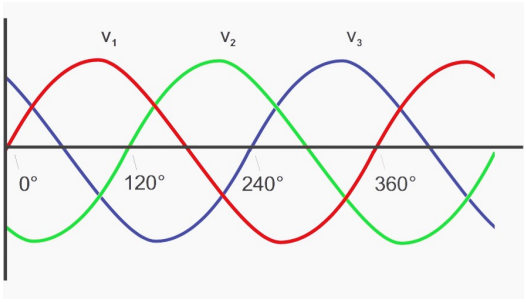
MAHATRANSCO
Maharashtra State Electricity Transmission Co. Ltd.

Report on Voltage collapse event on 12.03.2025



Maharashtra State Load Despatch Centre, Airoli

26th March 2025

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Preface

The Maharashtra power system has evolved into one of the most complex and dynamic grids in the country, serving a diverse and rapidly growing consumer base. The **Maharashtra State Load Despatch Centre (MSLDC)** plays a pivotal role in ensuring the secure and reliable operation of this vast interconnected network by balancing demand and supply in real time, managing contingencies, and enforcing grid discipline.

The **voltage collapse event of 12th March 2025** posed a significant challenge to system operators, leading to widespread load shedding across key urban centers, including MMR, Pune, and Nashik**.** While the event was mitigated through swift operator intervention, including emergency generation ramp-ups, HVDC support, and load relief measures, this report highlights the urgent need for transmission system strengthening and advanced grid resilience mechanisms**.**

SLDC, Maharashtra is making all efforts to ensure that Maharashtra's grid operates with reliability and resilience within available resources. This report presents a comprehensive analysis of the incident, examining its causes, impact, and the effectiveness of the mitigation strategies deployed. It also provides key lessons learned and recommendations for enhancing grid stability through improved planning, automation, and coordination between stakeholders, including transmission utilities, generating stations and distribution utilities.

I extend my sincere thanks and appreciation to the SLDC team, WRLDC, transmission utilities, generation and distribution companies and all power system engineers and operators who worked tirelessly to restore normalcy and minimize the impact of the disturbance. I am confident that the insights from this report will serve as a valuable reference for grid planners, policymakers, and system operators in shaping a more resilient Maharashtra power system.

Shashank Jewalikar
Executive Director, Maharashtra SLDC
March 2025

Executive Summary

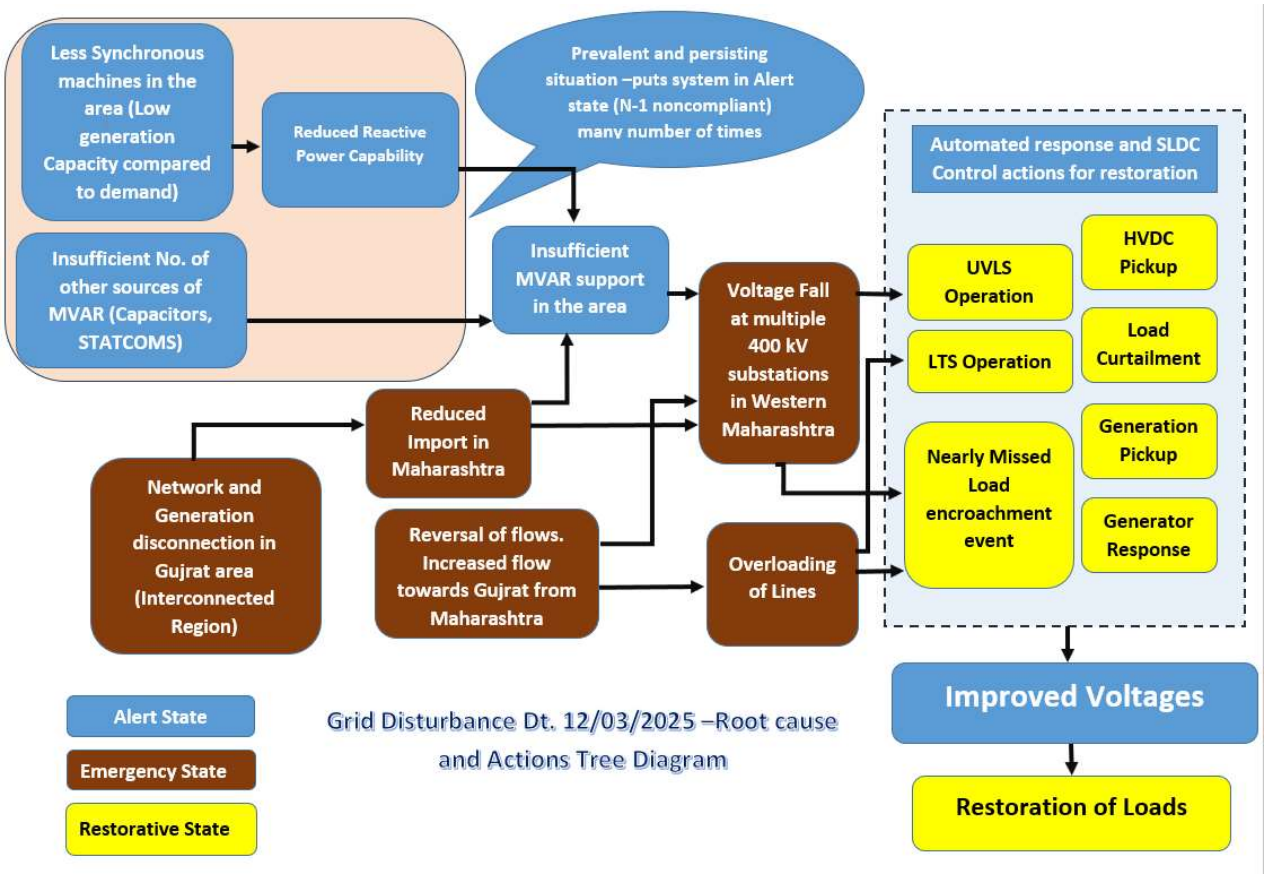
Brief Overview of the Grid Disturbance in Maharashtra, on 12.03.2025

1. Overview of the Disturbance

- A severe **voltage collapse** occurred in **Mumbai, MMR, Pune, Nashik, Boisar, and Nagothane** at **14:55 hrs on 12th March 2025**.
- The disturbance is classified as **Grid Disturbance (GD)-1** under IEGC, 2023.
- The event would have developed into a **near-blackout** scenario due to **critical voltage instability which was avoided due to automated operation of LTS and UVLS systems in Maharashtra, swift actions of SLDC and response from all the stakeholder transmission, generation and distribution licensees in Maharashtra**.

2. Key Findings & Root Cause Analysis

- **Primary Cause:**
  - Multiple transmission lines and generators tripping in South Gujarat led to excessive power flow from Maharashtra to Gujarat.
  - Reversal of power flow on key **400 kV transmission corridors** (e.g., **Tarapur–Padghe, Boisar–Padghe**).
  - Severe voltage drops at multiple important 400 kV substations from **390 kV to ~350 kV or even less**.
- **Contributing Factors:**
  - Urban load concentration in Mumbai, MMR, Pune, with inadequate transmission infrastructure and less synchronous machine support in this area.
  - Lack of adequate reactive power compensation.
  - Heavy pre-existing line loadings and low system voltages**.**



3. Impact on the Grid & Stakeholders

- **Load Shedding** of **~3922 MW** across Maharashtra to stabilize the system.
- **Energy Not Served (ENS): 7.16 MUs** during the disturbance period (14:55 - 17:45 hrs).
- Significant generator ramping up, **HVDC flow ramp-ups** and **hydro generation pick-ups** for voltage support.

4. Restoration & Mitigation Measures

- **Restoration Time: 14:55 hrs - 17:58 hrs** (Full recovery in ~3 hours).
- **HVDC Support:** Chandrapur–Padghe HVDC ramped up from **950 MW to 1500 MW**.
- **Hydro Support: Koyna & Tata Power Hydro stations ramped up** to stabilize voltages.
- **Load Curtailment:** Manual shedding was implemented across key regions.

5. Lessons Learned & Recommendations

- **Short-Term Measures:**
    - Strengthening **load shedding schemes (LTS, UVLS)**.

    - Enhancing **real-time voltage monitoring** & **reactive power management**.

- **Long-Term Measures:**
    - Expanding **transmission capacity** in **urban load centers**.
    - Deployment of adequate reactive compensation in this area.
    - Improvements in grid automation, communication, and operator training**.**

1.0 Event Description

1.1 Event Date & Time

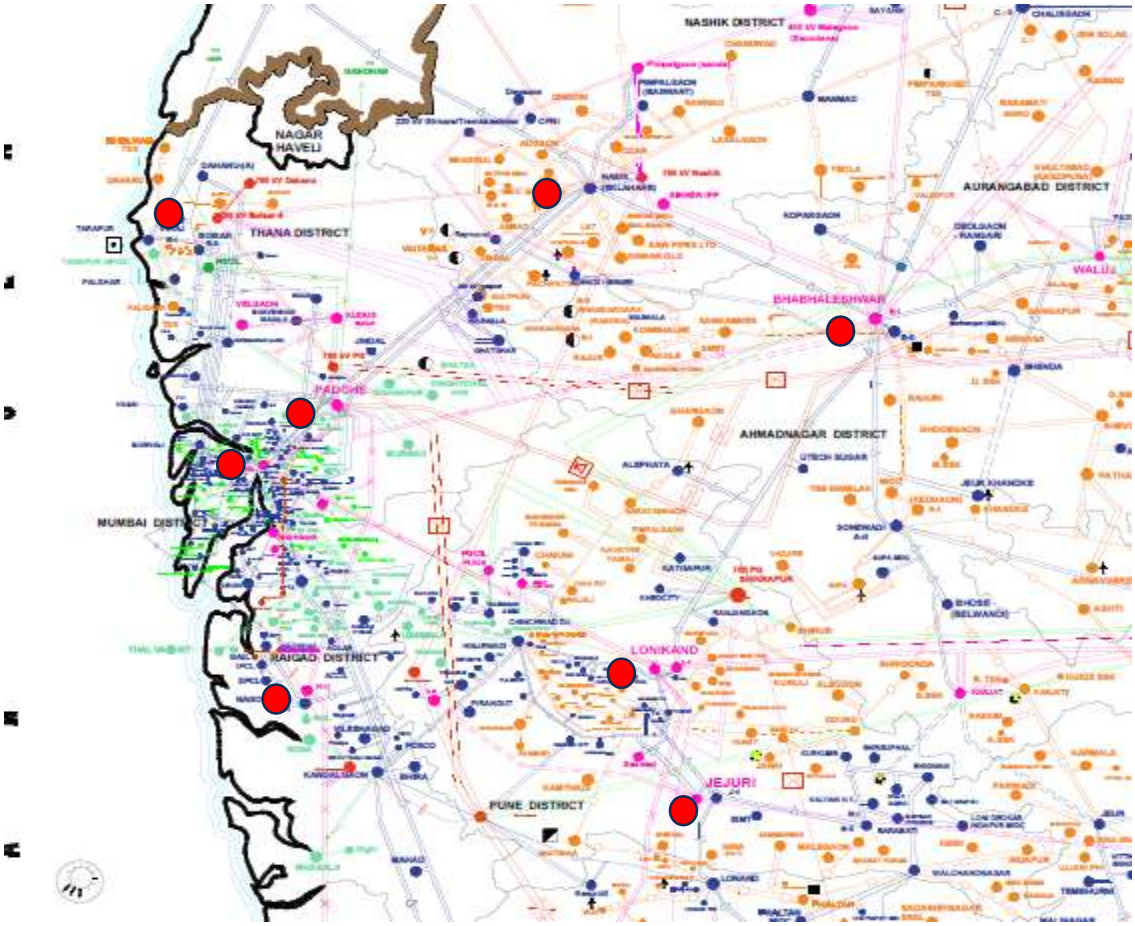
The event of Voltage Collapse resulting in to large load shedding in Mumbai, MMR, Pune & Nashik area occurred on 12.03.2025 at 14:55 hrs.

1.2 Geographical Area Affected

In Western Maharashtra region, area affected was Mumbai, MMR, Pune, Nashik, Boisar & Nagothane.

This area was fed from 400kV Padghe, 400kV Babhaleshwar, 400kV Kalwa, 400kV Lonikand, 400kV Jejuri, 400kV Nagothane, 220kV Boisar & 220kV Nashik GCR-OCR Sub-stations.

Affected areas are marked in geographic map shown in Figure – 1 below:



Geographical locations of Affected region

1.3 Type of Disturbance

In accordance with the IEGC, 2023, the event is categorized as Grid Disturbance (GD)-1.

This event was a near miss Blackout event due to severe Voltage Collapse in Western Maharashtra having concentrated loads.

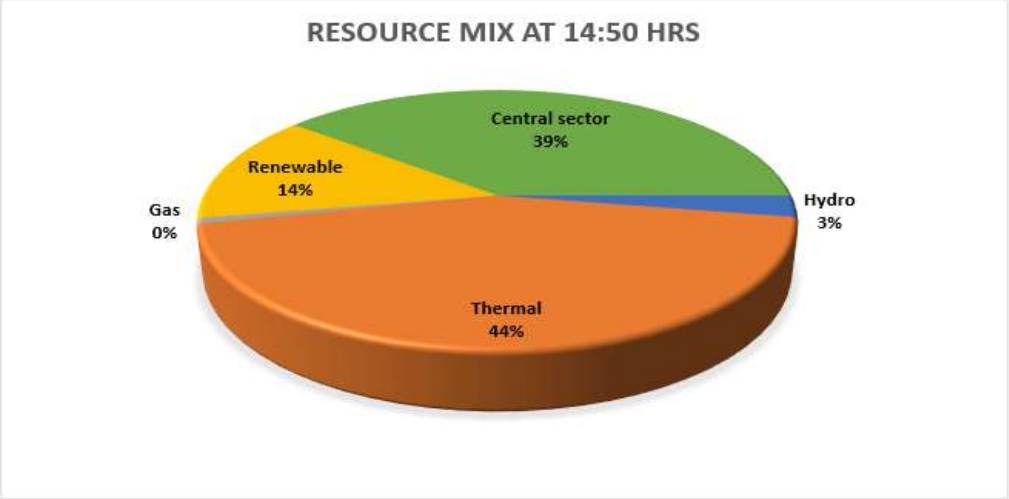
1.4 Initial Observations

- Maharashtra Power System was operating in condition as consistently observed during this season. The voltages of 400 kV Sub-stations in MMR & Pune area were in the range of 390-375 kV.
- At 14:50 Hrs, loading on 400kV Padghe – Babhaleshwar D/C reached up to 2000 MW (1000 MW each ckt). Also, voltage started decreasing drastically. This resulted in to LTS & UVLS operation at 400/220kV Padghe Sub-station.
- Normally, power is imported to 400 kV Padghe S/s from 400kV Tarapur – Padghe D/C and 400 kV Boisar (PG) – Padghe S/C lines.
- However, reversal of power flow from 217 MW (import) to 507 MW (export) was observed on each circuit of 400kV Tarapur – Padghe D/C lines. Also, reversal of power flow on 400 kV Boisar (PG) – Padghe S/C line from 570 MW (import) to 873 MW (export) was observed.
- LTS operation was also seen at 220 kV Nashik substation due to overloading of 220 kV Babhaleshwar Nashik D/C lines.
- UVLS operation was seen at 400 kV Babhaleshwar substation.
- 220 /132 kV ICTs tripped at 220 kV Nashik GCR. The 220kV Nashik – Navsari D/C tripped on Over-current protection at 220 kV Nashik OCR substation.
- Considering above scenarios, MSLDC Grid Operator immediately instructed Padghe Sub-Station to ramp-up HVDC to full capacity of 1500 MW, picked-up Koyna Generation and Tata Hydro generation. Load shedding was also instructed at multiple locations.
- It was informed by WRLDC that there are multiple trippings of Generating Units & Transmission Lines is South Gujrat, which has resulted into the severely low voltages in the Grid.

2.0 Antecedent Conditions of the System

2.1 Grid Demand & Generation Profile

- On 12th March 2025, before the grid disturbance, at 14:50 hrs, Maharashtra State Demand was 30,006 MW, State generation was 18308 MW and Receipt from central sector through Interstate lines was 11698 MW. The Resource mix is shown in the figure – 2.



Resource Mix before the event

2.2 Voltage Profile

- The voltage profile of various 400 kV Sub-stations in the affected area at 14:49 Hrs are shown below:

Sr. No.	Name of Sub-station	Voltage (kV)
1	400 kV Babhaleshwar	383.2
2	400 kV Padghe	381.7
3	400kV Kalwa	384.7
4	400kV Nagothane	397.4
5	400kV Kharghar	398.3
6	400kV Vikhroli	380.1
7	400kV Lonikand I	373.4
8	400 kV Lonikand II	374.7
9	400 kV Chakan	375.3
10	400 kV Jejuri	376.4
11	400 kV Talegaon (PG)	381

Source: (SCADA)

Voltages of affected substations before the event

2.3 Intrastate resource availability and schedules with resource margin

- The declared capacity (DC) of the Intra-State Thermal Generators was 14,185 MW & Schedule was 12,382 MW. Thus, up margin of 1,803 MW was available for Generation pick-up.

Block No.	Time Block	Declared Capacity (MW)	Schedule (MW)	Up margin (MW)
60	14:45-15:00	14,185	12,382	1,803

Intra state resource availability with resource margin

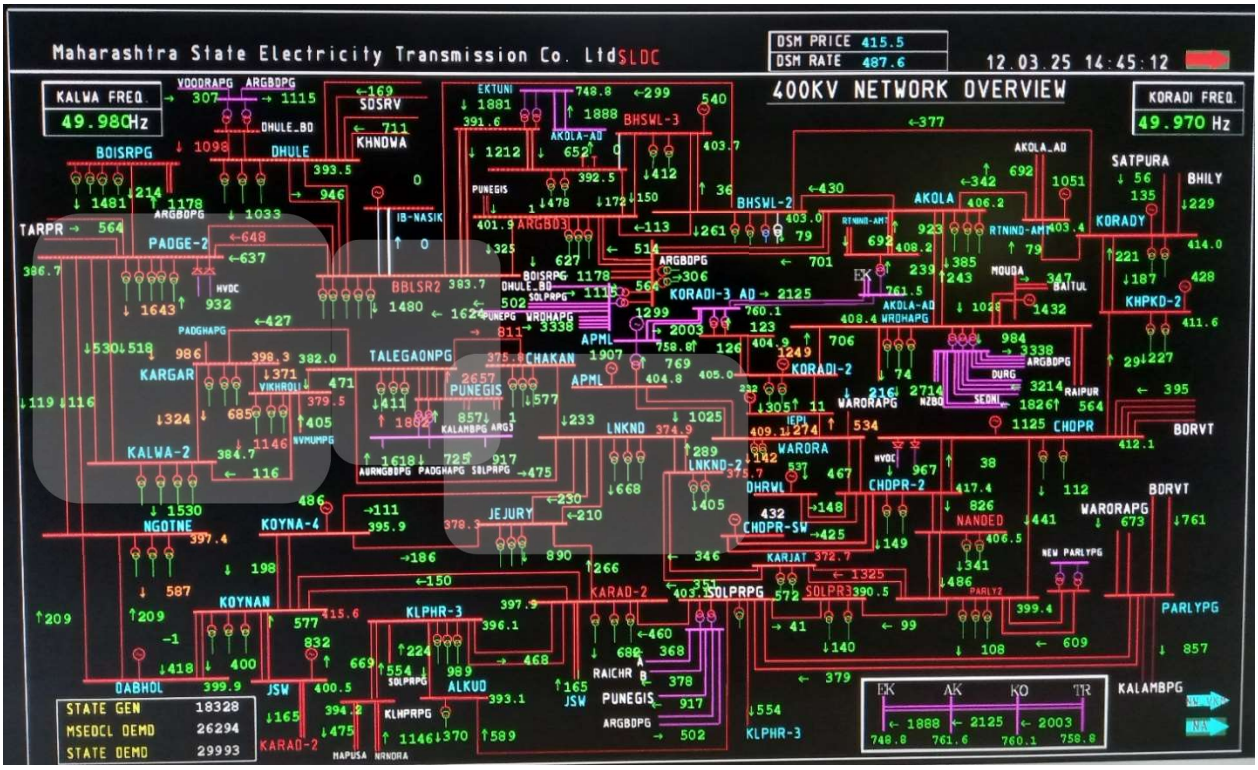
2.4 Inter-state Exchange (OD/UD)

- Before the event, i.e. at 14:50 Hrs, share from the Central sector Generators was 11,430 MW and drawl was 11,698 MW. Thus, System was over-drawing 268 MW from Inter-State network.

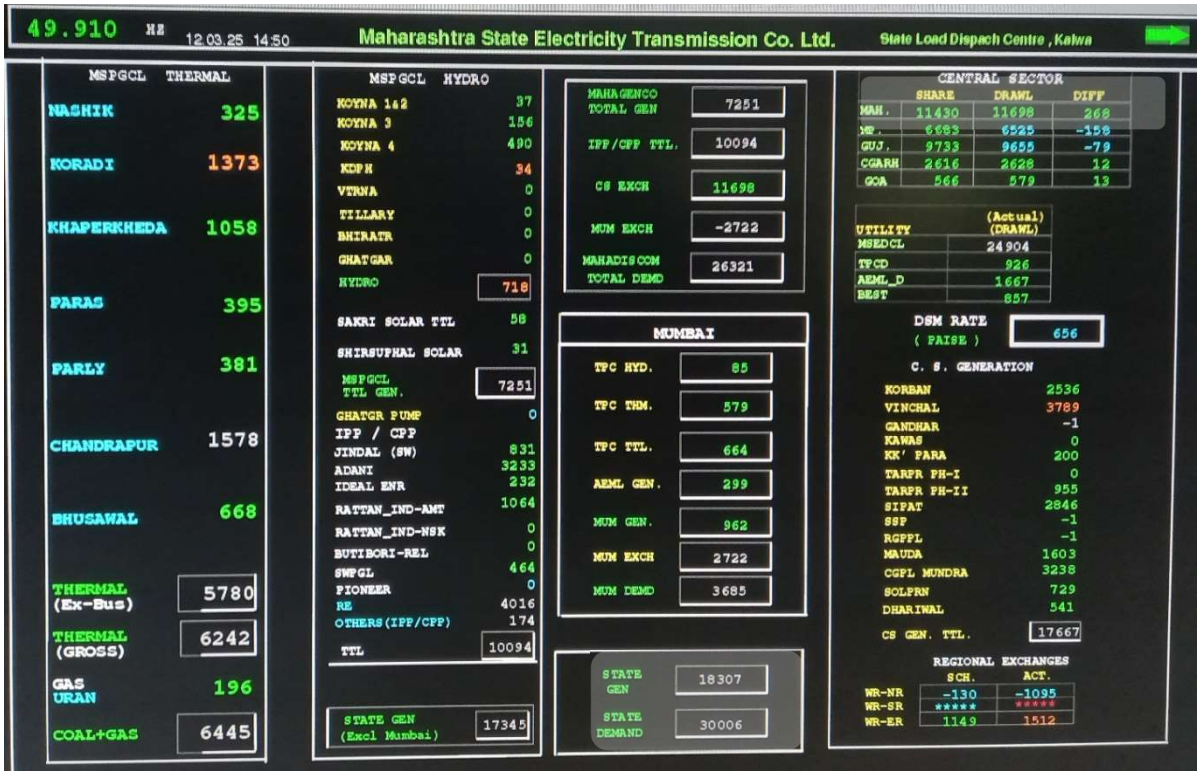
State	Share (MW)	Drawl (MW)	Difference (MW)
Maharashtra	11,430	11,698	268 (Over-drawl)

Interstate exchange before the event

2.5 SCADA Screenshots



400 kV Network Overview (SCADA)



Resource Overview of the State (SCADA)

2.5.1 Generation & Transmission System Status

- During the event, total 2,851 MW generating capacity was not available. Out of this 2,851 MW capacity, 625 MW capacity is under long duration shutdown.

2.5.1.1 Generating units under outage during the event

Name of Unit	Capacity (MW)	Date Trip	Time Trip	Date Sync	Time Sync	Outage Type	Reason
Ghatghar Unit-2	125	26-05-24	13:17		Continued	FORCED	Stator Earth Fault
Chandrapur Unit 9	500	11-01-25	18:55		Continued	FORCED	Generator Protection operated
Uran Unit 7	108	04-03-25	14:15		Continued	FORCED	Turbine bearing vibration high
Bhusawal Unit 6	660	05-03-25	0:04	15-03-25	6:14	FORCED	PG TEST preparation
Uran Unit A0	120	10-03-25	3:09	16-03-25	5:27	FORCED	Turbine Vibration
Uran Unit 5	108	11-03-25	20:00	12-03-25	15:49	ZEROSCH / RSD	Emergency Pick Up Given due to grid occurrence

RPL(AMT) U-4	270	11-03-25	21:00	13-03-25	21:13	FORCED	Bottom Ash evacuation problem
Koradi Unit-10	660	12-03-25	13:21	12-03-25	20:48	FORCED	Governing Valve Oil Leakage of Main Turbine.
JSW (J) U1	300	12-03-25	14:30		Continued	FORCED	Turbine Vibration
Total Capacity	**2851**						

Table – 5: Generating units under outage

2.5.1.2 Transmission system Outages or maintenance activities

Name of Line	Inter State / Intra State	Tripped Date	Tripped Time	Sync. Date	Sync. Time	Outage Type	Reason of Outage
400 KV element Outages/Trippings							
400/11.5 KV 110MVA STN T/F 6A @ DEEPNAGAR	InterState	08-03-2025	10:44			T	WINDING TEMP TRIPPED, MTR OPTD.
MAIN BAY (410) OF ICT-2 @ KUDUS	IntraState	12-03-2025	14:24	12-03-2025	17:12	PO	Annual Maintenance of bays equipment & Diagnostics Testing Work
CHANDRAPUR 2 - DHARIWAL CKT – 2	IntraState	12-03-2025	06:02	12-03-2025	17:08	PO	Line & its Bay Equipment PM & Testing work
DEEPNAGAR - THAPTI TANDA	IntraState	12-03-2025	07:16	12-03-2025	16:59	PO	To increase the ground clearance at span 202-203 and other maintenance work like disc repalcement and nut-bolt tightning work
400KV 125MVAR BUS REACTOR @ CHANDRAPUR 2	InterState	12-03-2025	09:36	13-03-2025	00:16	PO	Diagnostic testing and allied bay maintenance work
BUS REACTOR (80 MVAr) - 1 @ TIRORA	IntraState	10-03-2025	09:38		Continued.	PO	Dia Equipment Maintenance
220 KV element Outages/Trippings							
PRINT HOUSE - NAVI MUMBAI (PG)	InterState	05-12-2024	23:09			EO	1) For bunching at TL no 678/1 with 220kV Kalwa-Panchanand line to provide 2nd source to Panchanand & Taloja s/stn. 2)For opening jumpers at TL no 678/1.

220KV YAWATMAL-WARDHA(DEOLI) PG CKT 1	InterState	12-03-2025	14:31	12-03-2025	18:49	EO	For attending Hot glow on Line Isolator Rph Pad towards CB (Temp -180¿C) Nut Bolt
220 kV-Wardha(PG)-Yawatmal Ckt-1	InterState	12-03-2025	14:31	12-03-2025	18:49	EO	Attending Hot glow on line isolator R-ph pad towards CB temp-180 deg nut bolt.
PUSAD - WARDHA (PG)	IntraState	08-03-2025	20:26		Continued.	PO	1)Shifting of Line on ERS for Erection & Conductor Stringing of Inline Towers under ORC work for the work of Diversion of 220kV Deoli - Pusad Line at Loc. No. 181-182 by considering Monopole Tower for Wardha - Yavatmal - Nanded Railway Line Crossing. 2) ORC WORK - Diversion of 220KV Deoli PG-Pusad line at loc 250-251 due to four lanning of NH-361 (Butibori-Tuljapur)- shifting of line on ERS thereof. 3)ORC WORK - Diversion of 220KV Deoli PG-Pusad line at loc 250-251 due to four lanning of NH-361 (Butibori-Tuljapur)- shifting of line from ERS to newly erected tower thereof.
PUSAD-GHATODI	IntraState	10-03-2025	19:47			HT	IN VIEW OF OUTAGE ON PUSAD-WARDHA PG-CKT.
KHAPARKHEDA- BUTIBORI	IntraState	12-03-2025	09:38	12-03-2025	16:25	PO	Replacement of Y-ph CT due to ageing and CB timing
GOREGAON - VERSOVA CKT – 1	IntraState	12-03-2025	09:45	12-03-2025	17:13	PO	Annual Maintenance of Circuit Breaker

220KV KURUNDA -GIRWALI CKT	IntraState	12-03-2025	12:01	12-03-2025	13:31	EO	Attend Hotspot at R-ph CT P1 side.
THEUR-PHURSUNGI CKT II	IntraState	12-03-2025	12:29	12-03-2025	18:57	EO	Replacement of flashover SSN string Rph at loc. no. 37 and chemical washing of disc insulator
LAMBOTI - TULJAPUR CKT – 2	IntraState	12-03-2025	12:49	12-03-2025	20:35	PO	Outage is required for Replacement of string at Loc. No. 28, 41, & cold washing of Insulator String.
MALINAGAR - TEMBHURNI	IntraState	12-03-2025	12:53	12-03-2025	19:50	PO	Outage is required for Quarterly Maintenance
PEDHAMBE ONI LINE	IntraState	12-03-2025	13:02	12-03-2025	18:42	PO	For replacement of damaged rusted jump nut bolt at loc no-202, 223, 227.
OSMANABAD – BARSHI	IntraState	12-03-2025	14:38	12-03-2025	17:37	PO	Outage is required for Quarterly Maintenance
220/132 KV 80 MVA ICT 1 @ HINGANGHAT	IntraState	19-02-2025	12:45			HT	H/T Due to end of expected life of paper insulation of ICT
220/33 KV, 50MVA, PTR NO 2 @ ALEPHATA	IntraState	10-03-2025	11:02	13-03-2025	19:57	PO	ABB make HV CB pole overhauling work & HV CB testing by agency
220/132KV 200MVA ICT 4 @ EKLAHARE (OCR)	IntraState	12-03-2025	08:23	12-03-2025	23:16	PO	Shifting of LA & CT of ICT 4 LV side from RCC structure to Lattice structure
220/132 KV 200 MVA ICT 1@ BALE(SOLAPUR)	IntraState	12-03-2025	08:51	12-03-2025	15:55	PO	Outage is required for Tandelta Testing of Bushing & Winding & SFRA Test By MTU, Pune
220/132 KV 100MVA ICT - 1 @ MANMAD	IntraState	12-03-2025	14:07	12-03-2025	17:25	PO	SFRA & DFR measurement & Quarterly Bay maintenance work.
132 KV element Outages/Trippings							
132 KV PATHRI-MAJALGAON CKT	IntraState	06-01-2025	13:05			HT	After completion of outage on 132kv patri parbhani ckt
HT : Hand Tripping, T : Tripping, PO : Planned Outage, EO : Emergency Outage							

Note: Elements in the affected area are highlighted.

