Operations Challenges Driven by Oscillatory Modes in the Southern African Region

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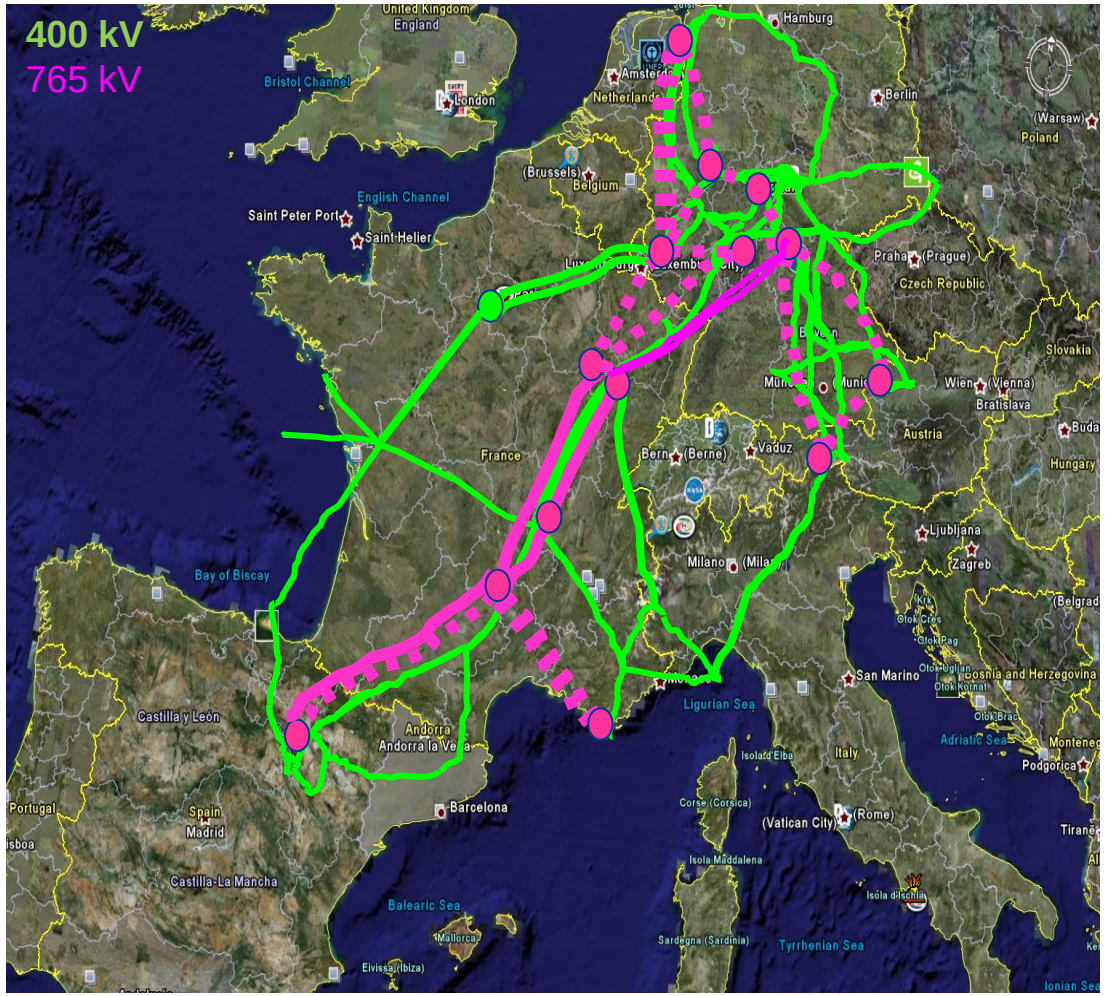
- **Lessons learnt in Controlling and Managing oscillatory modes in SAPP**

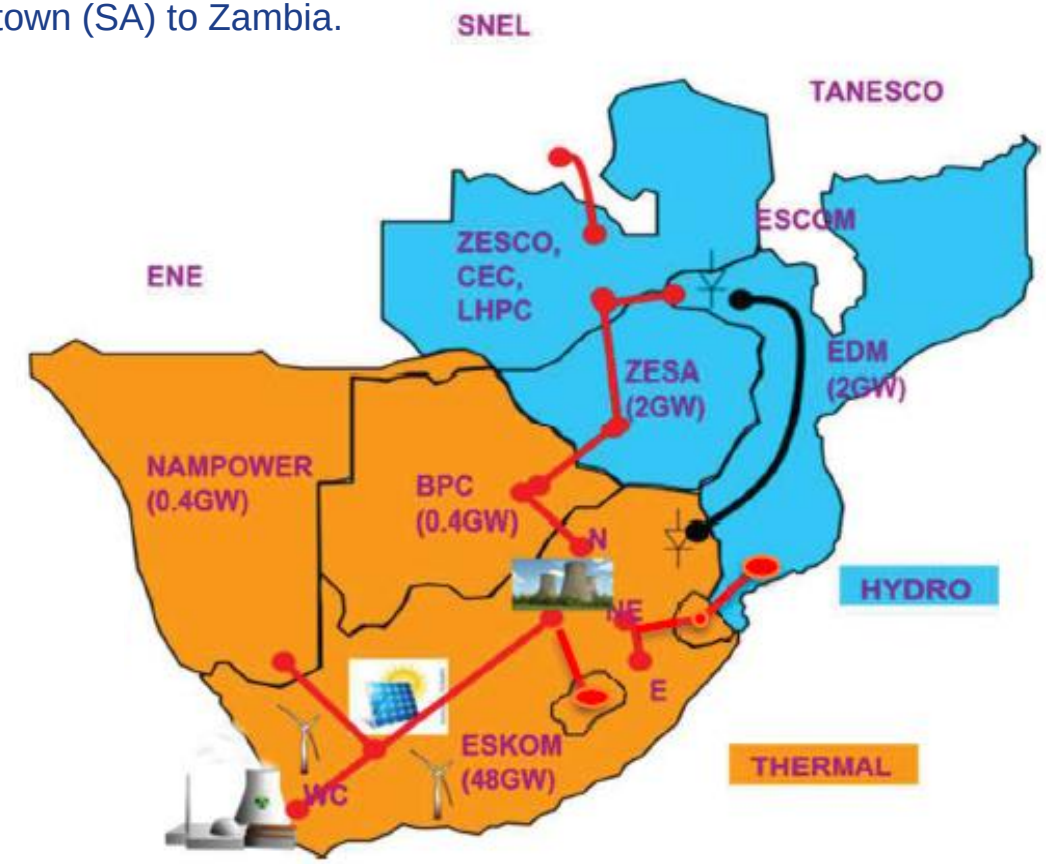
Eskom Grid in relation to Europe and SAPP network Overview

South Africa's Transmission network superimposed on Europe



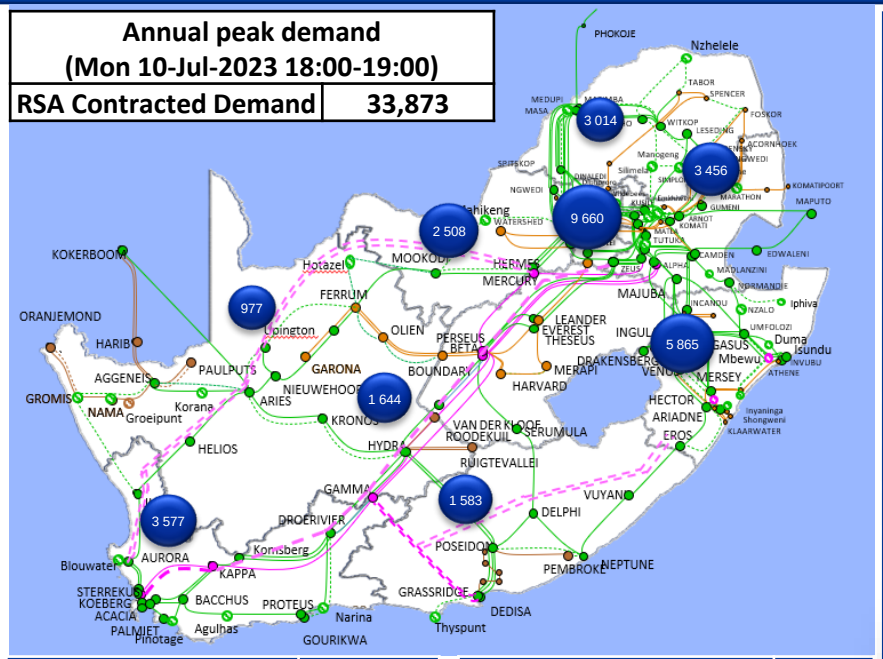
- SAPP has three control areas - **Eskom**, **ZESA** and **ZESCO**
- Approximately **3400km (2,112 miles)** from Cape town (SA) to Zambia.

