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ABB Protective Relay School Webinar Series

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ABB Protective Relay School Webinar Series

Wide area monitoring, control and protection using synchrophasor measurements

Galina Antonova

July 29, 2014

Presenter

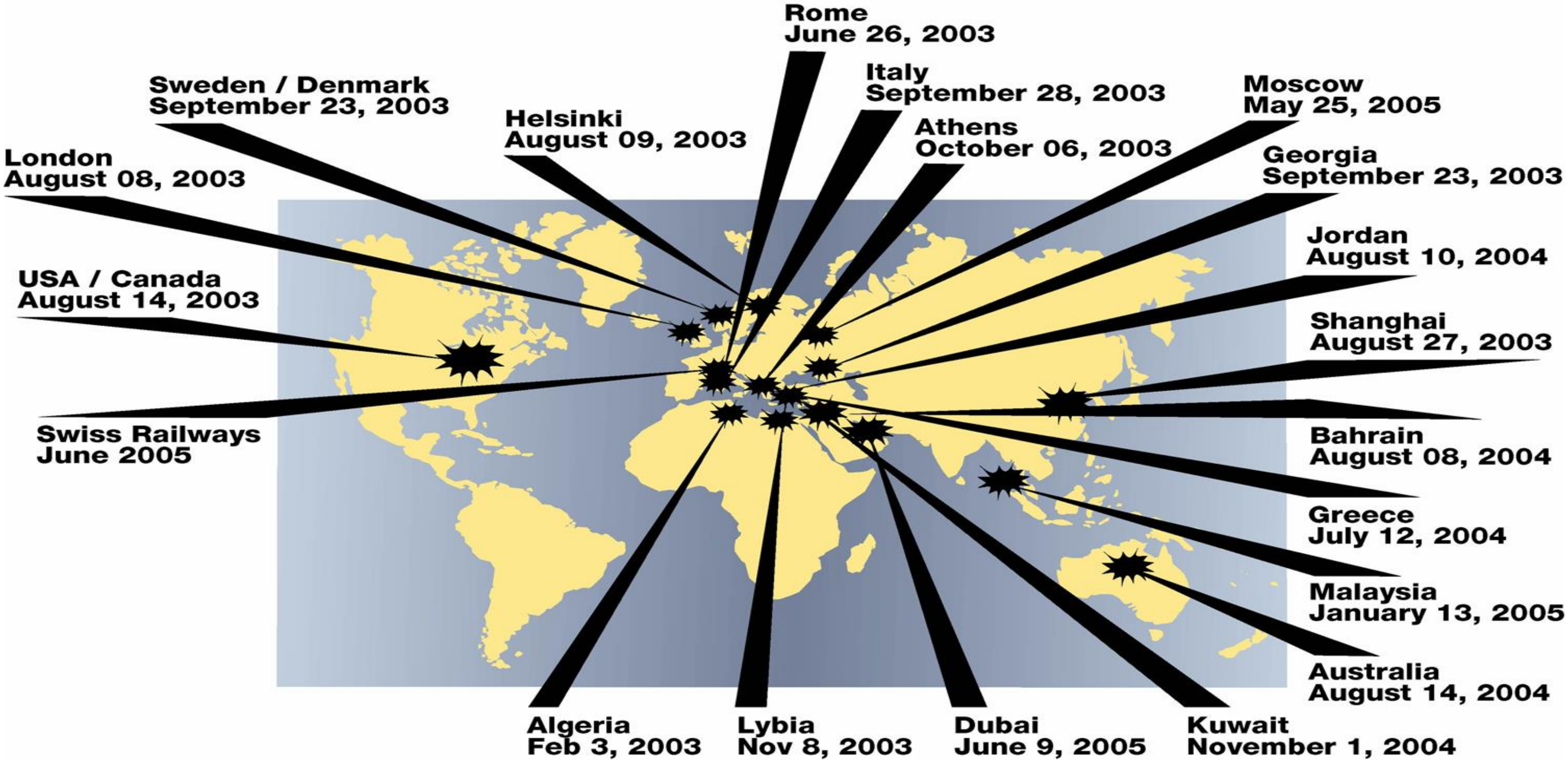
Galina Antonova

Galina Antonova is with ABB Substation Automation and Communication group, North America. She has over 15 years of experience in the area of electrical engineering, data communications and time synchronization, which she mainly applied to the power industry. In her current role with ABB, Galina is applying her expertise to substation automation and protective relaying applications. Galina received her M. Sc. degree (1993) and a Ph.D. (1997) in Electrical Engineering and Data Communications from the State University of Telecommunications, St. Petersburg, Russia, and spent one year at University of British Columbia (UBC) on a scholarship from the Russian President. She is actively involved with IEEE PSRC and is a Canadian member of the IEC TC57 WG10.

Learning objectives

- Understand the synchrophasor technology and its use in power systems
- Become aware of related industry standards and guides
- Learn about synchrophasor-based monitoring, control and protection applications
- Review examples of synchrophasor-based applications deployed in existing power systems world wide

Hot summer blackouts



Rome
June 26, 2003

Sweden / Denmark
September 23, 2003

Helsinki
August 09, 2003

Italy
September 28, 2003

Athens
October 06, 2003

Moscow
May 25, 2005

London
August 08, 2003

Georgia
September 23, 2003

Jordan
August 10, 2004

USA / Canada
August 14, 2003

Shanghai
August 27, 2003

Swiss Railways
June 2005

Bahrain
August 08, 2004

Greece
July 12, 2004

Malaysia
January 13, 2005

Australia
August 14, 2004

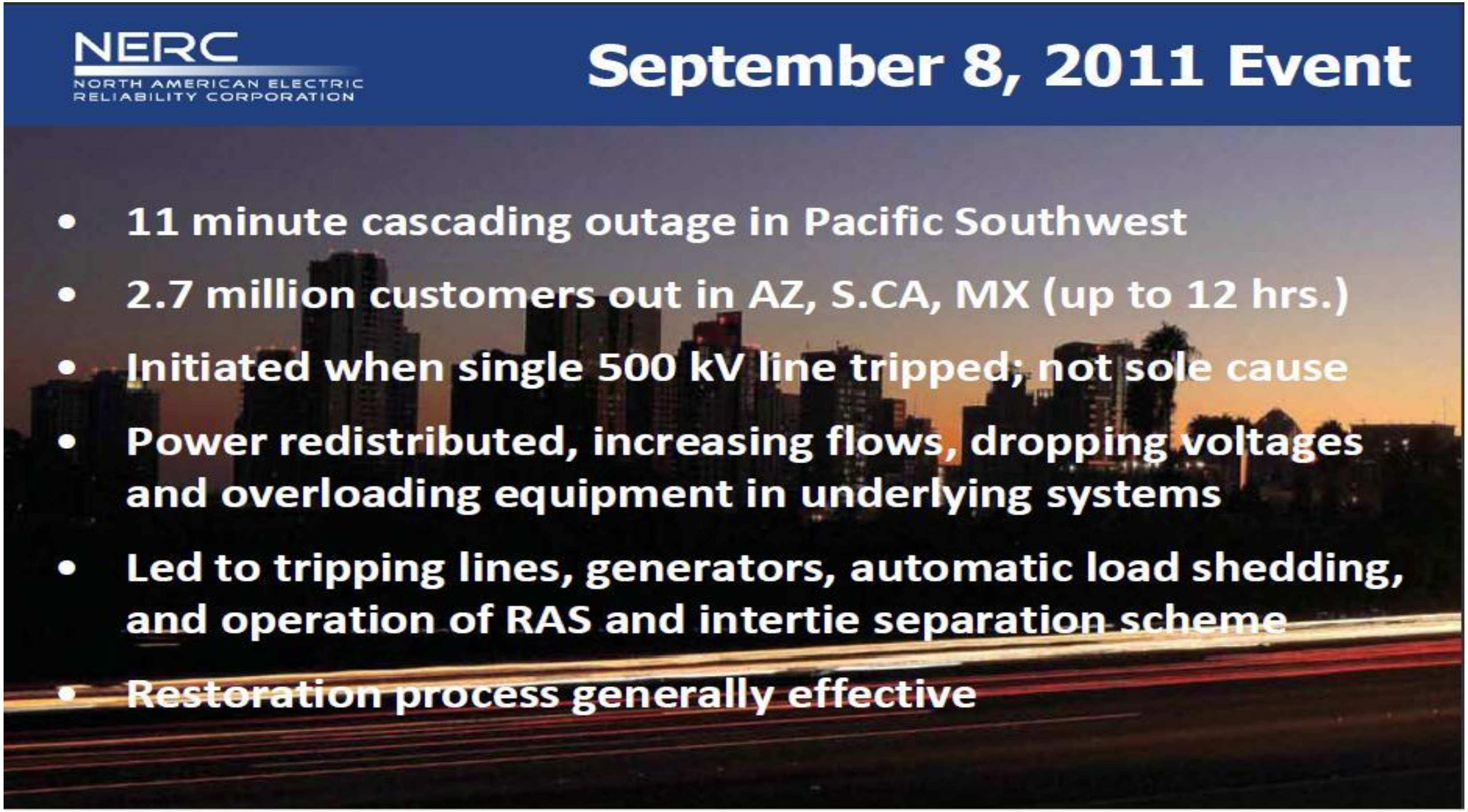
Algeria
Feb 3, 2003

Lybia
Nov 8, 2003

Dubai
June 9, 2005

Kuwait
November 1, 2004

September 2011 Southwest US Outage



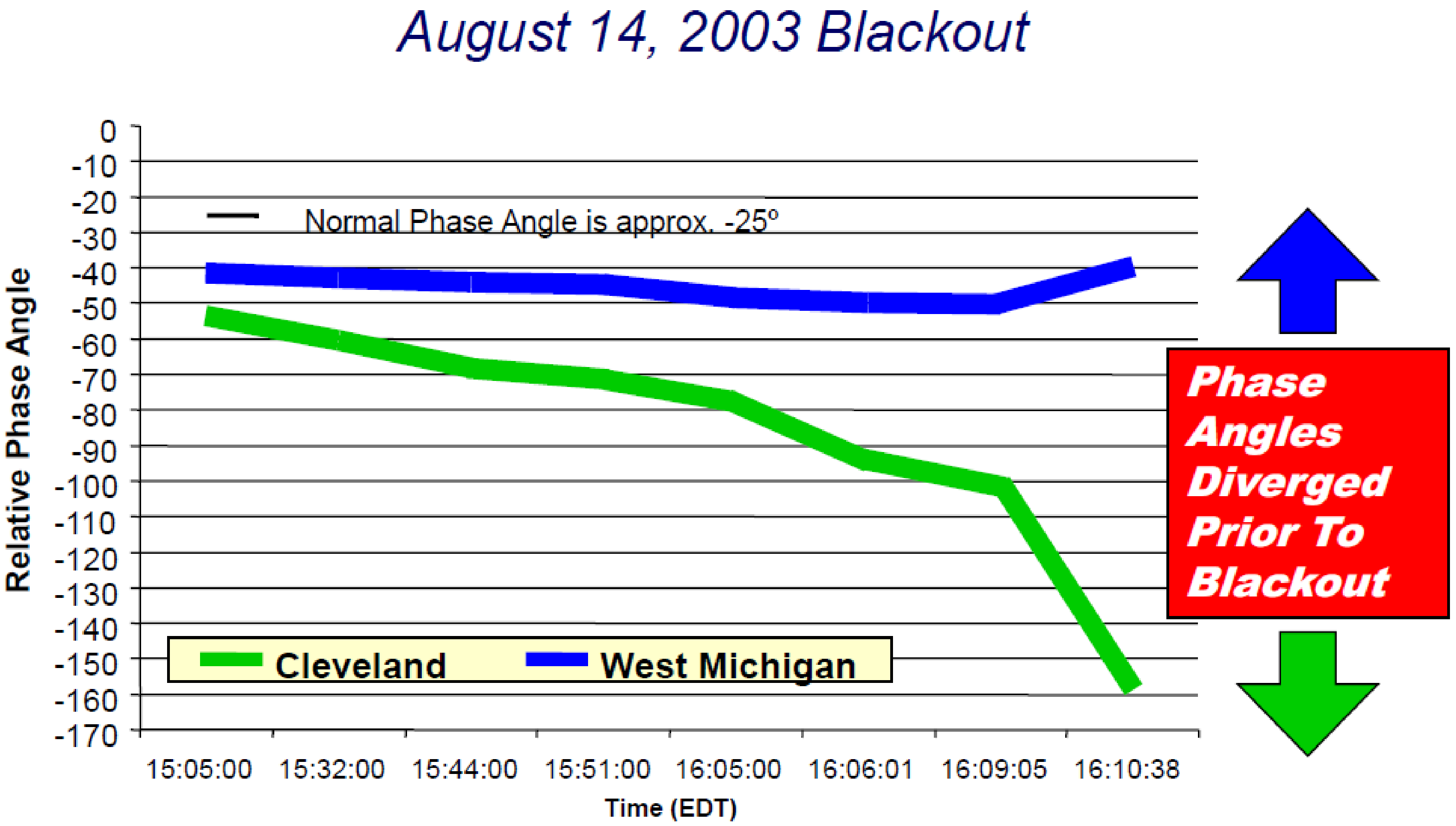
NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

September 8, 2011 Event

- 11 minute cascading outage in Pacific Southwest
- 2.7 million customers out in AZ, S.CA, MX (up to 12 hrs.)
- Initiated when single 500 kV line tripped; not sole cause
- Power redistributed, increasing flows, dropping voltages and overloading equipment in underlying systems
- Led to tripping lines, generators, automatic load shedding, and operation of RAS and intertie separation scheme
- Restoration process generally effective

Source:NERC Recommendations from 2011 Southwest Outage May 8 2012

What can help ?



Phase Angles Diverged Prior To Blackout

Power Systems Challenges and Solutions

Applications and technologies

- Gateways with bi-directional communication for consumer interaction
- Smart meters, Internet/mobile telecom, smart houses
- Customer service systems including billing
- Fault detection, isolation and restoration; voltage optimization
- FACTS, HVDC,
- **WAMS → WAMPACS**

1) Integration of renewables

- Remote grid operation with distributed generation (wind/solar farms)
- Increase grid capacity and stability
- Balance load to supply

2) Integration of electric vehicles

- Charging / billing
- Energy storage
- Load management

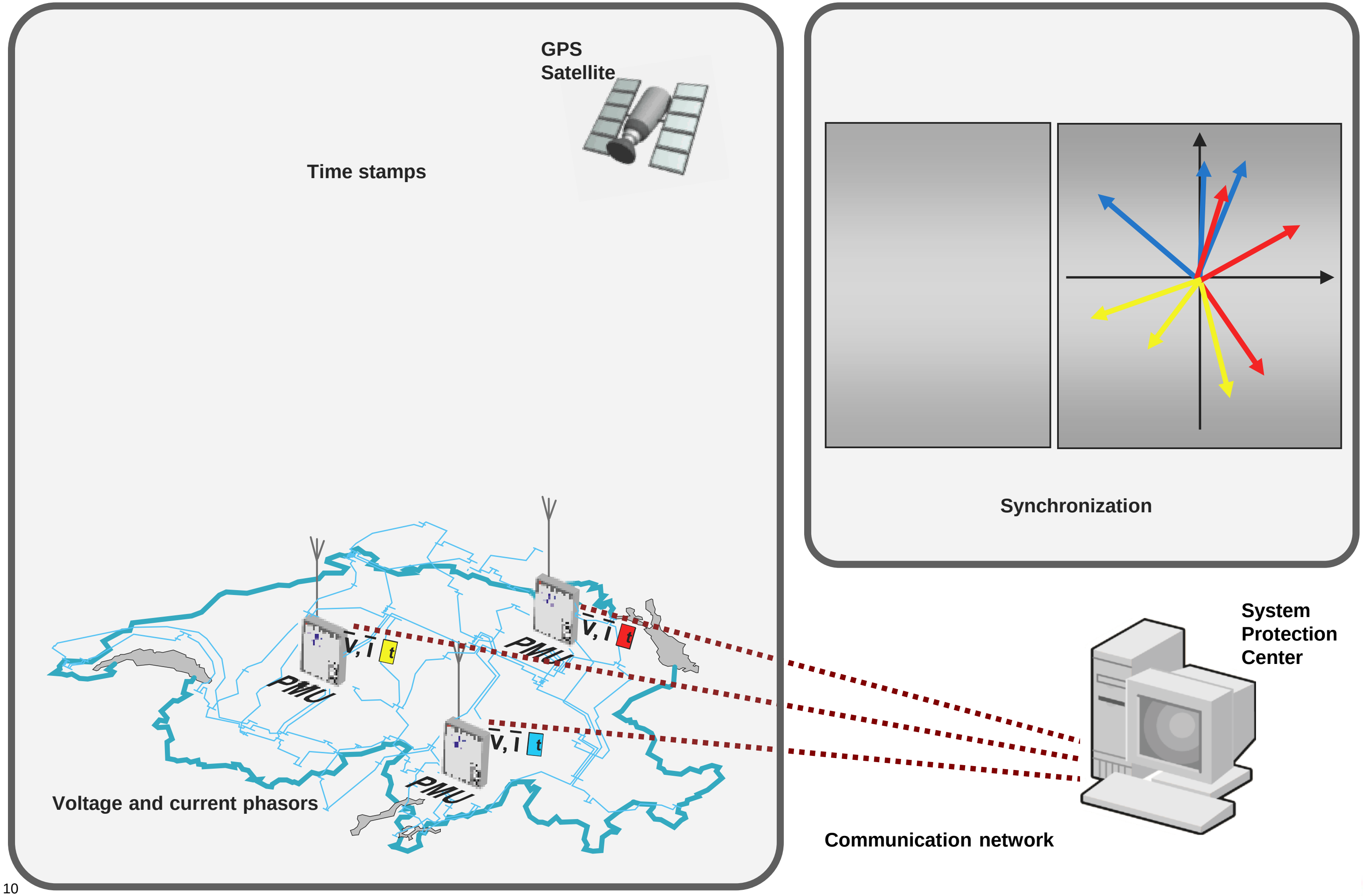
3) Demand response

- Real time pricing / tariffs
- Home automation / load management
- Distributed generation / storage

