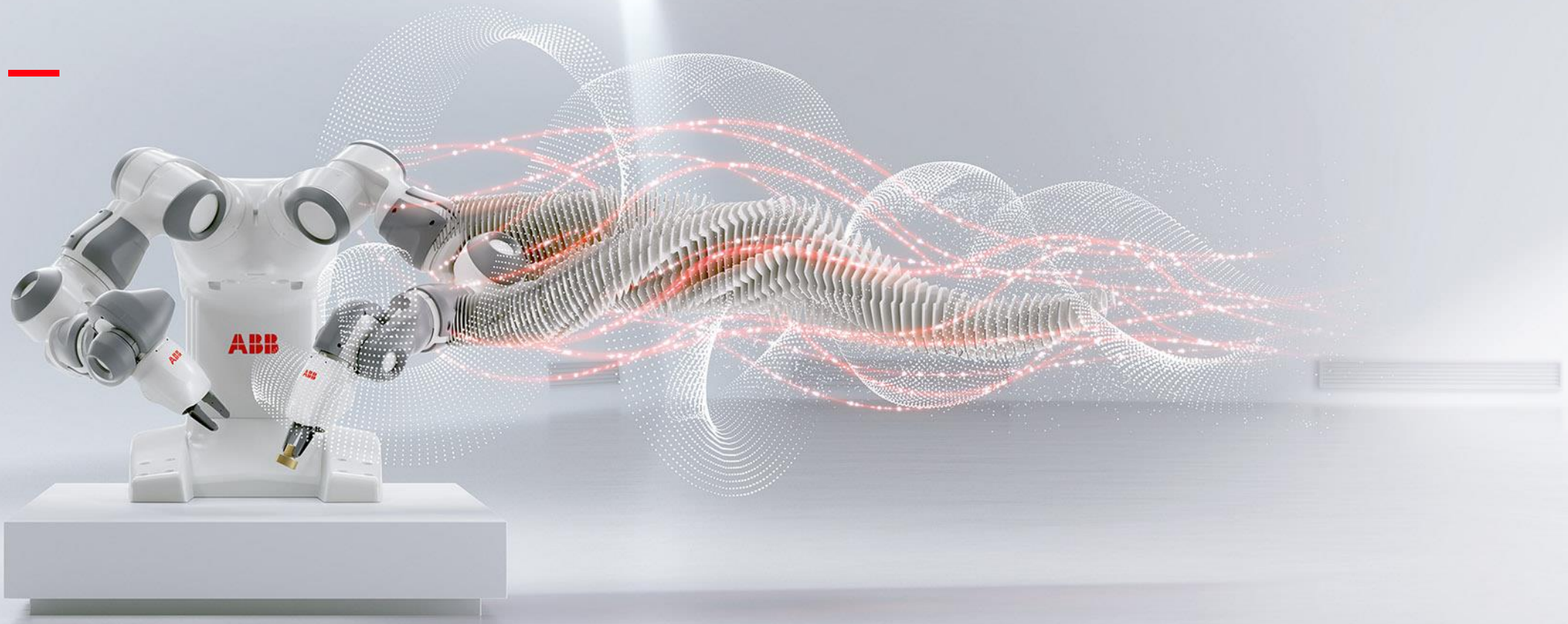


HANDS ON RELAY SCHOOL, MARCH 2018

SYNCHROPHASOR APPLICATIONS

EXISTING AND FUTURE APPLICATIONS

Galina S. Antonova, Technical Sales Engineer

Agenda

Introduction

Phasor-enhanced state calculator

Power system stability applications

Fault location application

Wide-area control applications

IEEE Guide on use of synchrophasors for protection and control applications

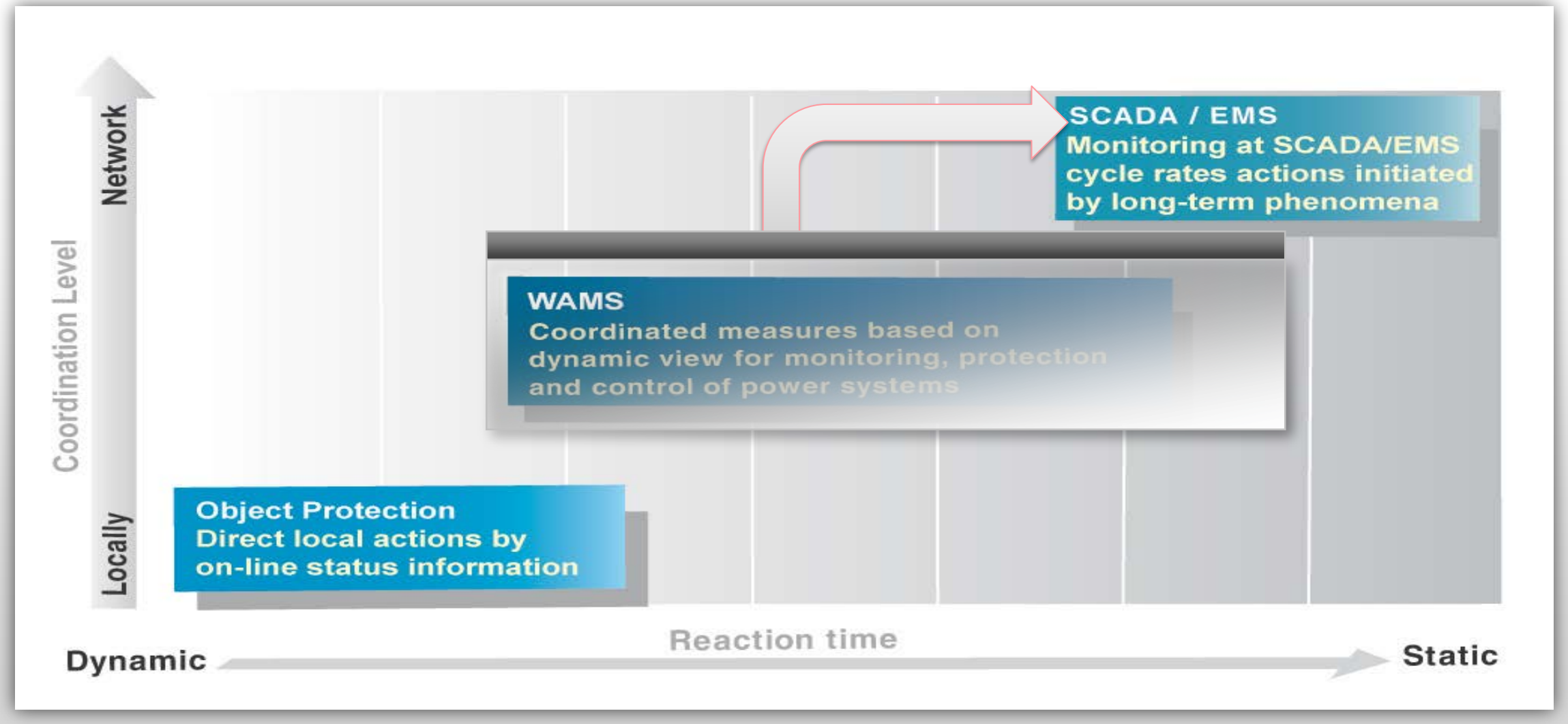
Synchrophasor projects:

- North American Synchrophasor Initiative (NASPI)
- Western Interconnection Synchrophasor Program (WISP)

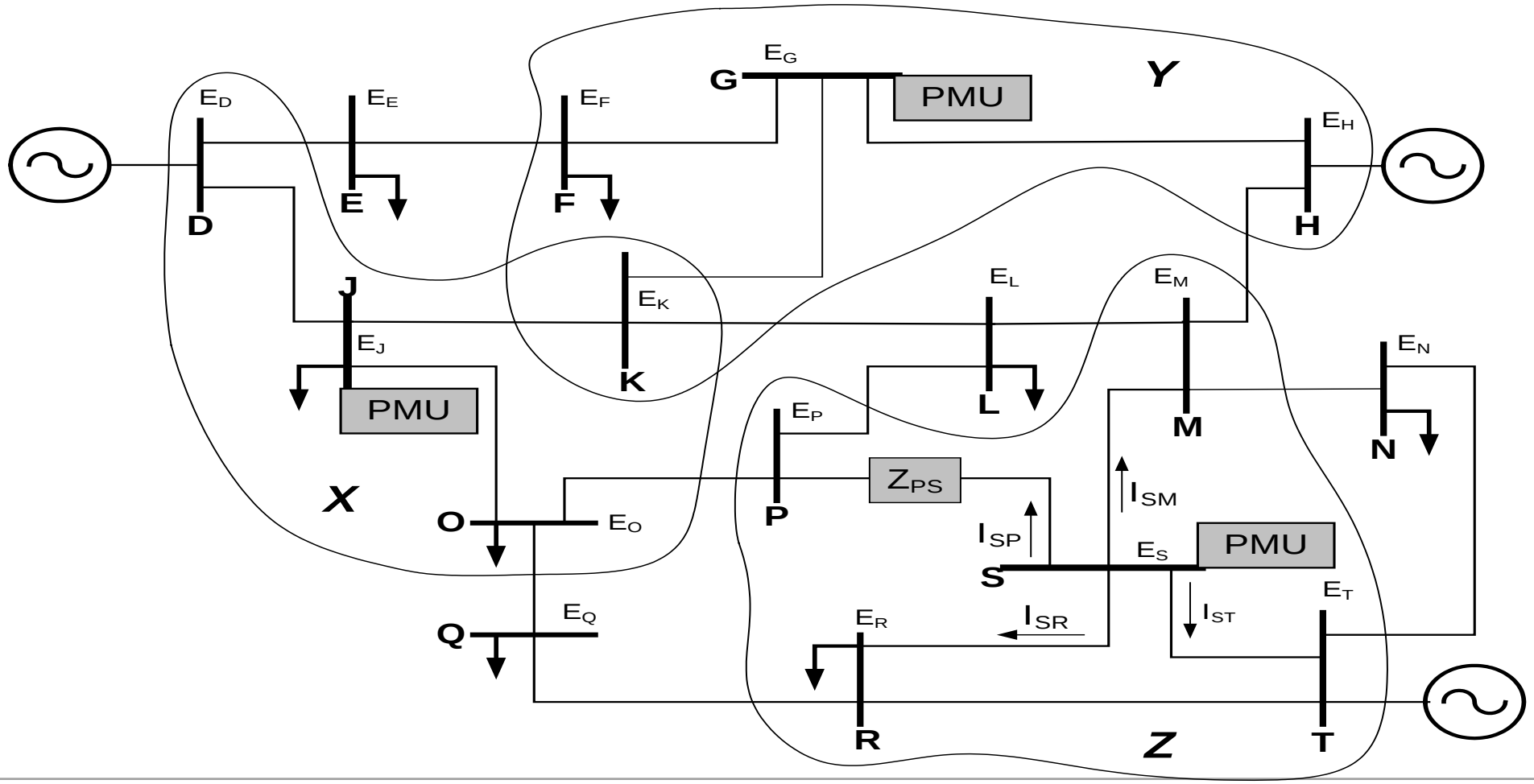
Ways to learn:

- PG&E Synchrophasor proof of concept facility

Synchrophasor-based applications



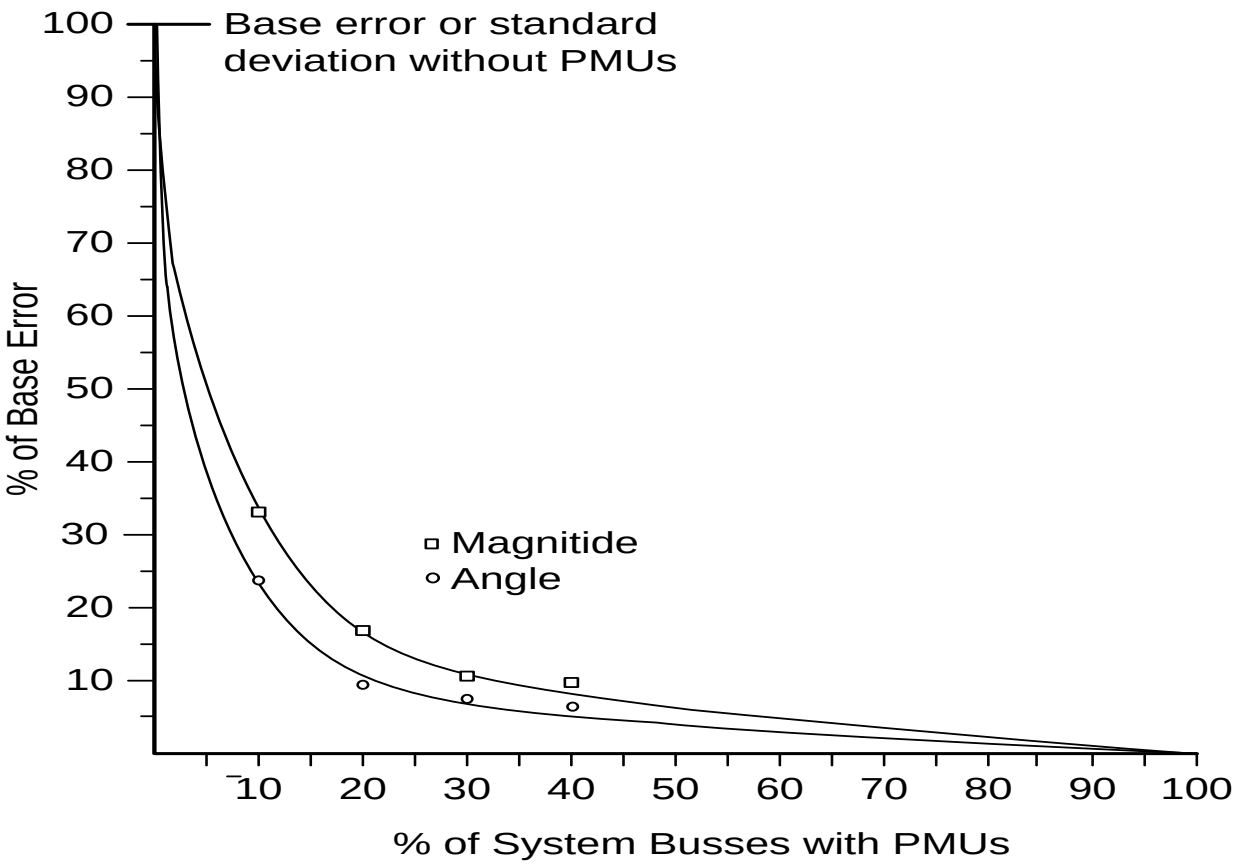
Phasor-Enhanced State Estimator



Phasor-Enhanced State *Calculator*

Benefits are increased observability, redundancy, accuracy, and bad data detection capability

The application of a sufficient number of PMUs across the system will improve the State Estimation solutions to the point they will be called state calculations.



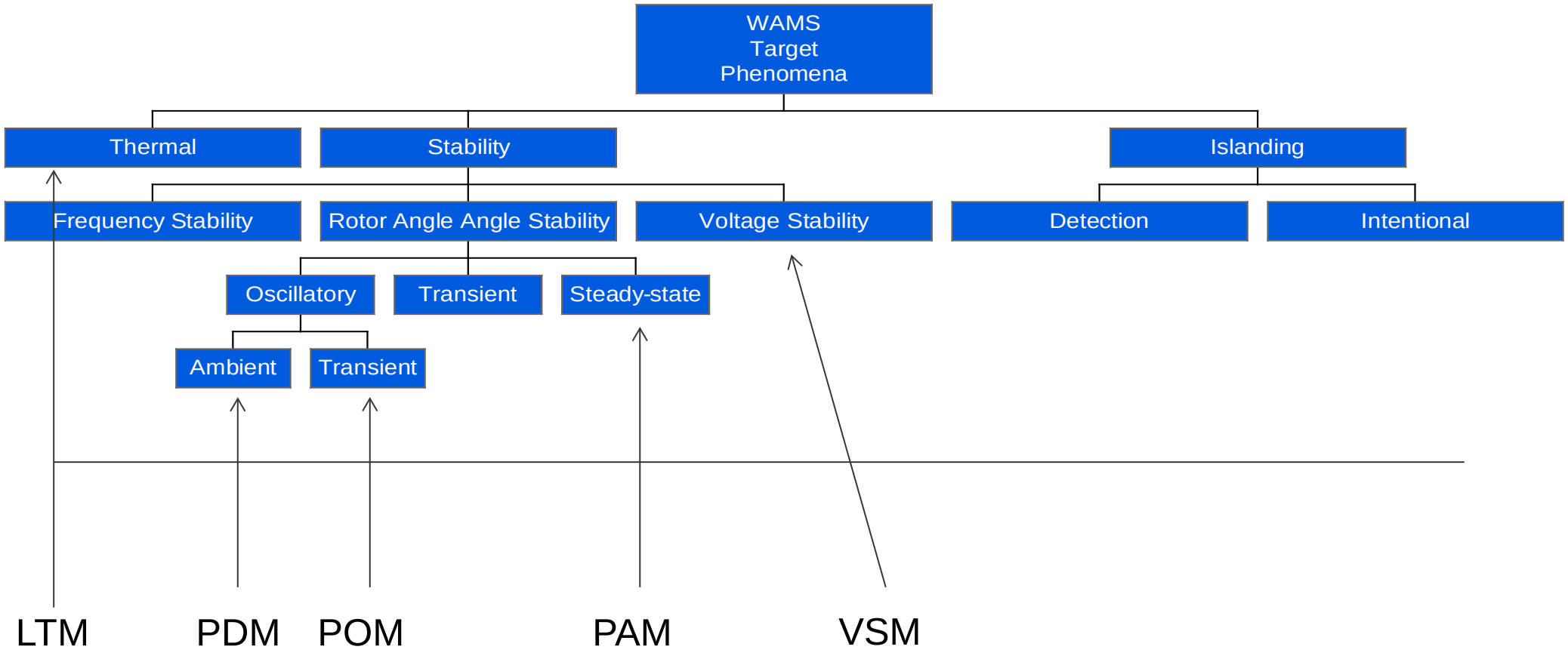
Power System Stability Constrains

Loadability of (AC) transmission lines are limited by

- Thermal constraints
- Voltage contraints
- Dynamic angle constraints
  - Oscillatory stability
  - Transient stability
- Steady-state angle constraints

WAMS Applications provide a way of monitoring the proximity to the stability limits and constraints

Power System Stability Applications

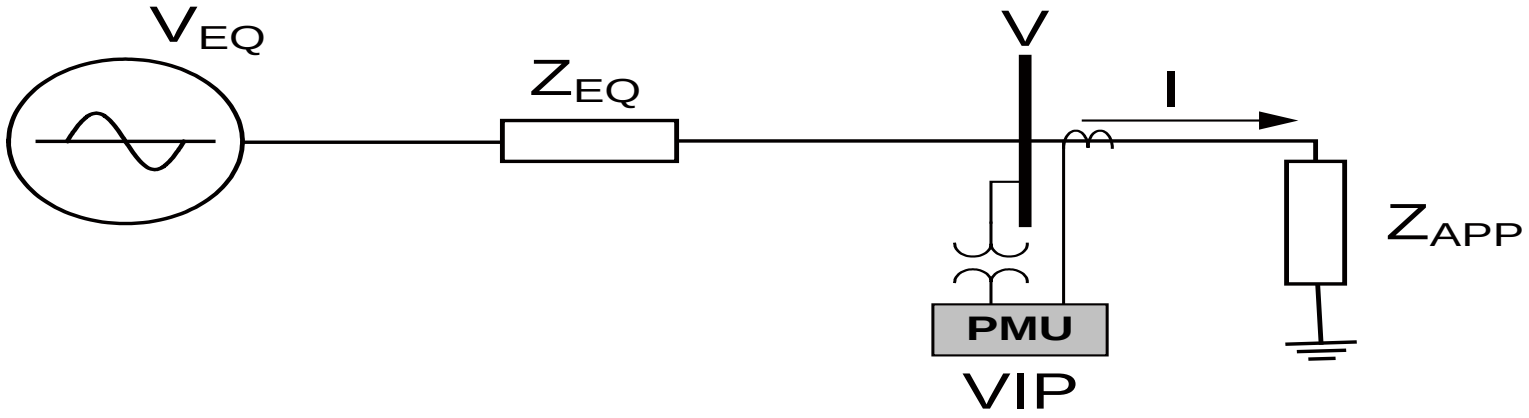


PSGuard: Wide-Area Monitoring System

PSGuard Applications

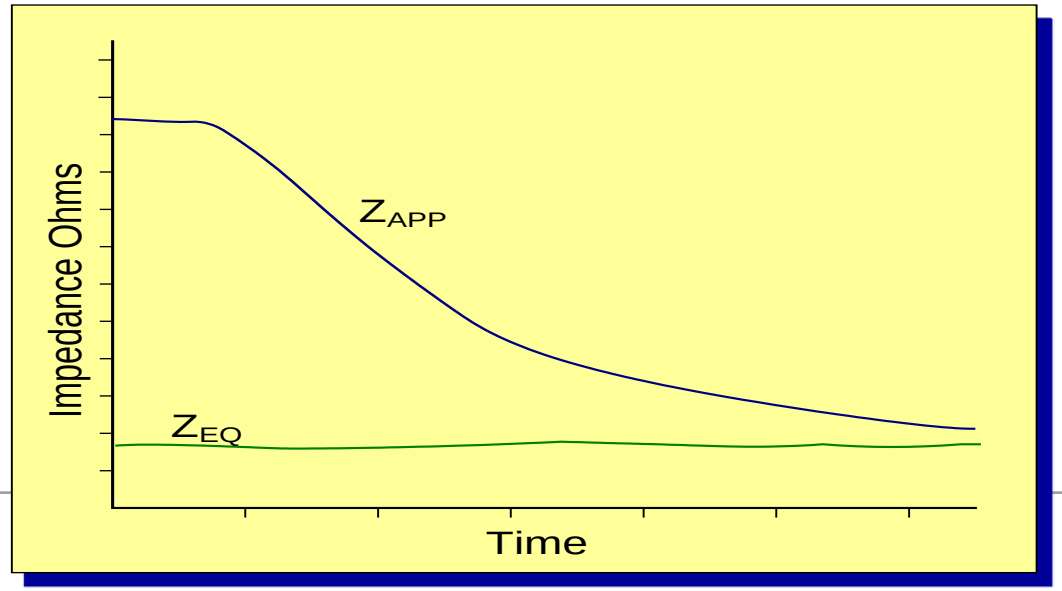
- Phase Angle Monitoring
- Voltage Stability Monitoring
- Line Thermal Monitoring
- Event Driven Data Archiving
- Power Oscillation Monitoring
- Power Damping Monitoring
- SCADA/ EMS integration
- Communication gateway