A large, isolated, sparse transmission network with long, high voltage lines



South Africa's Demand, Transmission and Supply

Annual peak demand (Mon 10-Jul-2023 18:00-19:00)	
RSA Contracted Demand	33,873



Transmission lines	km
765 kV	2 784
533 kV HVDC	1 032
400 kV	19 916
275 kV	7 342
220 kV	1 352
132 kV	766
Total	**33 192**

Transmission substations	#
Substations	169
Transformers (> 30 MVA)	449
Transformer MVA installed (>30MVA)	154 500

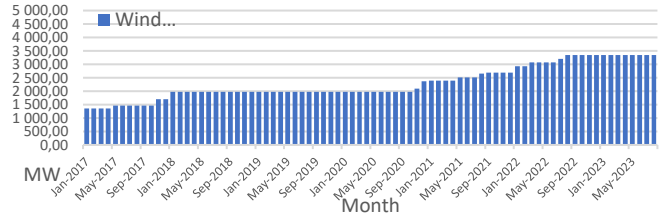
Type	Number	Nominal capacity
Coal-fired	14 stations	39 099 MW
Gas/liquid fuel turbine	4 stations	2 409 MW
Hydroelectric	6 stations	661 MW
Pumped storage	3 stations	2 724 MW
Nuclear	1 station	1 854 MW
Wind energy	1 station	100 MW
Dispatchable IPP	2 stations	1 005 MW
Wind IPP	34 stations	3 343 MW
Solar PV IPP	45 stations	2 287 MW
CSP IPP	6 stations	500 MW
Other renewable IPP	7 stations	51 MW
Total Eskom	29 stations	46 847 MW
Renewable (IPP)	93 stations	6 181 MW

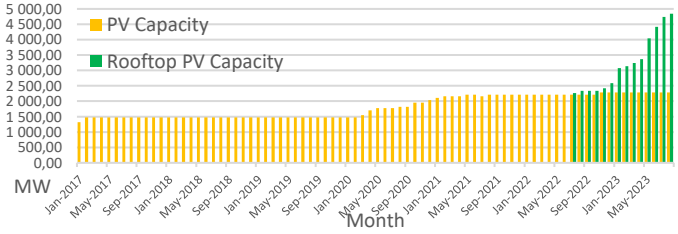
Arnot Power Station

Sere Wind Farm

The **Energy Availability Factor (EAF)** for the Eskom generators for the financial year to date is **55.6%**

Current Installed Capacity (MW)	
CSP	500.0
PV	2,287.1
Wind (Eskom+IPP)	3,442.6
Total (Incl other REs)	6,280.2
Estimated Rooftop PV	4,841.0



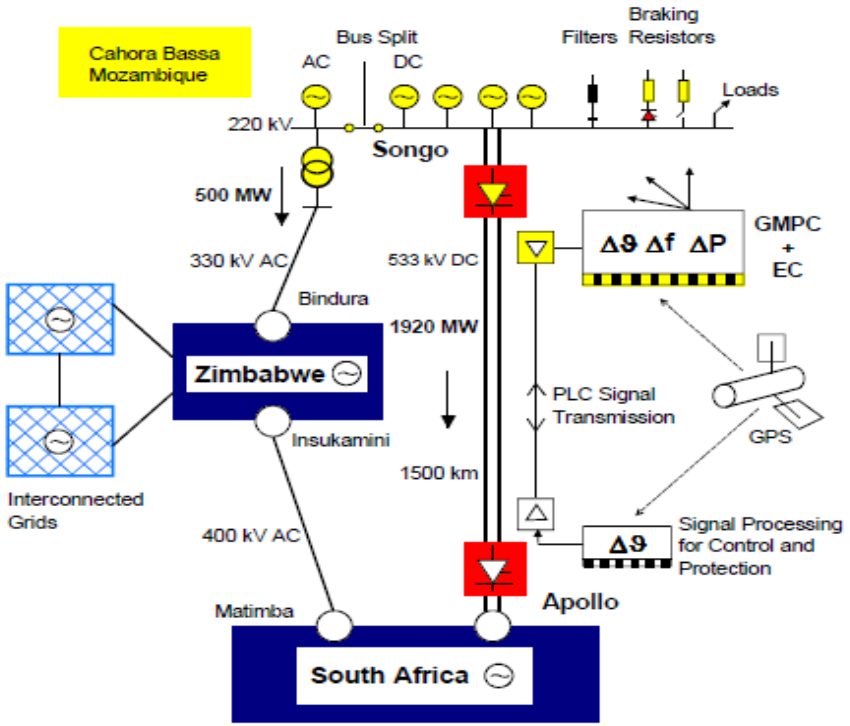


Maximum Contribution (MW) - based on System Operator data (subject to metering verification)

Cal Year	Indicator	CSP	PV	Wind (Eskom+IPP)	Total (Incl other REs)
All Time	Maximum	506.2	2,099.5	3,102.2	5,126.1
	Max Date	15-Mar-2022 15:00	24-Oct-2021 12:00	25-Aug-2023 20:00	05-Sep-2022 12:00

The highest **contribution** from **renewables** was **21.8%** on 20 February 2023 at 15:00

Grid Master Power Controller (GMPC)



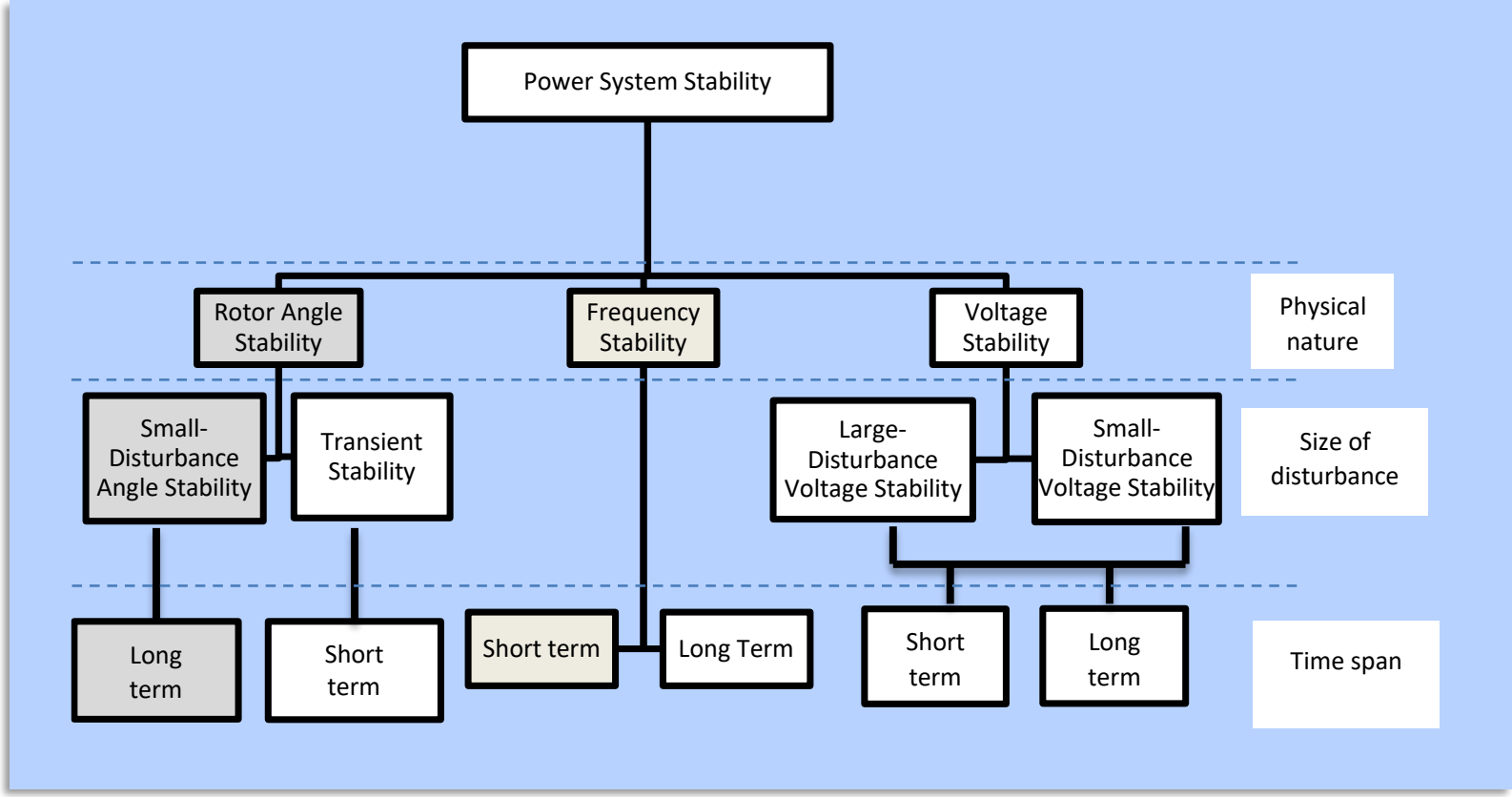
The GMPC role is to control:

- **Voltage angle** between two control areas to facilitate safe parallel operation of the AC system and HVDC system
- **Frequency** control of generators in split mode
- **Power balancing** between AC generation and DC transmission

To protect **harmonic filters** at Songo, the GMPC **opens** the **Songo breaker** in the event of the **loss of a pole**, **angle between Songo and Apollo** exceeds a preset value or a **frequency threshold (settings below)**

If Frequency **f ϵ** [**49,2 < f < 49,6**] for continuous t ≥ 18 seconds - Underfrequency
If Frequency **f ϵ** [50,4 < f < 50,8] for continuous t ≥ 18 seconds - Overfrequency
Instantaneous (200 milliseconds delay):
If Frequency **f ≤** 49,2 (Δ Hysteresis = 0,05 HZ) - Underfrequency
If Frequency **f ≥** 50,8 (Δ Hysteresis = 0,05 HZ) - Overfrequency

Hierarchy of different power system stability classifications



The **ability** of the power system to **maintain synchronism** under **small disturbances**.