4) Reliability and efficiency

- cyber security
- customer outage information
- emergency / peak power

Wide-area Monitoring and Control



GPS
Satellite

Time stamps

Voltage and current phasors

Synchronization

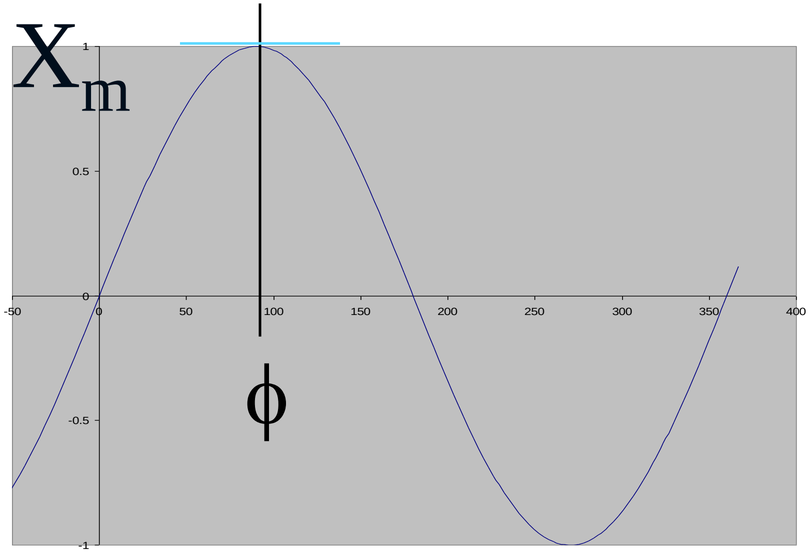
System
Protection
Center

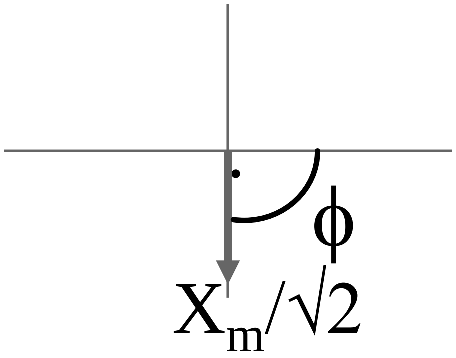
Communication network

What is Phasor ?

A complex number that represents the phase and magnitude of an AC waveform

$$X_m \cos(2\pi 60 t + \phi) \qquad X_m/\sqrt{2}\, e^{j\phi}$$

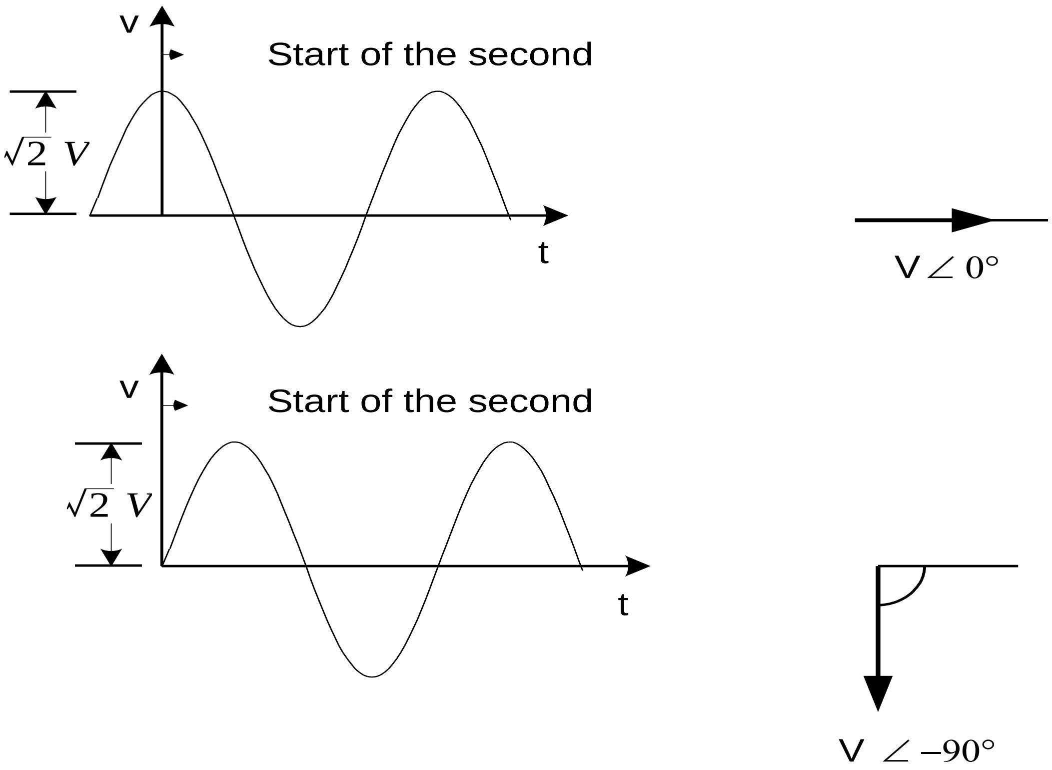




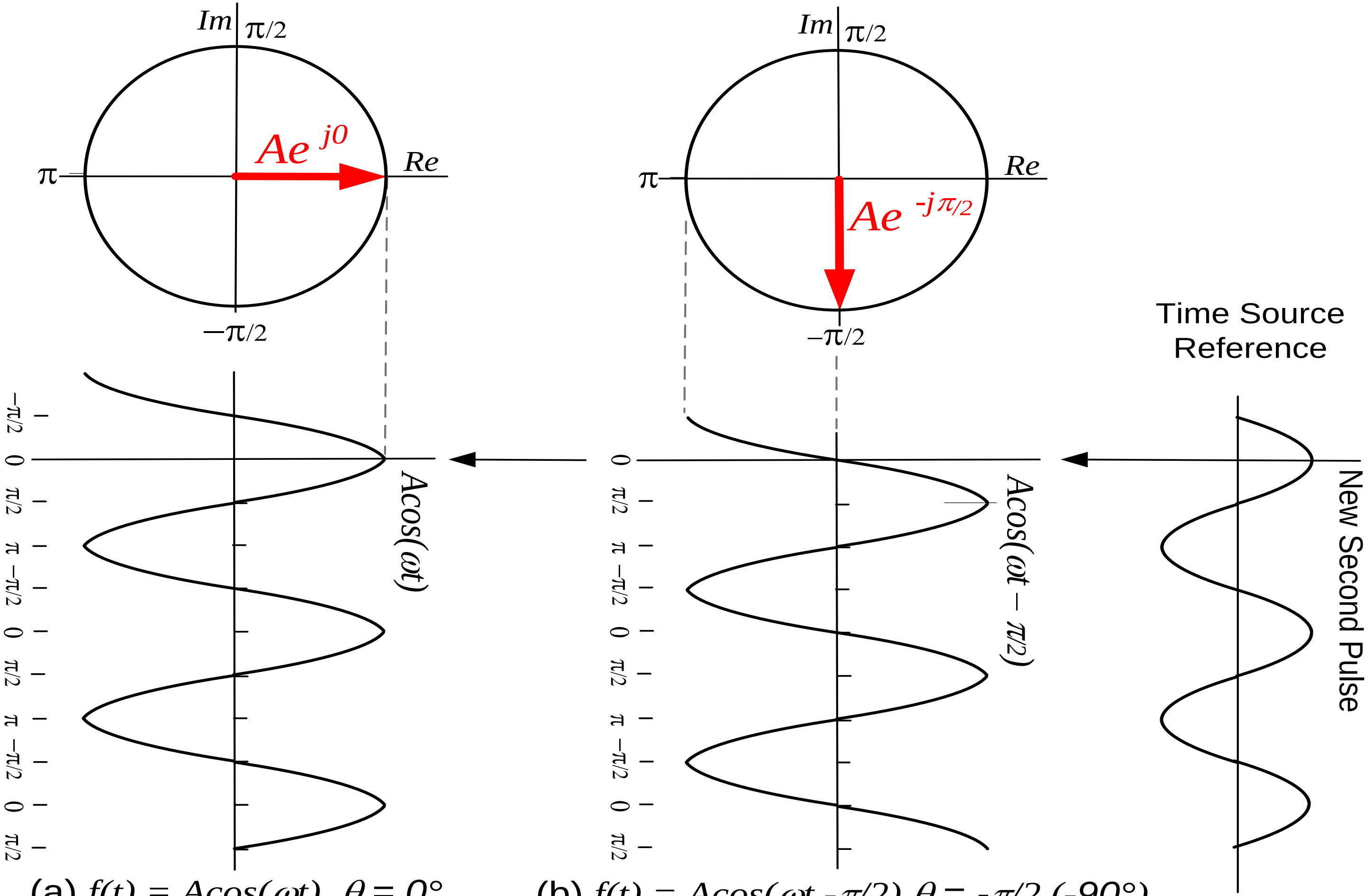
What is Synchrophasor ?

$$v(t) = \sqrt{2}\, V \cos(\omega_0 t + \varphi)$$

- Synchrophasor is a phasor with a **phase** determined by UTC time (start of the second)
- Reference waveform is cos(wt) at a nominal system frequency
  - Angle = 0° for positive maximum at the start of UTC second
  - Angle = -90° for positive zero crossing at the start of UTC second



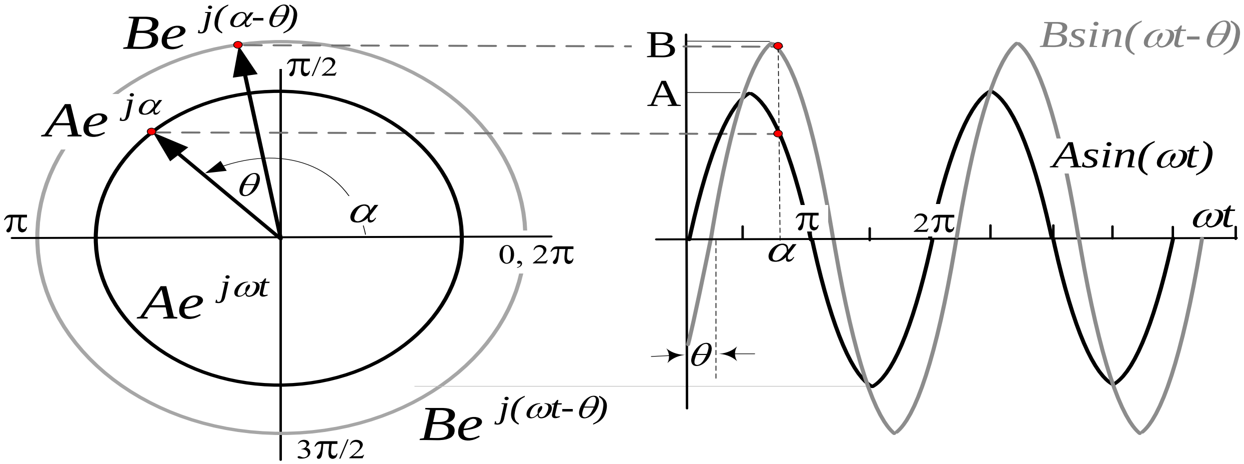
Synchrophasor definition



(a) $f(t) = A\cos(\omega t),\ \theta = 0°$

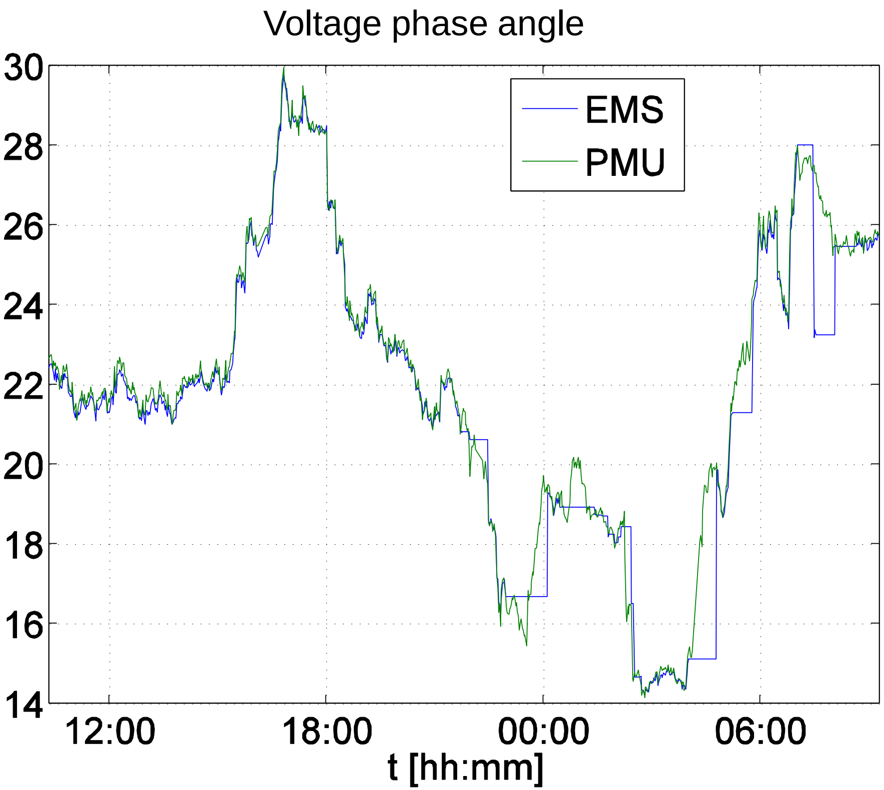
(b) $f(t) = A\cos(\omega t - \pi/2), \theta = -\pi/2\ (-90°)$

Why use Synchrophasors



- Consider the ability to measure the voltage magnitude and phase angle at every system bus and current magnitude and phase angle at every branch (lines, transformers and other series elements) in the power system network simultaneously and continuously and having them instantly available where we need them when we need them

PMU measurements vs SCADA/EMS



What is new ?