Voltage Instability Predictor

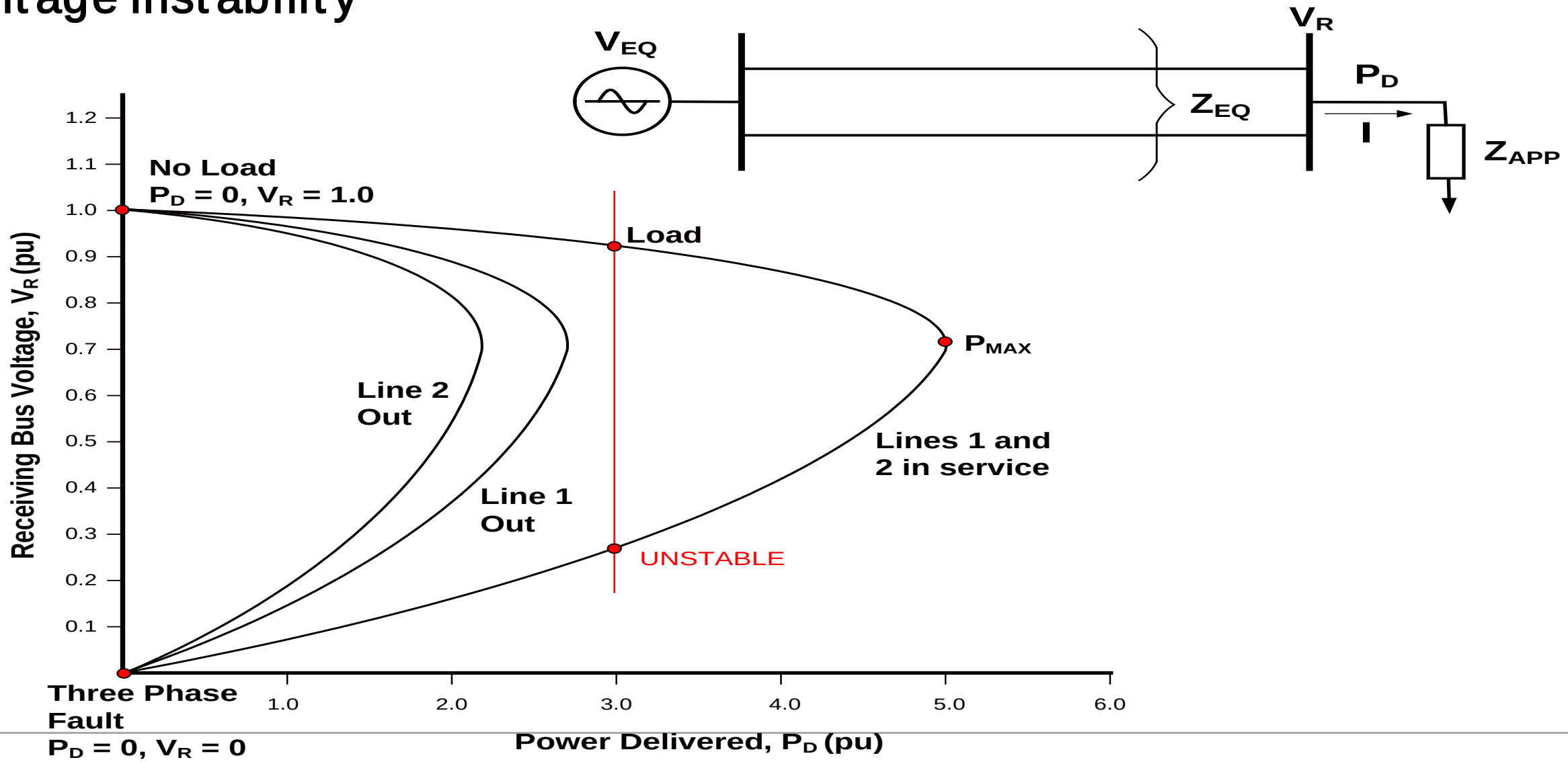


$$Z_{APP} = \frac{V}{I}$$

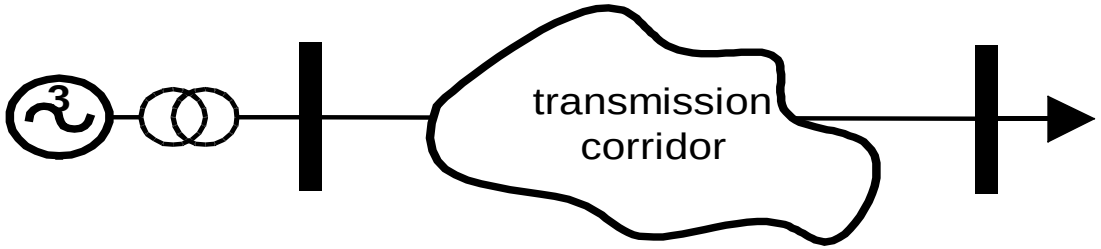
$$Z_{EQ} = \frac{V_{EQ} - V}{I}$$

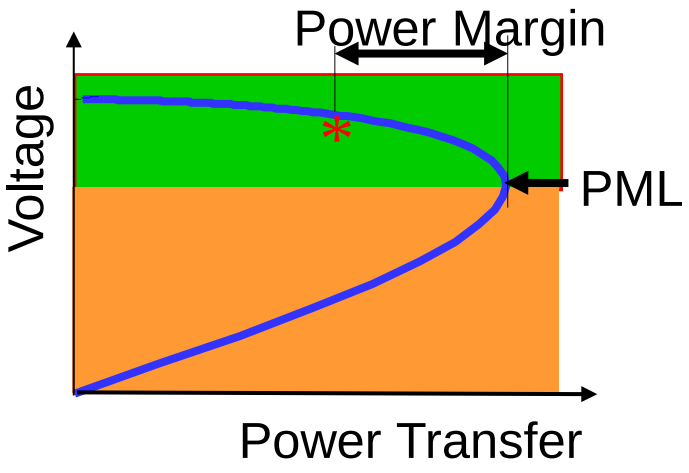


Voltage Instability



Voltage Stability Monitoring (VSM) Principle



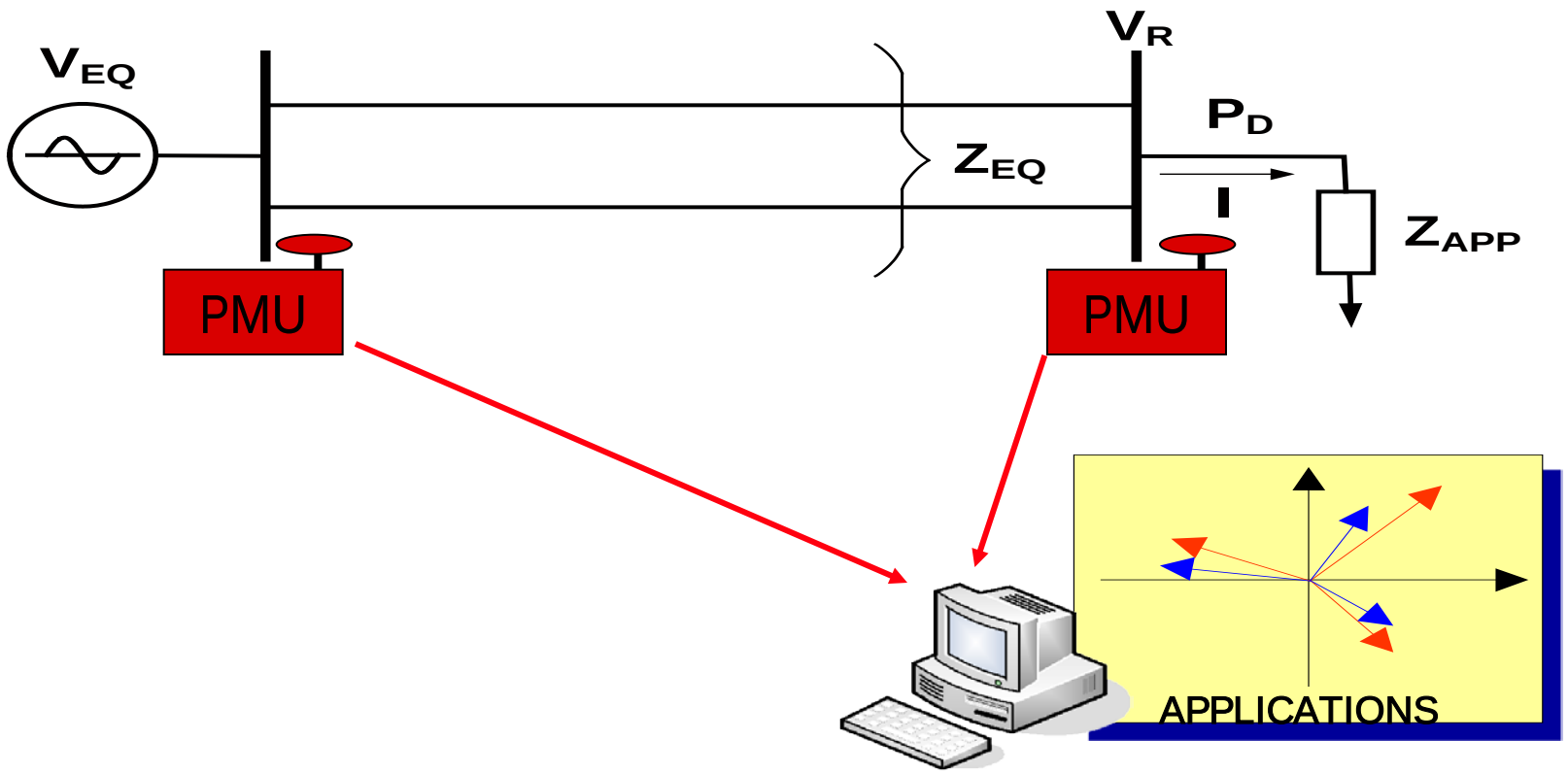


Assessment of distance to Point of Maximum Loadability, PML

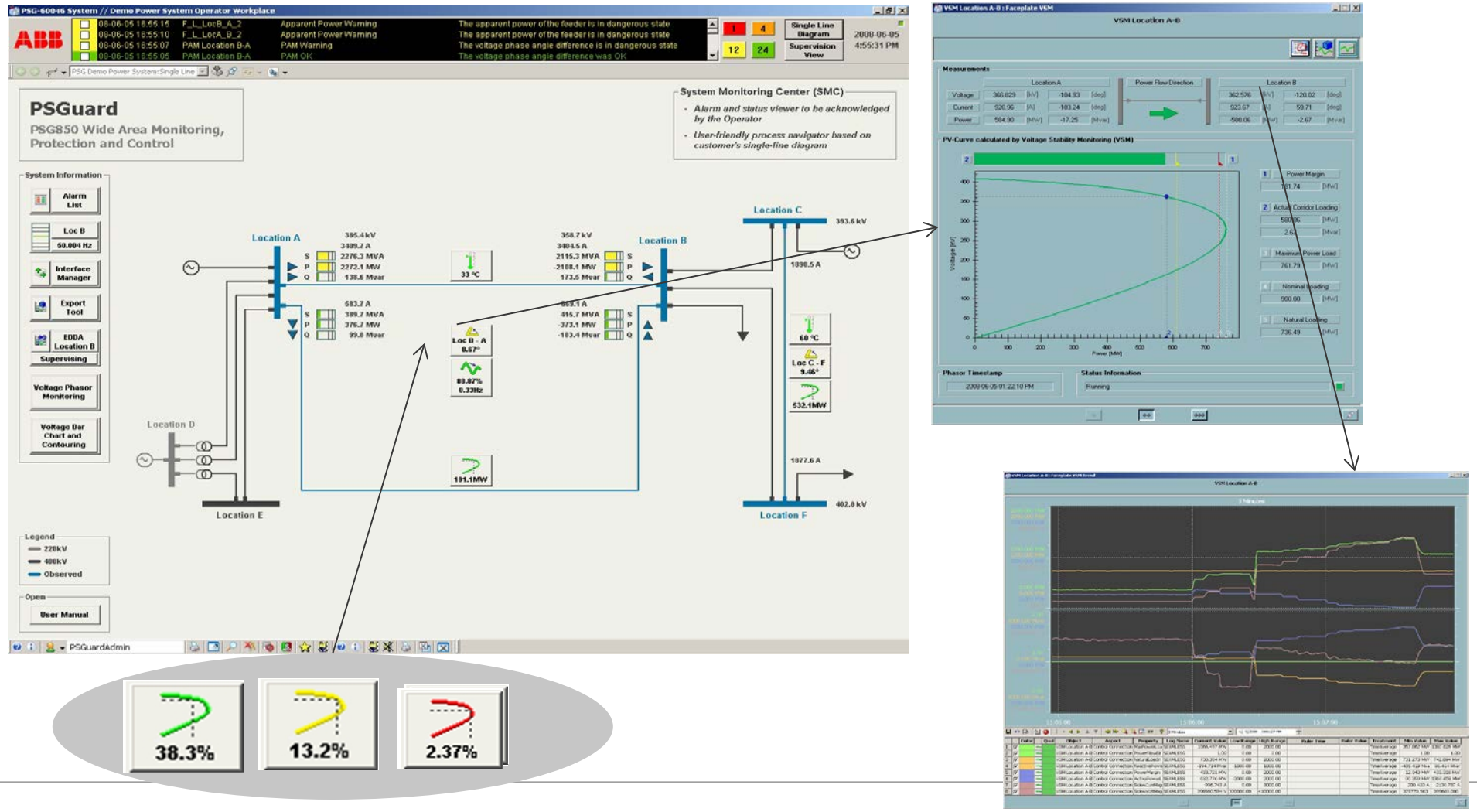
- Identify network equivalent
- Stay on top section of PV Curve !
- Trigger emergency actions when Power Margin too small
- Patented Method