2.5.1.3 Reactor and capacitor positions Pune, Nashik, MMR:

Bus reactor position in the State at 14:30 Hrs before the event

Sr. No.	Voltage level	Name of substation	Reactor in Service (In MVAr)	Reactor out of Service (In MVAr)
1	765kV	Akola 2	--	240
2	765kV	Ektuni	--	240
3	765kV	Koradi 3	--	240
4	765kV	Tiroda	--	240
5	400kV	Akola	--	125
6	400kV	Alkud	--	125
7	400kV	Babhaleshwar	--	205
8	400kV	Khadka	--	50
9	400kV	Chandrapur 2	--	125
10	400kV	Deepnagar	--	125
11	400kV	Dhule	--	125
12	400kV	Jaigad	--	100
13	400kV	Karjat	--	125
14	400kV	Karad	--	205
15	400kV	Kalwa	--	125
16	400kV	Khaperkheda	--	125
17	400kV	Kharghar	--	80
18	400kV	Koradi	--	50
19	400kV	Koradi 2	--	125
20	400kV	Lonikand 1	--	50
21	400kV	Lonikand 2	--	125
22	400kV	Nagothane	--	80
23	400kV	Nandgaonpeth	--	80
24	400kV	Nanded	--	125
25	400kV	Padghe	--	80
26	400kV	Parli-M	--	50
27	400kV	Solapur-M	--	125
28	400kV	Tiroda	--	160
29	400kV	Vikhroli	--	125
30	400kV	Warora	125	
31	400kV	Kolhapur	--	125
32	400kV	Dhule	--	80
33	400kV	Kolhapur	--	80
34	220kV	Karanjade	--	80
35	110kV	Karanjade	--	20
36	220kV	Salsette	--	125
37	220kV	Gorai	--	120
Total MVAr			**125**	**4405**

Capacitor position at 14:30 hrs before the event

Utility	Total Capacitor bank (in MVAr)	Capacitor bank in service (in MVAr)	Capacitor bank out of service (in MVAr)
AEML	588.13	318.96	269.17
TPCL	503	289	214
Nashik Zone	1845.5	1316.1	529.4
Pune Zone	799.98	684.98	115
Karad Zone	353.18	238.18	115
Vashi Zone	25	25	0
Total	**4114.79**	**2872.22**	**1242.57**

2.5.1.4 List of elements not available

220kV Nashik (OCR) – Padghe & 220kV Nashik (GCR) – Airoli Knowledge Park were hand-tripped for load management in Nashik corridor.

Name of Line	Inter State / Intra State	Tripped Date	Tripped Time	Sync. Date	Sync. Time	Outage Type	Reason of Outage
400 KV element not available							
50 MVAR LINE REACTOR OF 400KV KUMBHARGAON(NANDED) CKT 1 AT 400KV PARLI	IntraState	05-03-2025	20:45			HT	Due to Voltage constraint LR kept out at Parly ss.
AURANGABAD(MS) - PUNE (GIS) CKT – 1	IntraState	03-03-2025	10:00	12-03-2025	15:15	HT	For load management
AURANGABAD(MS) - PUNE (GIS) CKT – 2	IntraState	10-03-2025	06:46	12-03-2025	15:15	HT	H/T AT WALUJ END ONLY.
220 KV element not available							
BUS COUPLER @ PHURSUNGI	IntraState	11-03-2025	07:36	14-03-2025	21:04	HT	Load management
220KV BUS SECTION BAY @ PEDAMBE	IntraState	03-04-2024	15:55			T	Tripped due to Y ph CT burst
WAGHIVALI (MSETCL) - ULWE GIS CKT - 2	IntraState	25-06-2024	08:05			T	Tripped on differential protection.
220KV KORADI II(400KV) - BUTIBORI 3 CKT II	IntraState	01-10-2024	13:11			HT	H/T From Koradi 2 end
KALWA - PANCHANAND	IntraState	17-10-2024	12:10			EO	For providing bunching at Loc. No. 691 by fixing T clamps & jumper

							connections to provide 2nd source to 220kV Taloja.
WAGHIVALI (MSETCL) - WAGHIVALI (TATA) CKT - 1	IntraState	30-12-2024	10:44			HT	Hand tripped only at Waghivali (TATA) End only For load management on 220kV Ulwe - Waghivali ckt -1
WAGHIVALI (MSETCL) - WAGHIVALI (TATA) CKT - 2	IntraState	30-12-2024	10:44			HT	Hand tripped only at Waghivali (TATA) End only For load management on 220kV Ulwe - Waghivali ckt -1
TROMBAY - DHARAVI 9	IntraState	19-01-2025	18:38			EO	Attending hotspot on BS-3
SAKI (AEML) - SAKI (TATA) CKT - 2	IntraState	21-01-2025	15:26			HT	Fire Caught near Marve Bridge
SAKI (AEML) - SAKI (TATA) CKT - 1	IntraState	21-01-2025	15:26			HT	fire caught near Marve bridge
EKLAHARE (OCR) - PADGHE	IntraState	11-02-2025	18:35		Continued.	HT	H/T for load management.
EKLAHARE (OCR) - NAVASARI CKT - 2	IntraState	06-03-2025	19:27	12-03-2025	11:18	HT	H/T for load management.
MALEGAON-SATANA	IntraState	12-03-2025	01:18	12-03-2025	18:30	HT	Load management
ALEPHATA-PARGAON(KATHAPUR)	IntraState	12-03-2025	07:29	12-03-2025	22:34	HT	Load management
DAHANU - VIRAJ	IntraState	12-03-2025	09:55	12-03-2025	19:34	HT	MVAR Management
EKLAHARE (GCR) - AIROLI KNOW PARK	IntraState	12-03-2025	10:57	13-03-2025	01:03	HT	Load management
220/22KV 50MVA PTR 3 @ BHOSARI 2	IntraState	24-07-2024	23:02			T	Tripped due to caught fire.
220/132 KV 150 MVA PTR NO 7 @ CHINCHWAD	IntraState	11-11-2024	03:05			T	Bucholz Protection
220/132 KV 80 MVA ICT 1 @ HINGANGHAT	IntraState	19-02-2025	12:45			HT	H/T Due to end of expected life of paper insulation of ICT
132 KV element not available							

MANSAR-PENCH	InterState	12-02-2025	19:12			HT	System Constraints H/T at Pench End.
CHAKAN- CHINCHWAD-BAJAJ AUTO CHAKAN TAP	IntraState	16-10-2024	07:02			HT	For Load Management
NANDURBAR - RAILWAY TSS	IntraState	11-03-2025	17:00	12-03-2025	19:50	T	Distance protection
HT : Hand Tripping, T : Tripping, PO : Planned Outage, EO : Emergency Outage							

Note: Elements in the affected area are highlighted.

2.6 Weather Conditions

Weather conditions in the affected area were normal.

3.0 Details of LTS and UVLS schemes in the affected region

In the Maharashtra network, as a part of system security, Load trimming scheme (LTS) on some 400kV and 220 kV elements & Under voltage load shedding (UVLS) schemes at some of 400kV substations are designed & implemented to shed the load in view of overloading of ICTs / Lines & to prevent voltage collapse respectively.

3.1 LTS & UVLS schemes provided in Padghe S/s

- Load Trimming Scheme (LTS) on 400/220/100kV ICTs at Padghe:
  - Stage 1 – 302 MW, with 1 sec time delay
  - Stage 2 – 447 MW, with 3 sec time delay
- Under voltage load shedding setting on 400/220/100kV ICTs at Padghe:
  - Stage 1- 370kV, with 5 sec time delay
  - Stage 2- 370kV, with 10 sec time delay
- Load Trimming Scheme (LTS) on 400 Padghe – Babhaleshwar ckt 1& 2 at Padghe:
  - Stage 1- 1300 Amp, with 1.3 sec time delay

At 400kV Padghe substation, the load connected for relief from LTS operation of 400/220 ICTs, 400kV Babhaleshwar -1 & 2 lines & UVLS is same, i.e. Stage-1 -302 MW, & Stage-2-447 MW respectively.

3.2 UVLS scheme provided in 400kV Babhaleshwar S/s

- 220kV Babhaleshwar – A'nagar ckt – 1 – 371 kV with 5 sec time delay (Targeted load relief quantum – 218 MW)
- 220kV Babhaleshwar – A'nagar ckt – 2 – 371 kV with 5 sec time delay (Targeted load relief quantum – 218 MW)

3.3 UVLS scheme provided in 400kV Lonikand S/s

- Stage 1- 370kV, with 3 sec time delay
- Stage 2- 370kV, with 5 sec time delay
- Targeted load relief quantum – 242 MW

3.4 ULVS scheme provided in 400kV Jejuri S/s

- Stage 1- 370kV, with 5 sec time delay (Targeted load relief quantum – 125 MW)

3.5 LTS scheme provided in 220kV Nashik (GCR) S/s

- On 220kV Nashik (GCR) – Babhaleshwar ckt 1 & 2:
  - LTS setting – PSM - 70 % (840 A) with 1.3 sec time delay
  - Targeted load relief quantum – 140 MW
- On 220/132kV ICT 1,2 & 6:
  - LTS setting – 110% (576 A) with 1.3 sec time delay
  - Targeted load relief quantum – 179.06 MW

4.0 Sequence of Events (SoE)

As per flash report conveyed by WRLDC, on 12.03.2025 at 14:50, the 400 kV Degham-Jhanor D/C line tripped from the Jhanor end, while the 400 kV Jhanor - GPEC line also tripped due to an RYB fault. This further led to a generation loss at KAPS-3&4, KAPS-1&2, TAPS-3&4, and Ukai (T) in Gujarat State.

Hence, on 12.03.2025 at 14:50 hrs, Maharashtra grid experienced severe low voltages at multiple 400 kV locations.

Sr. No.	Name of substation	Before disturbance Voltage (kV) at 14:45 hrs *	After disturbance Voltage (kV) at 14:55 hrs *
1	400 kV Babhaleshwar	383.7	377.8
2	400 kV Padghe	386.7	**355.0**
3	400kV Kalwa	384.7	**353.4**
4	400kV Nagothane	388.7	**361.7**
5	400kV Kharghar	384.0	**361.0**
6	400kV Vikhroli	379.5	**349.8**
7	400kV Lonikand I	**374.9**	**361.7**
8	400 kV Lonikand II	**375.7**	**363.2**
9	400 kV Chakan	**375.8**	**360.9**
10	400 kV Jejuri	378.3	**368.0**
11	400 kV Talegaon (PG)	382.0	**364.0**
12	400 kV Kudus	387.0	**361.0**

* Source: Data from MSLDC SCADA & from Substation

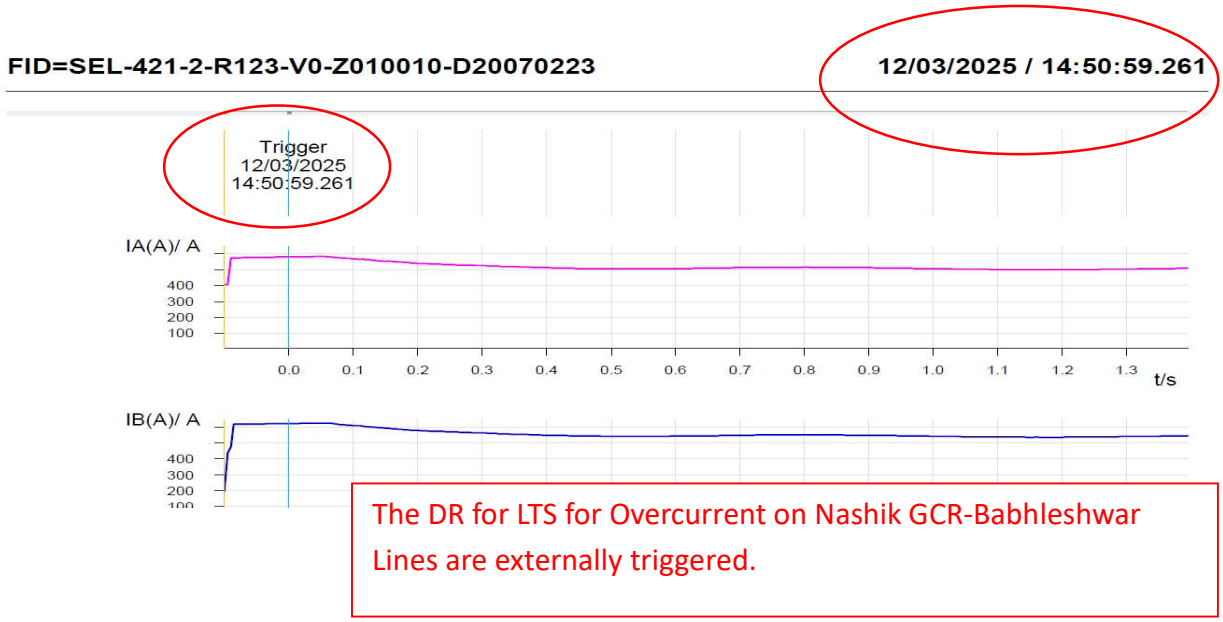
4.1 Sequence of Auto Defense Mechanism operation in Maharashtra

4.1.1 Sequence of Auto Defense Mechanism in Maharashtra

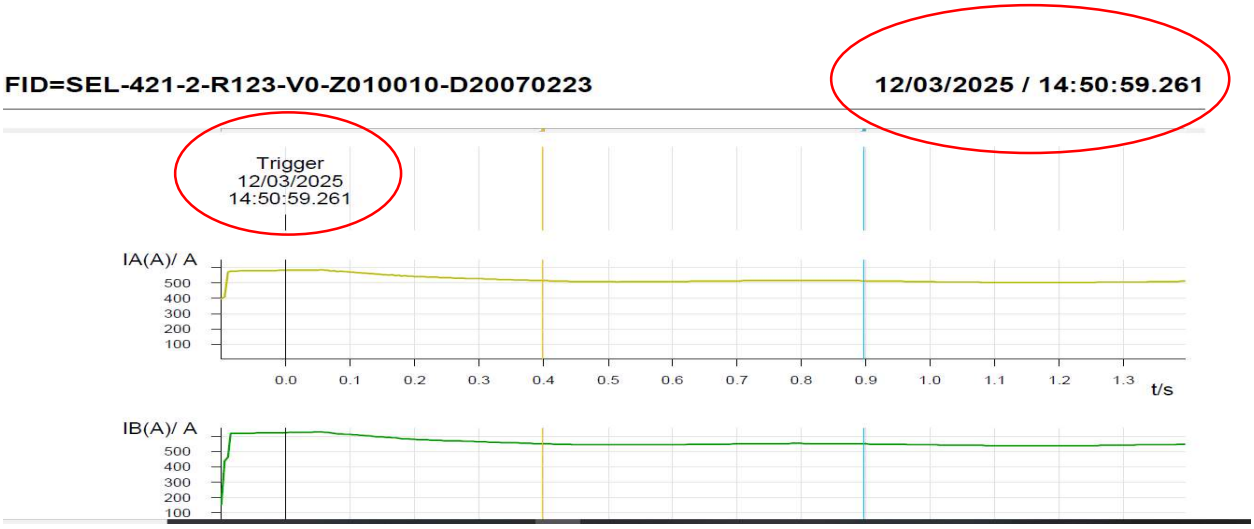
Date	*Time*	*Substation*	*Auto Defense mechanism operated*	*Remarks*	*Quantum Load Relief Obtained*
12-03-2025	14:50:59	220 kV Nashik GCR	Overcurrent LTS on 220 kV Nashik GCR - Babhleshwar-1& 2 lines Operated	Current above 840 A per circuit	179.06 MW
	14:51:07	400 kV Babhleshwar	Undervoltage LTS Stage-1 Operated	Voltage below 371 kV	436 MW
	14:51:18	400 kV PADGHE	Undervoltage LTS Stage-1 Operated	Voltage below 370 kV	547.89 MW
	14:51:23	400 kV PADGHE	Undervoltage LTS Stage-2 Operated	Voltage below 370 kV	
	14:51 *	400 kV PADGHE	Overcurrent LTS on 400kV Babhleshwar-1& 2 lines Operated	Current above 1300 A per circuit	
	14:51 *	400 kV Lonikand-1	Undervoltage LTS Stage-1&2 Operated	Voltage below 370 kV	242 MW
	14:51 *	400 kV Jejuri	Undervoltage LTS Stage-1 Operated	Voltage below 370 kV	74.64 MW
	14:51 *	220 kV Nashik GCR	Overcurrent LTS on 220/132kV ICT-1, 2 & 6 Operated	LTS Setting 110% (576A), 1.3Sec	34 MW
TOTAL Auto Defense mechanism Load quantum Relief					**1513.59 MW**

* Relay Time not synchronized with GPS; the sequence is as reported by SE PAC circles.

DR 220 kV Nashik GCR – Babhleshwar ckt 1&2 – Overcurrent LTS

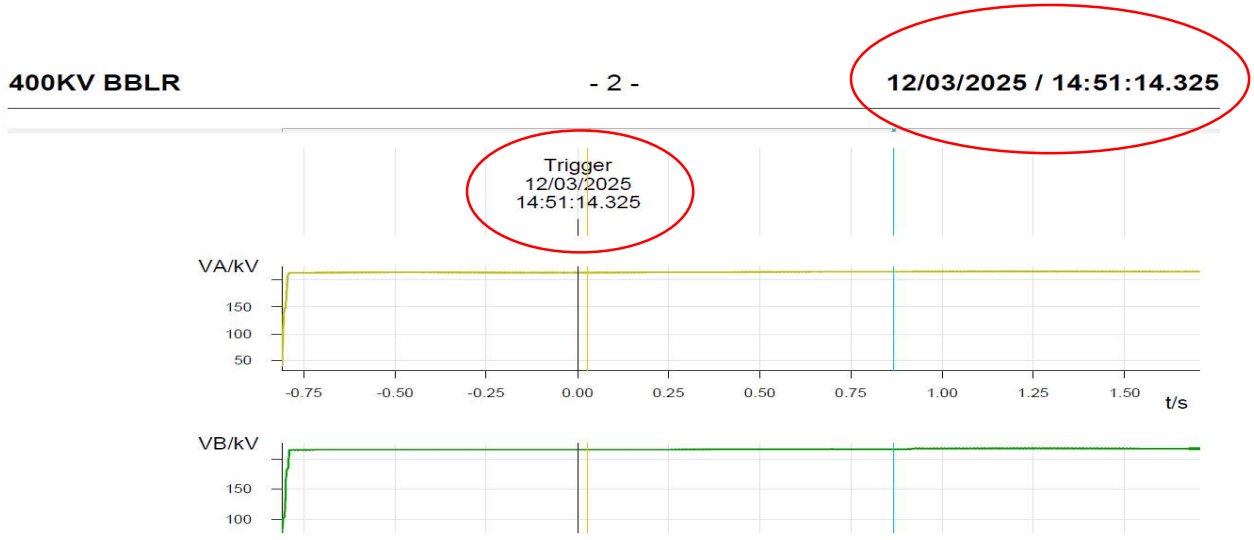


The DR for LTS for Overcurrent on Nashik GCR-Babhleshwar Lines are externally triggered.



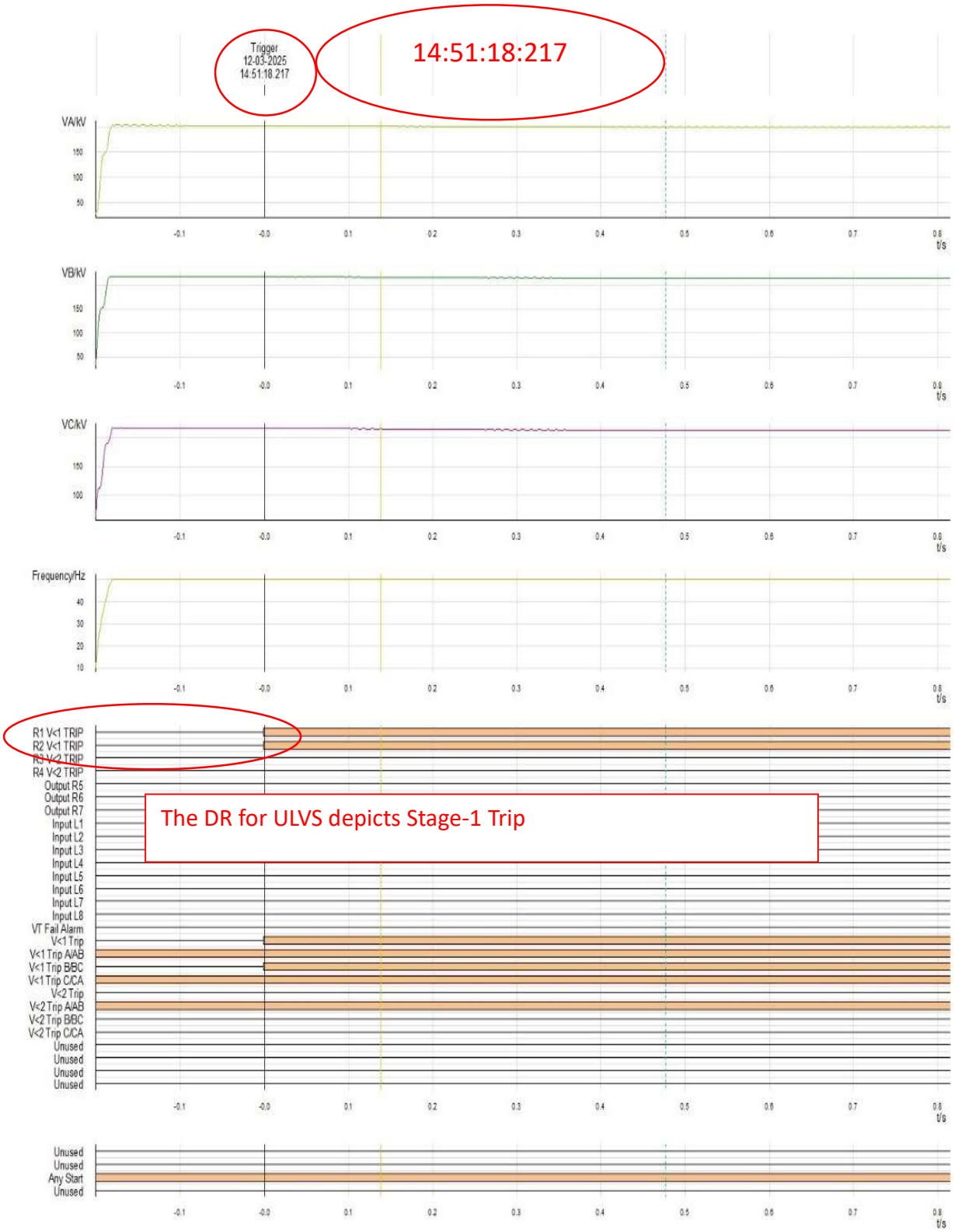
DR 400 kV Babhleshwar – Under Voltage Stage-1 LTS

The DR depicts low voltages at Babhleshwar

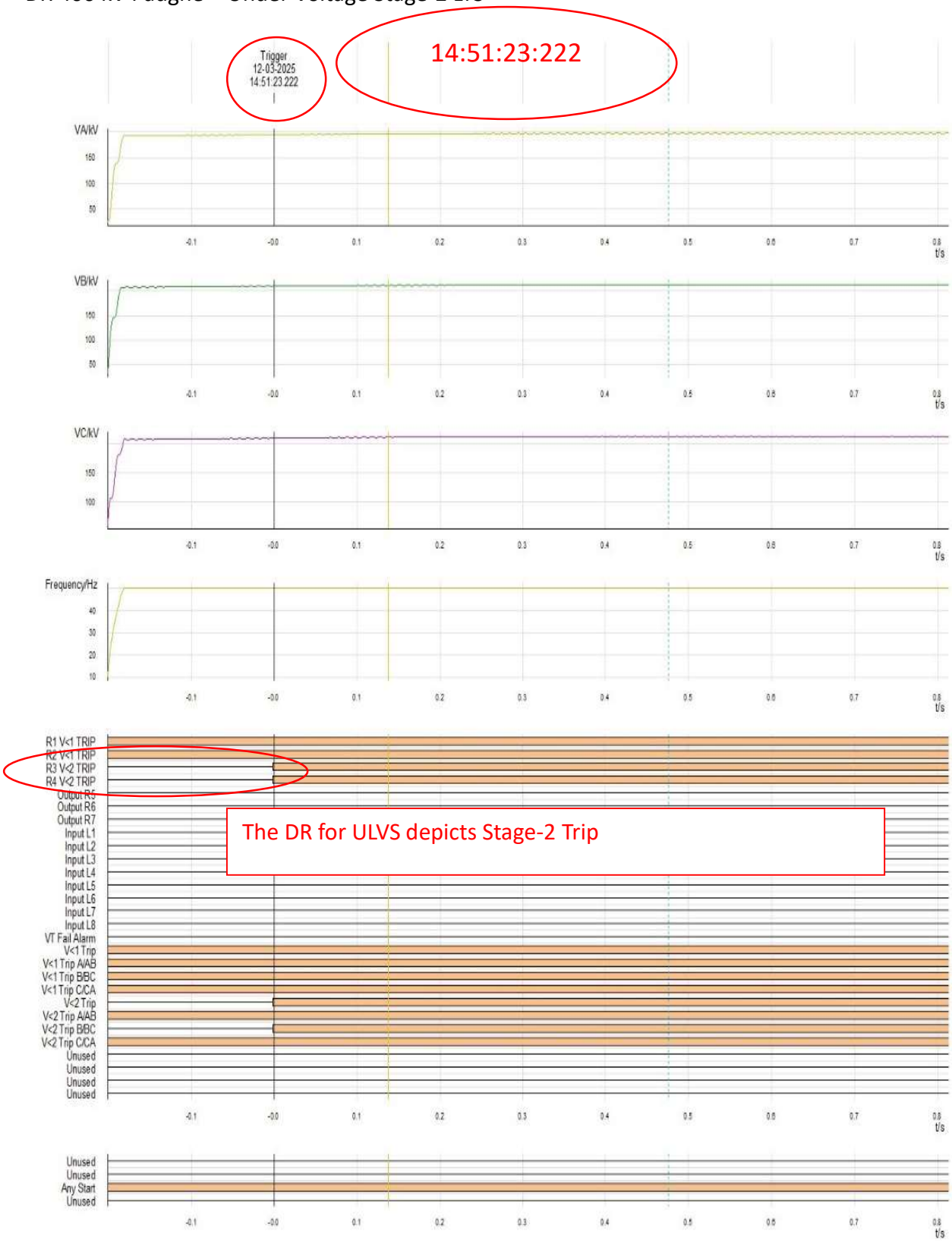


The second operation of UVLS DR depicts low voltages at Babhleshwar

DR 400 kV Padghe – Under Voltage Stage-1 LTS



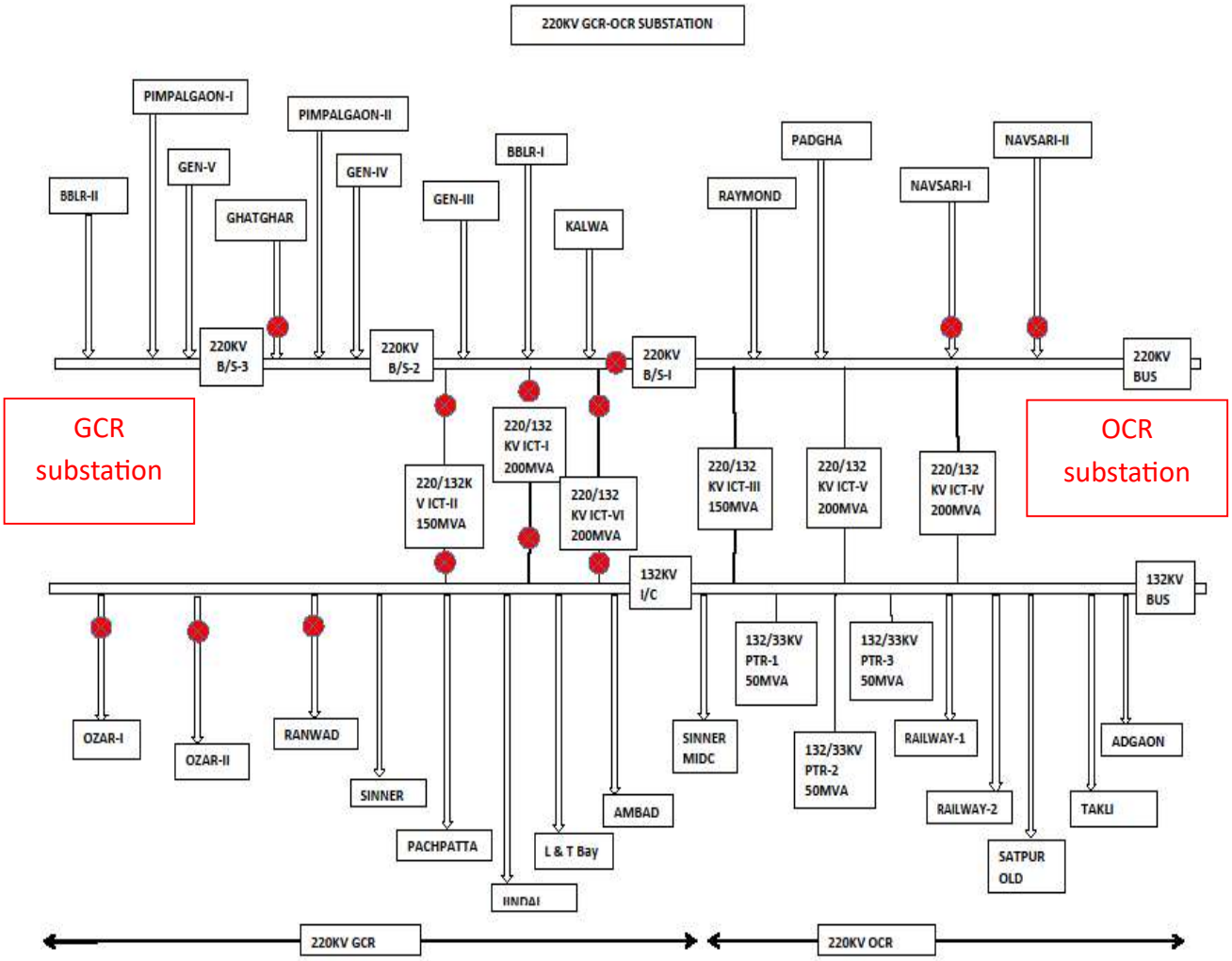
DR 400 kV Padghe – Under Voltage Stage-2 LTS



4.1.2 Disturbance observed in Nashik Region

On 12.03.2025 at 14:51hrs, sudden drop in grid voltage observed under Nashik & Ahilya Nagar region (reported, 370 kV & 180 kV against 400 kV & 220 kV resp.).