- Higher resolution
- Faster response
- Higher accuracy

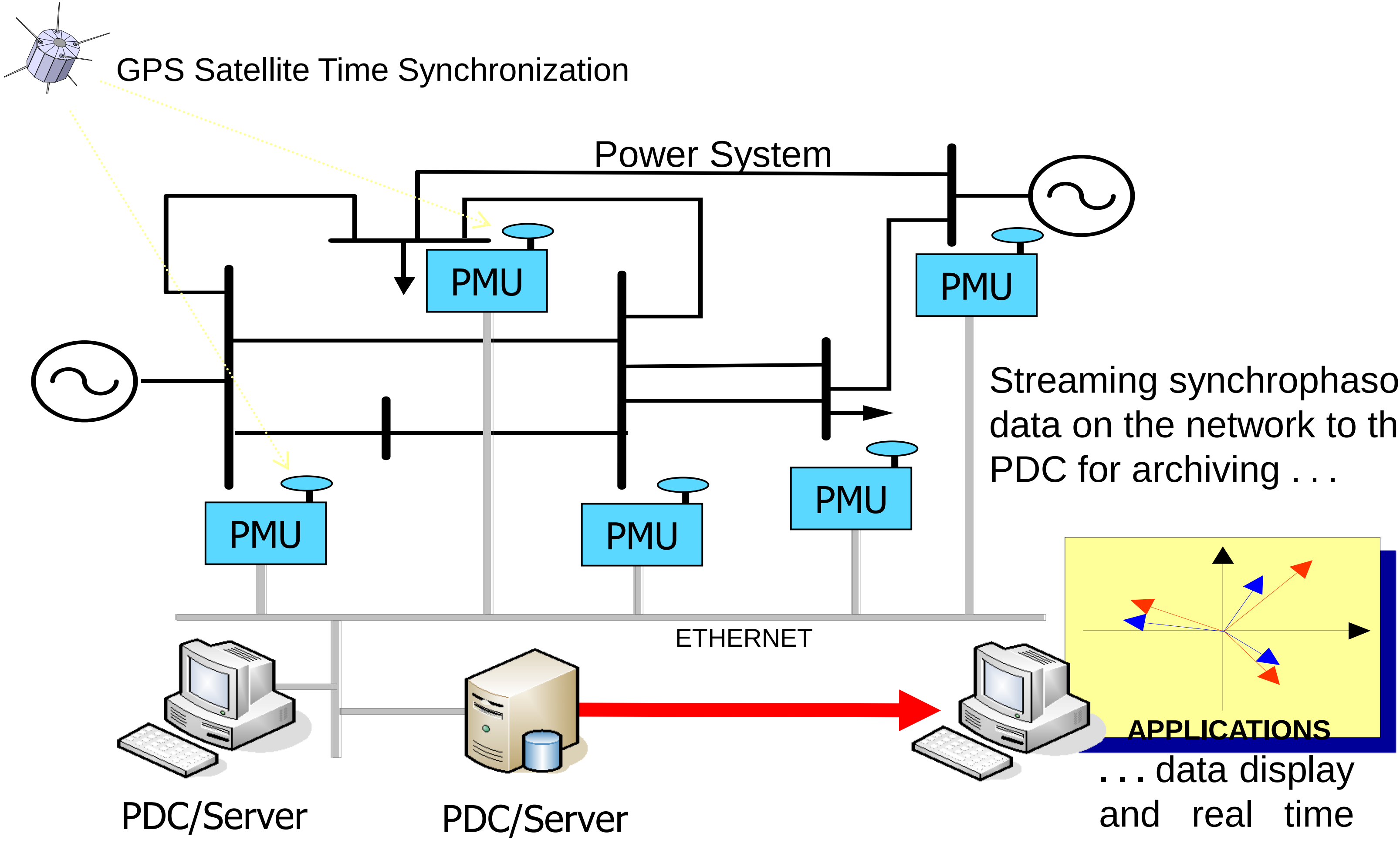
How to use:

- Supervision of dynamic phenomena
- Closed-loop control
- Model-calibration

Synchrophasors Terminology

- UTC - Universal Time Coordinated
- GPS – Global Positioning System with time traceable to UTC
- PMU – Phasor Measurement Unit
    - Measures bus voltages and line currents
    - Estimates phasors
    - Synchronizes each phasor with UTC time – 1.0 μs accuracy
    - Sends synchrophasor data at 240, 120, 60, 30 frames/s to clients, PDC, etc
- PDC – Phasor Data Concentrator
    - Merges, synchronizes and archives synchrophasor data

Synchrophasor Measurement System



Streaming synchrophasor data on the network to the PDC for archiving . . .

. . . data display and real time control actions

Synchrophasor Measurement Unit: RES670

- Up to 8 Analog Phasors
  - Positive / Negative / Zero sequence
  - Polar or Rectangular phasors
- Transmission rates
  - 8/10-200/240 frames/s at 50/60 Hz
- TVE < 1%
- Configurable time stamp position
- 8 fully configurable binary signals
- 8 independent users / data recipients
- 2 optical Ethernet ports
- Embedded GPS, electrical / optical IRIG-B
- Built on protective relay platform

Time synchronization options

GPS time synchronization
- 1us time accuracy to UTC
- Embedded GPS receiver, or external clock
- GPS cable (20m, 40m)

Electrical IRIG-B interface
- BNC cable
- 1 kHz Amplitude Modulated or DC shift

Optical IRIG-B interface
- Optical cable, with ST connector
- Immune to surrounding noises

Emerging Precision Time Protocol
- IEEE 1588 / C37.238 standards
- Ethernet, with 1us time accuracy to source

Synchrophasor Standardization

- IEEE 1344-1995 Synchrophasor standard superseded by IEEE C37.118-2005
- IEEE C37.118-2005 Synchrophasor standard superseded by
  - IEEE C37.118.1-2011 Standard for Synchrophasor Measurements
  - IEEE C37.118.2-2011 Standard for Synchrophasor Data Transfer
  - Amendment IEEE C37.118.1a-2014
- IEC 61850-90-5 Technical Report for Synchrophasor Data Transfer over in IEC 61850
- Joint IEC / IEEE Standard on synchrophasor measurements (initiated)

IEEE C37.118-2005 Synchrophasor Standard

- IEEE Std C37.118-2005 - Replaced IEEE 1344
- Measurement requirements
    - Phasor estimation characteristics
    - 2 performance levels
- Data transmission formats
    - Similar to 1344
    - Many improvements
    - Includes single or multiple PMU data
    - Simple Communication protocol (serial, Ethernet, IP)

IEEE

IEEE Standard for Synchrophasors for Power Systems

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee

C37.118™

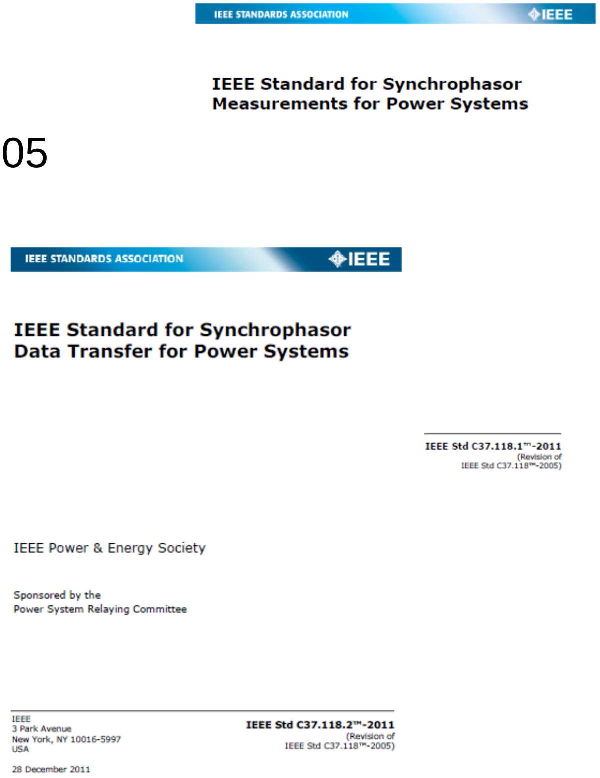
IEEE
3 Park Avenue
New York, NY 10016-5997, USA

22 March 2006

IEEE Std C37.118™-2005
(Revision of
IEEE Std 1344™-1995)

IEEE C37.118.1/2-2011 Standards

- IEEE Std C37.118.1/2 – 2011 Replaced IEEE C37.118-2005
  - C37.118.1 – Measurements
  - C37.118.2 – Communications (legacy)
  - Dynamic tests added
  - 2 classes – Measurement (M) and Protection (P)
  - Higher reporting rates recommended, new filtering
  - Dynamic tests, new configuration frame (CFG-3)
  - Continuous Time Quality
  - Locked definition



IEEE STANDARDS ASSOCIATION   IEEE

IEEE Standard for Synchrophasor Measurements for Power Systems

IEEE Std C37.118.1™-2011
(Revision of
IEEE Std C37.118™-2005)

IEEE STANDARDS ASSOCIATION   IEEE

IEEE Standard for Synchrophasor Data Transfer for Power Systems

IEEE Power & Energy Society

Sponsored by the
Power System Relaying Committee

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

28 December 2011

IEEE Std C37.118.2™-2011
(Revision of
IEEE Std C37.118™-2005)

Amendment to IEEE C37.118.1a-2014 contains corrections to performance parameters

Other Synchrophasor Standards

- IEC TR 61850-90-5 Approved and published in May 2012
  - Transport of synchrophasor data
  - Integration with IEC 61850 systems
  - Routable transport (targeted to substation to substation)
  - UDP transport, unicast and multicast (preferred)
  - Security included
  - Multiple communications layers

Work on joint IEC / IEEE standard on synchrophasor measurements started

IEEE Guides and Reports on Synchrophasors

IEEE PES PSRC Working Groups generated the following documents

- IEEE Report Published in August 2013

  Use of Synchrophasor Measurements in Protective Relaying Applications

- IEEE C37.242-2013 Published in March 2013

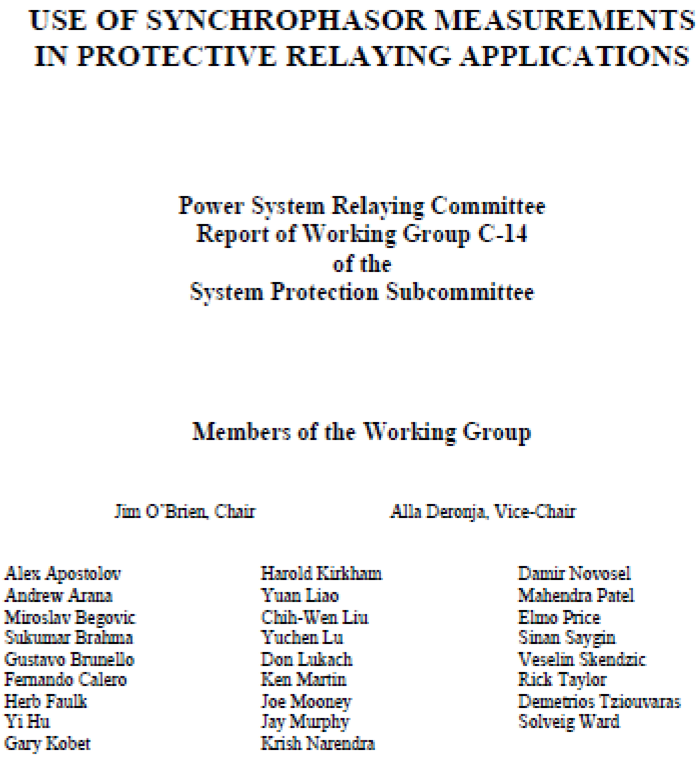
  Guide for PMU Synchronization, Calibration, Testing and Installation

- IEEE C37.244-2013 Published in May 2013

  Guide for PDC Requirements for Power System Protection, Control and Monitoring

Report on use of Synchrophasors for Protection

- 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

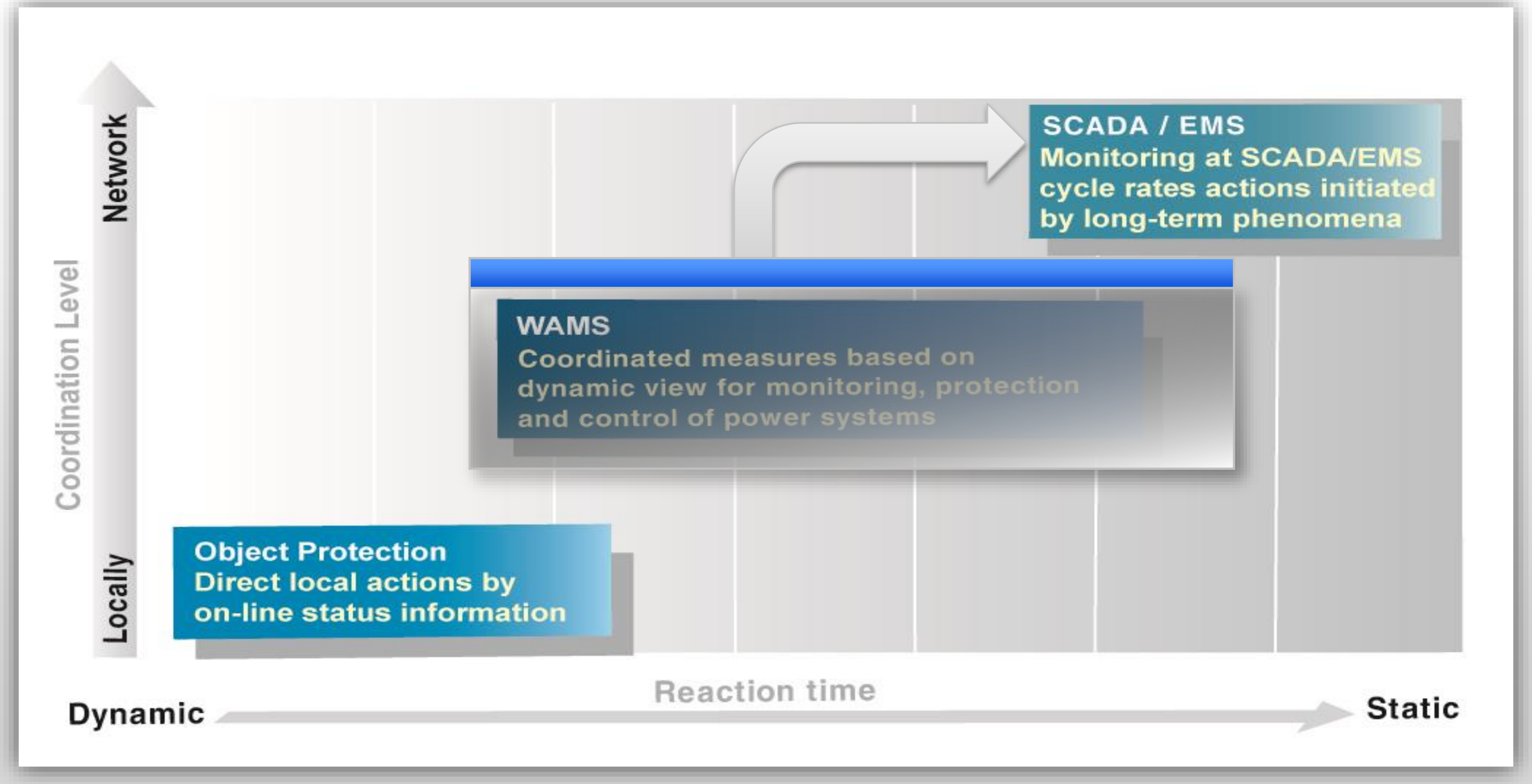
Jim O'Brien, Chair
Alla Deronja, Vice-Chair

Alex Apostolov
Andrew Arana
Miroslav Begovic
Sukumar Brahma
Gustavo Brunello
Fernando Calero
Herb Faulk
Yi Hu
Gary Kobet

Harold Kirkham
Yuan Liao
Chih-Wen Liu
Yuchen Lu
Don Lukach
Ken Martin
Joe Mooney
Jay Murphy
Krish Narendra

Damir Novosel
Mahendra Patel
Elmo Price
Sinan Saygin
Veselin Skendzic
Rick Taylor
Demetrios Tziouvaras
Solveig Ward