How will the move to low carbon economy impact operations?

- Lessons from the past network Disturbances
- Growth in the influence of Invertor Based Renewables

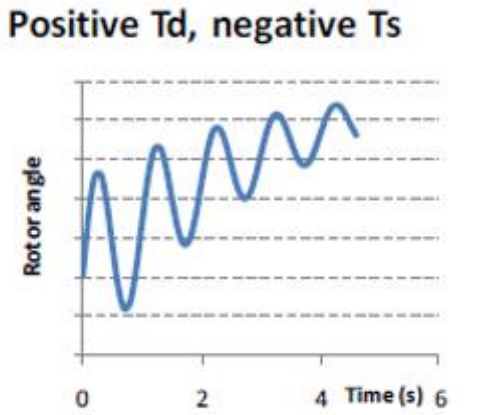
Events and themes

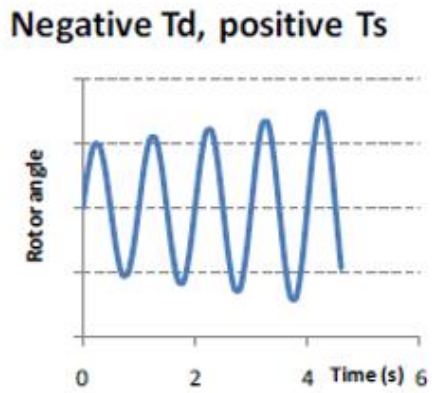
1. **Local-Area and Inter-Area modes of oscillation within South Africa's network (0.4 - 1.0Hz)**
   - Substation split incident that resulted in 0.6Hz mode of oscillation and near system collapse

2. **SAPP Inter-Area modes of oscillation (0.3Hz)**
   - HVDC Line faults leading to oscillations
   - Oscillations triggered by load rotation during load shedding
   - Undamped oscillation triggered by inoperable control systems
   - East power station multiple unit trip incident and the inter-area oscillations
   - Oscillations triggered from the North Pool affecting the manual and auto start schemes

3. **Undamped oscillations caused by a Northeastern generating unit's stuck governor valve**

1 Inter-area within Eskom grid – 0.4-1.0 Hz

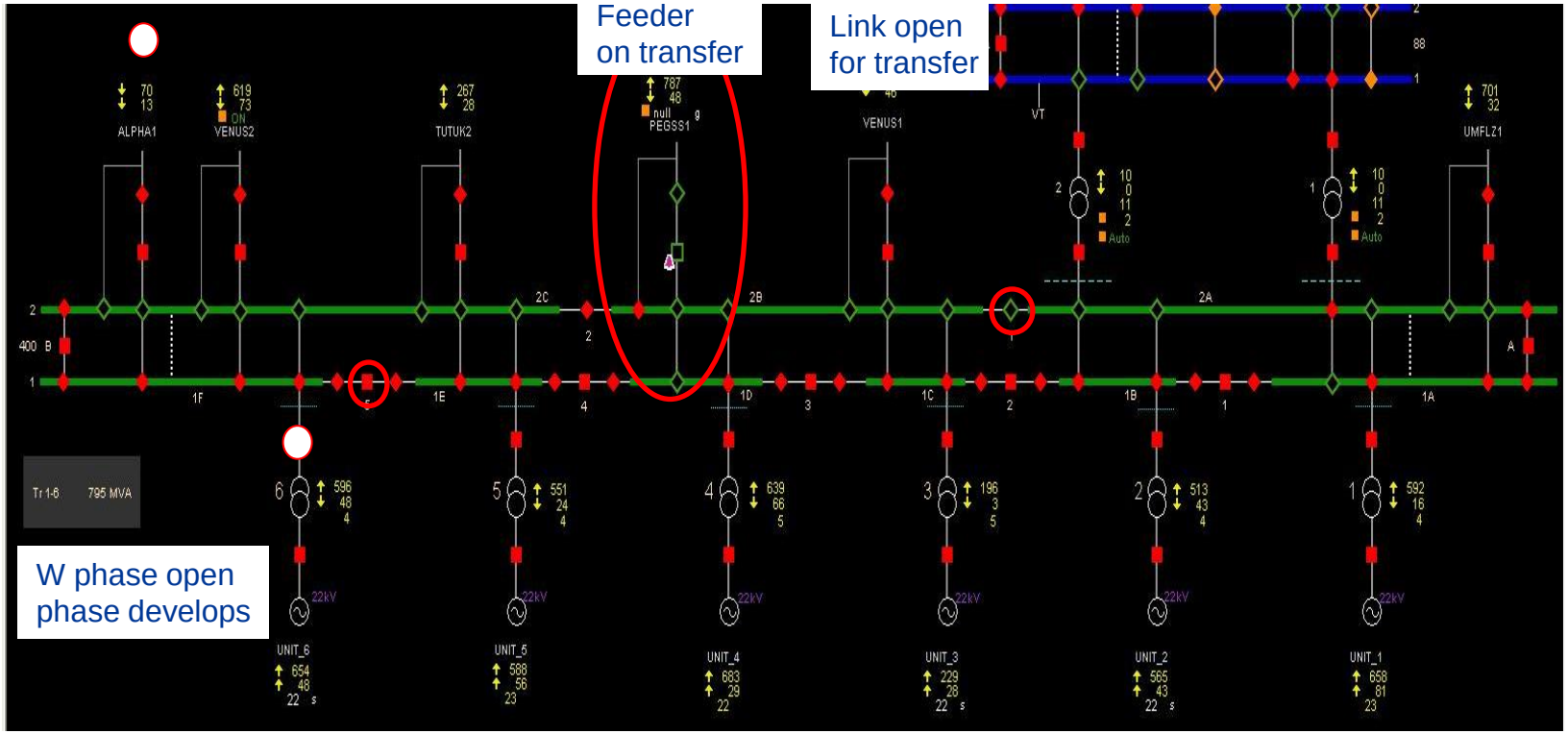


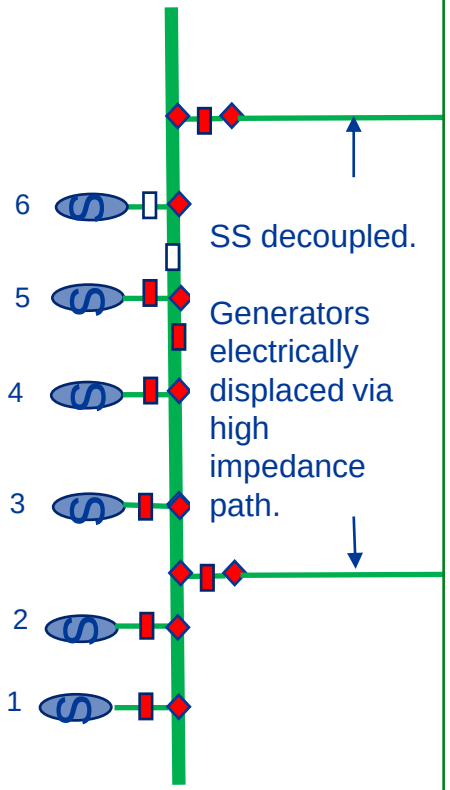


- Observed between North East and South-West clusters
- Oscillations between groups of generators
- Stability issues are affected by
  - **Types and locations of exciters**
  - Load characteristics
  - **Power transfer on corridors**
  - System loading
  - **Weak Interconnections/Post-contingency strength**
  - **Insufficient control systems (N-1)**

- Normally well damped (3.4s)
- Occasionally up to 12s
- Very lightly damped oscillations (50s)

1 Power station 400kV substation split incident resulted in 0.6Hz mode of oscillation - 10 January 2010





- Online generating units started Oscillating
- 5 generators tripped
- Oscillations lasted for about 3 hours
- Angles reduced, SS coupled by operator and system back to normal.
- There were no PSSs installed in and around East power station
- Poor network visibility (No PMUs installed)