4.1.2.1 Nashik GCR and OCR substation



At 14:50:59, LTS operated on 220 kV BBLR-1, 2 lines at GCR SS. On LTS 132 kV Ozar-1&2, Ranwad and 33kV load at 220 kV OCR, 132kV R'pimplas, Sinnar Old & Adgaon SS were cutoff.

PSB detection was recorded on Distance relay of Navsari 2 & Reliance LS (earlier Navsari-1) at 14:51:44Hrs at OCR SS.

Sequence of Events at 220 kV Nashik (OCR):

Name of SS	Name of Feeder / ICT TRIPPED	Date & TRIP Time	Relay Indications	
		Dt. 12.03.2025	W.I.	R.I.
220 kV Nashik GCR	220kV Bus Section -1	14:51:13 Hrs	B/Up OC/EF Optd.	ER Argus, IDMTL Phase A (IDMT)=0.80, Phase B (IDMT)=0.88, Phase C (IDMT)=0.84 EF=0
	200MVA 220/132kV ICT-1	14:51:15 Hrs	HV B/Up OC/EF Optd.	HV ER Argus, LS, IDMTL Phase A (FWD) (LS)=0.59, 58.9V, Phase B (FWD) (LS)=0.60, 59.8V, Phase C (FWD) (LS)=0.59, 58.9V, IE (Rev)= 0A, VN=1.1V (CTR-
	200MVA 220/132kV ICT-2	14:51:15 Hrs	B/Up OC/EF Optd.	HV ER Argus, LS, IDMTL Phase A (FWD) (LS)=0.42, 58.8V, Phase B (FWD) (LS)=0.42, 59.7V, Phase C (FWD) (LS)=0.42, 59.5V, IE (Rev)= 0A, VN=1.1V
	200MVA 220/132kV ICT-6	14:51:15 Hrs	B/Up OC/EF Optd.	HV ER Argus, LS, IDMTL Phase A (FWD) (LS)=0.59, 58.8V, Phase B (FWD) (LS)=0.61, 59.8V, Phase C (FWD) (LS)=0.59, 59.6V, IE = 0.01A, VN=1.2V
	220kV Ghatghar	14:51:16 Hrs	B/Up OC/EF Optd.	ER Argus, IDMTL Phase A (FWD) (IDMT)=1.00xIN, 61.9V, Phase B (FWD) (IDMT)=1.08, 60V, Phase C (FWD) (IDMT)=1.05, 61.3V IE (Rev)= 0.07A
220 kV Raymond	220kV Washala	14:55 Hrs	B/Up OC/EF Optd.	Siemens, Il1-0.97kA, IL2-1.05kA, IL3-1.02kA, Dir OC Trip, Ip Dir Trip
On 15:07 hrs, at Nashik GCR, 220 Bus Sectionaliser-1 was taken in service.				

220 kV Nashik OCR	220kV Navsari-2	15:07 Hrs	B/Up OC/EF Optd.	Sifang CSC211 (CTR-800/1A)
				3.552 INV OC FWD OP, Ia-1.242A, Ib-1.383A, Ic-1.305A
	220kV Reliance LS (Navsari-1)	15:07 Hrs	B/Up OC/EF Optd.	Sifang CSC211 (CTR-800/1A)
				3.451 INV OC FWD OP, Ia-0.985A, Ib-1.11A, Ic-1.039A

4.1.2.2 400/220 kV Babhaleshwar substation

At 400 kV BBLR SS at 14:51:07 Hrs, 400kV UVLS optd. & 220 kV A'nagar 1&2 lines tripped on UVLS. From DR 4 instances of undervoltage were recorded 14:51:07, 14:51:014, 14:56:01 and 14:59:15Hrs. Both Ahilya-Nagar lines tripped in the first instance. (Undervoltage LTS Settings: - Voltage – 371 kV, Time - 5 Sec.)

However, as the A'nagar Sub-station was also fed from 400/220 kV Karjat, overloading of Karjat A'nagar line occurred resulting into tripping of that line. This further created overloading of connected 220 kV and 132 kV network resulting into trippings as below.

At 220 kV Belwandi SS at 14:51 Hrs, 220 kV Bus section, 200MVA ICT-2 & 50MVA TF-2 tripped on over current.

At 132 kV Patherdi SS at 14:51 Hrs, 132 kV Khandke line tripped on overcurrent.

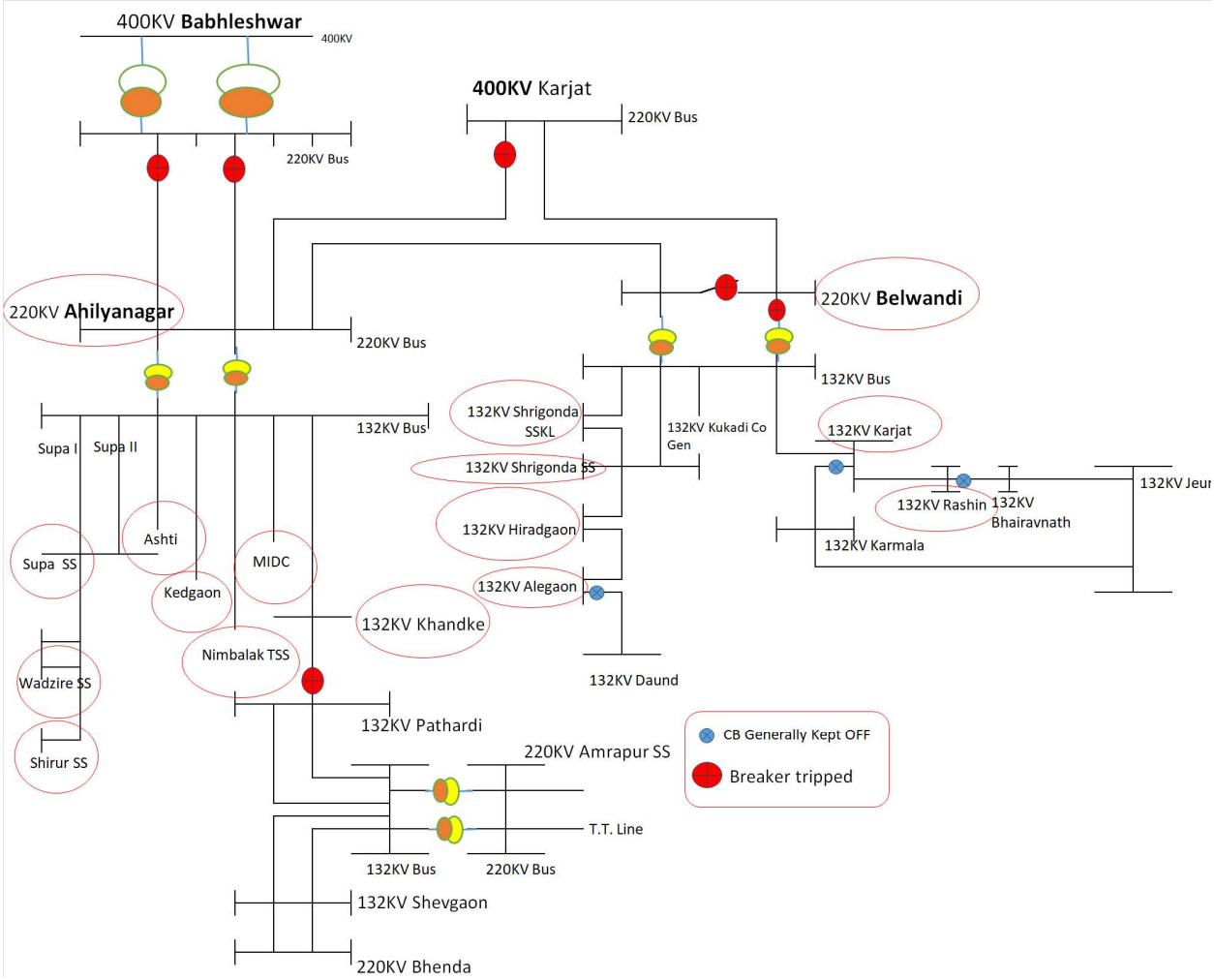
Due to above tripping, supply failed at 220 kV Sonewadi, 132 kV Kedgaon, MIDC A'nagar, Khandke, Shrigonda and Rashin SS.

Name of SS	Name of Feeder / ICT TRIPPED	Date & TRIP Time	Relay Indications	
		12.03.2025	W.I.	R.I.
400 kV Karjat	220kV A'nagar	14:51 Hrs *	B/Up OC/EF Optd.	OC Stg-1 Optd, Ia-1.441A, Ib-1.486A, Ic-1.461A
				Ua-52.842V, Ub-52.977V, Uc-52.977V
				(Prim Current Ia-1.152kA, Ib-1.188kA, Ic-1.168kA)
220 kV Belwandi	220kV Bus section	14:51 Hrs *	B/Up OC/EF Optd.	Trip B ph OC trip, start ph ABC, Trip ph-B, OC start I>1, Trip I>1, freq. 49.79Hz, Ia-695A, Ib-722A, Ic-705A, Vab-163.2kV, Vbc-164.5kV, Vca-161.5kV
	100MVA, 220/132kV ICT-2	14:51 Hrs *	HV B/Up OC/EF Optd.	Argus, Ia-1.24A, Ib-1.24A, Ic-1.23A,IE-0.02A, CTR-400/1A

132 kV Pathardi	132kV Khandke	14:51 Hrs *	B/Up OC/EF Optd.	51/67-1, Optd ABC, dir Fwd, Va-67.14kV, Vb-67.06kV, Vc-65.41kV, Vn-2.15kV, Ia-0.897kA, Ib-0.915kA, Ic-0.931kA, In-0.011kA.

* Relays are not GPS sync.

Area affected due to Trippings around Babhaleshwar substation



Observations: -

Due to source supply failure from Babhleshwar substation, Total load of 220 kV Ahilyanagar ss, has shifted to 220 kV Lines emanating from Karjat substation.

Further, 220 kV Karjat-A'nagar and 220 kV Bus-section at Belwandi s/stn tripped on overcurrent.

Hence, many downstream substations went into dark.

A) UVLS & LTS at Babhleshwar needs to be reviewed in view of connection with Karjat substation. Instead of network opening, the LTS & UVLS schemes should disconnect required quantum of loads.

B) 220 kV Karjat-A'nagar & 220 kV Karjat-Belwandi line overcurrent LTS is required.

C) Back-up Overcurrent Protection settings in this area needs to be reviewed.

Abstract of affected substations under EHV O&M DIV Babhleshwar						
Sr No.	***Voltage***	***Name of Substation***	***STATUS***	***From***	***To***	***Load affected (LBT) in MW***
1	220 kV	Belwandi	DARK	14:50	16:35	72.35
2	220 kV	Sonewadi	DARK	14:51	16:50	24.92
3	132 kV	Karjat	DARK	14:50	15:40	49.29
4	132 kV	Kedgaon	DARK	14:51	16:01	67.65
5	132 kV	Khandke	DARK	14:51	15:10	98.6
6	132 kV	MIDC A'Nagar	DARK	14:51	16:08	88.14
7	132 kV	Rashin	DARK	14:52	15:40	16.74
8	132 kV	Shrigonda	DARK	14:50	16:35	56.65
9	132 kV	Supa	DARK	14:51	16:01	72.63
10	132 kV	Wadzire	DARK	14:51	15:59	29.21
Total Load Affected						**576.18**

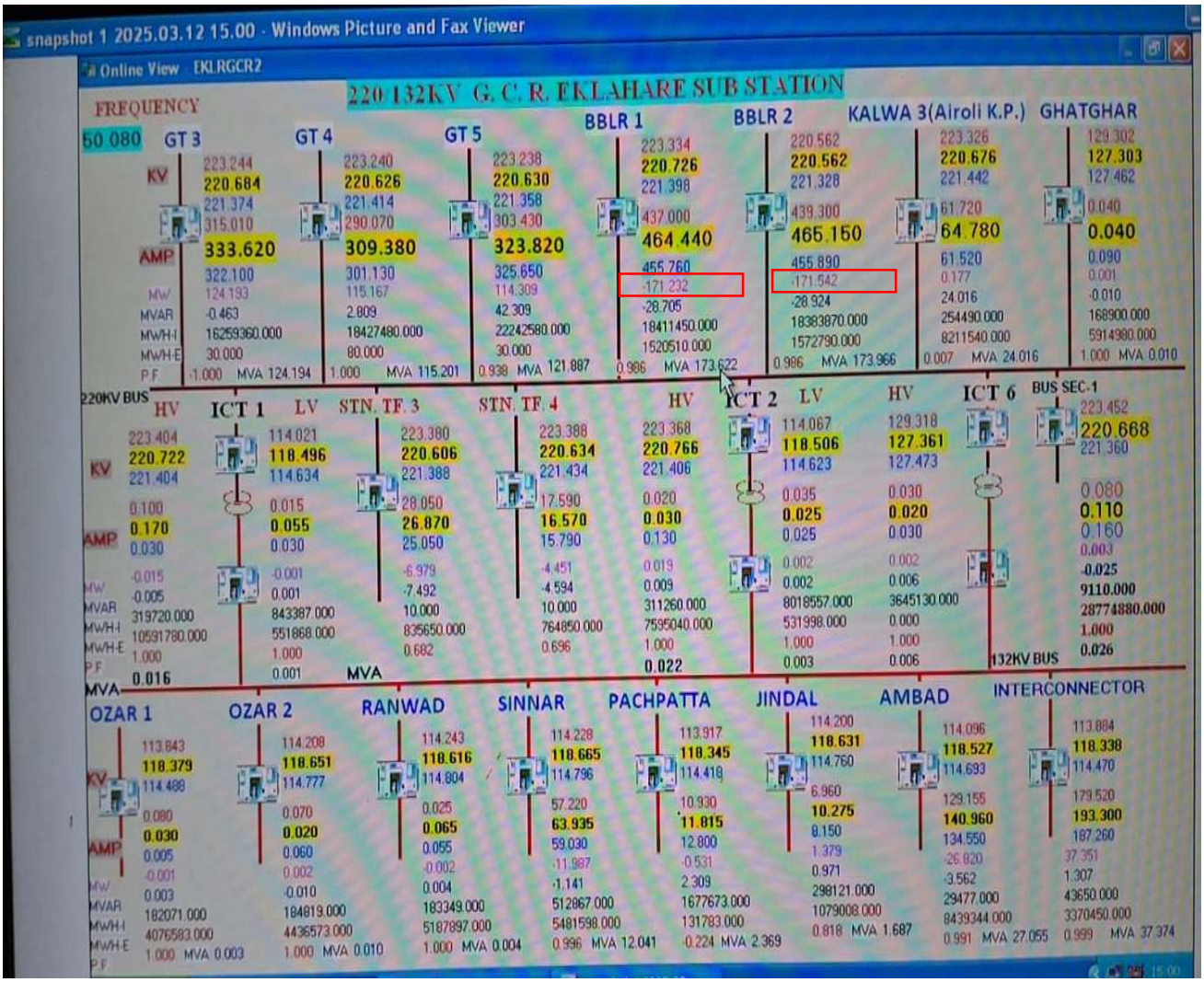
4.1.2.3 Observations of disturbance seen in Nashik region

Before the occurrence, 220kV Navsari-2 & Reliance LS (earlier Navsari-1) lines were importing (86MW each ckt) from Navsari at OCR SS.

After tripping of ICTs & Bus section at GCR SS, NTPS generation (GT3-124MW, GT4-115MW, GT5-114MW) were evacuated through 220kV BBLR 1&2 lines.

NTPS generation was evacuated through 220kV BBLR 1&2 lines

(POWER FLOW TOWARDS BABHLESHWAR)



During restoration while charging 220kV Bus section-1 (15:07Hrs) at GCR SS, 220kV Navsari 2 & Reliance LS (earlier Navsari-1) ckt started drawing heavily from OCR (NTPS generation being in service) causing tripping of both ckts on overcurrent (1040A each ckt).

4.2 SLDC Control Room Actions

4.2.1 Instruction by MSLDC to pick-up Hydro Generation of Maharashtra

Koyna Stage-IV Hydro generation (4 x 250 MW) was pickup up.

Around 14:30 hrs, low voltages (below 380 kV) were prevailing in Pune region. Till then, 2x250 MW units (Unit-2 and Unit-3) were under operation in generation mode, whereas 2x250 MW units (Unit-1 and Unit-4) were under operation in condenser mode.

Around 14:40 hrs, MSLDC instructed Koyna stage-IV Unit-4 (250 MW) to convert from condenser mode to generation mode, as per the requirement of Grid.

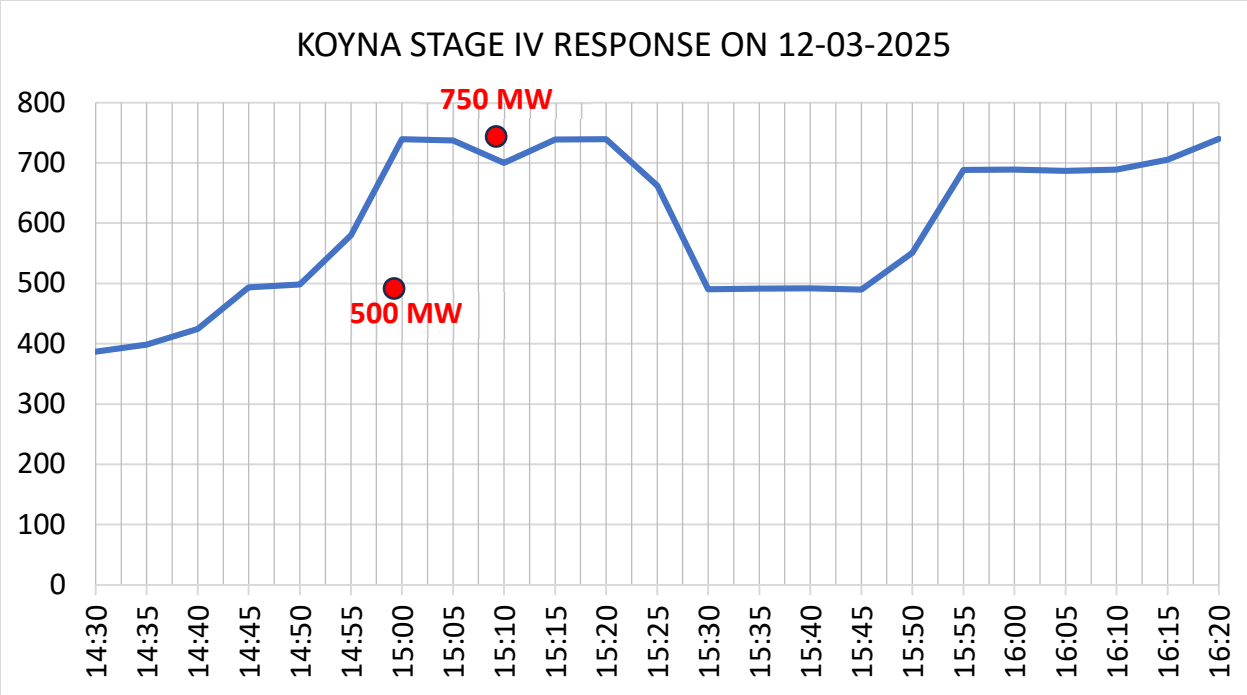
But, while converting from condenser mode to generation mode, Koyna stage-IV Unit-4 (250 MW) tripped at 14:45 hrs.

Around 14:47 hrs, MSLDC then instructed convert Koyna stage-IV Unit-1 (250 MW) from condenser mode to generation mode. Thus, around 14:50 hrs, Koyna stage-IV total generation pick-up from 500 MW to 750 MW.

Time	***Koyna Stage IV Generation as per SCADA (in MW)***
14:30	386.98
14:35	398.36
14:40	424.20
14:45	493.23
14:50	497.99
14:55	579.91
15:00	739.27
15:05	736.71
15:10	699.77
15:15	738.62
15:20	739.12
15:25	662.36
15:30	490.21

At 15:25 hrs, Koyna stage-IV Unit-1 (250 MW) withdrawn due to downstream seal leakage observed. Generation decreased from 750 MW to 500 MW.

At 15:50 hrs, Koyna stage-IV Unit-4 (250 MW) was restored. Koyna stage-IV generation again increased from 500 MW to 750 MW.

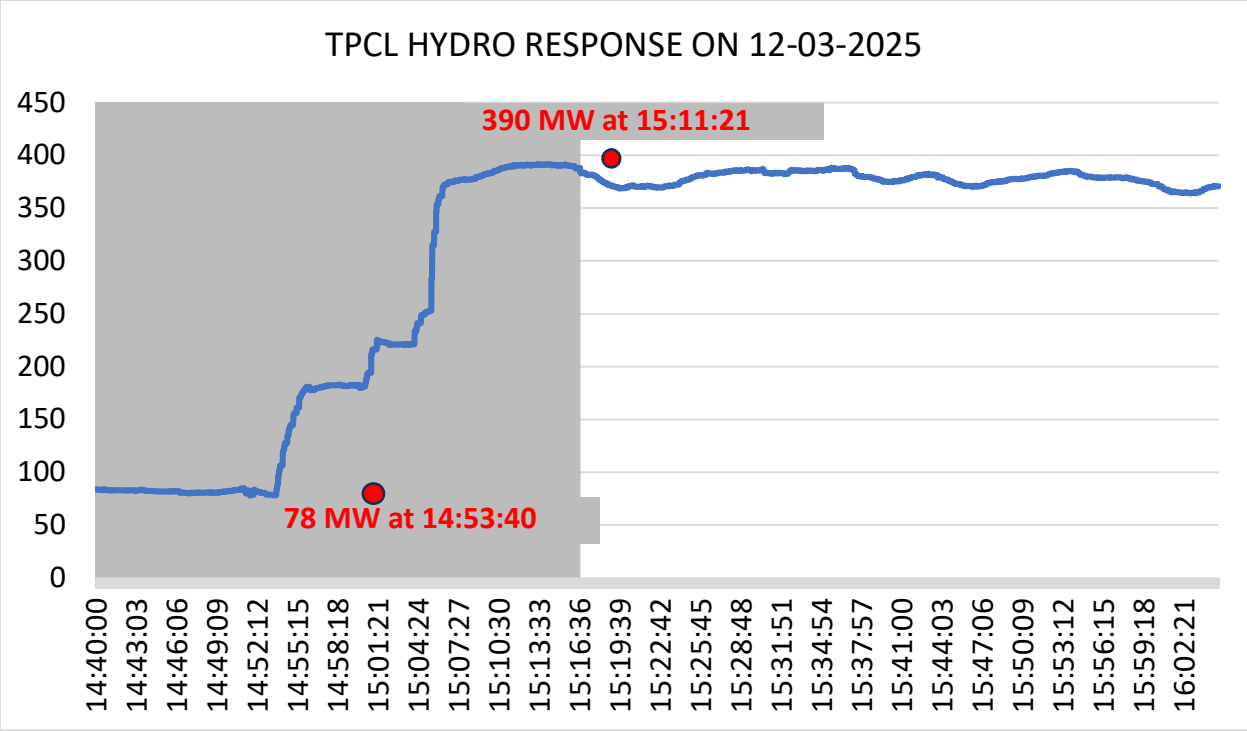


Source : 5 min SCADA Data

MSLDC instructed TPCL to pick up Hydro generation (447 MW) to its maximum around 15:51 hrs

Time	***TPCL Hydro Generation as per PSCC SCADA (in MW)***
14:41:00	83
14:45:00	82
14:50:00	82
14:55:00	154
15:00:00	180
15:05:00	251
15:10:00	383
15:15:00	390

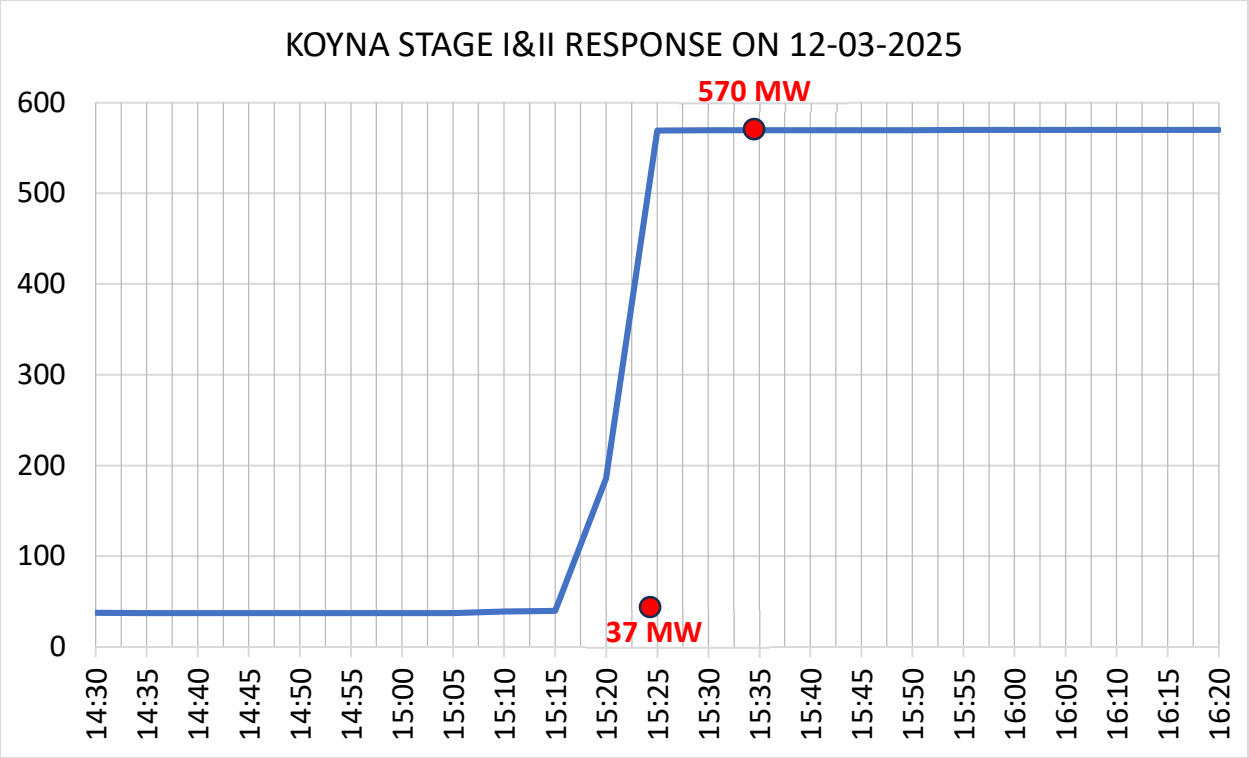
TPCL's Khopoli unit was not on bar as per requirement from TPC-D. It requires around 1 hour to pick up generation.



Source : 1 sec SCADA Data from TPCL PSCC

Koyna Stage-I&II Hydro generation (600 MW) was instructed to immediately pickup to full capacity. But the response from Koyna Stage I&II was slow. Repeated instructed has resulted in generation rise from 40 MW (min) to 580 MW at 15:25 hrs.