Synchrophasor-based applications

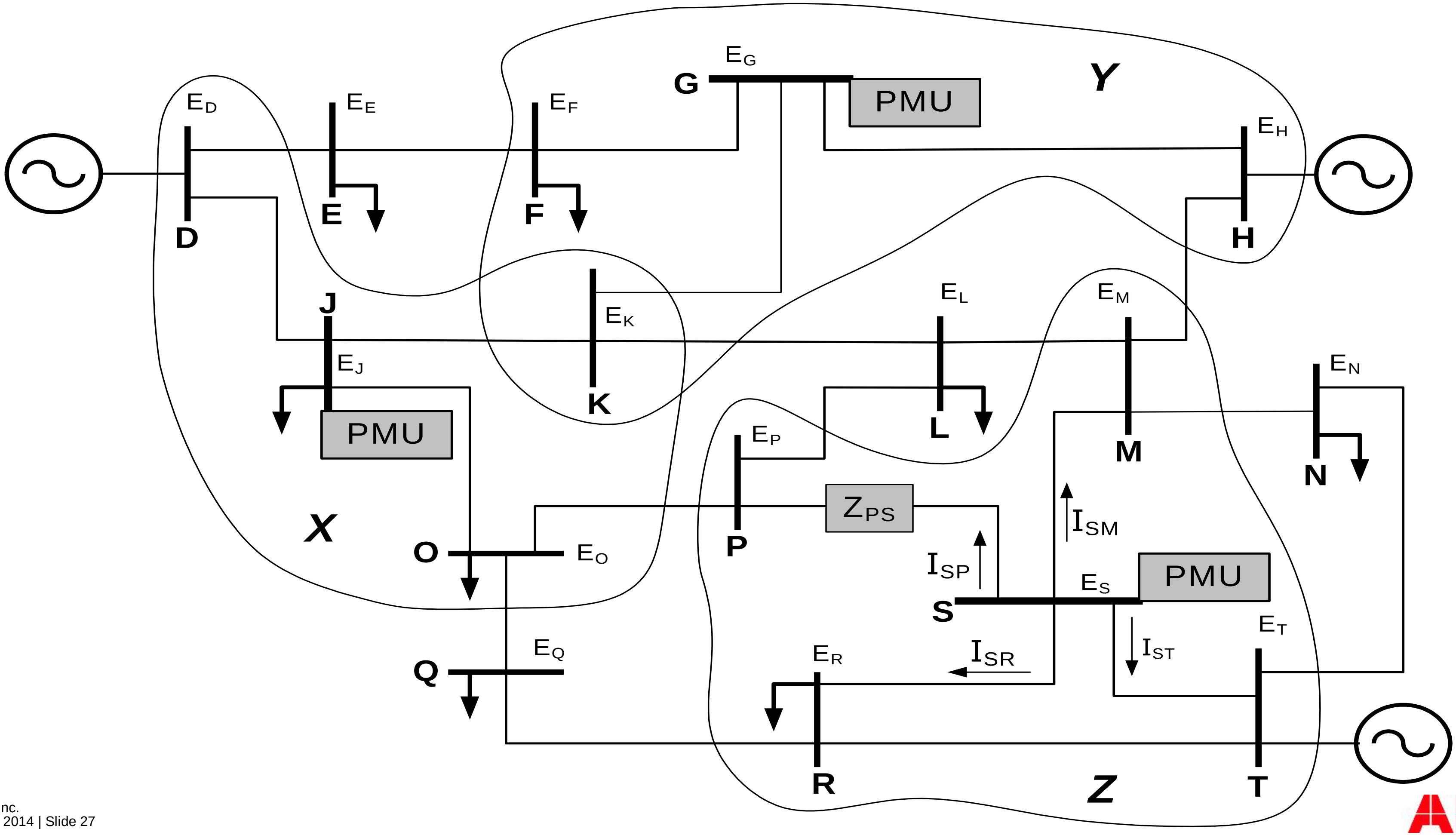


SCADA / EMS
Monitoring at SCADA/EMS cycle rates actions initiated by long-term phenomena

WAMS
Coordinated measures based on dynamic view for monitoring, protection and control of power systems

Object Protection
Direct local actions by on-line status information

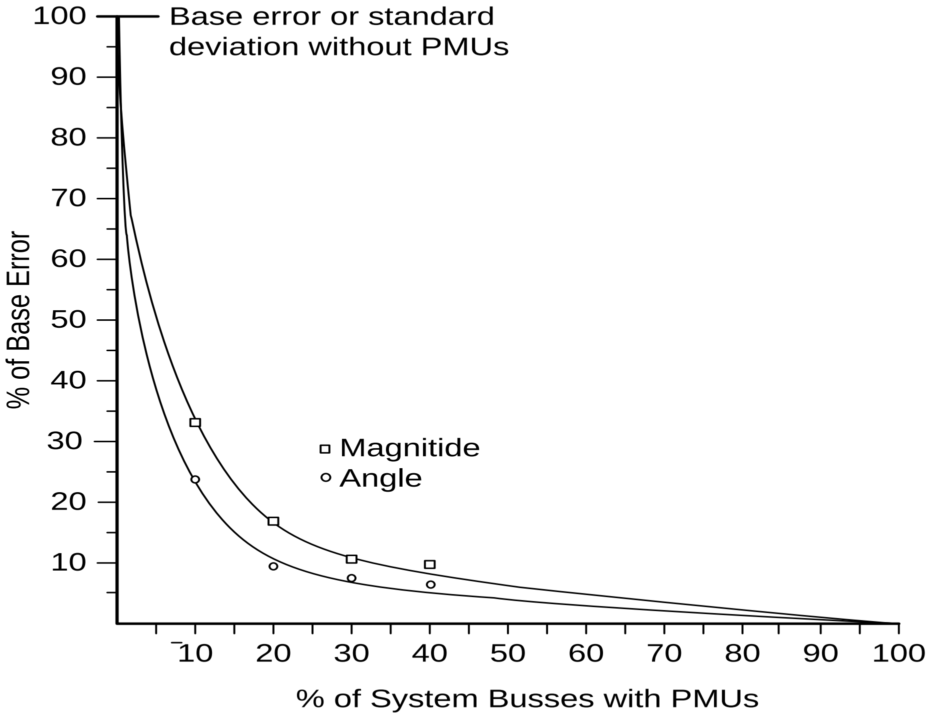
Phasor-Enhanced State Estimator



Phasor-Enhanced State Estimator

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

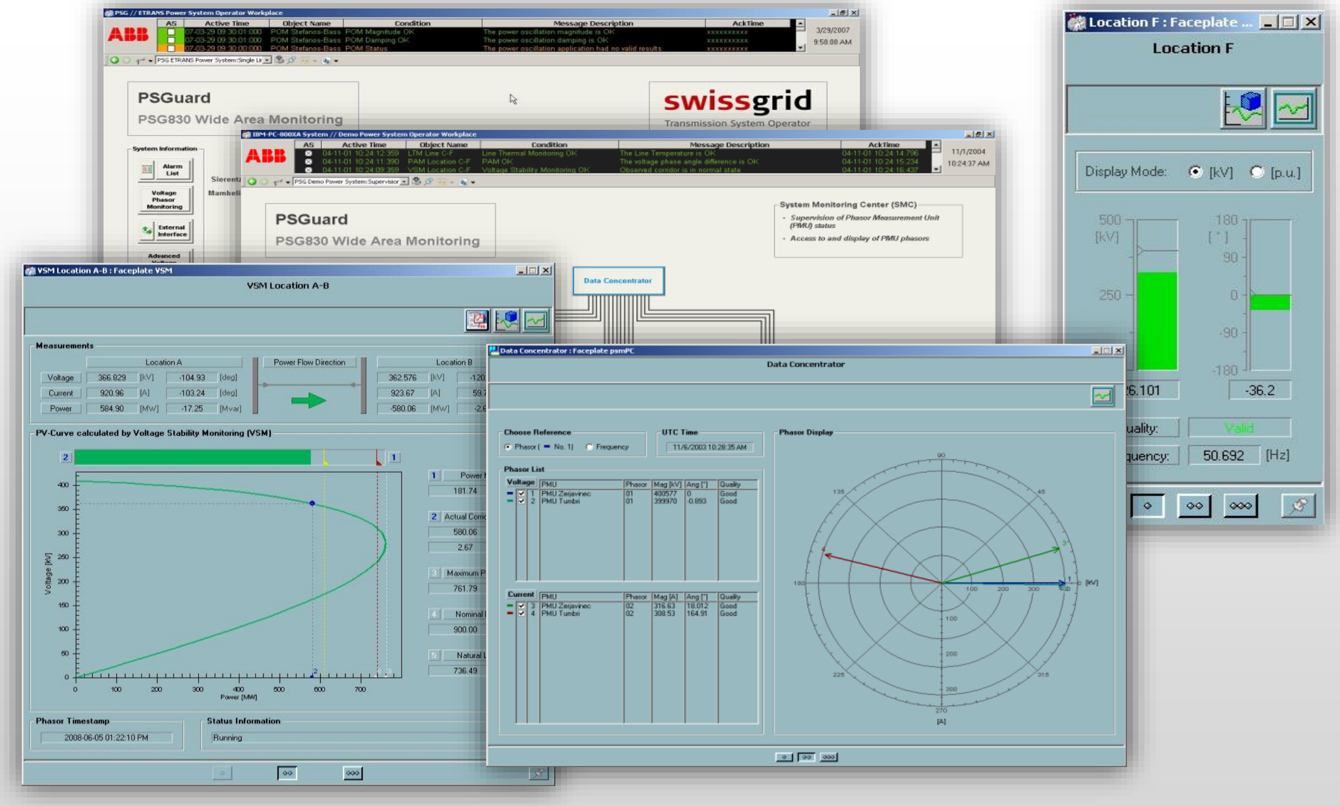
- The application of a sufficient number of PMUs across the system will improve the State Estimation solutions to the point they will be called state calculations.



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



PSG // ETRANS Power System Operator Workplace

AS	Active Time	Object Name	Condition	Message Description	AckTime
☐	07-03-29 09:30:01.000	POM Stefanos-Bass	POM Magnitude OK	The power oscillation magnitude is OK	xxxxxxxxxx
☐	07-03-29 09:30:01.000	POM Stefanos-Bass	POM Damping OK	The power oscillation damping is OK	xxxxxxxxxx
☐	07-03-29 09:30:00.000	POM Stefanos-Bass	POM Status	The power oscillation application had no valid results	xxxxxxxxxx

3/29/2007 9:58:08 AM

IBM-PC-800XA System // Demo Power System Operator Workplace

AS	Active Time	Object Name	Condition	Message Description	AckTime
⊠	04-11-01 10:24:12.359	LTM Line C-F	Line Thermal Monitoring OK	The Line Temperature is OK	04-11-01 10:24:14.796
⊠	04-11-01 10:24:11.390	PAM Location C-F	PAM OK	The voltage phase angle difference is OK	04-11-01 10:24:15.234
⊠	04-11-01 10:24:09.359	VSM Location C-F	Voltage Stability Monitoring OK	Observed corridor is in normal state	04-11-01 10:24:16.437

11/1/2004 10:24:37 AM

System Monitoring Center (SMC)
- *Supervision of Phasor Measurement Unit (PMU) status*
- *Access to and display of PMU phasors*

VSM Location A-B : Faceplate VSM

Measurements

	Location A				Power Flow Direction	Location B			
Voltage	366.829	[kV]	-104.93	[deg]		362.576	[kV]	-120	
Current	920.96	[A]	-103.24	[deg]		923.67	[A]	59.7	
Power	584.90	[MW]	-17.25	[Mvar]		-580.06	[MW]	-2.6	

PV-Curve calculated by Voltage Stability Monitoring (VSM)

1 Power
181.74
2 Actual Corric
580.06
2.67
3 Maximum P
761.79
4 Nominal
900.00
5 Natural L
736.49

Phasor Timestamp: 2008-06-05 01:22:10 PM

Status Information: Running

Data Concentrator : Faceplate psmPC

Choose Reference: ● Phasor (No. 1) ○ Frequency

UTC Time: 11/6/2003 10:28:35 AM

Phasor List

Voltage		PMU	Phasor	Mag [kV]	Ang [°]	Quality
☑	1	PMU Zerjavinec	01	400577	0	Good
☑	2	PMU Tumbri	01	399970	-0.893	Good

Current		PMU	Phasor	Mag [A]	Ang [°]	Quality
☑	3	PMU Zerjavinec	02	316.63	18.012	Good
☑	4	PMU Tumbri	02	308.53	164.91	Good

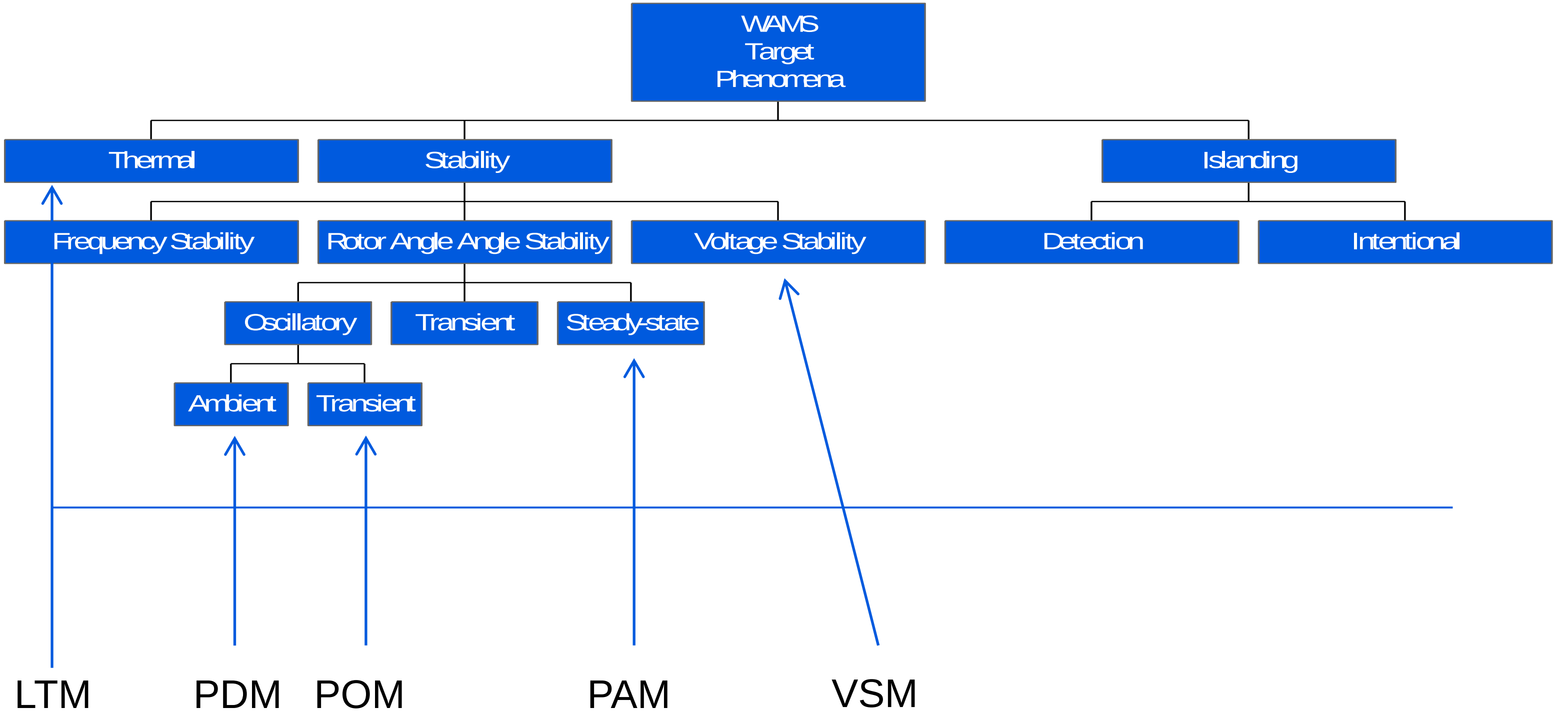
Location F : Faceplate ...

Display Mode: ● [kV] ○ [p.u.]

