

Operations Challenges Driven by Oscillatory Modes in the Southern African Region

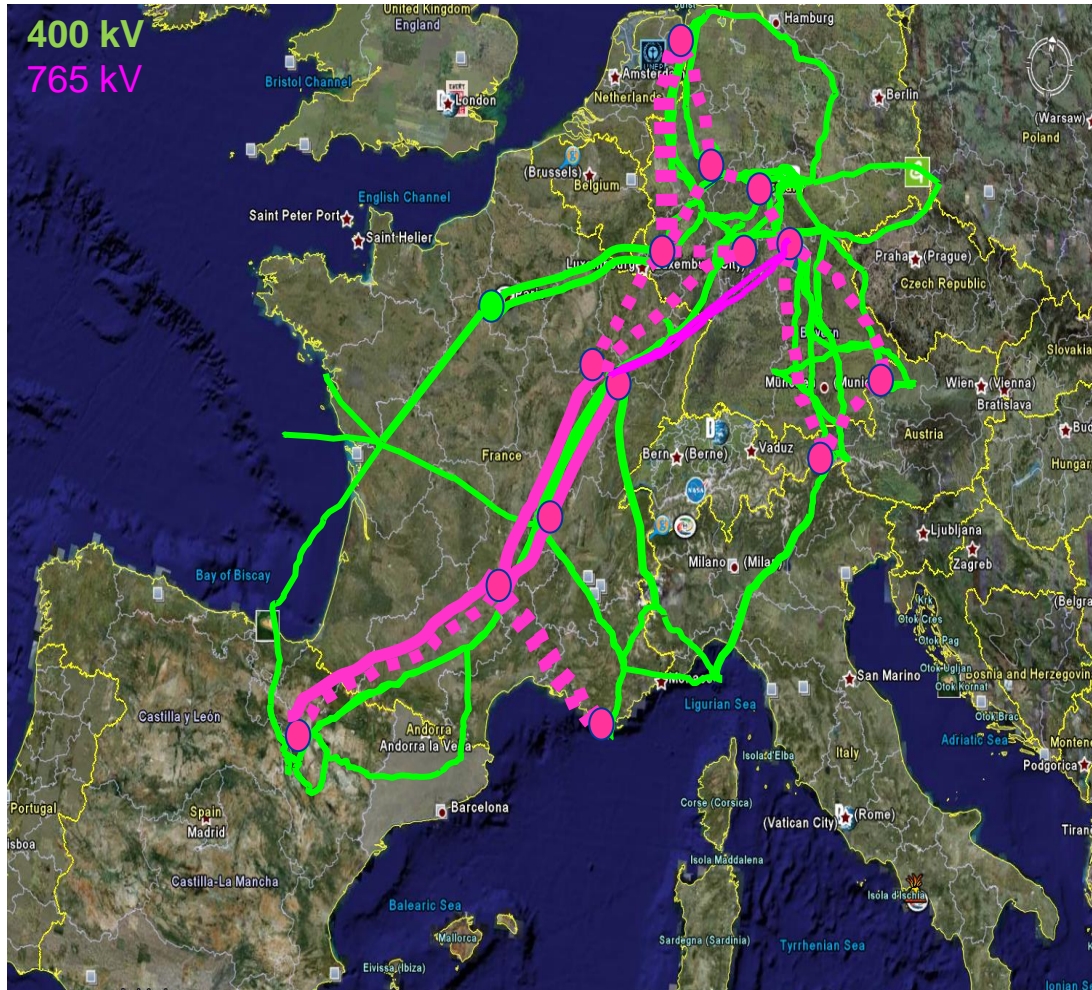
**Bonginkosi Sibeko, Chief Engineer
Eskom System Operator, South Africa**

25 October 2023



- **Southern African Power Pool (SAPP) Background**
 - Power system stability classifications affecting SAPP network
 - Generation capacity, load centres and transmission network layout
- **SAPP Oscillations events and themes**
 - Substation split incident that resulted in 0.6Hz mode of oscillation and near system collapse
 - 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
 - Undamped oscillations caused by a Northeast generating unit's stuck governor valve
- **Lessons learnt in Controlling and Managing oscillatory modes in SAPP**

South Africa's Transmission network superimposed on Europe



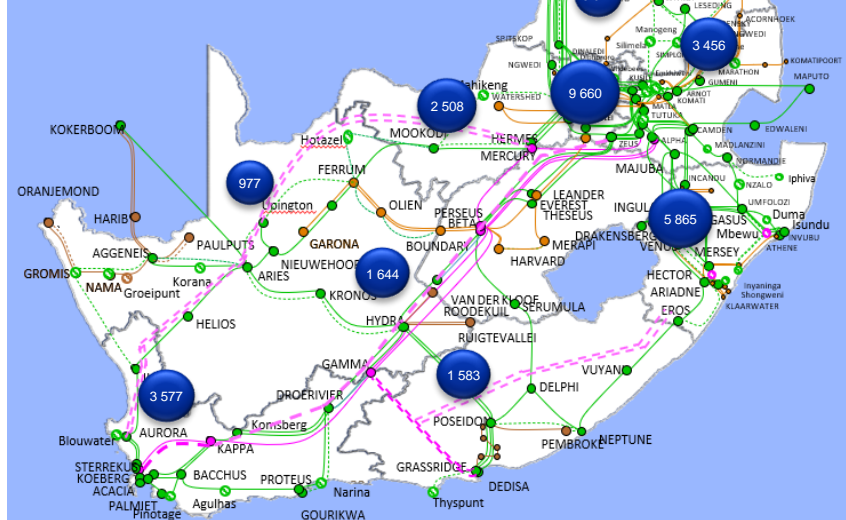
- SAPP has three control areas - **Eskom**, **ZESA** and **ZESCO**
- Approximately **3400km (2,112 miles)** from Cape town (SA) to Zambia.

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



South Africa's Demand, Transmission and Supply

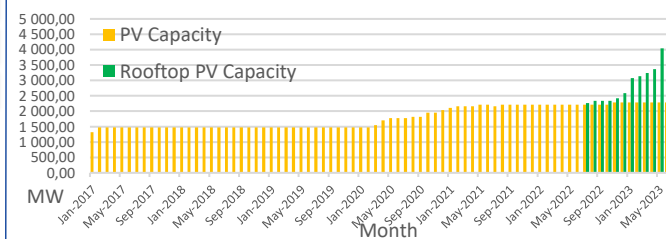
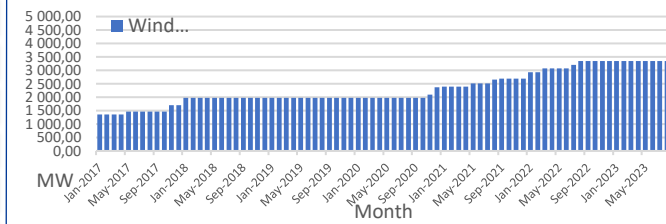
| | |
|------------------------------------------------------------|---------------|
| Annual peak demand (Mon 10-Jul-2023 18:00-19:00) | |
| RSA Contracted Demand | 33,873 |



