GE DIGITAL ENERGY

Regional Interconnections Solutions for Network Stability

Benoit Pradairol / Daudi Mushamalirwa

01 October 2018

Power System Analysis

INCIDENT ANALYSIS	**Solve and cure incidents from equipment involved up to overall network**	• Technical auditing • Failure analysis • Preventive solutions • Corrective solutions • Life-cycle analysis
NETWORK PERFORMANCE	**Optimize networks and equipment performance**	• Energy quality improvement • Reliability improvement • Upgrading & refurbishment • Maintenance priorities • Reinforcement and redesign • Harmonics filtering
NETWORK PLANNING	**Support network development Get efficient design and sizing recommendations**	• Project definition • Network design & expansion • Network interconnection • Network congestion analysis • Plant impact & integration • Equipment specifications




Agenda

- ❑ Benefits of Interconnection Systems
- ❑ Technical Challenges
- ❑ FACTS solutions to enhance stability
- ❑ Examples of FACTS projects
- ❑ HVDC solutions for long distance power transfer and system stabilization

Introduction

East African Power Pool as other power Pools in the world aim at getting benefits of developing interconnections between country members.

Expected benefits among others are:

- optimization of generation resources
- increase in inter-country electricity exchanges, i.e. enhance security of supply
- reserve sharing , i.e. improve power system reliability
- strengthen the network, i.e. improve stability
- reduce operating costs by using low cost units first and avoid unnecessary start-ups and shutdowns
- development of a regional market for electricity.

Introduction

Besides these benefits different challenges have to be considered.
These can be technical and non-technical. Let’s focus on technical.

Technical challenges

- Sufficient Generation to share
- Sufficient transfer capacity of interconnections
- Operating rules of the interconnected systems
- Stability of the interconnected systems
- Voltage control and management of reactive power

Introduction

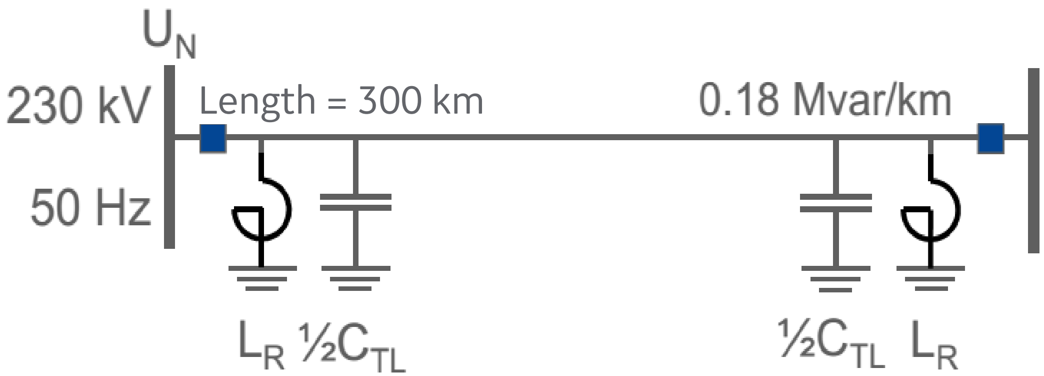
A number of interconnections have been identified in EAPP master plan to facilitate the exchange of power within the pool.

- Tanzania – Kenya 400kV
- Rusumo-Rwanda-Burundi-Tanzania 220 KV
- Ethiopia-Kenya 500 KV HVDC
- Uganda- Kenya 220KV
- Uganda- Rwanda 220 KV
- Etc…

Some of the interconnections are long distance lines (more than 300 km).
Such transmission lines can lead to operational issues that necessitate appropriate mitigating solutions.

Technical challenges

- One of the main challenges of long distance HVAC transmission lines are related to the **management of reactive** power generated by the line.



Example

- For a 230 kV line approximately **0.18 MVAR / km**
- For a 400 kV line, approximately **0.6 MVAR / km**
- For a 500 kV line, can reach **1 MVAR / km**

Technical challenges

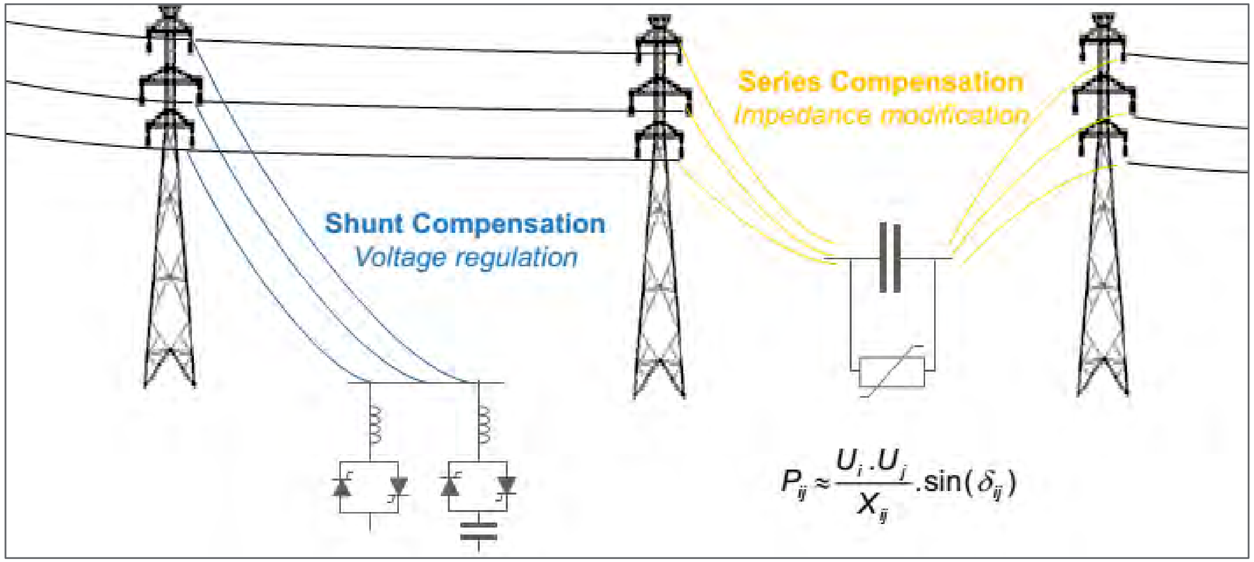
- **Why controlling Reactive Power**

  When the length of the line is high, the reactive power generated by the line can lead to instabilities and degradation of the system performances. Therefore controlling the reactive power is mandatory and will:

  - Improve the voltage fluctuations (voltage drops and voltage increases)
  - Increase transmission system stability, capacity and power quality
  - Adjust voltage to user defined level;
  - Dampen power oscillations in network and avoid system collapse
  - Reduce transmission system losses

Technical challenges

- **Transfer capacity and Stability of the system**: the transfer capacity of the line is inversely proportional to the reactance of the line, i.e. more the line is long less power can be transferred



FACTS Solutions to enhance Network Stability

FACTS Devices

Flexible Alternating Current Transmission Systems

- **Therefore it is important to control (compensate) the reactive** power for a good operation of the network.

- Different alternatives exist:
  - Fixed Shunt compensation (reactors, capacitors)
  - Variable shunt compensation type SVC or STATCOM
  - Fixed series compensation
  - Variable series compensation
  - Combination of the above

FACTS Solutions

Concerns

- Increase transmission capacity of existing lines
- Reduce losses
- Insure grid code compliance
- Improve system stability
- Improve quality of energy

Issues

- Fast voltage control
- Reactive power control
- Power oscillation damping
- Load flow control
- Harmonic control

Solutions

Shunt compensation

- ✓ MSC
  - Mechanically Switch Capacitor
- ✓ MSR
  - Mechanically Switch Reactor
- ✓ SVC
  - Static Var Compensator
- ✓ STATCOM
  - Synchronous Static Compensator

Series Compensation

- ✓ FSC
  - Fixed Series Capacitor

GE Innovative Solutions to manage HV transmission systems
Power Electronics Technologies

Improve quality & stability and maximize network performance

HVDC

- Transfer Bulk Power
- Infeed Urban Areas
- Connect Off Shore Wind
- Connecting Renewables
- Interconnecting Grids
- Multi Terminal

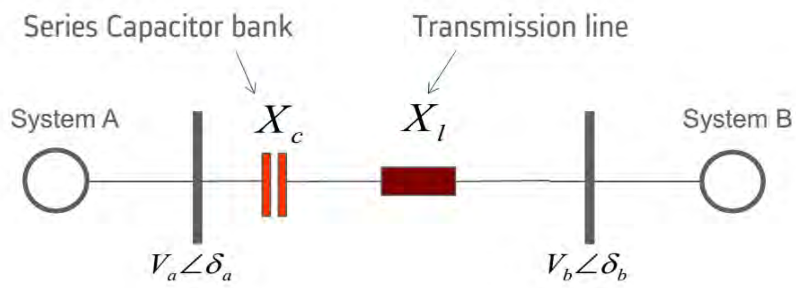
FACTS

- Increase Power Transfer Capability
- Dampen Power Oscillations
- Manage Reactive Power
- Improve Short Circuit Power

DC Power

- HV Aluminium Plants
- MV Industrials
- Grid Congestion

Series compensation



The idea of the FSC is to shorten the electrical distance of the transmission line

$$P = \frac{V_a \cdot V_b}{X_l - X_c} \cdot \sin(\delta_a - \delta_b)$$

$$s = \frac{X_c}{X_l}$$

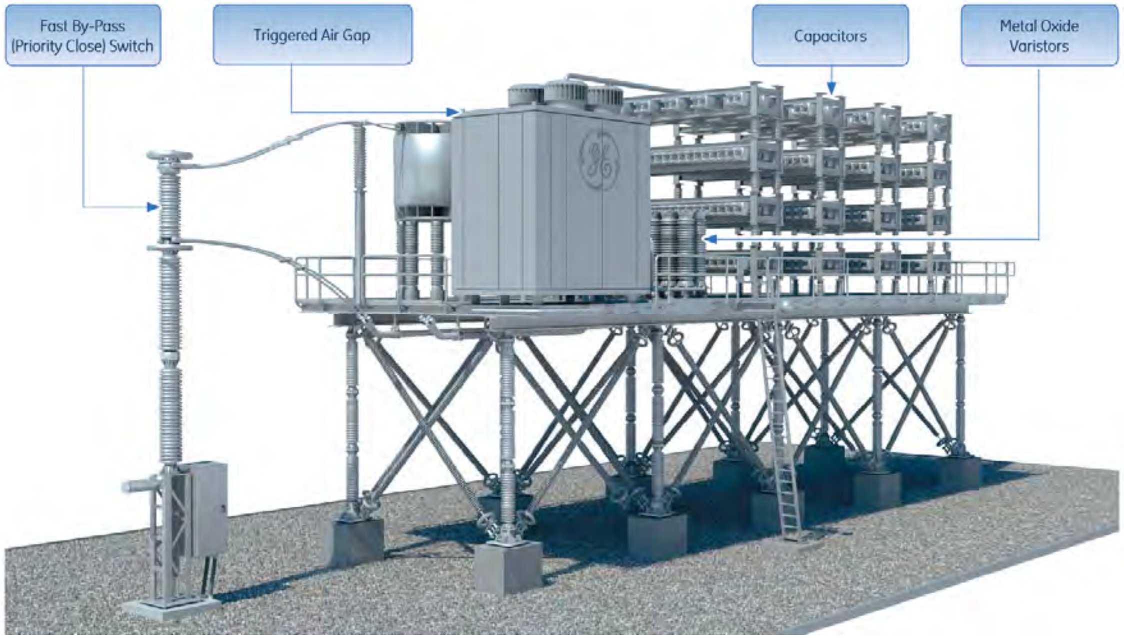
S = compensation degree

$$P = \frac{V_a \cdot V_b}{X_l (1 - s)} \cdot \sin(\delta_a - \delta_b)$$

Series Solutions - Fixed Series Compensation (FSC)

Description

Series Compensation is an integrated, custom-designed system that consists of **power capacitors arranged in series with the HV transmission line**. The capacitors are accompanied by a **parallel protective system** that will prevent damage to the capacitors under power system events (faults)