Quality: Valid

Frequency: 50.692 [Hz]

Power System Stability Applications



WAMS
Target
Phenomena

Thermal

Stability

Islanding

Frequency Stability

Rotor Angle Angle Stability

Voltage Stability

Detection

Intentional

Oscillatory

Transient

Steady-state

Ambient

Transient

LTM

PDM

POM

PAM

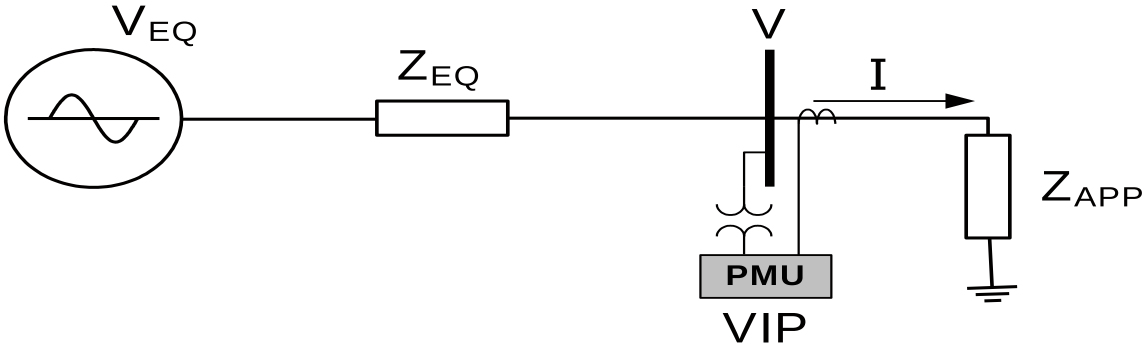
VSM

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

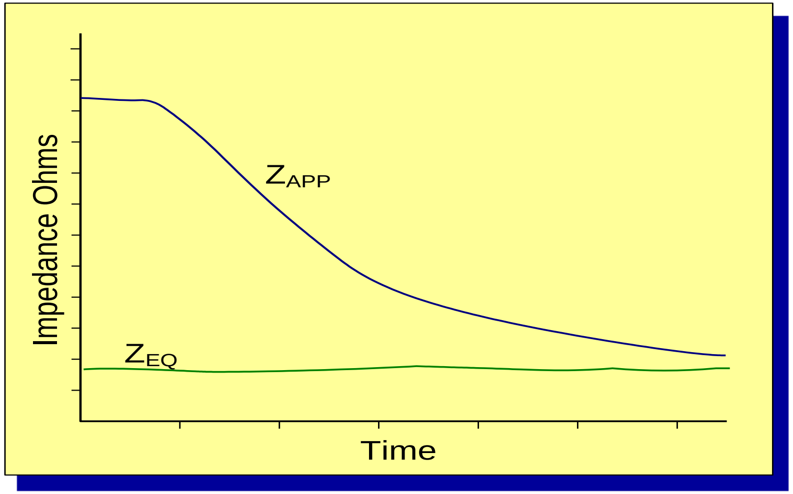
- WAMS Applications provide a way of monitoring the proximity to the stability limits and constraints

Voltage Instability Predictor

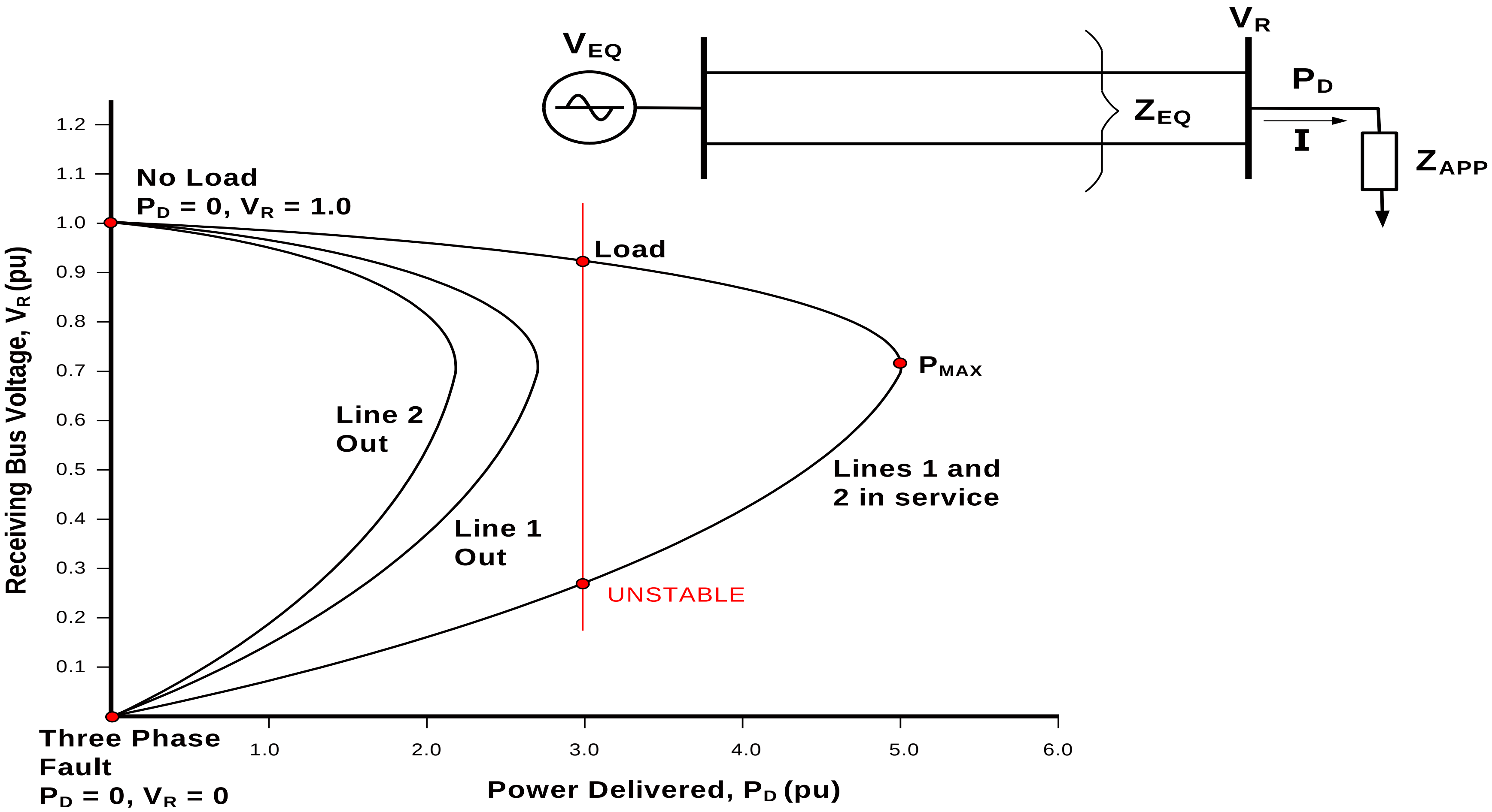


$$Z_{APP} = \frac{V}{I}$$

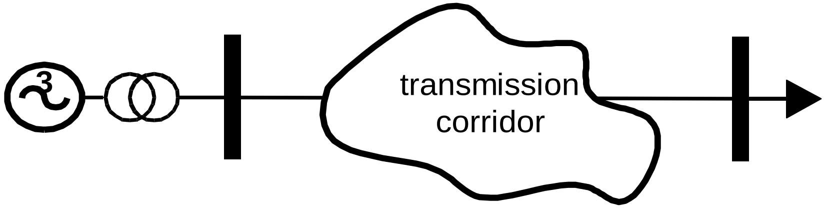
$$Z_{EQ} = \frac{V_{EQ} - V}{I}$$

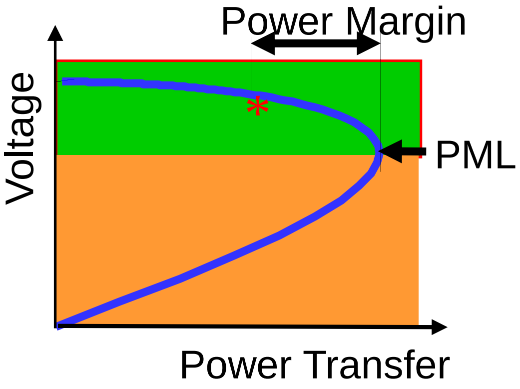


Voltage Instability



Voltage Stability Monitoring (VSM) Principle

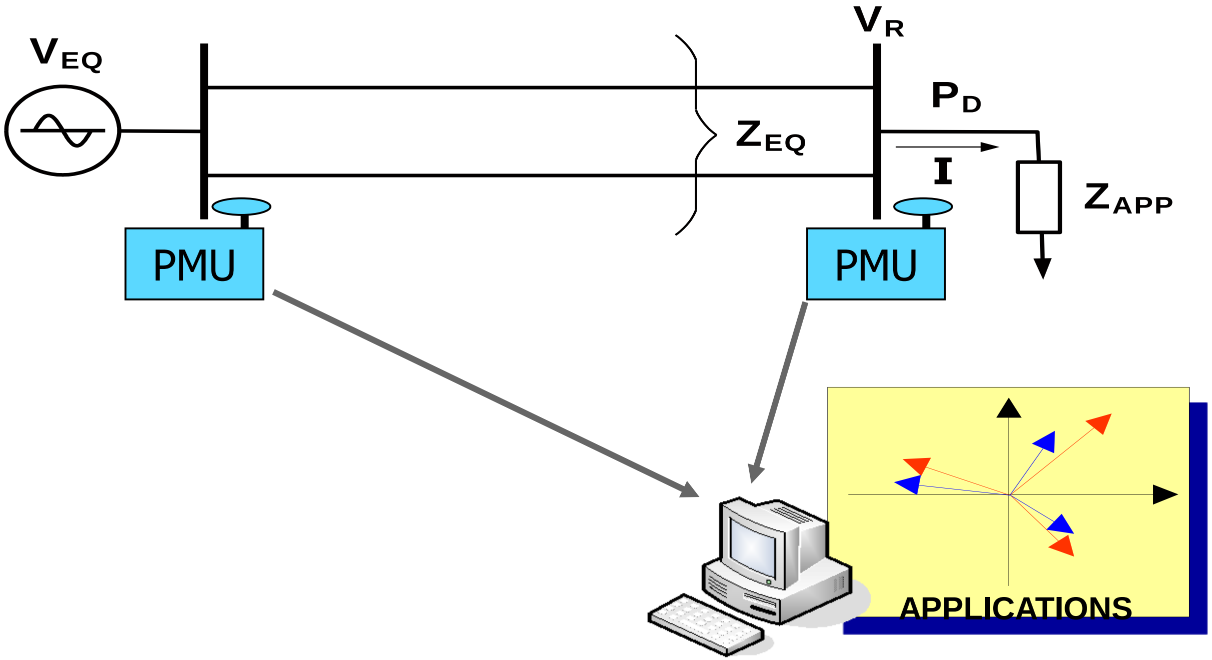




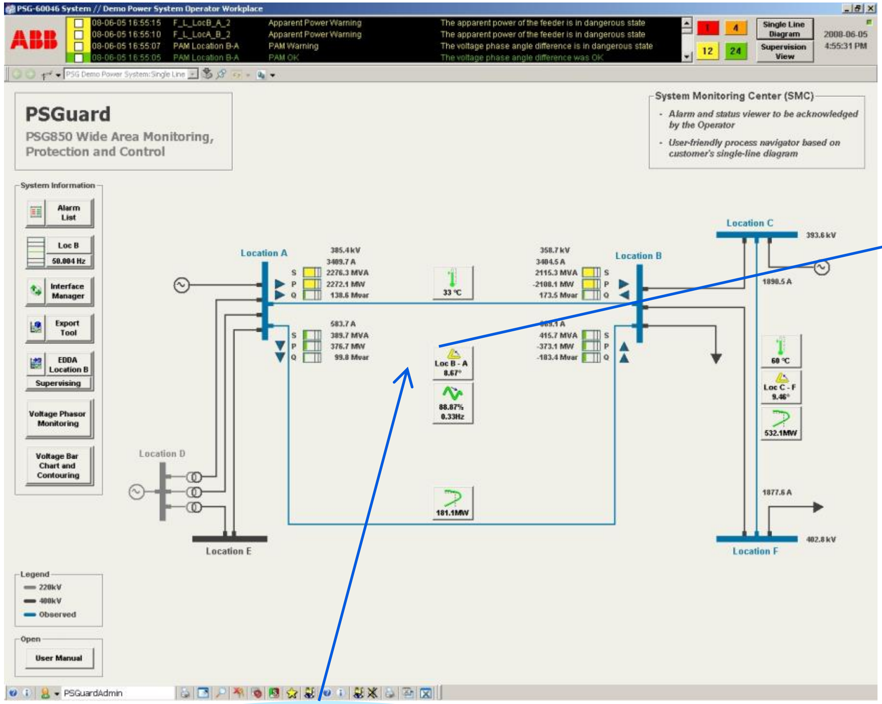
- Assessment of distance to Point of Maximum Loadability, PML
    - Identify network equivalent
    - Stay on top section of PV Curve !
    - Trigger emergency actions when Power Margin too small
    - Patented Method

Voltage Stability Monitoring (VSM) Application

PMU measurements from both ends of the line are used



Voltage Stability Monitoring (VSM) User Interface



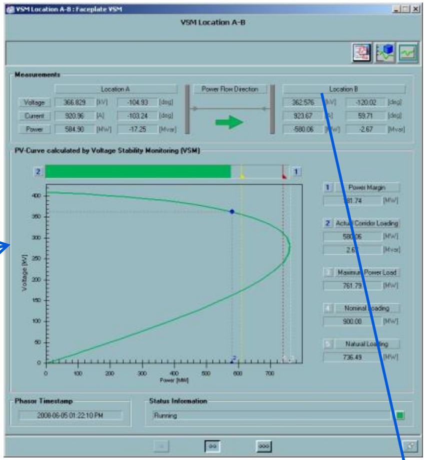
```
☐ 08-06-05 16:55:15   F_L_LocB_A_2       Apparent Power Warning   The apparent power of the feeder is in dangerous state
☐ 08-06-05 16:55:10   F_L_LocA_B_2       Apparent Power Warning   The apparent power of the feeder is in dangerous state
☐ 08-06-05 16:55:07   PAM Location B-A   PAM Warning              The voltage phase angle difference is in dangerous state
☐ 08-06-05 16:55:05   PAM Location B-A   PAM OK                   The voltage phase angle difference was OK
```

PSGuard

PSG850 Wide Area Monitoring, Protection and Control

System Monitoring Center (SMC)

- *Alarm and status viewer to be acknowledged by the Operator*
- *User-friendly process navigator based on customer's single-line diagram*



Measurements

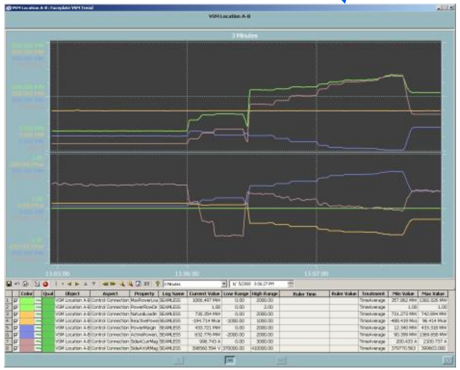
	Location A				Power Flow Direction	Location B			
Voltage	366.829	[kV]	-104.93	[deg]		362.576	[kV]	-120.02	[deg]
Current	920.96	[A]	-103.24	[deg]		923.67	[A]	59.71	[deg]
Power	584.90	[MW]	-17.25	[Mvar]		-580.06	[MW]	-2.67	[Mvar]

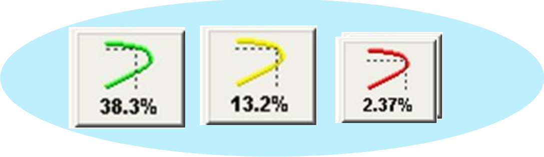
PV-Curve calculated by Voltage Stability Monitoring (VSM)

1	Power Margin	
	[illegible]81.74	[MW]
2	Actual Corridor Loading	
	580.06	[MW]
	2.6[illegible]	[Mvar]
3	Maximum Power Load	
	761.79	[MW]
4	Nominal Loading	
	900.00	[MW]
5	Natural Loading	
	736.49	[MW]