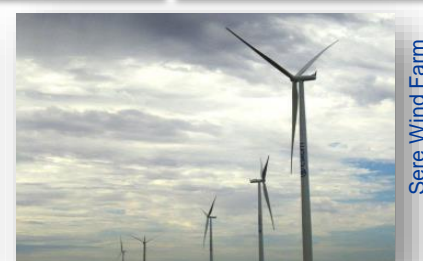
| Transmission lines | km | Transmission substations | # |
|--------------------|---------------|------------------------------------|-----|
| 765 kV | 2 784 | Substations | 169 |
| 533 kV HVDC | 1 032 | Transformers (> 30 MVA) | 449 |
| 400 kV | 19 916 | Transformer MVA installed (>30MVA) | 154 |
| 275 kV | 7 342 | | 500 |
| 220 kV | 1 352 | | |
| 132 kV | 766 | | |
| Total | 33 192 | | |

| 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 |

| 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 |



Arnot Power Station

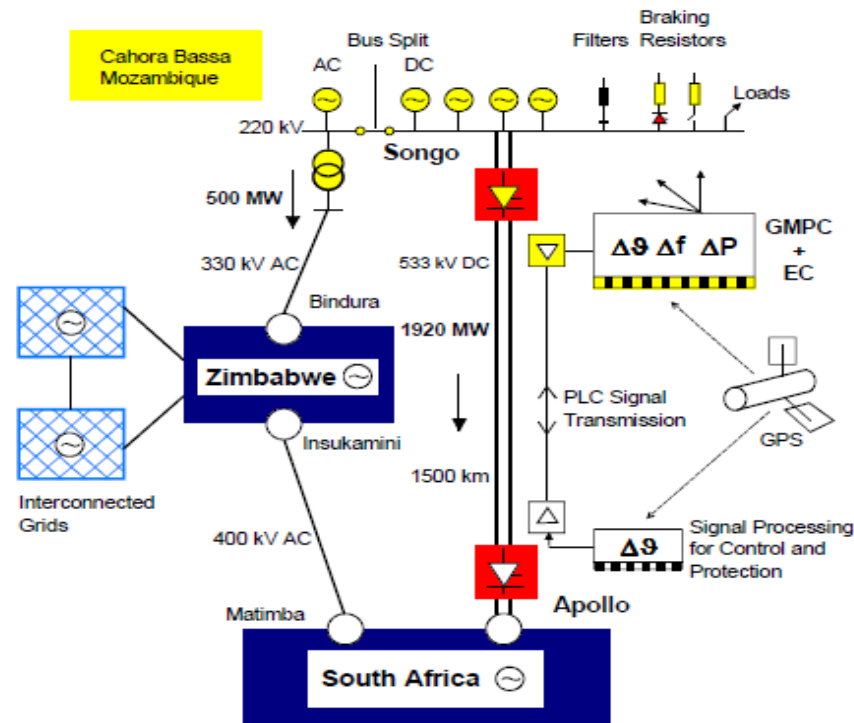


Sere Wind Farm

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

| 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



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)**

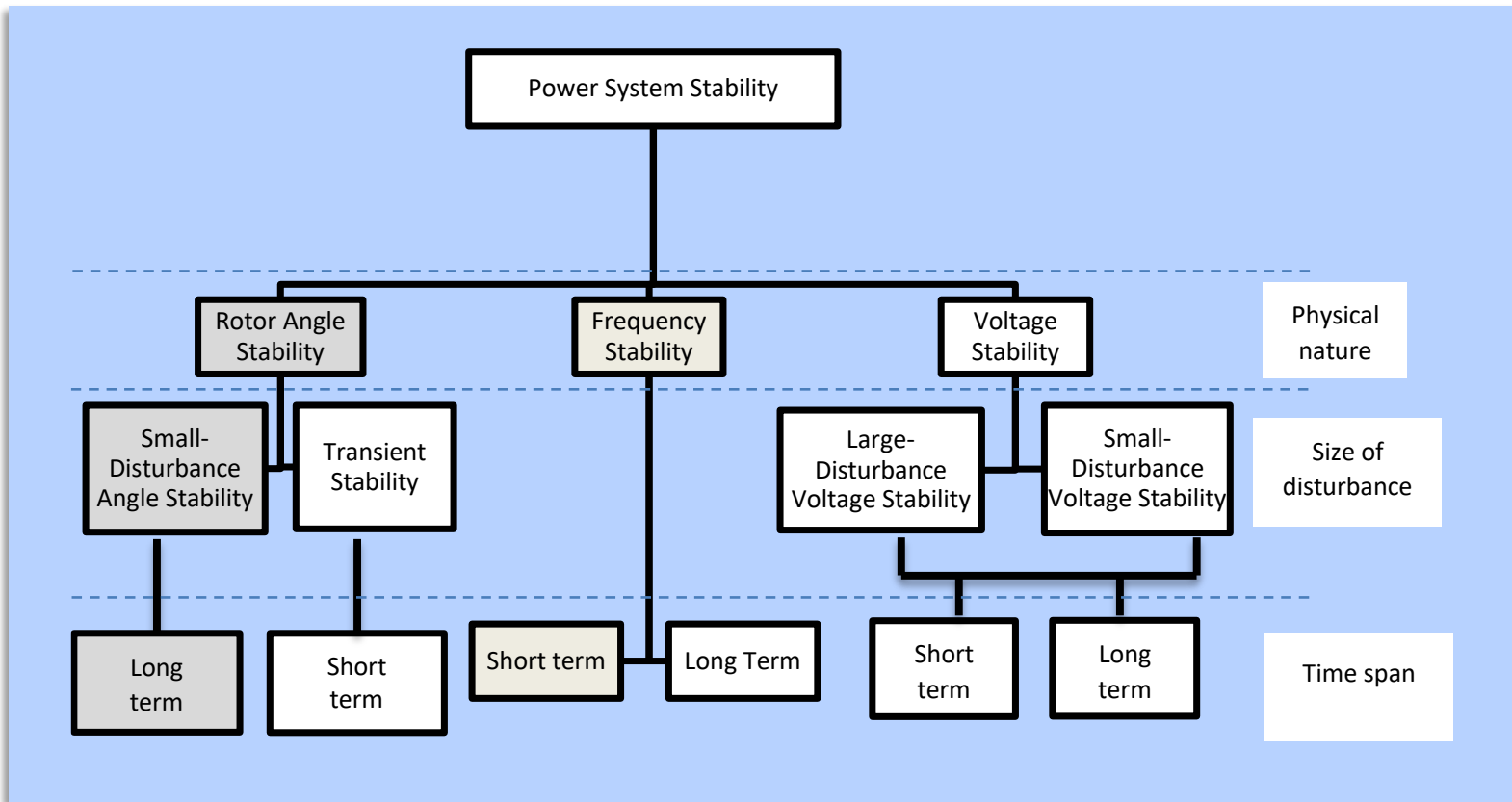
If Frequency $f \in [49,2 < f < 49,6]$ for continuous $t \geq 18$ seconds - Underfrequency

If Frequency $f \in [50,4 < f < 50,8]$ for continuous $t \geq 18$ seconds - Overfrequency

Instantaneous (200 milliseconds delay):

If Frequency $f \leq 49,2$ (Δ Hysteresis = 0,05 Hz) - Underfrequency

If Frequency $f \geq 50,8$ (Δ Hysteresis = 0,05 Hz) - Overfrequency



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 Inverter Based Renewables

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)**

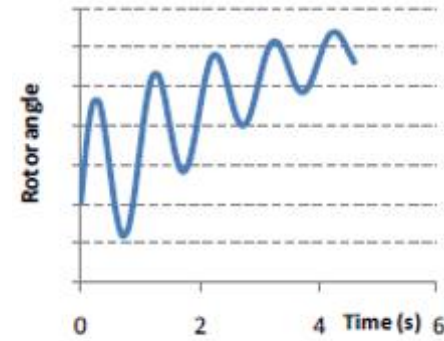
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3 **Undamped oscillations caused by a Northeastern generating unit's stuck governor valve**