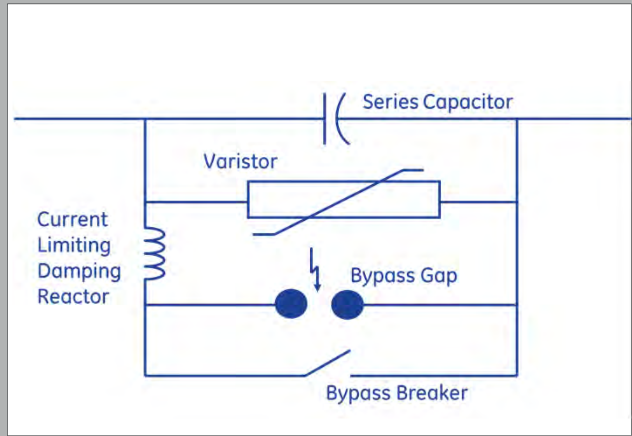
Series Solutions - Fixed Series Compensation

Key Customer Benefits:

- **Significantly increases the power transfer capability of the line**
- Reduces line voltage drops in load areas
- **Shares the load more evenly between parallel transmission lines**
- Improves steady state and transient stability
- Reduce system losses
- **Minimal land requirements**
- **Low environmental impact**

Main Characteristics:

- **Always an optimized, tailor-made solution** depending on network data and tasks to be performed
- All main equipment are inserted in series with the line and then are at UHV/HV line potential, up to 1100 kV
  - All main equipment are installed on an isolated to ground platform



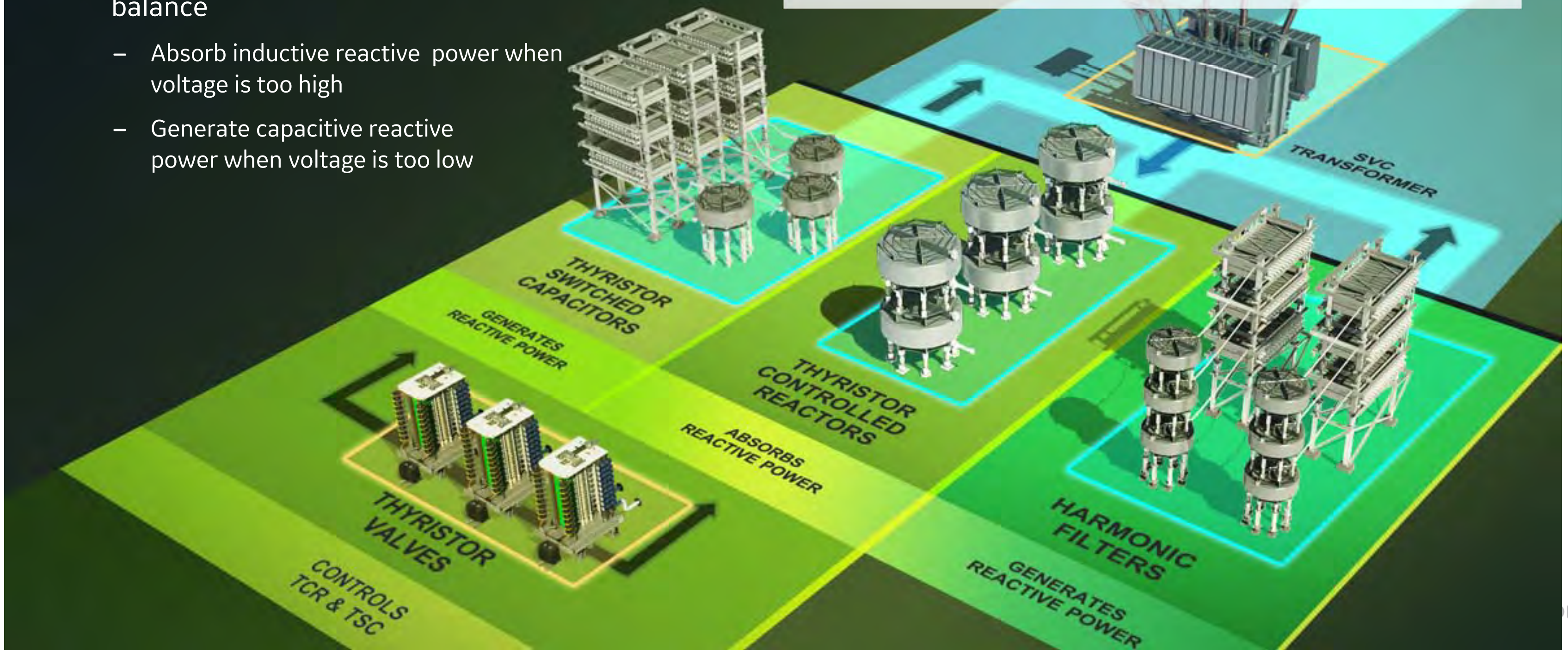
Fixed Series Compensation - Customer Examples

- **Elecnor (Chile)** – Alto Jahuel – 500 kV – 241 Mvar bank
- **Scottish Power (Scotland)** – 400 kV – 3 sites (4 banks) 2 x 560 Mvar & 2 x 442 Mvar
- **ENARSA (Isolux, Argentina)** – 500 kV, 378 Mvar bank
- **Beta Engineering \ SDG&E** -500 kV, 449 Mvar bank
- **Cross Texas Transmission** - Single site (2 banks) 715 Mvar each

Shunt Solutions – Static Var Compensator (SVC)

Description

- **Dynamically variable** sources of reactive power to stabilize the voltage, to damp system instabilities and to reduce flicker for both transmission and industrial applications.
  - 2 to 3 cycles response time
- Static Var Compensator (SVC) controls transmission line voltage to compensate for reactive power balance
  - Absorb inductive reactive power when voltage is too high
  - Generate capacitive reactive power when voltage is too low



RTE SVC, France, ±250 MVAr, 225kV

TCR reactors　　5th harmonic filter　　Main reactors

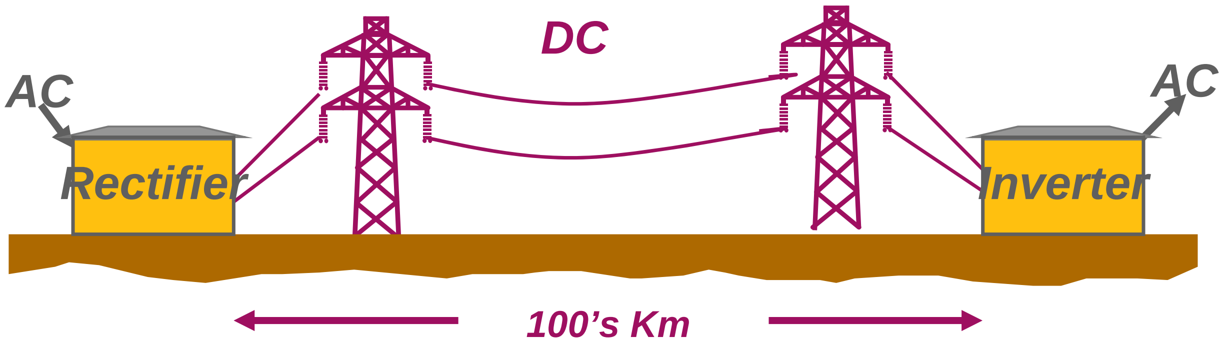
Power transformer

Thyristor valves room

MSE

HVDC Solutions

Transmission, to connect power across great distance

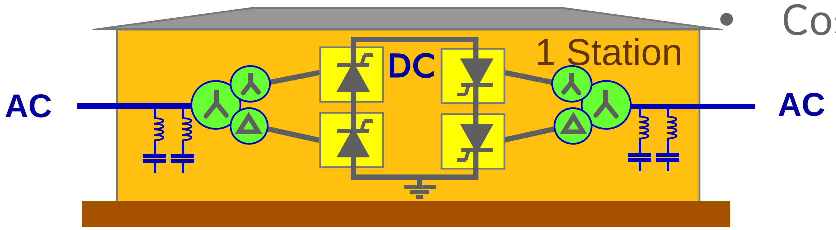


In case of long distance and large power to transfer, HVDC interconnection solution can be preferred

- Allows a complete separation between two AC systems which can operate at different frequencies.
- Reduces the losses
- Enhance stability of the interconnected system
- Cost effective

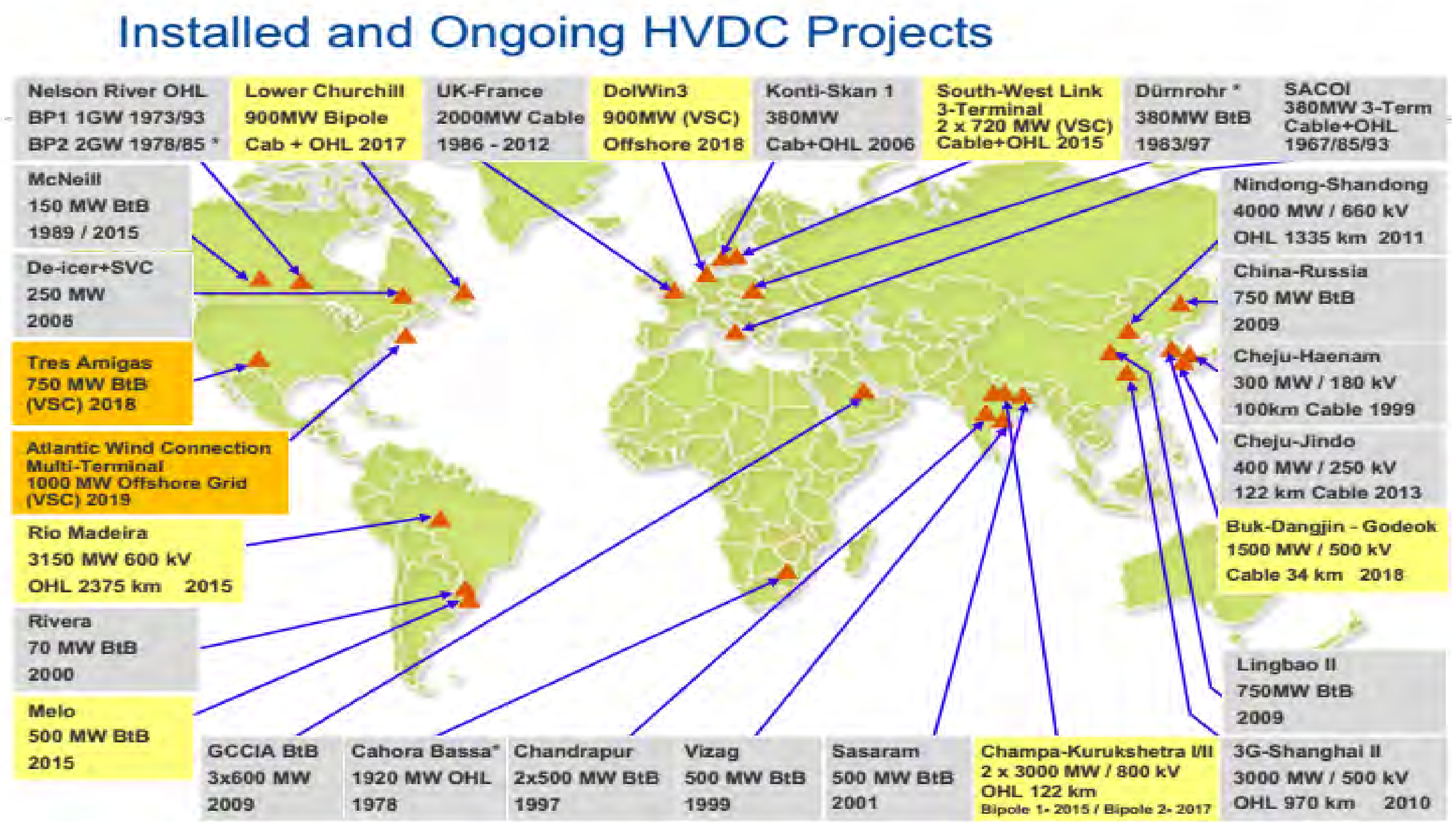
Back-to-Back

- frequency changing
- asynchronous connection

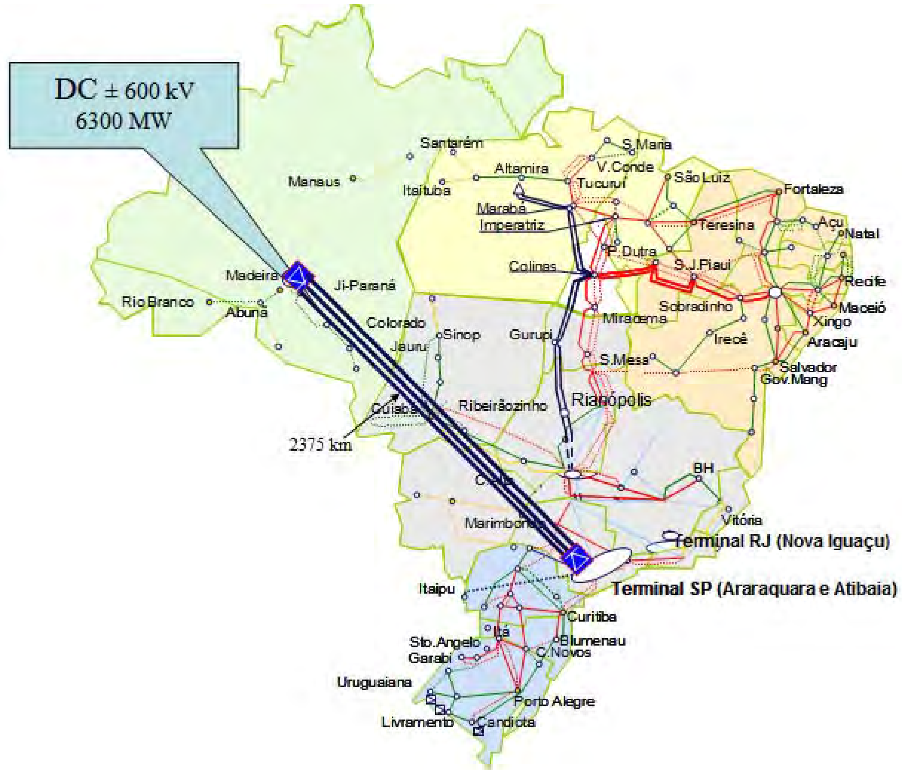


20

HVDC Solutions - Examples



HVDC Solutions



- Rio Medeira, Brazil:
  - 3150 MW.
  - 2375 km overhead cable.