Time	*Koyna Stage I&II Generation as per SCADA (in MW)*
14:30	37.6
14:35	37.4
14:40	37.4
14:45	37.4
14:50	37.4
14:55	37.4
15:00	37.4
15:05	37.4
15:10	38.9
15:15	39.7
15:20	185.8
15:25	569.1
15:30	569.4

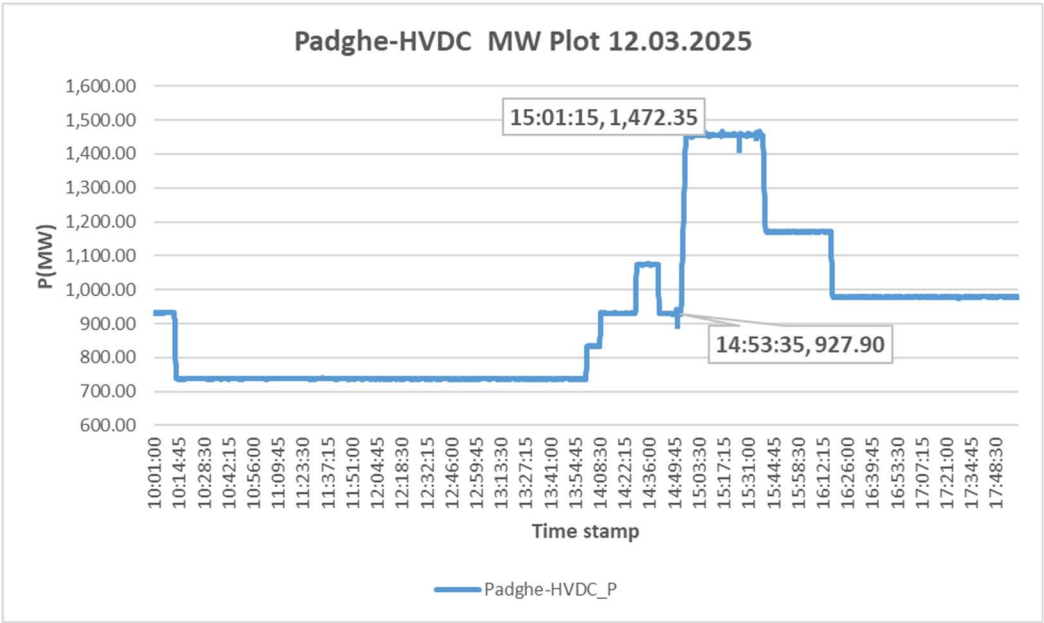


Source : 5 min SCADA Data

4.2.2 HVDC pickup instructions given by MSLDC

HVDC Bi-pole Power flowing from Chandrapur to Padghe was around 950 MW at 14:53:38 hrs, which was instructed for ramping to full capacity of 1500 MW, completed by 14:56:23 hrs.

PMU plot of HVDC total power seen at 400kV Padgha substation is shown below



HVDC response recorded in event list Padghe terminal is shown below

MSETCL

± 500KV HVDC TERMINAL STATION, PADGHA

Date : 12/03/2025 - 12/03/2025

EVENTS HISTORY

DATE	TIME	CH.	DESIGNATION	DESCRIPTION	STATUS	ALM. GROUP
12-03-2025	14:53:38.631	I-001-0211	S2.P1-AK-A41(A42)	POWER RAMP	- INPROGRESS	NORMAL-EVENT
12-03-2025	14:53:40.344	I-001-0005	S2.P1-AK-A41(A42)	CONTROL ORDER EXECUTED	- -	OPERATOR-LOG
12-03-2025	14:56:21.223	I-010-0081	S2.P1-WT-T1-L3	A&B BOTH POWER SUPPLY-XER COOLING	- NORMAL	CONV-XFMR
12-03-2025	14:56:23.414	I-001-0211	S2.P1-AK-A41(A42)	POWER RAMP	- COMPLETED	NORMAL-EVENT

14:53:38.631 POWER RAMP INPROGRESS

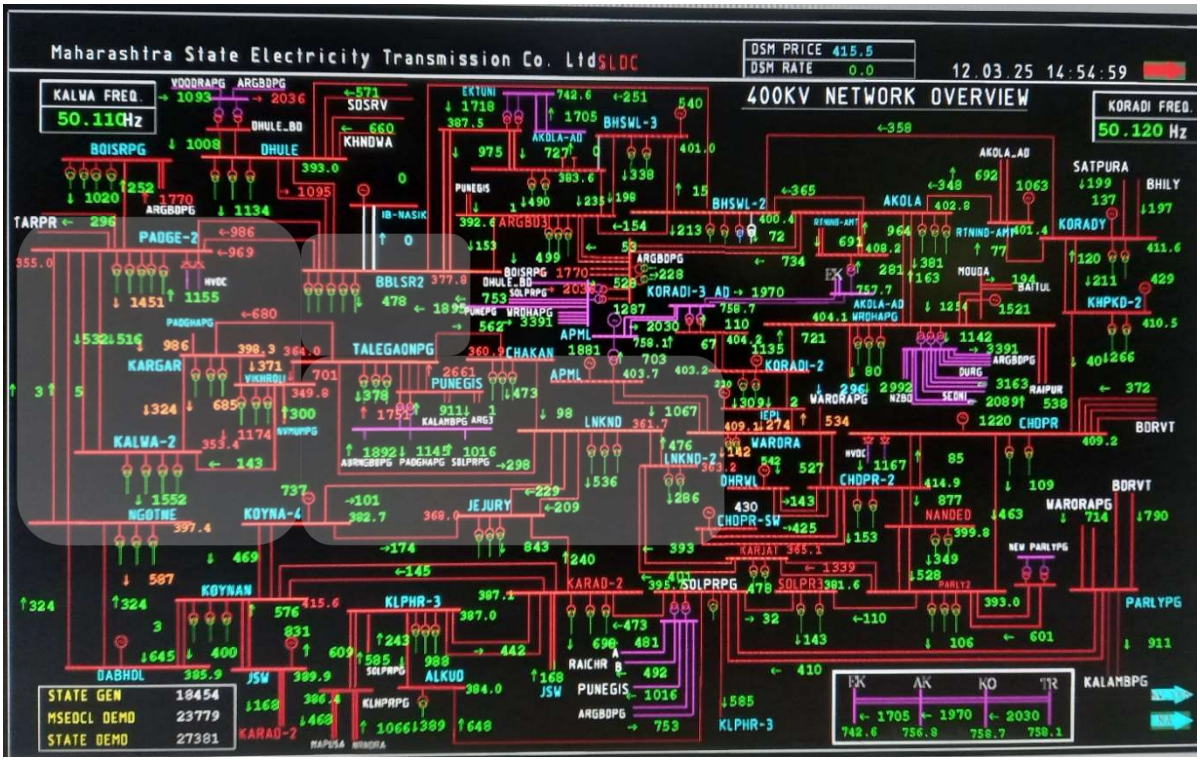
12-03-2025 14:56:23.414 POWER RAMP COMPLETED

4.2.3 Manual Load Curtailment instructed by MSLDC

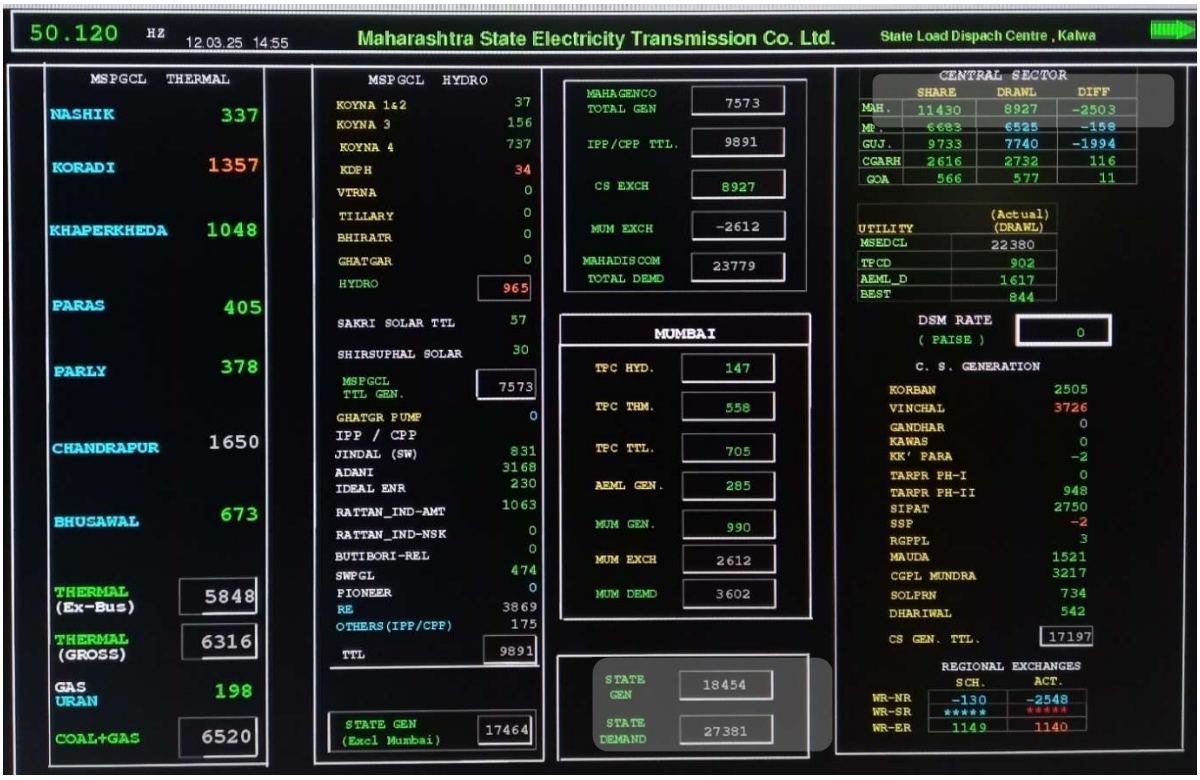
Sr. No.	Name of Substation	Load curtailment due to	District	Load affected (In MW)
1	400kV Padghe / 400kV Kalwa/ 220kV Boisar	DLS implementation	Thane/Raigad/Navi Mumbai	1061.34
2	400kV Nagothane	Emergency Handtripping of 220kV Nagothane – Wadkhal ckt 1 & 2 due to low voltage	Raigad	500
3	TPCL	DLS implementation	Kalyan	176
4	AEML	DLS implementation	Bhyander, Borivali, Mira road, Malad, Dahisar, Malvani, Charkop, Meghwadi & Juhu area	95
Total Load shedding quantum				**1832.34**

4.3 SCADA, PMU Plots & Snapshots

SCADA Snapshots at 14:55 Hrs i.e. after initiation of incidence:

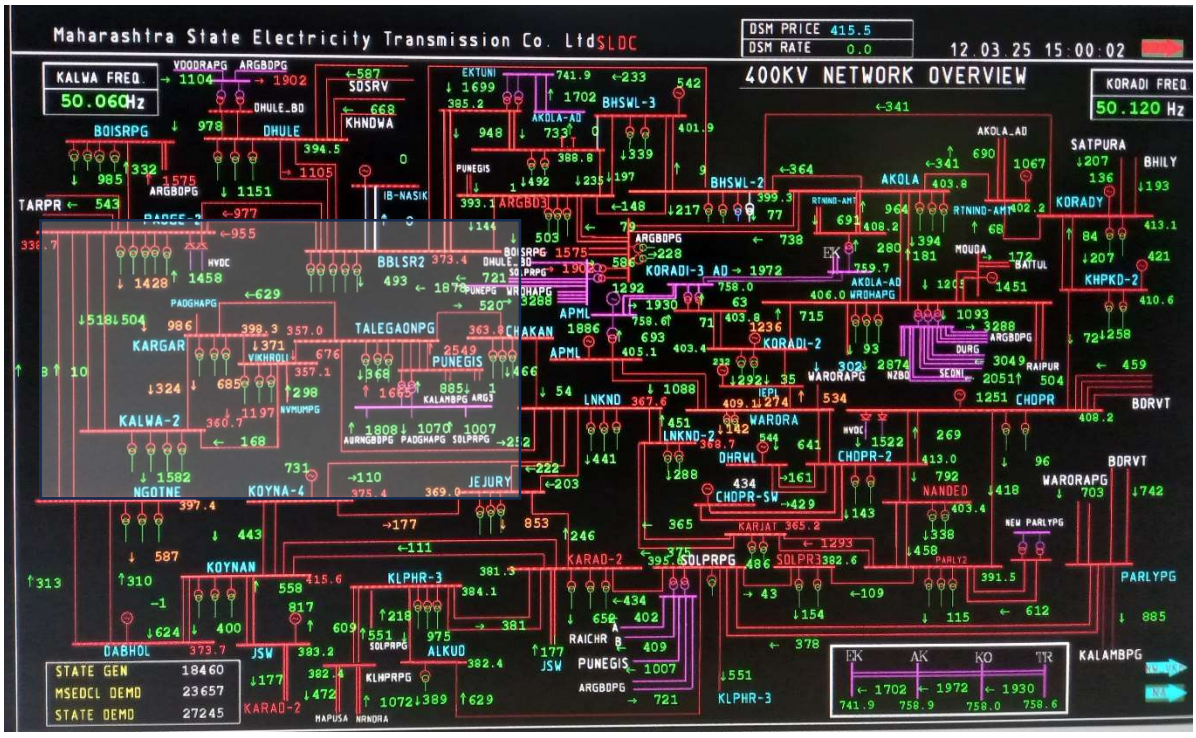


400 kV Network Overview_After Incidence (SCADA)

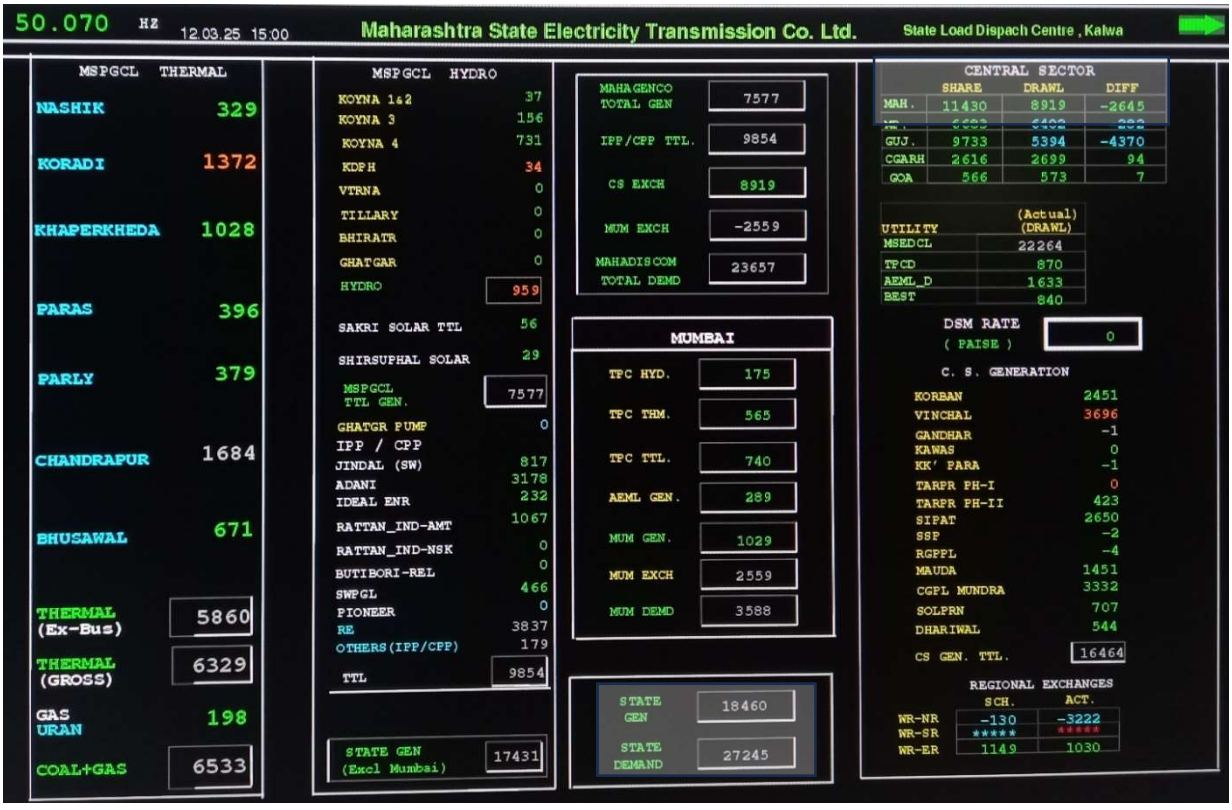


Resource Overview of the State_After Incidence (SCADA)

SCADA Snapshots at 15:00 Hrs:



400 kV Network Overview_After Incidence (SCADA)



Resource Overview of the State_After Incidence (SCADA)

5.0 Root Cause Analysis

5.1 Primary Cause

As per the Preliminary Flash report of Trippings in South Gujarat prepared by WRLDC on 12.03.2025, the primary cause is as below:

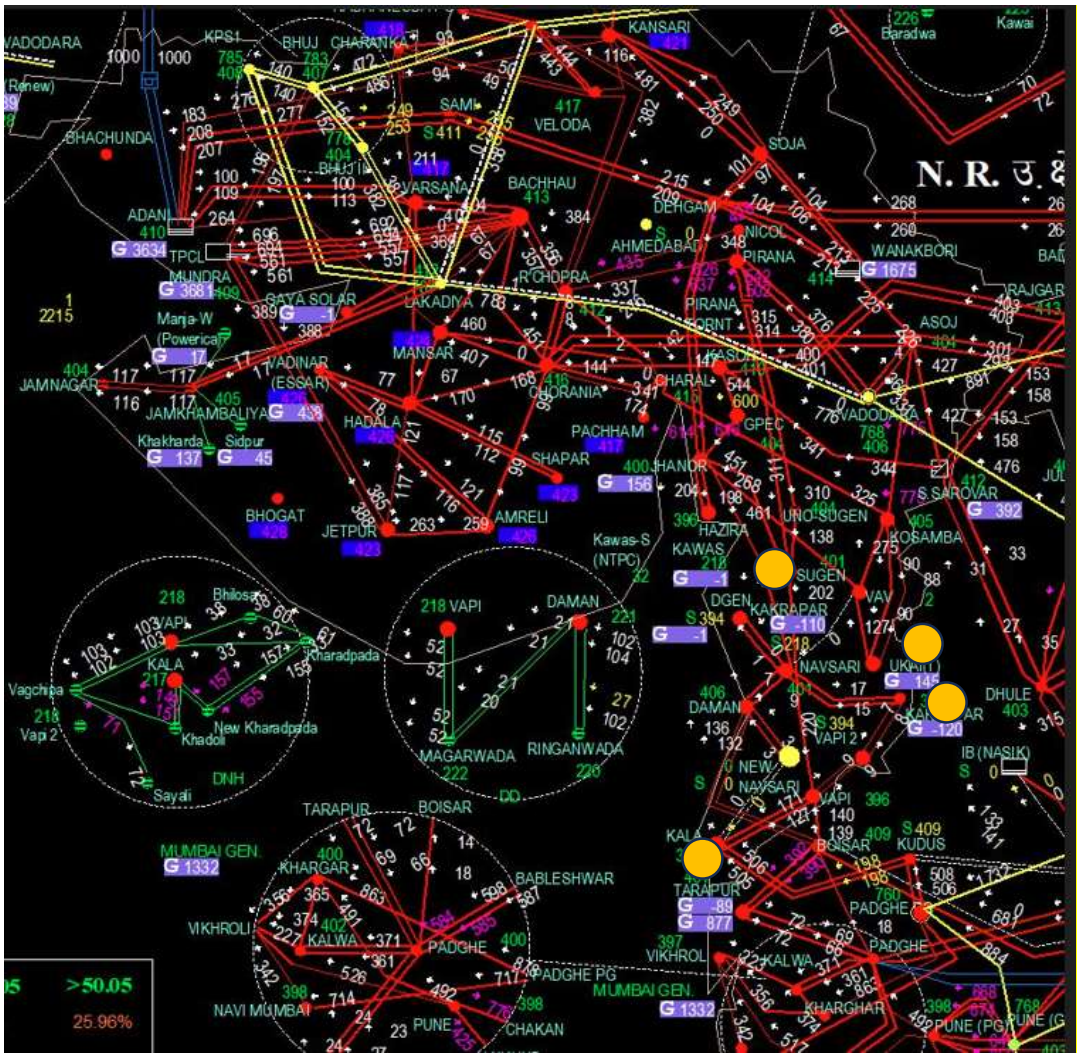
- Following lines in Gujrat were already out:

Name of line	Reason of outage
400 kV Vapi- Sugen	Planned outage
400 kV Kosamba- Chara	Planned outage
400 kV Kosmba- Paccham	Forced outage
220 kV Kawas- Haldarwa 1	Emergency outage

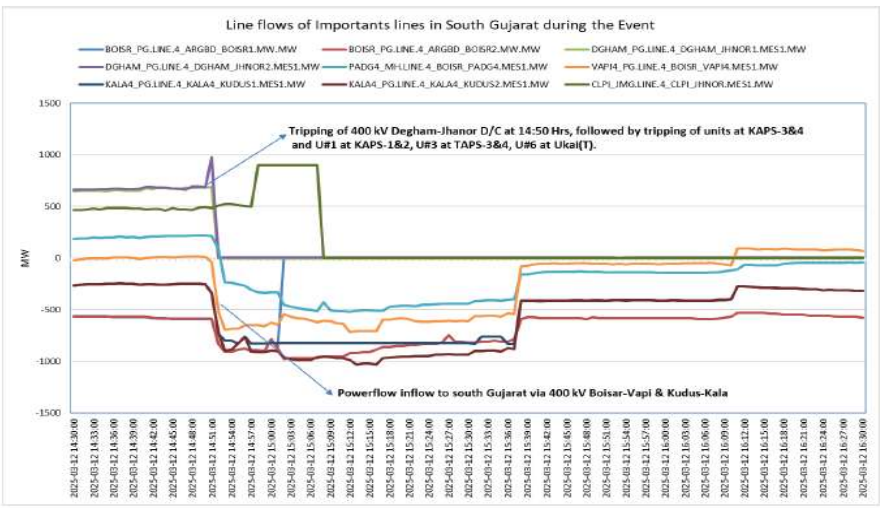
- At 14:50 Hrs on 12-03-2025, 400 kV Degham - Jhanor D/C (Tripped from Jhanor end B-E fault & RYB fault respectively, lines remain in charged from Degham end) and 400 kV Jhanor - GPEC tripped (RYB fault as intimated by NTPC Jhanor).
- The trippings followed by generation loss at KAPS-3&4, KAPS-1&2, TAPS-3&4 and Ukai(T).
- There was total 2804 MW of generation loss in Gujrat/Maharashtra. The details are tabulated below:

Name of Generating Plant	Loss of Generation (MW)
KAPS 3&4 Unit 3 & 4	1264
Ukai(T) Unit-3, 4 & 6	610
SLPP	198
TAPS3&4 Unit 3 & 4	500
KAPS Stage 1&2 Unit-1	220

- Thereafter severe low voltages were observed in south Gujarat.
- Due to heavy rush of power flow from Maharashtra to south Gujarat, severe low voltages were also observed in western Maharashtra.
- Due to conductor snapping of 400 kV Aurangabad-Boisar-2 at 15:01 Hrs, severe low voltages observed in 400 kV and 220 kV of Boisar, Kala, Magarwada stations etc.
- The geographic area affected in Gujrat is shown below:



Indicates Affected Generation location on Gujrat Map (WRLDC)



(Source-WRLDC Report)

5.2 Contributing Factors

- Mumbai, MMR & Pune area in the State are highly urbanized areas having concentrated demand.
- The transmission network in this area is not adequate in comparison with the demand catered. Thus, some of the 400 kV & 220 kV lines are overloaded.
- Less synchronous Generating sources are available in these areas i.e. generation at Trombay, Uran & Dahanu.
- There is inadequate reactive compensation in these areas.
- Due to all above factors, the voltages in this area are on lower side during high demand period.
- Prior to the incidence, the voltages at 400 kV Padghe, 400 kV Kalwa, 400 kV Kharghar, 400 kV Lonikand 1, 400 kV Lonikand 2 were between 390 kV to 375 kV.
- As system voltages were already on lower side and heavy flow from 400 kV Padghe to Gujrat system through Tarapur & Boisar lines, voltages were drastically reduced.
- All above factors contributed in aggravating the poor system conditions.

5.3 Earlier observations of System Operators

- Under voltage issues were earlier also observed by system operator in Pune, Mumbai & MMR region & Various State grid alert reports also issued from time to time. Few of them are listed below:
  - Under voltage in Mumbai, Pune, Nashik region on 12.03.2025
  - Pune Region: Tripping of 400kV Talegaon (PG) – Lonikand 1 on 23.02.2025
  - Under voltages in Mumbai & Pune Region on 16.01.2025
  - Critical high loading of multiple transmission lines and ICTs resulting in N-1 non-compliance & low voltages at multiple 400kV nodes in Pune, Mumbai, MMR region on 17.04.2024
  - Pune Region Tripping of 400kV Talegaon (PG) – Lonikand & Chakan – Talegaon (PG) 12.03.2024
  - Under-voltages in Pune region on 20.02.2024
  - Load shedding incidences in Pune region due to severe low voltages in Grid during Apr – June 2023 issued on 20.09.2023

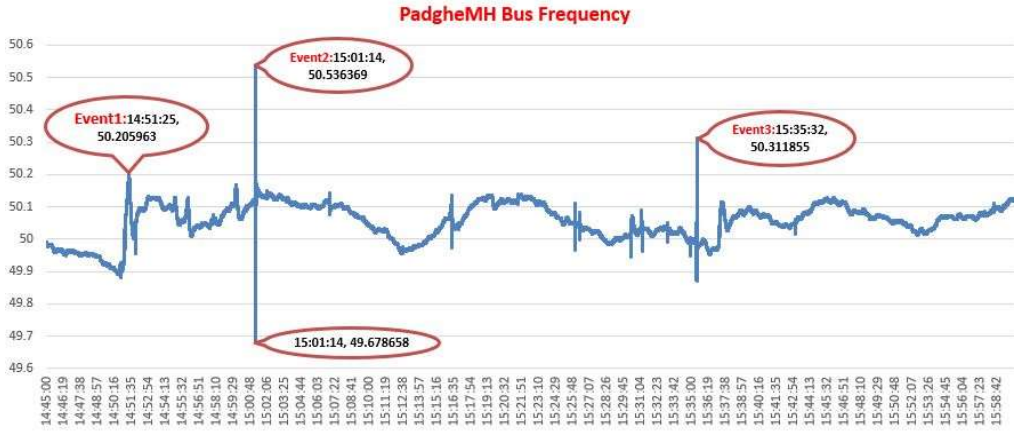
The prevailing and persistent under voltage scenario in this area pushes system into an alert operation state many times. SLDC had suggested for expediting the planned projects in this area; to relieve the 400 kV line overloading and under voltage issue. Particularly the schemes for evacuation of power from 400 kV Shikrapur needed an expedited completion. SLDC had also informed about the inadequate MVAR compensation available in this area causing the under voltage issue. The issue was also discussed at the state OCC. SLDC and STU have jointly conducted

a study and identified locations where capacitive compensation is needed in this area. The shortfall indicated was to the tune of more than 2000 MVAR.