Voltage Stability Monitoring (VSM) Application

PMU measurements from both ends of the line are used

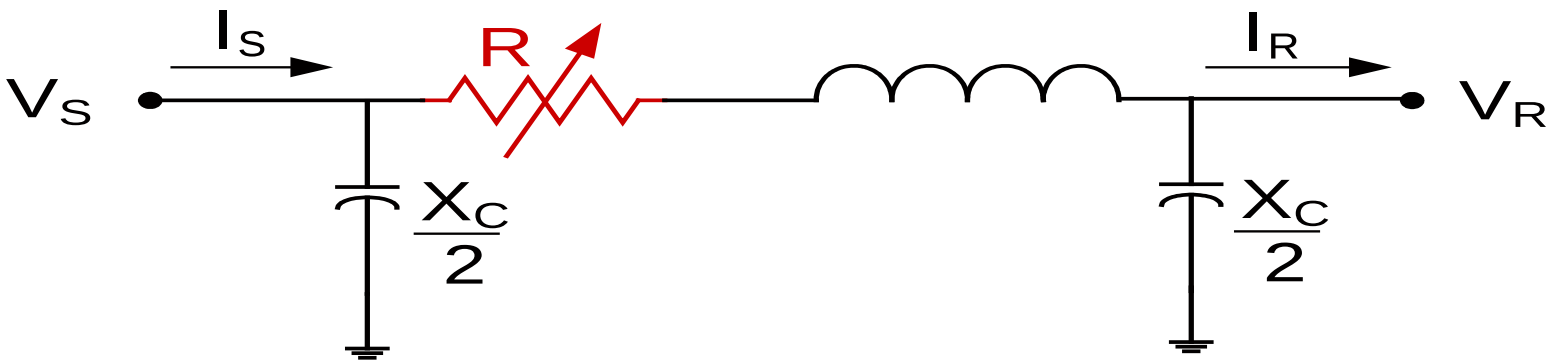


Voltage Stability Monitoring (VSM) User Interface



Line Thermal Monitoring (LTM) Application

Transmission Line Thermal Monitoring



Compute average conductor temperature to provide

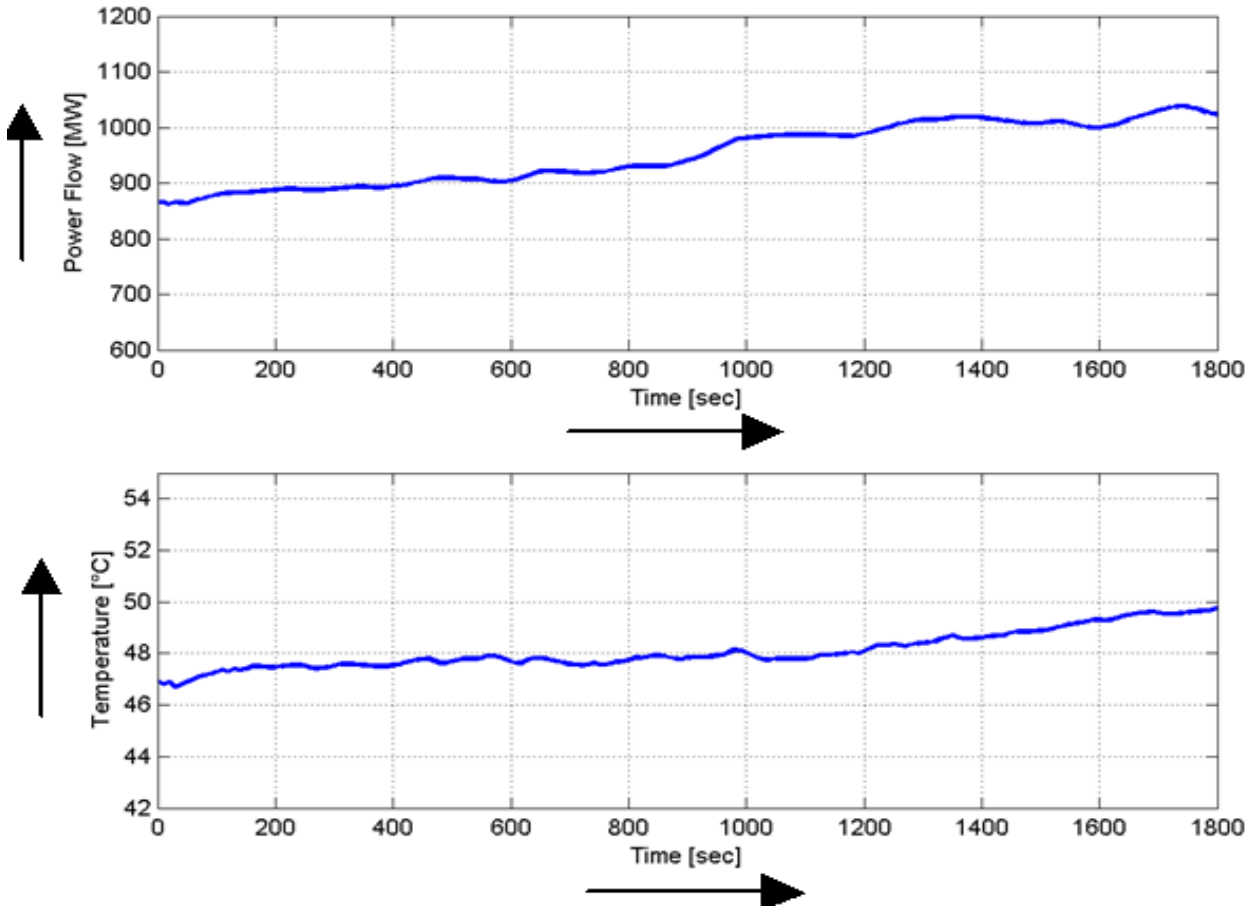
–Real-time assessment of loadability

–Early warnings in case of overload

–Available line capacity

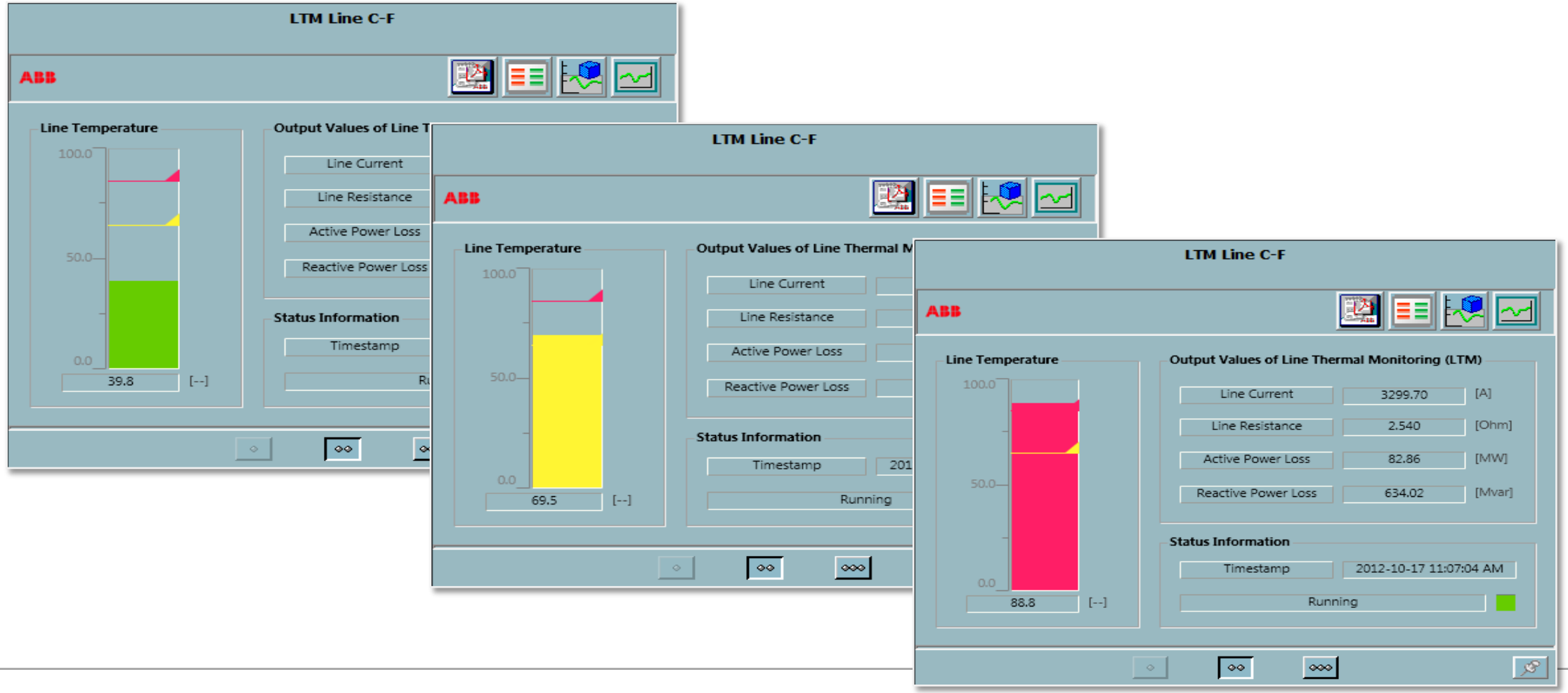
–Indirect estimation of line sagging

Line Thermal Monitoring (LTM) Example

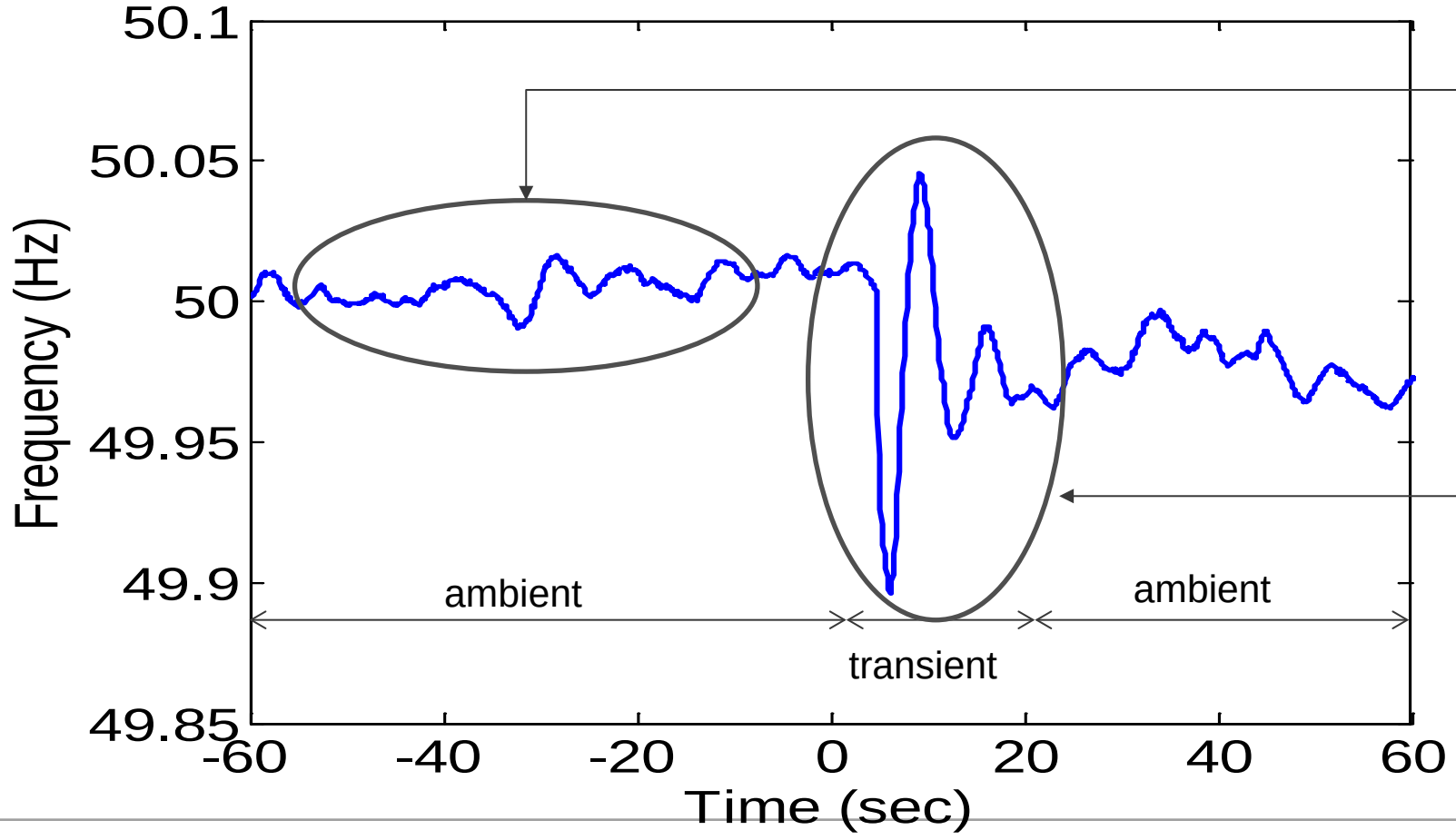


Field results correlate increased power transfer from 950 MW to 1150 MW leads to an average temperature increase from 46C to 49C over 30 min

Line Thermal Monitoring (LTM) User Interface



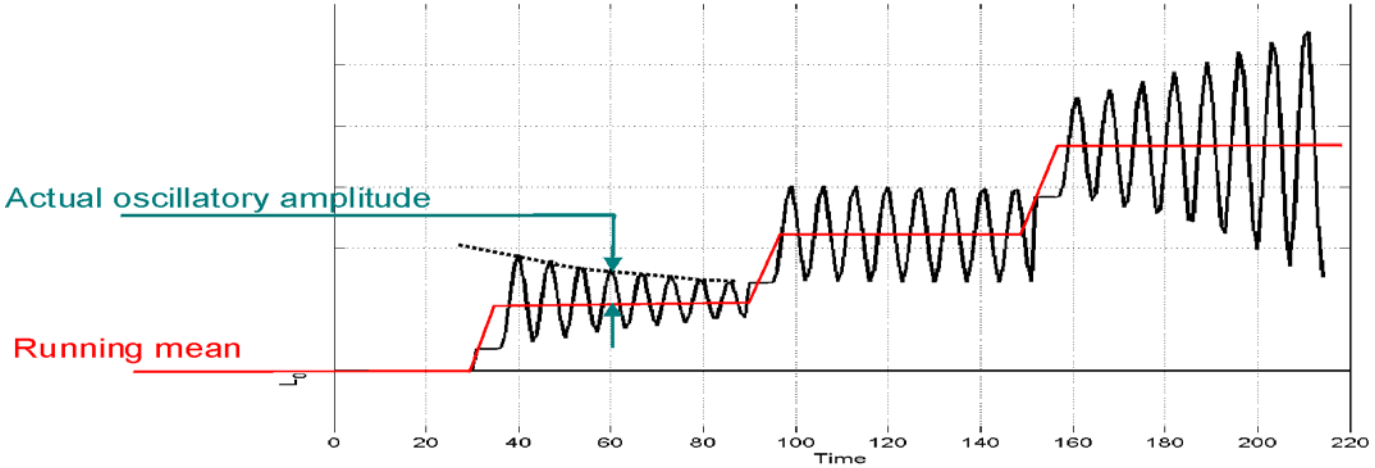
Ambient and Transient Power Oscillation Monitoring



PDM
determining modes and characteristics based on ambient variations

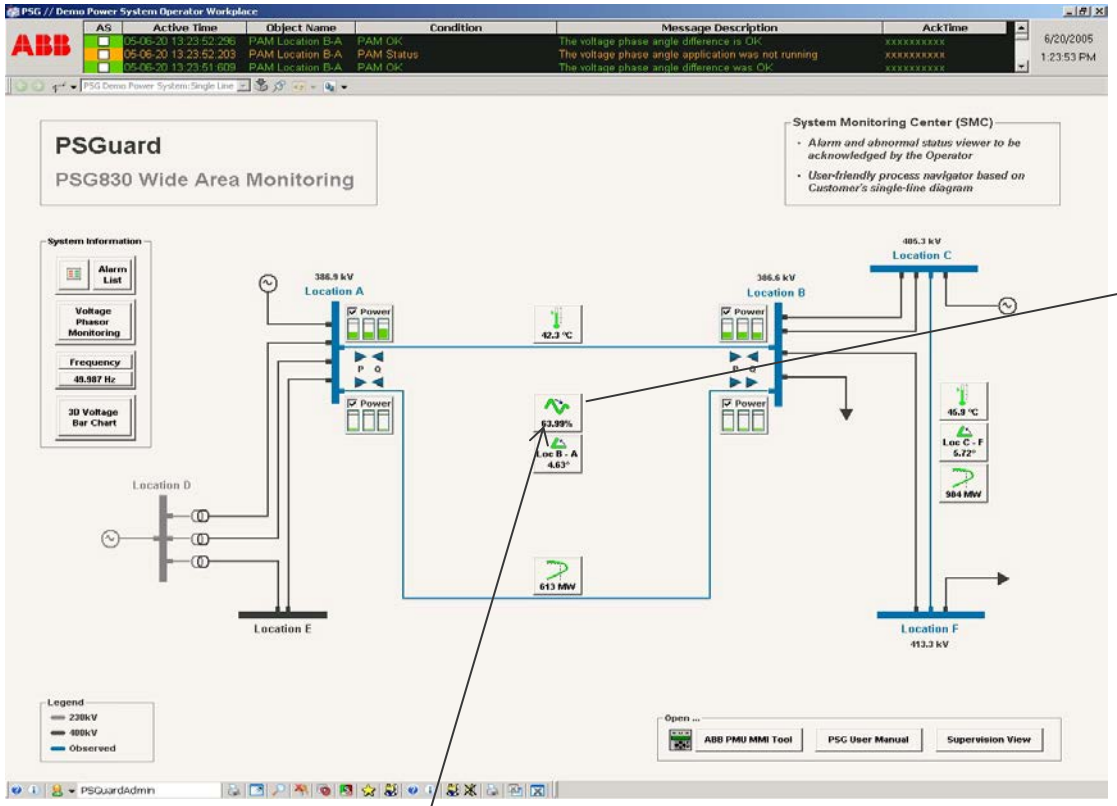
POM
detecting transient oscillations

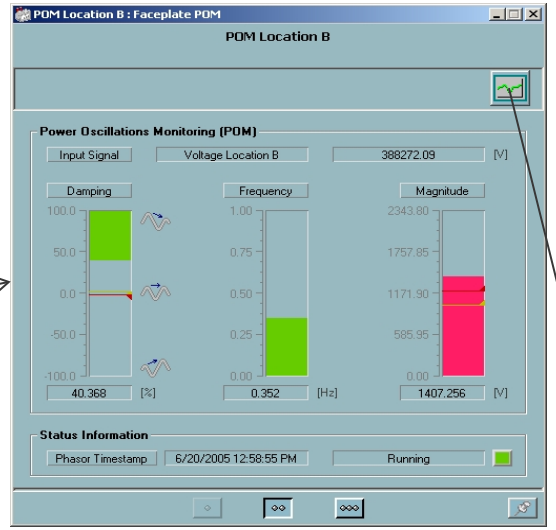
Power Oscillation Monitoring (POM) Application

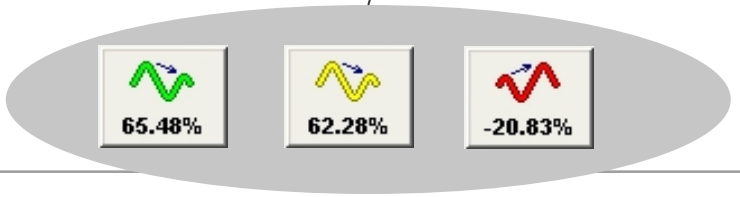


- Detection of power swings in a high voltage power system.
- Algorithm is fed with the selected voltage and current phasors.
- Detection of the various swing (power oscillation) modes.
- Quickly identifies the amplitude and frequency
- Negative damping identification

Power Oscillation Monitoring (POM) Use Interface



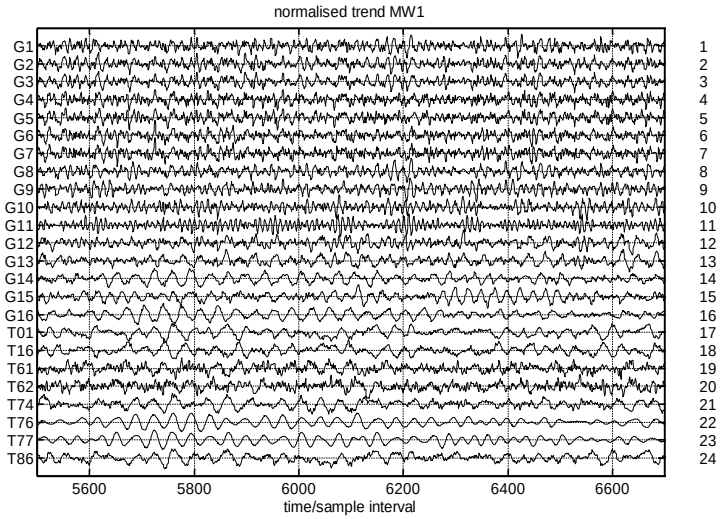




Power Damping Monitor (PDM) Application

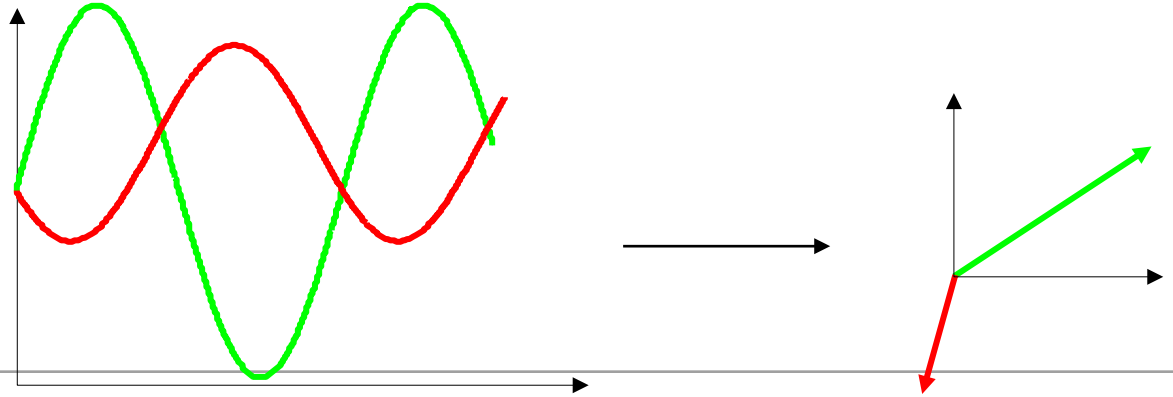
Determine in real-time from ambient oscillations

- Modal frequencies and damping
- Phase in each measurement signal
- Modal activity