HVDC Solutions – GCCIA Back-to-Back

GCCIA : Converter station loaction

GCCIA 3 x 600MW BtB HVDC

Software Solutions for Network Stability

GE DIGITAL ENERGY

INDUSTRY DRIVERS

RETIRING WORKFORCE

GRID MODERNIZATION
More devices, more data

DISTRIBUTED ENERGY RESOURCES

CONSUMER EXPERIENCE
Informing & empowering the consumer with more data, choices & better engagement - social media

CYBER-SECURITY

CAPEX & OPEX PRESSURE
Growing acceptance for hosted & managed solutions

SITUATIONAL INTELLIGENCE
Data finds the user, better insights = better decisions

RENEWABLE ENERGY

SYSTEM SCALABILITY
From energy cluster to large Interconnected grids

BUSINESS MODEL CHANGE
Regulatory shifts

ENVIRONMENT
Public Safety, Storm Restoration, Changing Weather, GHG

NEW SYSTEMS & TECHNOLOGIES
DER, DA, AMI, Smart Inverters,
Storage & Fuel Cells

SYSTEM DYNAMICS
Operating near to true real-time limits

DEV OPS
Acceleration of time to value via continuous integration & deployment over traditional waterfall IT projects

BATTERY STORAGE

Cor

proval.

GE DIGITAL ENERGY

SOFTWARE SOLUTIONS

End-to end, Integrated & Interoperable

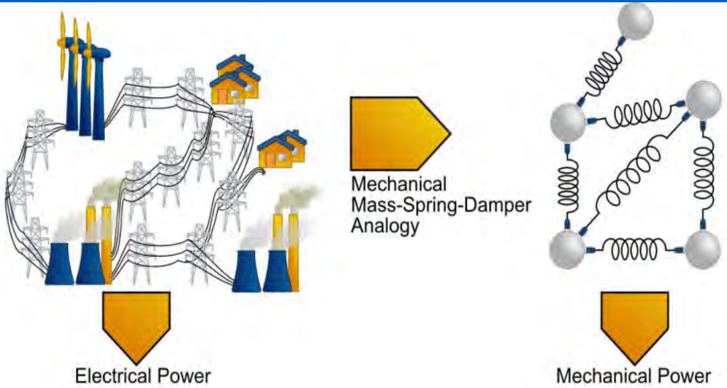
The **optimum way to solve** for the challenge of grid transformation is an integrated & interoperable grid management solution

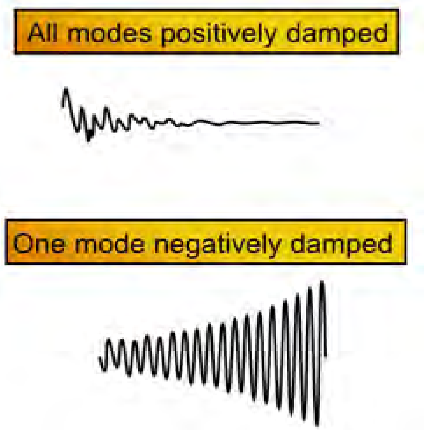
The **optimum response** is a portfolio solution that is predictive & prescriptive, connecting traditionally siloed systems & providing integrated workflows end-to-end, delivered via a brilliant UI/UX

The **optimum solution** connects & orchestrates in new ways, leveraging data across the enterprise using advanced analytics, machine learning & AI, & flexible in form—on-prem, on the edge & in the cloud

Introduction to Power Systems Stability

“The interconnected electric power grid is one of the largest dynamic system of today”



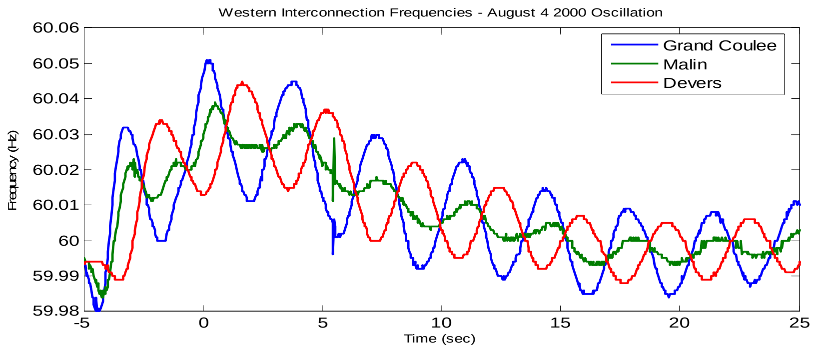


Oscillations seen by SCADA and PMU data

- Numeric SCADA displays today

Rapidly changing digits on a numeric display

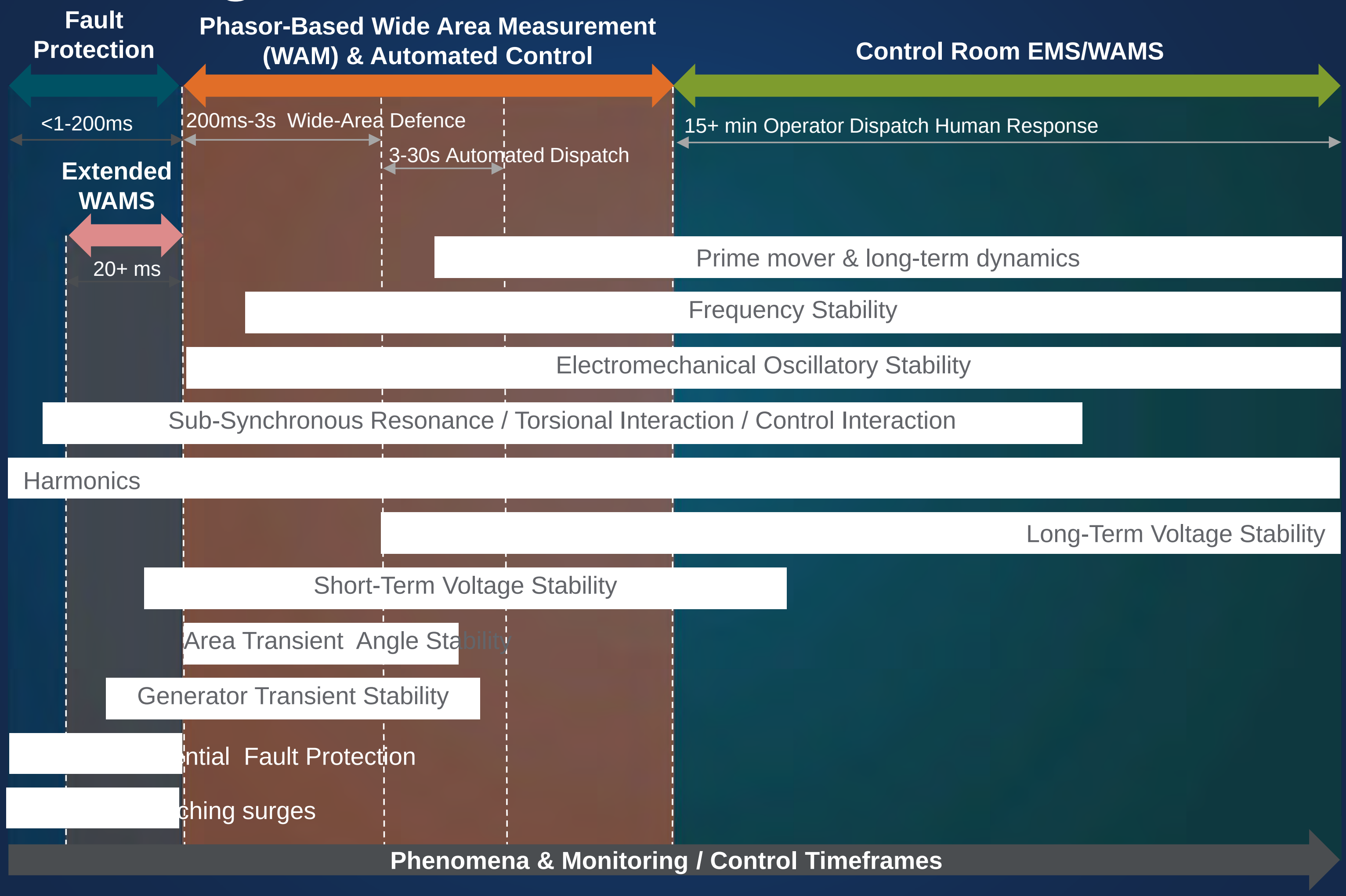
- With synchro-phasors – high resolution trend display



Issues to Address

- **Improvement of the power system security**
- **Identify the source of the instability**
- **Power system dynamics risk assessment**
- **Early warning of potential blackouts**
- **Management of islanded situations and resynchronization**
- **System Disturbance Management**
- **Transfer constraint relief**
- **Increasing the stability limits of existing assets, maintaining the security .**

System Monitoring and Control Timeframe



WAMS – EMS integration for Network Management

GE DIGITAL ENERGY

EMS WAMS SOFTWARE SOLUTIONS DESIGNED FOR THE DIGITAL UTILITY OF THE FUTURE

LEVEL 01
REACTIVE + RESPONSIVE

WAMS Monitoring

Waiting for a power loss to analyze stability issues
WAMS Improve Situational awareness
- *Fault location*
- *Power restoration process*
- *Model quality*

LEVEL 02
PREDICTIVE

GRID STABILITY ASSESSMENT
WAMS + TOPOLOGY

Model true demand & generation, predict impact of generation intermittency on network stability, capacity and failure

LEVEL 03
PRESCRIPTIVE

ONLINE SECURITY
WAMS + NETWORK + DSA

AI driven app optimization & orchestration from edge to cloud to prevent & minimize extent of outages.