Phasor Timestamp: 2008-06-05 01:22:10 PM

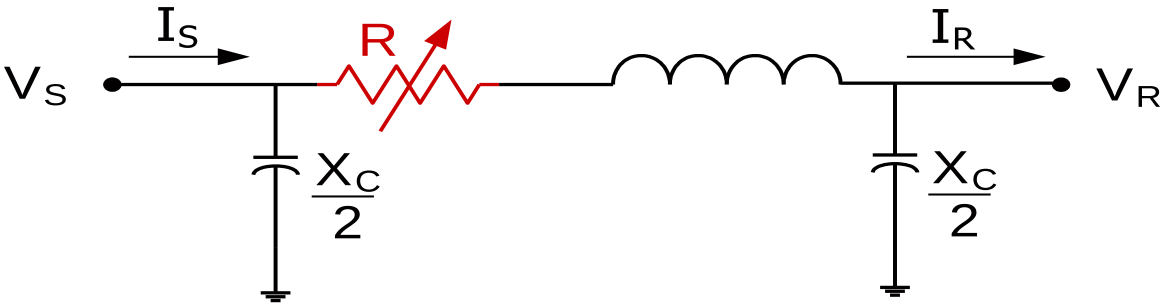
Status Information: Running





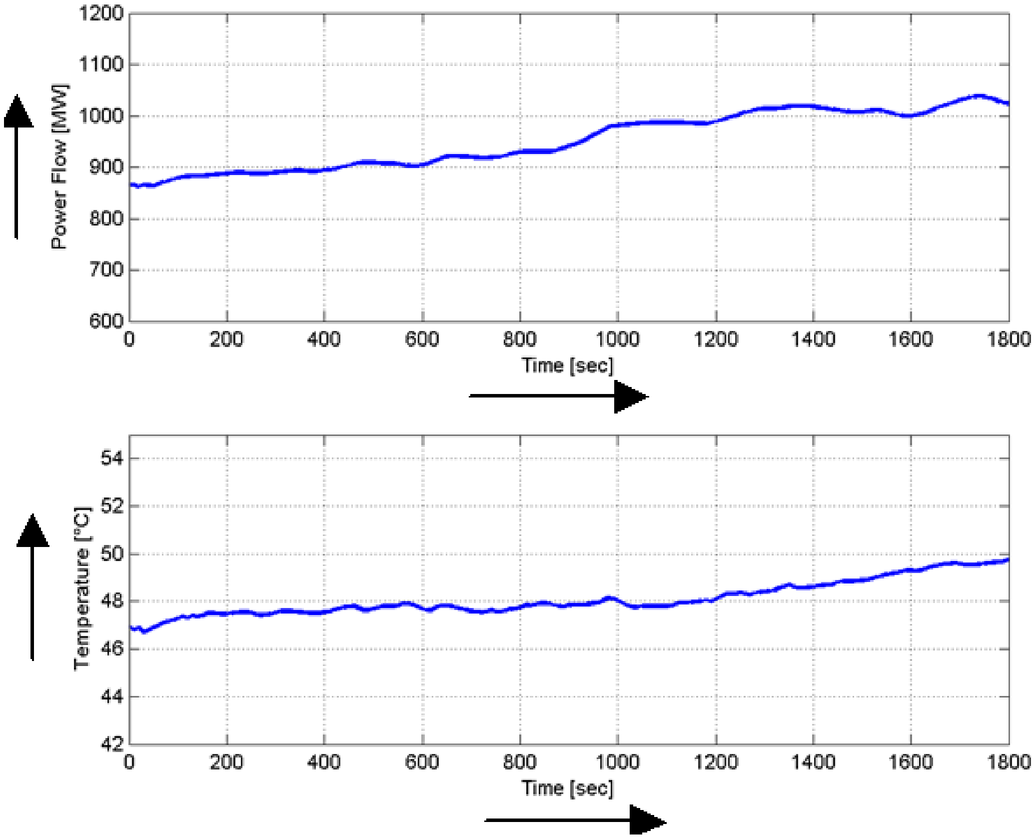
Line Thermal Monitoring (LTM) Application

- Transmission Line Thermal Monitoring



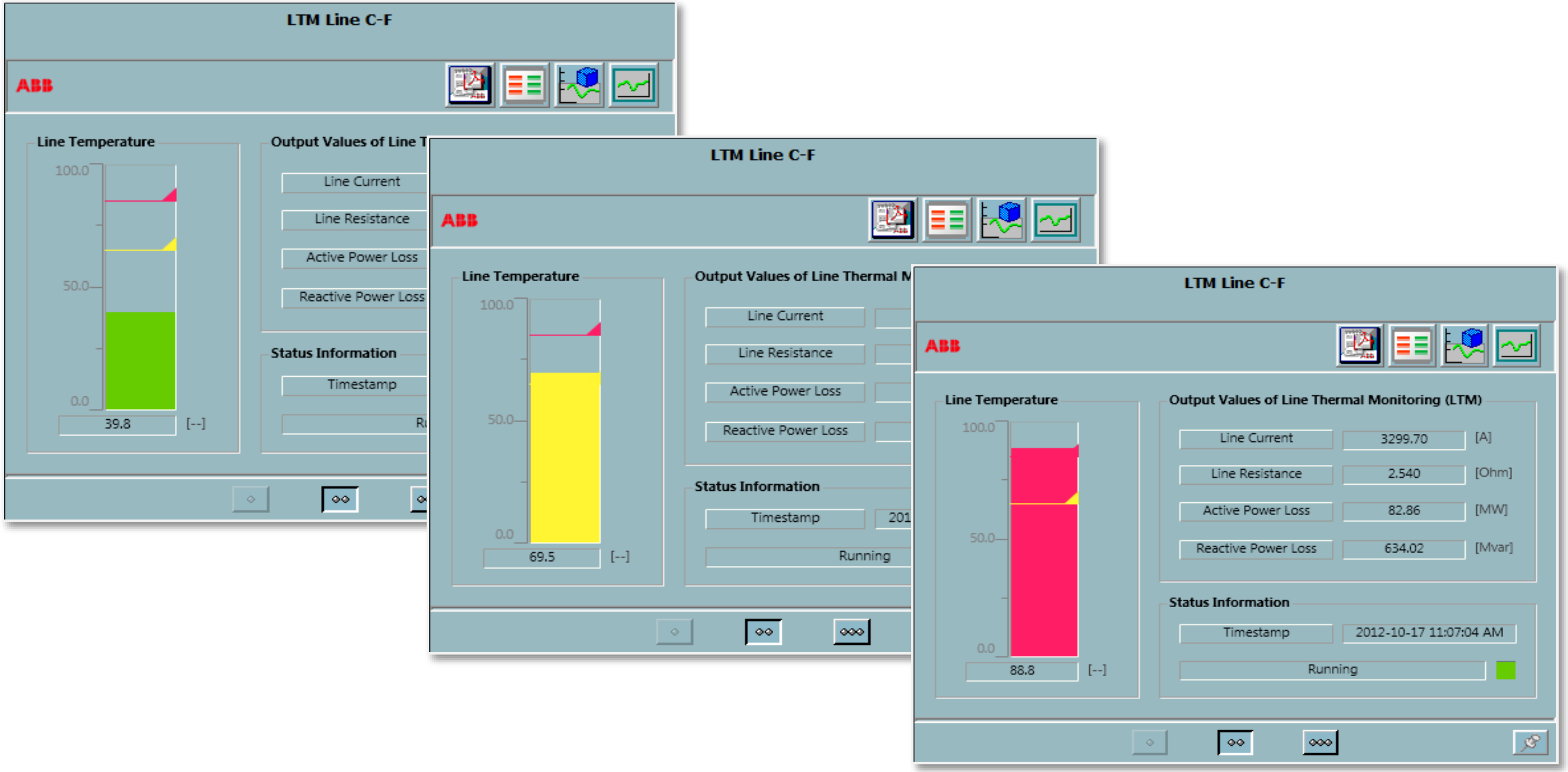
- Compute average conductor temperature to provide
  - Real-time assessment of loadability
  - Early warnings in case of overload
  - Available line capacity
  - Indirect estimation of line sagging

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



LTM Line C-F

Line Temperature

39.8	[--]

LTM Line C-F

Line Temperature

69.5	[--]

LTM Line C-F

Line Temperature

88.8	[--]

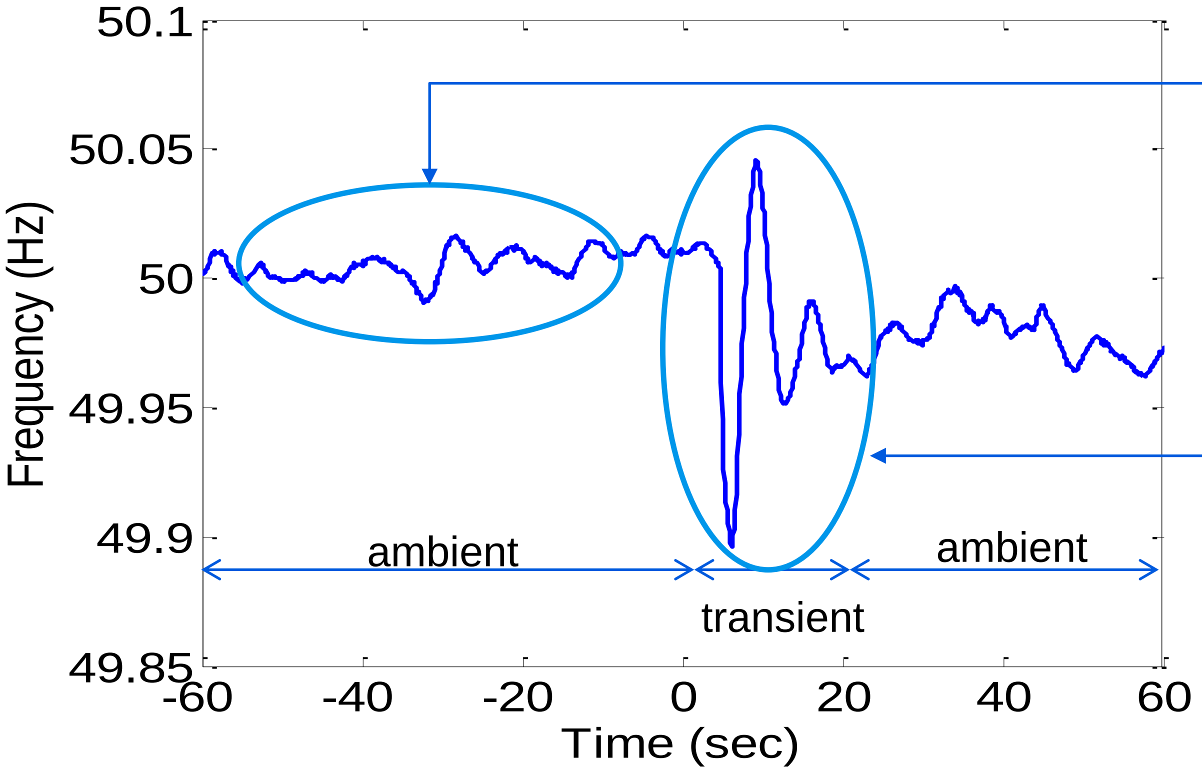
Output Values of Line Thermal Monitoring (LTM)

Line Current	3299.70	[A]
Line Resistance	2.540	[Ohm]
Active Power Loss	82.86	[MW]
Reactive Power Loss	634.02	[Mvar]

Status Information

Timestamp	2012-10-17 11:07:04 AM
Running	🟩

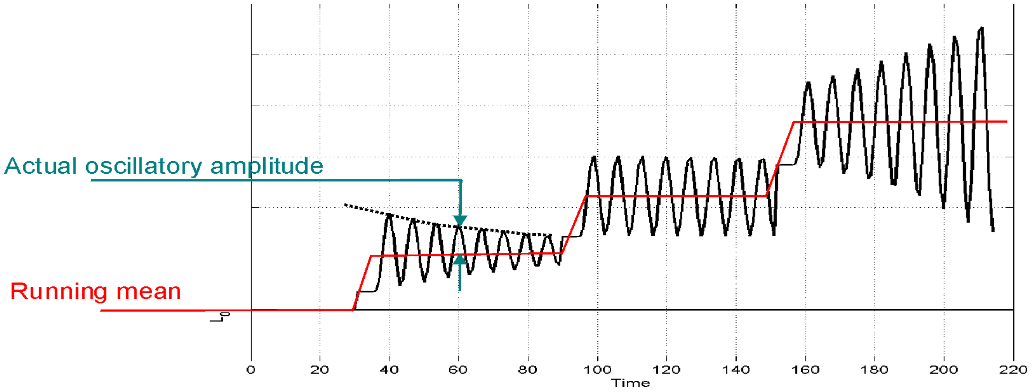
Ambient and Transient Power Oscillation Monitoring



PDM
determining modes and characteristics based on ambient variations

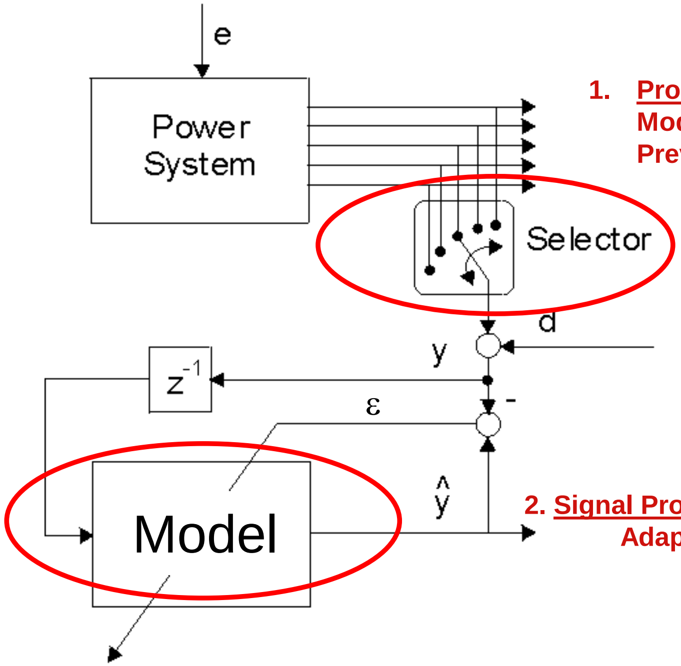
POM
detecting transient oscillations

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) Principle



1. **Proper selection of measured signal**
   Modal Analysis
   Previous experience

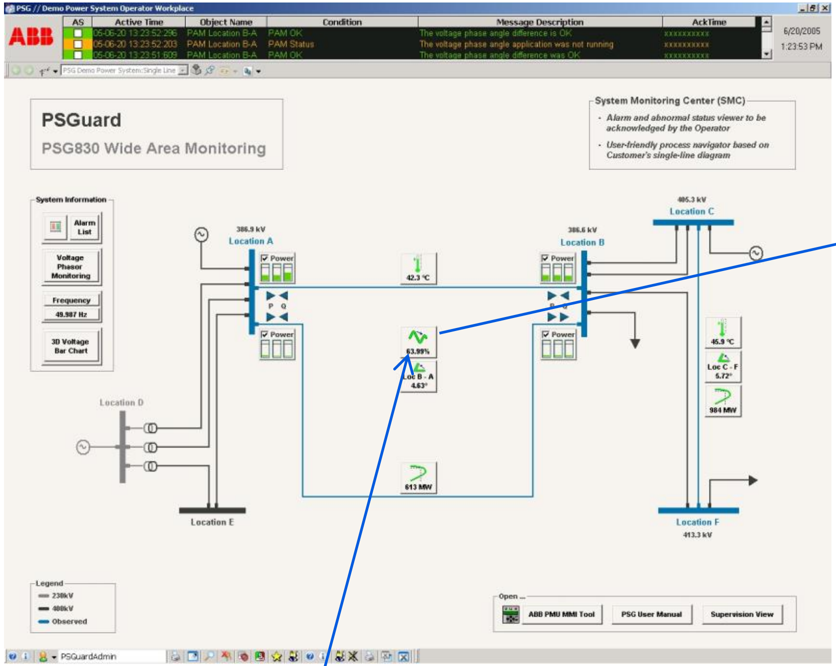
2. **Signal Processing**
   Adaptive Kalman-Filter

Model parameters

➔ Parameters of critical oscillations

Modal Frequency [Hz] + Damping [%] ➔ Amplitude (time-domain)

Power Oscillation Monitoring (POM) Use Interface



PSG // Demo Power System Operator Workplace

AS	Active Time	Object Name	Condition	Message Description	AckTime
☐	05-06-20 13:23:52:296	PAM Location B-A	PAM OK	The voltage phase angle difference is OK	xxxxxxxxxx
☐	05-06-20 13:23:52:203	PAM Location B-A	PAM Status	The voltage phase angle application was not running	xxxxxxxxxx
☐	05-06-20 13:23:51:609	PAM Location B-A	PAM OK	The voltage phase angle difference was OK	xxxxxxxxxx

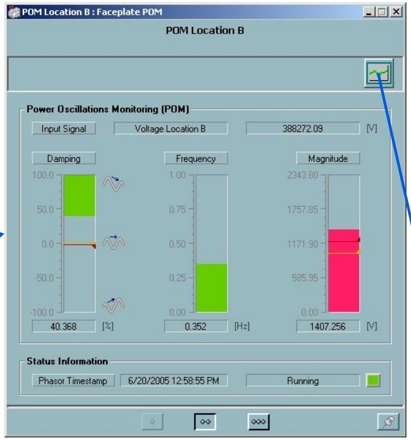
6/20/2005 1:23:53 PM

PSGuard

PSG830 Wide Area Monitoring

System Monitoring Center (SMC)

- *Alarm and abnormal status viewer to be acknowledged by the Operator*
- *User-friendly process navigator based on Customer's single-line diagram*



POM Location B : Faceplate POM

POM Location B

Power Oscillations Monitoring (POM)

Input Signal: Voltage Location B — 388272.09 [V]

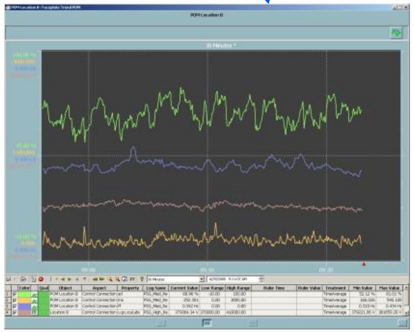
Damping: 40.368 [%]