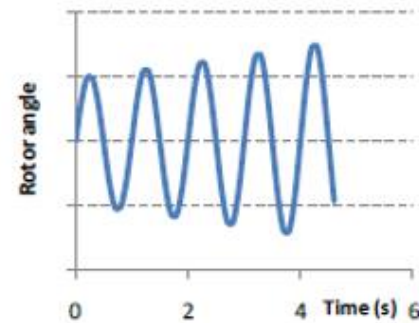
1 Inter-area within Eskom grid – 0.4-1.0 Hz



Positive T_d , negative T_s



Negative T_d , positive T_s

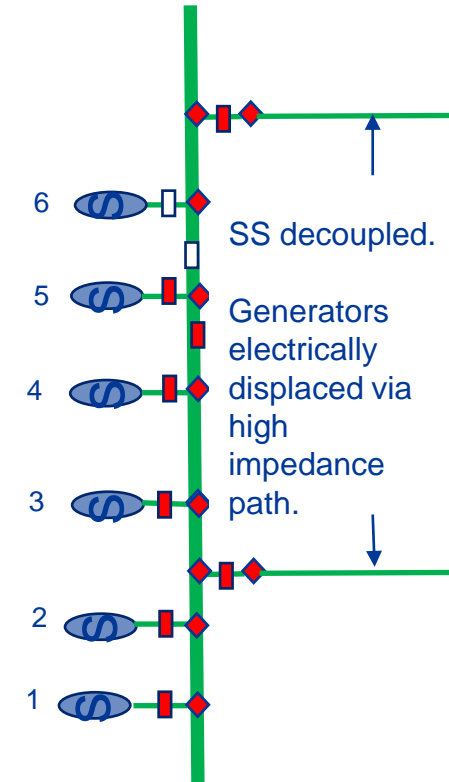
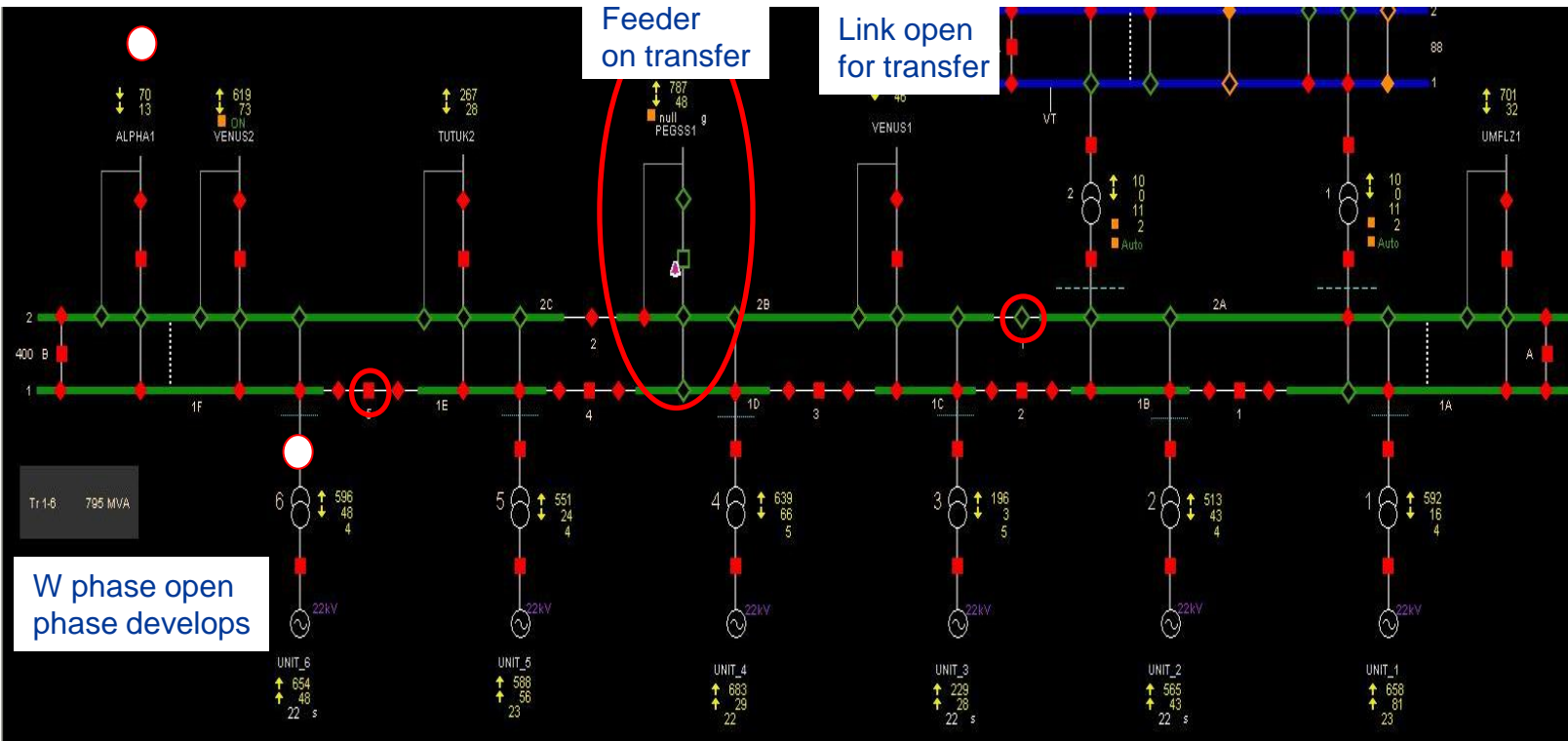


- Observed between North East and South-West clusters
- Oscillations between groups of generators
- Stability issues are affected by
 - **Types and locations of exciters**
 - Load characteristics
 - **Power transfer on corridors**
 - System loading
 - **Weak Interconnections/Post-contingency strength**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