5.4 Analysis of the Incidence

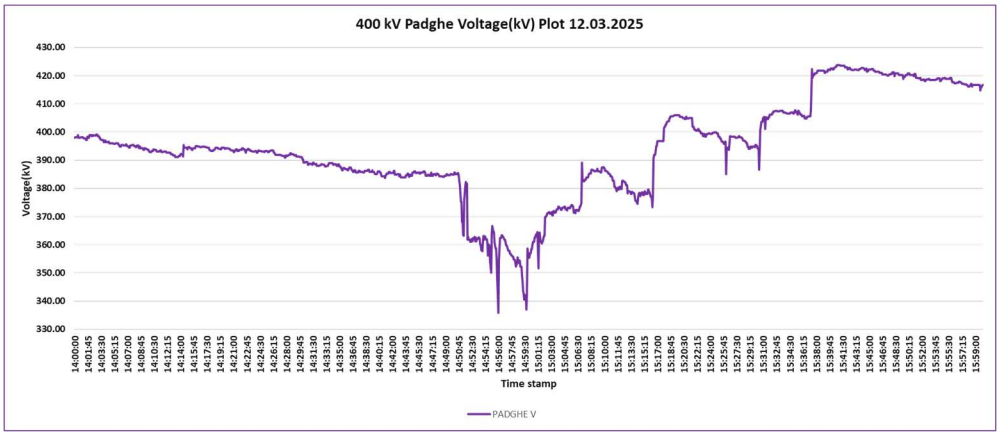
5.4.1 Analysis at 400 kV Padghe S/s

5.4.1.1 Frequency:

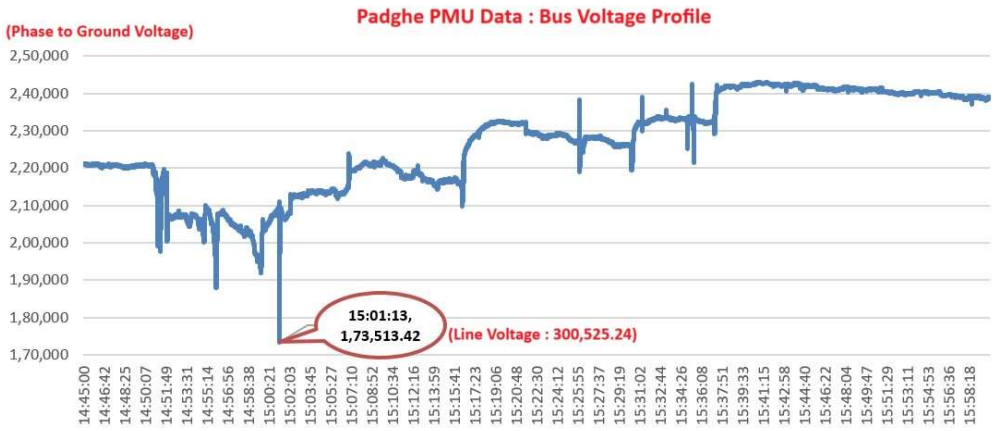


Frequency at 400 kV Padghe S/s. (PMU)

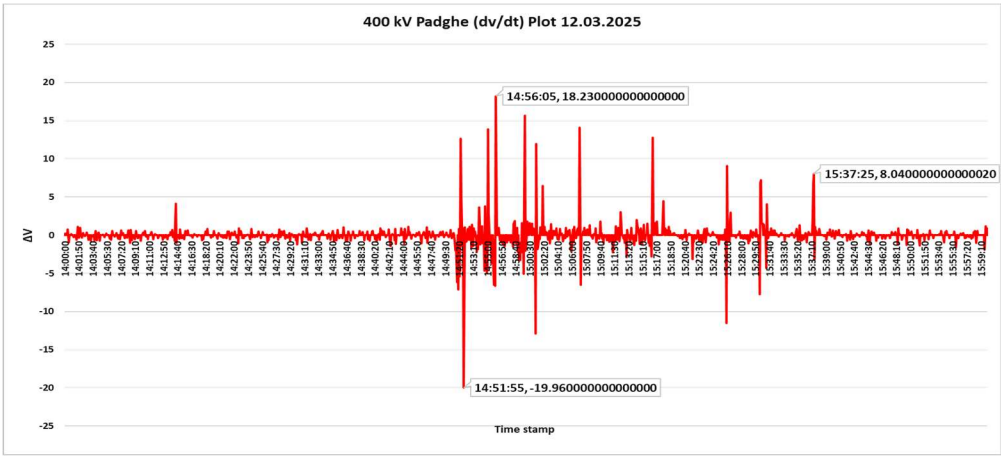
5.4.1.2 Voltages:



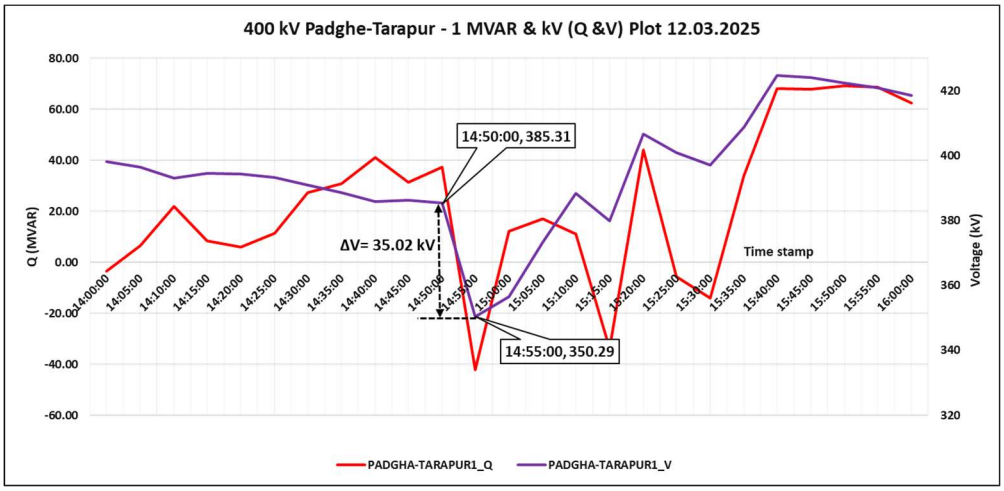
Voltage at 400 kV Padghe S/s. (SCADA)



Voltage at 400 kV Padghe S/s. (PMU)



dv/dt plot at 400 kV Padghe S/s. (SCADA)



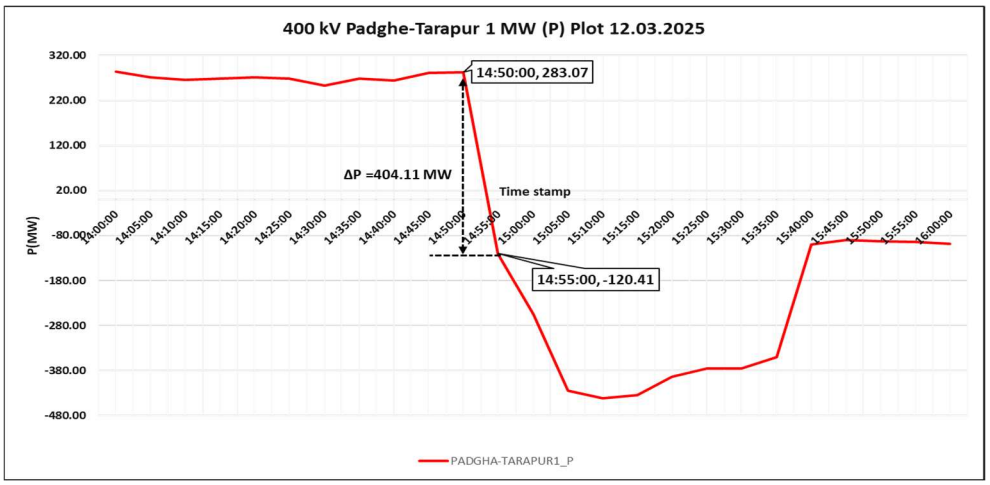
Reactive Power & Voltage plot of 400 kV Tarapur-Padghe-1 at Padghe end

From the above plots, it is observed that:

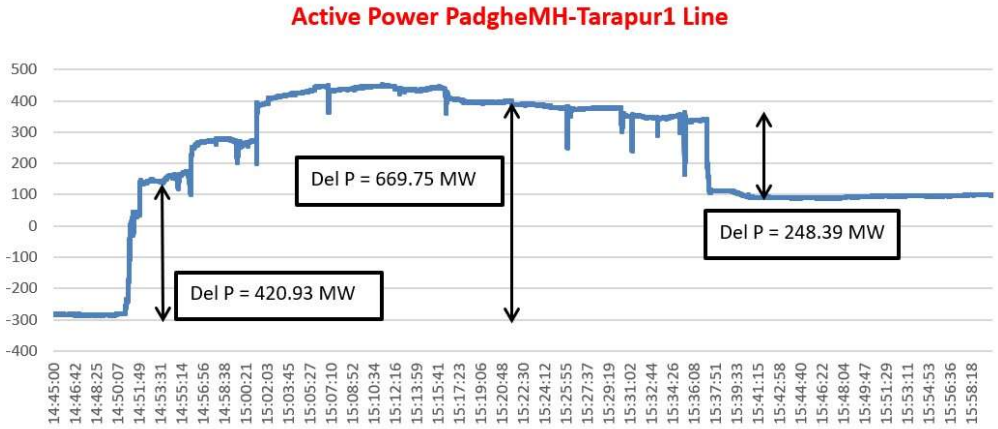
- Voltages at 400 kV Padghe S/s were already between the range of 400 to 390 kV.
- Voltage further reduced between 390-380 kV after 14:29 Hrs.

- During incidence, voltages further dipped to 338 kV at 14:56 Hrs from 385 kV at 14:49 Hrs.
- Thus, a drop of 35 kV was observed at 400 kV Padghe bus within a very short duration.

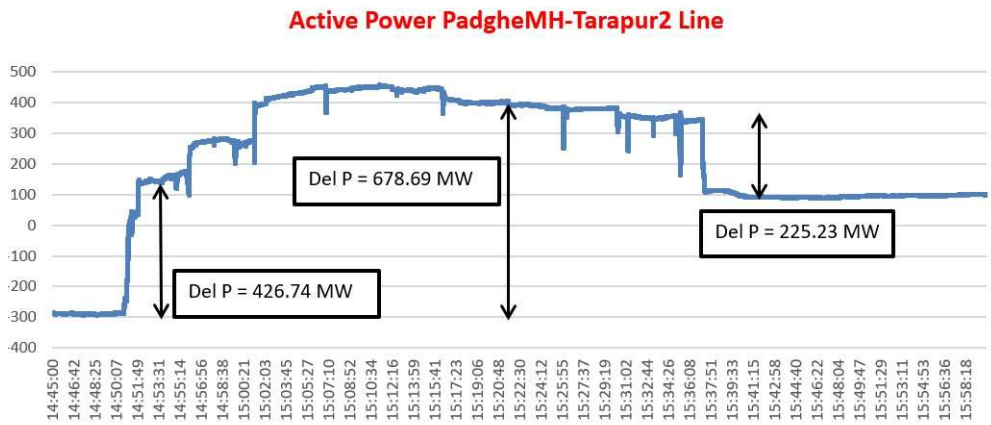
5.4.1.3 Sudden changes in Power flow on 400 kV lines connected to 400 kV Padghe



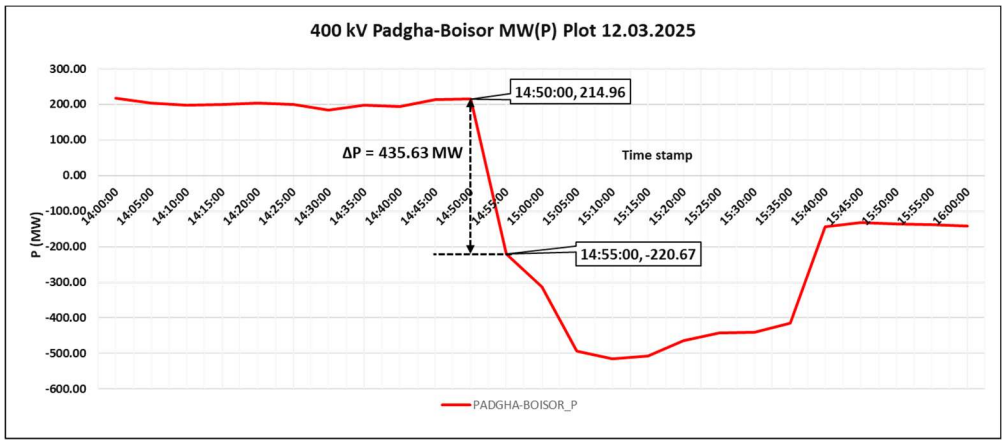
Active Power Flow on 400 kV Tarapur-Padghe-1 (SCADA)



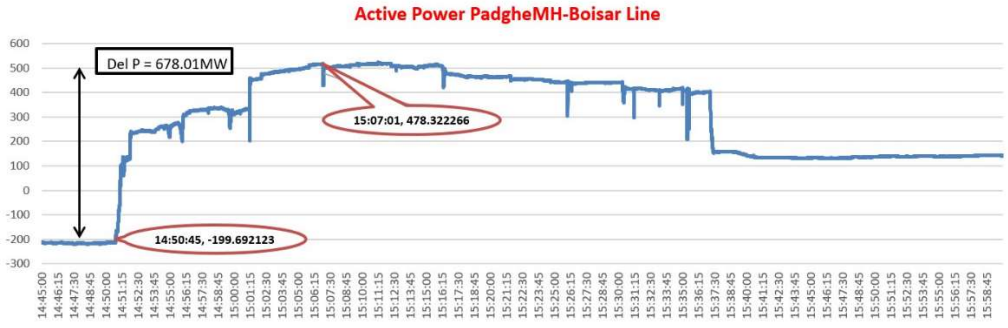
Active Power Flow on 400 kV Tarapur-Padghe-1 (PMU)



Active Power Flow on 400 kV Tarapur-Padghe-2 (PMU)



Active Power Flow on 400 kV Tarapur-Boisar (PG) (SCADA)



Active Power Flow on 400 kV Tarapur-Boisar (PG) (PMU)

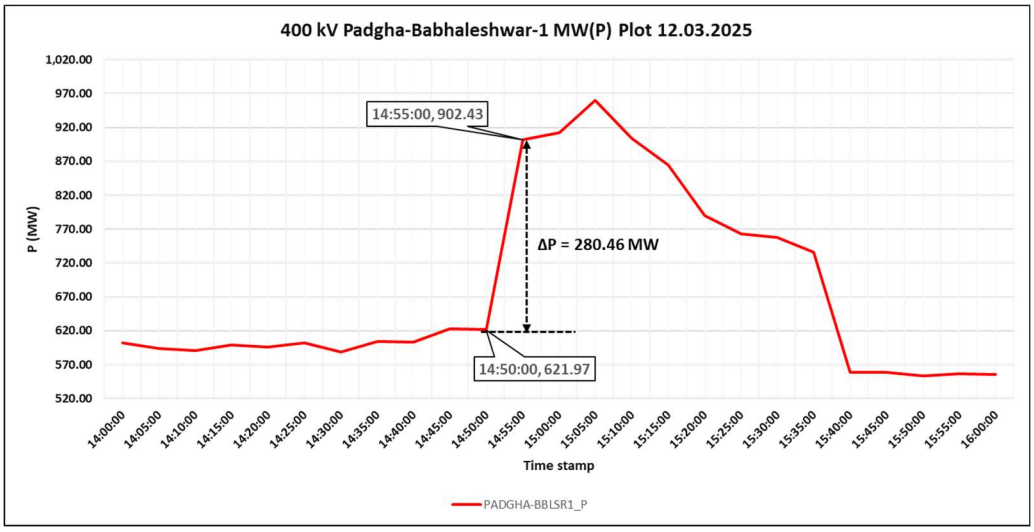
From the plots, it is observed that:

- Prior to the occurrence, there was import of power from Tarapur to Padghe S/s.
- After incidence, i.e. after 14:49 Hrs, the power flow reversed and power started flowing from Padghe to Tarapur.
- Thus, a change in Power flow to the tune of 400 MW was observed.
- Also, a voltage drop of 35 kV was observed.

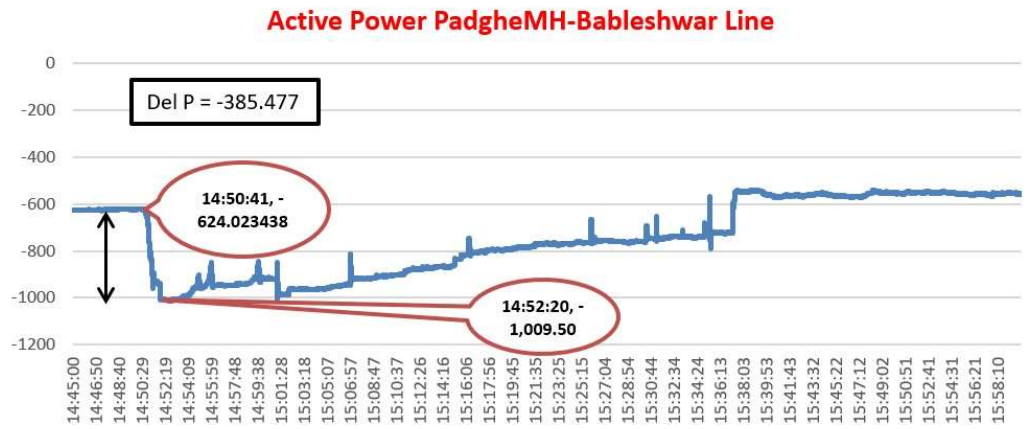
- A total power flow reversal of 724 MW was observed within a period of 15 minutes i.e. between 14: 49 Hrs to 15:10 Hrs on one circuit.
- There are two circuits of 400 kV Tarapur – Padghe line. Thus, total power flow reversal of 1450 MW was observed through both the circuits.
- Similarly, power reversal of 729 MW was observed on 400 kV Boisar (PG) – Padghe S/C line.
- Thus, total 2180 MW of power reversal was seen by the 400 kV Padghe bus.

Impact of Power export on other lines at 400 kV Padghe:

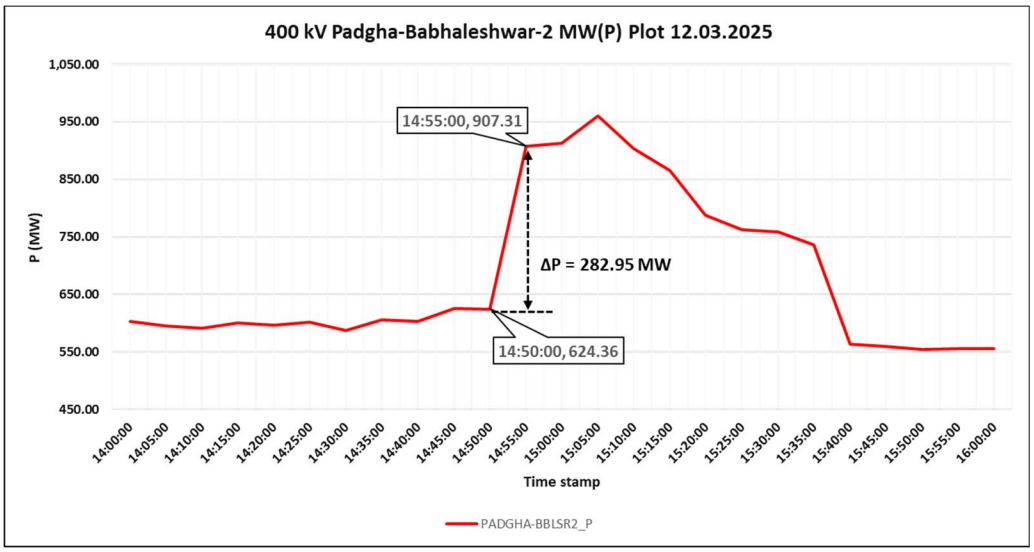
- The power reversal from Padghe to Tarapur & Boisar (PG) resulted in to increased power from on 400 kV Babhaleshwar – Padghe D/C lines.
- Further, there was export from Padghe to Nagothane through 400 kV Padghe – Nagothane D/C lines before the incidence.
- However, after the incidence, power flow on these lines reversed and import was observed from Nagothane to Padghe bus.
- Prior to the incidence, there was export of 1100 Mw of power from Padghe to Kalwa bus through 400 kV Padghe – Kalwa D/C lines.
- Export to Kalwa bus reduced to 788 MW with a reduction of 245 MW of power on these lines.
- Further, to limit the loading on 400 kV Babhaleshwar – Padghe D/C lines, MSLDC Grid Operator ramped up ± 500 kV Chandrapur-Padghe HVDC.
- The plots are shown below:



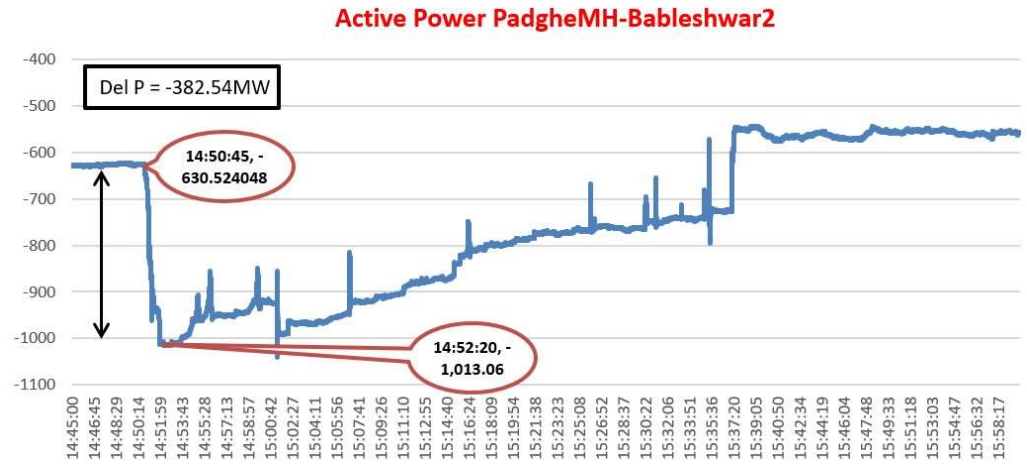
Active Power Flow on 400 kV Babhaleshwar-Padghe-1 (SCADA)



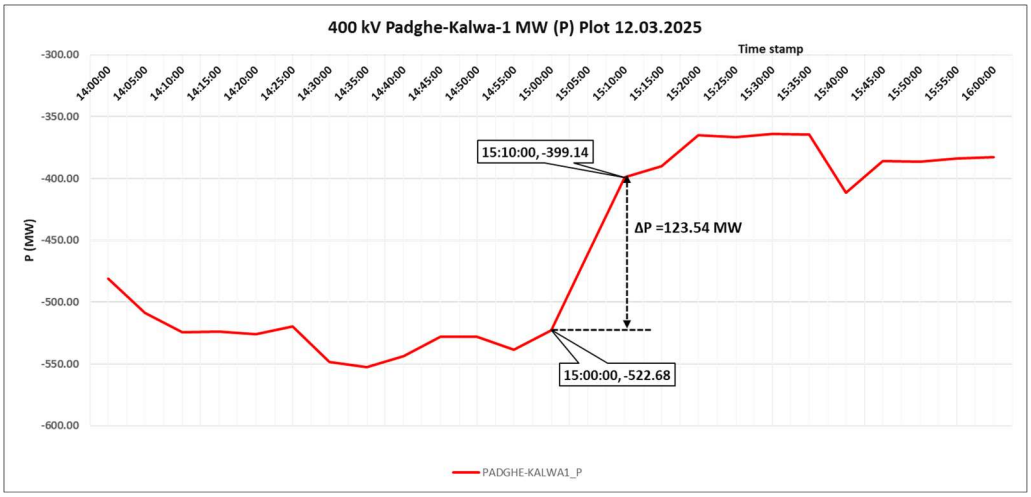
Active Power Flow on 400 kV Babhaleshwar-Padghe-1 (PMU)



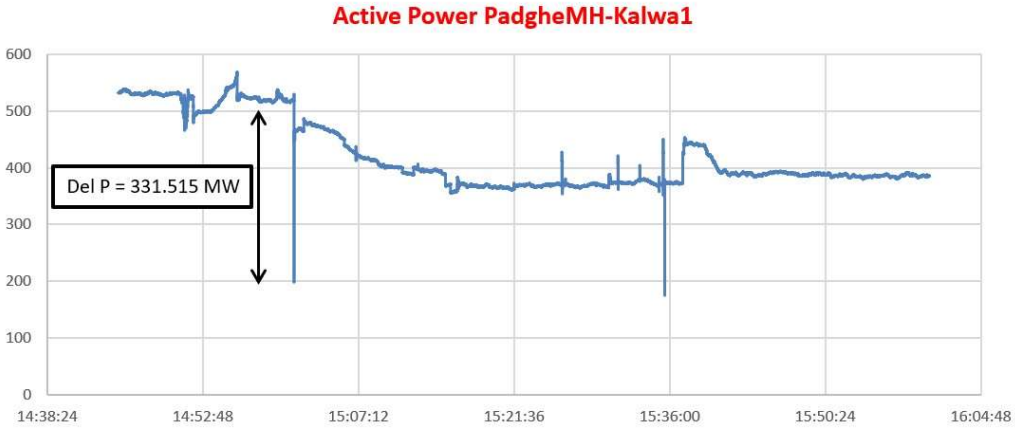
Active Power Flow on 400 kV Babhaleshwar-Padghe-2 (SCADA)



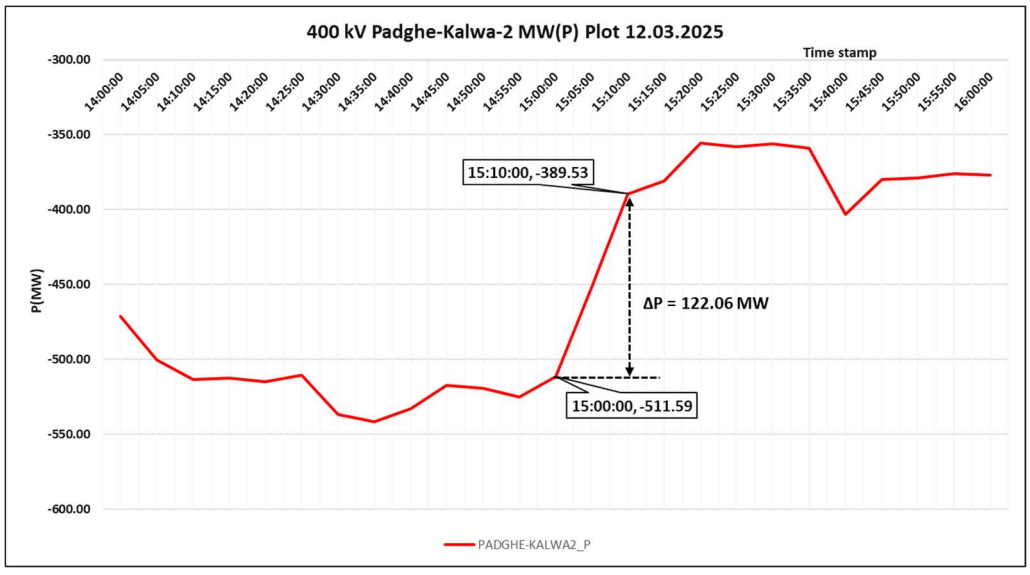
Active Power Flow on 400 kV Babhaleshwar-Padghe-2 (PMU)



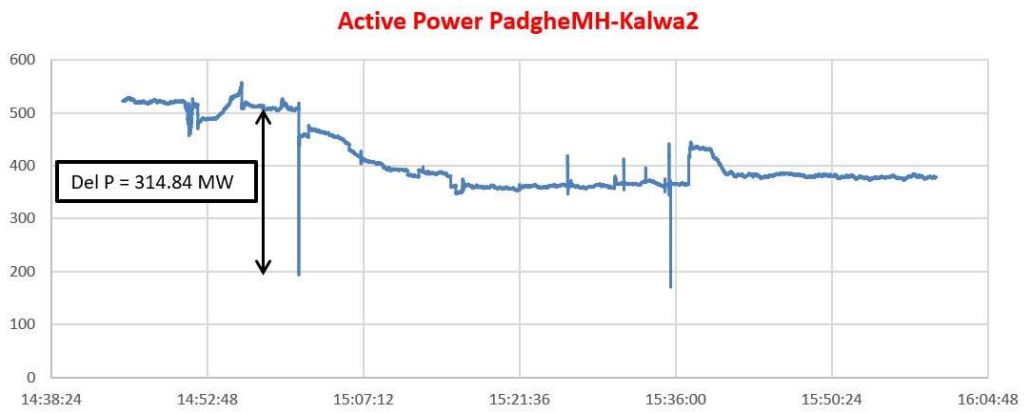
Active Power Flow on 400 kV Padghe-Kalwa-1 (SCADA)



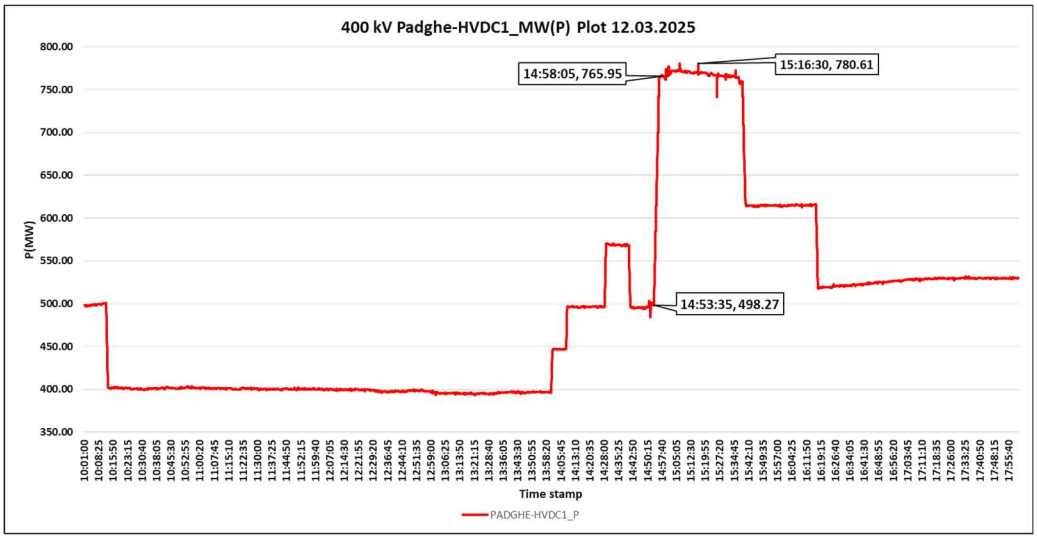
Active Power Flow on 400 kV Padghe-Kalwa-1 (PMU)



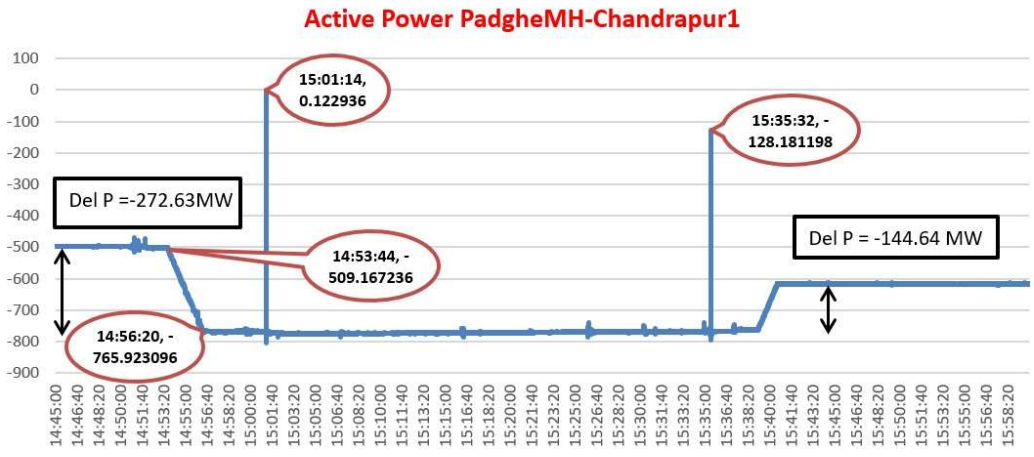
Active Power Flow on 400 kV Padghe-Kalwa-2 (SCADA)



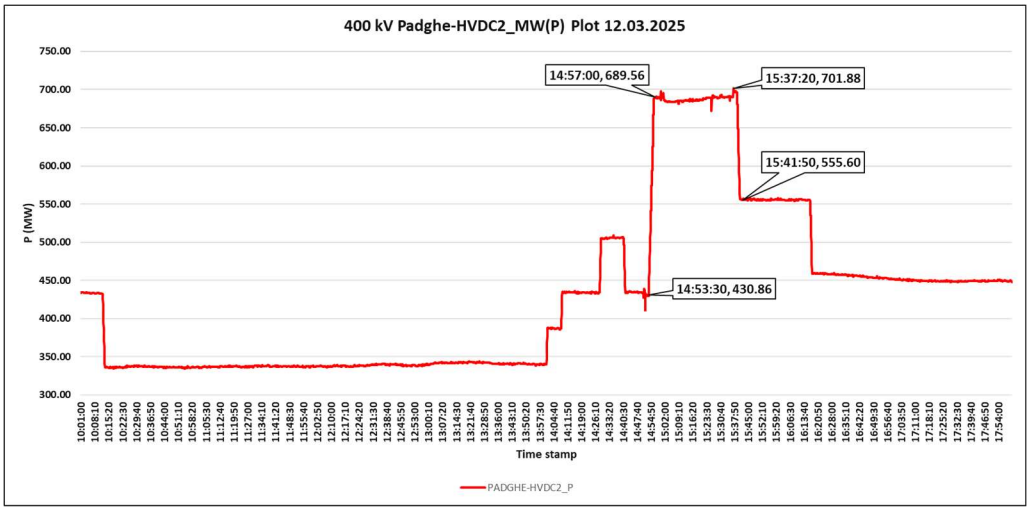
Active Power Flow on 400 kV Padghe-Kalwa-2 (PMU)