LEVEL 04
AUTONOMOUS

WAMS Control

Self-healing, self-provisioning & extensive autonomous operations with limited human intervention

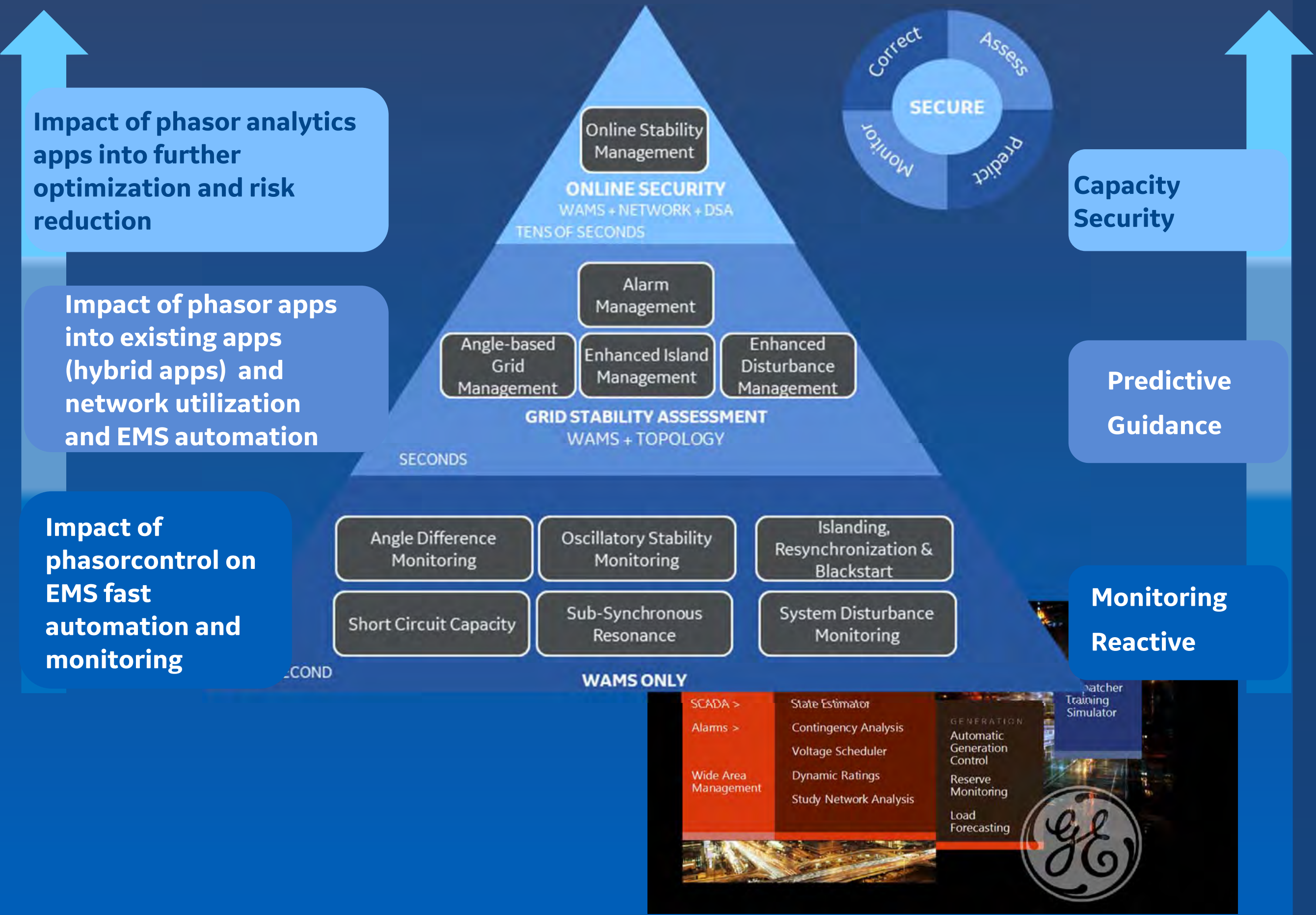
FUTURE

elevate every facet of your network operation

MODULAR APPS | **COMMON DATA LAYER** | **BRILLIANT UI/UX** | **INTEROPERABILITY**

GE DIGITAL ENERGY

ADVANCED EMS
EMS – WAMS



Solution Highlights

Full EMS WAMS OPERATIONAL INTEGRATION

Energy Network Visibility at WAMS resolution

Unlocking Network capacity ensuring Grid stability

Preventive stability assessment with WAMS and DSA Look Ahead

Enhanced Operation with WAMS controls

Capacity, Efficiency Utilization and Business Optimization with WAMS Predictive Analytics

Operator training with Dynamic DTS

GE DIGITAL ENERGY

Advanced EMS WAMS

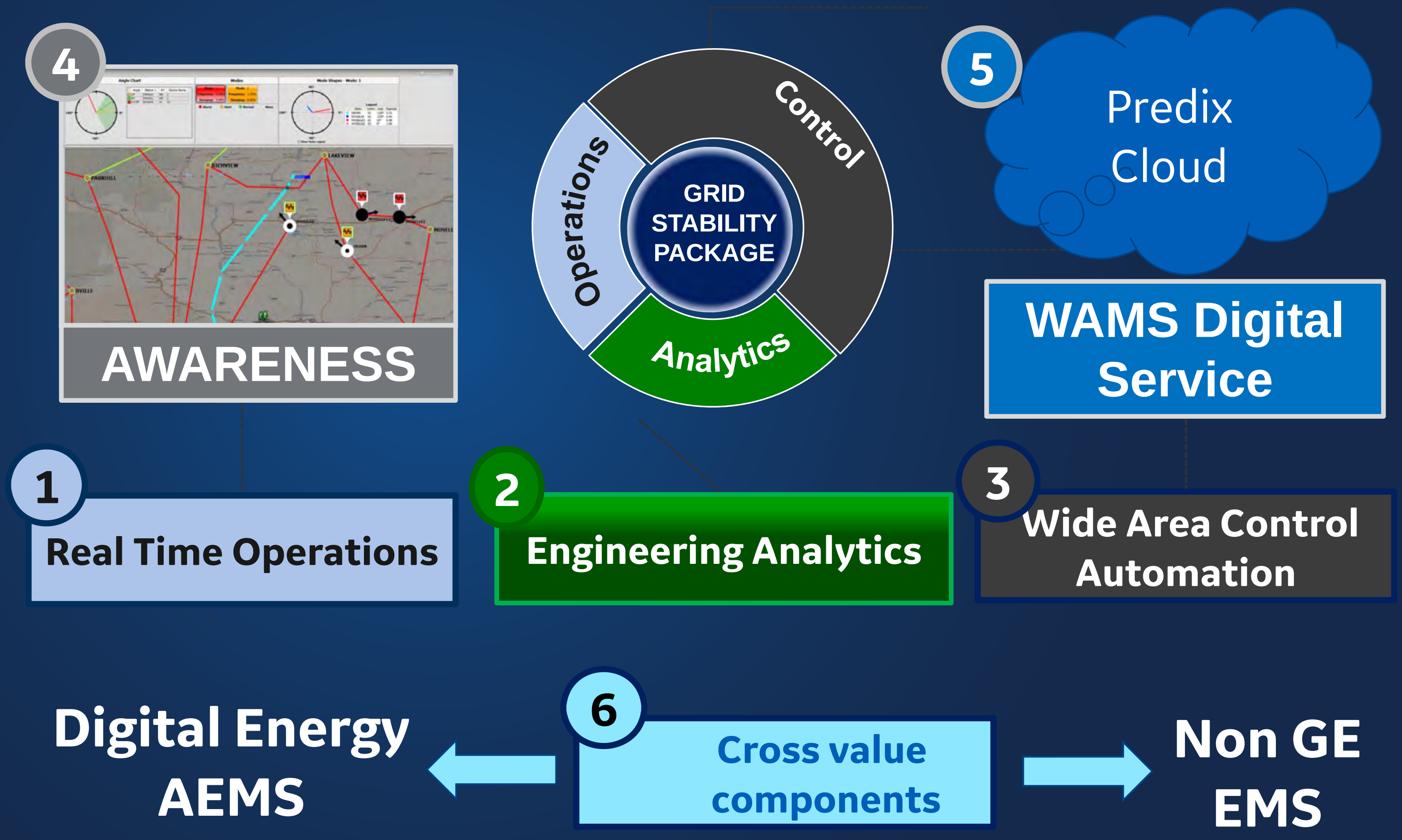
1 **Real Time**
Sub Synchronous oscillation

2 **Analytics**
Advanced analytics

3 **Control**
Wide Area closed loop control
Fast Frequency Response

4 **Awareness**
EMS-WAMS unified Situation Awareness

5 **WAMS as a service**
Predix WAMS - A cross boundary enabler with Big Data analytics capabilities



WAMS APPs in EMS

app: WAMS Alarms in EMS

Oscillatory Stability

- Mode Damping/Amplitude Thresholds

Islanding

Disturbances

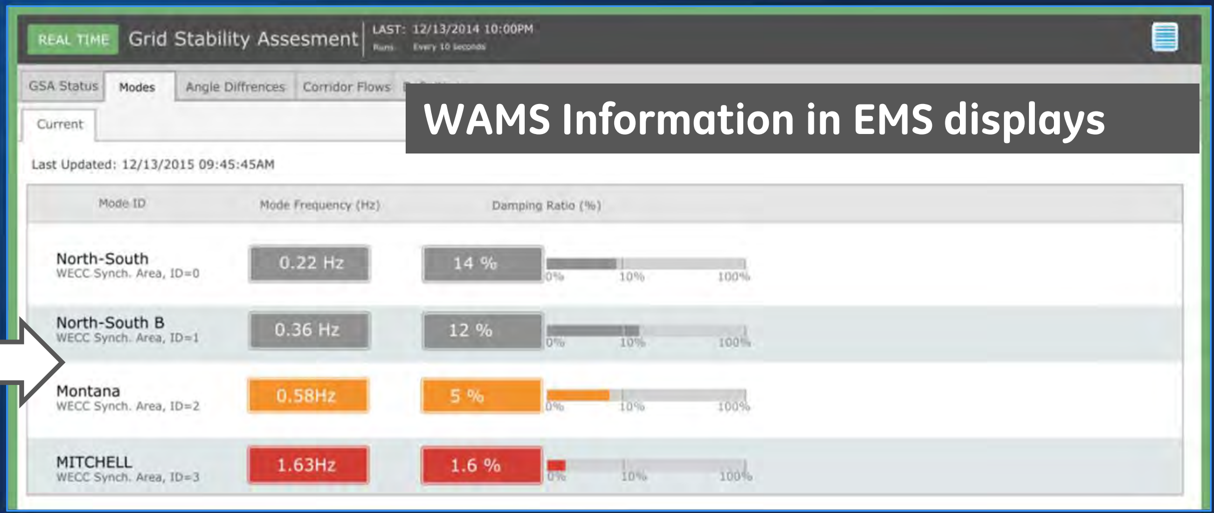
- General Rate of Change
- Disturbance Characterization

Composite Events

- User Defined

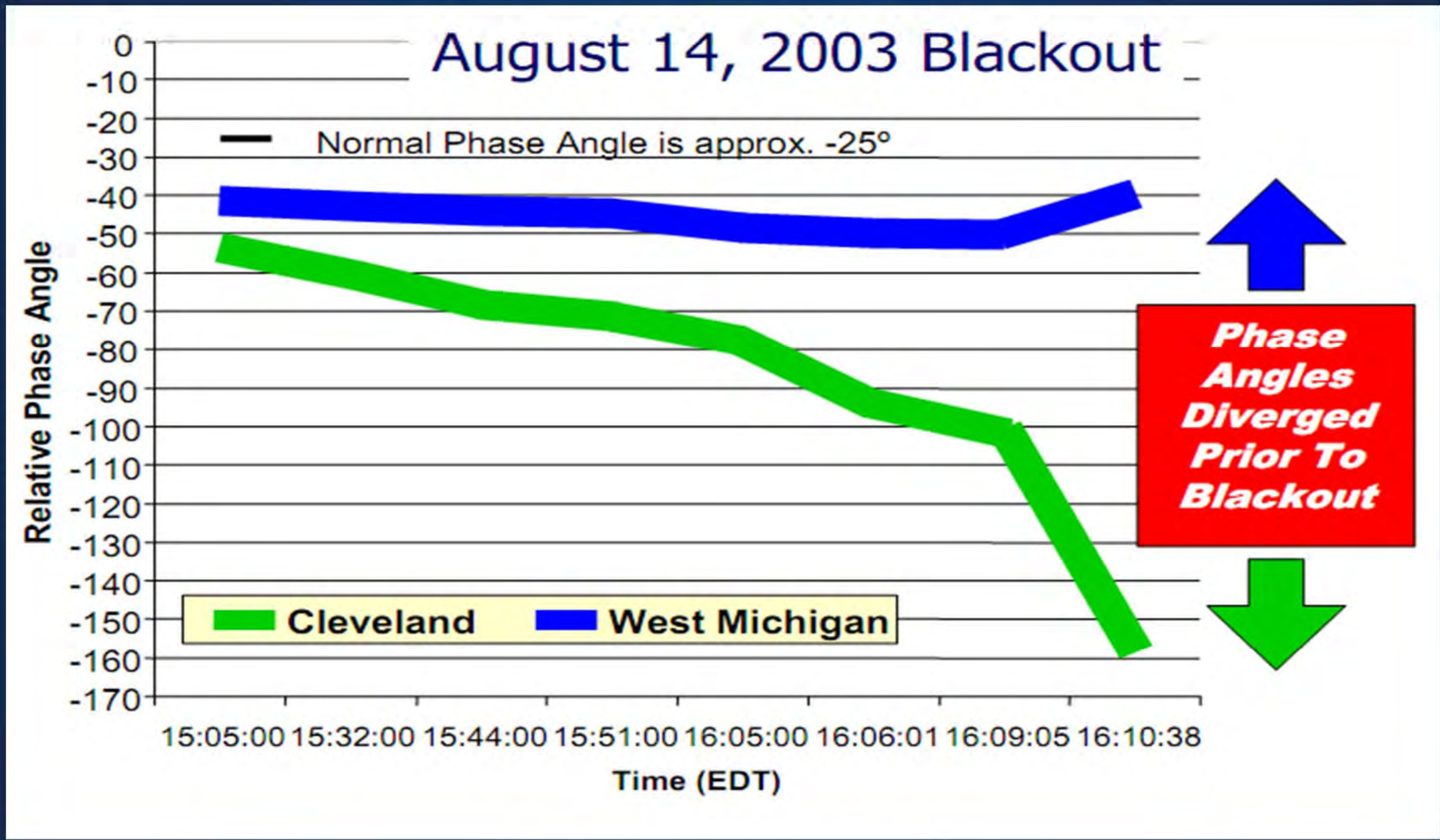
Magnitude Threshold Violations

- Voltage Magnitude
- Calculated Data
- Angle Difference
- Frequency / ROCOF
- P&Q / Power Corridors