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

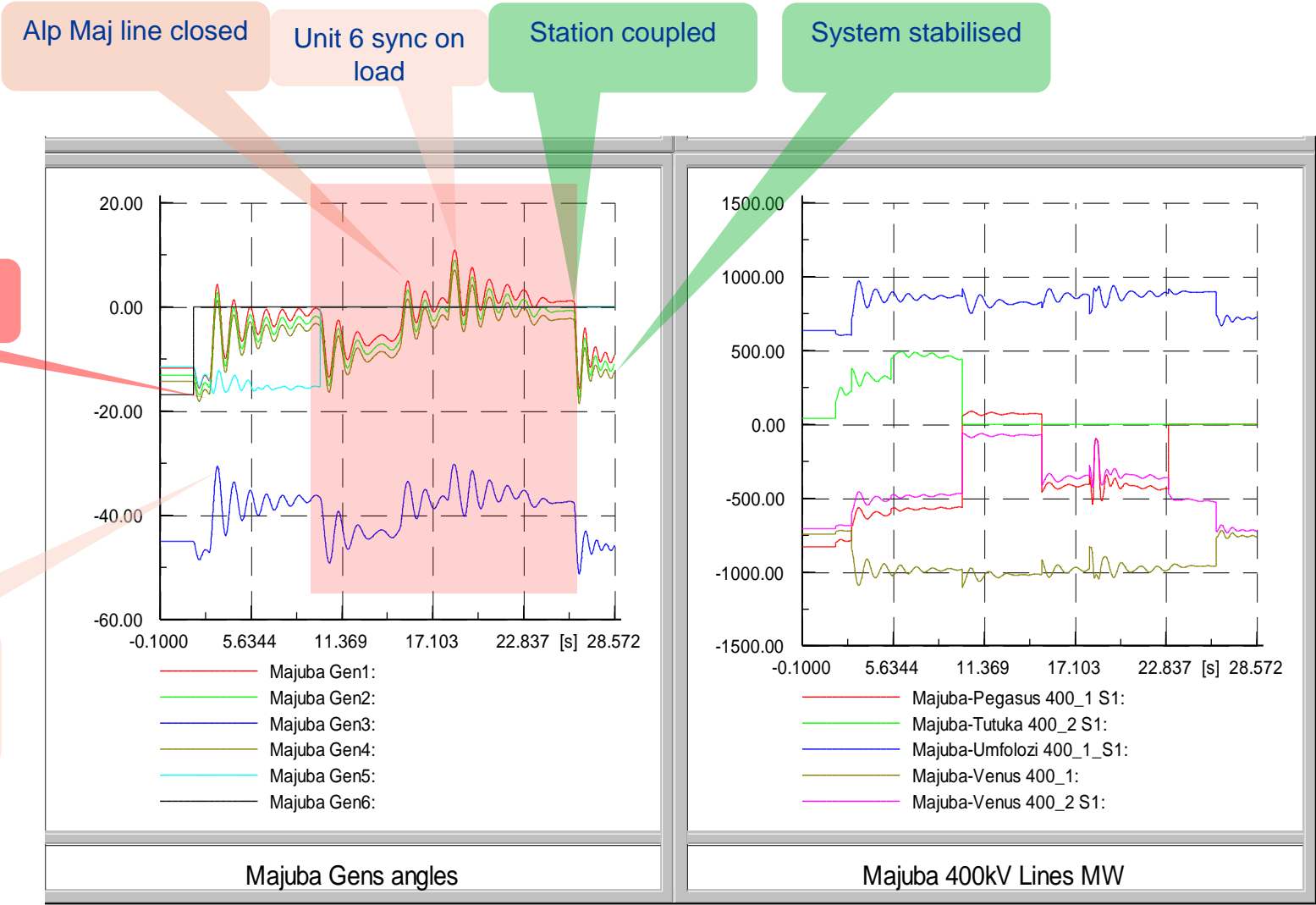
1

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)