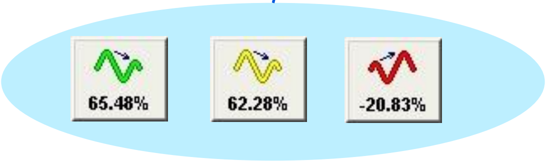
Frequency: 0.352 [Hz]

Magnitude: 1407.256 [V]

Status Information

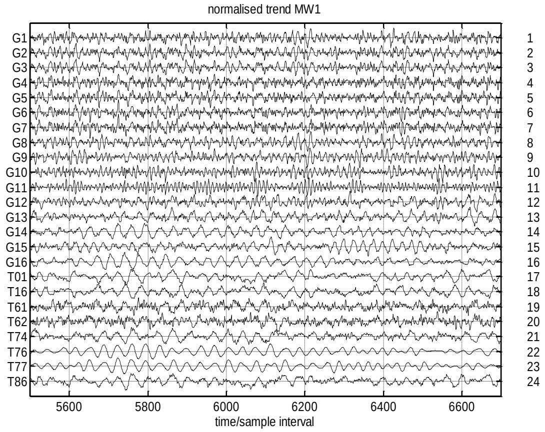
Phasor Timestamp: 6/20/2005 12:58:55 PM — Running



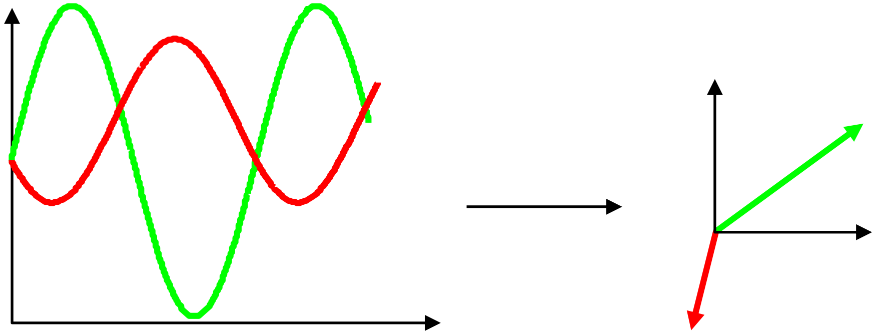


Power Damping Monitor (PDM) Application

- 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) Principle

- Sliding window of 10-15 minutes length
- Estimate MIMO statespace model

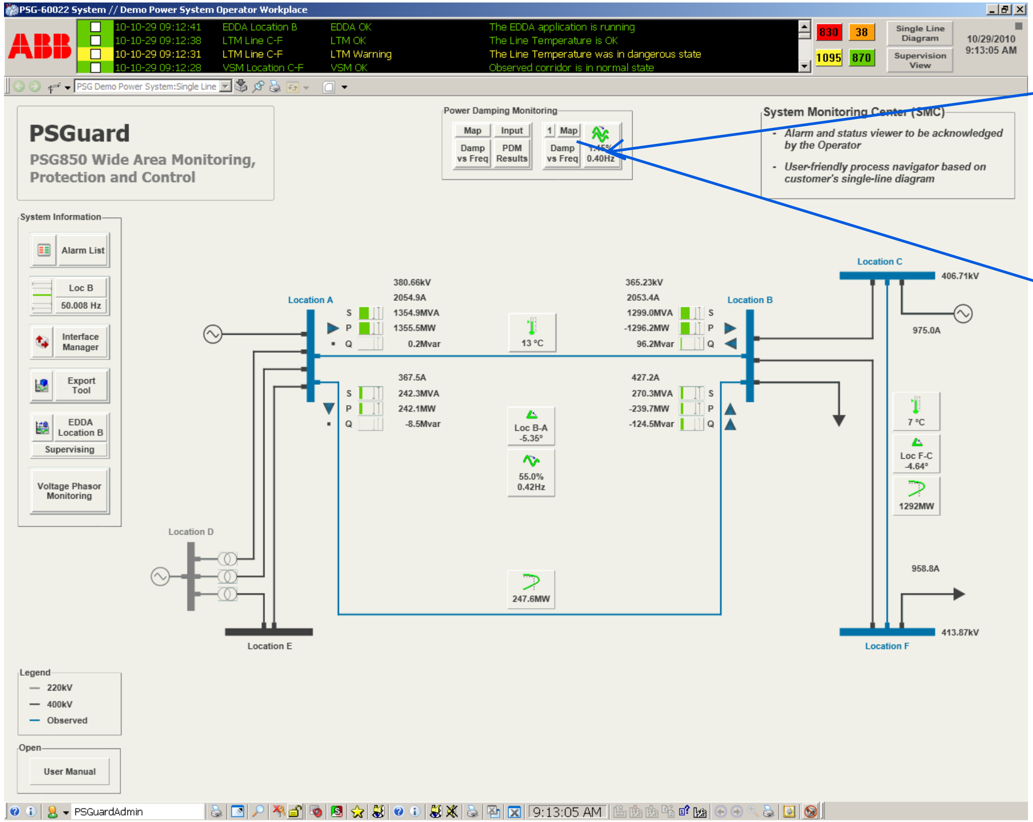
$$x(k+1) = Ax(k) + Ke(k)$$

$$y(k) = Cx(k) + e(k)$$

- $e(k)$ – background power system load variations
- $y(k)$ – frequency measurements

- Carry out modal analysis
  - Diagonalization of A
  - Damping & frequency of critical modes
  - Visibility in different measurements (mode shape)
  - Confidence intervals for damping and frequency

Power Damping Monitor (PDM) User Interace



PSG-60022 System // Demo Power System Operator Workplace

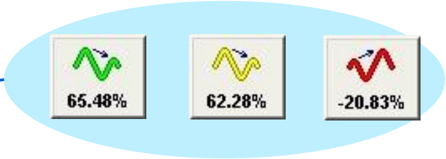
```
☐ 10-10-29 09:12:41   EDDA Location B   EDDA OK       The EDDA application is running
☐ 10-10-29 09:12:38   LTM Line C-F      LTM OK        The Line Temperature is OK
☐ 10-10-29 09:12:31   LTM Line C-F      LTM Warning   The Line Temperature was in dangerous state
☐ 10-10-29 09:12:28   VSM Location C-F  VSM OK        Observed corridor is in normal state
```

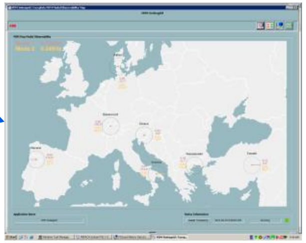
PSGuard

PSG850 Wide Area Monitoring, Protection and Control

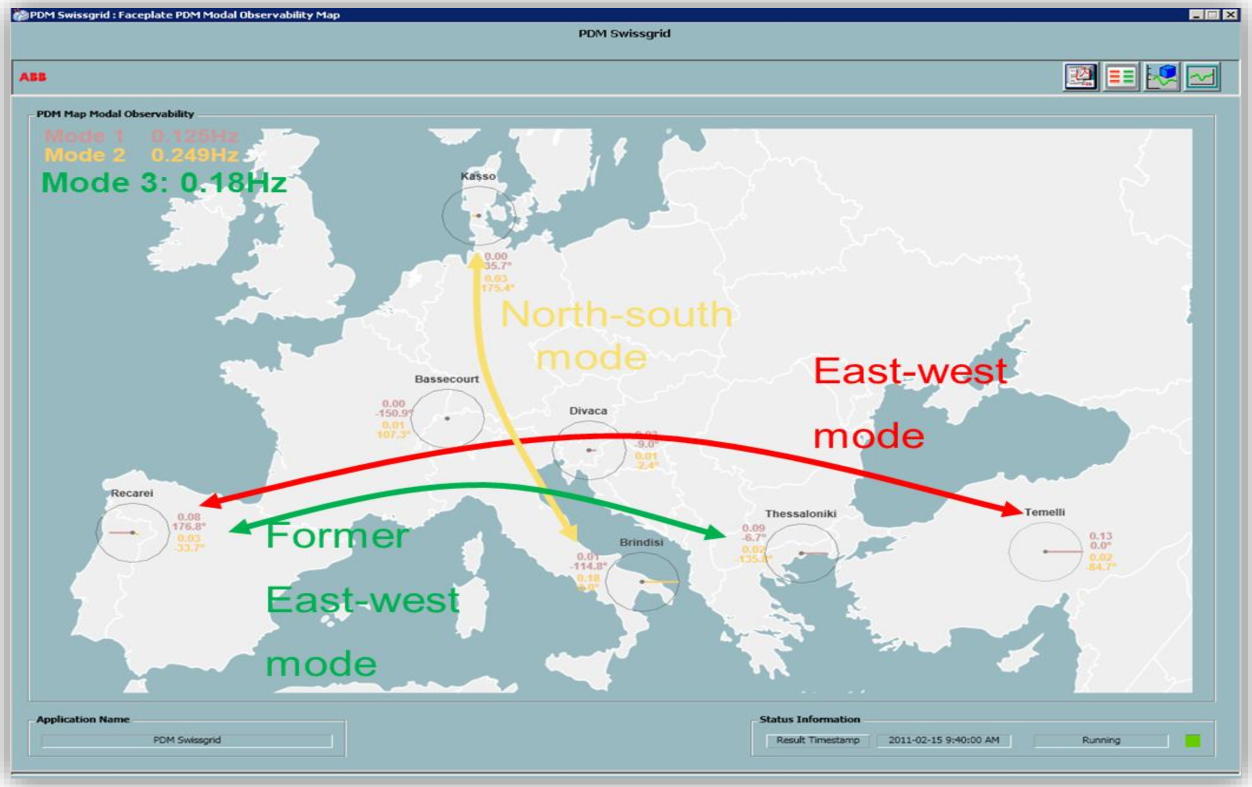
System Monitoring Center (SMC)

- *Alarm and status viewer to be acknowledged by the Operator*
- *User-friendly process navigator based on customer's single-line diagram*





Power Damping Monitor (PDM) Example


PDM Swissgrid : Faceplate PDM Modal Observability Map

PDM Swissgrid

PDM Map Modal Observability

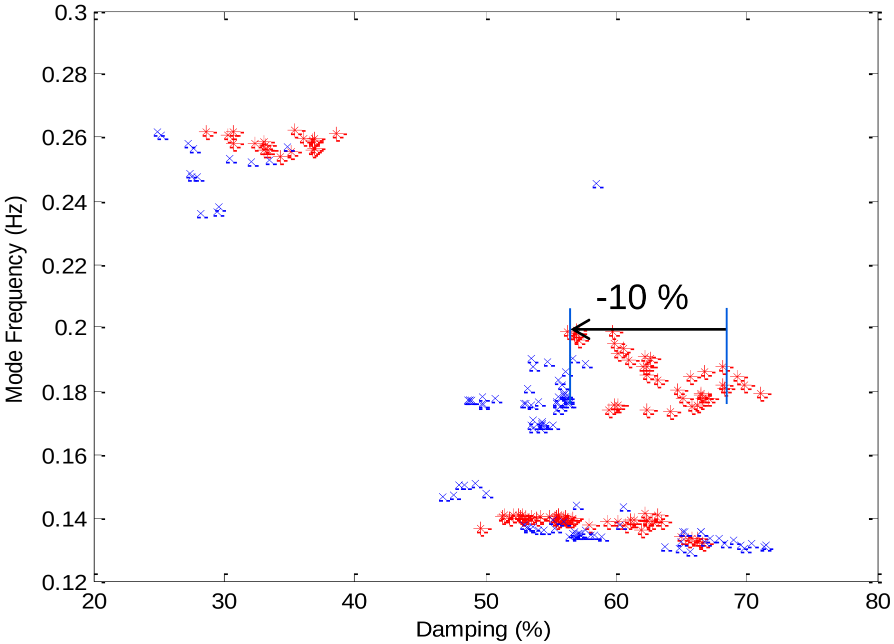
Mode 1 0.125Hz
Mode 2 0.249Hz
Mode 3: 0.18Hz

Application Name: PDM Swissgrid

Status Information: Result Timestamp 2011-02-15 9:40:00 AM Running 🟩

- East-west mode - ~0.13 Hz
- North-south mode - ~0.25 Hz
- Former east-west mode - ~0.17 Hz

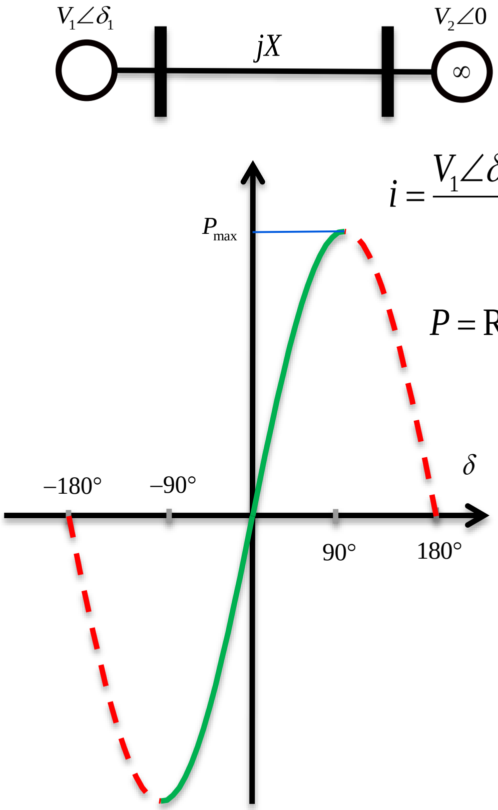
Power Damping Monitor (PDM) Output



- 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)

- North-south mode - 0.25 Hz
- East-west mode - 0.13 Hz
- Former east-west mode - 0.17 Hz

Phase Angle Monitoring (PAM) Principle



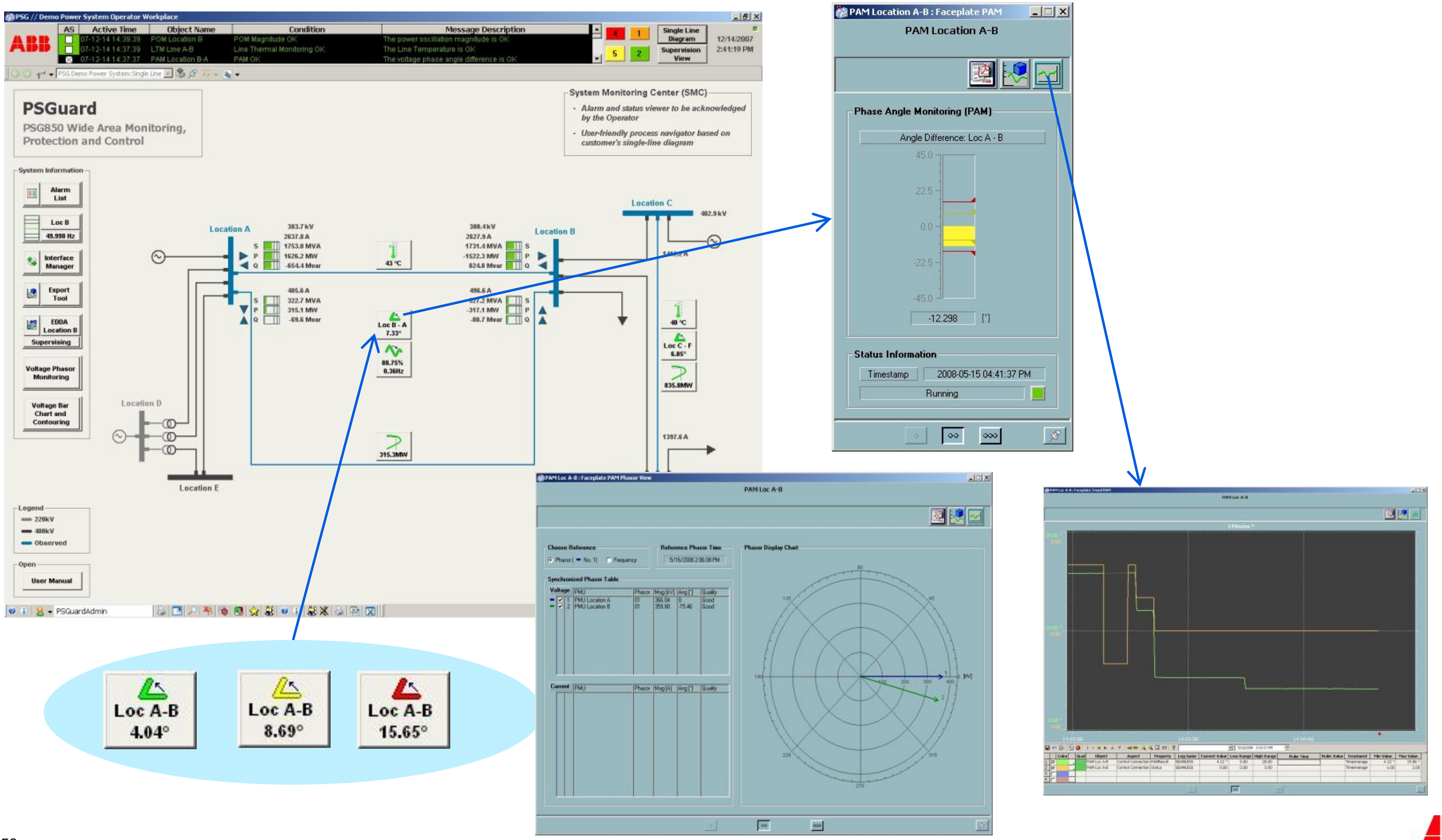
$$i = \frac{V_1\angle\delta - V_2\angle 0}{jX}$$