1 Reconstruction of 10 January 2010 incident using RMS simulation in Power factory

Alp Maj line closed

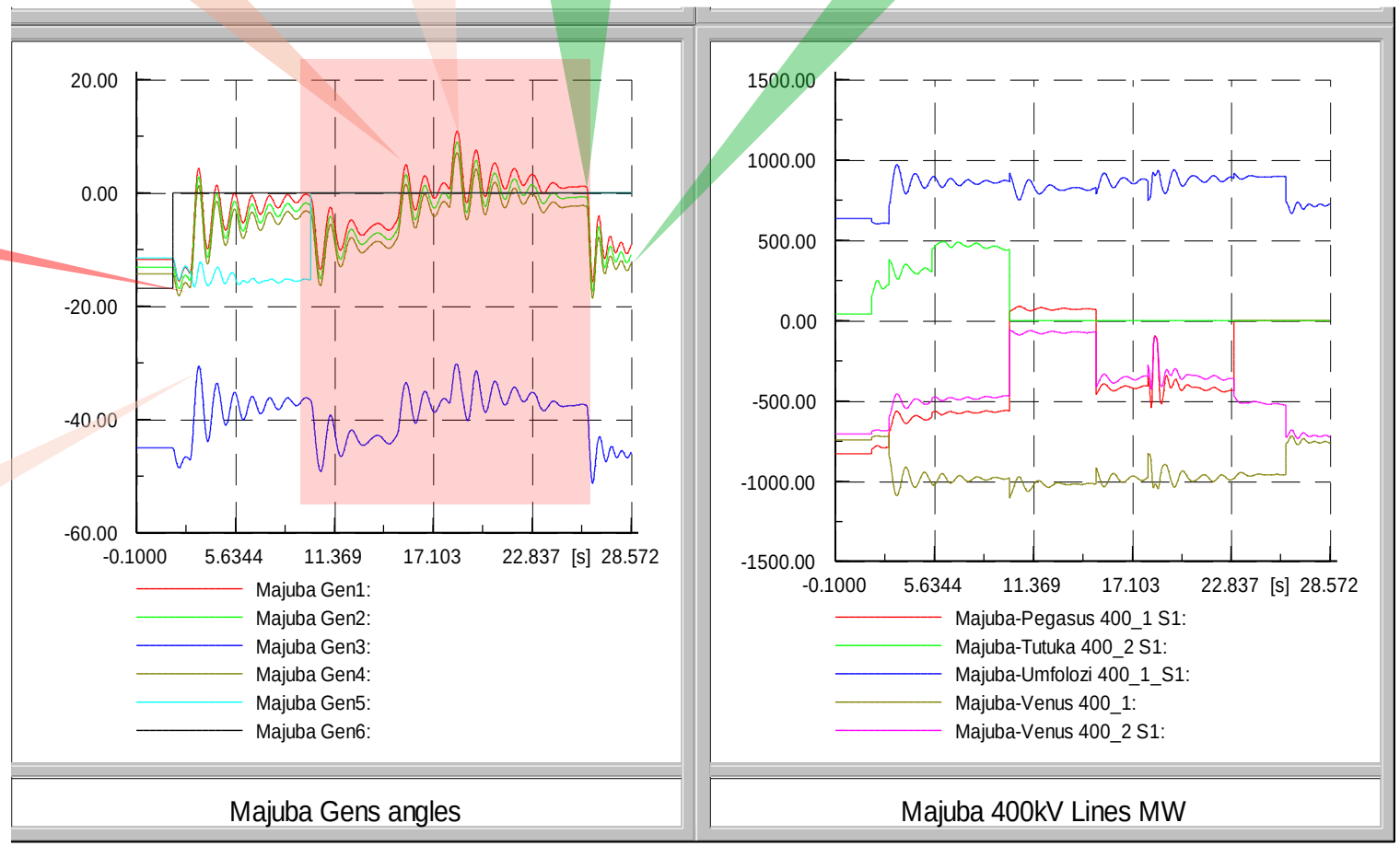
Unit 6 sync on load

Station coupled

System stabilised

Maj U6 & Alp Maj 400kV line trip

Bus-zone operation; Angle increased to 120



PMU Locations in South African Network

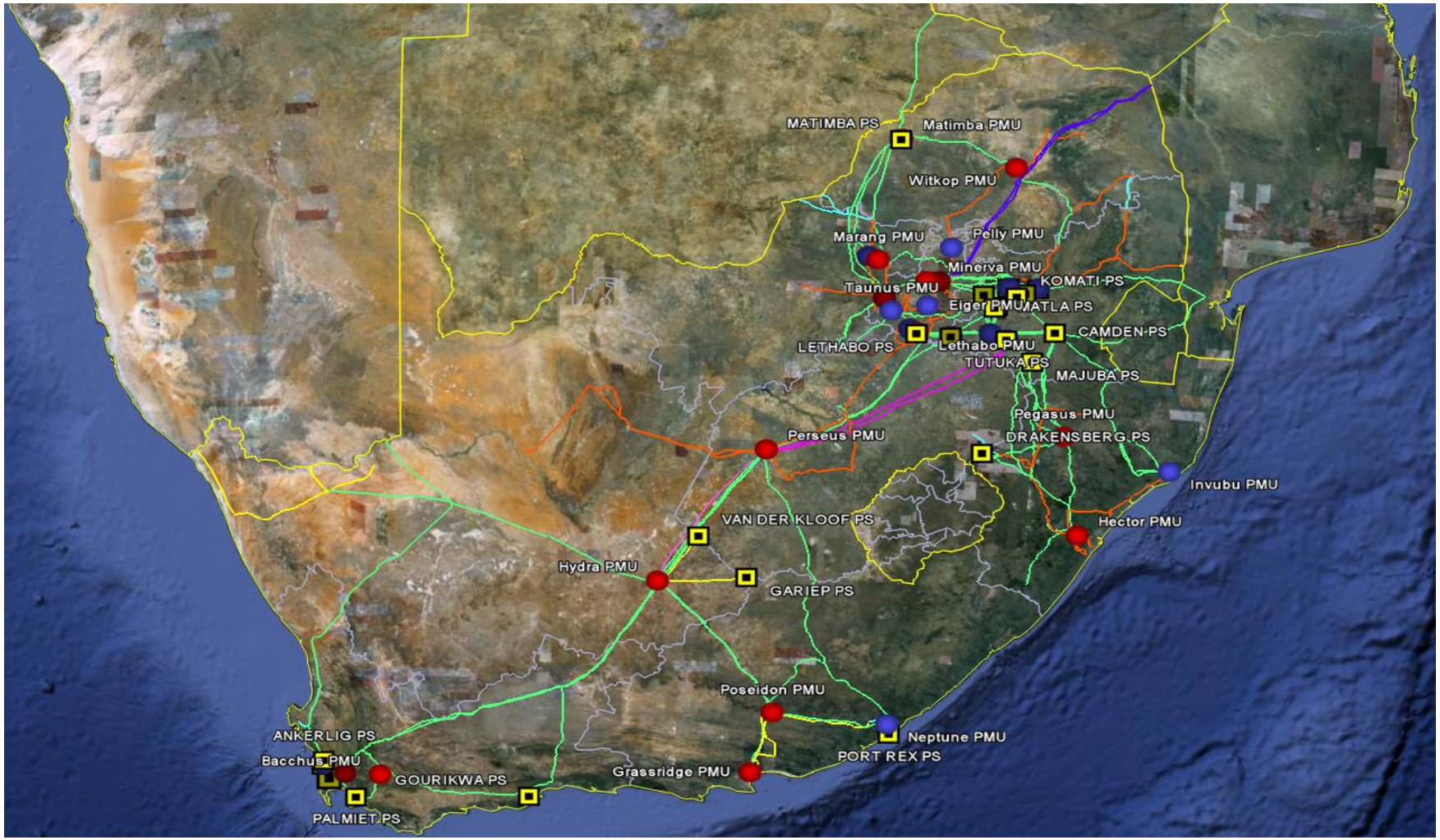
Power Station

15 PMU Substations

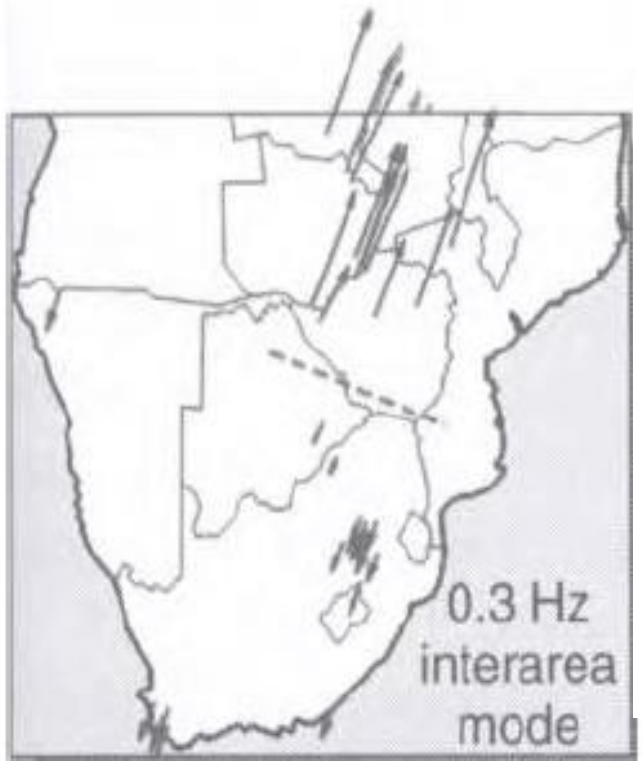
13 PMU Tx Substations

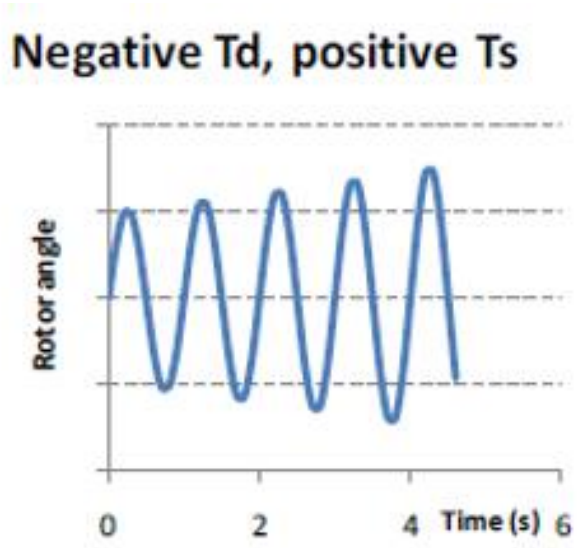
Total Installed 28

Operational 18



2 SAPP Inter-Area modes of oscillation – 0.3Hz



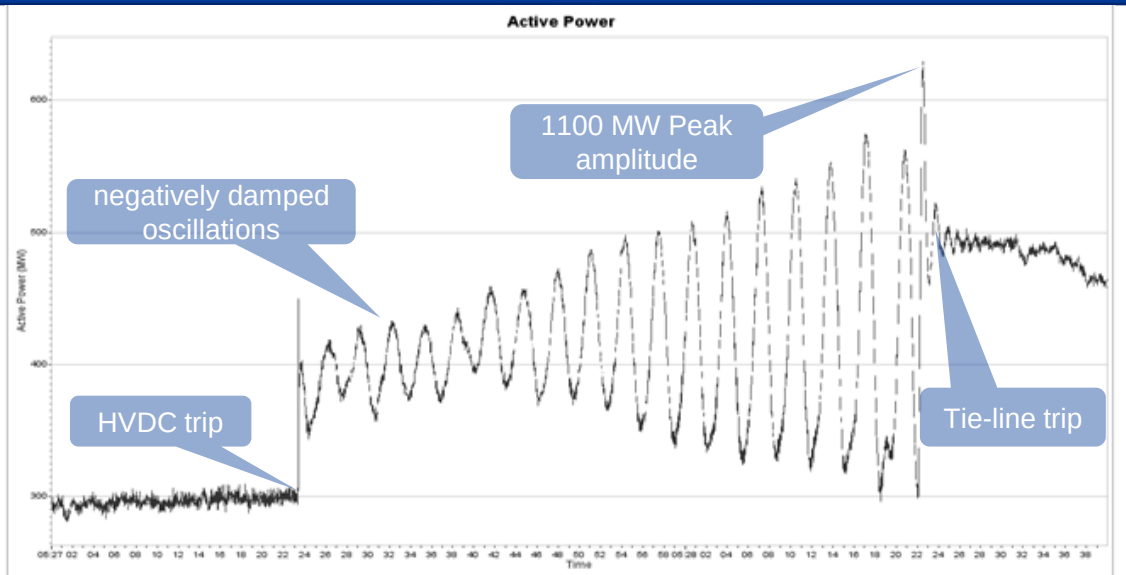


- Oscillations involving most generators e.g. 0.3Hz
- Stability issues are very complex and affected by
  - **Types and locations of exciters**
  - Load characteristics
  - **Power transfer on corridors**