app: Angle-based Grid Management

Holistic Approach to Angle-based Grid Management

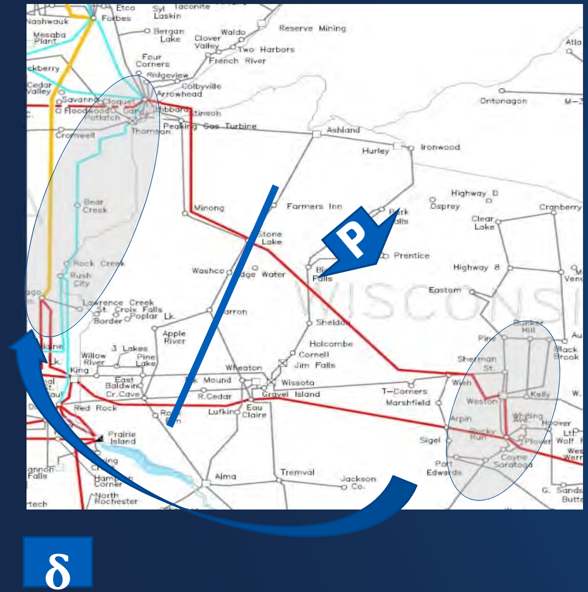


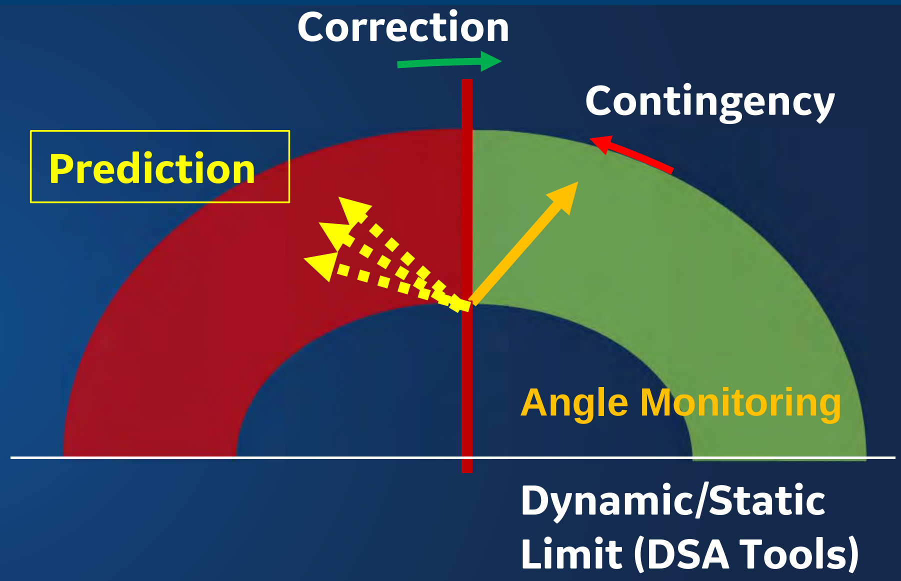
Voltage angle separation during the Northern American blackout of 2003

app: Angle-based Grid Management

Holistic Approach to Angle-based Grid Management

Transforming WAMS angle-based MONITORING into OPERATOR GUIDANCE





KEY BENEFITS

- Independent of State Estimation function (measurement & topology based approach).
- Capable of making recommendations for corrective control actions.

Observe ● Analyze ● Predict ● Correct

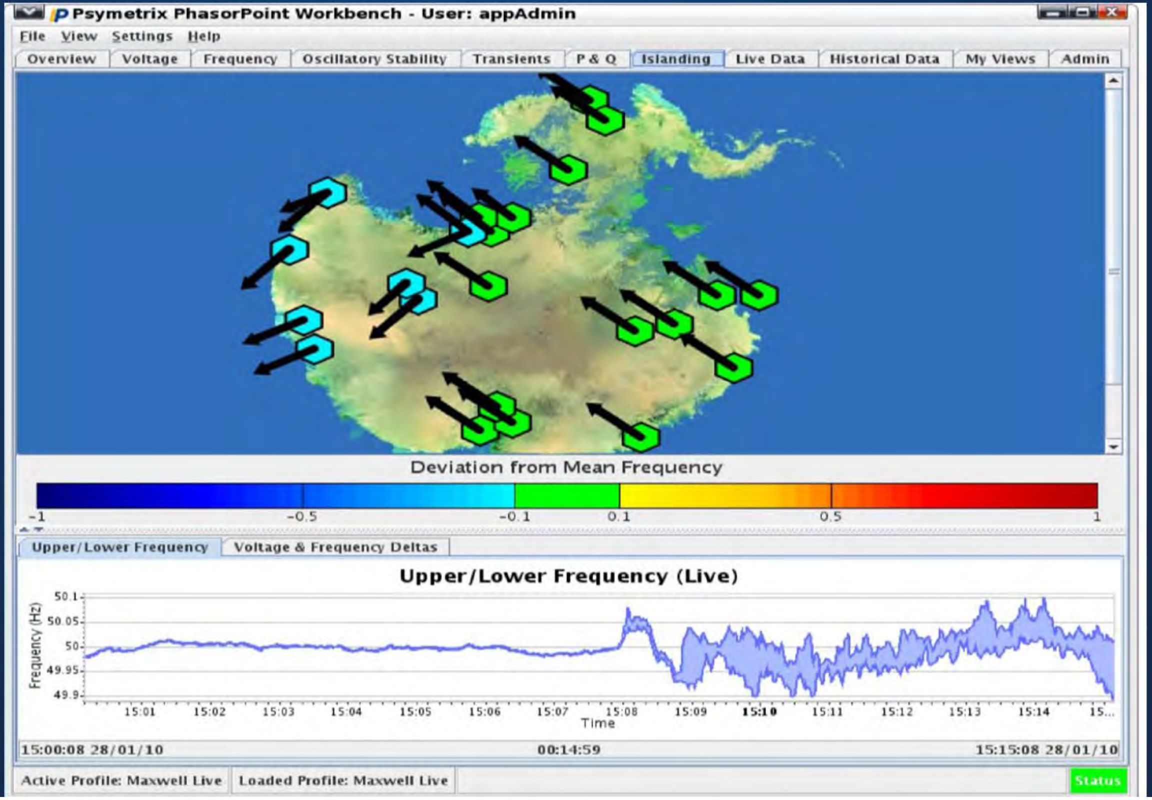
app: Islanding Management and Resynchronization

Concept

PMU-based methods to quickly detect an islanding condition, and assist with the re-synchronization process. Model-based topology processing to identify the islanded boundaries, and generation/load resources in each island.

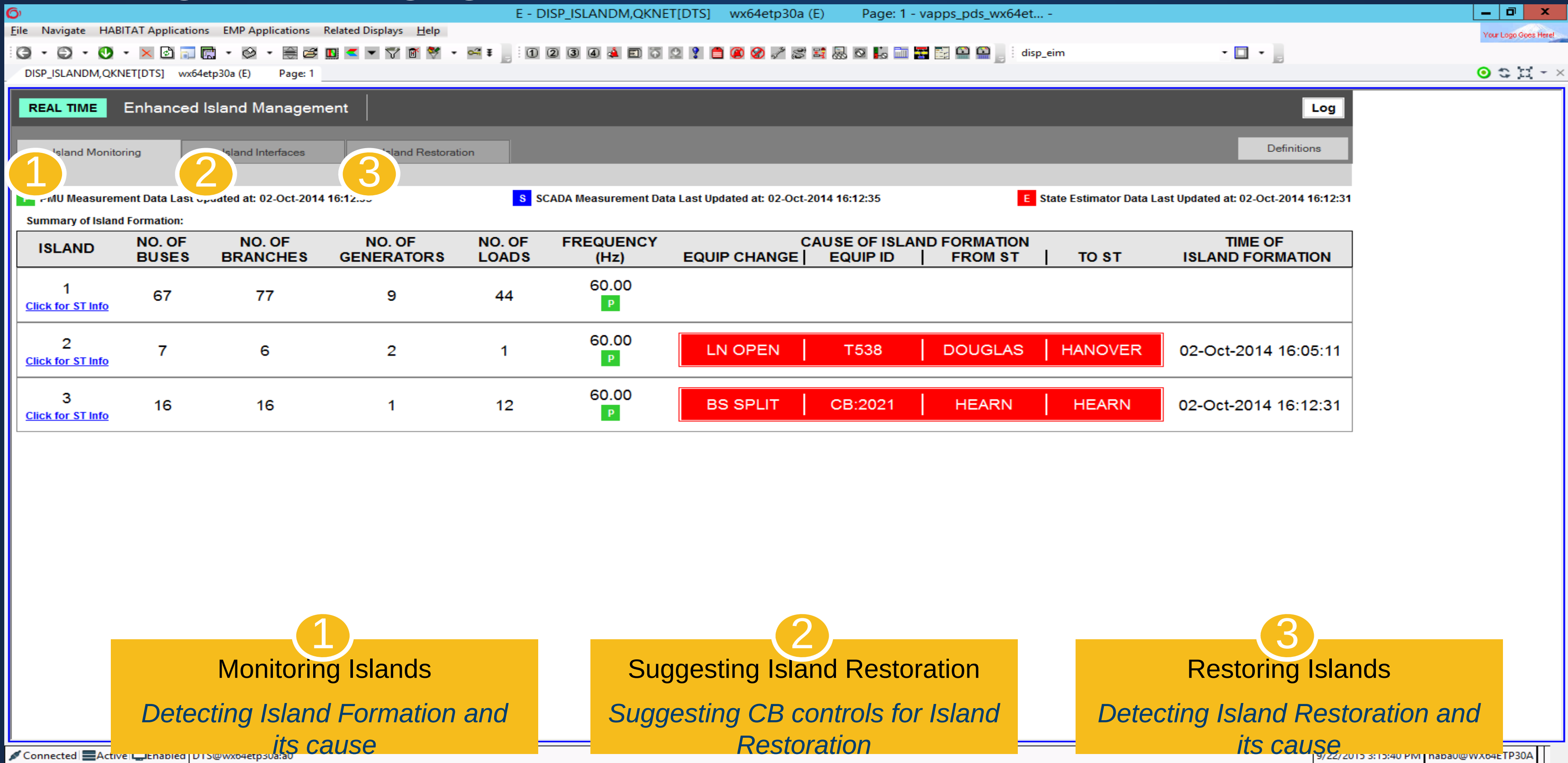
Benefits

Real-time alerts/alarms on islanding condition.
Visually identify the islanded regions.
Localized frequency and angle measurements to assist with the re-synchronization process (i.e. enabling the check-sync relay to ensure successful reclosure).