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

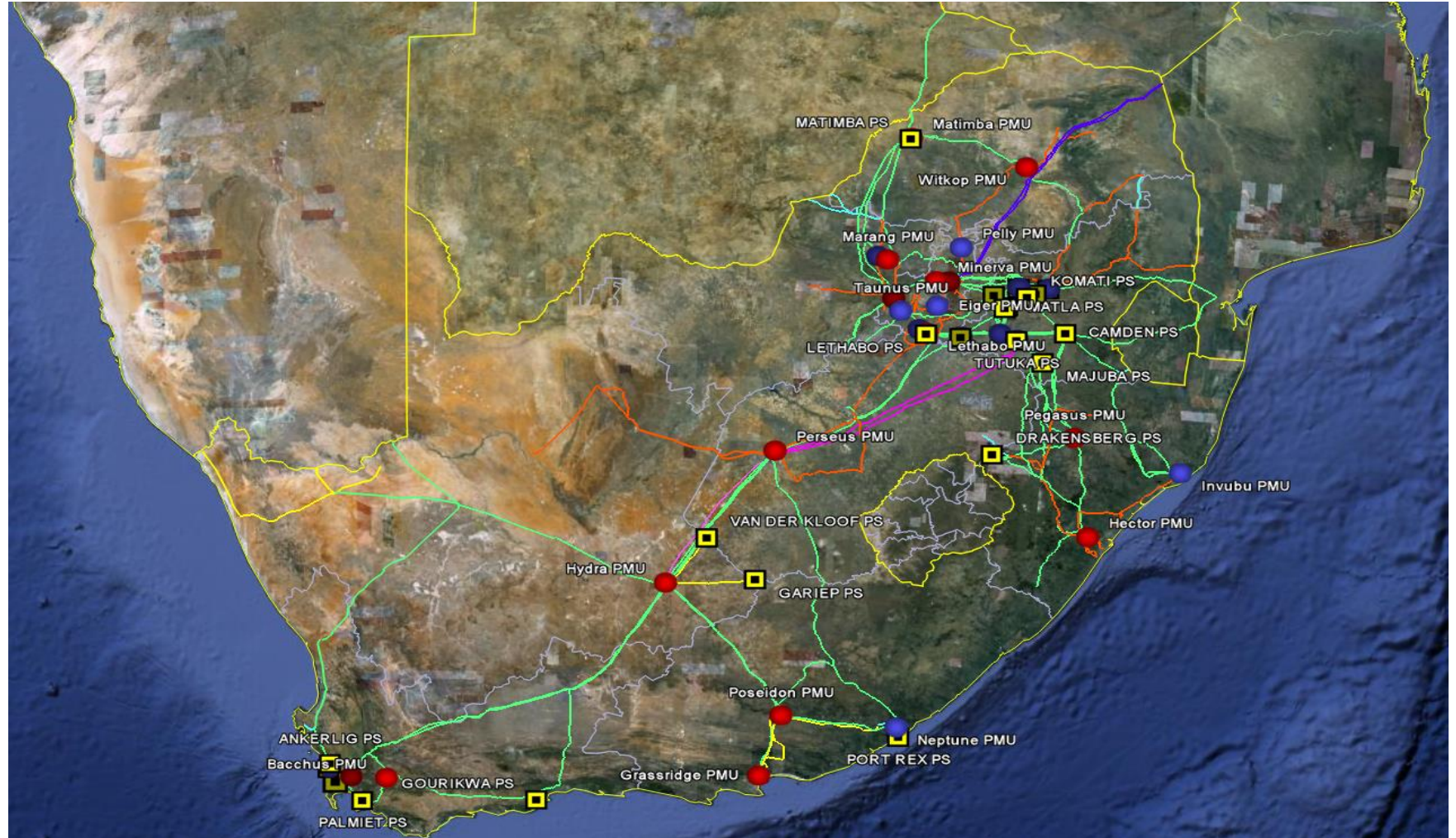


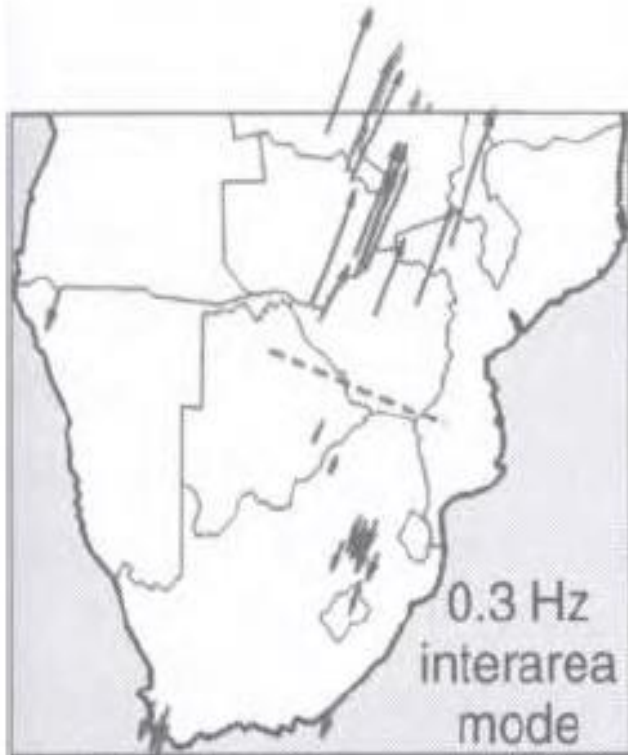
PMU Locations in South African Network

- Power Station
- 15 PMU Substations
- 13 PMU Tx Substations

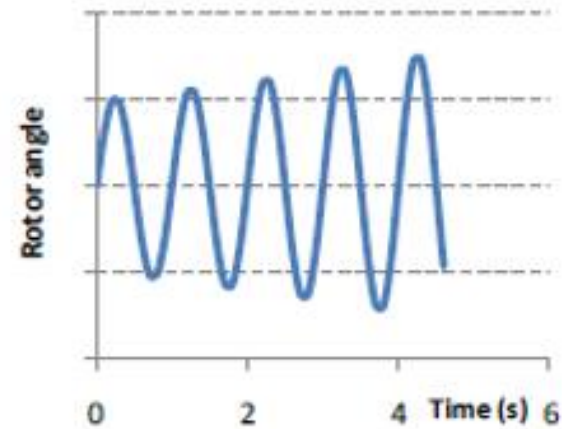
Total Installed 28

Operational 18





Negative T_d , positive T_s

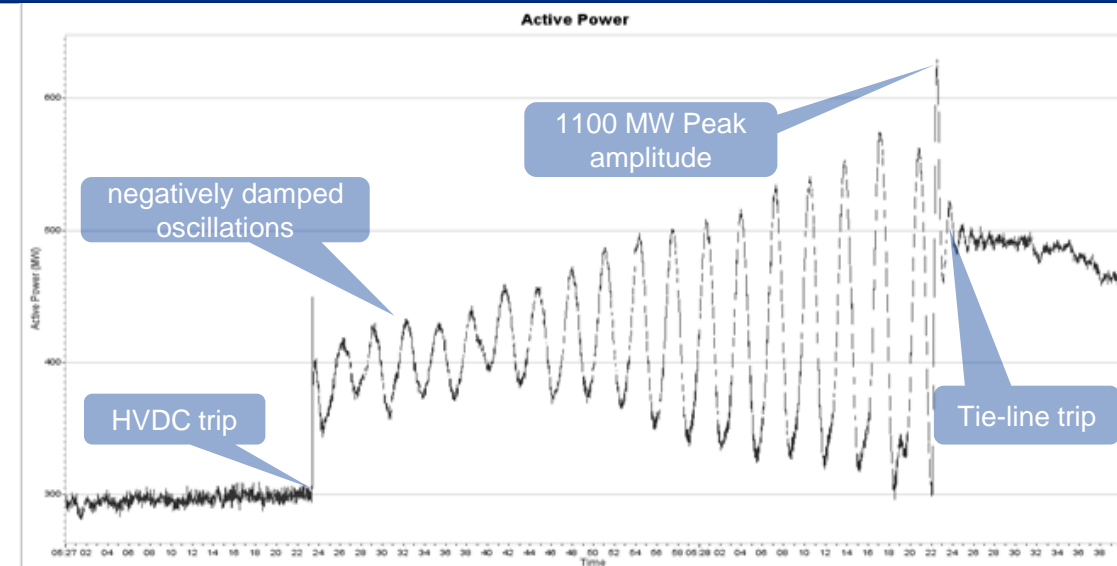


- Oscillations involving most generators e.g. 0.3Hz
- Stability issues are very complex and affected by
 - **Types and locations of exciters**
 - Load characteristics
 - **Power transfer on corridors**
 - System loading
 - **Weak Interconnections/Post-contingency strength**
 - **Insufficient stabilisers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

2 ACDC Line faults leading to oscillations – 13 October 2018

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

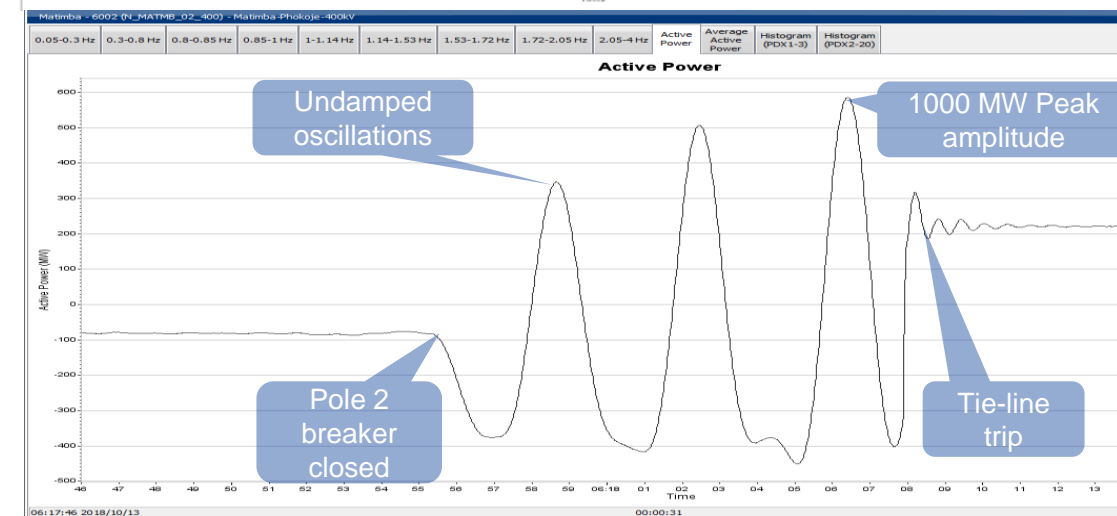
| | |
|-----------------------------------|-----------------------------------------------------------------------------------------------------|
| Weather | Heavy storms reported over Apollo DC lines |
| ROOT CAUSE OF OSCILLATIONS | Apollo Converter Station (CS) Pole trip due to a line fault. |
| LOSS 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