  - System loading
  - **Weak Interconnections/Post-contingency strength**
  - **Insufficient stabilisers control**

2 ACDC Line faults leading to oscillations – 13 October 2018

1st event: Start: 05:28; End: 05:52

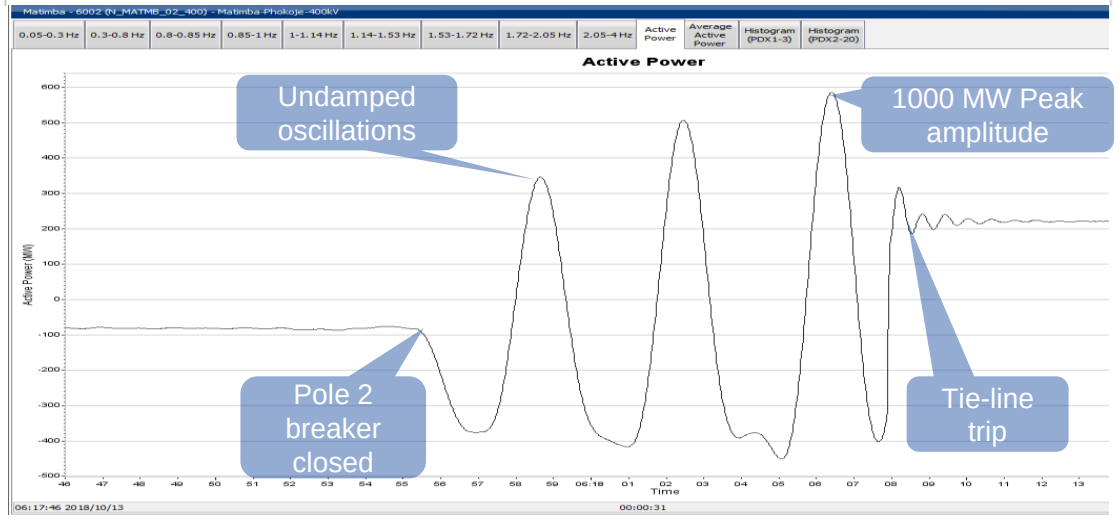
Weather	Heavy storms reported over Apollo DC lines
ROOT CAUSE OF OSCILLATIONS	Apollo Converter Station (CS) Pole trip due to a line fault.
LOSS OF GENERATION	Two coal fired units in Zesa control area One Gas turbine tripped from SCO mode in Eskom control
RESTORATION	The Oscillations lasted more than 50 Seconds Systems normalised after tie-line trip



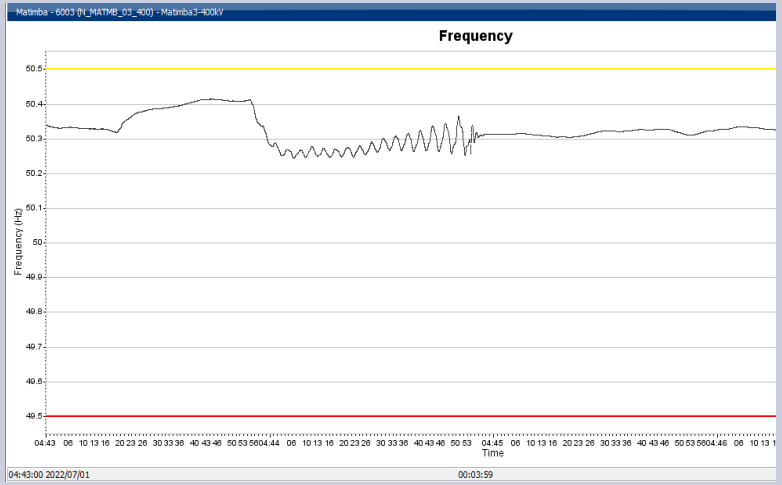
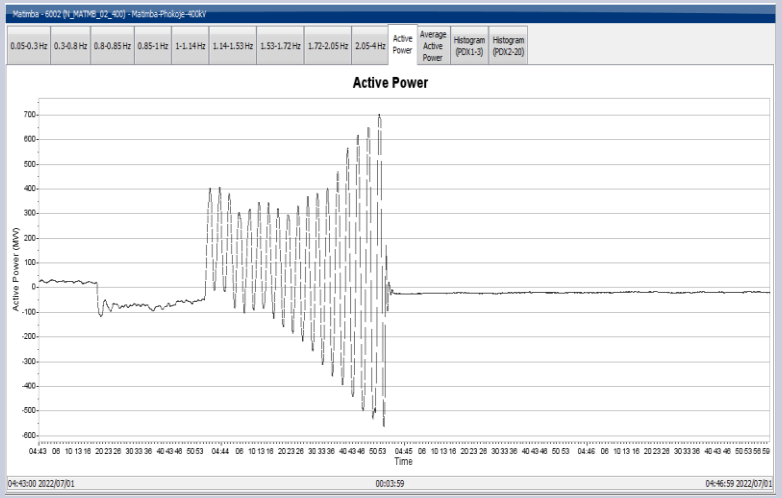
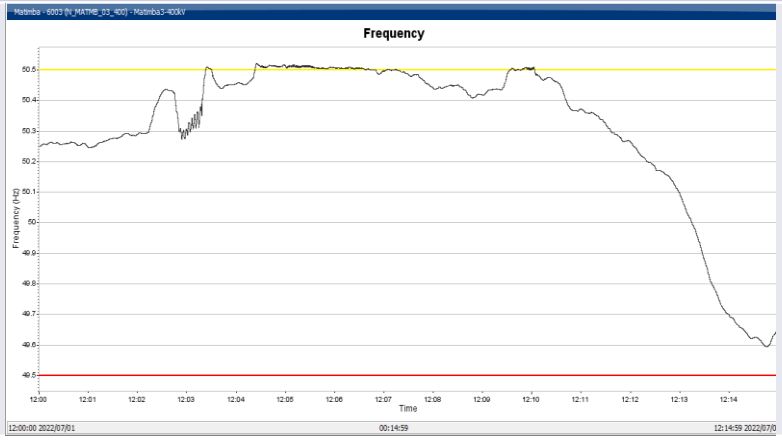
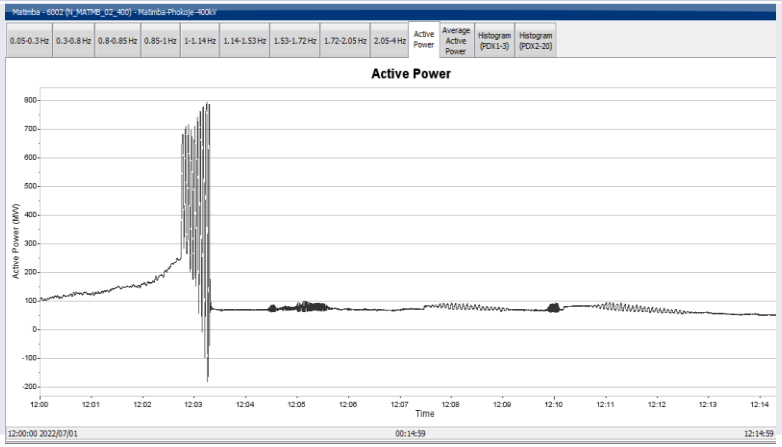
2nd event: Start: 06:18; End: 06:58

