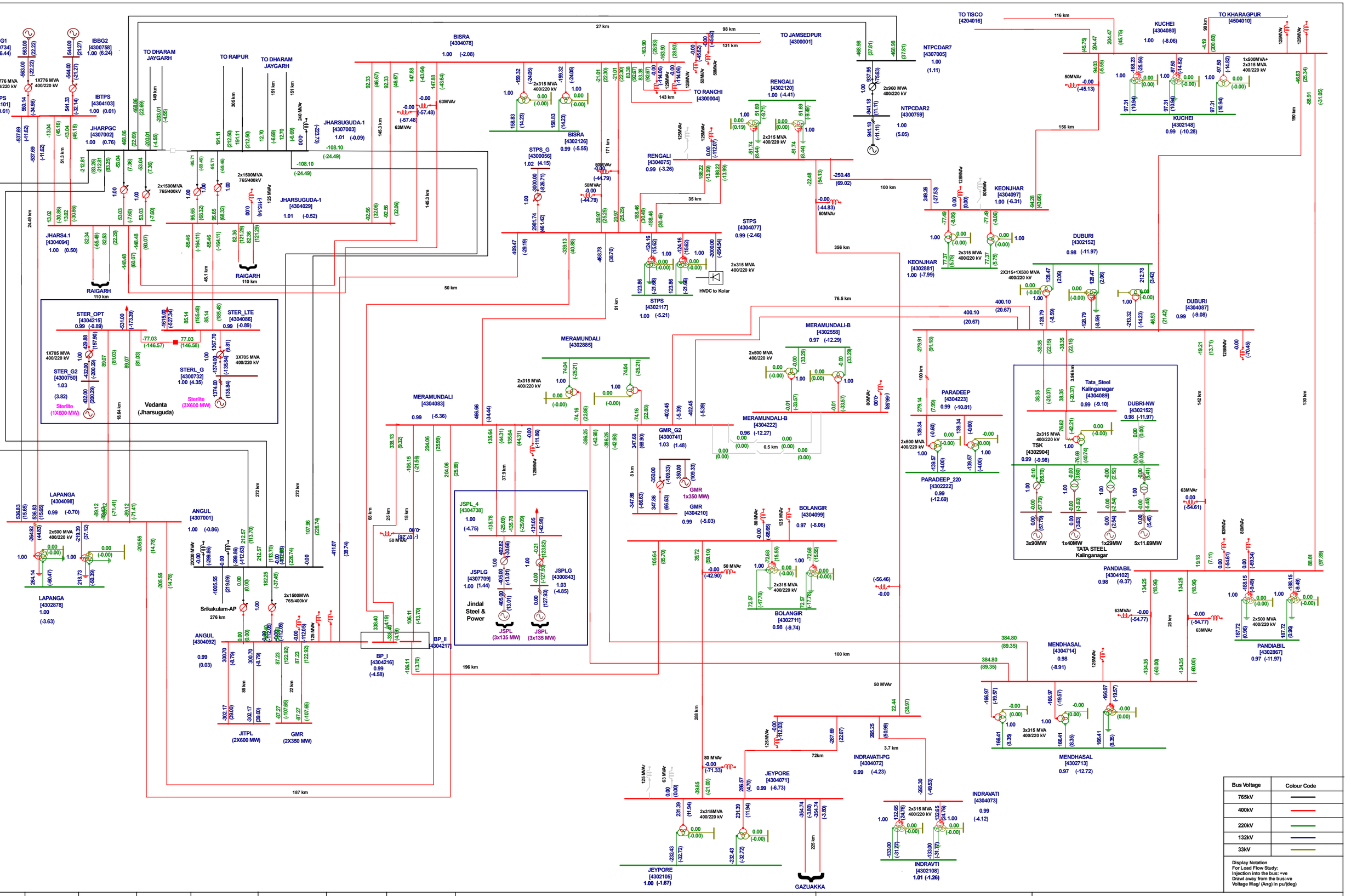
SL NO	NAME OF CGP	UNIT WISE INSTALLED CAPACITY in MW	TOTAL CAPACITY in MW	TYPE OF POWER PLANT	CONNECTIVITY VOLTAGE
1	AARTI STEEL LIMITED,Ghantikhal	1X40+1X50	90	THERMAL	132 KV
2	ACC, BARGARH	1X30	30	THERMAL	132 KV / DC line
3	ADHUNIK METALLIKS LTD,Jharsuguda	1X22.5	22.5	THERMAL	132 KV / SC LINE
4	ACTION ISPAT & POWER PVT.LTD,Jharsuguda	1X12+1X25+1X43	80	THERMAL	132 KV / SC LINE
5	ARYAN ISPAT & POWER PVT.LTD,Sambalpur	1X18	18	THERMAL	132 KV
6	ADITYA ALUMINIUM LTD,Rengali	6X150	900	THERMAL	220 KV / DC line
7	AM NIPPON STEEL INDIA LTD,Paradeep(Earlier ESSAR)	2X30	60	THERMAL	220 KV / DC line
8	BHUBANESWAR POWER PVT.LTD.Athagarh	2X67.5	135	THERMAL	132 KV / SC LINE
9	TATA STEEL LTD. Meramundali	1X33+1X77+2X150+ 2X165	740	THERMAL	220 KV / DC line
10	BHUSHAN POWER &STEEL LTD.Jharsuguda	1X60+1X40+3X130+2 X8+1X7	513	THERMAL	220 KV / DC line
11	EMAMI PAPER MILLS , Baleswar	1X18+1X10.5+1X5	33.5	THERMAL	132 KV / SC LINE
12	FACOR POWER LTD. Bhadrak	1X45	45	THERMAL	132 KV / SC LINE
13	HINDALCO INDUSTRIES LTD. Hirakud	1X67.5+4X100	467.5	THERMAL	220 KV / DC line
14	IMFA, Choudwar	2X54+1X30+2X60	258	THERMAL	132 KV / SC LINE
15	INDIA OIL CORPORATION LTD. , Paradeep	3X102+2X30	366	THERMAL	220 KV / SC Line
16	IFFCO LIMITED ,Paradeep	2X55	110	THERMAL	132 KV / DC line
17	JINDAL STAINLESS LTD.Duburi	2X125+1X13	263	THERMAL	220 KV / DC line
18	JINDAL STEEL & POWER LTD. Anugul	6X135	810	THERMAL	400 KV DC line
19	KJS AHLUWALIA STEEL, Barbil	1X20+1X8	28	THERMAL	33 KV / SC line

SL NO	NAME OF CGP	UNIT WISE INSTALLED CAPACITY in MW	TOTAL CAPACITY in MW	TYPE OF POWER PLANT	CONNECTIVITY VOLTAGE
20	NINL,Duburi	2X19.25+1X24	62.5	THERMAL	220 KV / SC Line
21	MAHAVIR FERRO ALLOYS PVT. LTD. Rourkela	1X15	15	THERMAL	33 KV / SC line
22	MAITHAN ISPAT NIGAM LTD.Jajpur	1X30	30	THERMAL	220 KV / DC line
23	MSP METALICS LTD, Jharsuguda	1X25	25	THERMAL	132 KV / SC Line
24	MGM MINERALS LIMITED	1X8	8	THERMAL	132 KV / SC line
25	NALCO, Angul	10X120	1200	THERMAL	220 KV / DC line
26	NALCO, Damanjodi	4X18.5	74	THERMAL	220 KV / DC line
27	NARBHERAM POWER & STEEL PVT. Dhenkanal	1X8	8	THERMAL	132 KV / SC line
28	NBVL, MERAMUNDULI	1X30+1X60	90	THERMAL	132 KV / DC line
29	OCL INDIA LTD., RAJGANGPUR	2 X 27	54	THERMAL	133 KV / SC line
30	OISL, Rajgangapur	1X35	35	THERMAL	132 KV / SC line
31	ORISSA SPONGE IRON & STEEL LTD,Barbil	1X24+1x12	36	THERMAL	132 KV / SC line
32	PARADEEP PHOSPHATES LTD,Paradeep	2X16+1X23	55	THERMAL	132 KV / DC line
33	MGM Minerals Ltd,Keonjhar(Earlier Patnaik Steel)	1X15	15	THERMAL	33 KV / SC line
34	RATHI STEEL & POWER LTD,Sambalpur	1X20	20	THERMAL	33 KV / SC line (Tapping from Rathi Udyog feeder)
35	RSP ROURKELA	2X60+4X25+1X250 + 1 X20+2X18+2X65	656	THERMAL	220 KV QUAD line
36	RUNGTA MINES-Dhenkanal or RML DSP	2X25+1X50	100	THERMAL	132 KV / SC line
37	RUNGTA MINES-Barbil RML Karakhendra	1X22	22	THERMAL	132 KV
38	RUNGTA MINES - Kamanda Steel Plant	3x20	60	THERMAL	132 KV / SC line
39	SEVEN STAR STEELS LTD, Jharsuguda	1X1.5	1.5	THERMAL	33 KV / SC line (Tapping from Industrial - I feeder)
40	SHYAM METALICS LTD,Sambalpur	3X30	90	THERMAL	132 KV

SL NO	NAME OF CGP	UNIT WISE INSTALLED CAPACITY in MW	TOTAL CAPACITY in MW	TYPE OF POWER PLANT	CONNECTIVITY VOLTAGE
41	SMC POWER GENERATION LTD,Hirma	1X12.6+1X25	37.6	THERMAL	132 KV / SC line
42	SMC POWER GENERATION LTD-II,Badmal	1x30+1X40	70	THERMAL	220 KV / SC line
43	SHREE GANESH METALICS LTD,Rourkela	1X32	32	THERMAL	132 KV / SC line
44	SHREE JAGANNATH STEEL & POWER, Barbil or Beekay Steel	1X30	30	THERMAL	132 KV
45	TATA STEEL LONG PRODUCT LTD, Joda	1X18.5+1X7.5	26	THERMAL	220 KV / SC Line
46	TATA STEEL LTD,Kalinga Nagar	3X90+1X40+1X29+5X 11.69	398	THERMAL	400 KV / DC line
47	UTKAL ALLUMINA,Laxmipur	3X30	90	THERMAL	220 KV / DC line
48	VEDANTA LTD(SEZ),Jharsuguda	3X600	1800	THERMAL	400 KV
49	VEDANTA LTD, Jharsuguda	9X135	1215	THERMAL	220 KV / DC line
50	VEDANTA LTD,Langigarh	3X30	90	THERMAL	132 KV
51	VISA STEEL LTD, New Duburi	3X25	75	THERMAL	220 KV / DC line
52	VIRAJ STEEL & ENERGY PVT LTD, Sambalpur	1X20+1X8	28	THERMAL	132 KV / SC line
53	YAZDANI STEEL & POWER LTD, Jajpur	1X10	10	THERMAL	33 KV / SC line
54	ABREL SOLAR LIMITED,Saintala	18.75	18.75	SOLAR	132KV
55	ABREL SOLAR SPV LIMITED,Khajuriakata	15.62	15.62	SOLAR	33KV
56	BHARAT ELECTRONICS LIMITED, Saintala	7.5	7.5	SOLAR	132 KV
57	SHREE CEMENT LIMITED(Solar)	1X7.3	7.3	THERMAL	33 KV / SC line
58	SIVA CEMENT LIMITED	1X8.9	8.9	THERMAL	132 KV / SC line
59	THAKUR PRASAD SAO & SONS PVT. LTD., UNIT-IV	1X18	18	THERMAL	33 KV / SC line

ANNEXURE 3

SLD for Load flow Analysis of OPTCL network for peak scenario in FY 23-24 (attached)



APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV	DATE	REMARKS

Load Flow Study Results

Single line Diagram of 765kV and 400kV transmisssion network- Odisha State 2024-25 condition

Odisha Power Transmission Corporation Ltd.
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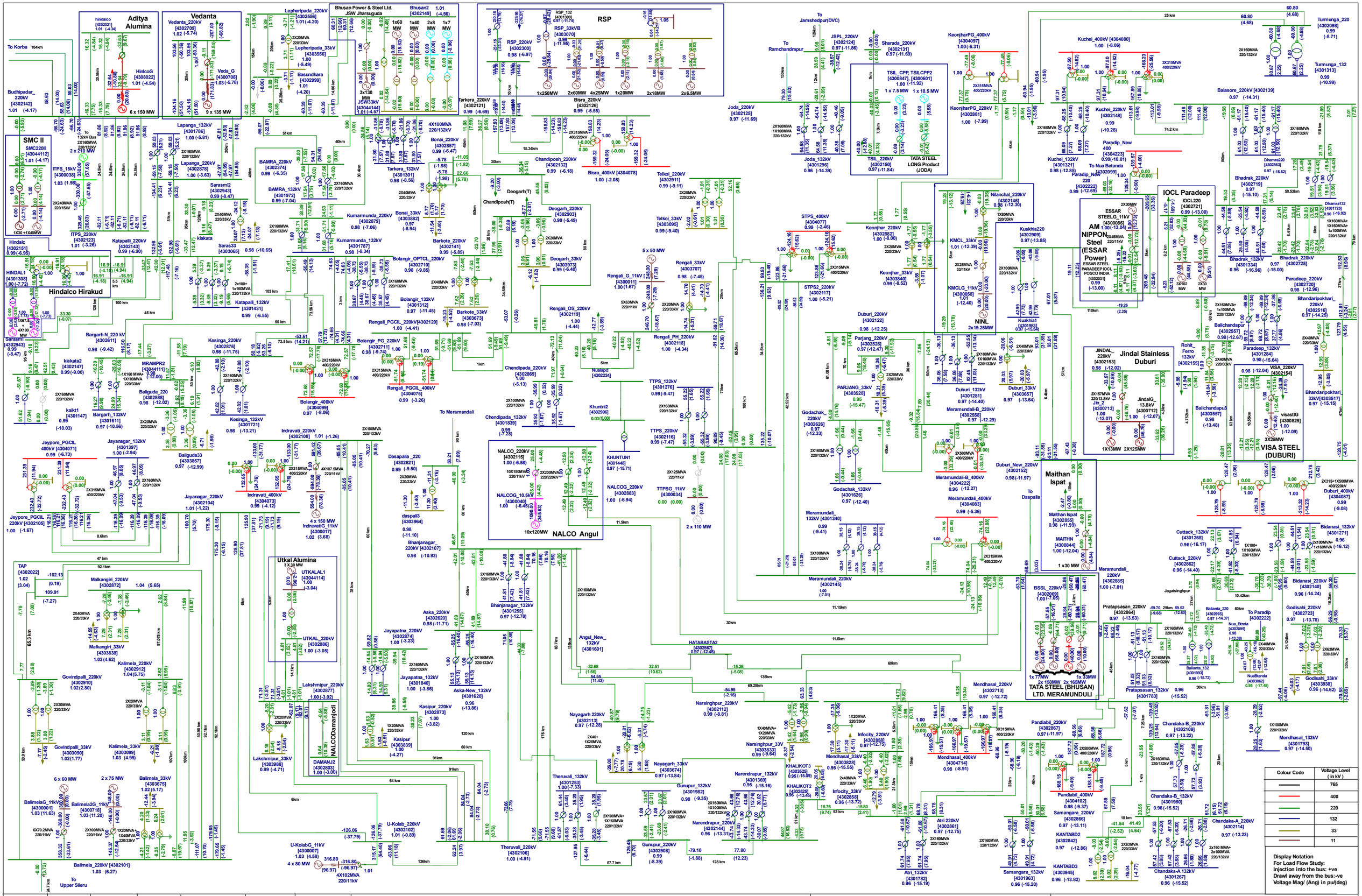
Fax: +91-080-2319 2210
E-mail : info@prdcinfotech.com