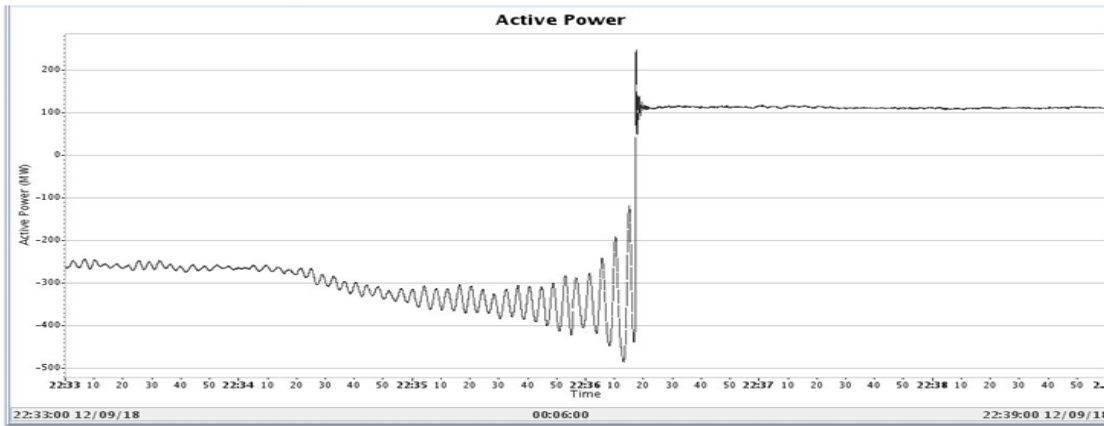


2 Oscillations triggered by load rotation during load shedding

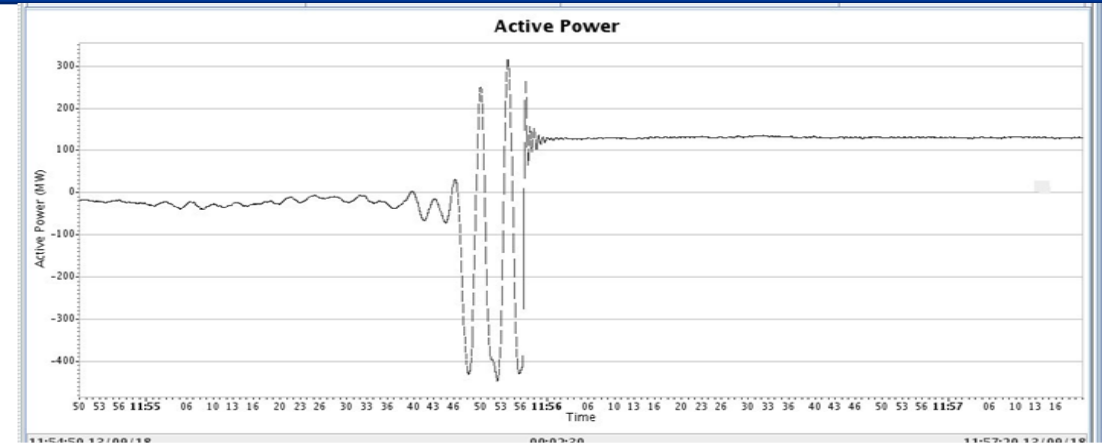
| Date & Time | Description Root cause | Frequency and Active Power plots Frequency vs time | Eskom – North control area Power (MW) |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|---------------------------------------|
| 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

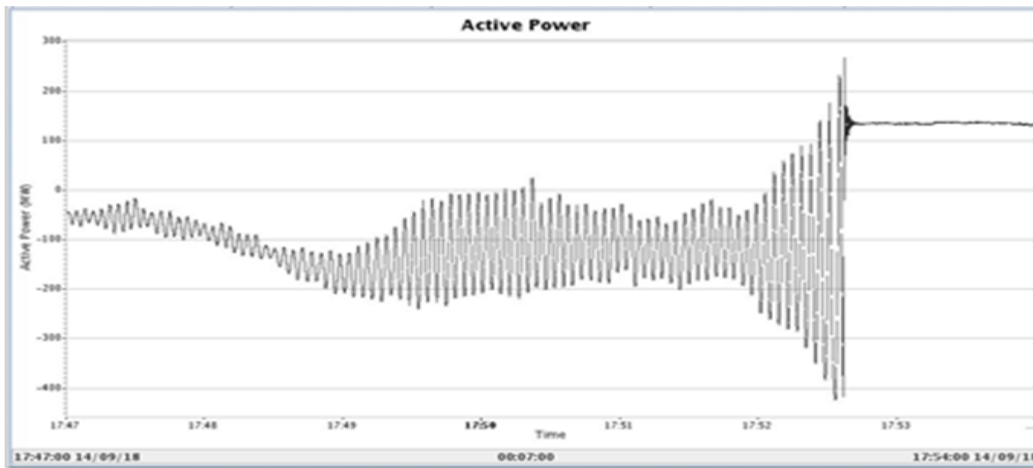
Undamped oscillation triggered by inoperable control systems (SVC with POD and PSS)



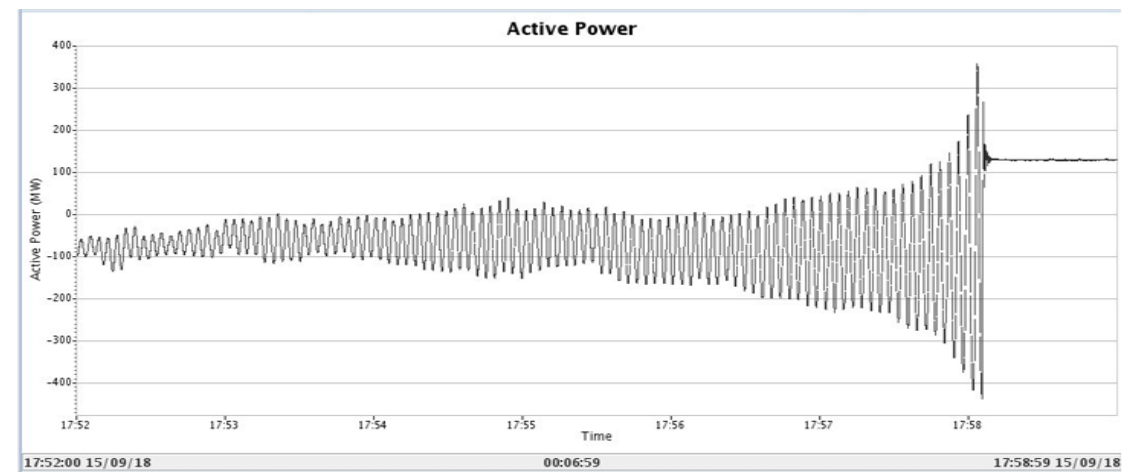
12 September 2018 – 22:34 Matimba-Phokoje (MW)