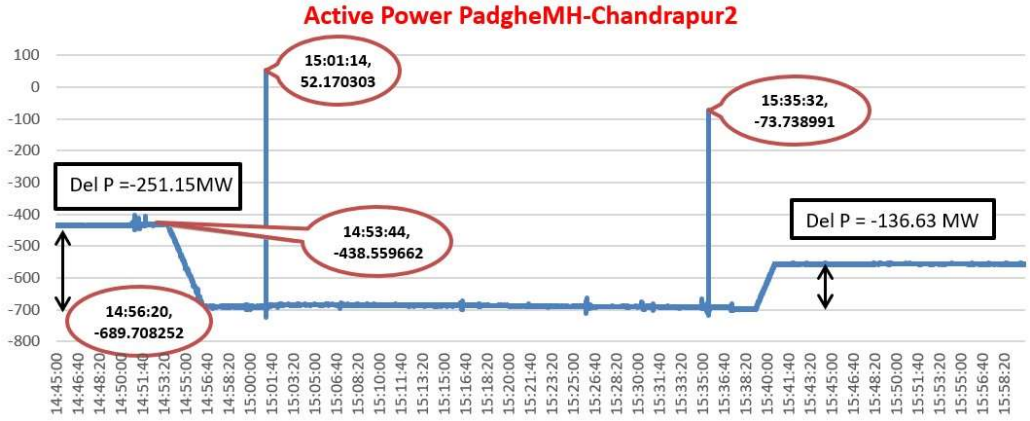
Active power flow on ± 500 kV Chandrapur-Padghe HVDC Pole-1 (SCADA)



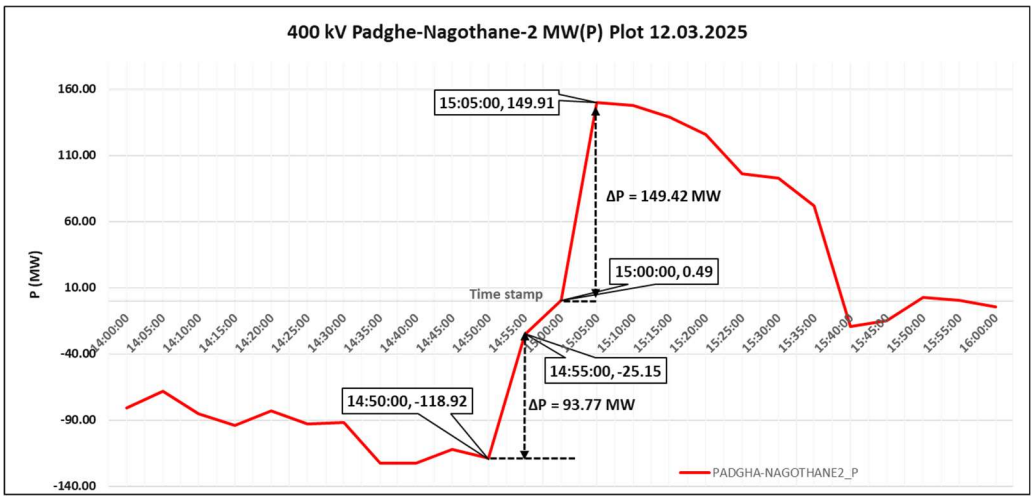
Active power flow on ± 500 kV Chandrapur-Padghe HVDC Pole-1 (PMU)



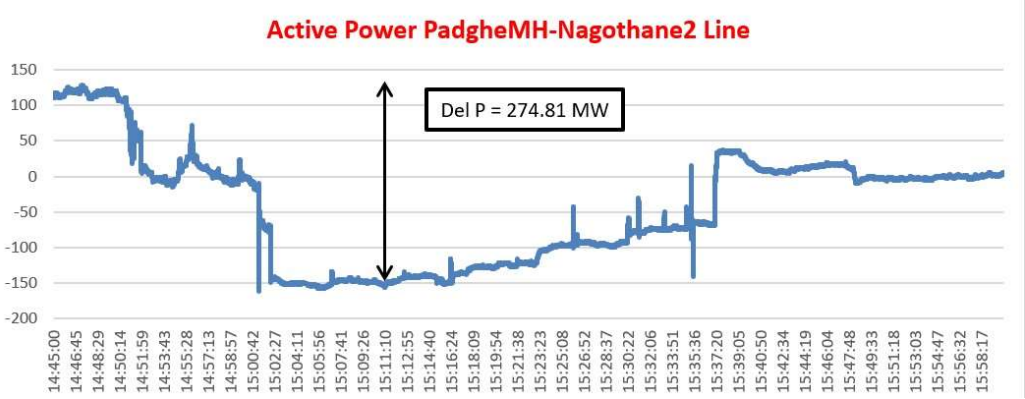
Active power flow on ± 500 kV Chandrapur-Padghe HVDC Pole-2 (SCADA)



Active power flow on ± 500 kV Chandrapur-Padghe HVDC Pole-2 (PMU)



Active Power flow on 400 kV Nagothane – Padghe-2 (SCADA)



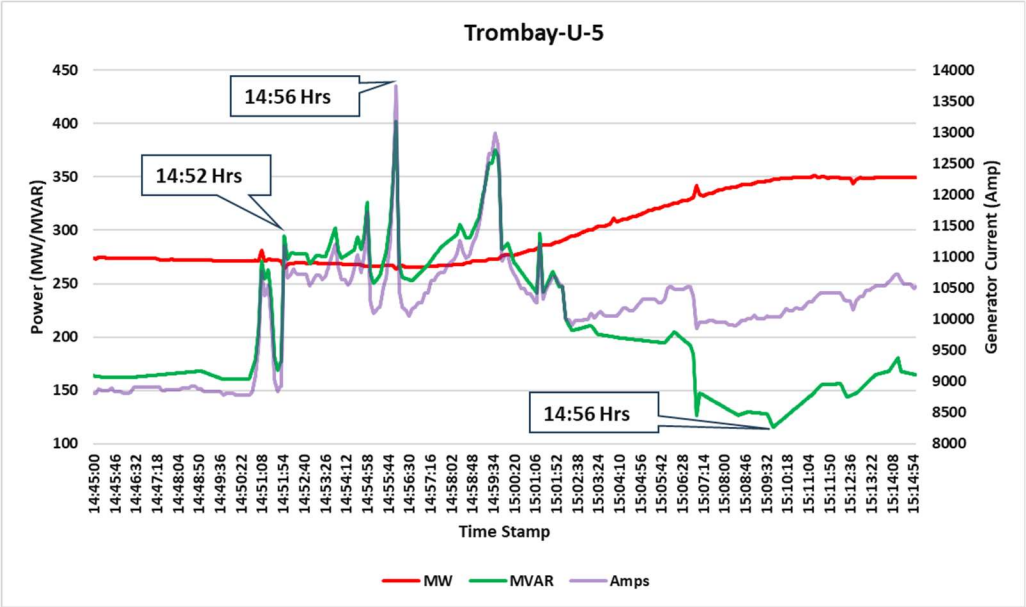
Active Power flow on 400 kV Nagothane – Padghe-2 (PMU)

From the above plots, it is observed that:

- The loading on 400 kV Babhaleshwar – Padghe D/C increased from 1246 MW to more than 2000 MW suddenly i.e. increase of around >754 MW was observed.
- The export on 400 kV Nagothane – Padghe – 2 line reduced from 119 MW to 25 MW from Padghe to Nagothane initially. After 14:55 Hrs, the power reversal was observed on this line and power was imported from Nagothane Bus. Thus, a total 243 MW was observed on this circuit. As there are two circuits, a total change in power flow to the tune of 500 MW was observed on 400 kV Nagothane – Padghe D/C lines.
- As the loading on 400 kV Babhaleshwar – Padghe D/C was increased drastically, MSLDC Grid Operator ramped up HVDC which was operating at 928 MW. HVDC was picked-up to its full capacity of 1500 MW by the Operator.

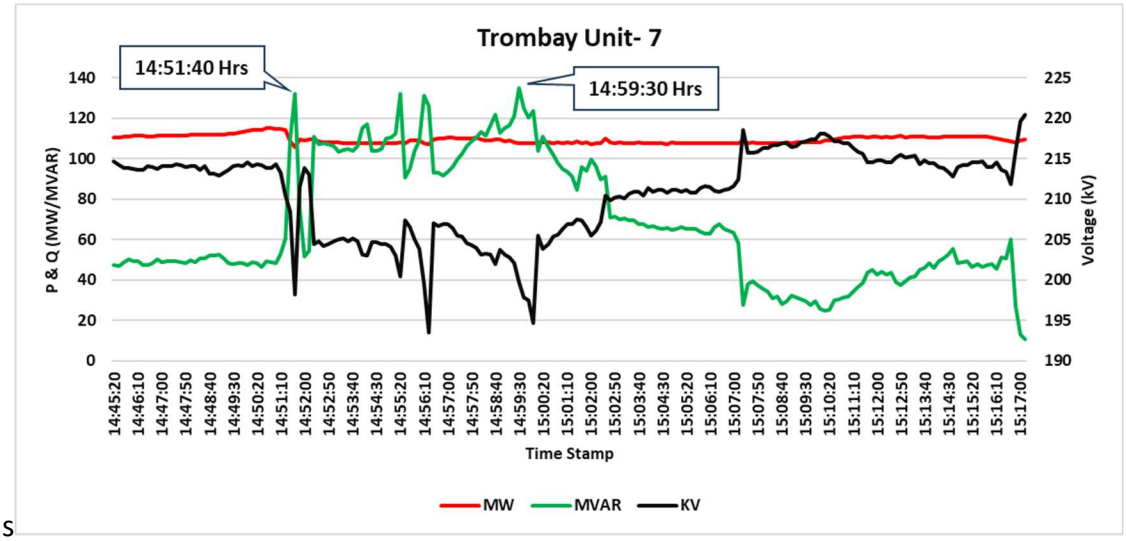
5.4.2 Behavior of Generators

5.4.2.1 Trombay Generating Units



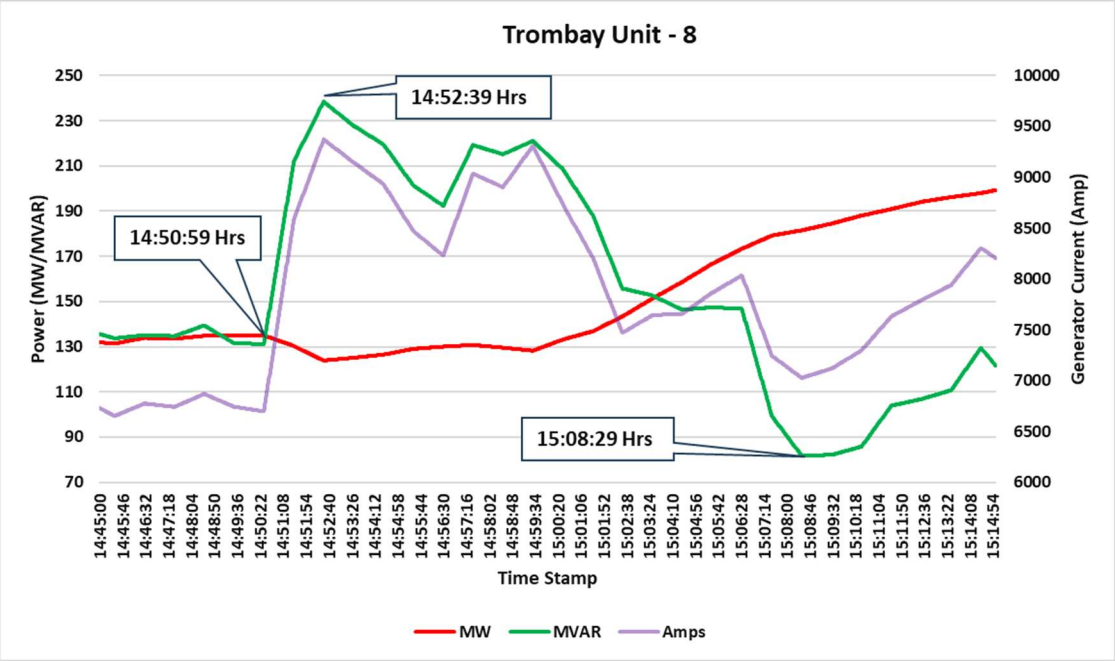
Trombay Unit-5 (500 MW): P, Q & Gen Current (Source: TPCL)

From the above, plot, it is observed that the Trombay Unit-5 supported the Grid by injecting Reactive Power. In Unit-5 Max Generator current recorded was 13755 amps for a very short duration reflected as a spike seen in the plot. The rated full load current is 10640 amps. In such case, there was possibility of loss of this unit if such overloading had continued.



is

Trombay Unit-7 (180 MW): P, Q & Bus Voltage (Source: TPCL)

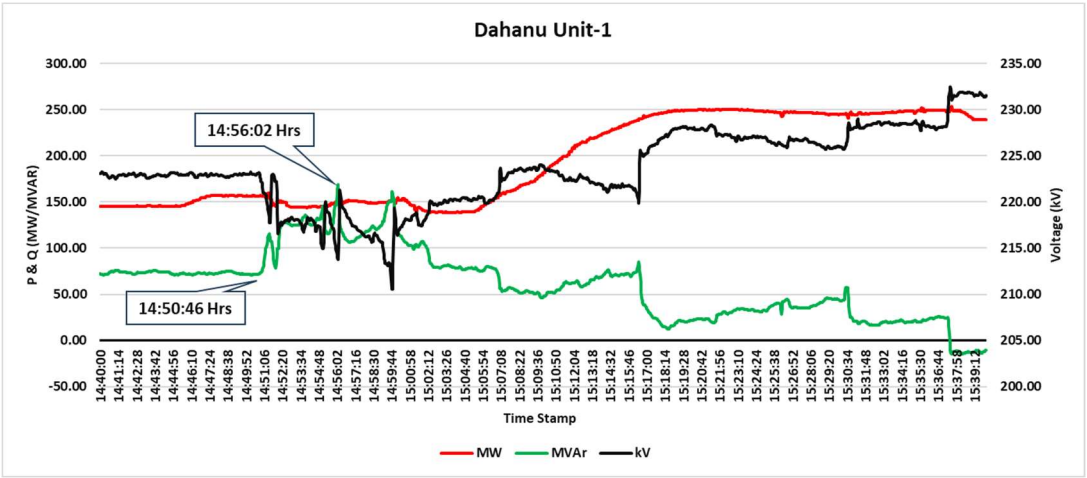


Trombay Unit-8 (250 MW): P, Q & Gen Current (Source: TPCL)

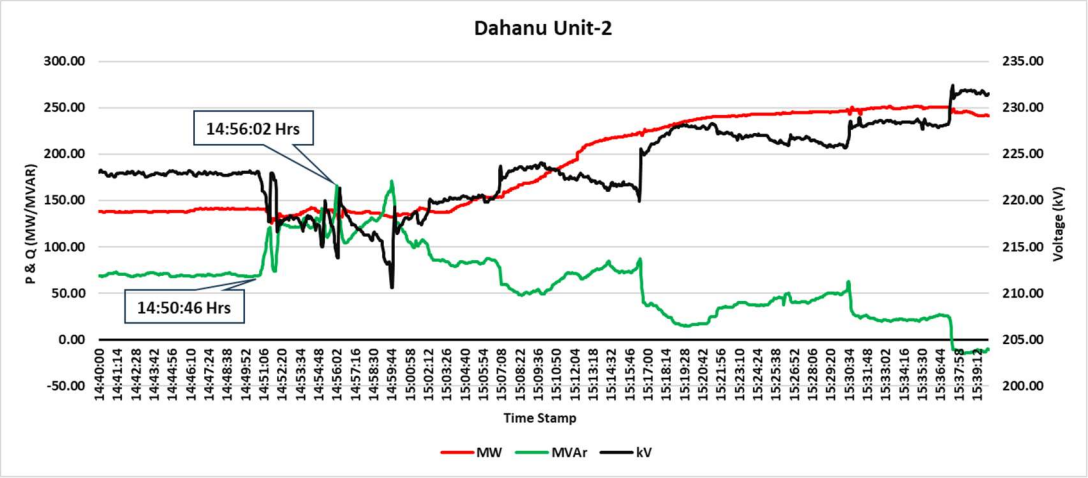
From the above plots, it was observed that the Trombay Units provided Active & Reactive Power Support to the Grid.

It was observed that due to very low Grid side voltages, there was a possibility of tripping of auxiliary systems.

5.4.2.2 Dahanu Generating Units:



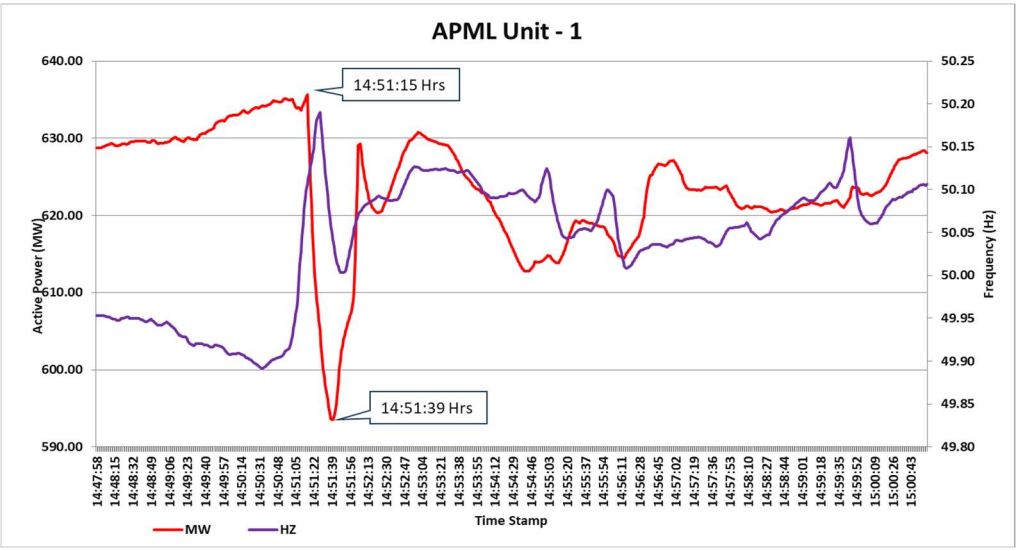
Dahanu Unit-1 (250 MW): P, Q & Bus Voltage (Source: AEML)



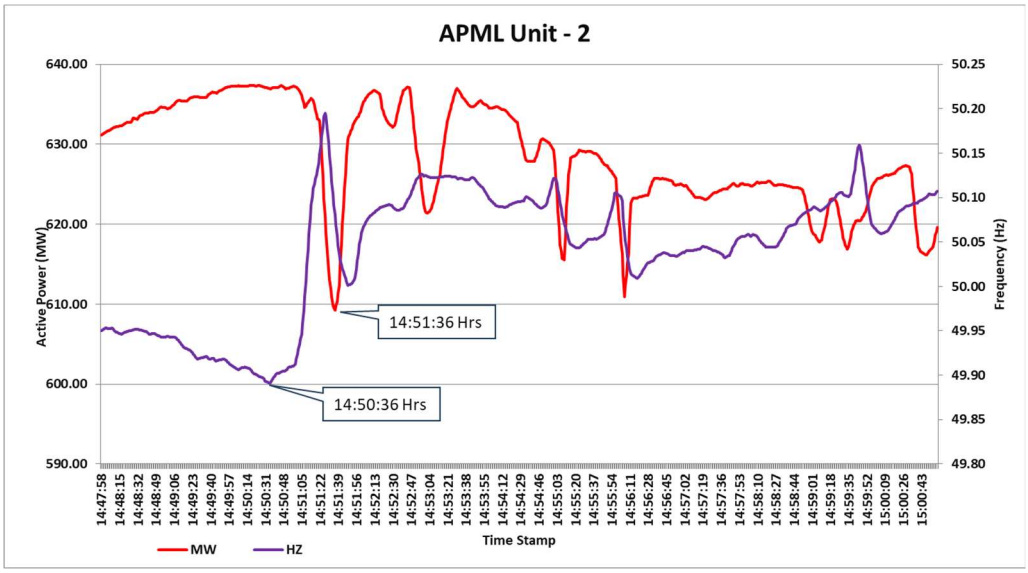
Dahanu Unit-2 (250 MW): P, Q & Bus Voltage (Source: AEML)

From the above plots, it is observed that AEML Dahanu units provided Active & Reactive Power support to the Grid.

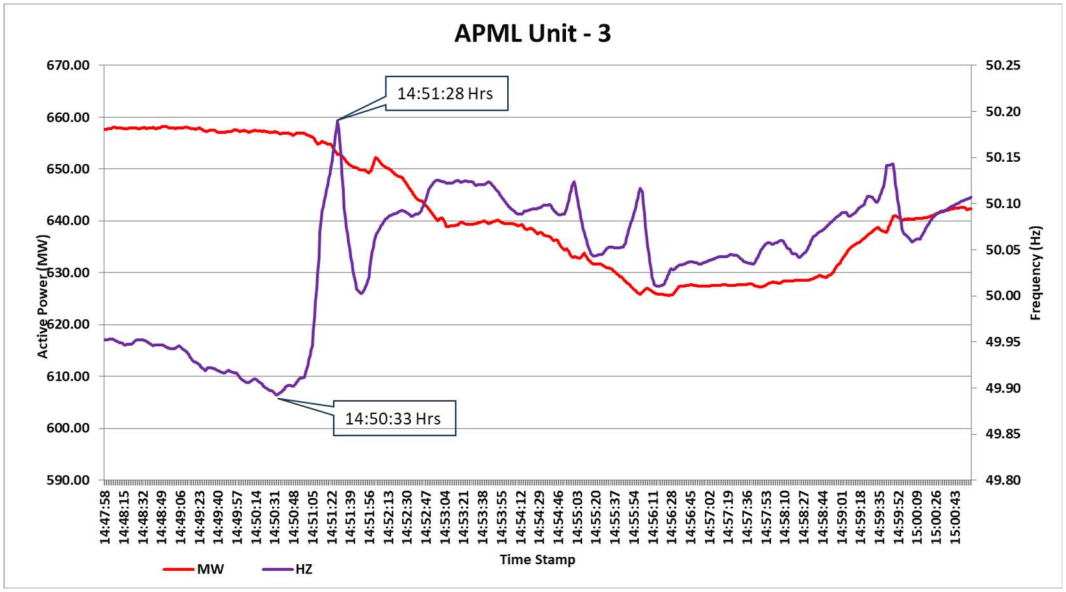
5.4.3. APML Units, Tiroda:



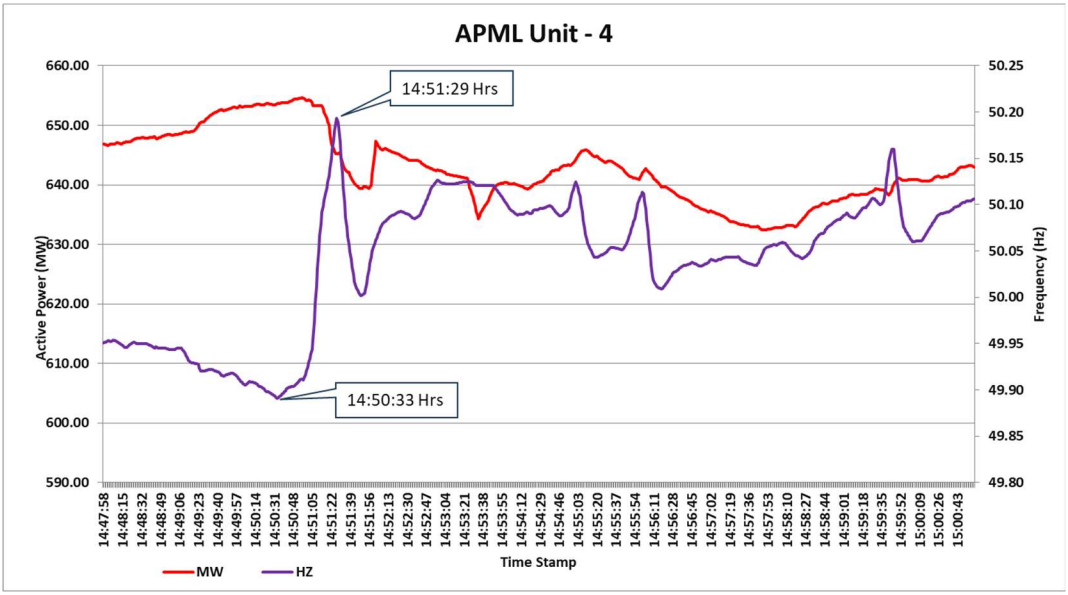
APML Unit-1 (660 MW): Active Power & Frequency (Source: APML)



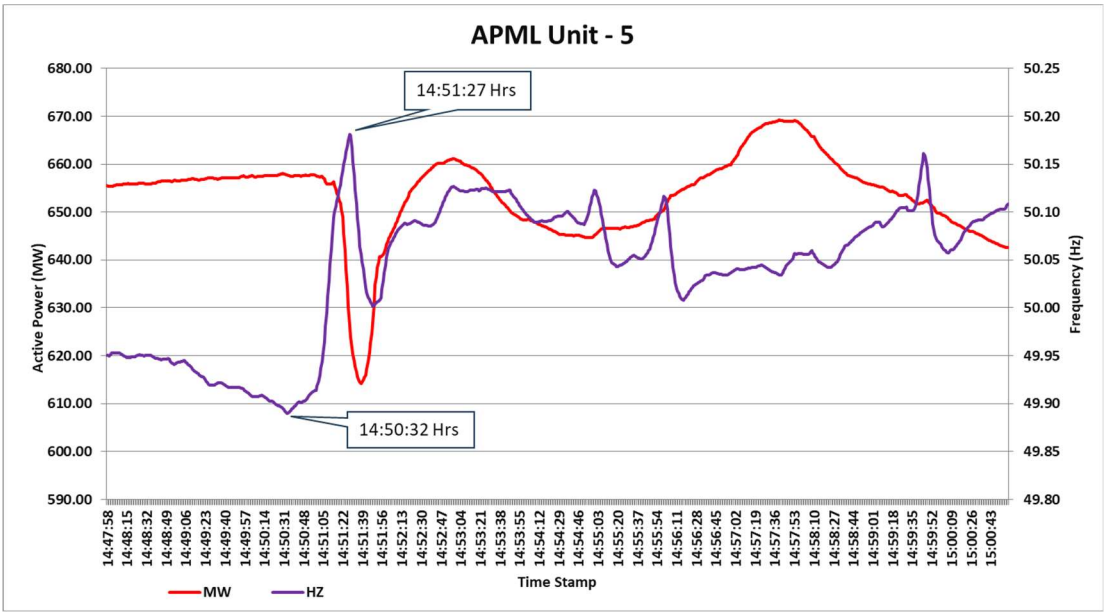
APML Unit-2 (660 MW): Active Power & Frequency (Source: APML)



APML Unit-3 (660 MW): Active Power & Frequency (Source: APML)



APML Unit-4 (660 MW): Active Power & Frequency (Source: APML)



APML Unit-5 (660 MW): Active Power & Frequency (Source: APML)

From the plots of APML Units, it is observed that the active power injection is varying according to the Grid Frequency. Further, the incidence was away from the Generating units, however, these units have responded to the changes in the System conditions.

5.5 Impact on Grid Stability

5.5.1 Possibility of load encroachment of Distance protection in Zone-3

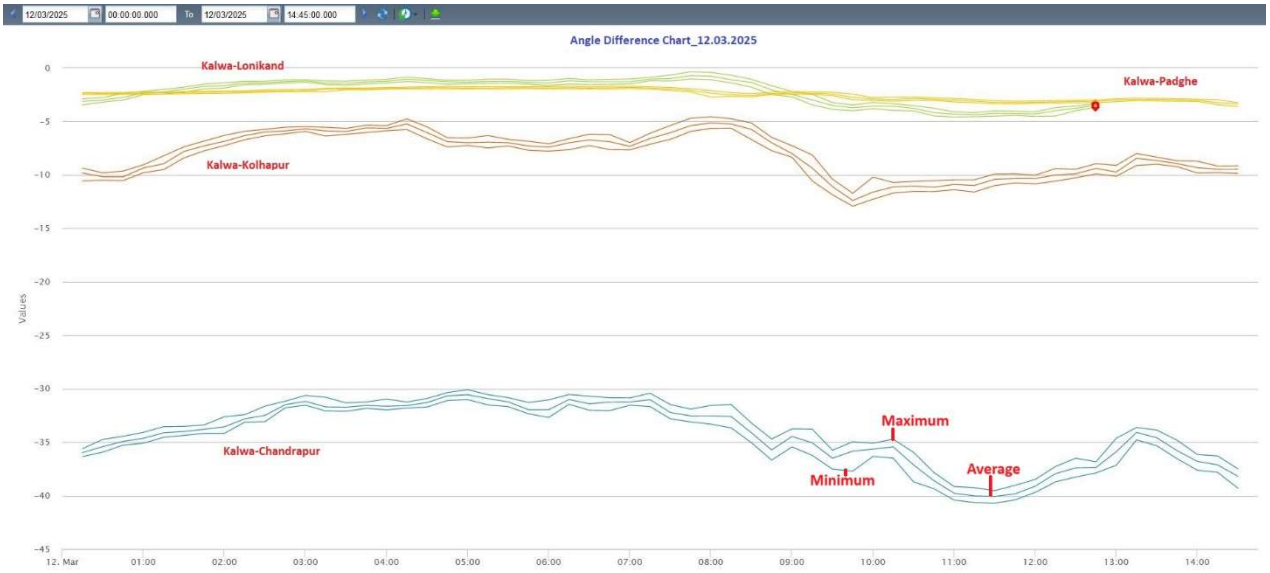
From the SoE recorded in SCADA System, it has been observed that for 400 kV Babhaleshwar – Padghe-2 line, Zone-3 signal had picked up indicating possibility of load encroachment, however it was cleared after one second. Also, PSD was initiated. In such case, there was possibility of tripping of this line which would have worsened the grid conditions.