DRAWN IN: MiPower ™

DWG. NO :PEAK\LFA\2024-25\765-400kV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Vedanta
SMC II
Hindalco Hirakud
NALCO Angul
Utkal Alumina
TATA STEEL (BHUSAN) LTD. MERAMUNDULI
AM NIPPON Steel (ESSAR Power)
IOCL Paradeep
Jindal Stainless Duburi
VISA STEEL (DUBURI)
Maithan Ispat
To Korba 184km
To Ramchandrapur
To Jamshedpur(DVC)
To Upper Sileru
To Daspalla
To Nua Betanda
Bhusan Power & Steel Ltd.
JSW Jharsuguda
RSP
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Chandiposh_220kV [4302132]
Tarkera_132kV [4301301]
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Kumarmunda_220kV [4302879]
Kumarmunda_132kV [4301787]
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Bolangir_OPTCL_220kV [4302710]
Rengali_PGCIL_220kV [4302120]
Rengali_PG_220kV [4302711]
Rengali_OS_220kV [4302119]
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Rengali_G_11kV [4300011]
Rengali_33kV [4303707]
Duburi_220kV [4302122]
Parjang_220kV [4302528]
Duburi_132kV [4301281]
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Godachak_132kV [4301626]
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Paradip_New 220 [4302222]
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Balianta_132 [4301993]
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Nua_Btnda [4302099]
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Hindalc [4302151]
HINDAL1 [4301308]
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Katapalli_132kV [4301431]
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Saras33 [4303065]
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Nuapad [4302224]
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KHUNTUN1 [4301448]
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ESSAR STEEL
PARADEEP IOCL
POSCO INDIA
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Joda_132kV [4301296]
Bhusan2 [4302149]
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2x8 MW
1x7 MW
1x250MW
2x60MW
4x25MW
1x20MW
2x18MW
2x6.5MW
3x130 MW
JSW33kV [4304414]
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3X160MVA 220/132kV
2X160MVA 220/132kV
2X240MVA 220/15kV
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2X315MVA 400/220kV
2X100MVA 220/132kV
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2X25MW
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2X30 MW
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9 x 135 MW
6 x 60 MW
2 x 75 MW
4 x 150 MW
2 x 110 MW
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3 X 30 MW
4 x 80 MW
4X102MVA 220/11kV
1X30 +1X40MW
2X40 +1X60MW
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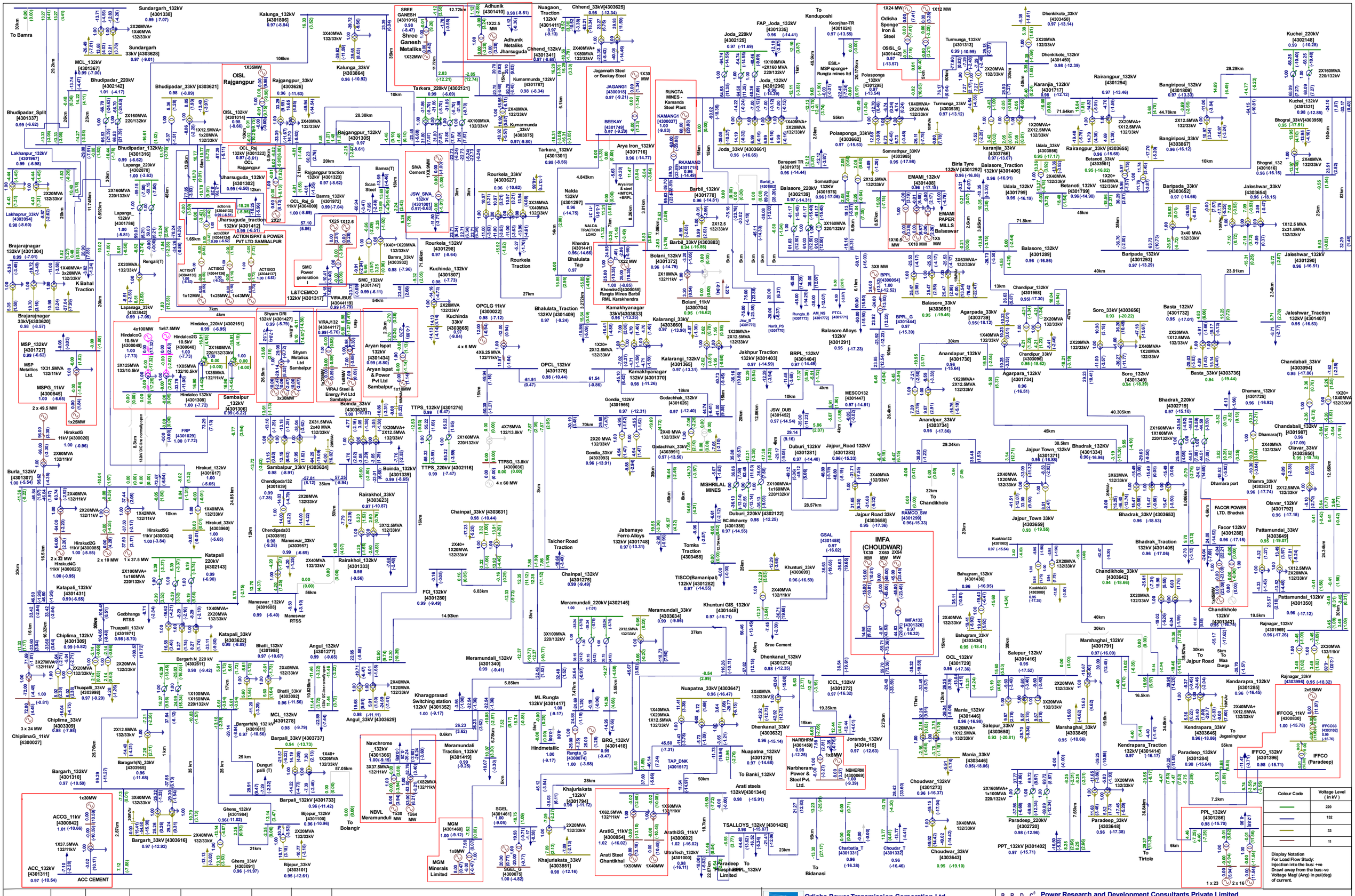
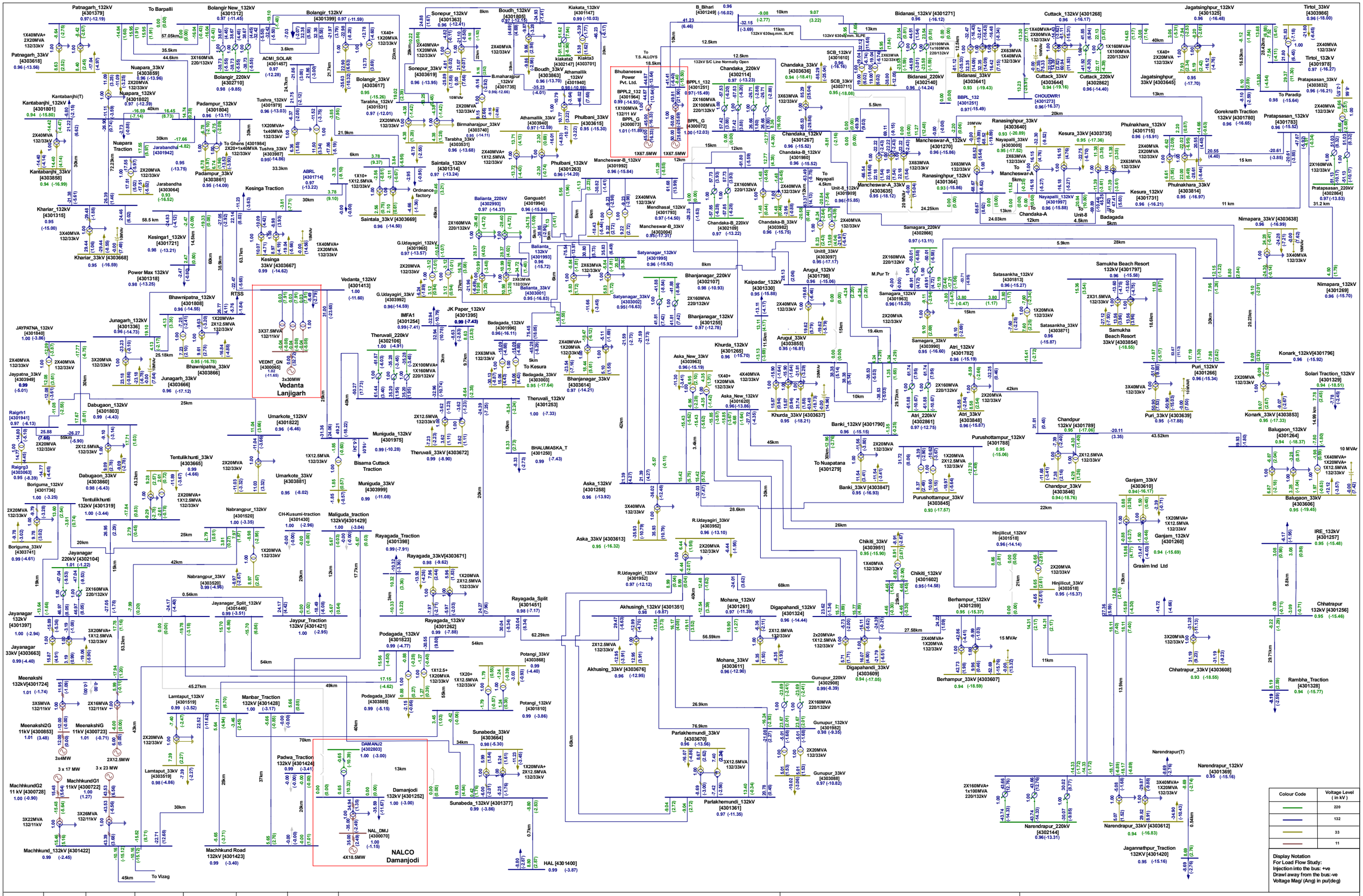

Load Flow Study Results
Single line diagram of 132 kV(North) transmission network - Odisha State 2024-25 condition
Odisha Power Transmission Corporation Ltd.,
Registered Office: Janpath, Bhubaneshwar-751022
Phone: (0674)-2541320/254232
Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road, Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com
Drawn using: MiPower™
DWG. NO :PEAK\LFA\2024-25\132kV(North)
APPROVED
REVIEWED
CHECKED
DRAWN
DESCRIPTION
REV.
DATE
Colour Code
Voltage Level (in kV)
220
132
33
11
Display Notation
For Load Flow Study:
Injection into the bus: +ve
Drawl away from the bus:-ve
Voltage Mag' (Ang) in pu/(deg) of current.



APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

Load Flow Study Results

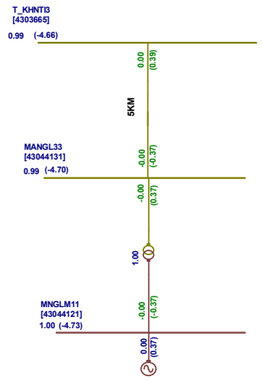
Single line diagram of 132 kV(South) transmission network - Odisha State 2023-24 condition

Odisha Power Transmission Corporation Ltd.,
Registered Office: Janpath,
Bhubaneshwar-751022
Phone: (0674)-2541320/2542320

Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road,
Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

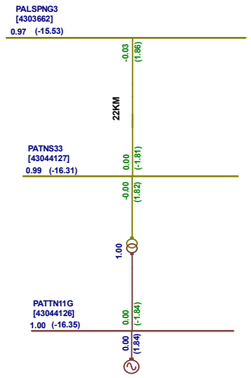
Drawn using: MiPower™

DWG. NO : SP/LFA\2024-25\132kV(South)



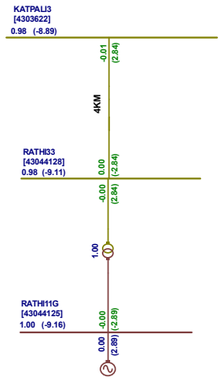
1 X 3 MW

Mangalam Timber

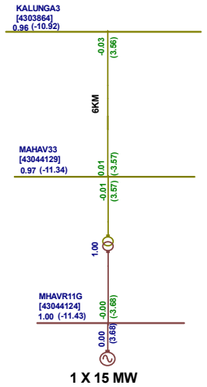


1X8MW

Pattanaik Steel
or
MGM Minerals

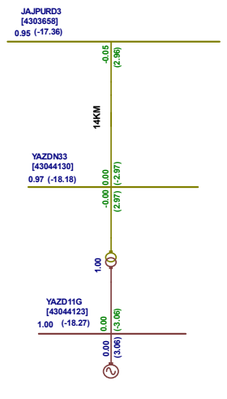


Rathi Steel
1 x 20 MW



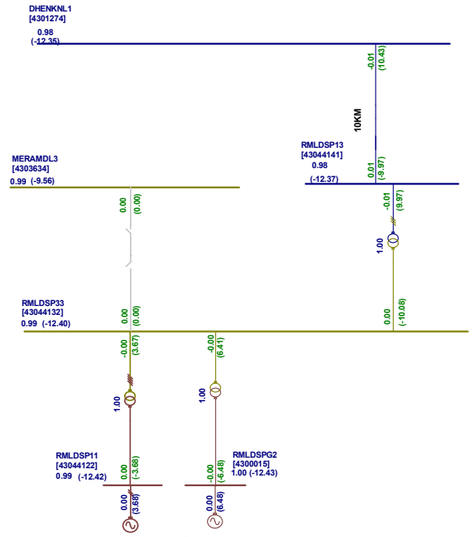
1 X 15 MW

Mahaveer



1X10 MW

Yazdani Power



1X50 + 2X25 MW

RML DSP, Dhenkanal
or
Rungta Mines Dhenkanal

Sree Solar

Dalmia Cement

1X1.5MW

Seven Starts Limited

1X20MW 1X8MW

KJS AHLUWALIA STEEL, Barbil

Colour Code	Voltage Level (in kV)
	220
	132
	33
	11

Display Notation
For Load Flow Study:
Injection into the bus: +ve
Drawl away from the bus:-ve
Voltage Mag/ (Ang) in pu/(deg)
Flows in MW and (MVAR)

APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

Load Flow Study Results

Single line diagram of 33 kV transmission network - Odisha State 2024-25 condition

Odisha Power Transmission Corporation Ltd.,
Registered Office: Janpath,
Bhubaneshwar-751022
Phone: (0674)-2541320/254232

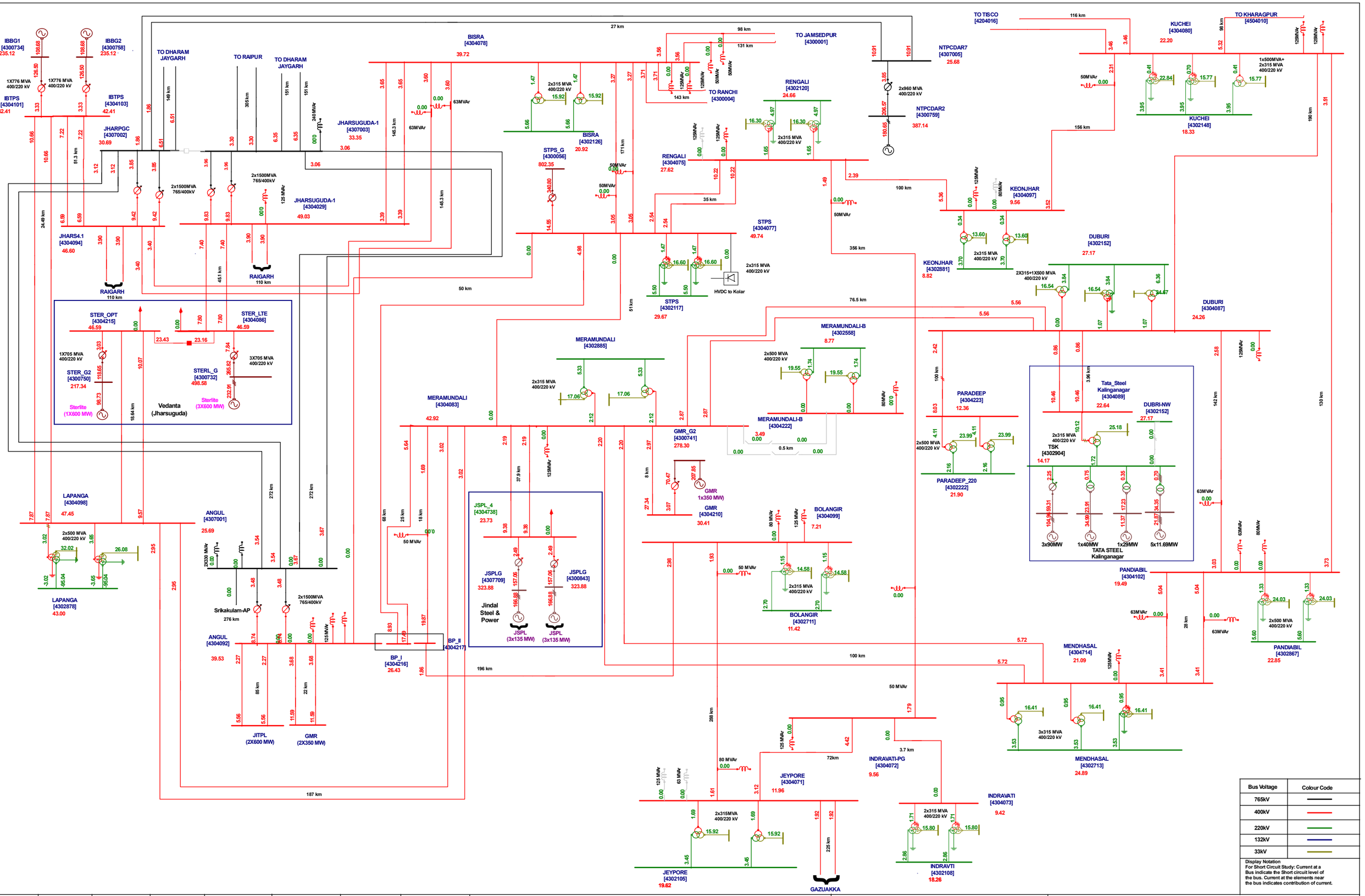
Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road,
Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