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

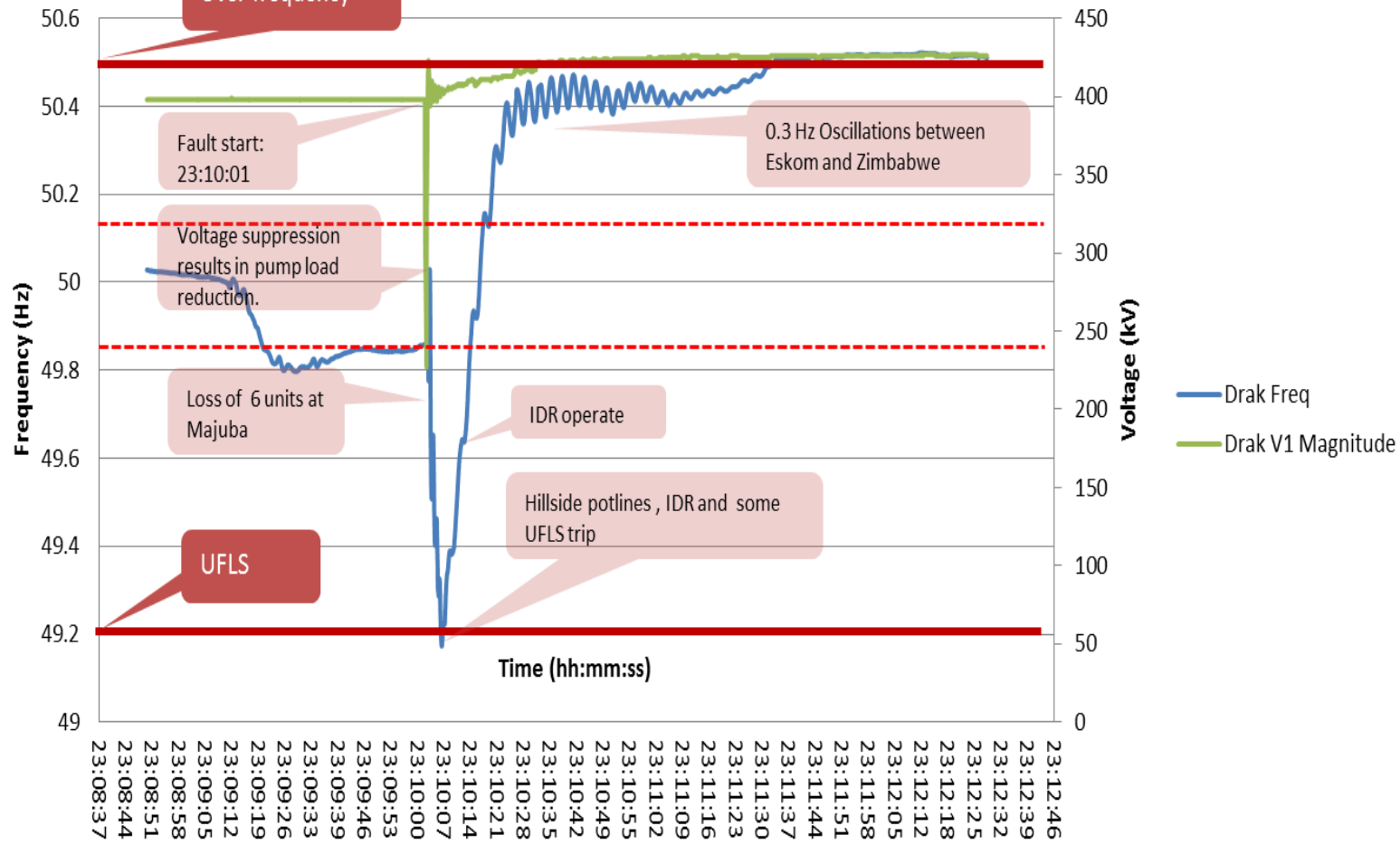


14 September 2018 – 17:40 Matimba-Phokoje (MW)

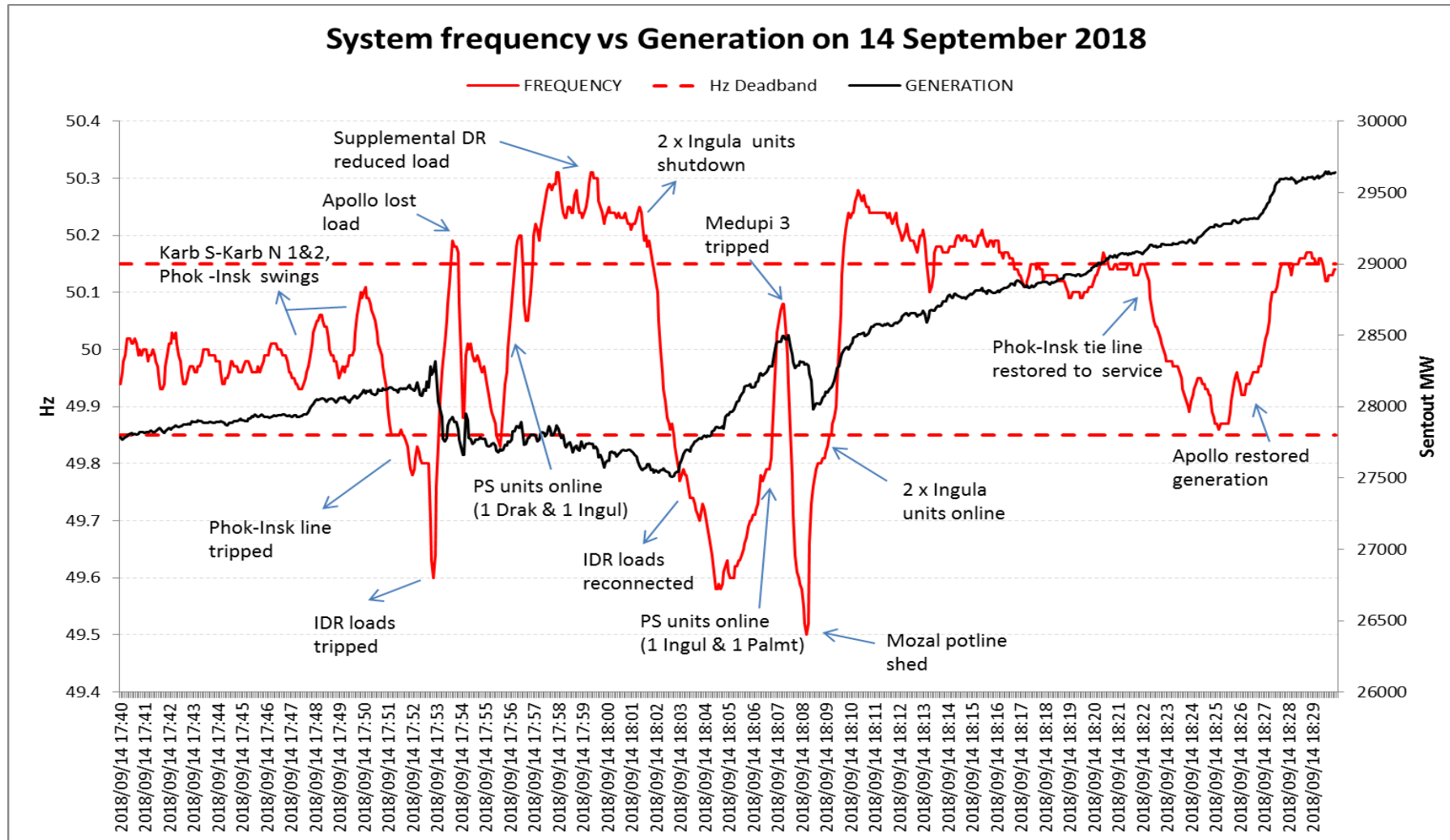


15 September 2018 – 17:45 Matimba Phokoje (MW)

Frequency and Voltage plot

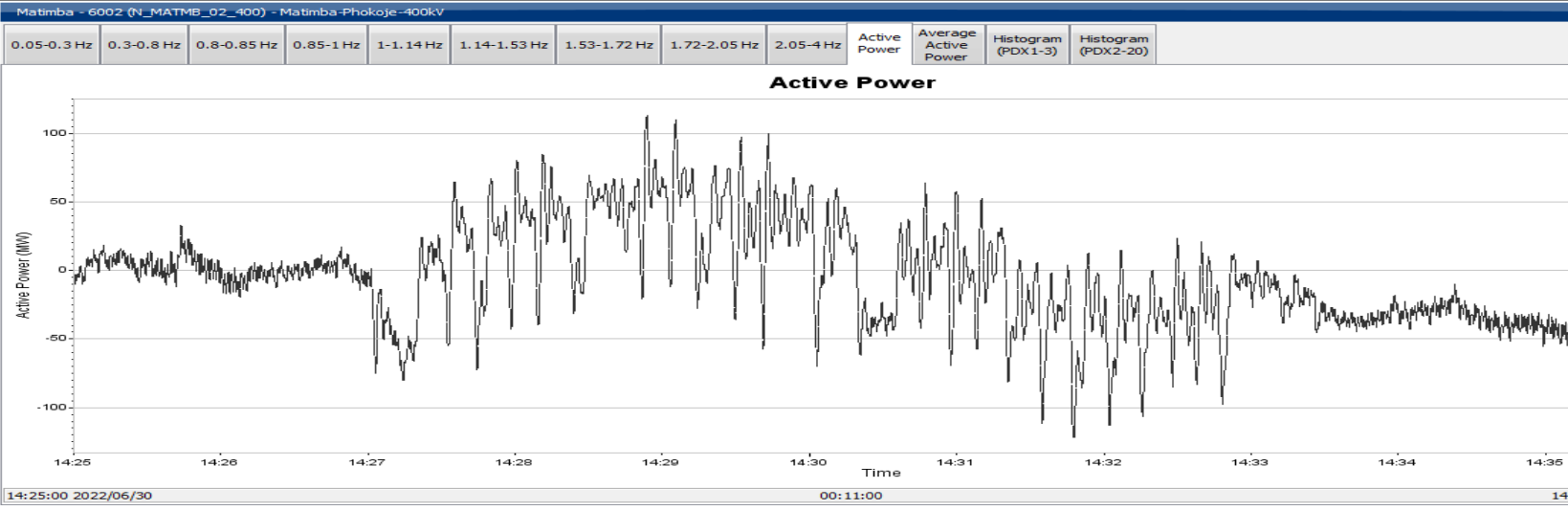
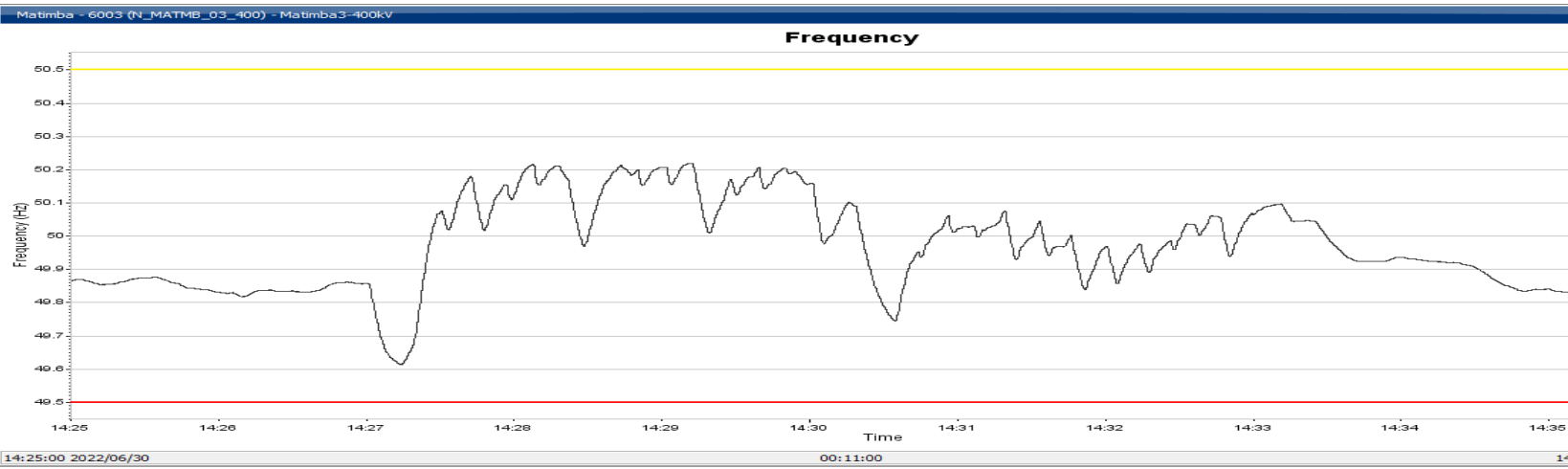


- 30 December 2018 MUT incident
- Power station HV yard fault