Date	Time	Message Group	WinCC Message Text	Value
12-03-2025	14:55:34	PADGHE\400kV\BABHALESHWAR-2\MAIN-1	PSD START	RAISED
12-03-2025	14:55:34	PADGHE\400kV\BABHALESHWAR-2\MAIN-1	PSD START	CLEARED
12-03-2025	15:01:11	PADGHE\400kV\TARAPUR-2\MAIN-2	ZONE-3 START	RAISED
12-03-2025	15:01:12	PADGHE\400kV\TARAPUR-2\MAIN-2	ZONE-3 START	CLEARED
12-03-2025	15:40:37	PADGHE\400kV\BABHALESHWAR-2\MAIN-1	PSD START	RAISED
12-03-2025	15:40:37	PADGHE\400kV\BABHALESHWAR-2\MAIN-1	PSD START	CLEARED

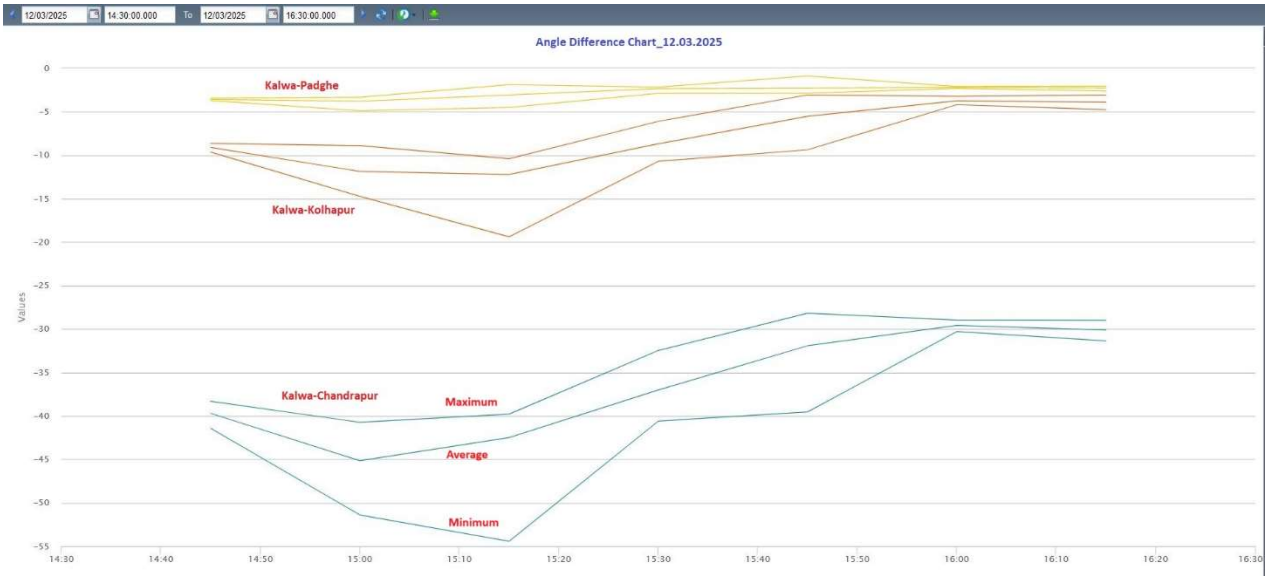
5.5.2 Analysis of Angular Difference from PMU data

Voltage angle monitoring using Phasor Measurement Unit (PMU) data is a critical tool for system operators to assess grid stability, detect stress conditions, and prevent large-scale disturbances**.** The angular separation between buses provides a real-time indication of power system stress—large angular differences can signal instability, while sudden deviations may indicate system stress or potential islanding events**.** By continuously tracking voltage angle trends**,** operators can identify early warning signs of oscillations, power flow reversals, and potential separation risks between different regions of the grid. PMU-based angle monitoring also aids in post-event analysis**,** helping to understand dynamic responses to disturbances, validate system models, and improve operational decisions. With high-speed data acquisition (milliseconds resolution), PMUs enable rapid corrective actions**,** such as adjusting power flows via HVDC modulation, FACTS devices, or generation re-dispatch**,** ensuring grid security under stressed conditions. In the event of voltage collapse in Maharashtra on 12.03.2025**,** angular difference monitoring helped reveal inter-area stability issues, assisting operators in deploying timely mitigation strategies.

Voltage Angles between 400 kV Kalwa-Lonikand-1, 400 kV Kalwa-Kolhapur & 400 kV Chandrapur-Kalwa buses is shown below:



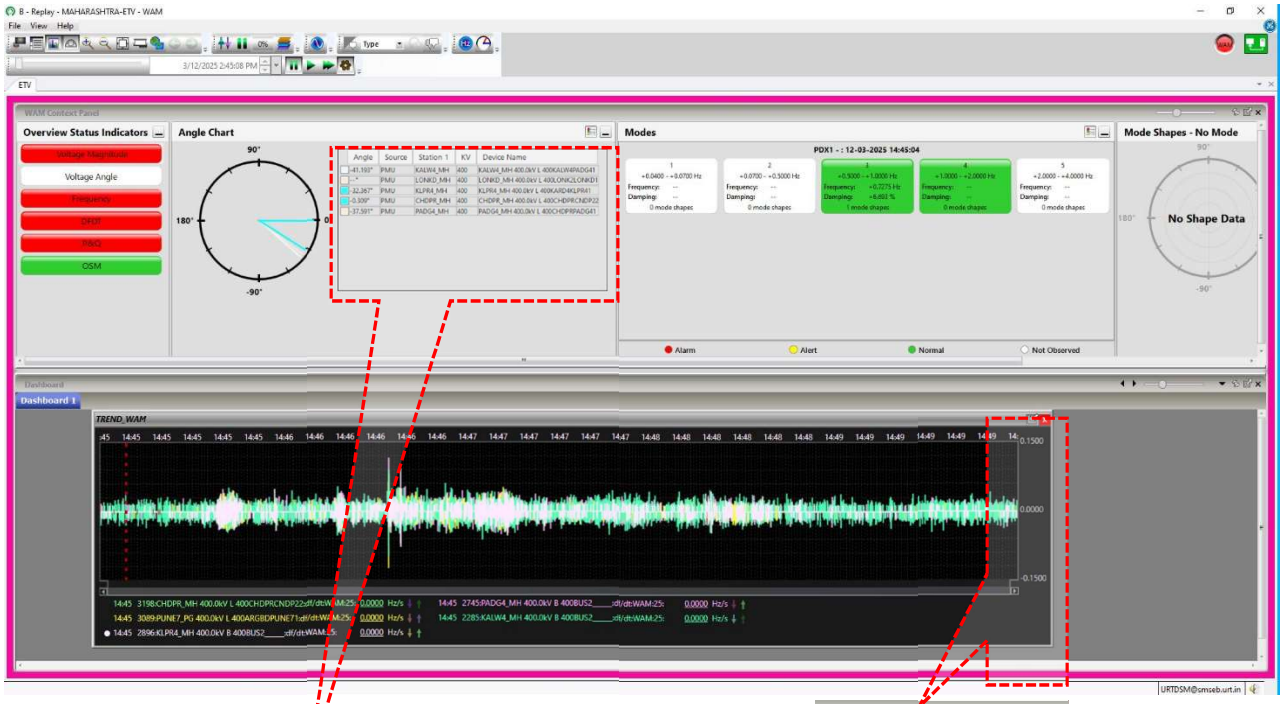
Angular Difference before incidence (PMU)



Angular Difference After incidence (PMU)

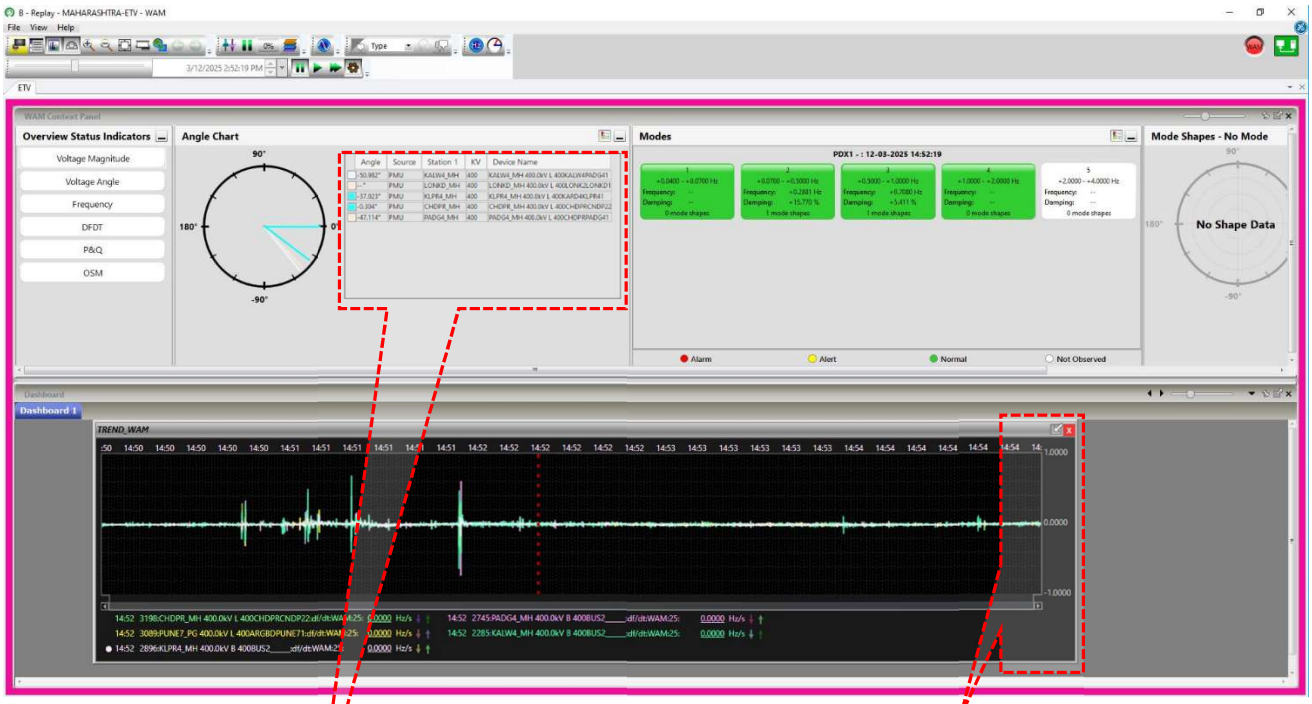
5.5.2.1 Snapshots of PMU Screen indicating Angular difference & df/dt:

At 14:45:08 Hrs: (Before incidence)

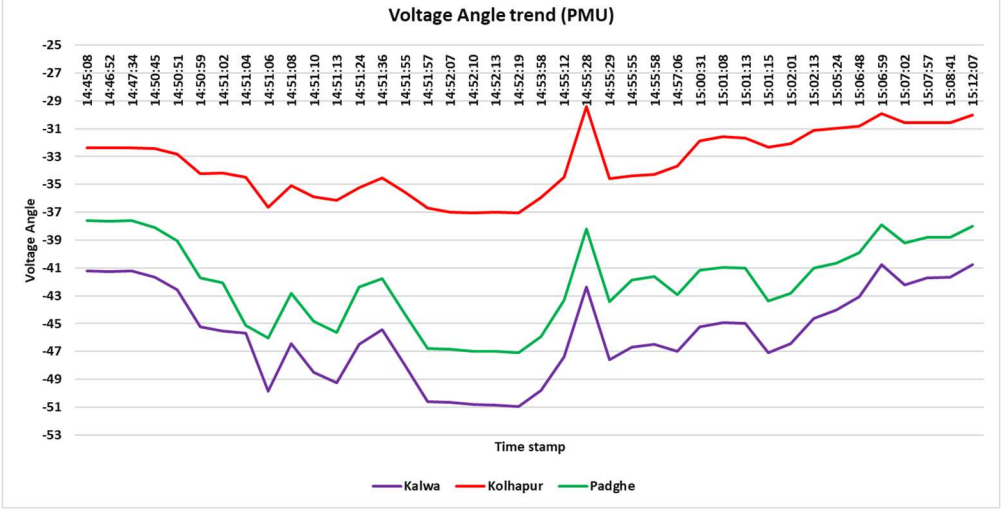


Angle	Source	Station 1	KV	Device Name
-41.193°	PMU	KALW4_MH	400	KALW4_MH 400.0kV L 400KALW4PADG41
--°	PMU	LONKD_MH	400	LONKD_MH 400.0kV L 400LONK2LONKD1
-32.367°	PMU	KLPR4_MH	400	KLPR4_MH 400.0kV L 400KARD4KLPR41
-0.309°	PMU	CHDPR_MH	400	CHDPR_MH 400.0kV L 400CHDPRCNDP22
-37.591°	PMU	PADG4_MH	400	PADG4_MH 400.0kV L 400CHDPRPADG41

At 14:52:19 Hrs: (After incidence)



Angle	Source	Station 1	KV	Device Name
-50.982°	PMU	KALW4_MH	400	KALW4_MH 400.0kV L 400KALW4PADG41
--°	PMU	LONKD_MH	400	LONKD_MH 400.0kV L 400LONK2LONKD1
-37.023°	PMU	KLPR4_MH	400	KLPR4_MH 400.0kV L 400KARD4KLPR41
-0.304°	PMU	CHDPR_MH	400	CHDPR_MH 400.0kV L 400CHDPRCNDP22
-47.114°	PMU	PADG4_MH	400	PADG4_MH 400.0kV L 400CHDPRPADG41



Voltage Angle Plot (PMU)

5.5.2.2 Observations on Voltage Angle Behavior

- **Before the Incident (14:45:08 hrs)**:
  - The voltage angle at Kalwa bus was within the normal operating range of -30° to -40°**.** The angular difference between Padgha and Kalwa bus is usually @ 3-4°
  - Angular differences across major corridors were within acceptable stability margins.

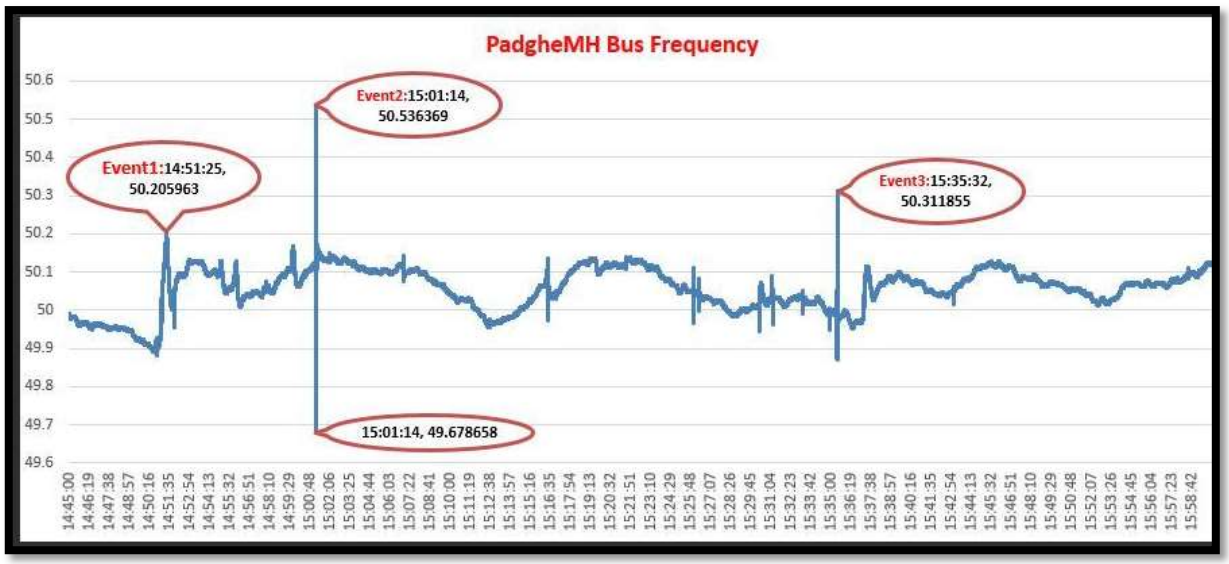
- **After the Incident (14:52:19 hrs)**:
  - The voltage angle at Kalwa bus spiked to -51°, indicating increased stress on the system.
  - A significant increase in angular difference of 9.78° was observed post-disturbance, highlighting a possible separation risk between Eastern and Western Maharashtra.
  - The rapid increase in angular separation suggests low generation availability in Western Maharashtra**,** leading to higher power imports from Eastern Maharashtra.

5.5.2.3 Interpretation of Angular Plots

- A sharp rise in angular difference indicates increased system stress and reduced synchronism across regions.
- Large angular separation (>50°) between buses can lead to system instability or islanding.
- The observed change of ~9.78° suggests the grid was approaching critical stability limits**,** requiring immediate corrective actions.

5.5.3 Frequency deviation

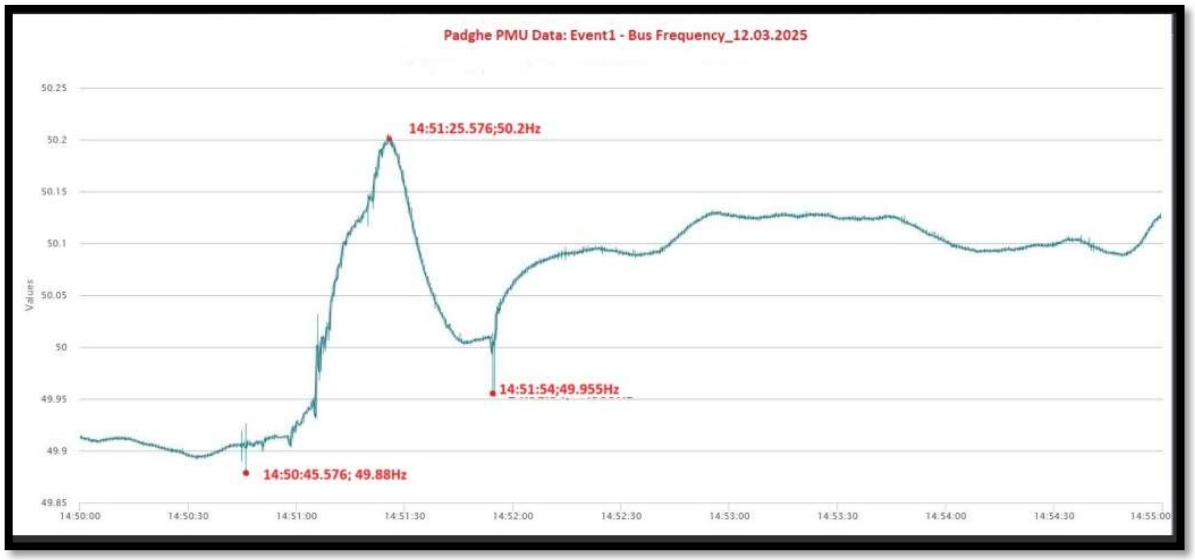
The maximum & minimum frequency recorded during the event was 50.53 Hz & 49.67 Hz respectively. Padghe Bus frequency deviation is shown in the following graph:



During the Event 1:

At 14:50:45:576 hrs, frequency was 49.88 Hz, suddenly, at 14:51:25:576 hrs it reaches to 50.2 Hz.

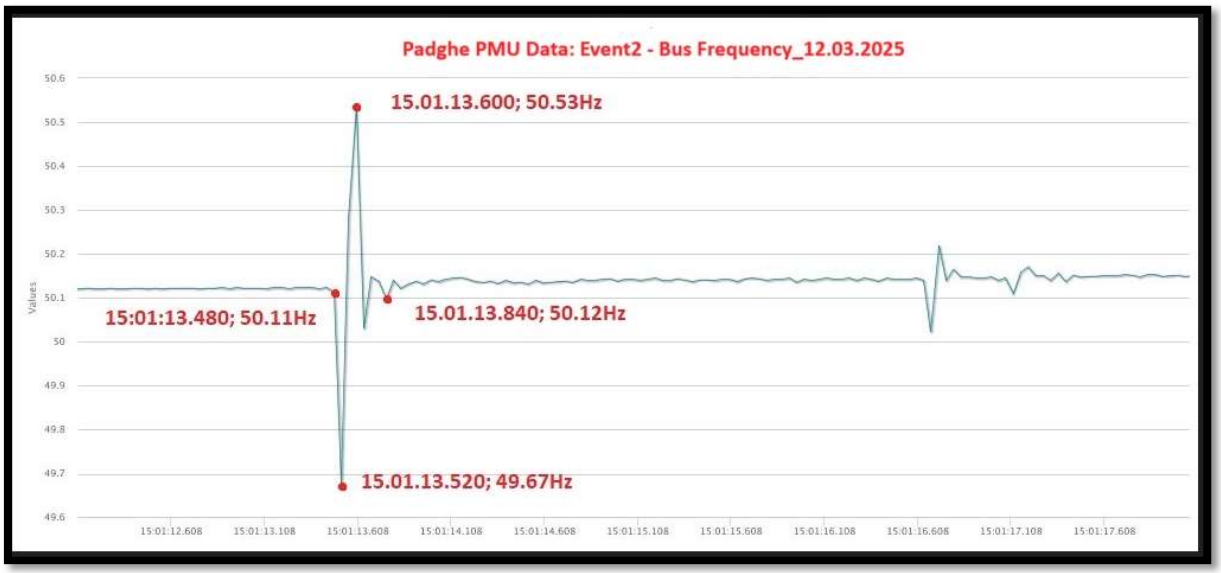
At 14:51:54 Hrs frequency dropped to 49.955 Hz.



During the Event 2:

At 15:01:13.480 hrs, frequency was 50.11 Hz, suddenly, at 15:01:13.520 hrs (within 40 ms) frequency dropped to 49.67 Hz.

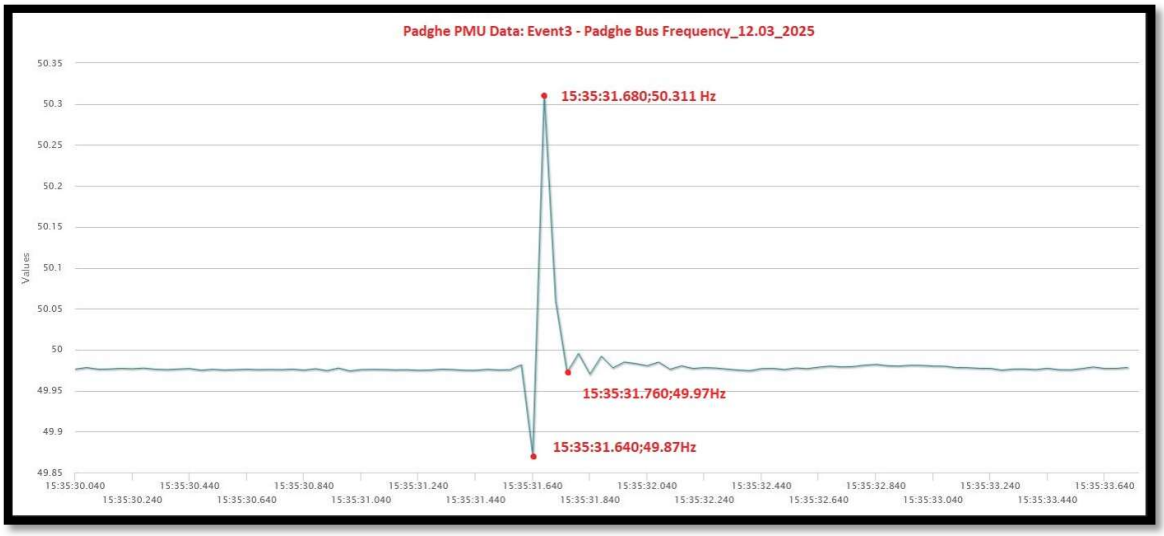
At 15:01:13.600 hrs frequency reached to 50.53 Hz, whereas at 15:01:13.840 hrs (after 240ms) frequency dropped to 50.12 Hz.



During the Event 3:

At 15:35:31.640 hrs, frequency was 49.87 Hz and within 40 msec, i.e. at 15:35:31.680 hrs, frequency reached to 50.311 Hz.

Again at 15:35:31.760 hrs (after 80ms), frequency dropped to 49.97 Hz.



During the grid disturbance, significant frequency deviations were recorded across the Maharashtra grid, particularly at the Padghe Bus**.** The maximum frequency reached 50.53 Hz**,** while the minimum dropped to 49.67 Hz, indicating severe system stress.

5.5.3.1 Key Frequency Deviations Observed:

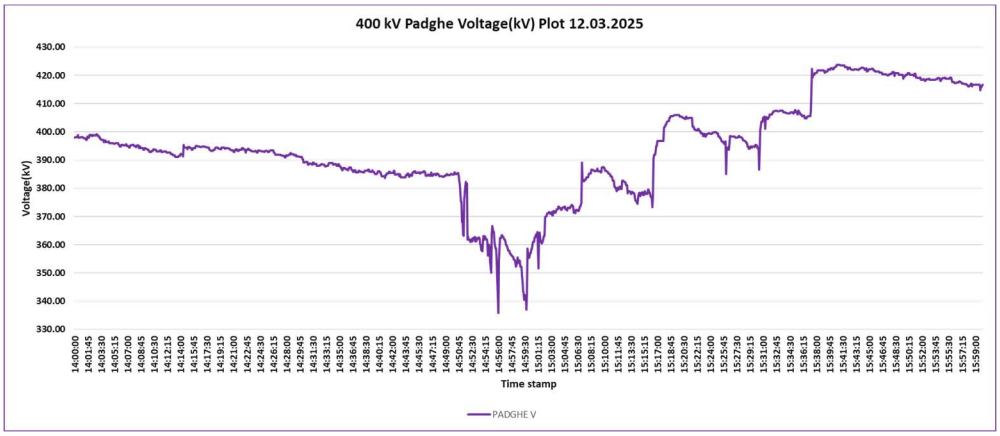
1. **Event 1 (14:50:45:576 - 14:51:54 hrs):**
    - Frequency initially recorded at **49.88 Hz**.
    - Within **40 seconds**, it surged to **50.2 Hz**.
    - Shortly after, it dropped again to **49.955 Hz**, reflecting system instability.
2. **Event 2 (15:01:13:480 hrs):**
    - At **15:01:13.480 hrs**, frequency was **50.11 Hz**.
    - Within **40 milliseconds**, it dropped to **49.67 Hz**.
    - At **15:01:13.600 hrs**, it peaked to **50.53 Hz**, before falling again to **50.12 Hz** in **240 ms**.
3. **Event 3 (15:35:31:640 hrs):**
    - At **15:35:31.640 hrs**, frequency was **49.87 Hz**.
    - In just **40 milliseconds**, it surged to **50.311 Hz**.
    - At **15:35:31.760 hrs (after 80 ms)**, it dropped again to **49.97 Hz**.

5.5.3.2. Analysis & Impact:

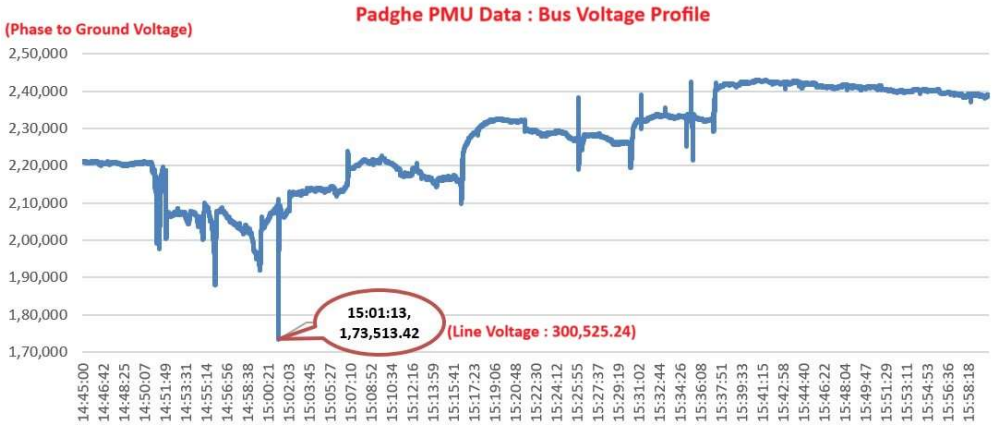
- These rapid frequency swings indicate generator tripping, sudden load variations, and reactive power deficiencies**.**
- The high rate of change of frequency (df/dt) suggests a dynamic instability in response to grid fluctuations.
- The df/dt did not trigger even after such variations as the frequency did not reach the pick value of 49.2 Hz.