Drawn using: MiPower™

DWG. NO :PEAK\LFA\2024-25\33kV

ANNEXURE 4

SLD for Short Circuit Analysis of OPTCL network for peak scenario in FY 23-24 (attached)



APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV	DATE	REMARKS

Three Phase to Ground Fault in kA

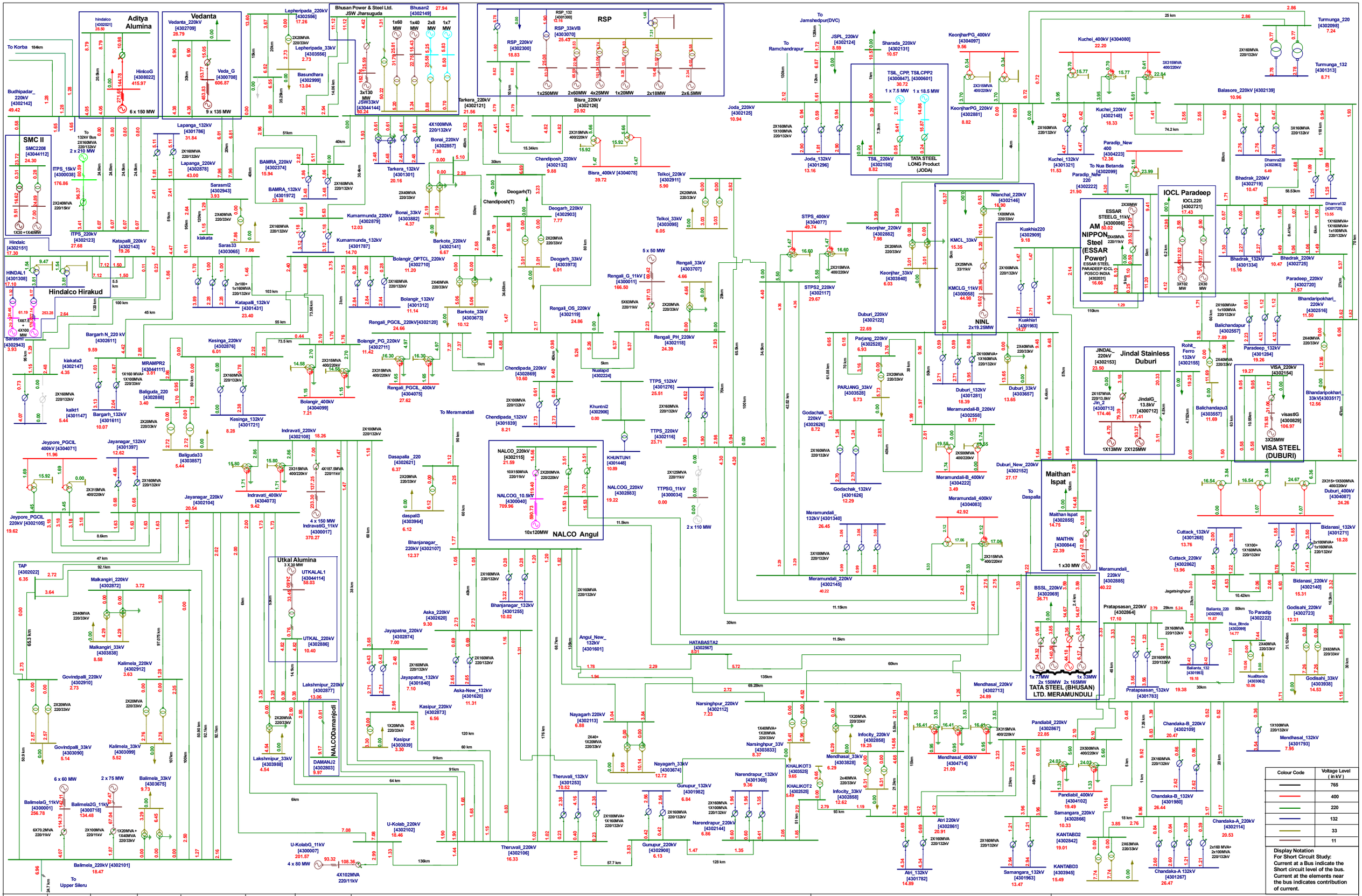
Single line Diagram of 765kV and 400kV transmisssion network- Odisha State 2024-25 condition

Odisha Power Transmission Corporation Ltd.
Registered Office: Janpath, Bhubaneswar-751022
Phone: (0674)-2541320/2542320

Power Research & Development Consultants Private Limited
#5, 11th Cross, 2nd Stage, West of Chord Road, Bangalore- 560086, INDIA
Ph : +91-080-2319 2209,2159
Fax: +91-080-2319 2210
E-mail : info@prdcinfotech.com

DRAWN IN: MiPower™

DWG. NO :PEAK\SCS-3PHG\2024-25\765-400kV



APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

Three Phase to Ground Fault in kA

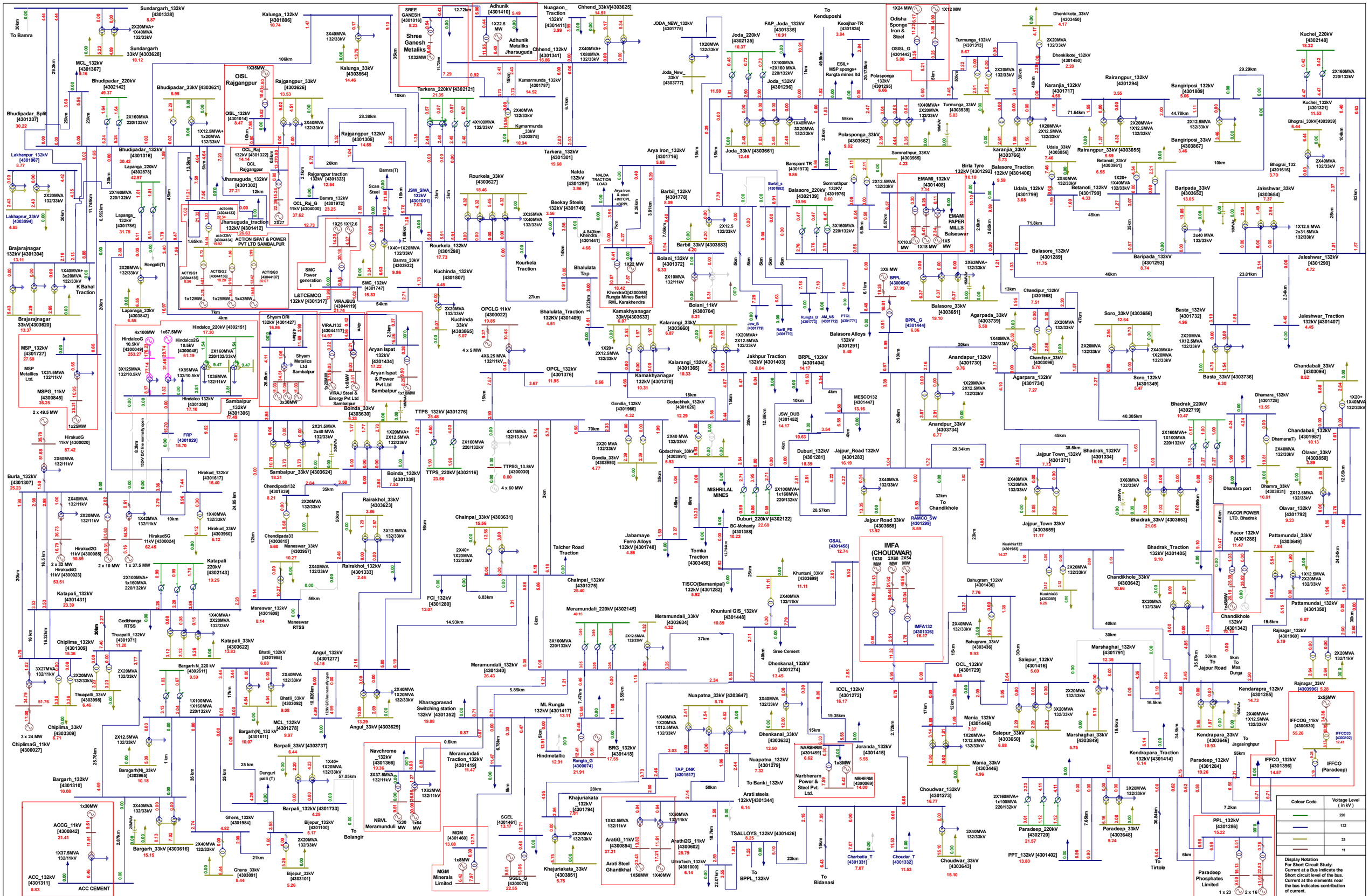
Single line diagram of 220 kV transmission network - Odisha State 2024-25 condition

Orissa Power Transmission Corporation Ltd.
Registered Office: Janpath, Bhubaneshwar-751022
Phone: (0674)-2541320/2542320

Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road, Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

Drawn using: MiPower™

DWG. NO : PEAK\SCS-3PHG\2024-25\220kV



Three Phase to Ground Fault in KA

Single line diagram of 132 kV(North) transmission network - Odisha State 2024-25 condition

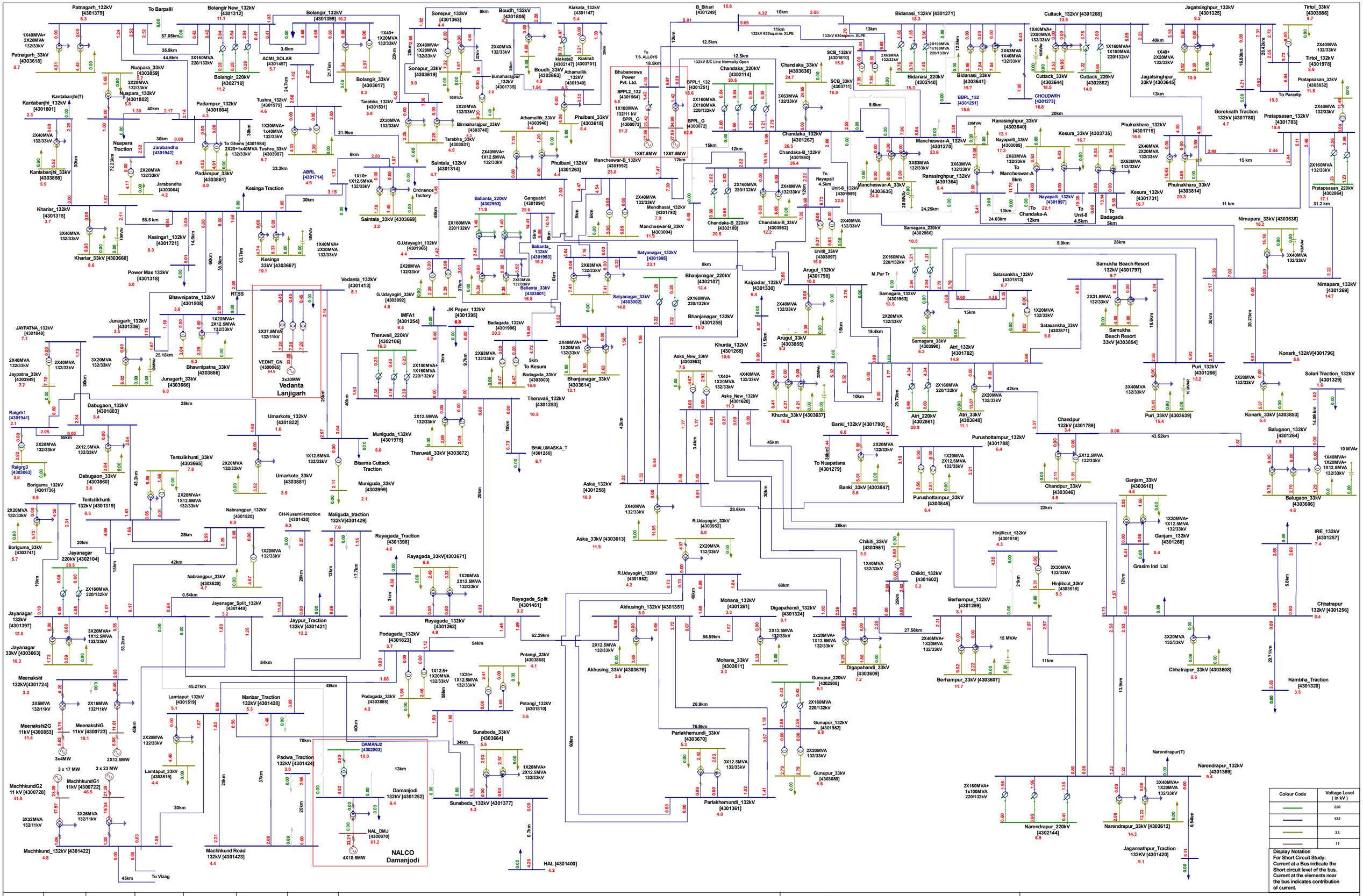
APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

Odisha Power Transmission Corporation Ltd.,
Registered Office: Janpath,
Bhubaneshwar-751022
Phone: (0674)-2541320/254232

Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road,
Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

Drawn using: MiPower™

DWG. NO :PEAK\SCS-3PHG\2024-25\132kV(North)



APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

Three Phase to Ground Fault in KA

Single line diagram of 132 kV(South) transmission network - Odisha State 2023-24 condition

Odisha Power Transmission Corporation Ltd.,
Registered Office: Janpath,
Bhubaneshwar-751022
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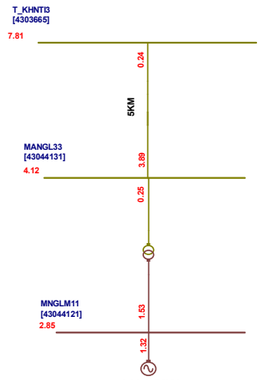
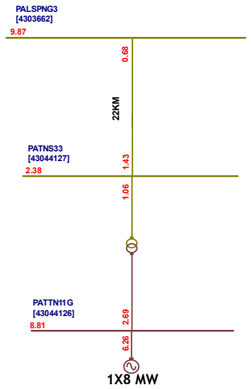
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

Drawn using: MiPower™

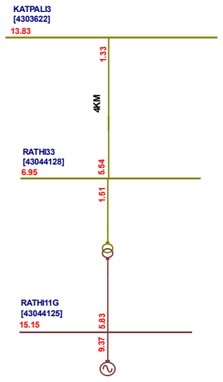
DWG. NO : SP\SCS-3PHG\2024-25\132kV(South)



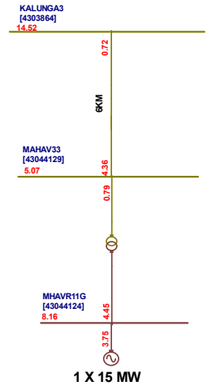
1 X 3 MW
Mangalam Timber



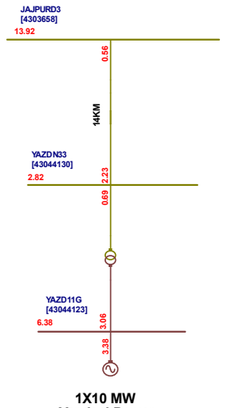
1X8 MW
Pattanaik Steel
or
MGM Minerals



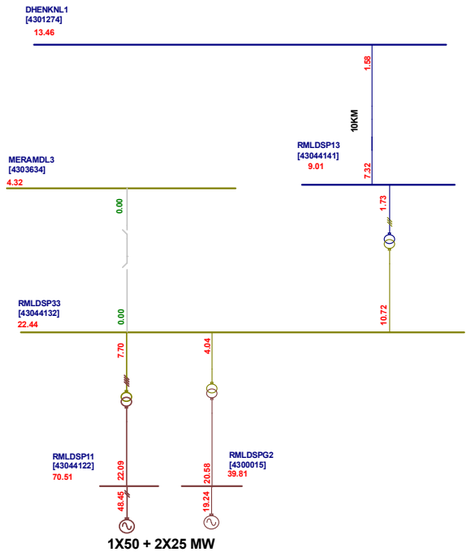
Rathi Steel
1 x 20 MW



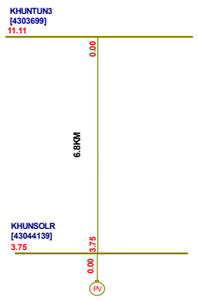
1 X 15 MW
Mahaveer



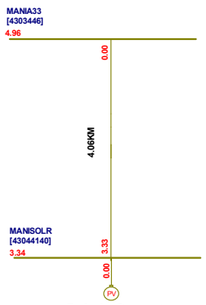
1X10 MW
Yazdani Power



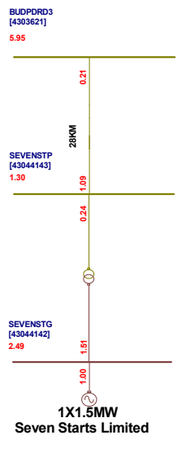
1X50 + 2X25 MW
RML DSP, Dhenkanal
or
Rungta Mines Dhenkanal



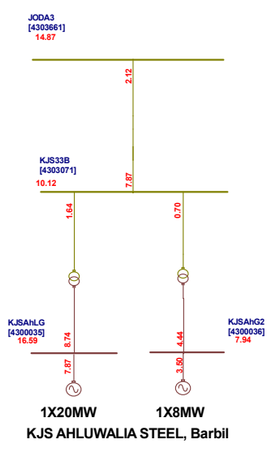
Sree Solar



Dalmia Cement



1X1.5MW
Seven Starts Limited



1X20MW 1X8MW
KJS AHLUWALIA STEEL, Barbil

Colour Code	Voltage Level (in kV)
	220
	132
	33
	11

Display Notation
For Short Circuit Study:
Current at a Bus indicate the Short circuit level of the bus.
Current at the elements near the bus indicates contribution of current.

APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

Three Phase to Ground Fault in KA

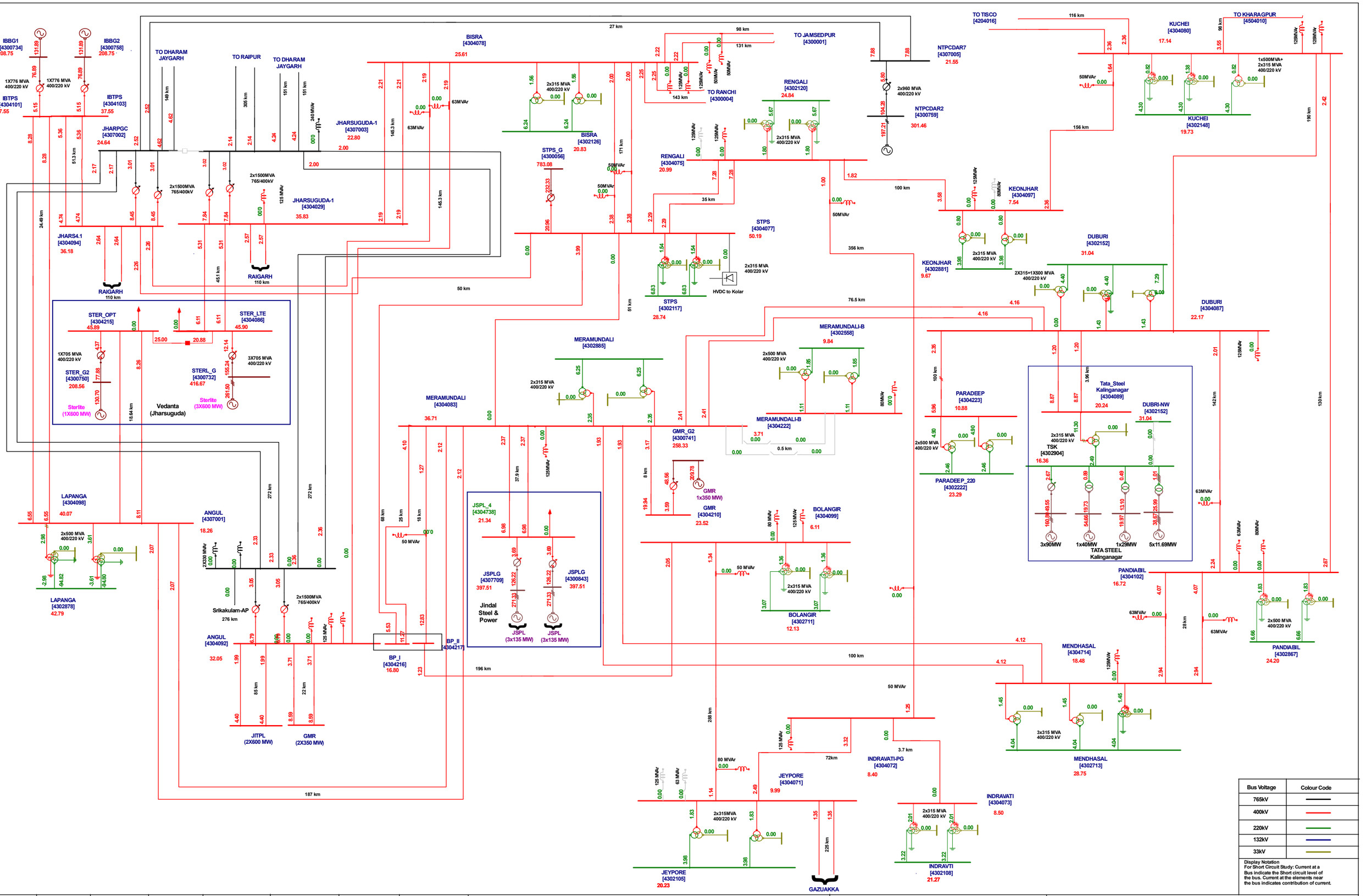
Single line diagram of 33 kV transmission network - Odisha State 2024-25 condition

Odisha Power Transmission Corporation Ltd.,
Registered Office: Janpath,
Bhubaneshwar-751022
Phone: (0674)-2541320/254232

P R D C® Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road,
Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

Drawn using: MiPower™

DWG. NO :PEAK\SCS-3PHG\2024-25\33kV



APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV	DATE	REMARKS

Single Line to Ground Fault in kA

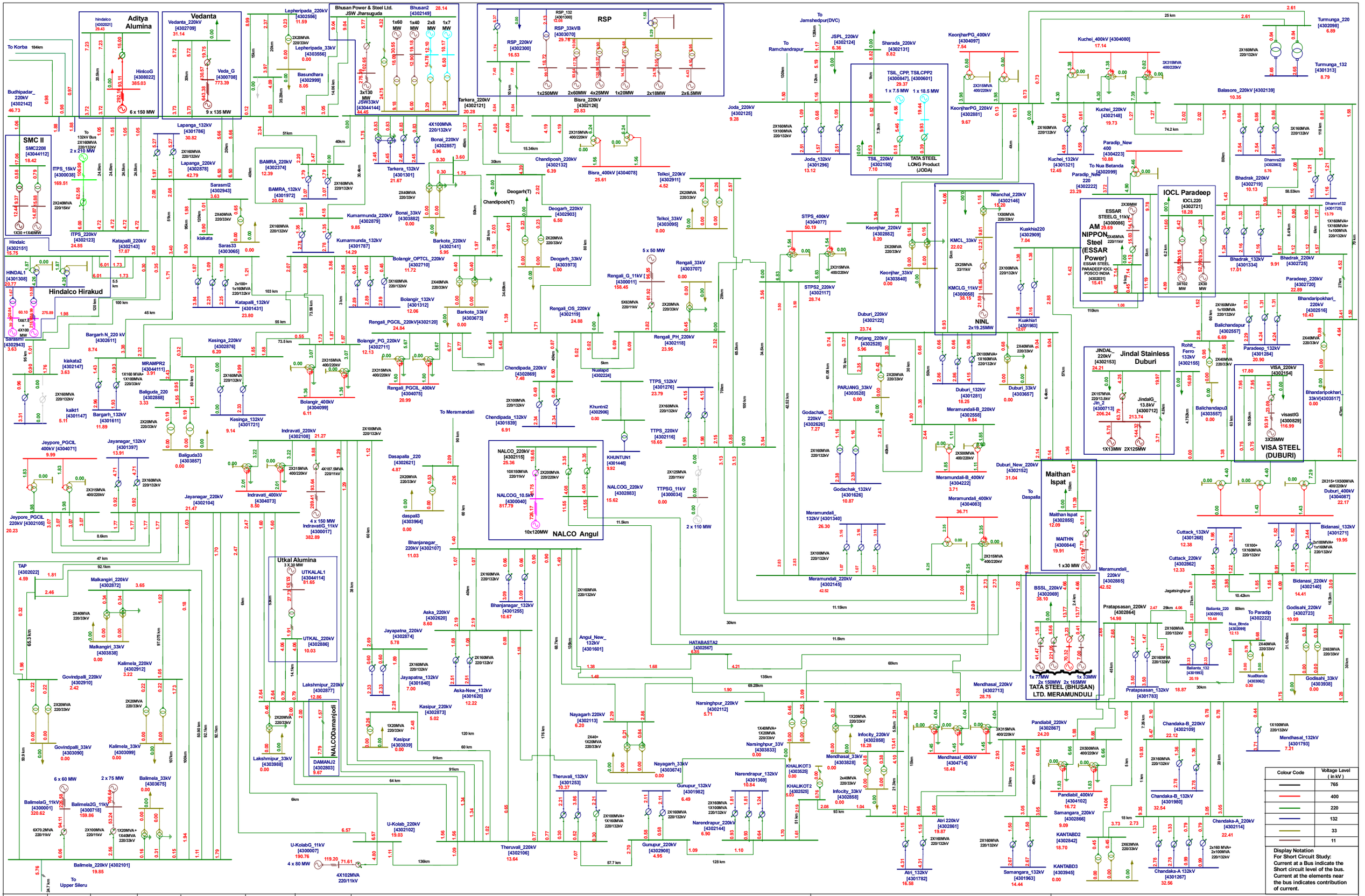
Single line Diagram of 765kV and 400kV transmisssion network- Odisha State 2024-25 condition

Odisha Power Transmission Corporation Ltd.
Registered Office: Janpath, Bhubaneswar-751022
Phone: (0674)-2541320/2542320

Power Research & Development Consultants Private Limited
#5, 11th Cross, 2nd Stage, West of Chord Road, Bangalore- 560086, INDIA
Ph : +91-080-2319 2209,2159
Fax: +91-080-2319 2210
E-mail : info@prdcinfotech.com

DRAWN IN: MiPower ™

DWG. NO :PEAK\SCS-SLG\2024-25\765-400kV



APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

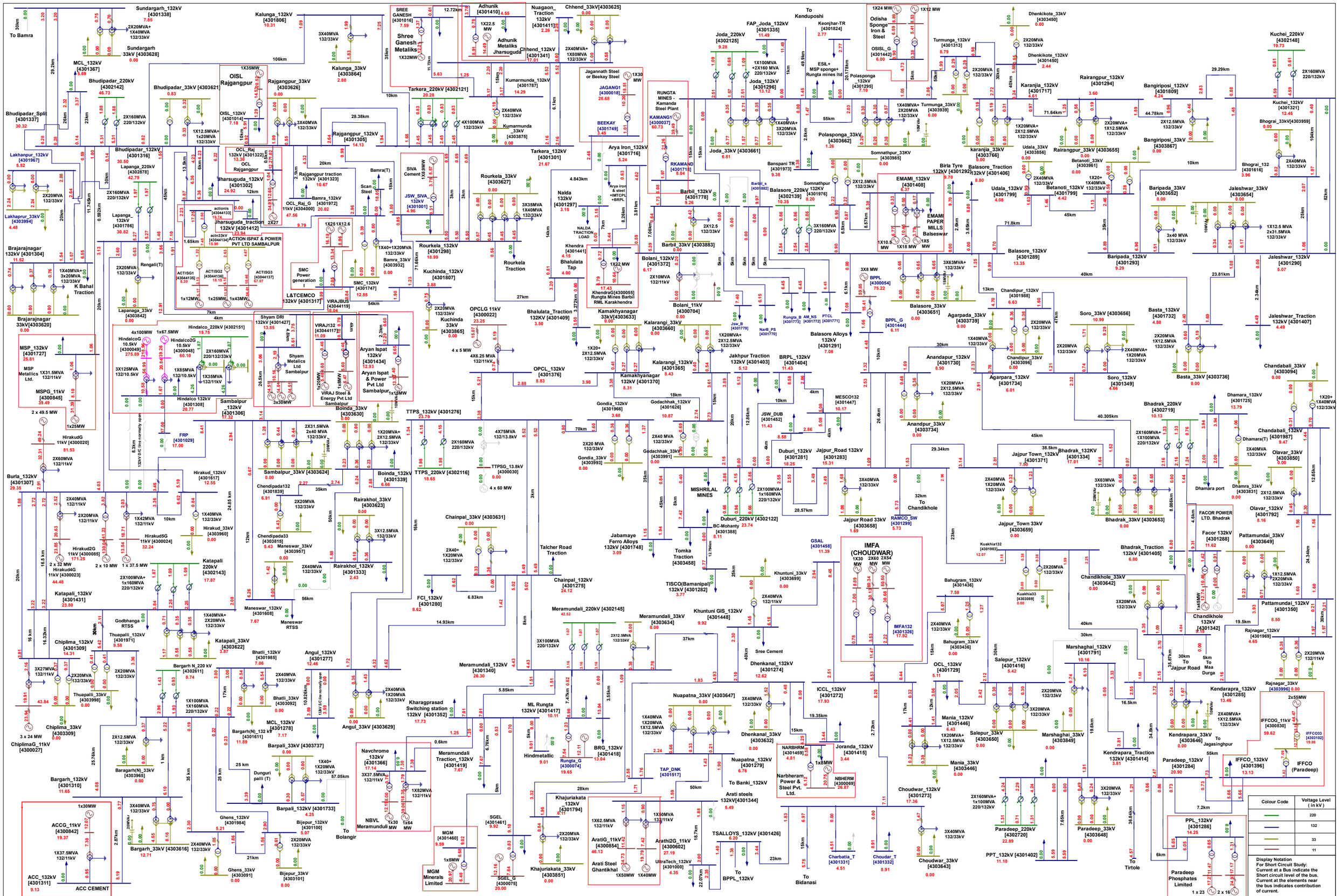
Single Line to Ground Fault in kA

Single line diagram of 220 kV transmission network - Odisha State 2024-25 condition

Orissa Power Transmission Corporation Ltd.
Registered Office: Janpath, Bhubaneshwar-751022
Phone: (0674)-2541320/2542320

Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road, Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

Drawn using: MiPower™ | DWG. NO : PEAK\SCS-SLG\2024-25\220kV



Colour Code	Voltage Level (in kV)
	220
	132
	33
	11

Display Notation
For Short Circuit Study:
Current at a Bus indicate the Short circuit level of the bus.
Current at the elements near the bus indicates contribution of current.

APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

Single Line to Ground Fault in KA

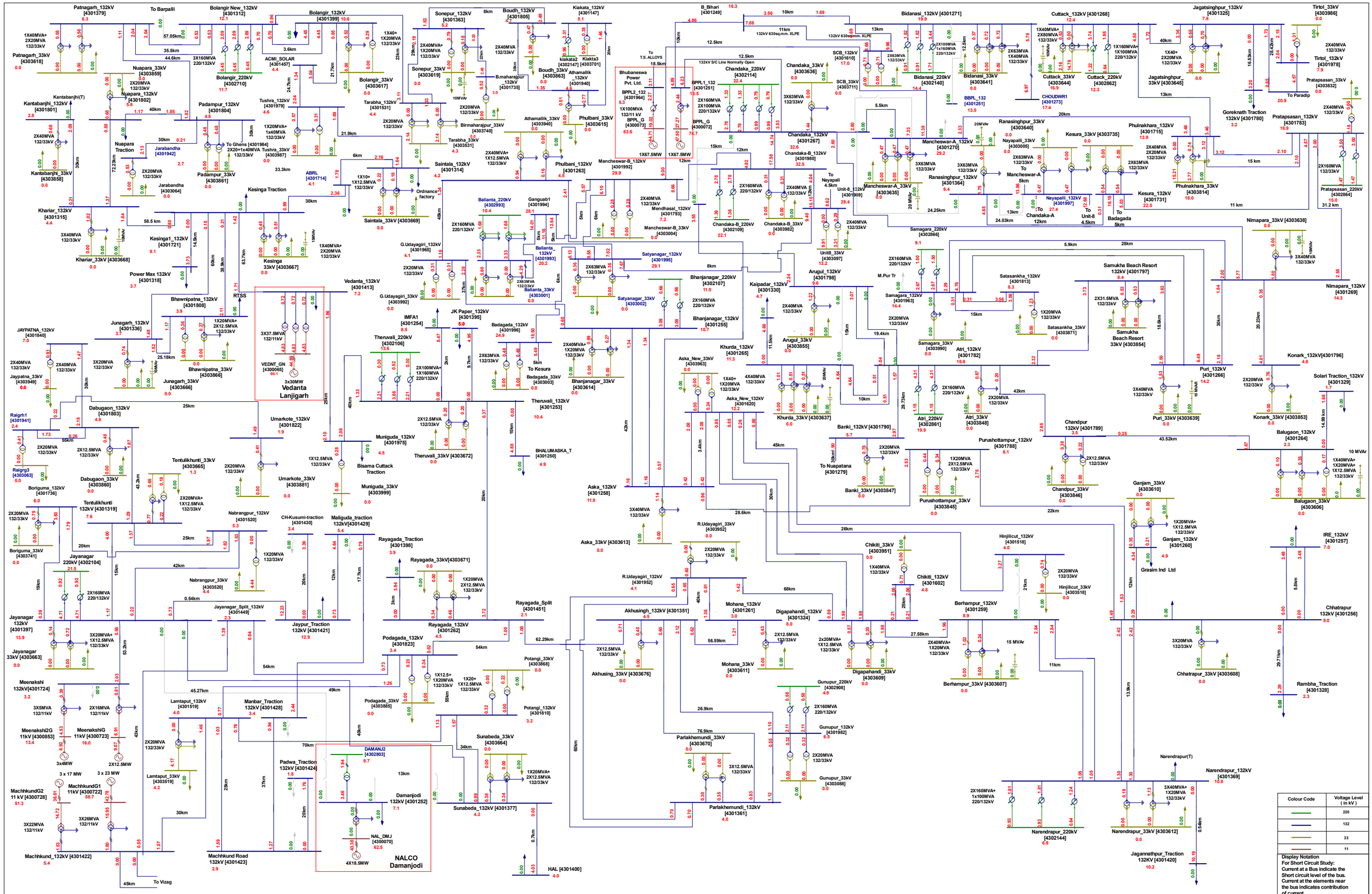
Single line diagram of 132 kV(North) transmission network - Odisha State 2024-25 condition

Odisha Power Transmission Corporation Ltd.,
Registered Office: Janpath, Bhubaneshwar-751022
Phone: (0674)-2541320/254232

Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road, Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

Drawn using: MiPower™

DWG. NO :PEAK\SCS-SLG\2024-25\132kV(North)



APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

Single Line to Ground Fault in KA

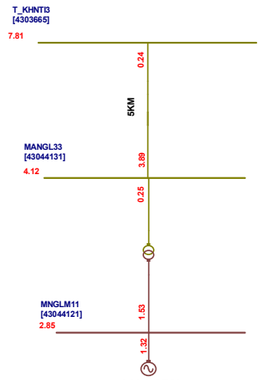
Single line diagram of 132 kV(South) transmission network - Odisha State 2023-24 condition

Odisha Power Transmission Corporation Ltd.,
Registered Office: Janpath,
Bhubaneshwar-751022
Phone: (0674)-2541320/2542320

Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road,
Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

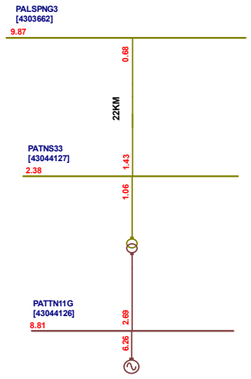
Drawn using: MiPower™

DWG. NO : SP\SCS-SLG\2024-25\132kV(South)



1 X 3 MW

Mangalam Timber

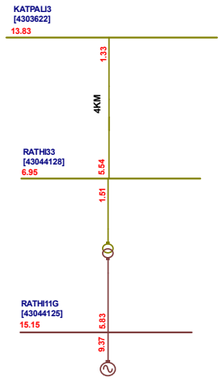


1X8 MW

Pattanaik Steel

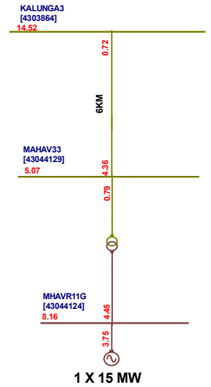
or

MGM Minerals



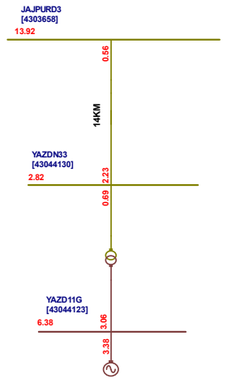
Rathi Steel

1 x 20 MW



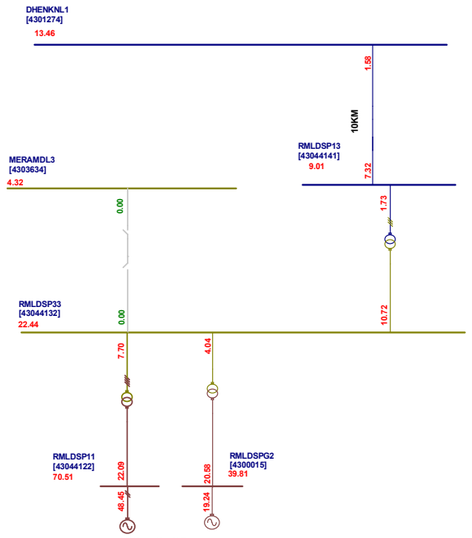
1 X 15 MW

Mahaveer



1X10 MW

Yazdani Power

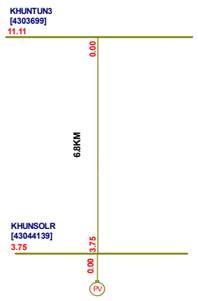


1X50 + 2X25 MW

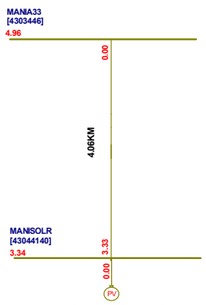
RML DSP, Dhenkanal

or

Rungta Mines Dhenkanal



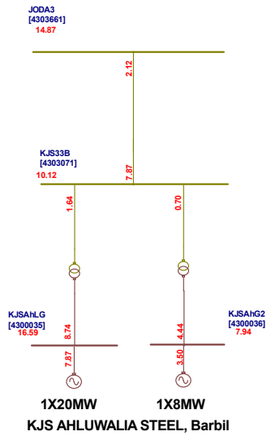
Sree Solar



Dalmia Cement

1X1.5MW

Seven Starts Limited



1X20MW

1X8MW

KJS AHLUWALIA STEEL, Barbil

Colour Code	Voltage Level (in kV)
	220
	132
	33
	11

Display Notation
For Short Circuit Study:
Current at a Bus indicate the Short circuit level of the bus.
Current at the elements near the bus indicates contribution of current.

APPROVED	REVIEWED	CHECKED	DRAWN	DESCRIPTION	REV.	DATE

Single Line to Ground Fault in KA

Single line diagram of 33 kV transmission network - Odisha State 2024-25 condition

Odisha Power Transmission Corporation Ltd.,
Registered Office: Janpath,
Bhubaneshwar-751022
Phone: (0674)-2541320/254232

Power Research and Development Consultants Private Limited
#5, 11th Cross, 2nd Stage,WOC Road,
Bangalore-560 086, INDIA.
Tel : +91-080-23192159,23192168,
E-mail : info@prdcinfotech.com

Drawn using: MiPower TM

DWG. NO :PEAK\SCS-SLG\2024-25\33kV

ANNEXURE 5

Reactive Power exchange at different metering points (attached)

A DRAFT REPORT FOR DETAILED REACTIVE ENERGY EXCHANGES OF THE TPCODL DURING MAY 2024

From Date : 01-May-2024 To Date : 31-May-2024

SL. NO.	SUBSTATION	METERING POINT	Monthly Reactive Energy Injection in MVArH	Monthly Reactive Energy Drawal in MVArH	Net Reactive Energy High (Voltage > 103%) in MVArH	REACTIVE CHARGE_MVArH_High (Rs)	Net Reactive Low (Voltage <97%) in MVArH	REACTIVE CHARGE_MVArH_Low (Rs)
1	Angul	MCL Feeder1 132kV (C)	-3.67	3037.83	1298.40	38952	0.00	0
2	Angul	MCL Feeder2 132kV (C)	-3.45	2830.25	1126.20	33786	0.00	0
3	Angul	PGCIL Stn. Tertiary				0		0
4	Angul	Trf1-40MVA 132/33kV	-0.40	2345.47	0.00	0	400.00	12000
5	Angul	Trf2-40MVA 132/33kV	-0.36	2471.12	2.00	60	416.00	12480
6	Angul	Trf3-20MVA 132/33kV	0.00	1615.93	0.00	0	266.62	7999
7	Arati Steel	Arati Steel 132kV	-1816.90	273.66	-563.10	-16893	-37.10	-1113
8	Argul	Trf 1-40MVA 132/33kV	-3.17	834.10	43.22	1297	171.46	5144
9	Argul	Trf2-40MVA 132/33kV	-2.78	840.09	50.98	1529	150.86	4526
10	Badagada	Trf1-63MVA 132/33kV	-0.27	2059.40	294.00	8820	354.00	10620
11	Badagada	Trf2-63MVA 132/33kV	-3.23	1380.28	206.00	6180	245.00	7350
12	Balugaon	Keshpur Feeder 33kV	-0.23	961.64	85.00	2550	132.90	3987
13	Balugaon	Khallikote Feeder 33kV	-0.59	1354.27	94.49	2835	237.65	7130
14	Balugaon	SOLARI Traction 132kV	-825.41	289.63	-27.88	-836	-69.43	-2083
15	Balugaon	Trf1-40MVA 132/33kV	-0.12	2238.50	180.55	5417	360.25	10808
16	Balugaon	Trf2-20MVA 132/33kV	-0.10	1406.32	118.90	3567	220.20	6606
17	Balugaon	Trf3-12.5MVA 132/33kV	-0.11	748.97	53.00	1590	125.00	3750
18	Banki	Trf1-20MVA 132/33kV	-0.10	1332.51	434.78	13043	88.15	2645
19	Banki	Trf2-20MVA 132/33kV	0.00	1373.59	473.30	14199	86.15	2585
20	Baranga	S.N. Mohanty(Solar) 11kV	-8.93	2.96	0.00	0	0.00	0
21	Barkote	Pallhara Feeder 33kV	-1.21	435.79	0.00	0	0.00	0
22	Bhubaneswar	Trf1-63MVA 132/33kV	-0.01	4154.85	794.75	23843	653.74	19612
23	Bhubaneswar	Trf2-63MVA 132/33kV	0.00	4162.17	821.90	24657	639.70	19191
24	Bhubaneswar	Trf3-63MVA 132/33kV	0.00	4225.02	781.45	23444	679.62	20389
25	Bidanasi	Trf1-63MVA 132/33kV	-0.30	3187.16	781.00	23430	386.00	11580
26	Bidanasi	Trf2-63MVA 132/33kV	-0.29	3157.52	767.10	23013	381.60	11448
27	Bidanasi	Trf3-40MVA 132/33kV	0.00	2214.03	543.00	16290	259.00	7770
28	Boinda	Traction Feeder 132kV	-1261.92	295.77	-289.60	-8688	-239.00	-7170
29	Boinda	Trf1-20MVA 132/33kV	-0.36	1223.58	84.40	2532	237.80	7134
30	Boinda	Trf2-12.5MVA 132/33kV	-1.38	731.40	52.10	1563	136.80	4104
31	Boinda	Trf3-12.5MVA 132/33kV	-0.01	963.91	91.47	2744	169.98	5099
32	BPPL S/W	BPPL Fdr-I(TS Alloy)	-106.99	3267.27	0.00	0	0.00	0
33	BPPL S/W	BPPL Fdr-II(Bidanasi)	-53.35	9430.79	0.00	0	0.00	0
34	Brajabiharipur	Trf1-40MVA 132/33kV	-0.45	1397.95	200.00	6000	198.00	5940
35	Brajabiharipur	Trf2-40MVA 132/33kV	-0.45	1413.42	196.00	5880	202.00	6060

36	Chainpal	Talcher Fert. Ltd 132kV	-4.51	32.09	**4.40**	**132**	**0.00**	**0**
37	Chainpal	Traction Feeder 132kV	-20.08	1935.09	**346.30**	**10389**	**5.30**	**159**
38	Chainpal	Trf1-40MVA 132/33kV	-0.40	3078.39	**245.68**	**7370**	**34.87**	**1046**
39	Chainpal	Trf2-40MVA 132/33kV	-0.67	2951.10	**246.90**	**7407**	**30.80**	**924**
40	Chainpal	Trf3-20MVA 132/33kV	-0.11	1774.44	**179.35**	**5381**	**12.90**	**387**
41	Chandaka	Trf1-63MVA 132/33kV	0.00	5038.15	**273.00**	**8190**	**572.50**	**17175**
42	Chandaka	Trf2-63MVA 132/33kV	-0.07	4546.74	**245.50**	**7365**	**530.30**	**15909**
43	Chandaka	Trf3-63MVA 132/33kV	-0.08	4556.22	**251.00**	**7530**	**524.00**	**15720**
44	Chandaka GIS	Trf1-40MVA 132/33KV	-2.90	1170.03	**33.40**	**1002**	**269.40**	**8082**
45	Chandaka GIS	Trf2-40MVA 132/33KV	-1.38	1138.36	**35.20**	**1056**	**256.60**	**7698**
46	Chandikhol	Badachana Feeder 33kV	0.00	1590.77	**25.00**	**750**	**1100.00**	**33000**
47	Chandikhol	Kundala Feeder 33kV	-0.50	1006.20	**13.40**	**402**	**734.30**	**22029**
48	Chandikhol	MTPCL(IPP) Ckt-1 132kV	-220.36	37.17	**-6.00**	**-180**	**-195.00**	**-5850**
49	Chandikhol	MTPCL(IPP) Ckt-2 132kV	-351.14	76.21	**-18.00**	**-540**	**-424.00**	**-12720**
50	Chandpur	MGM SOLAR	-4.94	1.26	**0.00**	**0**	**0.00**	**0**
51	Chandpur	Trf1-12.5MVA 132/33kV	-0.58	1218.87	**364.10**	**10923**	**101.10**	**3033**
52	Chandpur	Trf2-12.5MVA 132/33kV	-5.14	377.05	**97.00**	**2910**	**38.30**	**1149**
53	Chandpur	Trf3-20MVA 132/33kV	0.00	2205.77	**674.45**	**20234**	**178.80**	**5364**
54	Chandpur(Solar)	VIVACITY Solar	-8.61	1.86	**0.00**	**0**	**0.00**	**0**
55	Choudwar	Traction Feeder 132kV	-81.02	1451.56	**186.80**	**5604**	**166.50**	**4995**
56	Choudwar	Trf2-40MVA 132/33kV	-0.12	2452.09	**323.00**	**9690**	**474.00**	**14220**
57	Choudwar	Trf3- 40MVA 132/33kV	-0.10	2457.68	**321.48**	**9644**	**475.23**	**14257**
58	Choudwar	Trf4-40MVA 132/33kV	-0.04	2529.09	**334.00**	**10020**	**469.00**	**14070**
59	Choudwar	Ultra tech Feeder 132kV	-25.58	1296.95	**151.90**	**4557**	**169.70**	**5091**
60	Cuttack	Trf1-40MVA 132/33kV	-0.16	2889.64	**616.40**	**18492**	**392.80**	**11784**
61	Cuttack	Trf2-40MVA 132/33kV	-0.14	2927.56	**613.60**	**18408**	**404.10**	**12123**
62	Cuttack	Trf3-40MVA 132/33kV	-0.19	2883.77	**606.10**	**18183**	**395.90**	**11877**
63	Dhenkanal	Joranda Tr. Feeder 132kV	-105.66	1338.53	**4.00**	**120**	**136.00**	**4080**
64	Dhenkanal	Narveram Feeder 33kV	-42.64	232.05	**5.00**	**150**	**-8.60**	**-258**
65	Dhenkanal	Trf1-40MVA 132/33kV	-0.14	2877.49	**11.00**	**330**	**489.00**	**14670**
66	Dhenkanal	Trf2-40MVA 132/33kV	0.00	3084.10	**20.00**	**600**	**417.00**	**12510**
67	Dhenkanal	Trf3-40MVA 132/33kV	-0.11	2858.53	**13.24**	**397**	**436.91**	**13107**
68	Global	Heavy Water Feeder 132kV	-36.42	0.95	**-6.80**	**-204**	**0.00**	**0**
69	Global	Trf1-20MVA 132/33 kV (Ind.)	-32.11	110.04	**0.00**	**0**	**42.60**	**1278**
70	Goda	Trf1-20MVA 132/33KV	-1.61	330.24	**49.00**	**1470**	**1.00**	**30**
71	Goda	Trf2-40MVA 132/33KV	0.00	859.23	**139.90**	**4197**	**2.60**	**78**
72	Godisahi	Trf1-63MVA 220/33kV	-1.69	934.29	**15.00**	**450**	**129.00**	**3870**
73	Godisahi	Trf2-63MVA 220/33kV	-1.87	929.28	**17.00**	**510**	**125.00**	**3750**
74	Grid Steel & Alloy Ltd	GSAL Feeder 132kV	0.00	0.00	**0.00**	**0**	**0.00**	**0**
75	Infocity-II GIS	Trf1-40MVA 220/33kV	-0.18	0.06	**0.00**	**0**	**0.00**	**0**
76	Infocity-II GIS	Trf2-40MVA 220/33kV	-4.69	1245.61	**131.15**	**3935**	**90.69**	**2721**
77	Jagatsinghpur	Traction Feeder 132kV	-887.06	208.95	**-1.00**	**-30**	**-343.00**	**-10290**
78	Jagatsinghpur	Trf1-20MVA 132/33kV	0.00	1510.51	**35.15**	**1055**	**623.00**	**18690**
79	Jagatsinghpur	Trf2-20MVA 132/33kV	-0.09	1188.47	**20.99**	**630**	**508.43**	**15253**
80	Jagatsinghpur	Trf3-40MVA 132/33kV	0.00	2565.38	**51.00**	**1530**	**1090.00**	**32700**