- Loss of 6 units (about 15% of total generating units on the day)

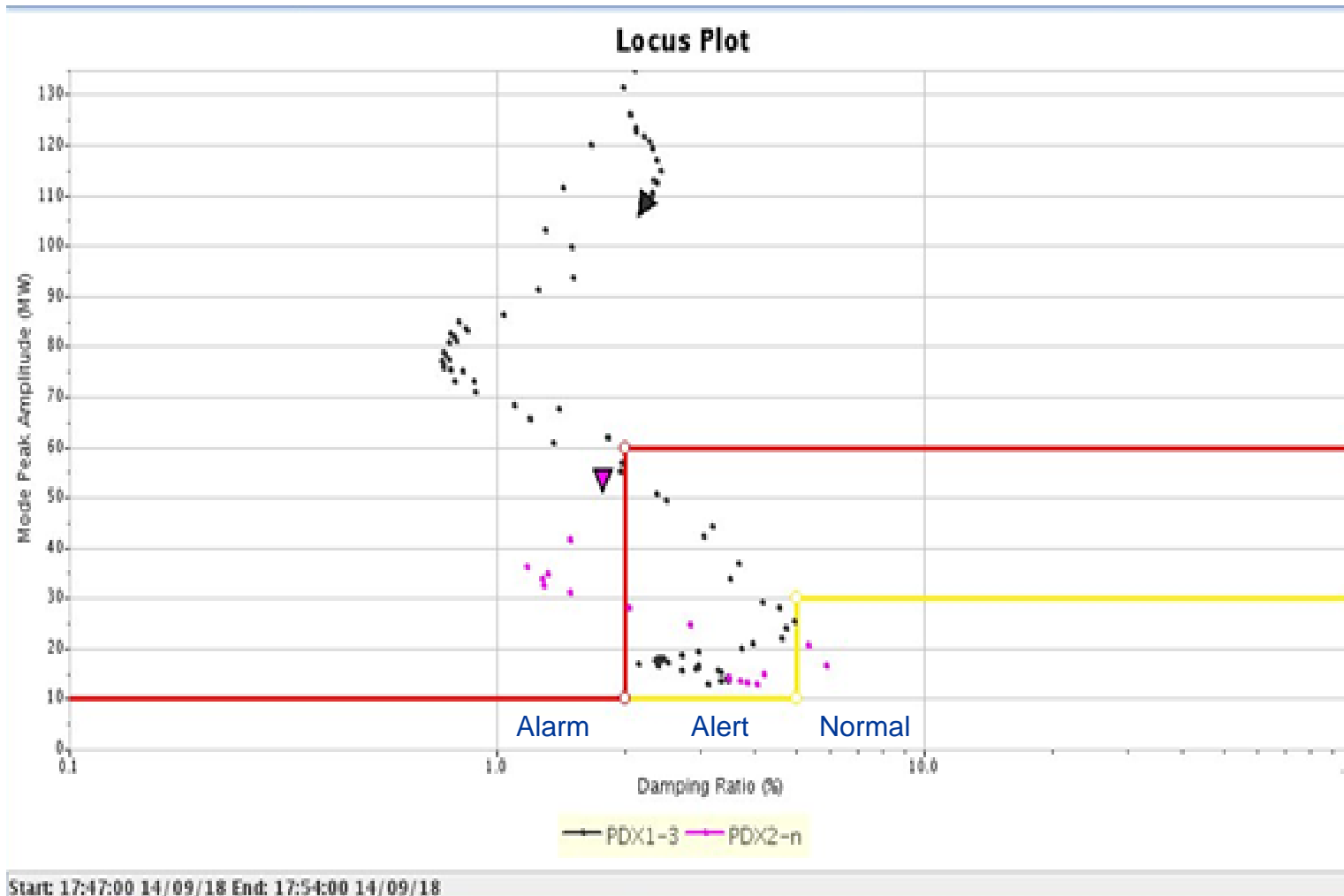


3

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



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.

- Importance of Joint fault investigation and sharing of data
- Modeling and Simulations events post disturbances
- Tuning 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