app: Islanding Management and Resynchronization

Detecting and Managing Multiple Islands



1 Monitoring Islands

Detecting Island Formation and its cause

2 Suggesting Island Restoration

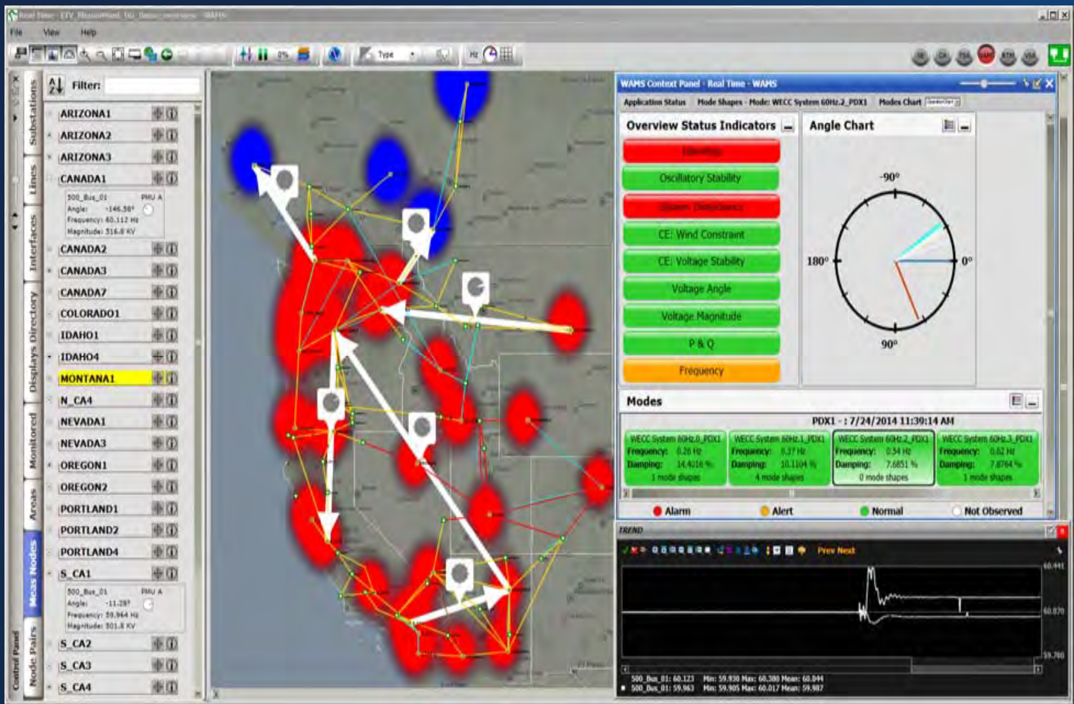
Suggesting CB controls for Island Restoration

3 Restoring Islands

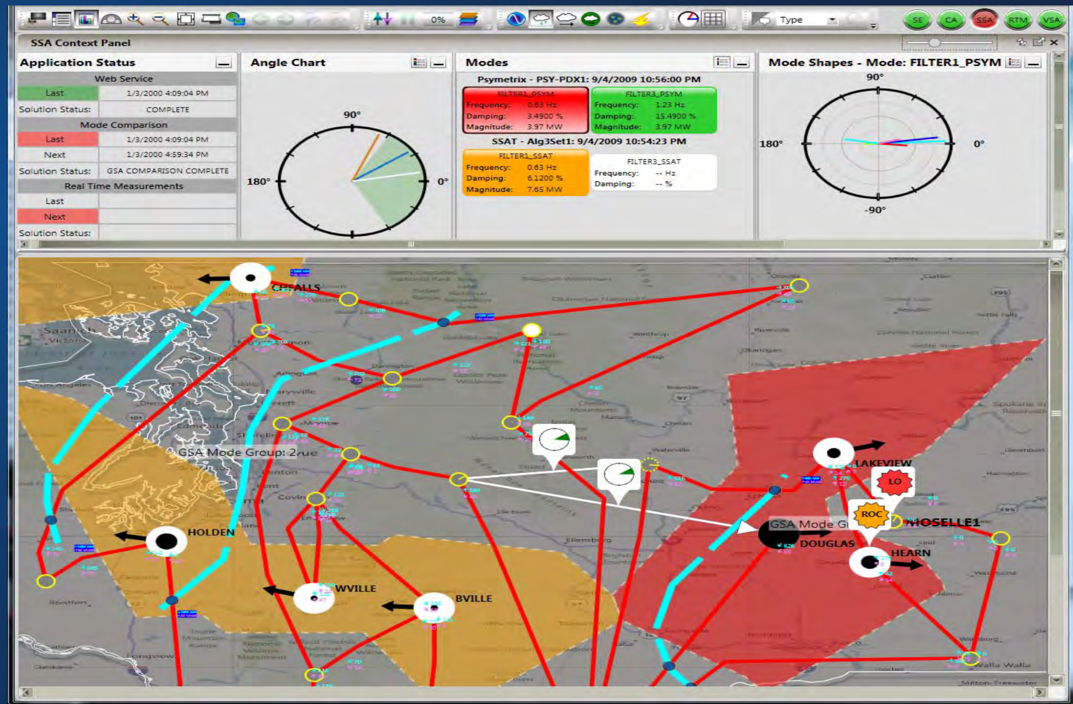
Detecting Island Restoration and its cause

User Experience
Unified Situational Awareness Tool

Islanding



Small Signal Analysis
System and Local Modes



Dynamic Training Environment

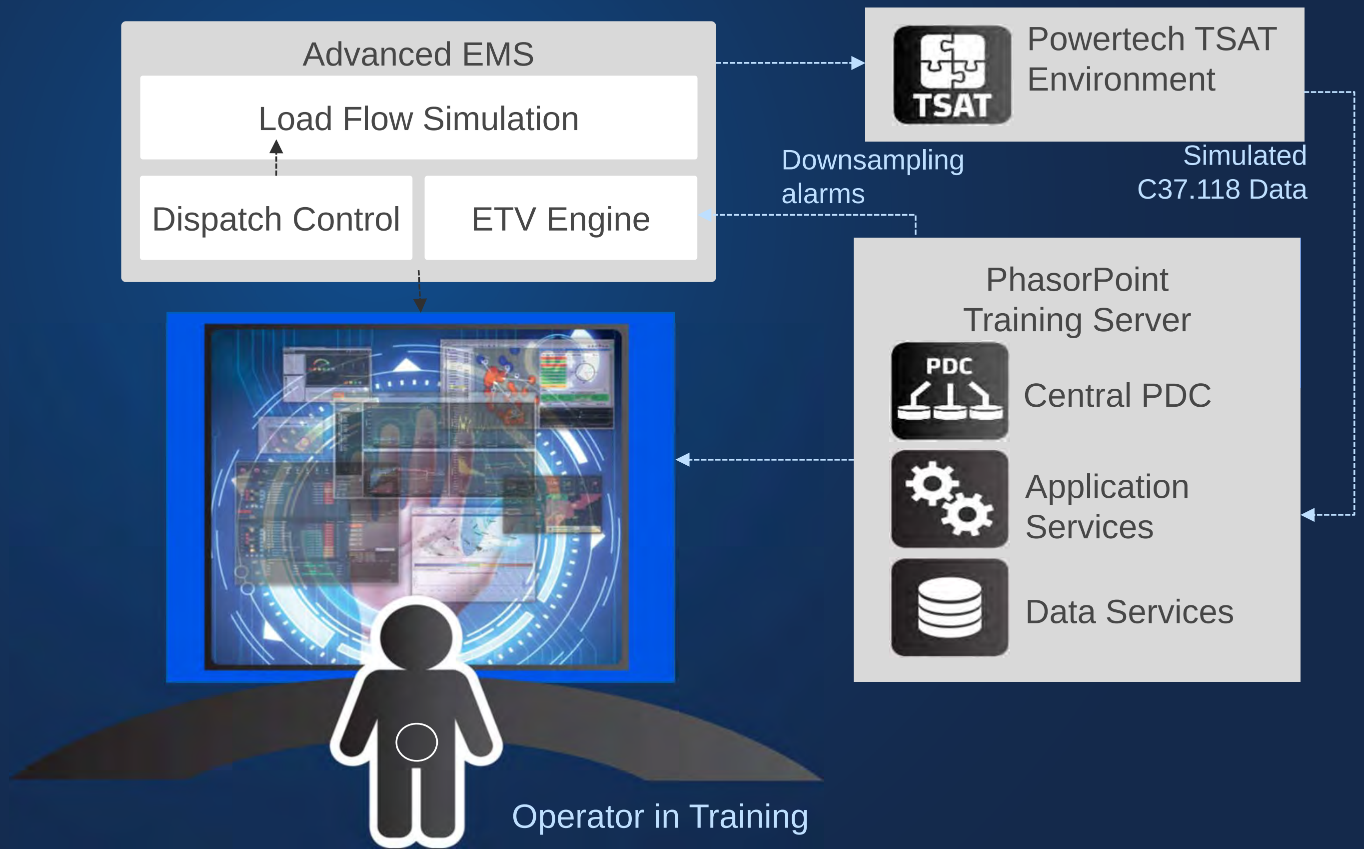
Dynamic Dispatcher Training Simulator (DTS) utilizing Transient Stability Engine (PowerTech TSAT)

Dynamic Grid Simulator

Control Room Training Environment

Integrated Dispatcher Training System:

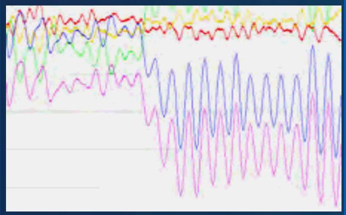
- Real-time simulator based on Powertech TSAT
- Simulated data is fed directly into PP as C37.118 streams
- Data is also downsampled and sent to the EMS & DSA Tools
- EMS integrated with PhasorPoint and DSA tools



Case Studies

GCCIA System Stability Monitoring Goals

Maintain Stable Oscillations



Avoid Instability

Achieve acceptable damping through

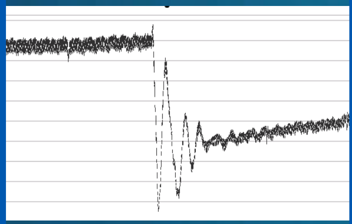
- Real-time response
- PSS Tuning

Manage Risk of Separation

Reduce Outage

Minimise impact by fast identification & restoration

Respond to Disturbances

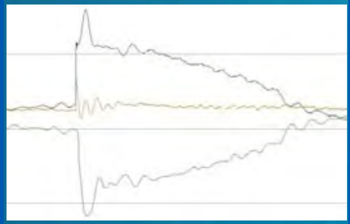


Emergency Plan

Real-time event location/sequence

Post-event dynamic analysis

Co-ordinate 50/60Hz Interaction



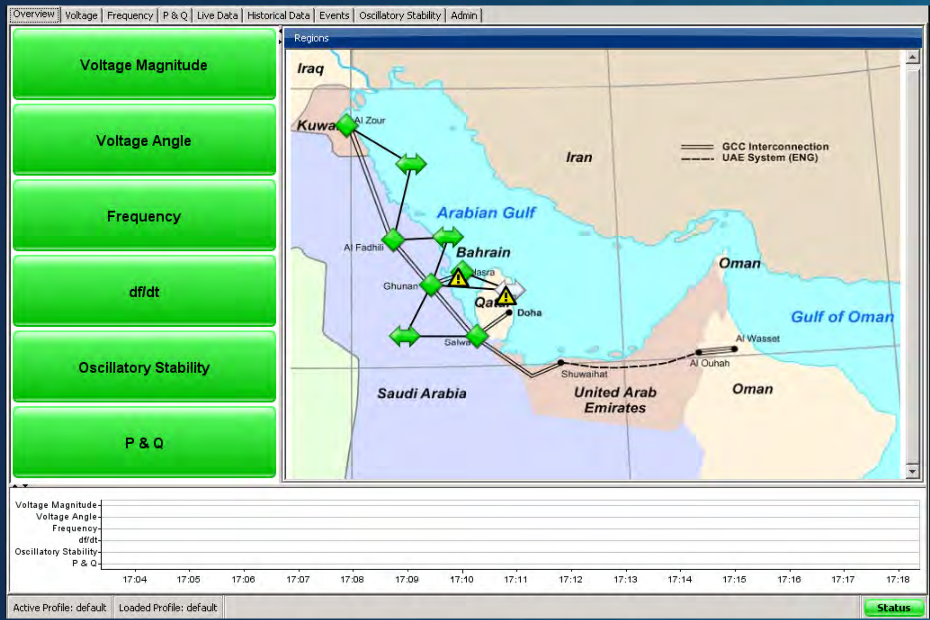
Optimal Control

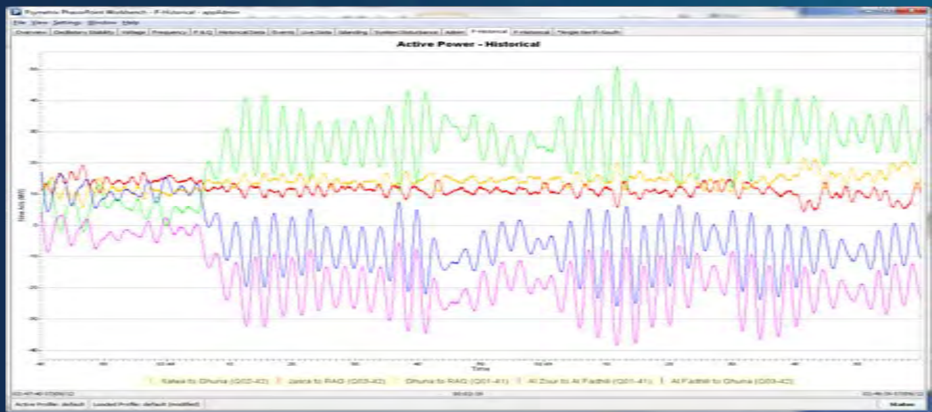
Observe & tune HVDC response for mutual disturbance support. Observe power quality.