81	Kalarangi	Trf1-12.5MVA 132/33kV	-0.84	200.78	18.40	552	0.70	21
82	Kalarangi	Trf2-12.5MVA 132/33kV				0		0
83	Kalarangi	Trf3-20MVA 132/33kV	-0.97	320.30	32.20	966	1.10	33
84	Kamakhyanagar	Traction Feeder 132kV	-1426.23	136.62	-435.80	-13074	-1.00	-30
85	Kamakhyanagar	Trf1-20MVA 132/33kV	0.00	1126.83	0.02	1	162.50	4875
86	Kamakhyanagar	Trf2-12.5MVA 132/33kV	0.00	675.69	0.01	0	100.05	3002
87	Kamakhyanagar	Trf3-12.5MVA 132/33kV	0.00	747.39	0.00	0	115.57	3467
88	Kendrapada	Trf1-12.5MVA 132/33kV				0		0
89	Kendrapada	Trf2-40MVA 132/33kV	0.00	2724.71	104.80	3144	1233.20	36996
90	Kendrapada	Trf4-40MVA 132/33kV	-0.22	2590.24	92.29	2769	1199.56	35987
91	Khajuriakata	ABREL Solar 33kV	-281.90	11.50	0.70	21	64.50	1935
92	Khajuriakata	Trf1-40MVA 132/33kV	-267.21	359.01	7.39	222	129.44	3883
93	Khajuriakata	Trf2-40MVA 132/33kV	-260.88	336.63	7.15	215	124.87	3746
94	Kharagprasad	Jagannath Power & Infra Ltd 132kV (Biomass)	-1736.88	39.71	-915.00	-27450	0.00	0
95	Kharagprasad	M.muhudi (Traction Feeder 132kV	-493.25	468.62	-32.00	-960	0.00	0
96	Kharagprasad	MGM Feeder 132kV	-1789.73	3.64	-412.27	-12368	0.00	0
97	Kharagprasad	Navabharat Fdr1 132kV(IPP)	-5354.75	0.03	-1414.99	-42450	0.00	0
98	Kharagprasad	Navabharat Fdr2 132kV(CGP)	-3436.08	46.17	-786.00	-23580	0.00	0
99	Kharagprasad	Trf1-20MVA 132/33kV	-0.41	667.93	15.90	477	0.00	0
100	Khuntuni GIS	Shree Cement Fdr 132KV	-149.27	96.19	-18.00	-540	-16.00	-480
101	Khuntuni GIS	Trf1-40MVA 132/33kV	0.00	1656.40	24.90	747	283.90	8517
102	Khuntuni GIS	Trf2-40MVA 132/33kV	-7.08	1170.45	12.70	381	197.50	5925
103	Khurda	Kaipadar Tr. Feeder 132kV	-444.21	797.36	-0.60	-18	77.00	2310
104	Khurda	Trf1-40MVA 132/33kV				0		0
105	Khurda	Trf2-40MVA 132/33kV	-0.01	4064.87	181.80	5454	1037.20	31116
106	Khurda	Trf3-40MVA 132/33kV	0.00	4005.65	164.00	4920	1016.00	30480
107	Khurda	Trf4-40MVA 132/33kV	-0.59	4046.85	180.28	5408	1048.39	31452
108	Konark	Trf1-20MVA 132/33kV	0.00	1084.10	61.75	1853	337.28	10118
109	Konark	Trf2-20MVA 132/33kV	0.00	1115.56	62.36	1871	358.59	10758
110	Mancheswar-B GIS	Trf1-40MVA 132/33kV	-0.29	2479.07	113.20	3396	560.80	16824
111	Mancheswar-B GIS	Trf2-40MVA 132/33kV	-0.04	3105.57	157.10	4713	668.60	20058
112	Mania	Trf1-12.5MVA 132/33kV	-0.07	440.35	8.72	262	127.42	3823
113	Mania	Trf2-20MVA 132/33kV	-1.85	652.44	6.01	180	210.69	6321
114	Marshaghai	Kendrapada Traction 132kV	-1442.09	67.20	-30.90	-927	-624.70	-18741
115	Marshaghai	Trf1-20MVA 132/33kV	-0.02	1128.53	116.80	3504	334.25	10028
116	Marshaghai	Trf2-20MVA 132/33kV	-0.01	1142.21	105.23	3157	363.24	10897
117	Mendhasal	Trf1-20MVA 220/33kV	-1.83	398.07	-0.99	-30	67.87	2036
118	Mendhasal	Trf2-20MVA 220/33kV	-0.35	675.00	0.55	17	109.95	3299
119	Meramundali	BRG Feeder 132kV	-379.47	737.39	203.40	6102	0.00	0
120	Meramundali	JSPL Feeder1 400kV	-8133.04	9842.44	-1070.00	-32100	0.00	0
121	Meramundali	JSPL Feeder2 400kV	-7931.13	9868.37	-380.00	-11400	0.00	0
122	Meramundali	RUNGTA Feeder 132kV (MLP)	-120.97	978.52	116.92	3508	0.39	12
123	Meramundali	RUNGTA Mines 132kV	-260.19	1749.08	-345.00	-10350	-1.00	-30
124	Meramundali	TATA Power BSL-1 220kV	-1440.53	5035.72	-429.40	-12882	0.00	0
125	Meramundali	TATA Power BSL-2 220kV	-1438.75	4935.60	-258.30	-7749	0.00	0

126	Narsinghpur	Trf1-40MVA 220/33kV	-0.27	834.07	**0.00**	**0**	**48.70**	**1461**
127	Narsinghpur	Trf2-20MVA 220/33kV	0.00	631.59	**0.00**	**0**	**34.70**	**1041**
128	Nayagarh	Trf1-40MVA 220/33kV	-0.02	3627.79	**139.60**	**4188**	**497.10**	**14913**
129	Nayagarh	Trf2-20MVA 220/33kV	-0.06	1974.68	**86.85**	**2606**	**258.85**	**7766**
130	Nayagarh	Trf3-40MVA 220/33kV	0.00	3609.62	**146.00**	**4380**	**488.00**	**14640**
131	Nimapara	Trf1-40MVA 132/33kV	-12.63	727.64	**15.90**	**477**	**263.30**	**7899**
132	Nimapara	Trf2-40MVA 132/33kV	-15.29	718.31	**13.00**	**390**	**259.00**	**7770**
133	Nimapara	Trf3-40MVA 132/33kV	-14.51	683.92	**15.00**	**450**	**246.00**	**7380**
134	Nuapatana	Trf1-20MVA 132/33kV	-0.06	1056.68	**477.40**	**14322**	**37.30**	**1119**
135	Nuapatana	Trf2-40MVA 132/33kV	-0.12	1972.98	**876.83**	**26305**	**70.25**	**2108**
136	Nuapatana	Trf3-12.5MVA 132/33kV	0.00	720.05	**323.15**	**9695**	**25.60**	**768**
137	Olaver	Trf1-12.5MVA 132/33kV	0.00	980.02	**6.49**	**195**	**615.39**	**18462**
138	Olaver	Trf2-12.5MVA 132/33kV	-0.47	929.52	**4.55**	**137**	**597.65**	**17930**
139	Pandiabil PG	PGCIL Stn. Tertiary				**0**		**0**
140	Paradeep	A. M. Nippon Steel Feeder1 220kV	-1097.69	71.13	**-2.00**	**-60**	**-535.00**	**-16050**
141	Paradeep	A. M. Nippon Steel Feeder2 220kV	-875.98	396.44	**-1.00**	**-30**	**-677.00**	**-20310**
142	Paradeep	IFFCO Feeder1 132kV	-875.98	396.44	**42.50**	**1275**	**210.60**	**6318**
143	Paradeep	IFFCO Feeder2 132kV	-249.82	53.96	**-3.10**	**-93**	**-123.10**	**-3693**
144	Paradeep	IOCL Feeder 220kV	-626.34	1369.71	**15.00**	**450**	**315.00**	**9450**
145	Paradeep	PPL Feeder1 132kV	-29.82	237.41	**-3.42**	**-103**	**-101.38**	**-3041**
146	Paradeep	PPL Feeder2 132kV	-134.67	980.22	**4.78**	**143**	**334.45**	**10034**
147	Paradeep	PPT Feeder1 132kV	-286.48	124.10	**-3.70**	**-111**	**-40.80**	**-1224**
148	Paradeep	PPT Feeder2 132kV	-79.49	1656.15	**6.60**	**198**	**770.00**	**23100**
149	Paradeep	Siju RTSS Feeder 132kV	-7.59	1722.32	**89.00**	**2670**	**390.00**	**11700**
150	Paradeep	Trf1-20MVA 132/33kV	-0.42	1338.04	**147.43**	**4423**	**431.23**	**12937**
151	Paradeep	Trf2-20MVA 132/33kV	0.00	1486.69	**166.83**	**5005**	**475.26**	**14258**
152	Paradeep	Trf3-20MVA 132/33kV				**0**		**0**
153	Pattamundai	Trf1-20MVA 132/33kV	-0.17	862.66	**5.30**	**159**	**544.03**	**16321**
154	Pattamundai	Trf2-20MVA 132/33kV	-0.70	728.86	**4.17**	**125**	**459.67**	**13790**
155	Pattamundai	Trf3-12.5MVA 132/33kV	0.00	917.68	**7.60**	**228**	**563.50**	**16905**
156	Phulnakhara	Trf1-20MVA 132/33kV	-0.12	1638.99	**168.80**	**5064**	**380.25**	**11408**
157	Phulnakhara	Trf2-20MVA 132/33kV	0.00	2089.64	**209.00**	**6270**	**515.25**	**15458**
158	Phulnakhara	Trf3-40MVA 132/33kV	-0.14	3282.13	**338.80**	**10164**	**813.20**	**24396**
159	Pratapsasan	Trf1-40MVA 132/33kV	-0.21	3070.17	**509.00**	**15270**	**558.00**	**16740**
160	Pratapsasan	Trf2-40MVA 132/33kV	-0.17	3254.19	**538.00**	**16140**	**587.00**	**17610**
161	Puri	Trf1-40MVA 132/33kV	-0.01	1698.57	**12.70**	**381**	**983.40**	**29502**
162	Puri	Trf2-40MVA 132/33kV	-19.94	1672.33	**18.70**	**561**	**855.00**	**25650**
163	Puri	Trf3-40MVA 132/33kV	-0.01	1547.97	**13.00**	**390**	**892.00**	**26760**
164	Rairakhol	Bamur Feeder 33kV	-0.10	257.12	**0.00**	**0**	**158.42**	**4753**
165	Rajnagar	Trf1-20MVA 132/33kV	-0.07	699.23	**59.60**	**1788**	**222.40**	**6672**
166	Rajnagar	Trf2-20MVA 132/33kV	-0.08	699.83	**58.70**	**1761**	**221.80**	**6654**
167	Ranasinghpur	Trf1-63MVA 132/33kV	-0.35	2921.91	**26.70**	**801**	**802.10**	**24063**
168	Ranasinghpur	Trf2-63MVA 132/33kV	-0.42	2901.80	**22.98**	**689**	**823.47**	**24704**

169	Ranasinghpur	Trf3-63MVA 132/33kV	-0.04	3291.90	24.00	720	960.00	28800
170	Rengali	BUDHAPAL Feeder 33kV	-1.05	214.00	0.00	0	14.56	437
171	Rengali	PGCIL Stn. Tertiary				0		0
172	Rengali	Trf1-20MVA 220/33kV	-0.37	1338.91	0.00	0	120.77	3623
173	Rengali	Trf2-20MVA 220/33kV	-1.76	1093.82	0.00	0	81.80	2454
174	Salipur	OCL Feeder 132kV	-192.35	346.20	25.90	777	106.20	3186
175	Salipur	Trf1-20MVA 132/33kV	-0.03	1644.98	389.40	11682	400.00	12000
176	Salipur	Trf2-20MVA 132/33kV	-0.13	1771.40	417.65	12530	439.30	13179
177	Salipur	Trf3-20MVA 132/33kV	0.00	1830.41	438.20	13146	440.70	13221
178	Samangara	Malatipatapur Tr. Fdr 132kV	-1253.62	169.95	-16.00	-480	-405.00	-12150
179	Samangara	Trf1-20MVA 132/33kV	-5.86	411.46	3.75	113	199.05	5972
180	Samangara	Trf2-20MVA 132/33kV	-7.52	404.32	1.95	59	211.84	6355
181	Satasankha	Trf1-20MVA 132/33kV				0		0
182	Satasankha	Trf2-20MVA 132/33kV	-0.18	1534.22	101.30	3039	565.20	16956
183	Shamuka	Trf1-31.5MVA 132/33kV	-5.63	748.53	27.10	813	507.00	15210
184	Shamuka	Trf2-31.5MVA 132/33kV	0.00	0.52	37.32	1120	90.27	2708
185	Tata Steel Minning Ltd	Tata Steel Minning Ltd 132KV	-72.39	1277.38	158.00	4740	171.00	5130
186	Tirtol	Trf1-40MVA 132/33kV	-1.16	1512.41	103.70	3111	442.70	13281
187	Tirtol	Trf2-40MVA 132/33kV	0.00	2171.30	48.30	1449	763.70	22911
188	TTPS	Trf ST-12 20MVA 132/33kV	0.00	185.09	158.00	4740	0.00	0
189	TTPS	Trf ST-2A 20MVA 220/132kV	0.00	135.31	16.00	480	0.00	0
190	TTPS	Trf ST-2B 20MVA 220/132kV	0.00	144.39	16.00	480	0.00	0
191	TTPS	Trf ST-34 20MVA 132/33kV	0.00	280.74	238.00	7140	0.00	0
192	Unit-8 GIS	Trf 1-40MVA 132/33kV	0.00	2562.80	220.00	6600	443.00	13290
193	Unit-8 GIS	Trf 2-40MVA 132/33kV	0.00	1885.11	161.10	4833	346.00	10380
		TOTAL=	-48613.038	292781.422	17753.746	₹ 5,32,612	46766.521	₹ 14,02,996

SL. No.	VOLTAGE LEVEL	Threshold Voltage limit for Reactive High (103% of Vnominal)	Threshold Voltage limit for Reactive Low (97% of Vnominal)
1	400kV	412	388
2	220kV	226.6	213.4
3	132kV	135.96	128.04
4	33kV	33.99	32.01

Note:

1) Rate of Reactive Energy Charge has been considered in report@ 3 paise/KVArH as per OERC Order in Case No. 50/2017 and subsequently OPTCL has provisionally proposed the same as Reactive Energy Charges FY 2024-25.