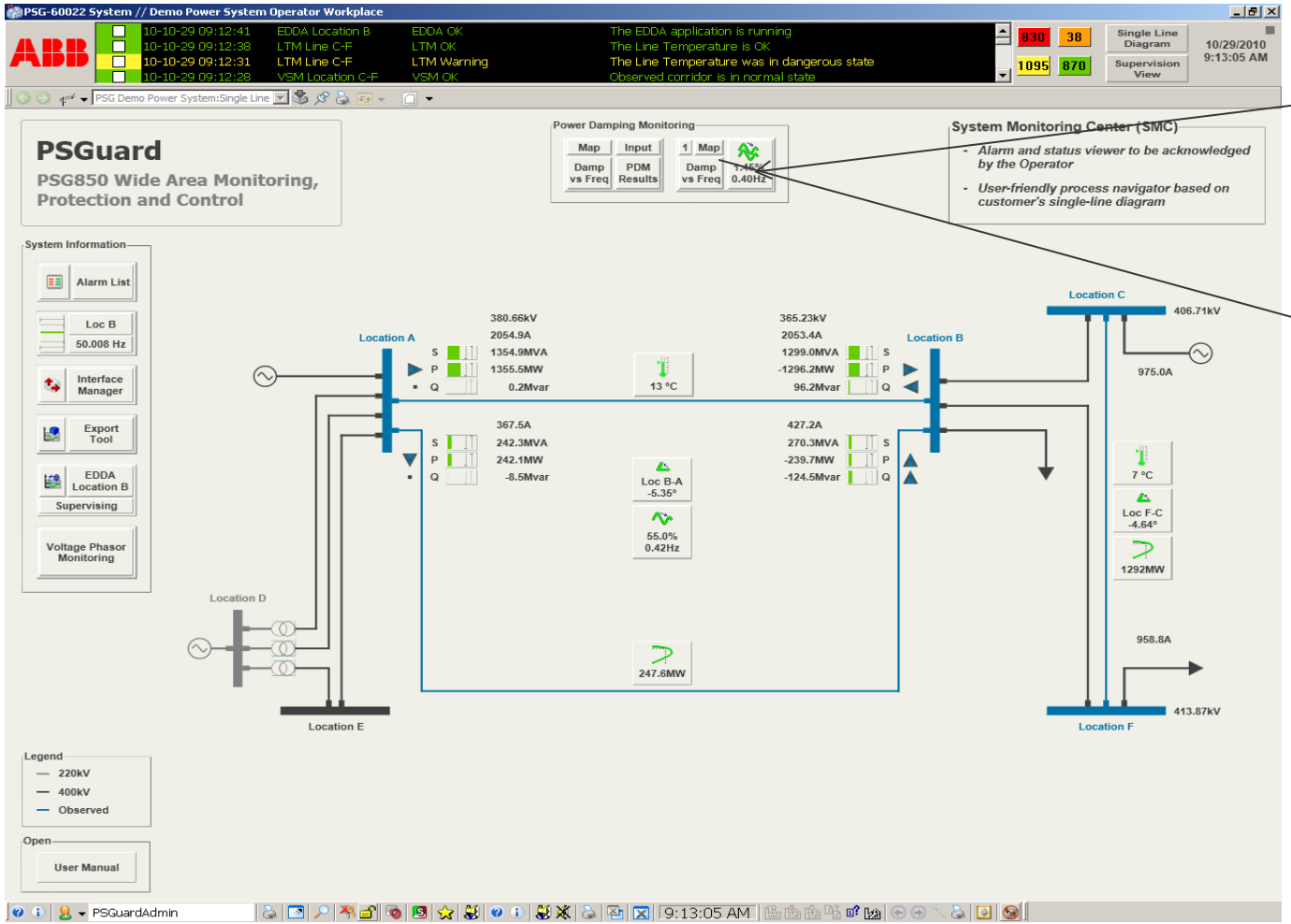


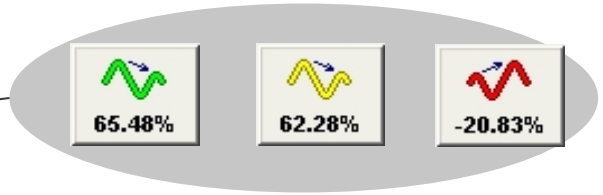
Challenge

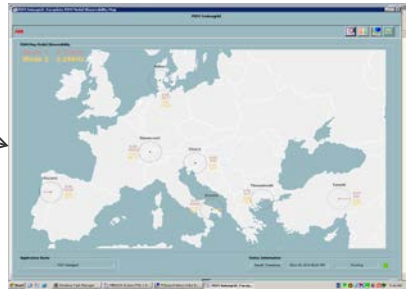
- Ambient noise small



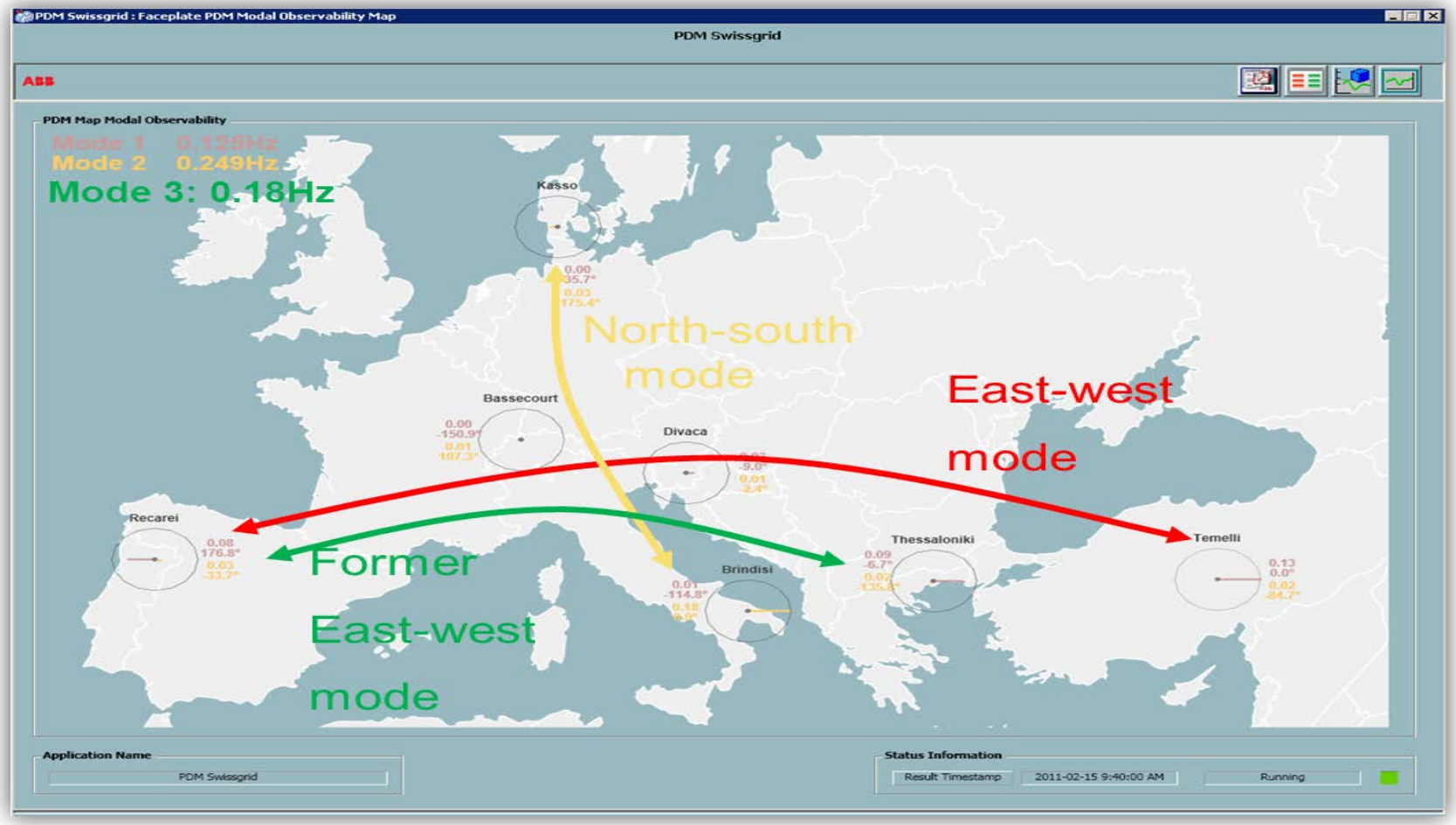
Power Damping Monitor (PDM) User Interface







Power Damping Monitor (PDM) Example

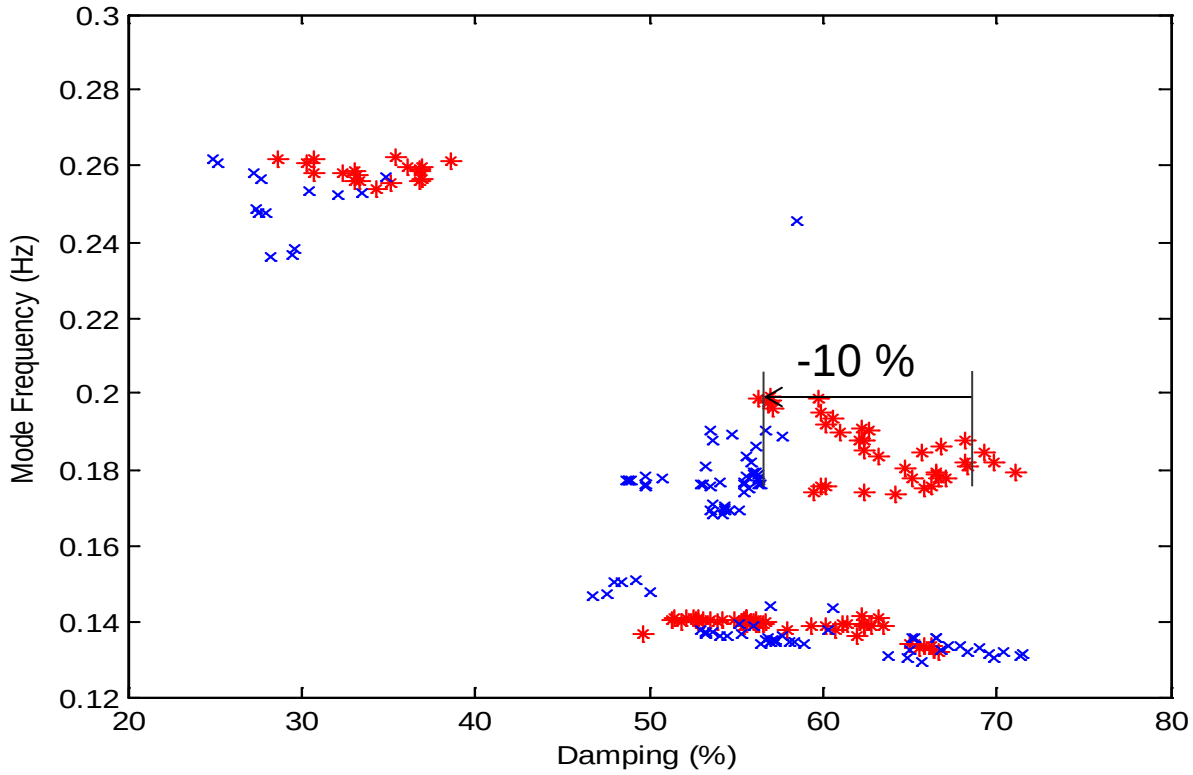


East-west mode - ~0.13 Hz

North-south mode - ~0.25 Hz

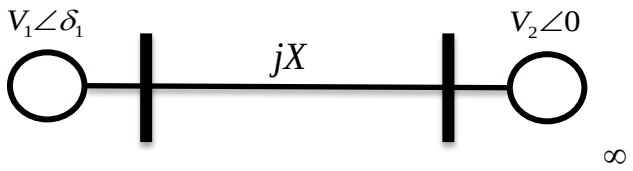
Former east-west mode - ~0.17 Hz

Power Damping Monitor (PDM) Output



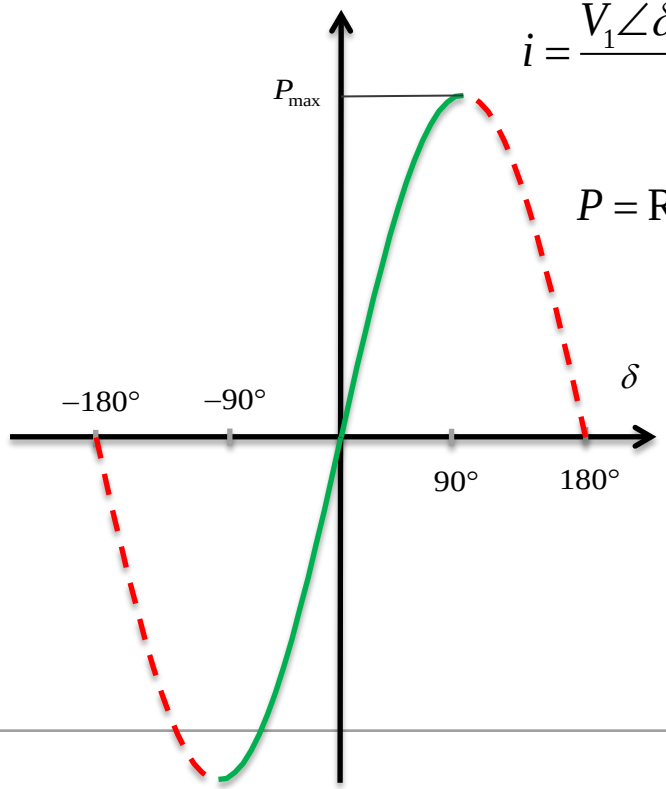
- Results for October 25, 2011 event
  - 14:30 -14:59 CET during fault
  - 15:00 – 15:30 CET post fault
- Trip reduced damping of the former east-west mode by 10%
- PDM reported around 60% damping of the east-west mode before and disturbance (nearly unaffected)

Phase Angle Monitoring (PAM) Principle



$$i = \frac{V_1\angle\delta - V_2\angle 0}{jX}$$

$$P = \mathrm{Re}\{v_1 i_1^*\} = \frac{V_1 V_2}{X}\sin\delta$$



Phase Angle Monitoring

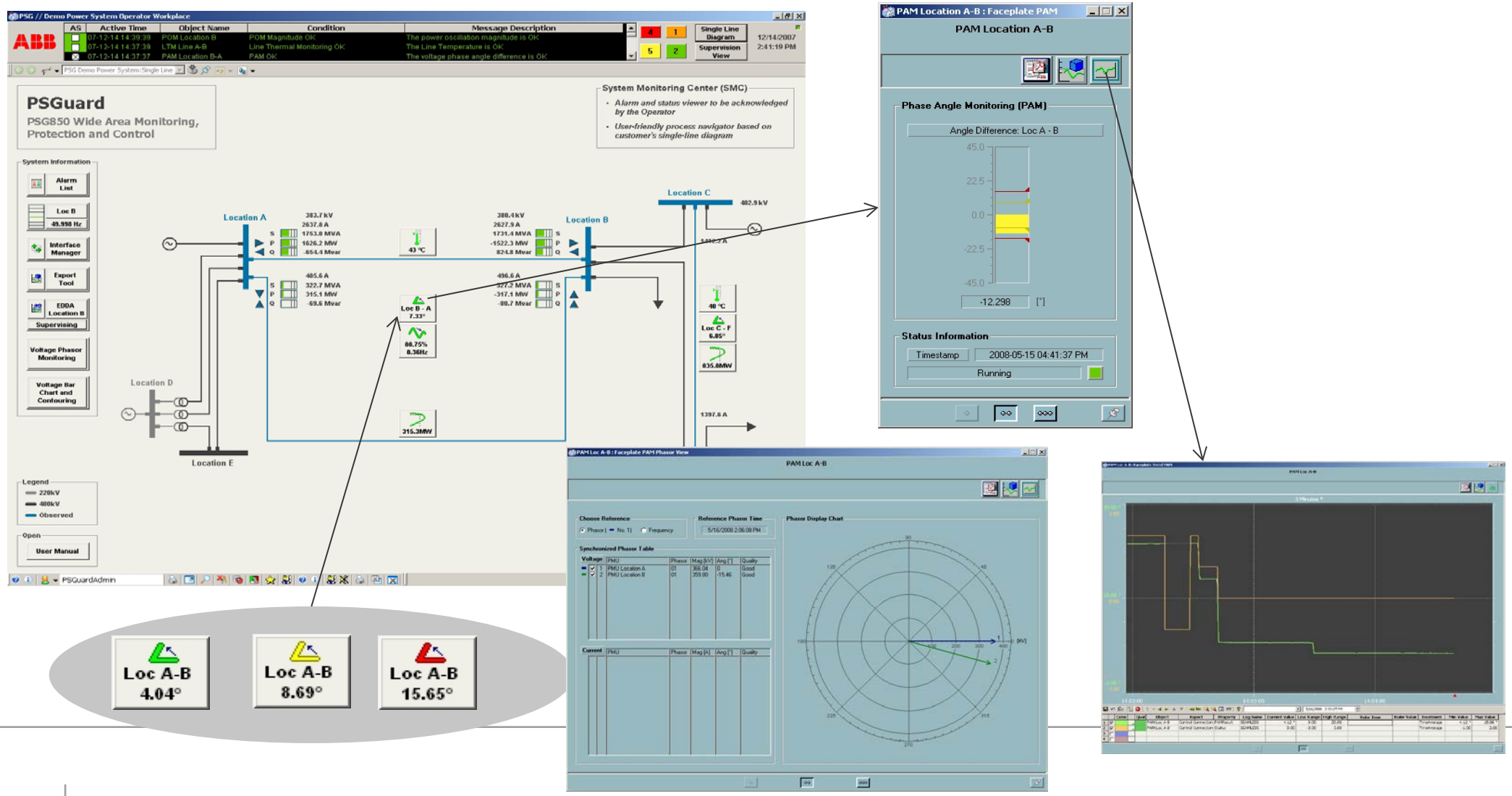
Phase angle difference (δ) is indicative of:

- Relation between grid strength and power transfer

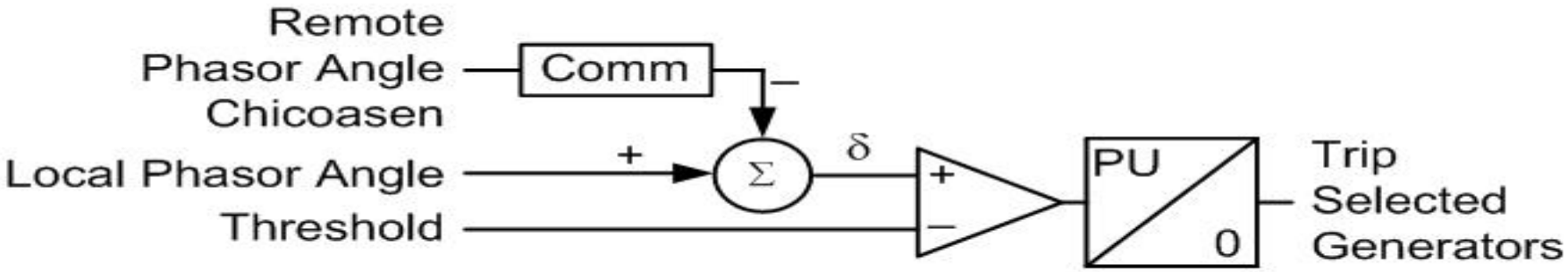
Abnormal values of the phase angle difference is indicative of

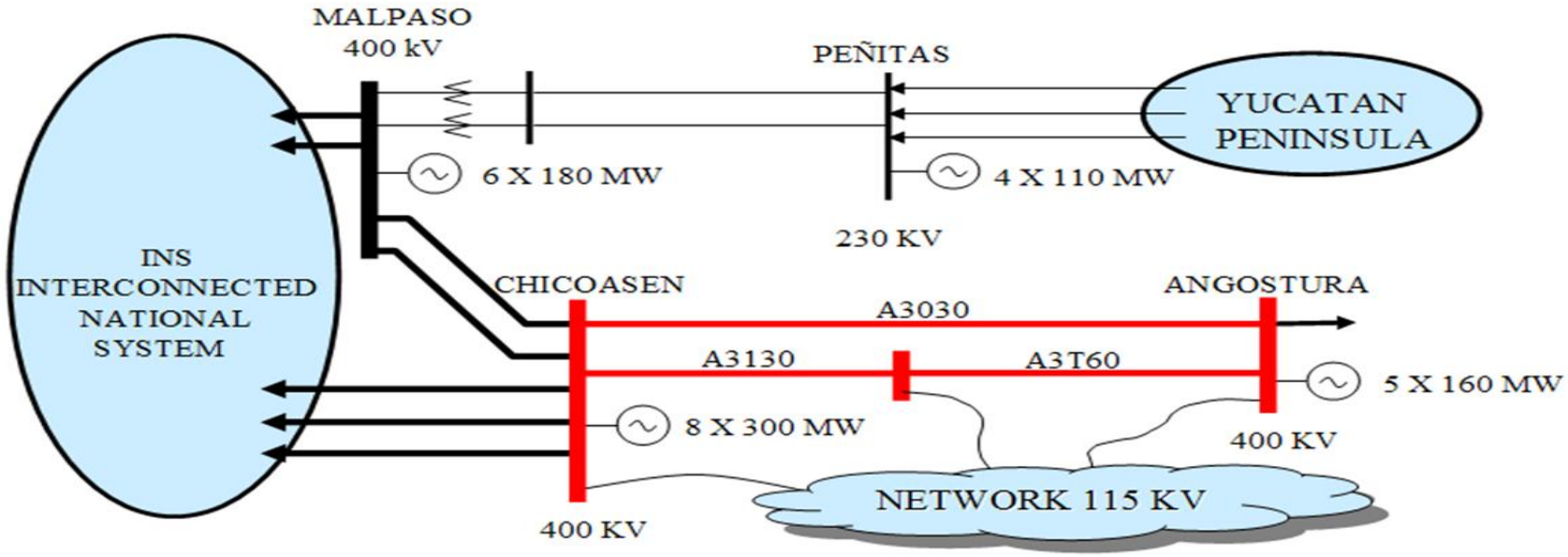
- Unusual power transfer
- Line trips
- Abnormal voltage levels

Phase Angle Monitoring (PAM) User Interace



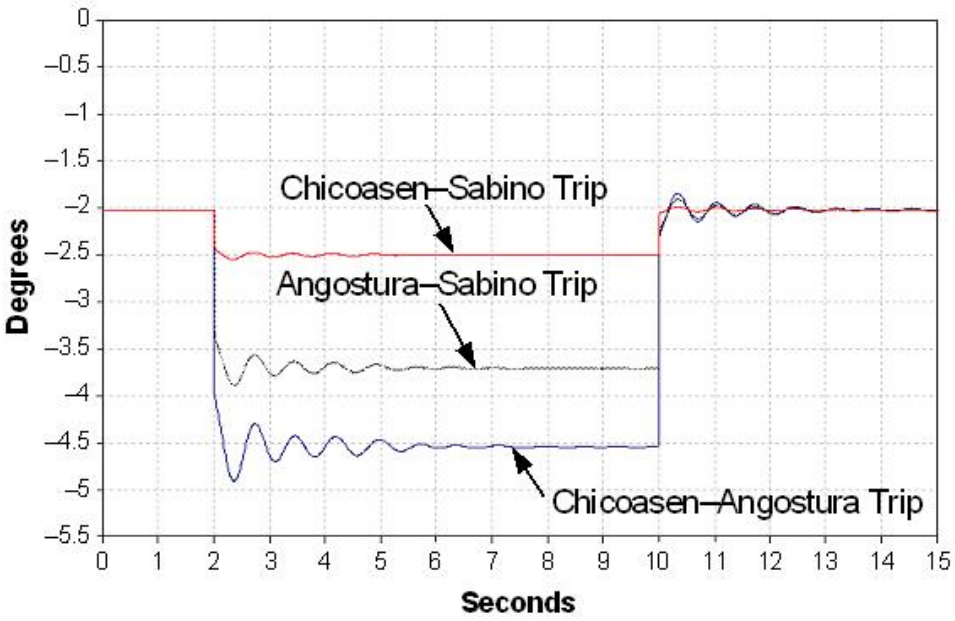
Angular Differential Protection Example

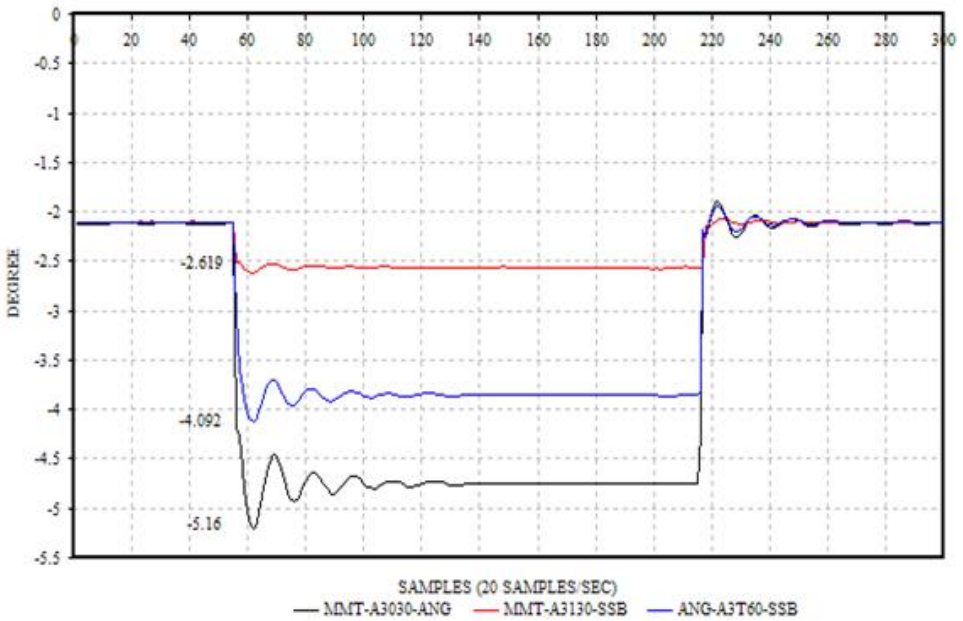




Source: E.Martinez Angular Difference Protection Scheme, Conference on Actual Trends in Development of Power System development and Automation, Sept 2009, Moscow, Russia