Improving Security & Transfer Level

→ Efficient Stakeholder Asset Use

GCCIA WAMS Real-time Overview Display





Event Type
Tabs on Left show GREEN/YELLOW/RED alarm status for EVENT TYPE

Location Alarms on map

Timing for each Event Type.

User Defined Views
Plots can be user-configured to show real-time or historic data.

Rapid access to key headline information in real-time without overload

By permission of:
Mohamed Al-Shaikh *Director Maintenance & Asset Management*
4th General Conference, Arab Union of Electricity, Dec 2012

WAPP (West African Power pool) System

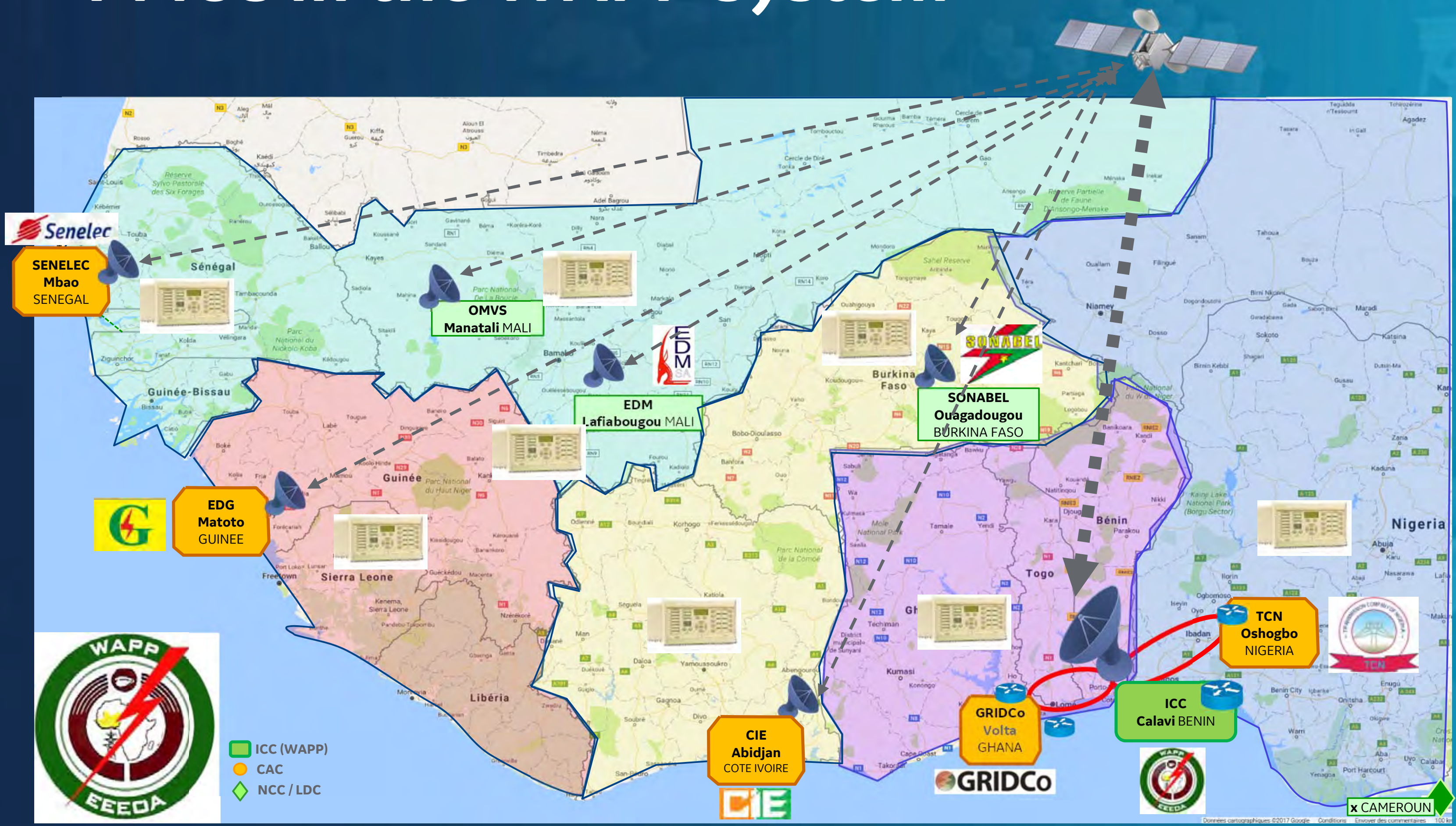
Western Africa dispatching and interconnection