2) For reactive energy, (-) means injection and (+) means drawal with respect to DISCOM utility

2) For reactive energy, (-) means injection and (+) means drawal with respect to DISCOM utility.

3) For reactive energy charge :

i) **Net reactive energy High (MVArH_High) :**
Reactive energy drawal (+) means receivable by the DISCOM utility and Reactive energy injection (-) means payable by the DISCOM utility.

ii) **Net reactive energy Low (MVArH_Low) :**
Reactive energy drawal (+) means payable by the DISCOM utility and Reactive energy injection (-) means receivable by the DISCOM utility.

4) "**NA**" means meter reading not available.

T FOR PROVISIONAL REACTIVE ENERGY CHARGE STATEMENT FOR THE MONTH OF MAY			
SL.No.	FROM	TO	AMOUNT PAYABLE (RS)
1	TPCODL	OPTCL REACTIVE POOL	₹ 8,70,383

Note:
a) Reactive Energy Charge calculation is done as per clause 1.7 and 6.6 of IEGC
b) Receivables from the Reactive Pool are reduced to zero.

ANNEXURE 6

Reply to comments mentioned by the honorable commission (Case 44/2024)

OERC Case No-44/2024

Point wise reply to Para-10 of the Order heard on dated 9th July-2024

Para-10:

a) It must be ensured that the study report includes an analysis of the impact of Inertia, Harmonics (Current THD), Reactive Power, and Power Factor. These parameters should be measured at the point of common coupling (PCC) and the generator output point both in isolated mode and Grid connection mode.

The abovementioned parameters including Harmonics (Current THD), Reactive Power, and Power Factor are measured at the point of common coupling and are included in the report. The analysis associated to impact of inertia is mentioned in the report with suitable simulation results. The measurement of above-mentioned electrical parameters at the generator output point is unable to be recorded due to unavailability of permission. In other words, the measurement of parameters for the CGP at the point of common coupling is sufficient enough to prove the Grid support provided by STU to the CGP.

Brief analysis on impact of inertia

A connectivity with a grid having high inertia helps to reduce the rate of rise of grid frequency following the occurrence of a disturbance. It also helps when the system recovers after the disturbance is removed or the source of disturbance is disconnected. If the CGPs are working in parallel with the grid, they are part of the grid, with a high overall inertia and the rate of frequency change is slow or moderate. This helps in avoiding 'Rate of frequency change based relays' to pick up and island the CGP.

Frequent islanding may call for frequent synchronization and loss of production time. If the CGP is islanded and there is a load generation balance, the ' house load operation' may sustain, but because of low inertia of CGP the rate of change in frequency will be higher and recovery may be slower. The swings in load angle 'delta' and frequency could trigger protection settings of the generator or the turbine and one of the generators of CGP may trip.

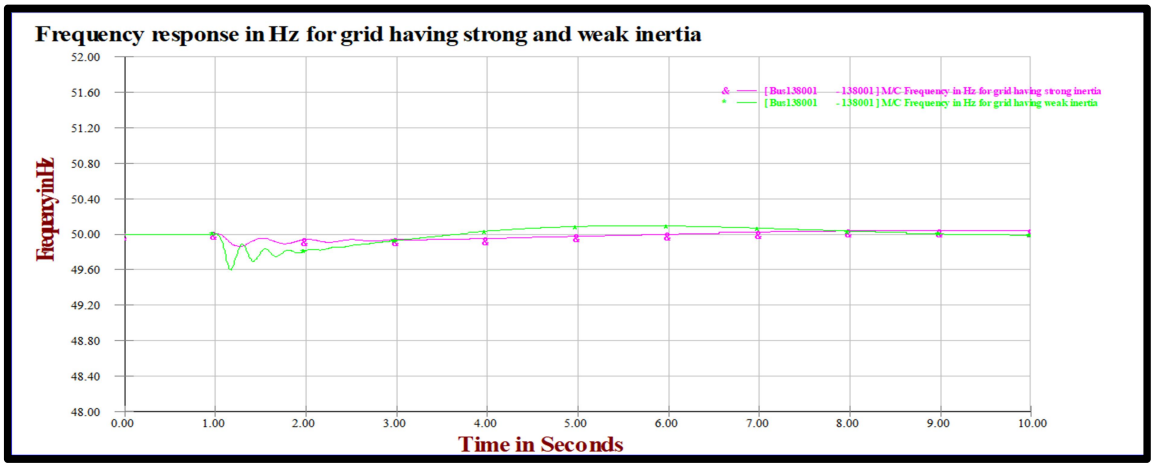


Figure 1 An example of frequency response of CGP due to impact of inertia support provided by Grid

Even if protection does not operate, frequent islanding and synchronization does affect the life of Generator and Turbine. Parallel operation therefore is advisable because total inertia helps in reducing rate of change in frequency and load angle. The islanded CGP has low inertia, which leads to

the magnitude in rotor angle swing and the change in frequency could go high and threaten turbine blade life which is the worst thing that can happen to CGP generators. The usually sluggish controller in CGP may not be able to make the system dynamically stable.

In dynamic stability studies of an integrated power system, all machines and their swing frequency is as per their inertia. Big machines swing together at low frequency, and small machines some distance away, swing at higher frequency and load angle. Eventually the low inertia machines are seen to run away first. CGP owners are aware that long operation under house load conditions makes the system vulnerable to more tripping and loss of production. A connectivity to a high inertia system gives them transient and emergency protection.

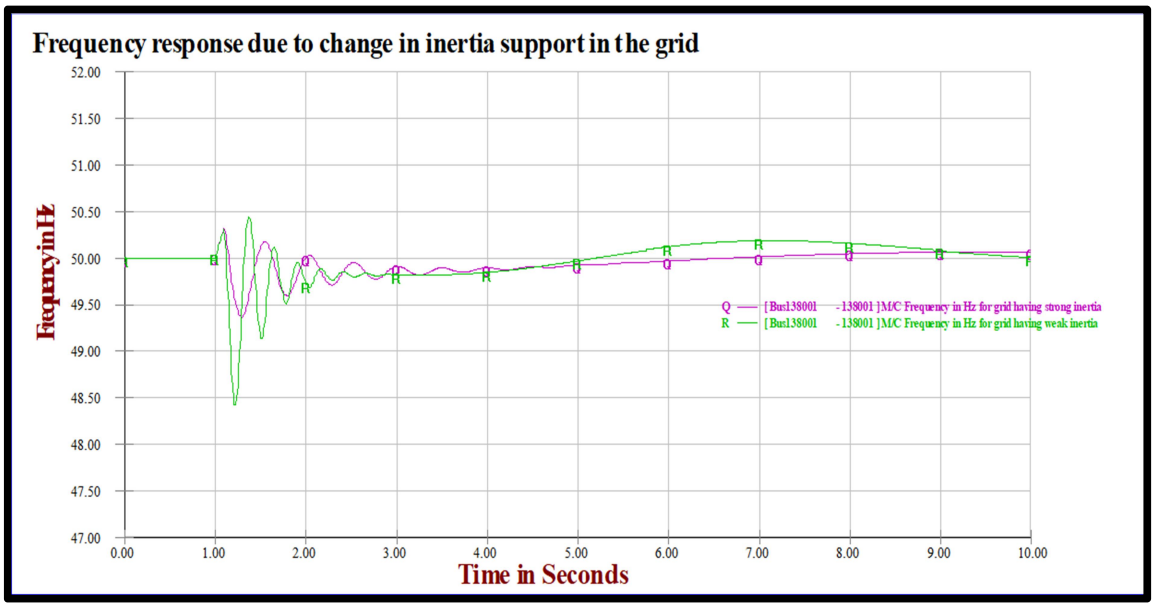


Figure 2 An example of frequency response of CGP due to impact of inertia support provided by Grid

Brief analysis of Reactive power support provided by CGPs (Concerning Power factor also)

CGPs do take care of the reactive requirements of their load in selecting the size of their generation. Thermal sets can support up to 50% of their active generation by maintaining a 0.85 or 0.9 power factor at the PCC. For example, a 44 MVA machine (at Arati steel) with 40 MW active generations can support 19MVAR reactive power. Apart from this, the CGPs do maintain necessary reactive compensation equipment that is going to maintain the power factor at the PCC (to avoid the penalty). This is the main reason, why the scheduled power factor is always maintained near unity during the steady state measurement procedure available at OPTCL (15 minute block of measurement). During discrepancy of the reactive power, the DISCOM charges necessary penalty to the concerned CGPs. An example of power factor and reactive power is shown in following table.

Name of the CGP	MW	MVAR	Power Factor	Date of recording
IMFA	33.71	11.24	0.95	3rd Oct-2023
Bhubaneswar Power (P) Ltd	115	34.5	0.96	15th Nov- 2023
NBVL	37.12	7	0.98	15th Nov-2023
Tata Sponge Iron	18.6	4.65	0.97	15th Nov- 2023

However, according to the physics of thermal sets, unfortunately the thermal sets in CGP cannot absorb reactive power. Any reactive power supplied or absorbed will have to be at the expense of active power which CGPs do not like. In order to get the best from CGP, the operator keeps the operation at fixed governor mode. This also controls the contract demand.

Whenever possible, CGPs operate at around 0.98 to 0.99 power factor to reduce reactive power supply from their own generators. This occurs mainly during peak load in the grid, which maintains grid voltage around 1.0. The grid does push some reactive power to CGP load, which allows the CGP to optimize on its active power production. During light load in the grid with higher voltages, the CGPs cannot help by absorbing reactive power any way.

Although, in the steady state measurement data available from the OPTCL PCC measurement infrastructure (15 minute block of measurement) the power factor is near unity, but in the transient period, the power factor variation is clearly visible from the data recorded at the PCC (using high sampling measurement range). According to the recorded data the power factor varies near 1 but during some transients it goes near 0.1 as well. Reactive power changes are proportional to voltage changes, and when voltage dips during a disturbance, the grid spontaneously pushes reactive power to arrest the extent of dip. The support continues for some time as the voltage recovers. The oscillation frequency is due to inductance and capacitance present in the neighbourhood circuit. In those transient periods of time, the reactive support is provided by the STU grid by virtue of its impedance.

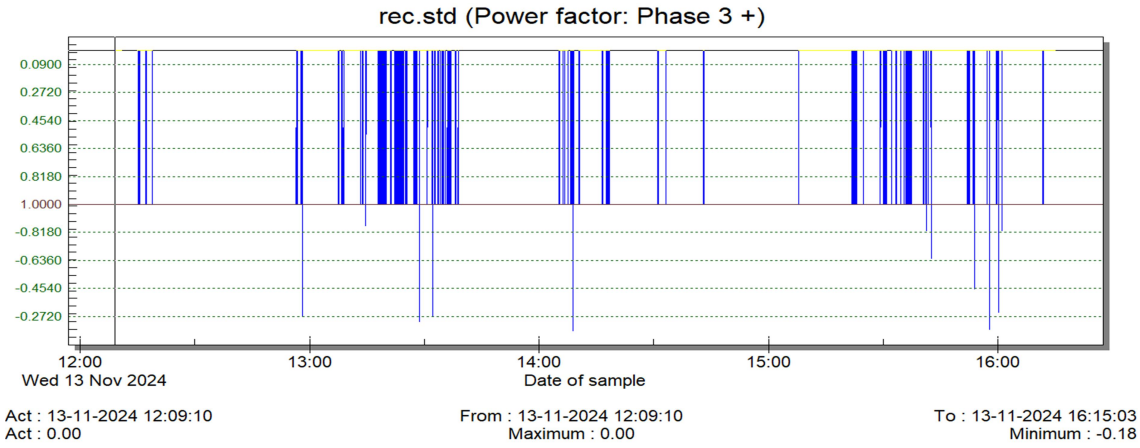


Figure 3 Power factor measured at PCC for JSW (in a particular Phase)

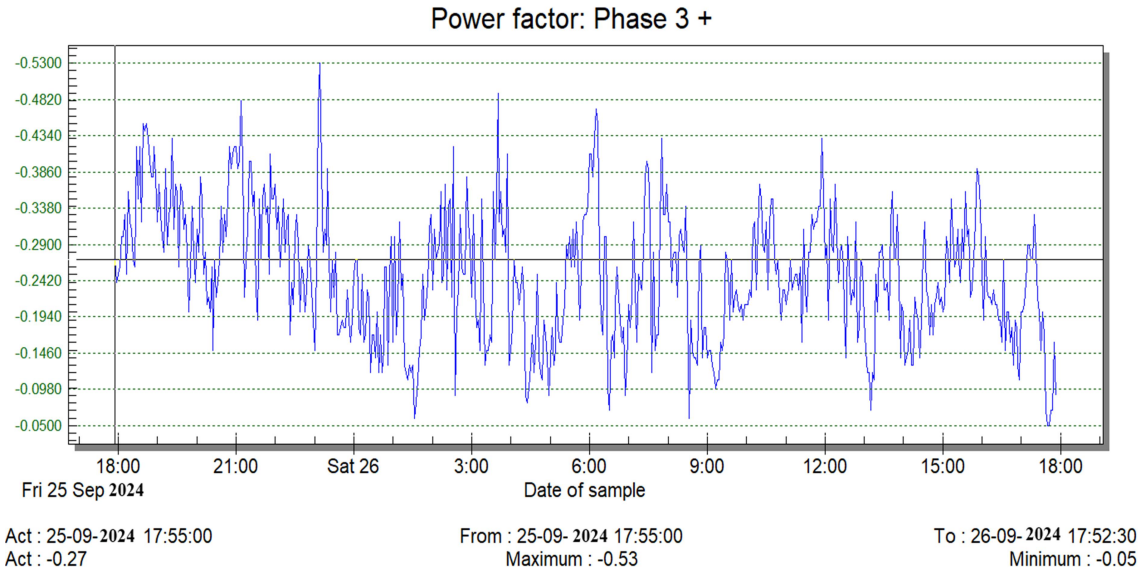


Figure 4 Power factor measured at PCC for IMFA (in a particular Phase)

The graph shows a typical variation of power factor for an unbalanced inductive furnace load.

The graph showing near zero power factor represents occasional swing in power drawl. This can happen only if there is no load except an open circuit transformer load. (Furnace open circuit).

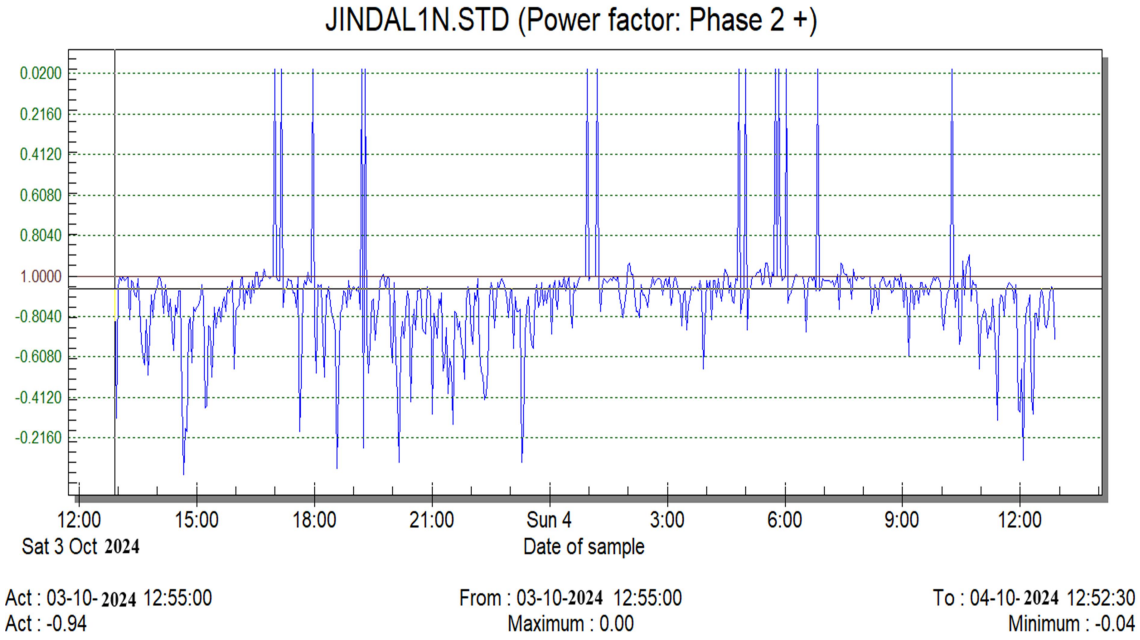


Figure 5 Power factor measured at PCC for Jindal power factor (in a particular Phase)

These plots show that the average PF is 1.0 except sharp reactive swings for short periods. For these periods the grid provides the support.