Negatively damped power oscillations were observed from the Matimba, Phokoje 400 kV line following Apollo-Songo pole 2 service returning to service.

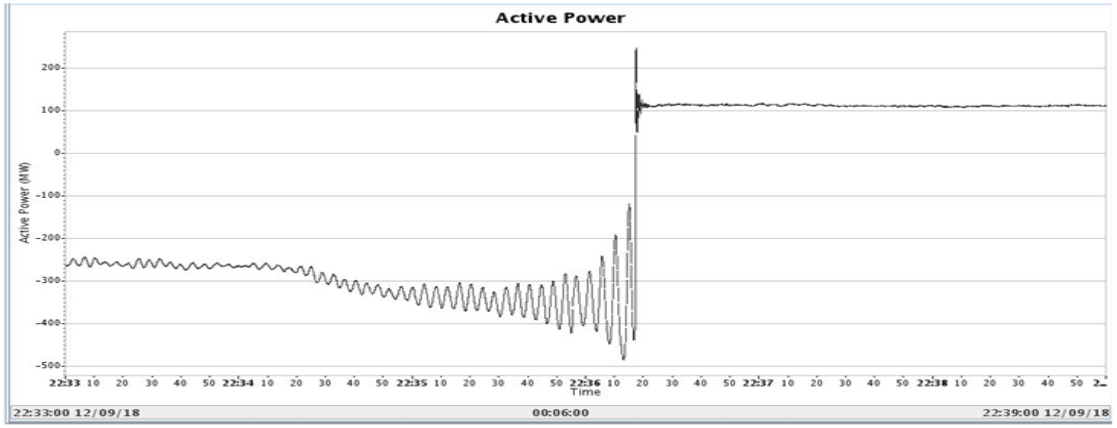
The Oscillations lasted more than 17 Seconds



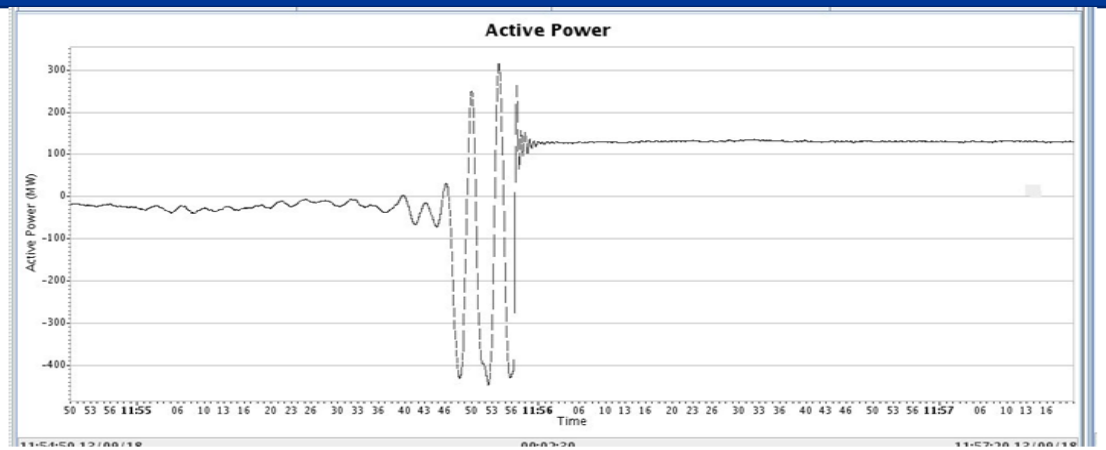
2 Oscillations triggered by load rotation during load shedding

Date & Time	Description Root cause	Frequency and Active Power plots Frequency vs time	Eskom – North control area Power (MW)
1 July 2022 04:45:00	Load block rotation during stage 2 (2000MW) load shedding leading to bus coupler trip, splitting the parallel AC and DC network		
1 July 2022 at 12:03	Load block rotation during stage 4 (4000MW) load shedding leading to bus coupler trip, splitting the parallel AC and DC network		

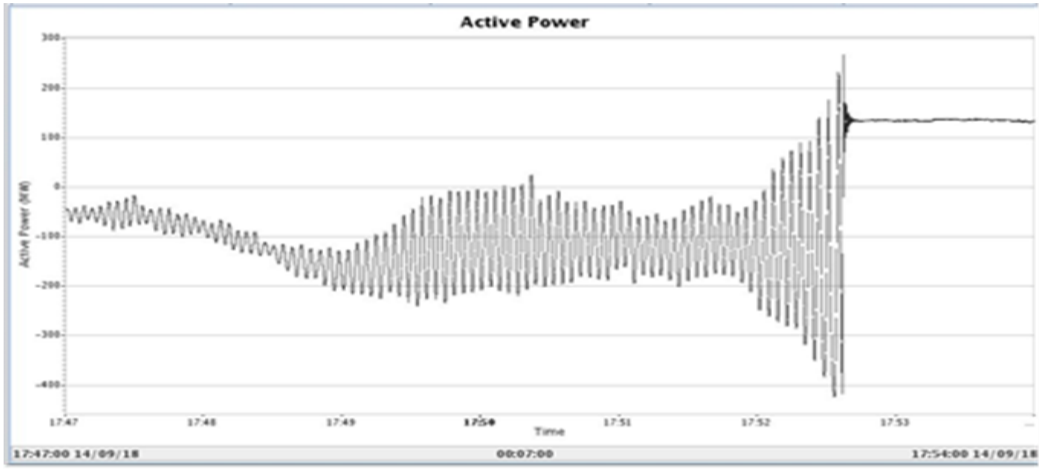
2 Undamped oscillation triggered by inoperable control systems (SVC with POD and PSS)



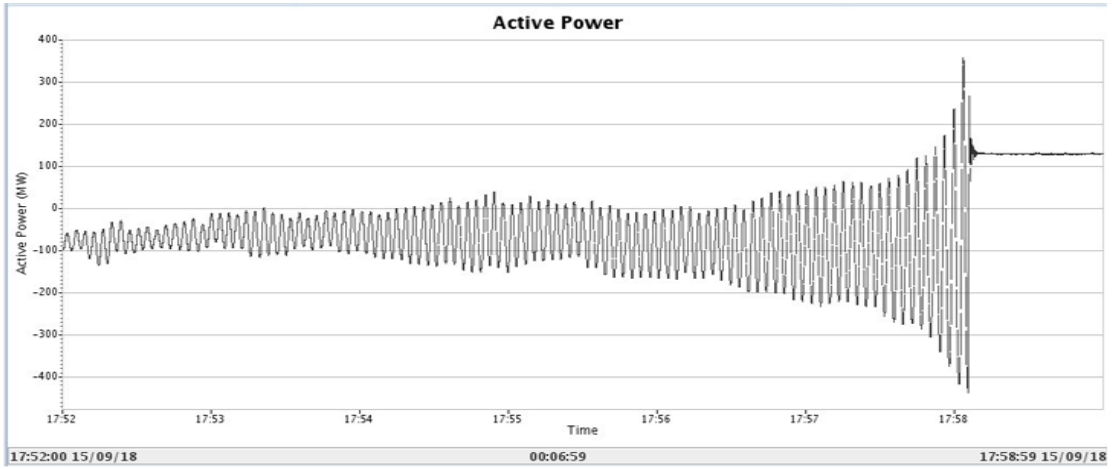
12 September 2018 – 22:34 Matimba-Phokoje (MW)