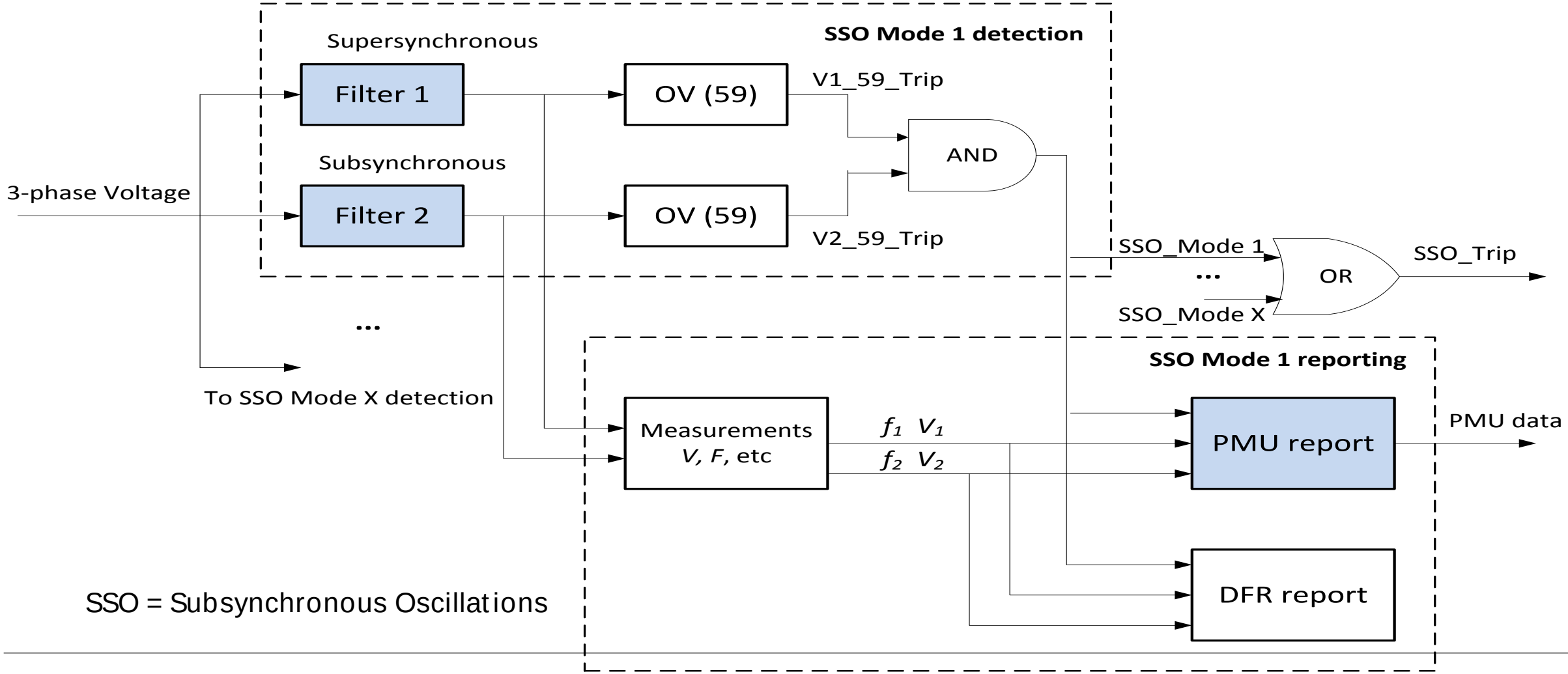
Angular Differential Protection Example





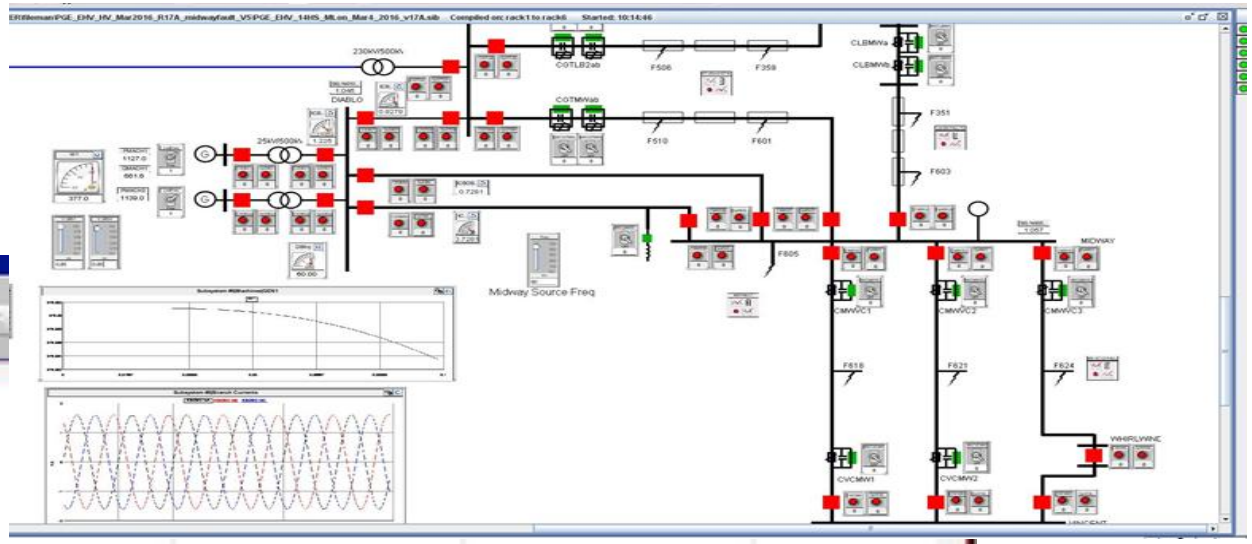
Source: E.Martinez Angular Difference Protection Scheme, Conference on Actual Trends in Development of Power System development and Automation, Sept 2009, Moscow, Russia

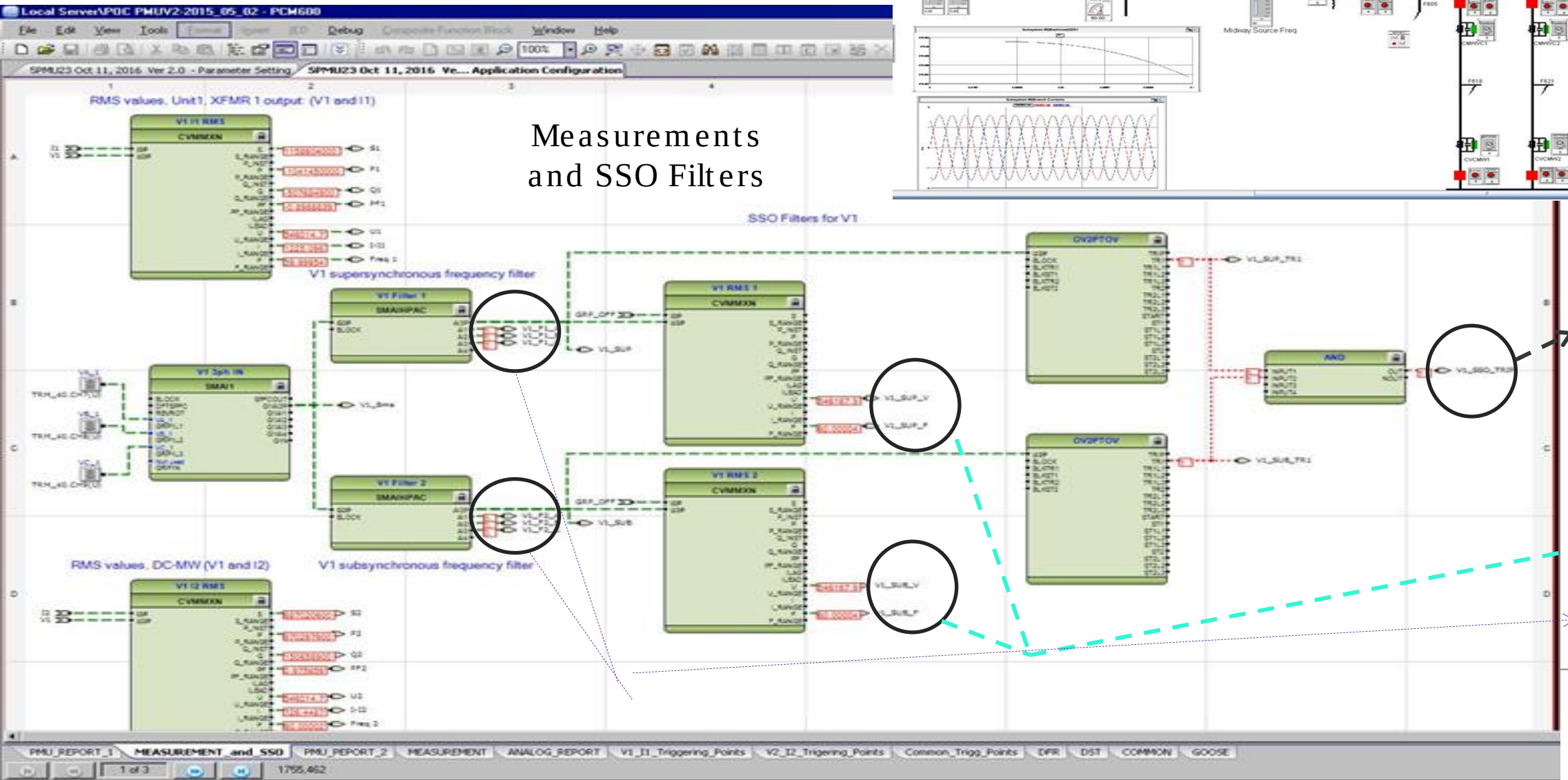
Integrating SSO and PMU Functionality



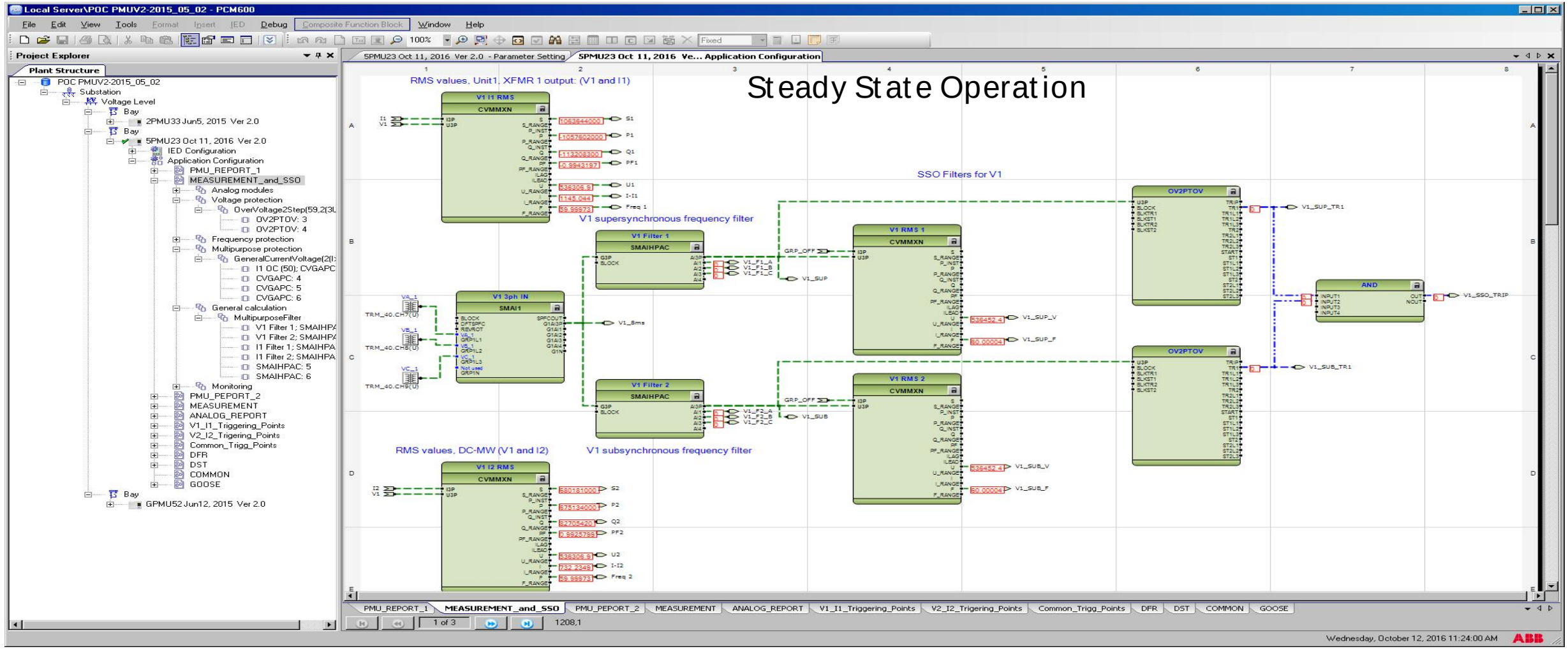
SSO = Subsynchronous Oscillations

Simulation model and system

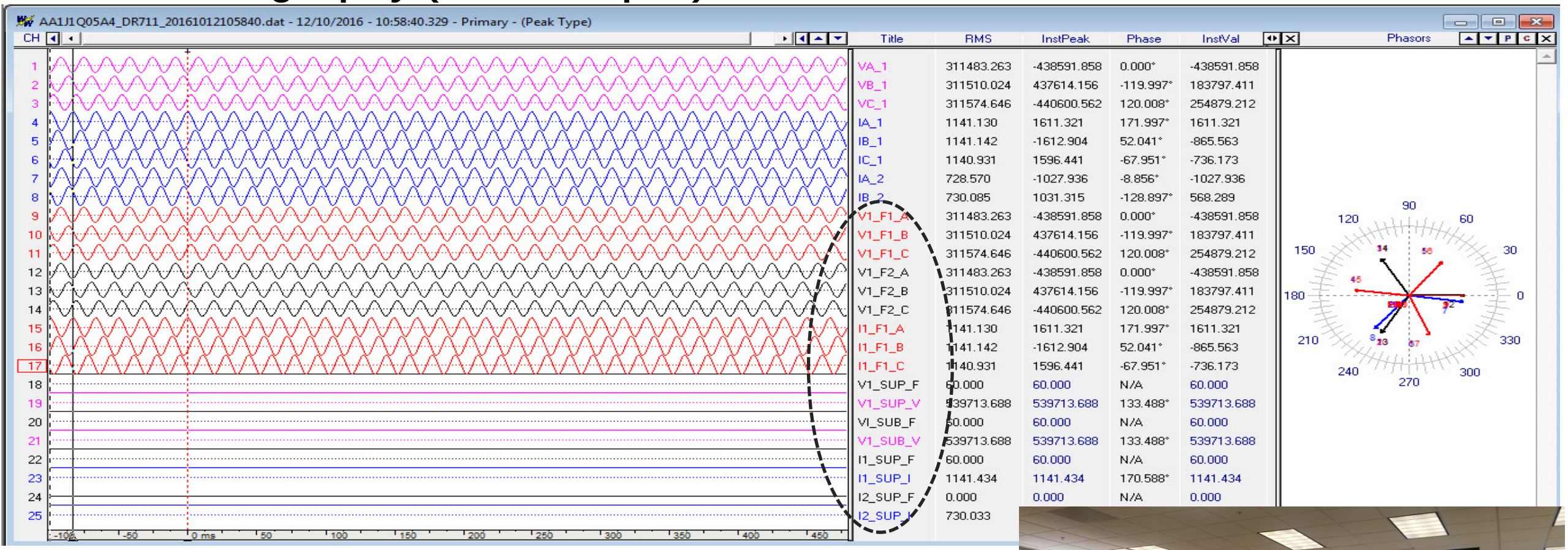




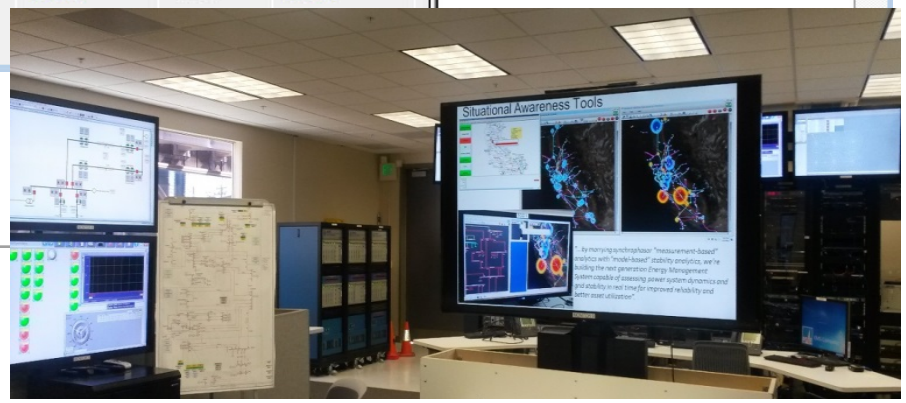
Configuration and SSO Filter Output



SSO Oscillography (filter output)