5.5.4. Voltage Collapse

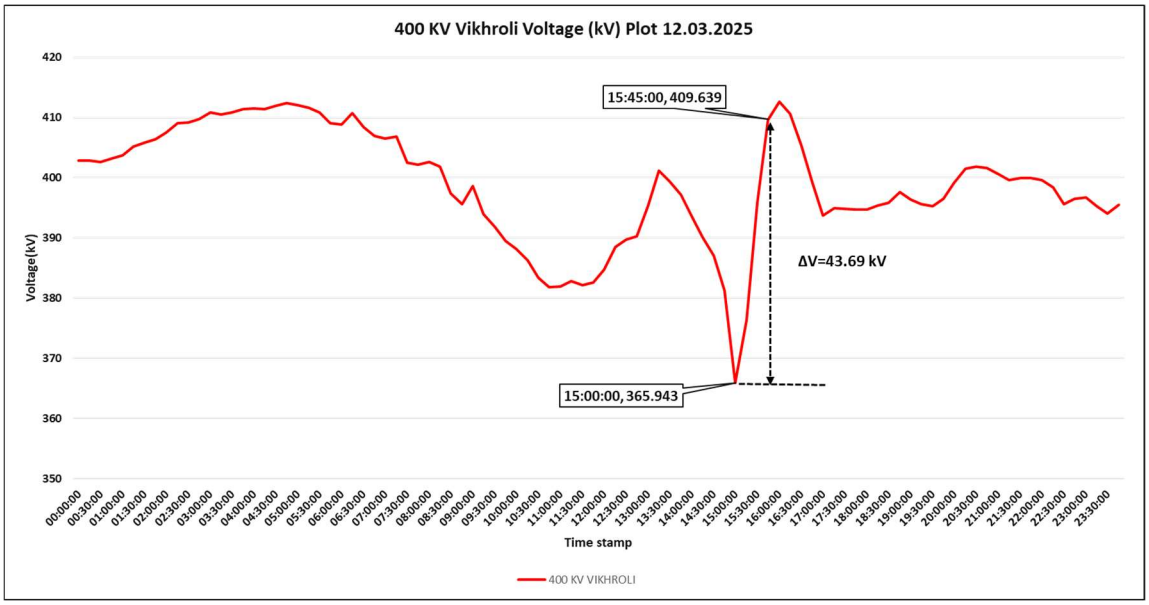
There was severe impact on 400 kV Voltages at multiple locations in the State especially in MMR & Pune area. Due to these low voltages load shedding under UVLS scheme took place. Further, to avoid further voltage collapse, manual load shedding was carried out in Mumbai, MMR & Pune area. The Voltage plots at various Sub-stations is shown below:



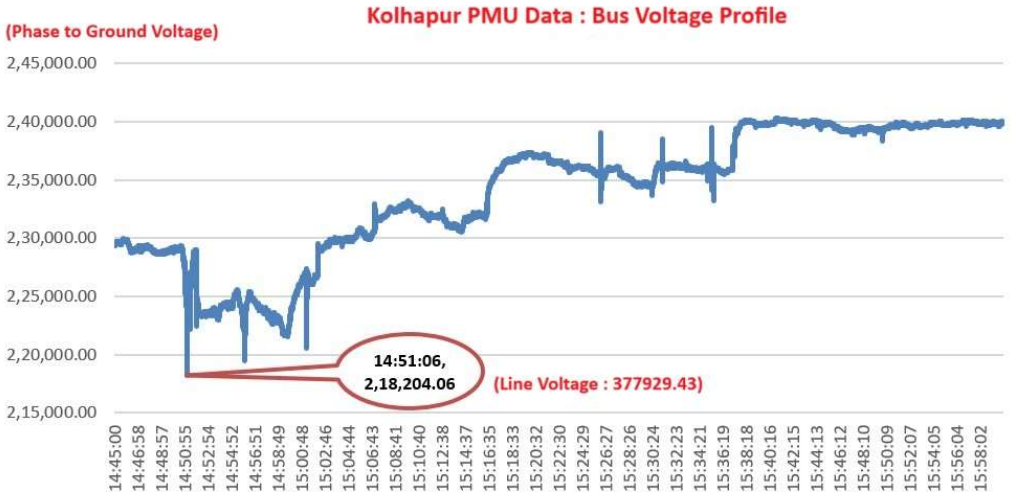
Voltage at 400 kV Padghe S/s. (SCADA)



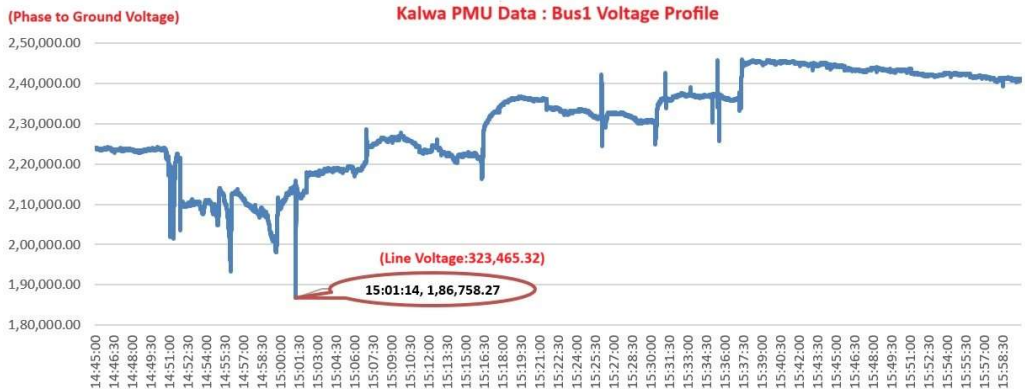
Voltage at 400 kV Padghe S/s. (PMU)



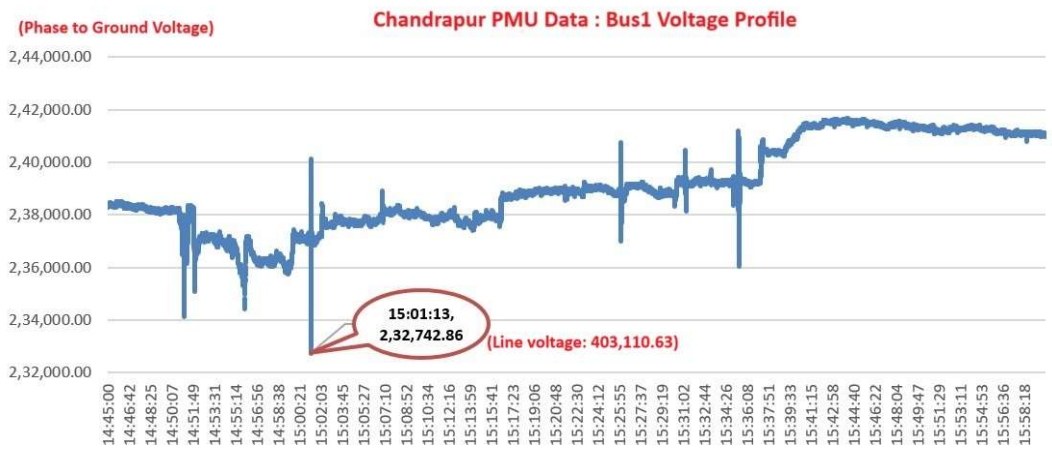
Voltage at 400 kV Vikhroli S/s. (SCADA)



Voltage at 400 kV Kolhapur S/s. (PMU)



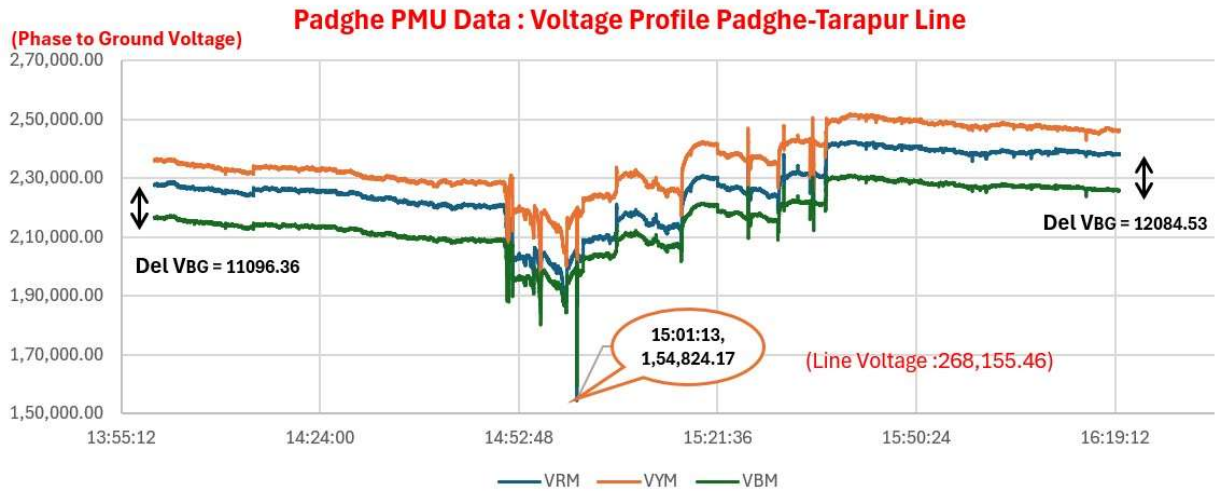
Voltage at 400 kV Kalwa S/s. (PMU)



Voltage at 400 kV Chandrapur S/s. (PMU)

5.5.5 Difference in Phase Voltages at Padghe

The Phase to Ground Voltage plot at 400 kV Padghe bus is shown below:



Phase to Ground Voltage plot at 400 kV Padghe (PMU)

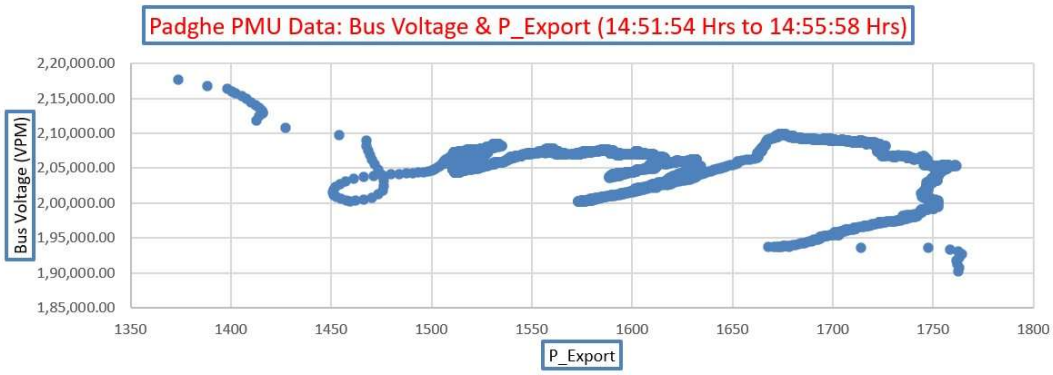
This data is recorded by PMU installed on 400 kV Tarapur – Padghe line at Padghe end. It is observed that there is significant difference of around 11 kV in the voltage of all the phases. Hence, checking of the instrument transformers (CVTs) and CVT circuits for identification cause of such errors is essential.

5.5.6 Analyzing P-V and Q-V Curves & Understanding Voltage Stability Margin (VSM)

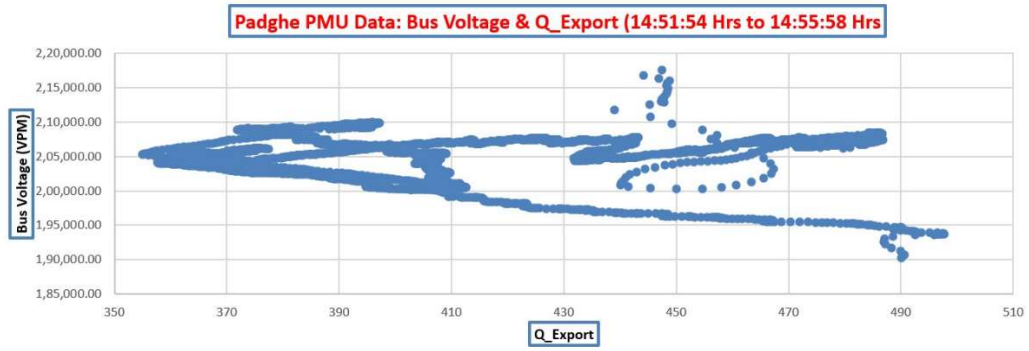
Analyzing P-V (Active Power vs. Voltage) and Q-V (Reactive Power vs. Voltage) curves is essential in power system studies to assess voltage stability and the system's ability to handle increasing loads**.** The P-V curve helps determine the maximum active power that can be transferred before voltage collapse, while the Q-V curve evaluates the reactive power support needed to maintain stable voltages. These curves help system operators identify weak points, set preventive control measures, and optimize reactive power compensation strategies.

The Voltage Stability Margin (VSM) is a critical metric derived from these curves that quantifies how close the system is to instability. In the P-V curve, VSM is the difference between the current operating power and the maximum power the system can sustain before voltage collapse. In the Q-V curve, VSM represents the available reactive power margin before voltage instability occurs. A low or negative VSM indicates a system at risk of voltage collapse, requiring reactive power support, load shedding, or transmission reinforcement to ensure stability.

Considering this, P-V and Q-V curves for a particular time frame of the incidence are plotted. The plots are shown below:



Export Active Power v/s Voltage plot at Padghe on all 400 kV lines (PMU)



Export Reactive Power v/s Voltage plot at Padghe on all 400 kV lines (PMU)

The observations from these plots are tabulated below.

P-Import	**Voltage**	**Delta P**	**Delta V**
2815.095	217618.11		
2857.614	200296.06	42.519	-17322.05
2994.42	200186.02	136.806	-110.04
3070.10	193740.78	75.68	-6445.24
		255.005	**-23877.33**

The VSM of 255 MW indicates the short margin for transfer of power was available with maintaining stability.

Q-Import	Voltage	Delta Q	Delta V
559.267	217618.11		
571.859	200296.06	12.592	-17322.05
524.842	200186.02	-47.017	-110.04
617.88	193740.78	93.038	-6445.24
		58.613	**-23877.33**

6.0 Impact Assessment

6.1 Affected Load & Generation

- During the event, to improve the system voltages, all thermal generation picked up to its full capacity.
- Koyna & Tata hydro picked up to its full capacity
- Instructions given to all generators for MVAR generation for voltage improvement.

6.2 Affected Areas

For bringing Maharashtra Power system to normal state of operation curtailment also carried out along with the LTS / UVLS operation.

Details of load loss due to LTS / UVLS operation and manual DLS is listed as below:

Sr.No.	Name of Substation	Load curtailment due to	District	Load affected (In MW)
1.	400kV Padghe	LTS & UVLS operation	Thane	547.89
2.	400kV Padghe / 400kV Kalwa/ 220kV Boisar	DLS implementation	Thane/Raigad/Navi Mumbai	1061.34
3.	400kV Nagothane	Emergency Handtripping of 220kV Nagothane – Wadkhal ckt 1 & 2 due to low voltage	Raigad	500
4.	400kV Babhaleshwar	UVLS Operation	Partly Ahmednagar District	436
5.	220kV Nashik GCR	LTS Operation	Nashik	213.06
6.	Other 220kV / 132 kV substation under Babhaleshwar	Load before tripping	Nashik	576.18
7.	400kV Jejuri	UVLS operation	Pune	74.64
8.	400kV Lonikand	UVLS operation	Pune	242
9.	TPCL	DLS implementation	Kalyan	176
10.	AEML	DLS implementation	Bhyander,Borivali, Mira road,Malad, Dahisar,Malvani, Charkop, Meghwadi & Juhu area	95
Total Load shedding quantum				**3922.11**

6.3 Energy Not Served (ENS)

Total 7.56 MUs were not served during the disturbance period from 14:55 Hrs to 17:45 Hrs.

7.0 Restoration Process

7.1 Time taken for Restoration

Load shedding was implemented at 14:55 hrs during under voltage condition and restoration process completed by 17:58 hrs.

Restoration details of load loss and curtailment carried for bringing Maharashtra power system to normal state of operation.

The details of load restoration at Kalwa circle depicted as follows:

Sr. No.	Name of Substation	Load relief (MW)	Restoration Time (Hrs)
1	220kV Boisar	14.65	16:43
2	220kV Nalasopara	24	16:48
3	220kV Vasai	18	16:13
4	220kV Viraj	14.90	16:42
5	100kV Vasai	45.40	15:32
6	220kV Bhaveghar	8.02	16:45
7	132kV Palghar	39.97	16:25
8	132kV Dahanu	50.75	16:40
9	132kV MIDC	33.70	16:18
10	220kV Wada	112.98	17:27
11	220kV Bapgaon	23	16:00
12	100kV Mumbra	24	16:10
13	220kV Kamba	50.2	16:40
14	220kV Mahape	15.8	16:06
15	220kV Temghar	77.3	16:38
16	100kV Bhiwandi	112	16:35
17	220kV Mulund	67.3	16:44
18	220kV Bhandup division	388.7	16:26
19	220kV Colorchem	46.67	16:25
20	220kV AKP	30	16:28
Total		**1197**	

The details of load restoration at Panvel circle depicted as follows:

Sr.No.	Name of Substation	Load relief (MW)	Restoration Time (Hrs)
1	400kV Kharghar	62	16:14
2	400kV Nagothane	510	16:04
3	EHV O&M DN., Panvel	9.36	15:08
4	EHV O&M DN., Dombivali	38	17:10
Total		**619.36**	

The details of load restoration at Padghe circle depicted as follows:

Sr. No.	Name of Substation	Load relief (In MW)	Restoration Time (Hrs)
1	100kV Ambernath	62.87	16:45
2	100kV Shahapur	38	16:50
3	100kV Bhiwandi	112	16:33
4	100kV Padghe	48	16:40
5	100kV Mohane	32	16:22
Total		**292.87**	

The details of load restoration at Pune Zone depicted as follows:

Sr. No.	Name of Substation	Load relief (In MW)	Restoration Time (Hrs)
1	400kV Lonikand	242	16:47
2	400kV Jejuri	74.64	17:58
Total		**316.64**	

The details of load restoration at Nashik Zone depicted as follows:

Sr. No.	Name of Substation	Load relief (In MW)	Restoration Time (Hrs)
1	400kV Babhaleshwar	436	16:15
2	EHV O&M Div Babhaleashwar	576.18	16:50
3	220kV Nashik GCR	213.06	15:48
Total		**1225.24**	

The details of load restoration at TPCL area depicted as follows:

Sr. No.	Name of Substation	Load relief (In MW)	Restoration Time (Hrs)
1	Ambernath	55	16:20
2	Kolshet	26	16:21
3	Kalyan	64	16:24
4	Salsette	31	16:02
Total		**176**	

The details of load restoration at AEML area depicted as follows:

Sr. No.	Name of Distribution Substation (DSS)	Load relief (In MW)	Restoration Time (Hrs)
1	Bhayander	6	15:56
2	Vinamra	7	15:58
3	CPWD	10	15:55
4	Dahisar	7	15:59
5	Mira road	6	16:01
6	Ganesh Nagar	7	15:56
7	Meghwadi	12	15:56
8	Malad	9	15:57
9	Juhu	13	16:06
10	Devidas Lane	12	15:36
11	Gokuldham	6	15:09
Total		**95**	

7.2 Actions taken by MSLDC

- The HVDC system ramped up to its full capacity of 1500 MW.
- Koyna and Tata hydro generation ramped up to their full capacity.
- All thermal generation units ramped up
- Load shedding was implemented at various locations, with total AG curtailment instructions issued through LM, Cell Management, and MSEDCL.
- Instructions were given to all generators to generate MVAR for voltage improvement.
- Centralized MOD was operated in DSM software as per system requirements.

7.3 Challenges faced during Restoration

The initiation of the fault was in Gujrat, which is beyond the control area of Maharashtra State, so immediate recognition of the issue was difficult to the Maharashtra System operation team. Still, taking cue from the line overloading, immediate actions were initiated by the operations team present at the control room.

The LTS and UVLS operations are currently not available in the SLDC SCADA system. Also, some communication gap was observed in reporting of these instances to the SLDC control room.

The Koyna hydro response was delayed for some machines than normal during the event.

The frequency fluctuations and severe under voltages created a difficult condition for the responding generators which were on FGMO, particularly in Mumbai area. Severe under voltage could have caused loss of auxiliaries.

After the last grid disturbance, a load curtailment protocol for Mumbai is decided and available with the SLDC control room. However, the spread of the occurrence being large, quick decision making about locations of load curtailment was challenging.

8.0 Recommendations & Mitigating measures

8.1 Short Term

8.1.1 System Strengthening:

1) Following Transmission Schemes proposed in MMR & Pune Area should be completed on top priority:

Sr. No.	Name of Scheme	Proposed Year
1	220 kV DC line from 765 kV Shikrapur PG to 220 kV Khed City - 18 kms	(2024-25)
2	220 kV DC line from 765 kV Shikrapur PG to 220 kV Ranjangaon S/s using existing corridor - 10 kms	(2024-25)
3	Reorientation of 220 kV Babhleshwar - Ranjagaon ckt & Lonikand - Ranjangaon Ckt at Khed City - 5 kms	(2024-25)
4	HTLS conductor of 400 kV Lonikand - Chakan (NEW)	(2025-26)
5	220kV TalegaonPG-Chakan DC with HTLS conductor - 6km	(2025-26)
6	HTLS conductor of 400 kV Talegaon (PG) - Chakan (NEW)	(2025-26)
7		
8	400kV LILO - Lonikand-I Jejuri at 765kV Shikrapur PG -30km approx.	(2026-27)
9	220kV Pune-III (ISTS-New) (PG) – Nandedcity 220kV D/C line.-60km (Western Region Network expansion scheme)	(2026-27)
10	LILO of both ckt of 220 kV Jejuri (M) – Phursungi (M) D/C line- 5km along with HTLS conductor at 765/400/220 kV Pune-III (ISTS-New) (PG) S/s with HTLS conductor (twin zebra equivalent) (Western Region Network expansion scheme)	(2026-27)
11	HTLS conductor of 400 kV Lonikand - Talegaon (PG) (NEW)	(2026-27)

2) To address low voltage issues in MMR, Pune & Nashik area:

- Commissioning of 1425 MVAR, 170 MVAR & 160 MVAR compensation planned at Pune, Vashi and Nasik respectively.

8.1.2 Protection

1) Review of provisioning of UVLS schemes at identified 400 kV Sub-stations where UVLS is presently not provided is essential.
2) Review of 400 kV Babhaleshwar UVLS scheme so as to have necessary load curtailment instead of network opening.
3) Provisioning of LTS scheme on 220/132 kV ICTs at Nashik.
4) Verification of protection settings of Bus coupler at 220 kV Nashik OCR.

5) Review of LTS Scheme of all 400 kV ICTs ensuring availability of such scheme on each individual ICT.

8.1.3 Automation & Communication

1) MSLDC has participated in the ULDC scheme of Grid-India for SCADA system in Western Region. WRLDC need to expediate the activities under ULDC project so that actual work can be initiated & SCADA system can be commissioned at MSLDC on priority.
2) All LTS schemes installed at important Transmission elements viz. ICTs & 400 kV lines, should be integrated in MSLDC & ALDC SCADA System.
3) Separate Screen with alert facility for all LTS Schemes to be maintained in MSLDC & ALDC Control Room.
4) List of Sub-stations in MMR & Mumbai area for installation of PMUs has been issued by STU to TPCL & AEML. Hence, TPCL & AEML along with MSETCL need to expedite the work of installation of PMUs and its integration with MSLDC URTDSM System.

8.1.4 Procedural Review

1) List of critical and non-critical loads/feeders for all the Sub-stations in the State should be prepared. Load Trimming Protocol for entire State like the protocol prepared for MMR & Mumbai region should be prepared for faster response & avoiding mis-communication during implementation. The list should be updated on six-monthly basis.
2) The PCC should review all the LTS, SPS, UVLS settings routinely. Healthiness of all the LTS, SPS, UVLS schemes should be ensured by all the transmission licensees and report should be sent to MSLDC.
3) Trials of LTS, SPS, UVLS schemes should be taken by all the transmission licensees and report should be sent to MSLDC.

8.2 Long Term

8.2.1 Grid Strengthening:

1) Integrated Resource Planning for Mumbai, MMR & Pune cluster:
   - Around 15000 MW load is concentrated in Mumbai, MMR & Pune area.
   - This area has limited embedded generation, inadequate transmission network and Reactive Power compensation.

- Hence, it is suggested that an integrated resource planning study for this area with increasing demand needs to be carried out by STU.
- While carrying out such integrated resource planning study, ensuring availability of enough synchronous generating sources for maintaining grid inertia, reactive support and fulfilling necessary active power support in case of islanding operation, these aspects shall be taken care of.

2) **Planning of Adequate Reactive power compensation and timely implementation:**

- Reactive Power Requirement Studies need to be carried out on yearly basis by STU.
- Dynamic compensation through STATCOM, SVC, etc in MMR & Pune region with high density of loads and changing nature of loads in future (with increasing no. of Data Centers, Metro in this area) need to be considered.
- With installation of around 25 GW Solar Generation under various schemes in the State, daily variations in the Thermal generation to the tune of around 4000 MW is expected. There might be need of two shift operation of thermal units. Thus, the reactive support from Thermal Generation will not be adequate. Hence, reactive power support from VRE sources needs to be ensured.
- STU & transmission licensees should ensure timely commissioning of the reactive compensation.

3) Upgradation of existing HVDC Capacity:

During the incidence, ± 500 kV, 1500 MW Chandrapur – Padghe HVDC played important role in providing additional power at 400 kV Padghe bus when high export started from Padghe to Tarapur & Boisar (PG) and limiting the loading on 400 kV Babhaleshwar – Padghe D/C lines.

Considering severely low voltages at multiple locations in MMR & Pune area, VSC based HVDC can provide reactive power support.

Hence, the option of upgrading the existing Chandrapur – Padghe HVDC to 3000 MW VSC based HVDC needs to be explored on top priority. It is learnt that the existing line capacity is adequate for 3000 MW capacity. Hence, upgradation of terminal stations only will be required. This aspect should be verified by STU on priority.

8.2.2 Protection, Communication & Automation

1) Enhancing full visibility of Maharashtra Power system at MSLDC:

At present complete visibility of all the 765 kV & 400 kV Sub-stations is available at MSLDC & ALDC.

The visibility of transmission elements at 220 kV level & below 50 %.

Hence, execution of planned schemes for ensuring full visibility of Maharashtra Power System to MSLDC needs to be expediated.

2) **Expansion of Optical Fibre Communication backbone:**

The utility of PMU data was seen during handling of this incidence as well as for post-incidence analysis as detailed in this report. Hence, an expansion of Optical Fibre communication backbone ensuring availability of necessary communication infrastructure for placing of PMUs at all critical locations in the Maharashtra Transmission System is required.

3) **Use of State Estimator & ADMS for reliable Grid Operation**s:

- MSLDC has already participated in the ULDC Scheme of Grid India. In the proposed SCADA System, features of State Estimator, ADMS, etc are covered.
- Hence, Grid India should expedite the issuance of LoI for the shortlisted vendor so that SCADA System can be commissioned on priority.

4) Installation of PMUs under Wide-Area Measurement System (WAMS) for situational awareness:

- For situational awareness, MSLDC is using PMU data installed at 5 Nos. of 400 kV Sub-stations.
- In first phase, MSLDC has already requested STU for installation of PMUs at critical locations in MMR region and all 400 KV s/stns of MSETCL. STU has further directed TPCL, AEML & MSETCL to install the PMUs at the earliest. This work needs to be completed on priority.
- In the second phase, STU should direct all transmission utilities to install PMUs at strategic locations & RE Plants. MSLDC should simultaneously arrange to install PDCs for integration of PMUs having latest configurations and softwares required for data analytics and decision support.

5) Requirement of Integrated Data handling Platform:

- While carrying out post-incidence analysis, SLDC faced some challenges for handling large data sets generated at different monitoring systems. The real time analysis or any post incidence analysis in the modern power system will require handling of very large data sets. The complexity increases with multiple types of data emerging out of different systems like SCADA, PMU, Metering, Protection systems, Scheduling systems, etc.
- In this respect, MSLDC has already explored option for the use of Integrated Data handling platform having capability of integration with various softwares over different communication protocols. A Proof of Value (PoV) is successfully completed in the month of Feb-2025. Hence, there is a need to use such data handling platform at MSLDC as large sized data is daily generated. This will enhance the performance of MSLDC & the State Grid.
- SLDC needs to expedite the creation of integrated data handling platform.

8.2.3 Needed Regulatory Framework in the State for handling Grid disturbances

- SLDC has identified following areas in which the supportive regulatory framework would be needed for handling of Grid disturbances.
  - Establishing mechanism for availability of Spinning Reserve in the Intra-State System.
  - Need of SCED & SCUC in the State.
    The High-Level Committee constituted by Hon'ble MERC for enquiry of the partial Grid disturbance in MMR & Mumbai area occurred on 12.10.2020 has recommended to carry out study for implementation of SCED & SCUC for scheduling embedded generation.

    Accordingly, MSLDC in collaboration with IIT, Bombay has undertaken studies using GAMS software to optimize internal resources & to consider security constraints prior to despatch of power in the State. MSLDC is the first SLDC carrying out such studies apart from NLDC.

    The preliminary study report has been submitted to Hon'ble MERC on 11.11.2024. further, a petition has been filed with Hon'ble MERC on 20.03.2025 for seeking approval for carrying out pilot operation of the same in the state. The petition has been admitted vide Case No. 51 of 2025.

8.3 Training & Awareness, Need for SLDC & Transmission Utilities:

- The Govt. of Maharashtra Committee constituted for enquiry of the partial Grid disturbance in MMR & Mumbai area occurred on 12.10.2020 has issued following recommendations:

  - *A task force should be set up to study emerging technologies and trends, and their impact on planning of the Mumbai network. The technologies/systems may include*
    - *Electrical Vehicles/ Battery charging infrastructure and management*
    - *Grid Scale battery storage*
    - *Roof-top solar PV systems*
    - *Fault Current Limiters.*
  - *The staff of all utilities should keep abreast of the evolving trends, practices and technologies. This requires the following. (**GoM Committee**)*
    - *Participation in national and international seminars, workshops and tutorials.*
    - *Presenting case studies and experiences.*
    - *Access to journals and periodicals of CIGRE, IEEE, standards etc.*
    - *Peer-to-peer interactions. Sharing of experiences, best practices with other utilities.*
    - *Visit to installations of new technologies in India and abroad.*
    - *Undergoing training in continuing education programs.*

  Hence, it is needed to review the existing training & awareness processes in line with above recommendations.

- MSLDC should consider creation of dedicated training cell.

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