13 September 2018 – 11:55 Matimba-Phokoje (MW)

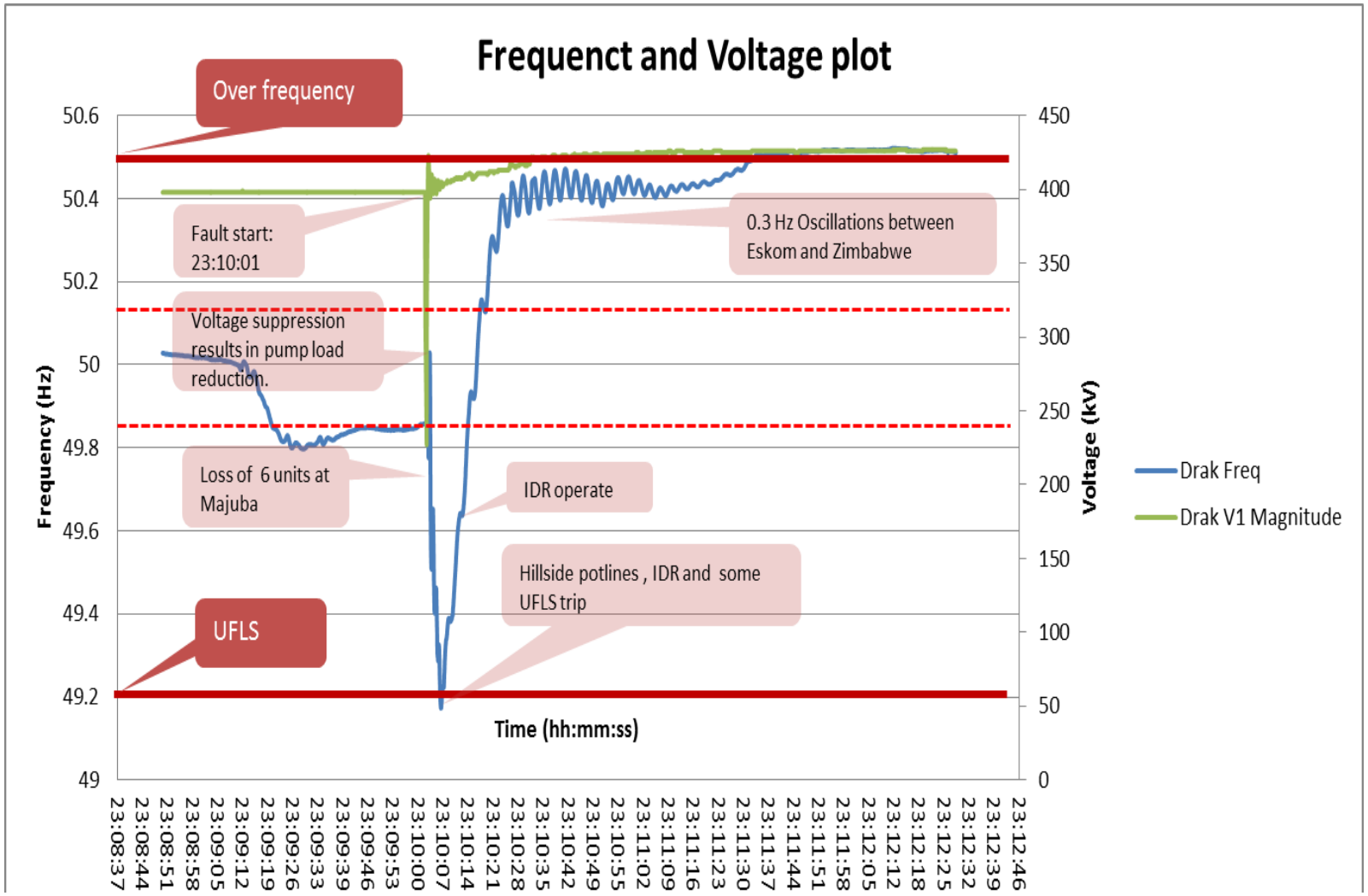


14 September 2018 – 17:40 Matimba-Phokoje (MW)



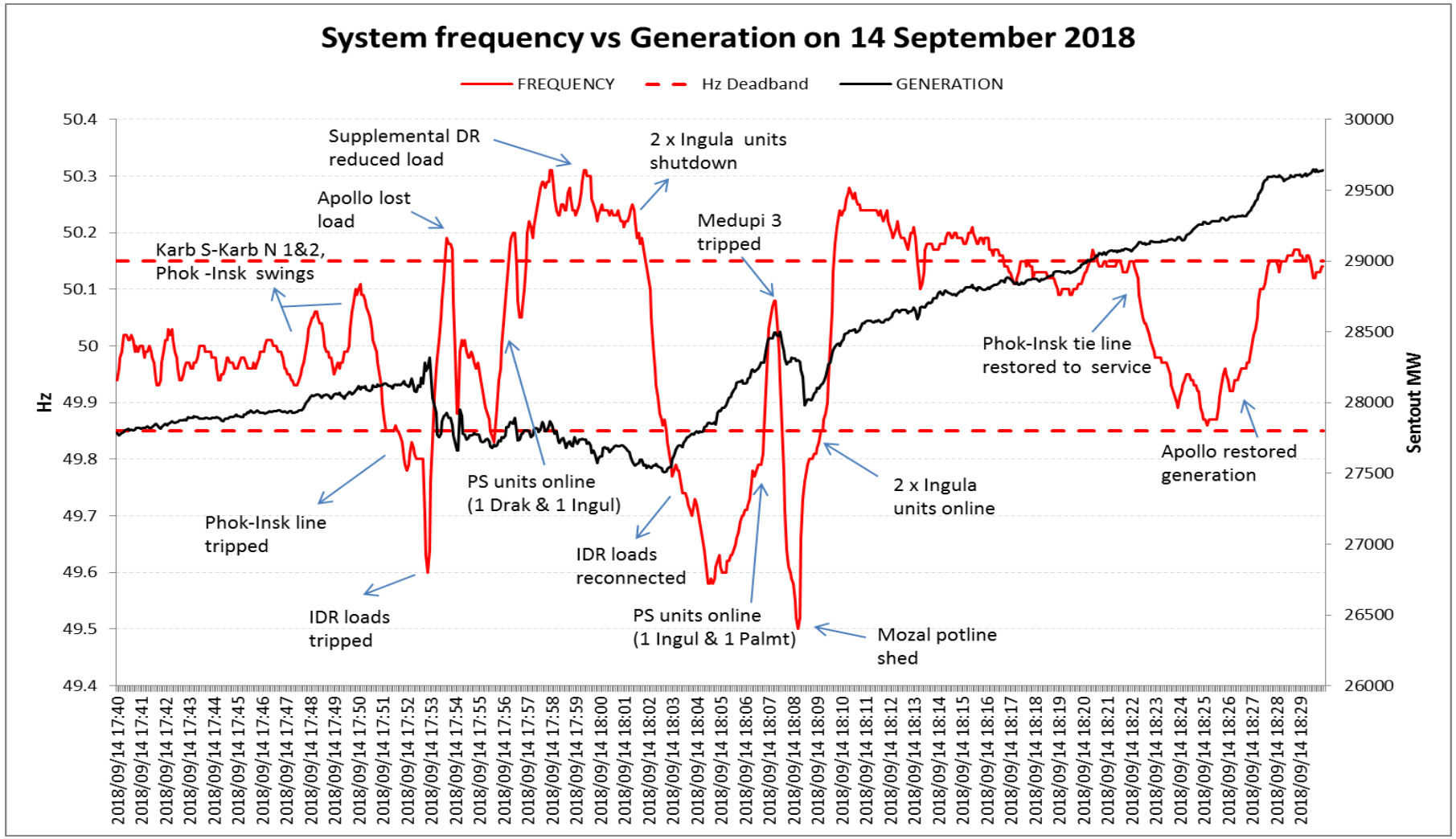
15 September 2018 – 17:45 Matimba Phokoje (MW)