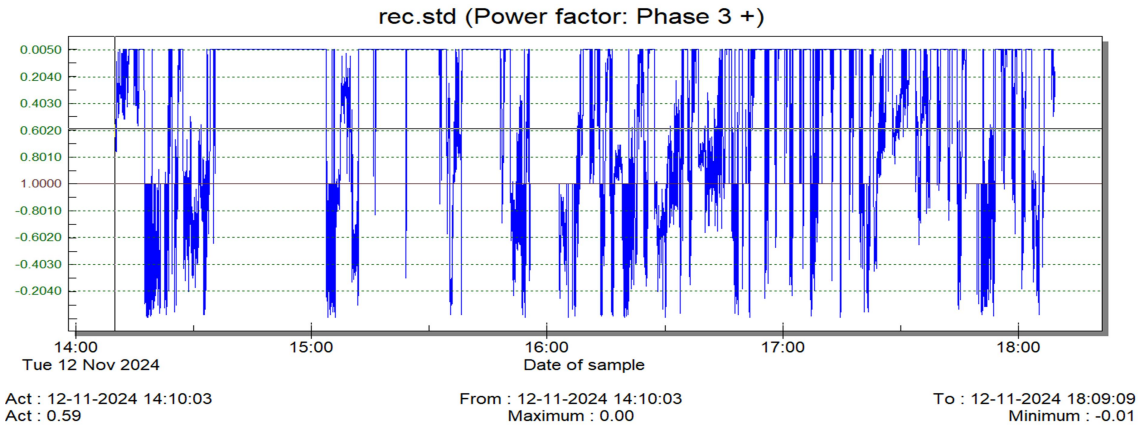


Figure 6 Power factor measured at PCC for Tata Steel Meramunduli (in a particular Phase)

Beyond this short time measurement, mathematically, the proof of reactive power is provided in the report (section 10.1). According to the simulation study, the reactive power support provided by the OPTCL with strong grid connectivity is much higher as compared to the weak grid or no grid connectivity.

Just like high grid inertia helps CGP in frequency management, the high short circuit MVA capacity of the grid helps in voltage management. The incremental change in voltage is roughly given by disturbing MVA divided by Short circuit MVA of system. In a stand-alone operation of the CGP, the change in voltage for a change in load is very high. Change in voltage and reactive power are

related. Higher is the short circuit MVA support, lower is the burden of voltage and reactive management.

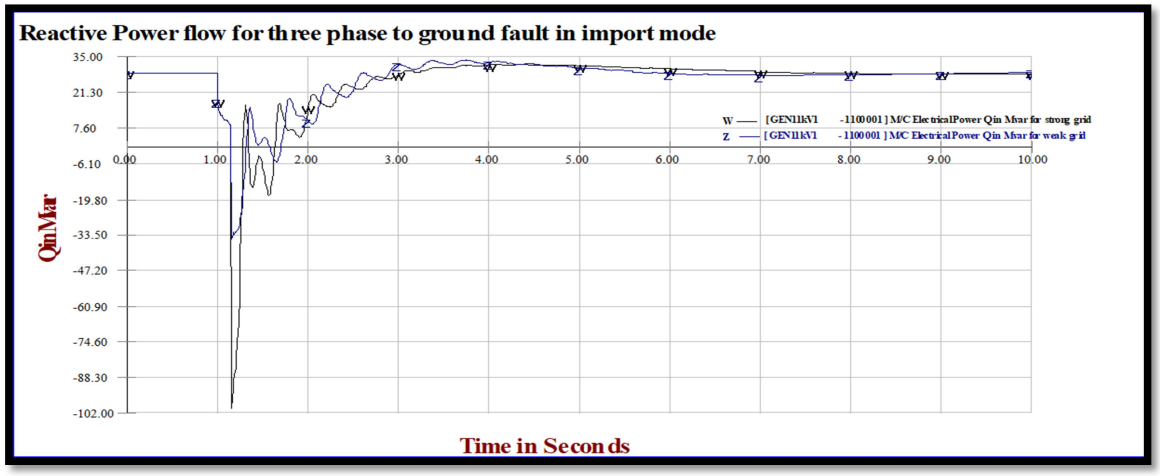


Figure 7 Reactive power for three phase to ground fault in import mode

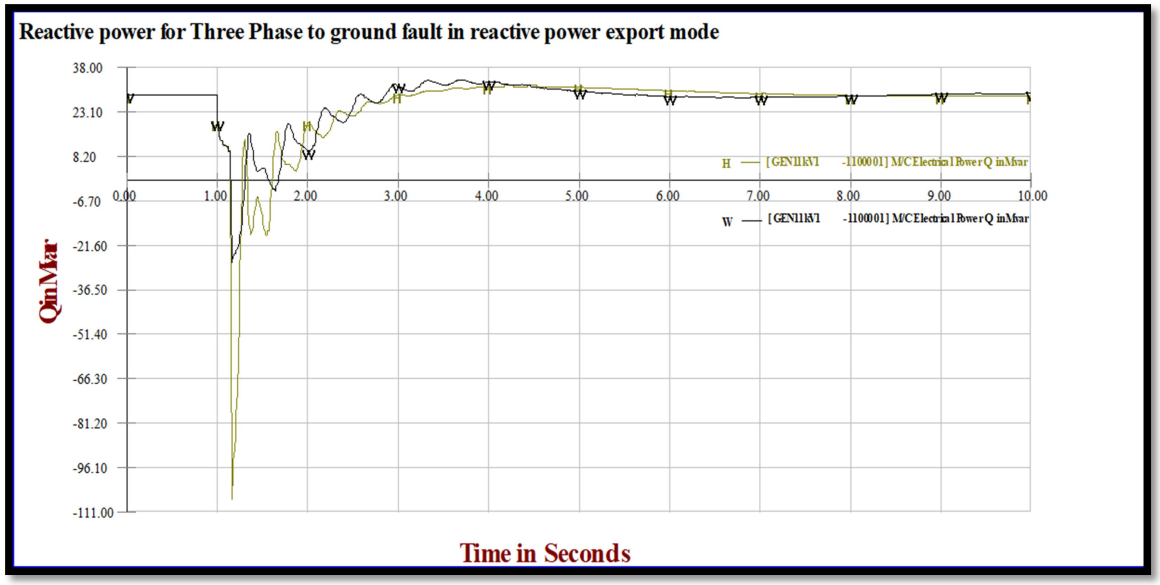


Figure 8 Reactive power for three phase to ground fault in export mode

Impact of harmonics

Harmonics/ inter harmonics always create a negative impact on the power system equipment. In recent times, the increase in the switch based devices lead to injection of more amounts of harmonics into the system. The main tendency is for the harmonic currents to flow from the harmonic-producing load to the power system source [1]. Due to the presence of harmonic components in the load current, the waveform is distorted from its original form. Waveforms of harmonic sources have somewhat arbitrary wave shapes depending on the distorting phenomena, but they contain several harmonics in significant quantities [1]. These currents when added with the source current, leads to distortion of the original current waveform shape.

The impact of these distorted waveforms is significant in power system equipment. The test results in [2] show that the voltage regulation of a synchronous generator under various load conditions is related to the different level of harmonic distortion produced by the load. Similarly, it is found that the impact of residential load harmonics on transformers is approximately proportional to the square of current THD [3]. In transformers, the harmonic injection leads to over-heating and over-loading which ultimately affects the equipment life. In industries, the investigation results in [4], show that traction load harmonic emissions can have a significant impact. A one point measurement approach will not always provide an adequate harmonic assessment on a network with multiple harmonic sources [4]. The Standard Oil filled transformers are derated according to the following formula:

$$F_K = \sqrt{1 + \frac{e}{e+1}\left(\frac{I_1}{I}\right)^2 \sum_{h=2}^{h=h_{max}} h^q \left(\frac{I_h}{I_1}\right)^2}$$

e is the eddy current loss due to sinusoidal current at the fundamental frequency, divided by the loss due to DC current equal to the RMS current of the sinusoidal current value, both at reference temperature. The exponent q is dependent on the type of windings and on the frequency. The variable $I_h$defines the current component of h order harmonics. The derating factor is given by 1/FK. This indicates that, with increase in the harmonic indices, the derating increases.

Parameter	Voltage		Current harmonic order for Isc/IL > 1000				
	THD (maximum value is considered for the duration where accurate reading was taken)	Individual harmonics	Harmonic order below 11	Harmonic order 11 to 17	Harmonic order 17 to 23	Harmonic order 23 to 35	Harmonic order 35 to 50
Limits	**1.5**	**1**	**7.5**	**3.5**	**3**	**1.25**	**0.7**
JSW Budhipadar	1.7	1.3	15.1	2.1	1.0	0.7	0.7
Jindal Duburi	2.1	0.6	11.2	3.5	2.6	3.3	1.2
Utkala Alumina Laxmipur	1.5	2.3	3.6	2.3	1.3	1.1	1.0
NINL Duburi	1.25	0.5	2.9	1.1	1.1	1.1	0.3
Paradeep Duburi	1.9	1.6	11.3	2.0	1.1	0.8	0.8
Sterlite Vedanta Lapanga	1.8	1.6	0.8	0.3	0.2	0.1	0.1
TATA Steel Meramunduli	1.8	1.5	8.4	1.8	0.4	0.3	0.3
Limits	**2.5**	**1.5**	**7.5**	**3.5**	**3**	**1.25**	**0.7**
BPPL Chandaka	2.6	1.6	6.2	0.8	0.4	0.2	0.2
NBVL, Kharagrasad	1.8	1.4	6.1	0.5	0.3	0.1	0.1

Parameter	Voltage		Current harmonic order for Isc/IL > 1000				
	THD (maximum value is considered for the duration where accurate reading was taken)	Individual harmonics	Harmonic order below 11	Harmonic order 11 to 17	Harmonic order 17 to 23	Harmonic order 23 to 35	Harmonic order 35 to 50
IMFA, Choudwar	1.9	0.8	3.9	0.7	0.7	0.7	0.2

References:

[1]. Roger C. Dugan, et al., "Electrical Power Systems Quality – Second Edition", McGraw-Hill.

[2]. A. H. Samra and K. M. Islam, "Harmonic effects on synchronous generators voltage regulation," Proceedings IEEE Southeastcon '95. Visualize the Future, Raleigh, NC, USA, 1995, pp. 376-380, doi: 10.1109/SECON.1995.513121.

[3]. P. Bagheri, W. Xu and K. Shaloudegi, "New indices to evaluate the impact of harmonic currents on power transformers," 2018 18th International Conference on Harmonics and Quality of Power (ICHQP), Ljubljana, Slovenia, 2018, pp. 1-6, doi: 10.1109/ICHQP.2018.8378885.

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The summary of results associated to Harmonic measurement in different CGP feeders are presented in the following table. The limits for the THD value or individual harmonic order as per IEEE guide lines are also mentioned in the table. It is to be noted that, the Voltage THD mentioned in the table are insignificant while considering the Harmonics contribution. In the context of current harmonics, the harmonics orders are considered for checking the limit according to the standard IEEE 519. Similarly, the Harmonics beyond 50th order are present but their impact is assumed to be negligible in this context of measurement.

b) As mentioned at Para-4 above, the Commission, vide its order dated 31.03.2014 passed in Case No.46 of 2012, had made certain observations in the matter of levying Grid Support Charges considering the existing provisions in Odisha Grid Code Regulations. In this context, OPTCL needs to clarify whether the provisions of the Odisha Grid Code (OGC) Regulations, 2015 particularly Regulation 1.7 (Charge/Payment for Reactive Energy Exchanges) and other provisions relating to control of other abnormalities are not contradicted, if GSC are imposed.

The method of levying the grid support charge proposed in this report finds its basis on the short circuit study of the Odisha network to assess the transient support provide by the grid during disturbances. This does not interfere or cross roads with any of the existing charge provisions for CGP according to OGC. The control of other abnormalities in scheduled power transfers are not taken into account for the calculation of grid support charge.

c) Whether the pollutants like injection of harmonics and VAR exchange etc. are only attributable to the industries having CGP and not to the industries without CGP.

In case of industries without CGP, as the contracted demand is near the peak loading, the grid support charge is recovered properly. However, in case of industry with CGP, as the contracted demand is less, the reliability charge for grid is not recovered.

The pollutants like injection of harmonics and VAR exchange are attributable to both the industries as well as the industries having CGP. However, the proposed grid support charge has taken into account the Short circuit level of the PCC which is independent of the pollutants. There are limits on harmonic distortions recommended by standards like IEEE 519. However for short times these limits could be getting violated by CPPs which go unnoticed. Hence, the measurements presented in the report show that industries with highly fluctuating loads do get support from the grid during short periods that are not captured. Harmonics circulating in CGP in stand alone mode increase negative sequence current in the generator neutral which could cause in generator tripping. However, with grid connection this may reduce upto some extent.

d) OPTCL must justify the methodology for the determination of uniform GSC rates on all CGPs when they have different capacities, contract demands, and power exports to the grid.

The methodology for levying the grid support charge should be dependent on (the total installed capacity of CGP – Contracted demand of CGP – the average scheduled export from the CGP). In the above - mentioned formula, the Contracted demand and export is subtracted from the installed capacity to avoid the contradiction of existing provisions in OGC. The CGP connected to the grid get similar umbrella protection to varying degrees during transients. The present method does distinguish the variations in grid support to different CGPs.
The industry having inbuilt CGP will have significant short circuit contribution to lesser variation at the PCC during transients. Similarly, Industry having smaller CGP, with furnace load will contribute more to the transients variation at PCC. Hence uniform charge is proposed.

e) In view of the integrated network of OPTCL & DISCOMs, whether DISCOMs has a role in providing Grid support. If so, how the GSC can be apportioned between OPTCL and DISCOMs.

DISCOM does provide marginal support, but the main support is from the grid. CGPs connected to 11kV are normally of low rating and do not affect grid stability. Primarily the dynamics is between grid generators and the CGP generators. The equation could somewhat change if a number of microgrids are installed in future and the Discoms or DSOs play a role in grid integration. However, in the recent context of grid support charge it is not applicable to the DISCOMs as most of the 48 CGPs considered in the study are connected to the STU network.

f) OPTCL should submit its views on the applicability of Grid Support Charges (GSC) on RE generators including CGP based on RE.

The performance of a solar based CPP would depend on the performance of the smart inverter. It should have reactive power capability, storage support, fault ride through capability and should have both grid forming and grid following features. The solar based CPP considered are assumed to have these ideal features.
It is to be noted that, the grid support received by a CGP having solar penetration receives full active power support similar to a conventional CGP. In return, the Solar based CGPs are not able to contribute to the fault level of the Grid connection. Apart from this, it is estimated that a solar plant is by virtue of its capacity, is dependent on the grid support for a duration of 4 hours in a day (i.e. 24 hours). Similar assumption is applicable for the Wind Turbine based CGPs with different effective production hours. Beyond that period of time, the CGP will act like a HT industry only, which is connected to the grid. Therefore, it is recommended to charge the solar based CGPs with one sixth of the proposed grid support charge.

g) If any case CGP loses its CGP status and becomes IPP, then what would be the methodology of charging GSC?

The existing GSC is applicable to CGP only. So, no charge to be levied if it becomes IPP. But CGP losing temporarily CGP status annually has to pay GSC. In case a CGP loses its CGP status during a FY, it has to pay the GSC for that entire FY without any fail.

h) OPTCL must suggest the methodology of recovery of GSC in case of default in light of the Section 56 of the Electricity Act 2003.

Disconnection of power supply as per OERC regulation in case of default is the only option to recover GSC.

i) Impact of GSC on Transmission Tariff and Retail Tariff of Industrial consumers.

The proposed GSC is aimed to be levied from the CGPs in return of investment made to improve reliability support in the transmission infrastructure. But part of revenue earned from GSC will be passed on to the consumer for reducing transmission tariff.
The part of revenue earned could be used to improve O &M and incorporate advanced operational improvements.