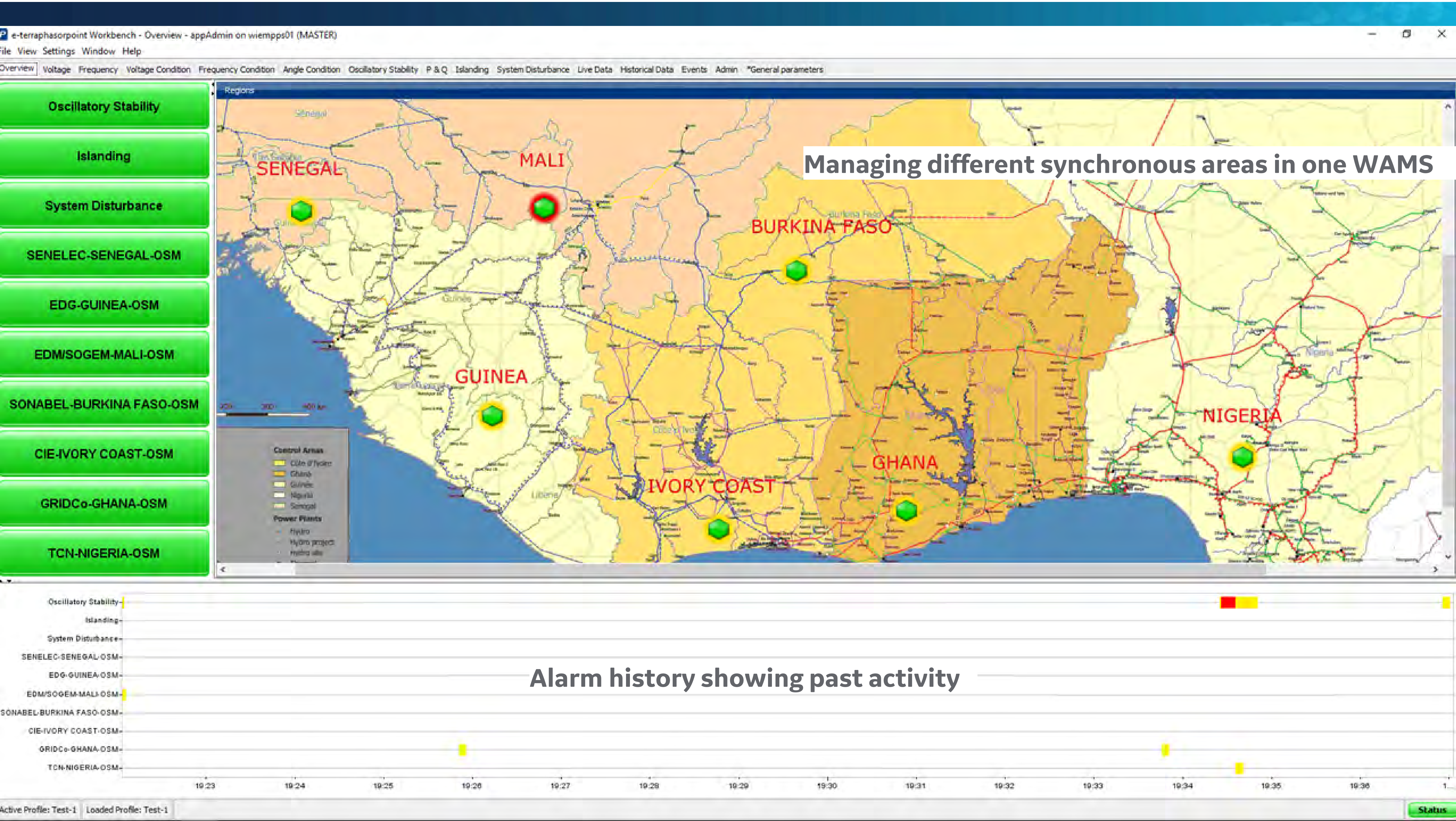
PMUs in the WAPP system

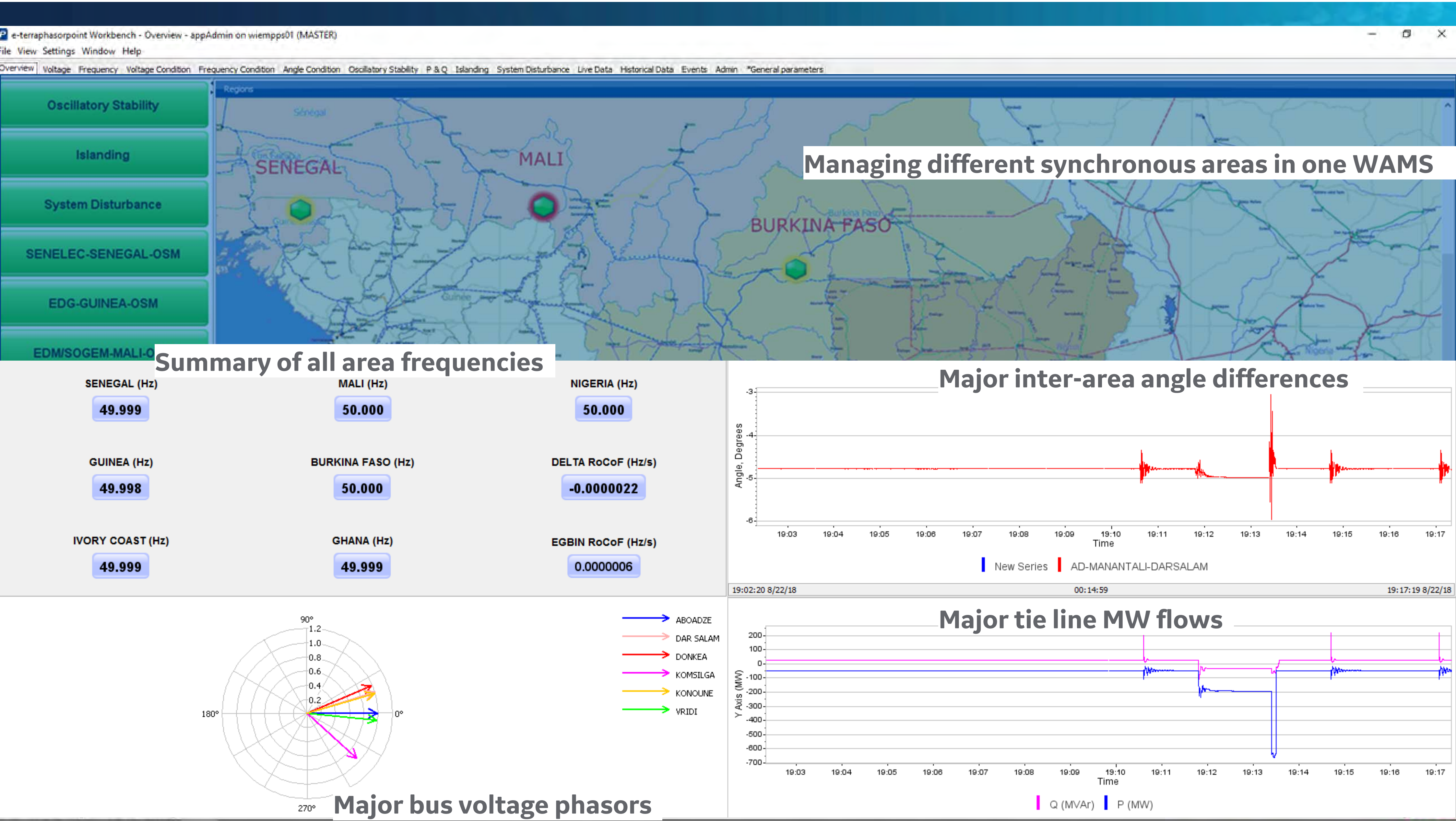
Dispatching

ICC

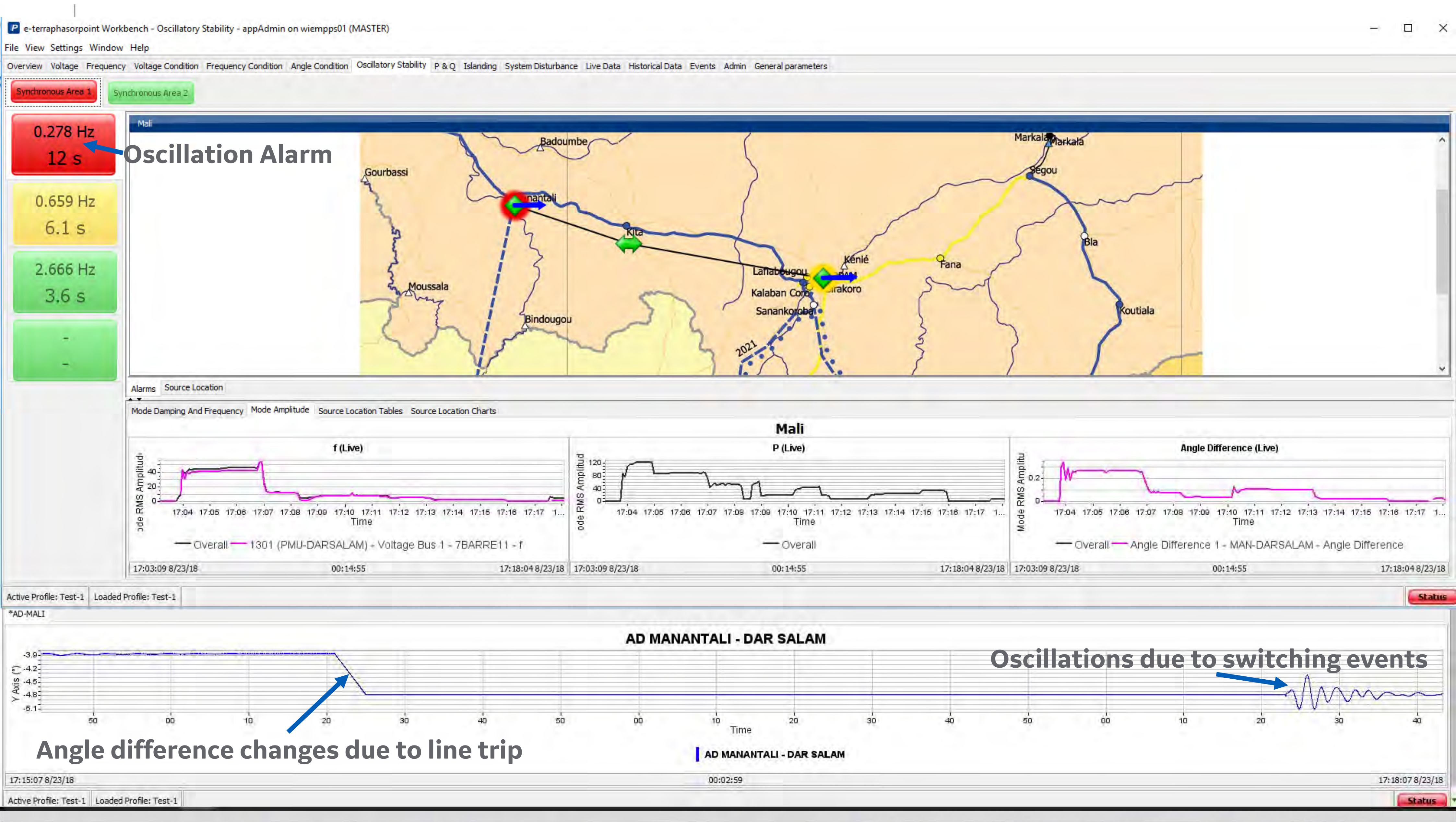
PMU

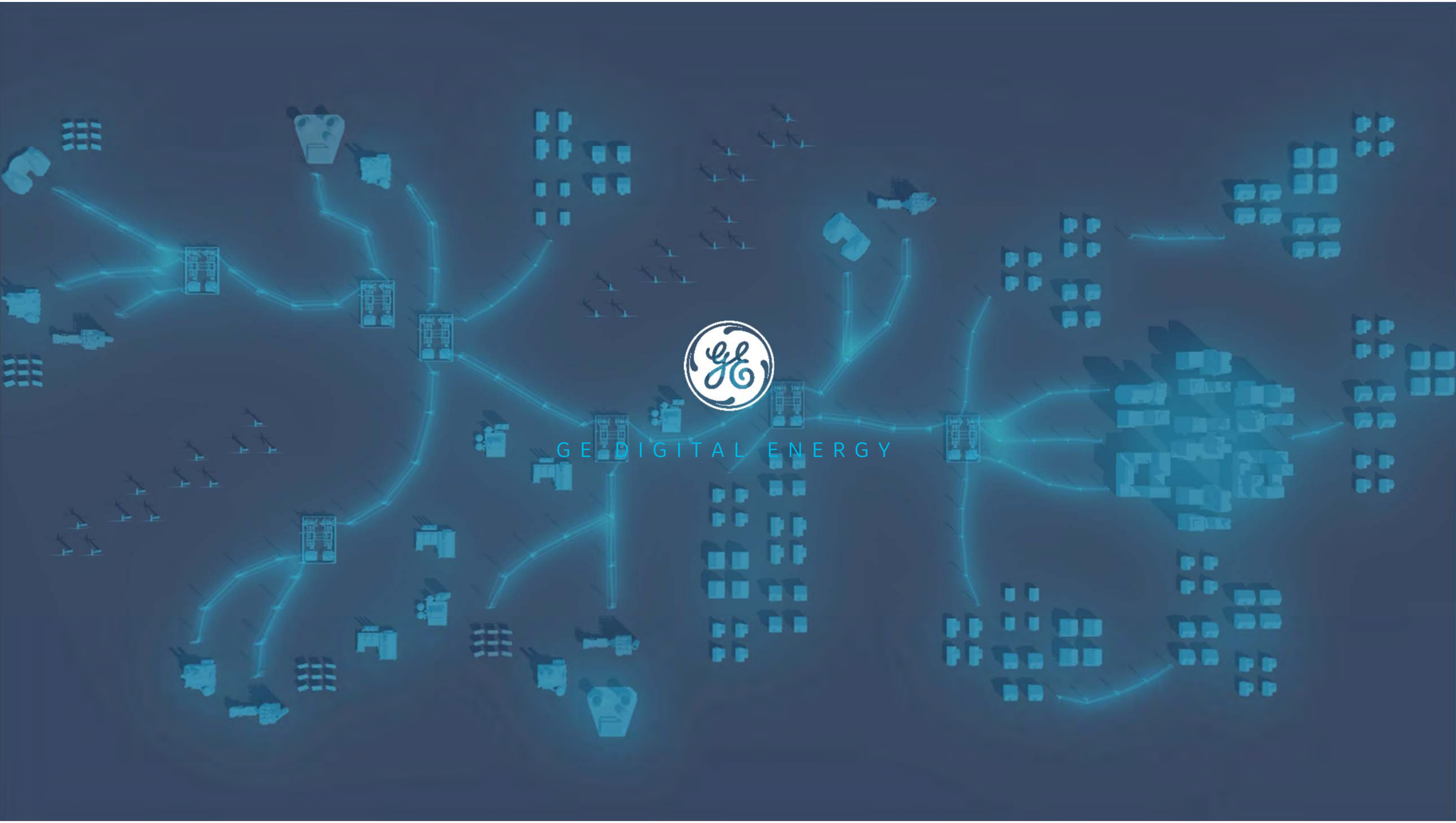



e-terraphasorpoint Workbench - Overview - appAdmin on wiempps01 (MASTER)
File View Settings Window Help
Overview Voltage Frequency Voltage Condition Frequency Condition Angle Condition Oscillatory Stability P & Q Islanding System Disturbance Live Data Historical Data Events Admin *General parameters
Oscillatory Stability
Islanding
System Disturbance
SENELEC-SENEGAL-OSM
EDG-GUINEA-OSM
EDM/SOGEM-MALI-OSM
SONABEL-BURKINA FASO-OSM
CIE-IVORY COAST-OSM
GRIDCo-GHANA-OSM
TCN-NIGERIA-OSM
Regions
SENEGAL
MALI
BURKINA FASO
GUINEA
IVORY COAST
GHANA
NIGERIA
Managing different synchronous areas in one WAMS
Control Areas
Power Plants
Alarm history showing past activity
19:23
19:24
19:25
19:26
19:27
19:28
19:29
19:30
19:31
19:32
19:33
19:34
19:35
19:36
Active Profile: Test-1
Loaded Profile: Test-1
Status



e-terraphasorpoint Workbench - Overview - appAdmin on wiempps01 (MASTER)
File View Settings Window Help
Overview Voltage Frequency Voltage Condition Frequency Condition Angle Condition Oscillatory Stability P & Q Islanding System Disturbance Live Data Historical Data Events Admin *General parameters
Oscillatory Stability
Islanding
System Disturbance
SENELEC-SENEGAL-OSM
EDG-GUINEA-OSM
EDM/SOGEM-MALI-O
Regions
SENEGAL
MALI
BURKINA FASO
Managing different synchronous areas in one WAMS
Summary of all area frequencies
SENEGAL (Hz) 49.999
MALI (Hz) 50.000
NIGERIA (Hz) 50.000
GUINEA (Hz) 49.998
BURKINA FASO (Hz) 50.000
DELTA RoCoF (Hz/s) -0.0000022
IVORY COAST (Hz) 49.999
GHANA (Hz) 49.999
EGBIN RoCoF (Hz/s) 0.0000006
Major inter-area angle differences
Angle, Degrees
Time
New Series
AD-MANANTALI-DARSALAM
19:02:20 8/22/18
00:14:59
19:17:19 8/22/18
Major tie line MW flows
Y Axis (MW)
Time
Q (MVAr)
P (MW)
90°
180°
0°
270°
ABOADZE
DAR SALAM
DONKEA
KOMSILGA
KONOUNE
VRIDI
Major bus voltage phasors


e-terraphasorpoint Workbench - Oscillatory Stability - appAdmin on wiempps01 (MASTER)
File View Settings Window Help
Overview Voltage Frequency Voltage Condition Frequency Condition Angle Condition Oscillatory Stability P & Q Islanding System Disturbance Live Data Historical Data Events Admin General parameters
Synchronous Area 1
Synchronous Area 2
0.278 Hz
12 s
Oscillation Alarm
0.659 Hz
6.1 s
2.666 Hz
3.6 s
Mali
Badoumbe
Gourbassi
Markala
Segou
Kita
Bla
Kenié
Fana
Moussala
Kalaban Coro
Sanankoroba
Koutiala
Bindougou
2021
Alarms
Source Location
Mode Damping And Frequency
Mode Amplitude
Source Location Tables
Source Location Charts
Mali
f (Live)
P (Live)
Angle Difference (Live)
Time
Overall
1301 (PMU-DARSALAM) - Voltage Bus 1 - 7BARRE11 - f
Angle Difference 1 - MAN-DARSALAM - Angle Difference
17:03:09 8/23/18
00:14:55
17:18:04 8/23/18
Active Profile: Test-1
Loaded Profile: Test-1
Status
*AD-MALI
AD MANANTALI - DAR SALAM
Oscillations due to switching events
Y Axis (°)
Angle difference changes due to line trip
AD MANANTALI - DAR SALAM
17:15:07 8/23/18
00:02:59
17:18:07 8/23/18


GE DIGITAL ENERGY