2 East power station multiple unit trip incident and the inter-area oscillations



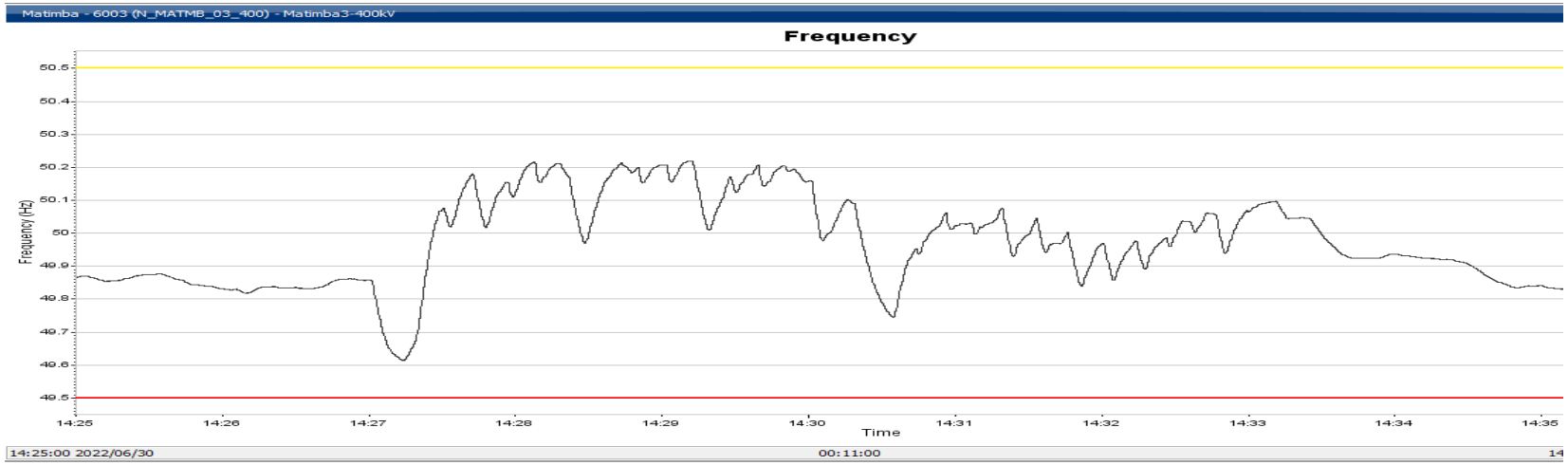
- 30 December 2018 MUT incident
- Power station HV yard fault
- Loss of 6 units (about 15% of total generating units on the day)

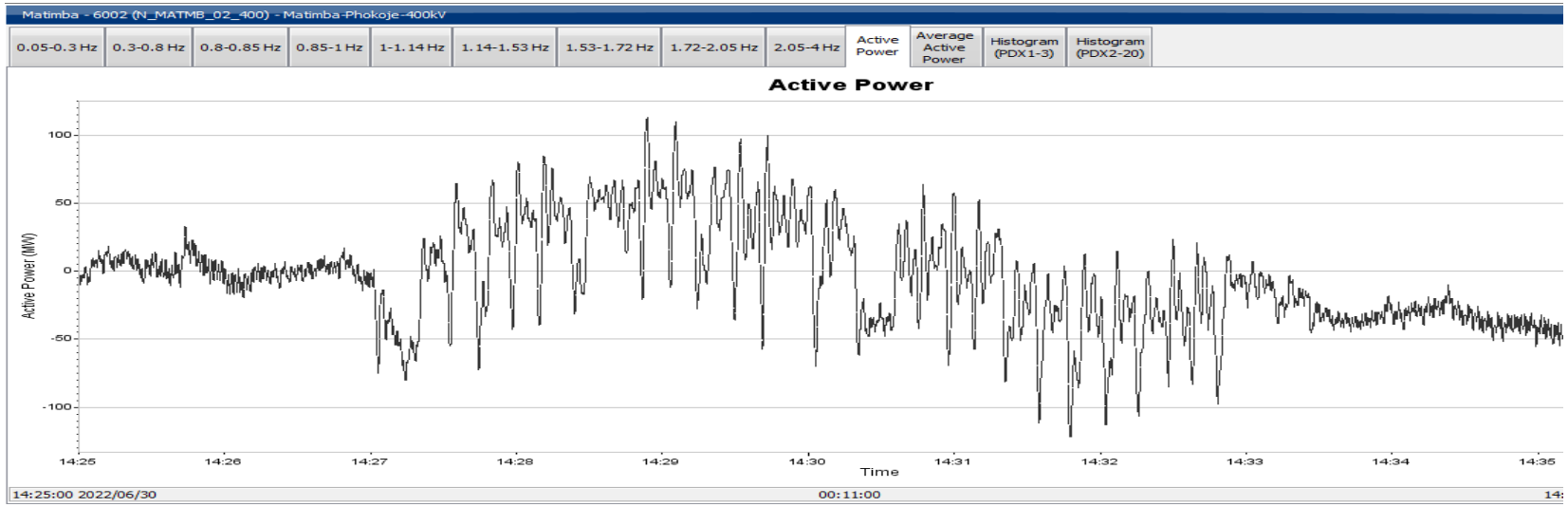
2 Oscillations triggered from the North Pool affecting the manual and auto start schemes



Uncoordinated events and consequences

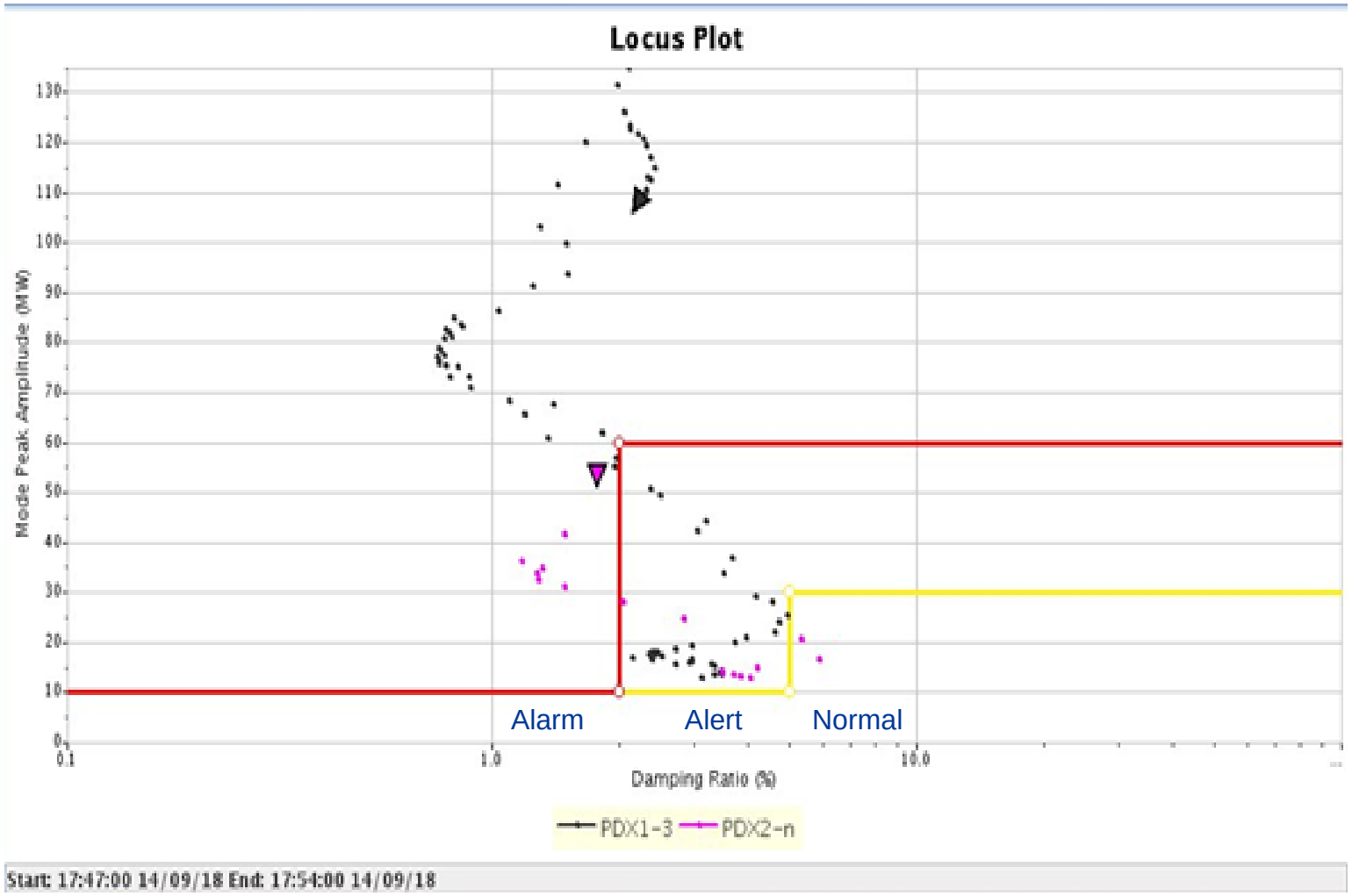
3 Undamped oscillations caused by a Northeastern generating unit's stuck governor valve





- 30 June 2022 14:25
- Unit 5 governor valve stuck on IP Turbine.
- Local mode observed for about 10 minutes!
- System Operator forced shutdown the unit

Monitoring area damping using Locus plot in WAMS



14 September 2018 incident

The 0.3Hz mode shown above was poorly damped with the damping ratio dropping to as low as 1%. The allowable damping ratio is above 2%.

Negatively damped oscillations resulted in two inter-area split due to power swing relay protection operating.

Lessons learnt and Effective Management oscillatory modes in SAPP

- Importance of Joint fault investigation and sharing of data
- Modeling and Simulations events post disturbances
- Tunning of Excitation control parameters – Model validation
- Installation of PSSs (PODs on FACTS devices)
- Coordination of primary and secondary plants planned outages within SAPP utilities
- Operating the network within limits
- Inputs to longer term grid expansion (System strengthening and Reinforcements)
- Use of WAMS system to monitor the system damping by using the Locus plot contributed significantly in monitoring and studying the nature of SAPP oscillations
- Development of real-time monitoring tools (In partnership with NREL and CSIR) for operators situational awareness

Thank you