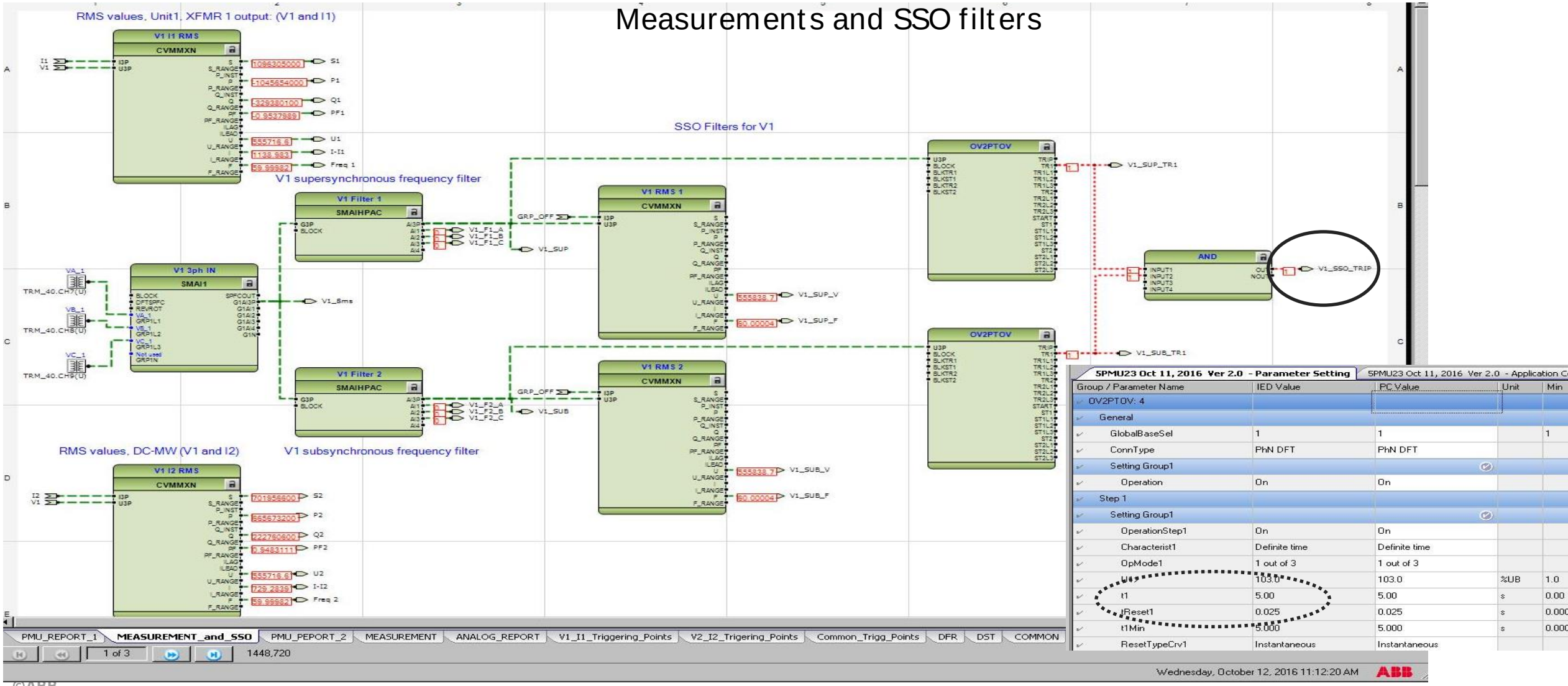


Steady state operation



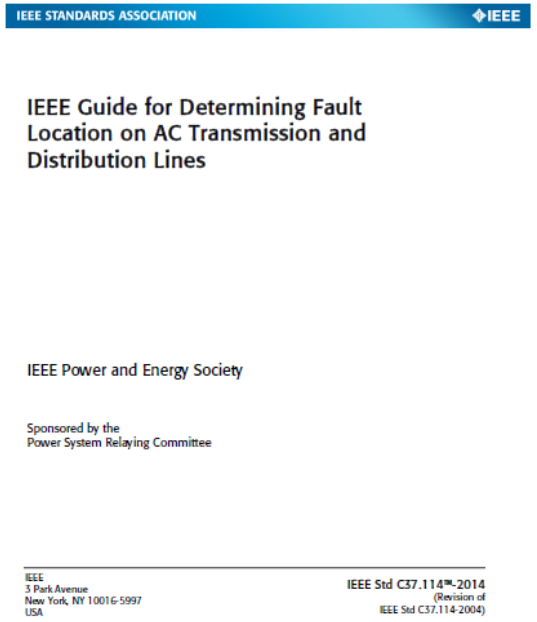
PG&E Proof of Concept Facility

Simulation: Overvoltage



Determining fault location using synchrophasor measurements

- One of possible fault location technologies described by IEEE C37.114 Fault Location Guide.
- Relies on negative sequence current and voltage measurements from 2 ends (a two-terminal method)
- Different algorithms and impedance matrixes used for different faults
- Dependent on time synchronization and communication
- Down to 2% accuracy in fault location were demonstrated
- Testing performed at PG&E synchrophasor proof of concept facility


IEEE STANDARDS ASSOCIATION IEEE

IEEE Guide for Determining Fault Location on AC Transmission and Distribution Lines

IEEE Power and Energy Society

Sponsored by the
Power System Relaying Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std C37.114™-2014
(Revision of
IEEE Std C37.114-2004)

Wide-Area Control Applications

Wide Area Power oscillation Damping control WA-POD

Choose feedback signals from any PMU equipped substation

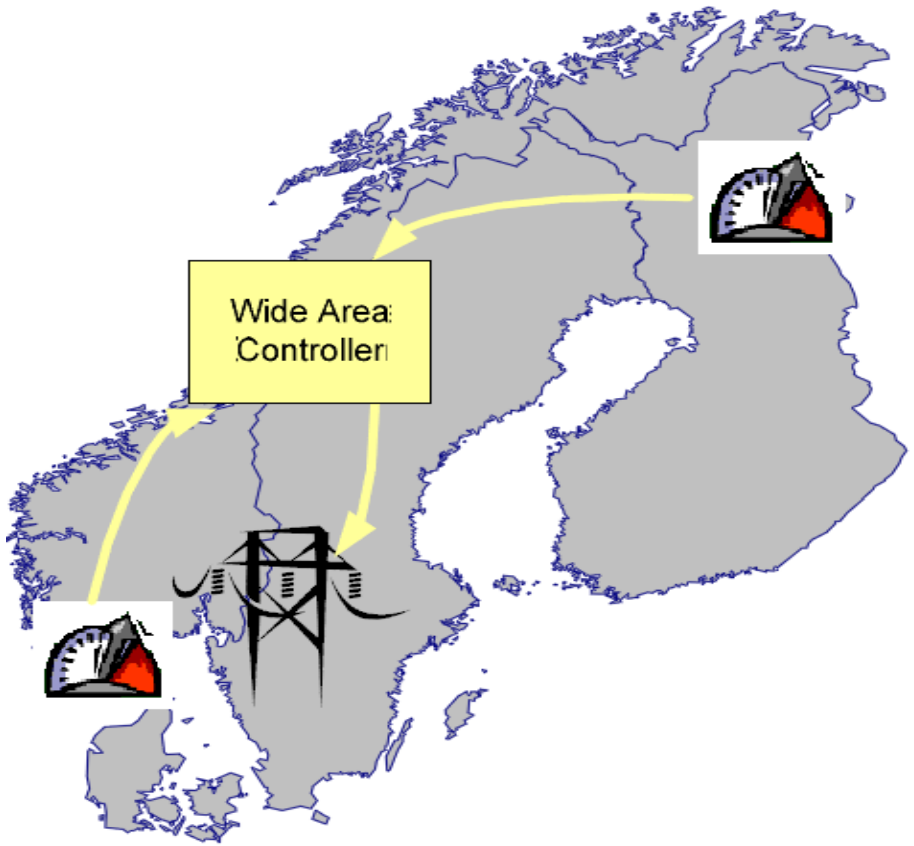
Coordinated POD action from several actuators (SVC, FACTS, Generators)

Prototype WACS implemented and tested

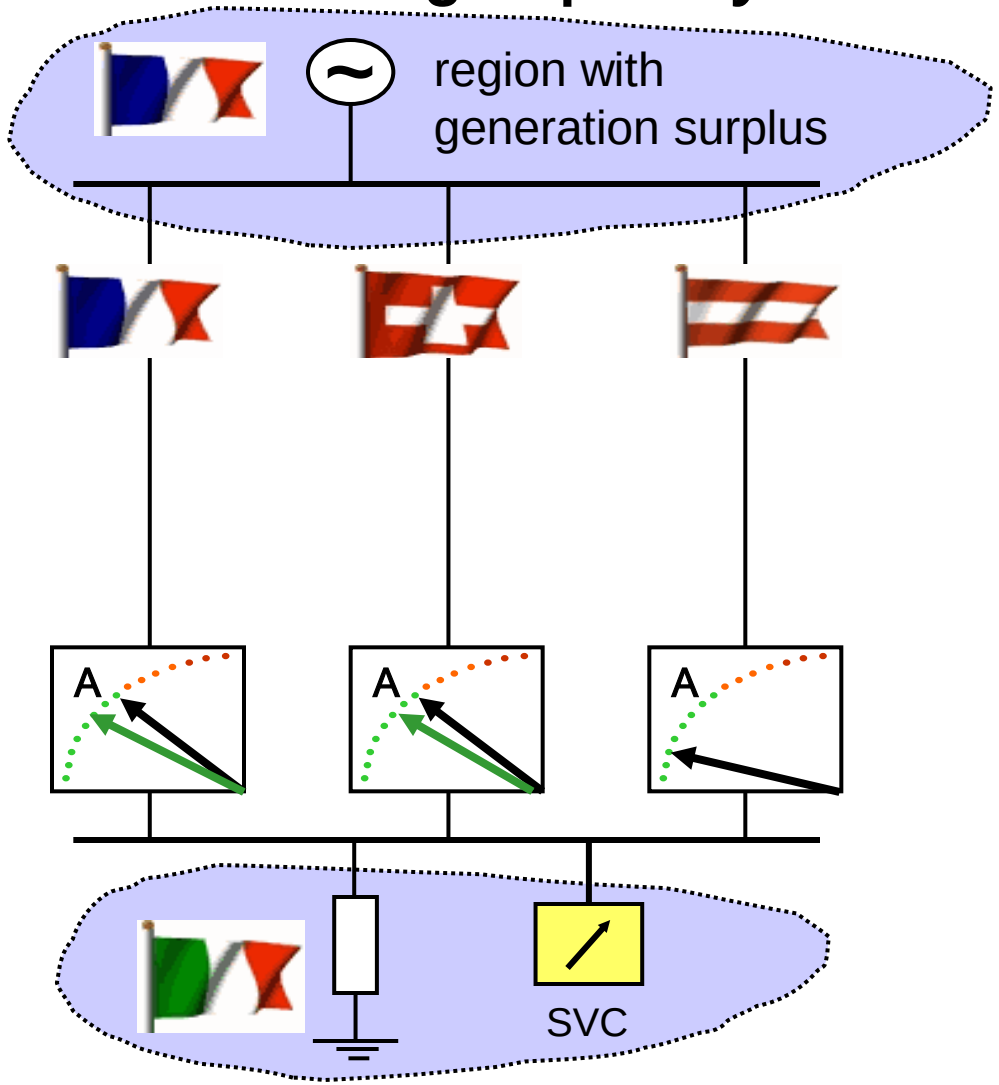
– PMU-PCU400 PDC-MACH2 control system

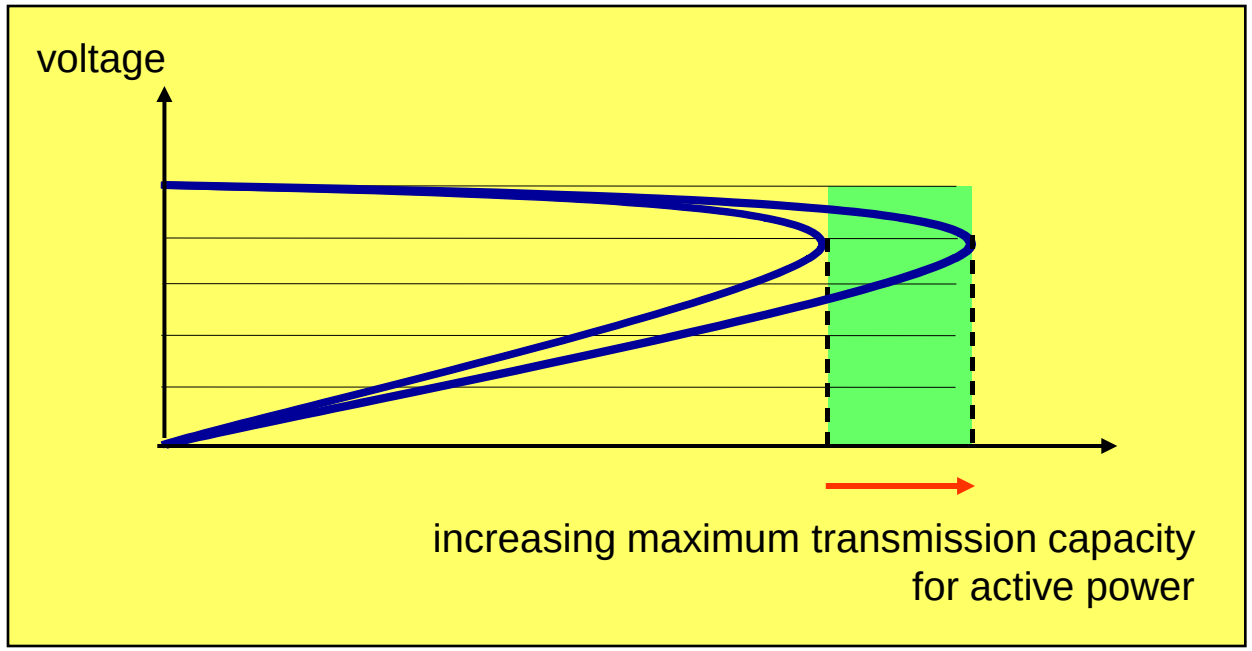
– Wide Area Power Oscillation Damper (POD) with local signal based POD as backup

Deployed in 2010



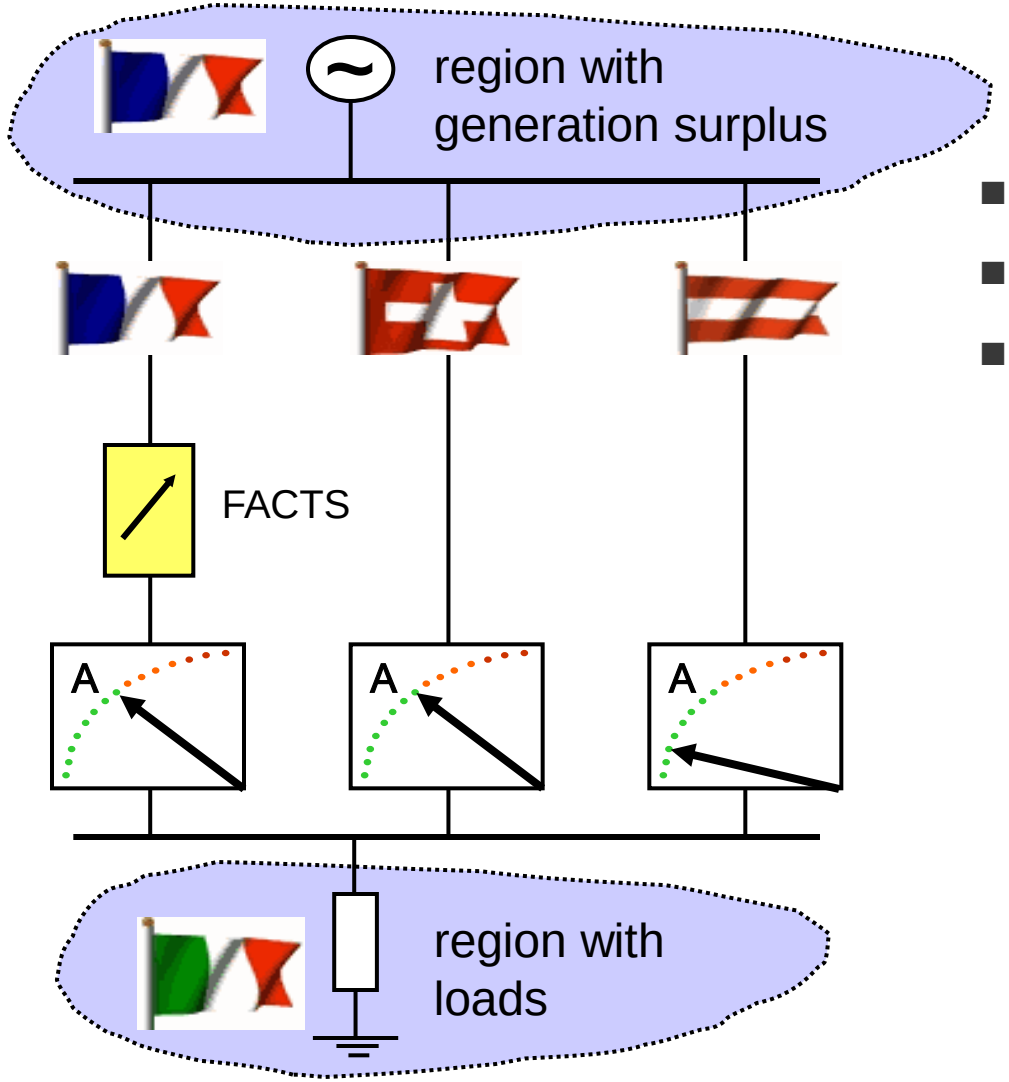
2004: Increasing capacity with SVC





SVC: static var compensation

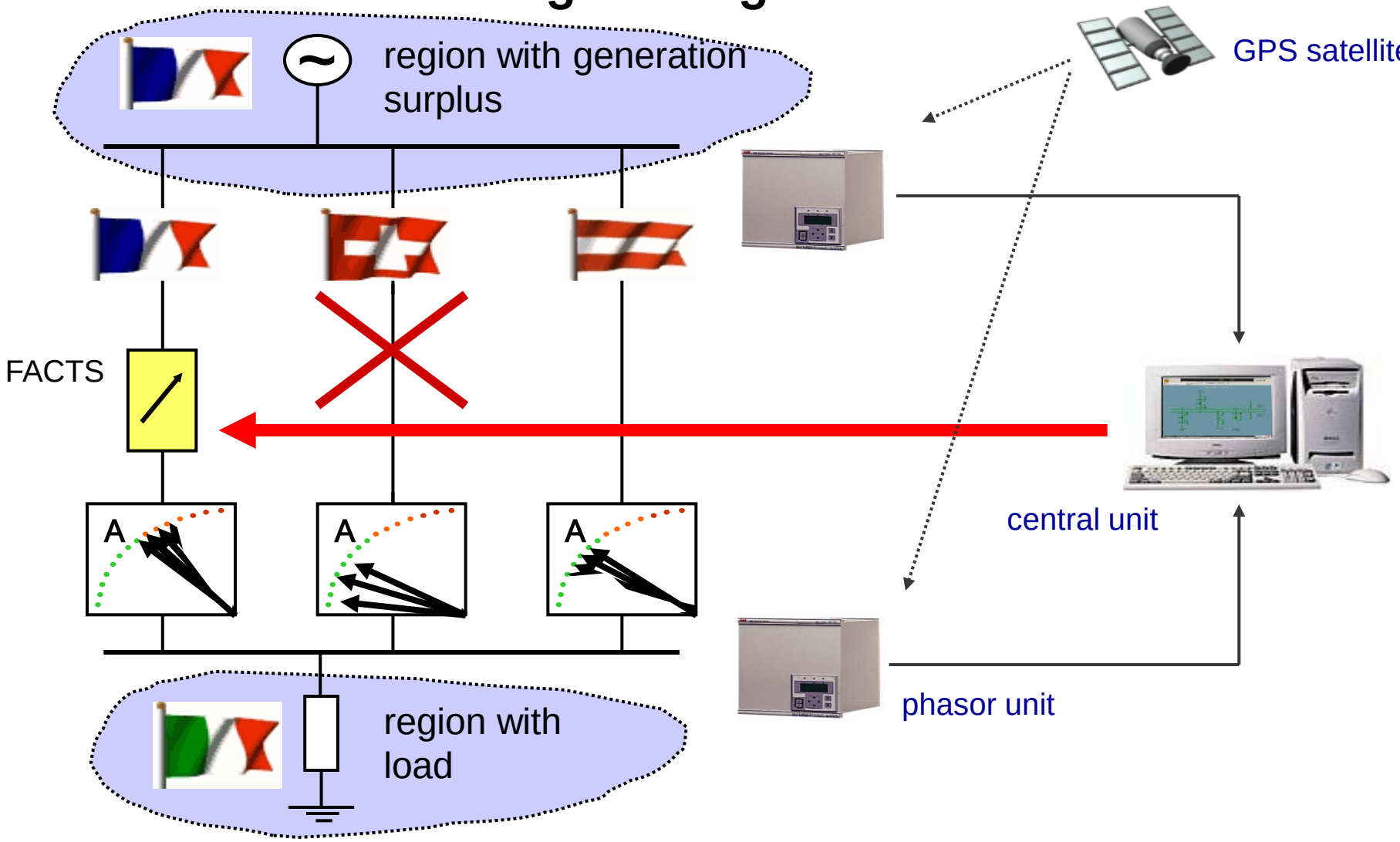
2004: FACTs for Power Flow Control



- switched series compensation (SC) *new 2004*
- thyristor controlled series compensation (TCSC)*
- dynamic flow control (DFC)* *vision*

* fast control

2004 vision: combining intelligent solutions



Step 1:

- system analysis
- free capacity available
- temporary overload acceptable

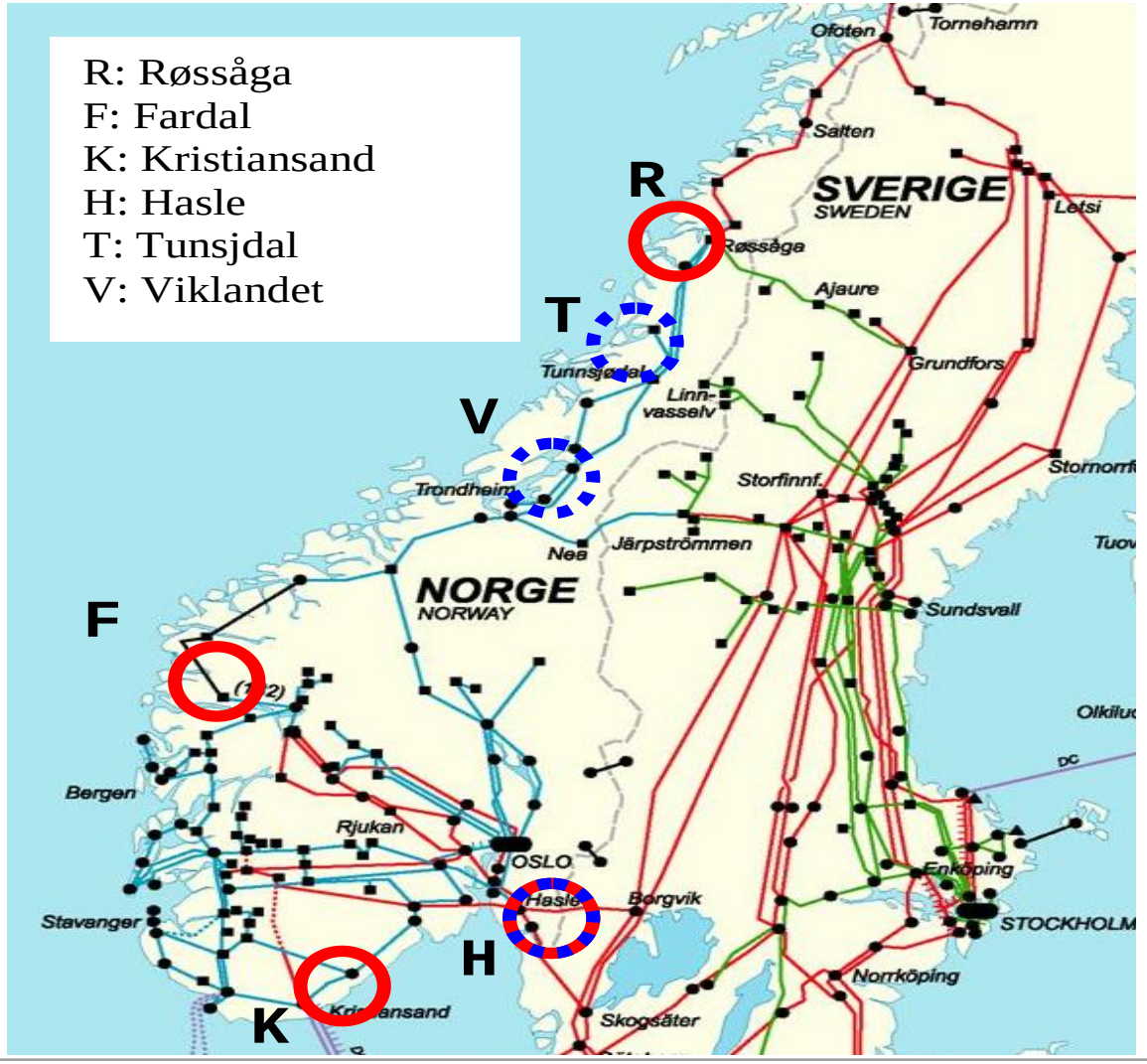
Step 2:

- increase reactance of overloaded line
- stable situation

Nordic Power System

Interconnected power systems
- Finland
- Sweden,
- Norway,
- East Denmark
- West Denmark
- Iceland (isolated)

Recently installed in Norway
- PMUs (locations R, F, K, H)
- SVCs (locations H, T, V)



Wide-area Power Oscillation Damper Control

PMUs streaming synchrophasors

– Nedre Røssåga

– Kristiansand

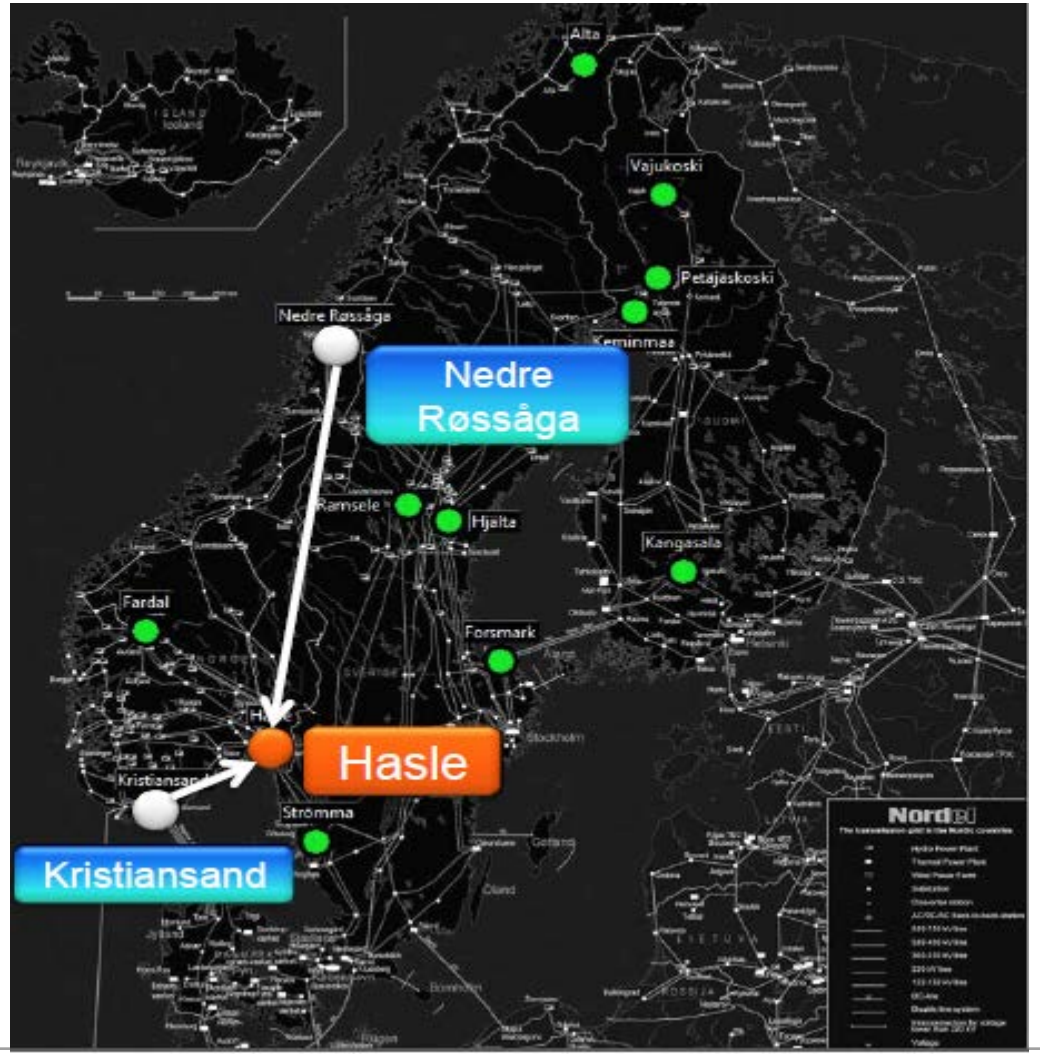
SVC is located at Hasle

– PDC

- receives voltage phasors
- extracts voltage phasor angle

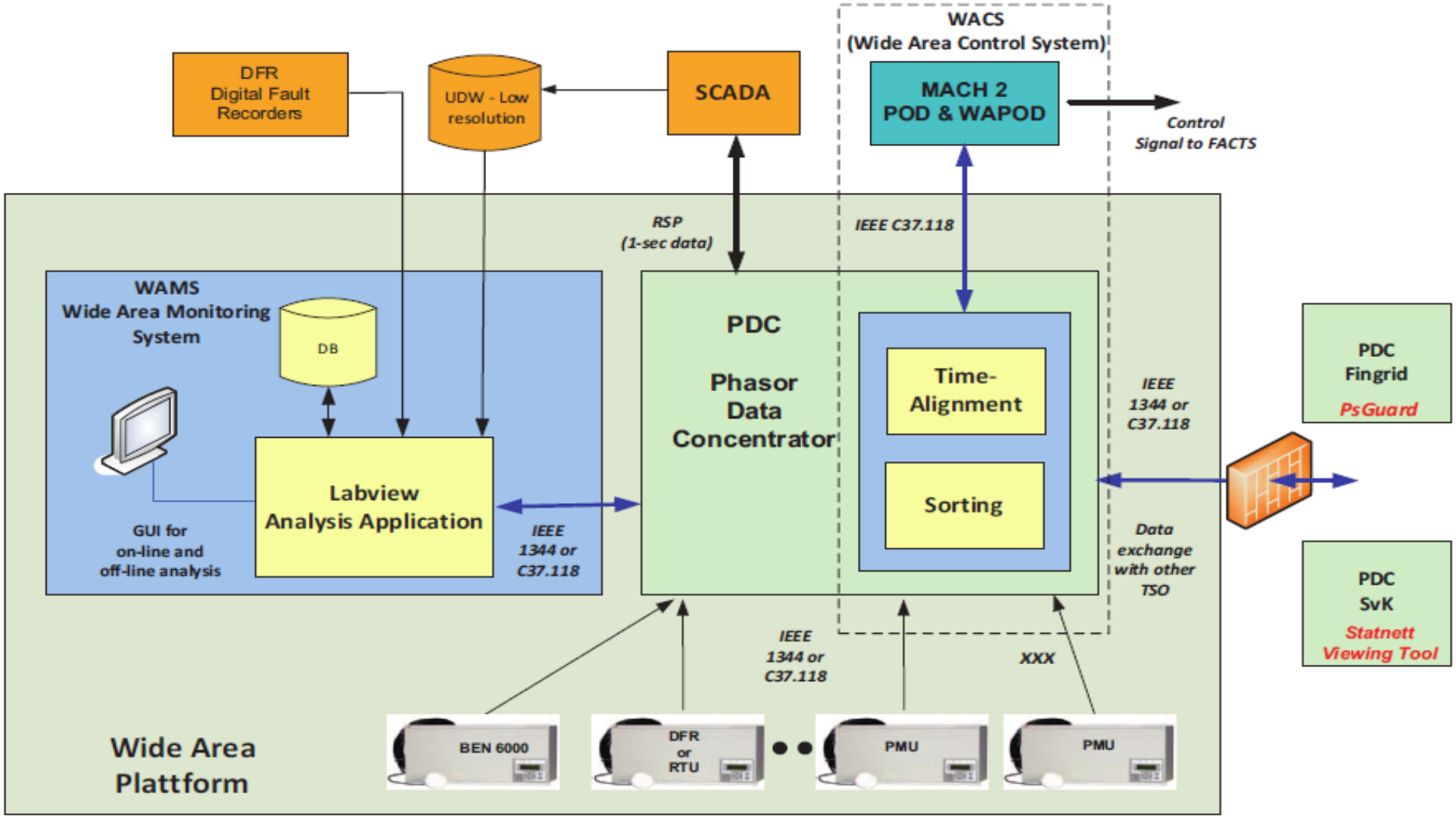
– ABB Mach2 Controller

- Local control
- WAPOD Control
- Switch-over logic



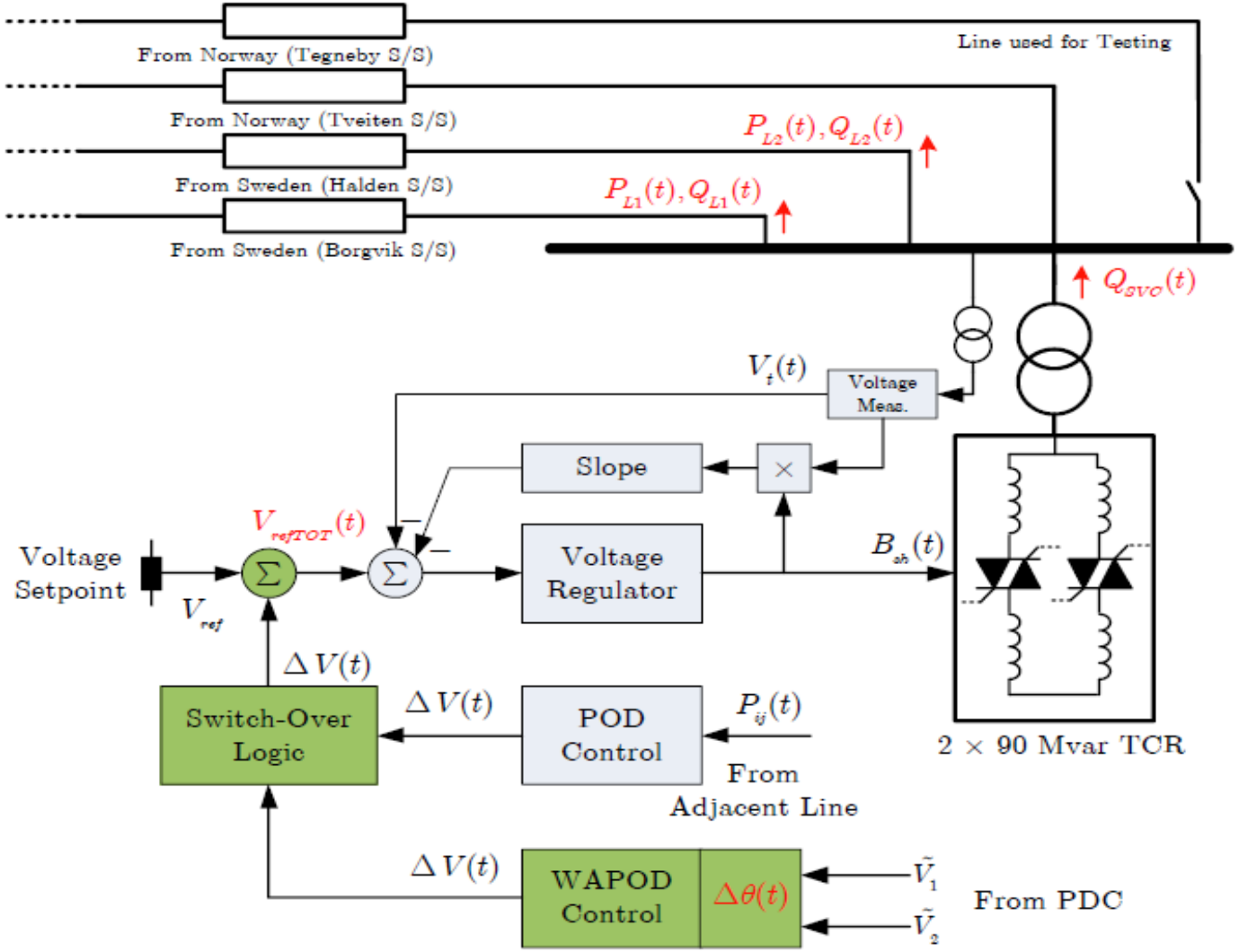
Source: K. Uhlen, etc Wide-Area Power Oscillation Damper Implementation and Testing in the Norwegian Transmission Network, IEEE PES 2012.

Wide-area Monitoring and Control System



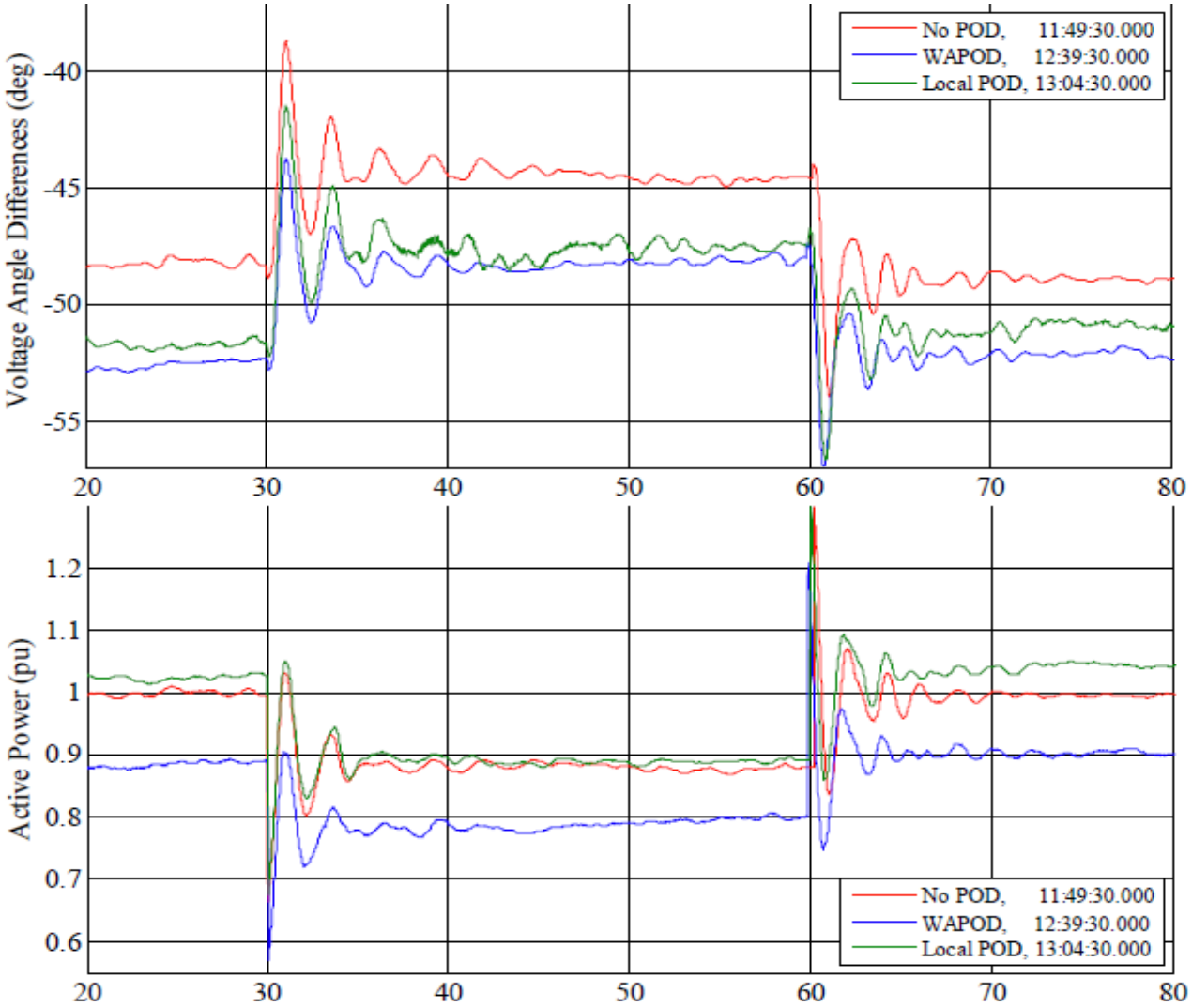
Source: K. Uhlen, etc Wide-Area Power Oscillation Damper Implementation and Testing in the Norwegian Transmission Network, IEEE PES 2012.

SVC Control Implementation



Source: K. Uhlen, etc Wide-Area Power Oscillation Damper Implementation and Testing in the Norwegian Transmission Network, IEEE PES 2012.

Field Test Results: Switching 420kV Hasle-Tegneby



Source: K. Uhlen, etc Wide-Area Power Oscillation Damper Implementation and Testing in the Norwegian Transmission Network, IEEE PES 2012.

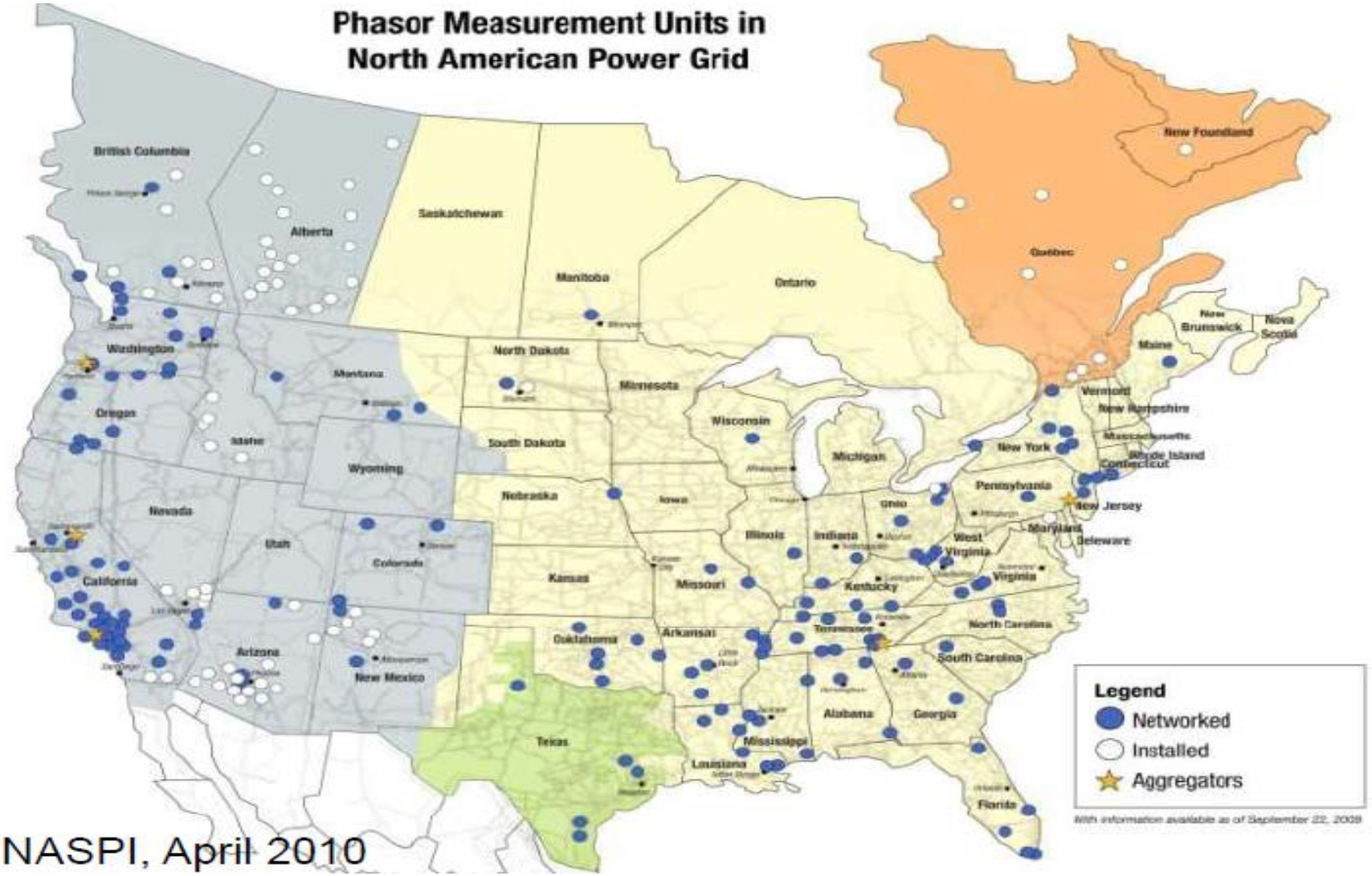
SVC at Hasle (4 x 90 Mvar TCR)

WAPOD Field Tests:

Completed on 2011-11-15

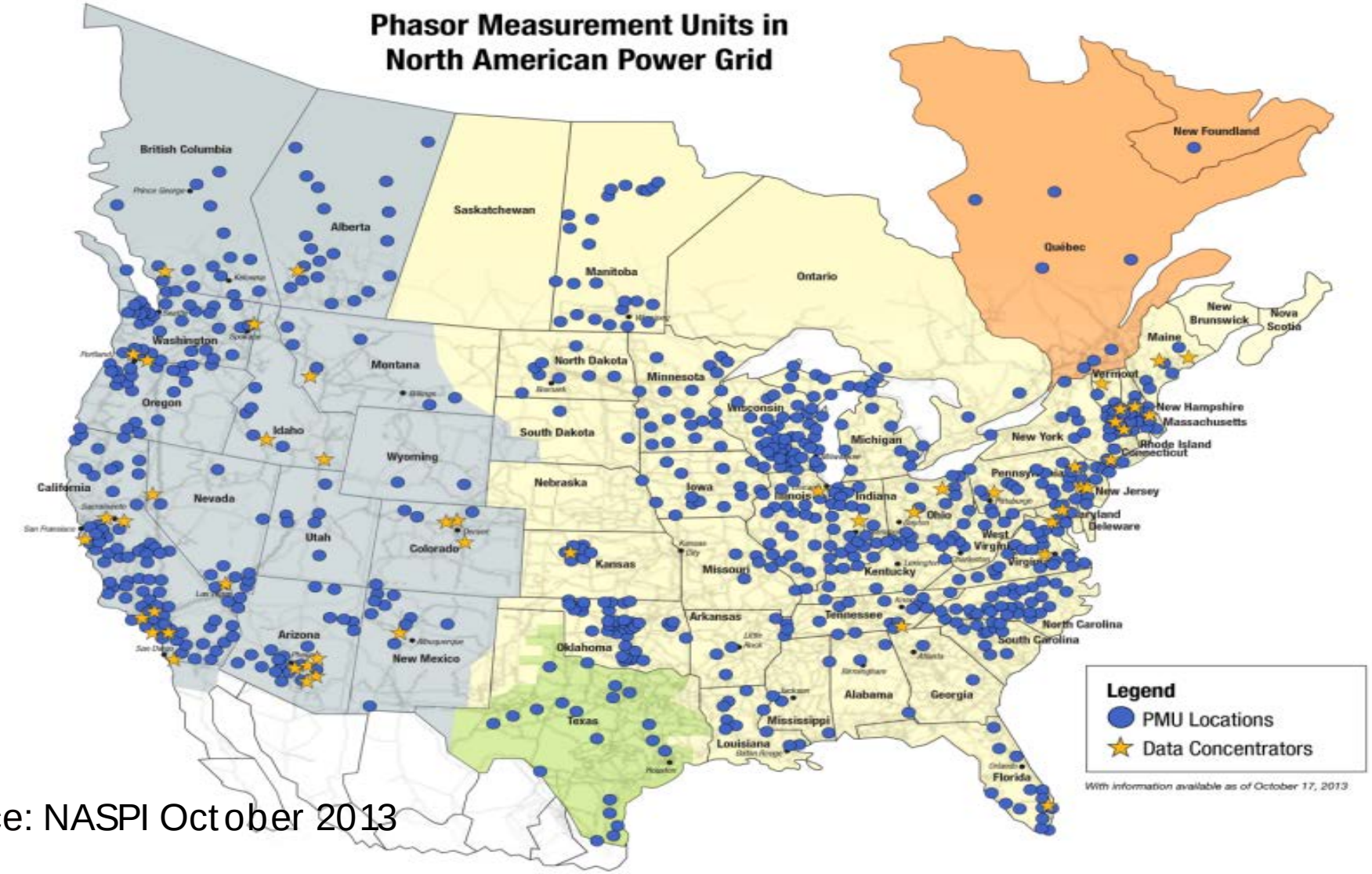
Source: K. Uhlen, etc Wide-Area Power Oscillation Damper Implementation and Testing in the Norwegian Transmission Network, IEEE PES 2012.

North American Synchrophasor Initiative



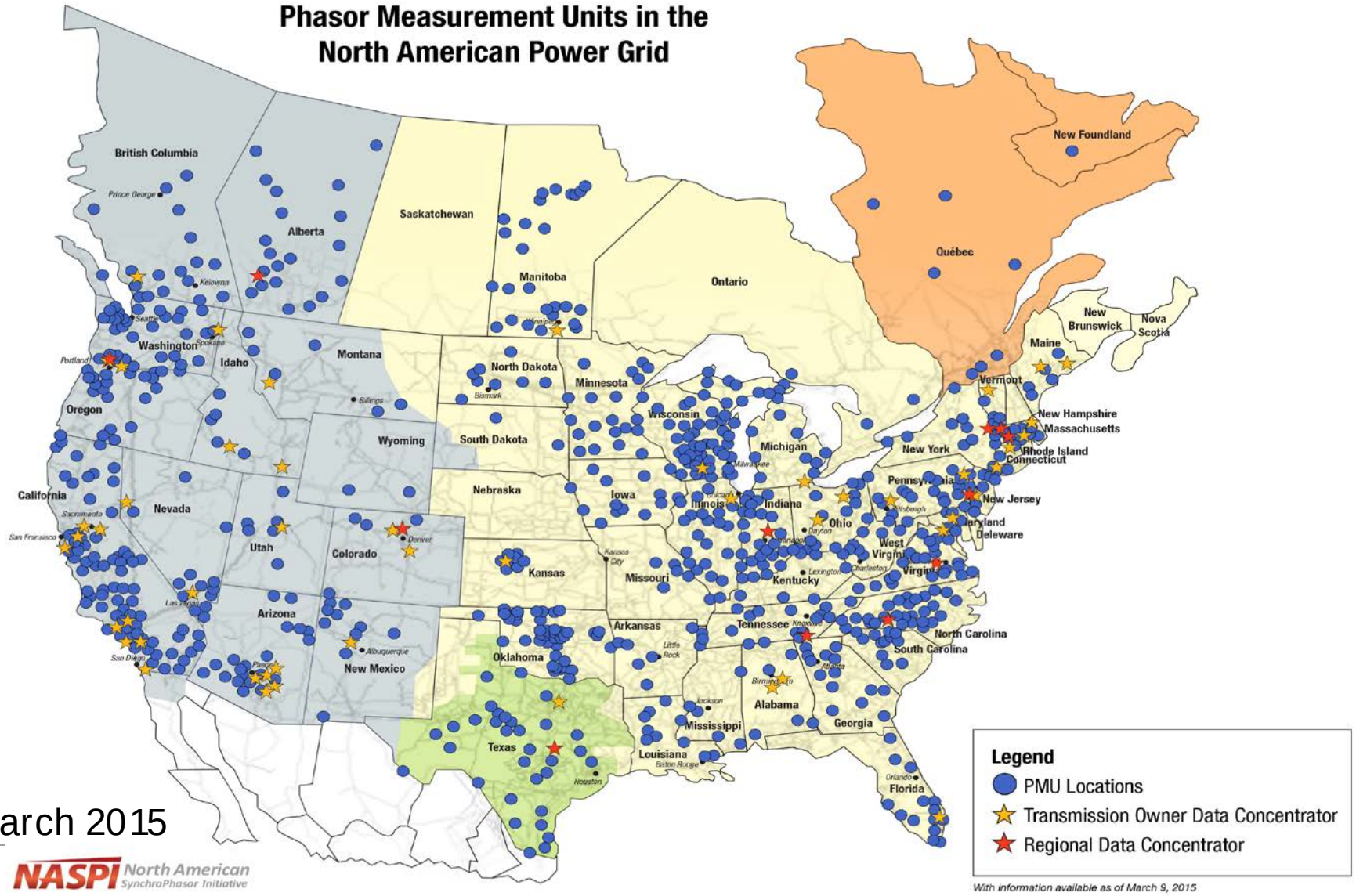
Source: NASPI, April 2010

North American Synchrophasor Initiative6



Source: NASPI October 2013

North American Synchrophasor Initiative



Source: NASPI March 2015

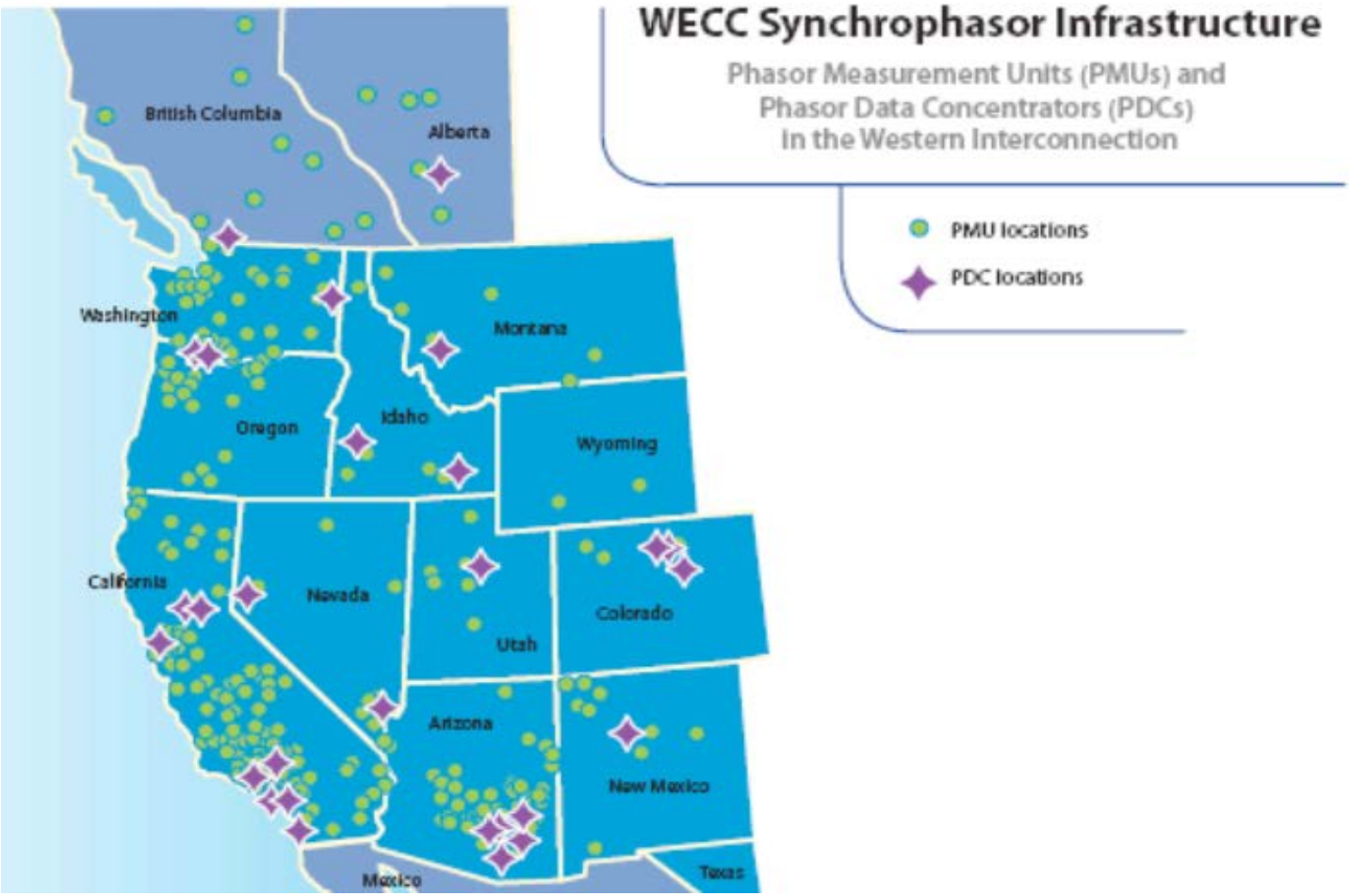
NASPI North American SynchroPhasor Initiative

Western Interconnection Synchrophasor Program

PNM
SDGE connected
Sempra Energy utility
BC hydro FOR GENERATIONS
CFE COMISIÓN FEDERAL DE ELECTRICIDAD
IDAHO POWER. An IDACORP Company
TEP
PACIFICORP A MIDAMERICAN ENERGY HOLDINGS COMPANY
SOUTHERN CALIFORNIA EDISON An EDISON INTERNATIONAL® Company
Western AREA POWER ADMINISTRATION
Los Angeles LADWP Department of Water & Power
California ISO Shaping a Renewed Future
PG&E
ROCKY MOUNTAIN POWER
BONNEVILLE POWER ADMINISTRATION
aeso ALBERTA ELECTRIC SYSTEM OPERATOR
aps
SRP Delivering More Than Power.
WECC Western Electricity Coordinating Council
NVEnergy

Western Interconnection Synchrophasor Program

- 244 Substations with PMUs
- Sampling Rate 30-120 sps
- Installation Rate:
  - 2011 Q3 22
  - 2011 EOY 38
  - 2012 EOY 267
  - 2013 Q1 362



Source: WECC WISP Western Interconnection Synchrophasor, Vickie VanZandt NASPI Work Group Meeting October 2011

WISP Communications

Harris Press Release

Printer Friendly Version

Harris Corporation Network to Provide the Communication Infrastructure for Enhancement of Reliability in the Western Interconnected Electric Grid for Western U.S., Canada, and Northern Mexico

Highlights

- Wide area network to support the Western Electricity Coordinating Council and other participating electric utility organizations
- Key infrastructure component in implementing real-time vulnerability detection in western region's electric grid
- Enables utilities to have better visibility into the condition of the power system and take timely actions to mitigate widespread electrical outages

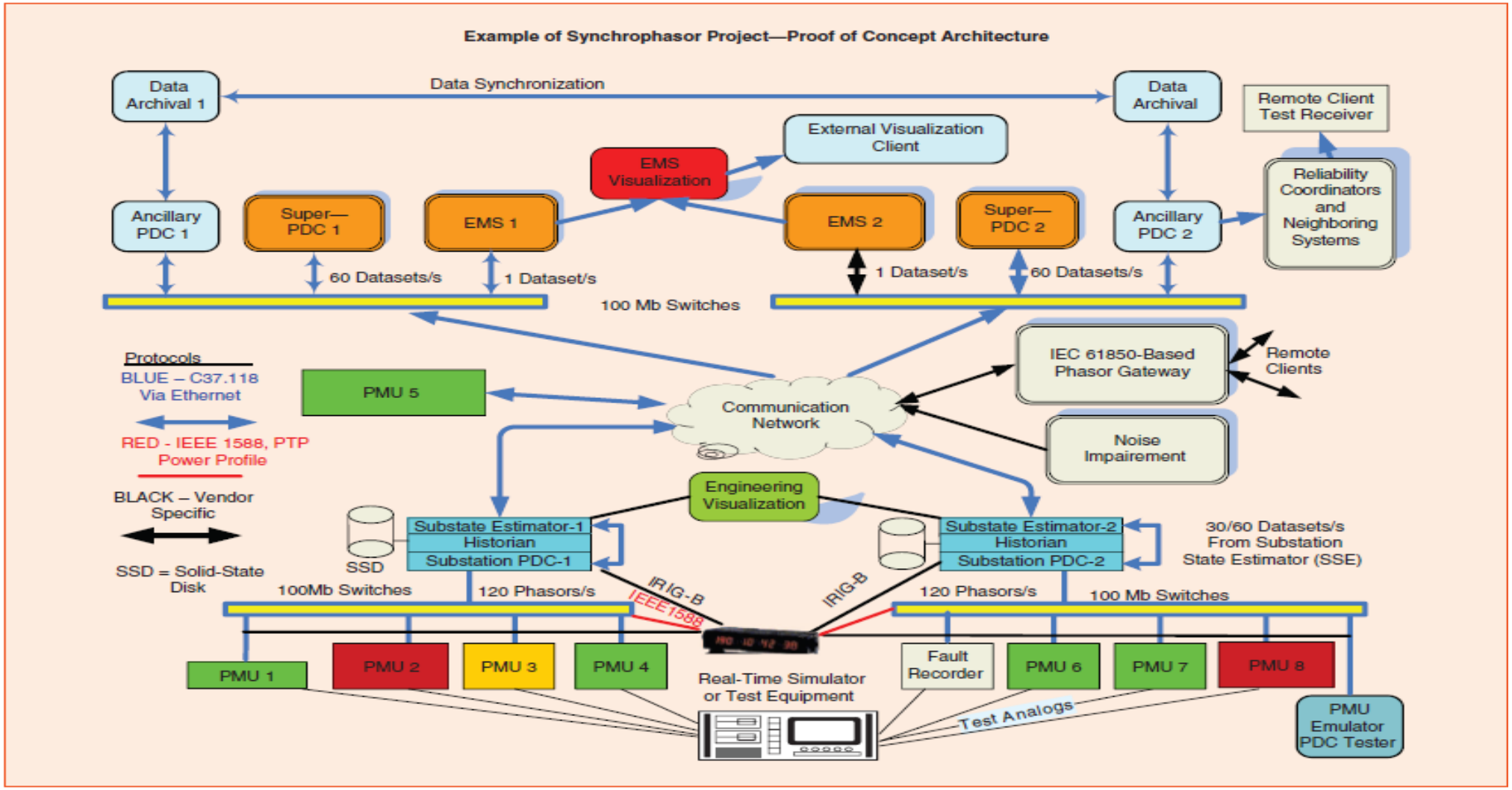
MELBOURNE, FL, July 14, 2011 — Harris Corporation (NYSE:HRS), an international communications and information technology company, has been awarded a five-year contract to provide a wide-area network that will help detect and assist in avoiding or mitigating regional electrical system disturbances in a service area that extends from Canada through 14 western U.S. states and northern Mexico.

The private network will enable the Western Electricity Coordinating Council (WECC) Reliability Coordinator, and other participating entities, to detect and take timely actions to mitigate the risk of impacts such as oscillations, grid instability and ultimately, widespread system blackouts.

PG&E synchrophasor proof-of-concept facility

PG&E Synchrophasor Proof-of-Concept Facility (POC) is a smaller scale synchrophasor system used to **test**, **validate**, and **demonstrate** various functions and interoperability before field deployment

PG&E synchrophasor proof-of-concept architecture



Source: Grid monitoring and situational awareness: PG&E synchrophasor proof-of-concept project presentation at ABB APW 2013

Synchrophasor applications for protection

IEEE PSRC Report on use of Synchrophasors for Protection Applications

Present applications
- Wide-area frequency monitoring
- Power swing detection
- Load shedding
- Automatic generator shedding
- Distributed generation anti-islanding
- Line reclosing selectivity
- Distance to fault

Future applications
- Bus differential relaying
- Line differential relaying
- Distance function
- Line backup protection

USE OF SYNCHROPHASOR MEASUREMENTS IN PROTECTIVE RELAYING APPLICATIONS

Power System Relaying Committee
Report of Working Group C-14
of the
System Protection Subcommittee

Members of the Working Group

Jim O'Brien, Chair Alla Deronja, Vice-Chair

Alex Apostolov	Harold Kirkham	Damir Novosel
Andrew Arana	Yuan Liao	Mahendra Patel
Miroslav Begovic	Chih-Wen Liu	Elmo Price
Sukumar Brahma	Yuchen Lu	Sinan Saygin
Gustavo Brunello	Don Lukach	Veselin Skendzic
Fernando Calero	Ken Martin	Rick Taylor
Herb Faulk	Joe Mooney	Demetrios Tziouvaras
Yi Hu	Jay Murphy	Solveig Ward
Gary Kobet	Krish Narendra	

Conclusions

Synchrophasor measurements have been used for various power system applications

- Power system stability applications
- Wide area control and protection applications

Synchrophasors dependency on time synchronization and communication present challenges

Research and development lead to growing use of synchrophasor for enhancing power systems

ABB