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

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



PSG // Demo Power System Operator Workplace

AS	Active Time	Object Name	Condition	Message Description
☐	07-12-14 14:39:39	POM Location B	POM Magnitude OK	The power oscillation magnitude is OK
☐	07-12-14 14:37:39	LTM Line A-B	Line Thermal Monitoring OK	The Line Temperature is OK
☒	07-12-14 14:37:37	PAM Location B-A	PAM OK	The voltage phase angle difference is OK

12/14/2007 2:41:19 PM

PSGuard

PSG850 Wide Area Monitoring, Protection and Control

System Monitoring Center (SMC)

- *Alarm and status viewer to be acknowledged by the Operator*
- *User-friendly process navigator based on customer's single-line diagram*

PAM Location A-B : Faceplate PAM

PAM Location A-B

Phase Angle Monitoring (PAM)

Angle Difference: Loc A - B

-12.298 [°]

Status Information

Timestamp: 2008-05-15 04:41:37 PM

Running

PAM Loc A-B : Faceplate PAM Phasor View

PAM Loc A-B

Choose Reference: ● Phasor (No. 1) ○ Frequency

Reference Phasor Time: 5/16/2008 2:06:08 PM

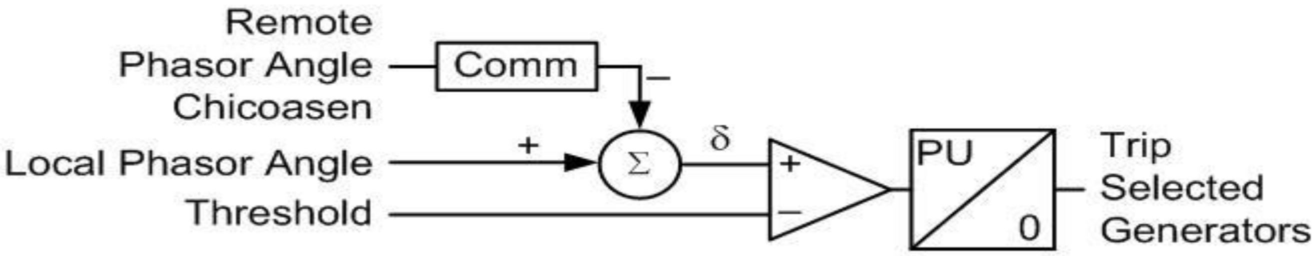
Synchronized Phasor Table

Voltage	PMU	Phasor	Mag [kV]	Ang [°]	Quality
☑ 1	PMU Location A	01	366.04	0	Good
☑ 2	PMU Location B	01	359.80	-15.46	Good

Current	PMU	Phasor	Mag [A]	Ang [°]	Quality

Phasor Display Chart

Angular Differential Protection Example



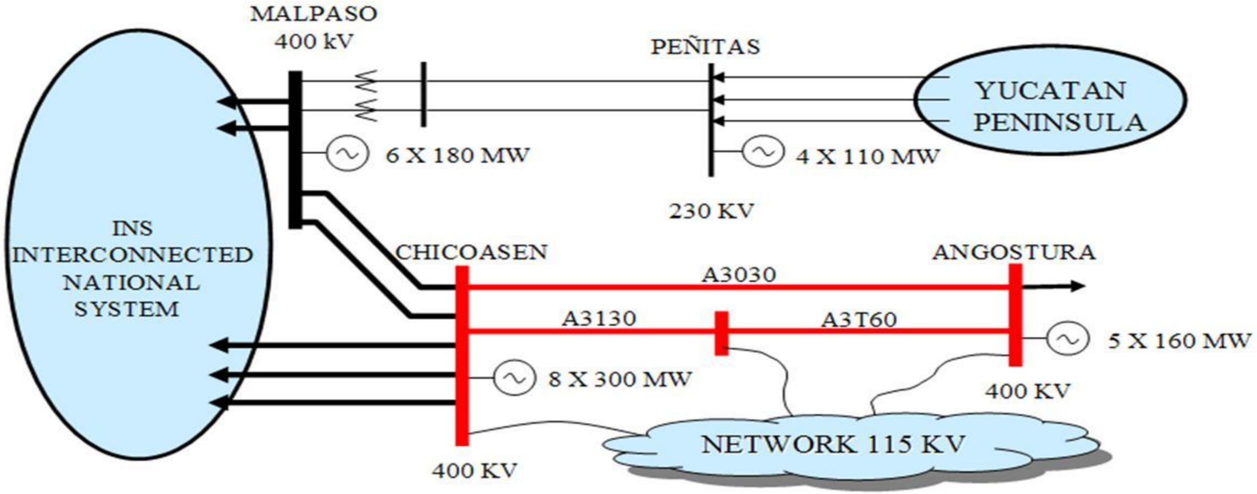
Remote Phasor Angle Chicoasen → Comm → −

Local Phasor Angle → + → Σ → δ

Threshold → −

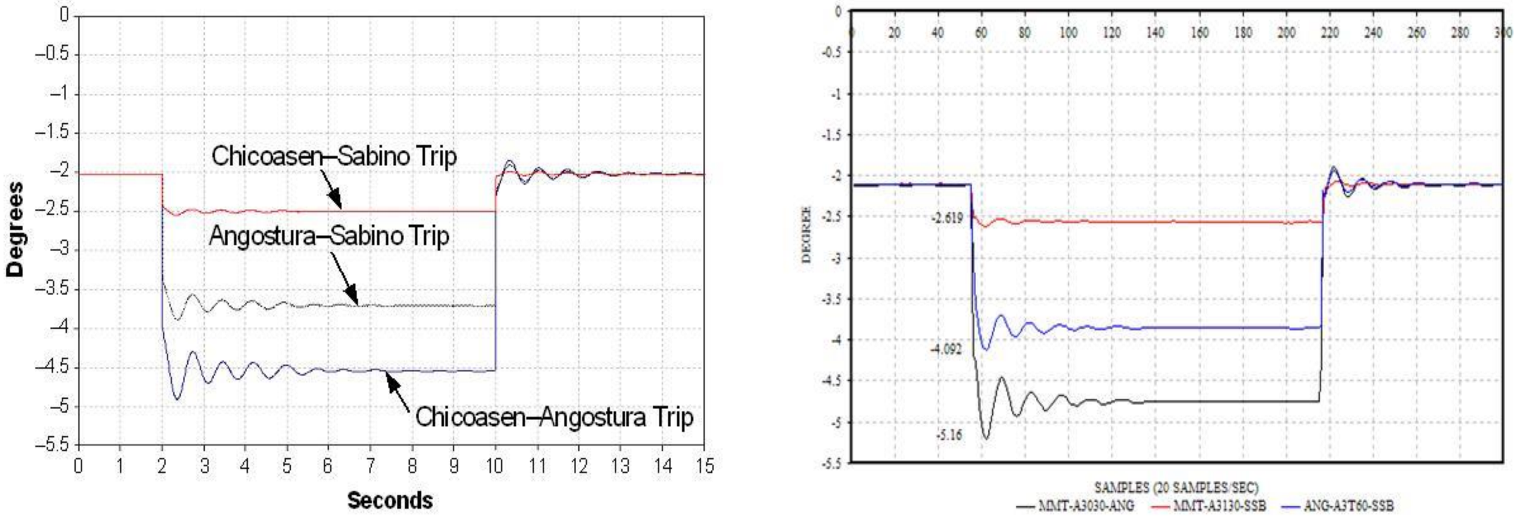
PU / 0

Trip Selected Generators



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

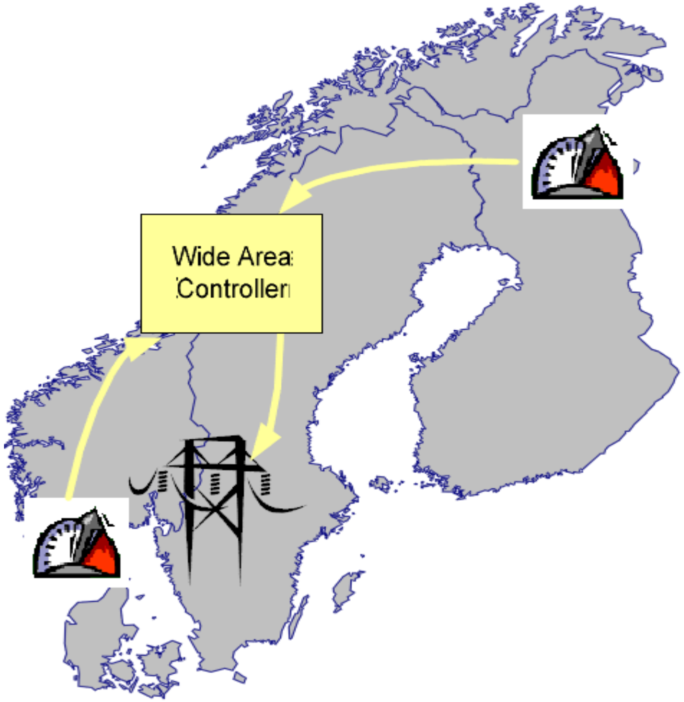


Source: E.Martinez Angular Difference Protection Scheme, Conference on Actual Trends in Development of Power System development and Automation, Sept 2009, Moscow, Russia

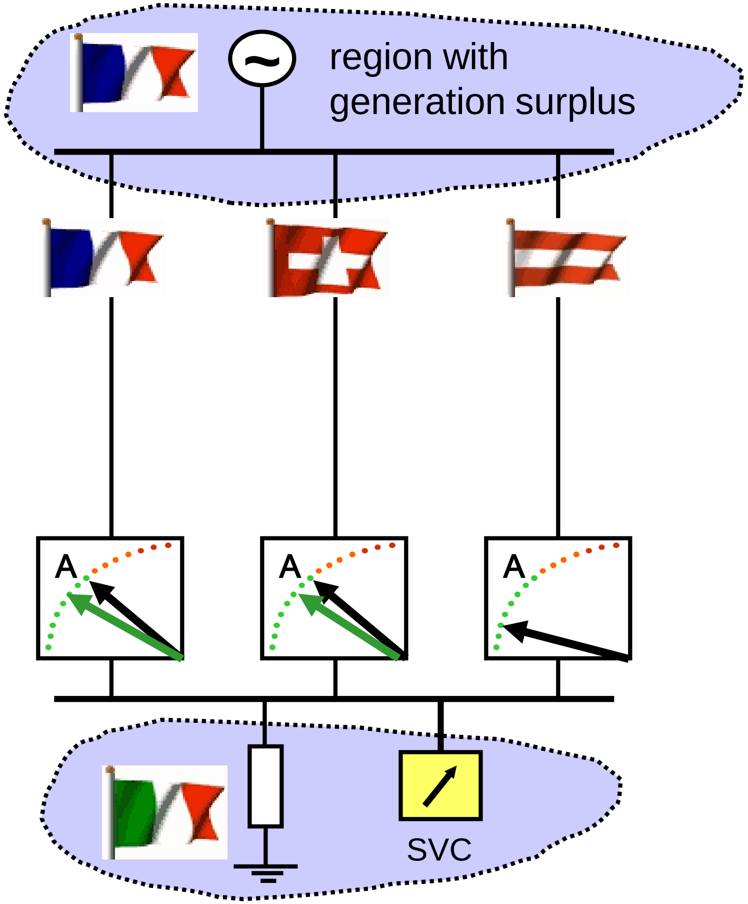
Wide-Area Control Applications

- 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)

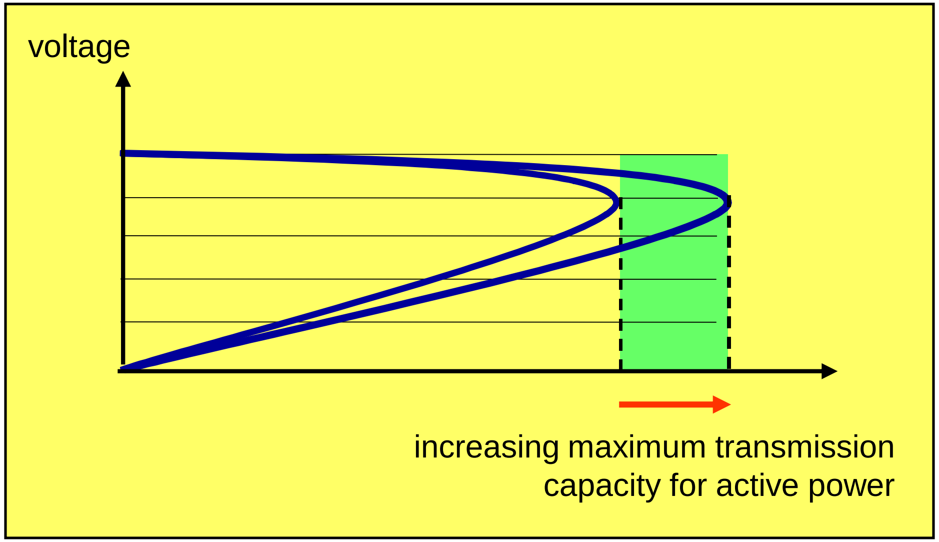
- Prototype WACS implemented and tested
    - PMU-PCU400 PDC-MACH2 control system
    - Wide Area Power Oscillation Damper (POD) with local signal based POD as backup
- Deployed in 2010



2004: Increasing capacity with SVC



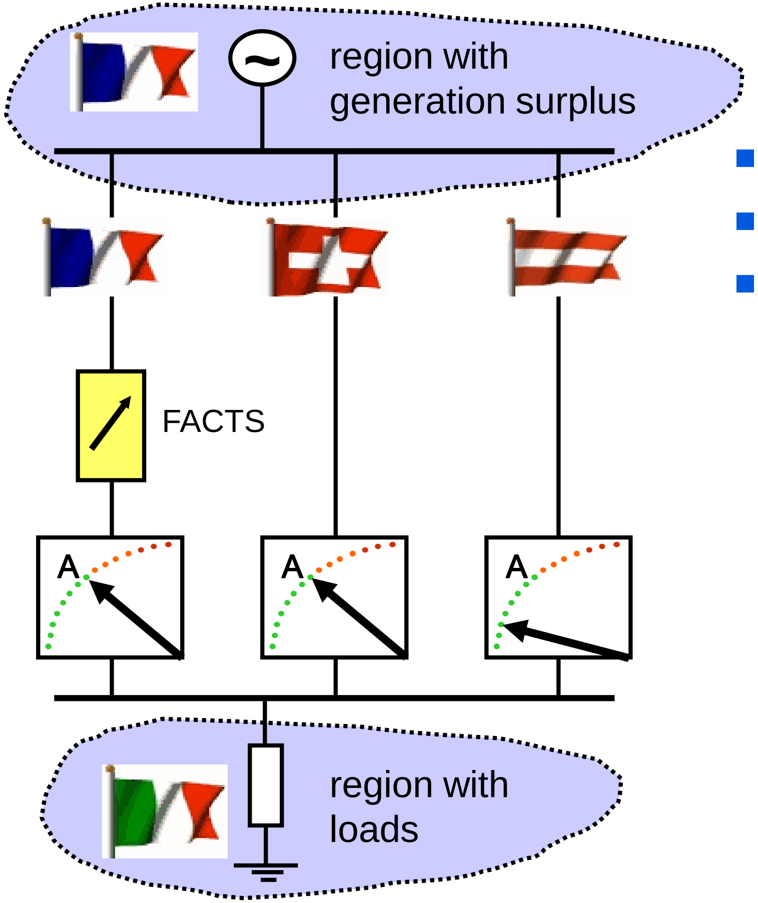
region with loads



increasing maximum transmission capacity for active power

SVC: static var compensation

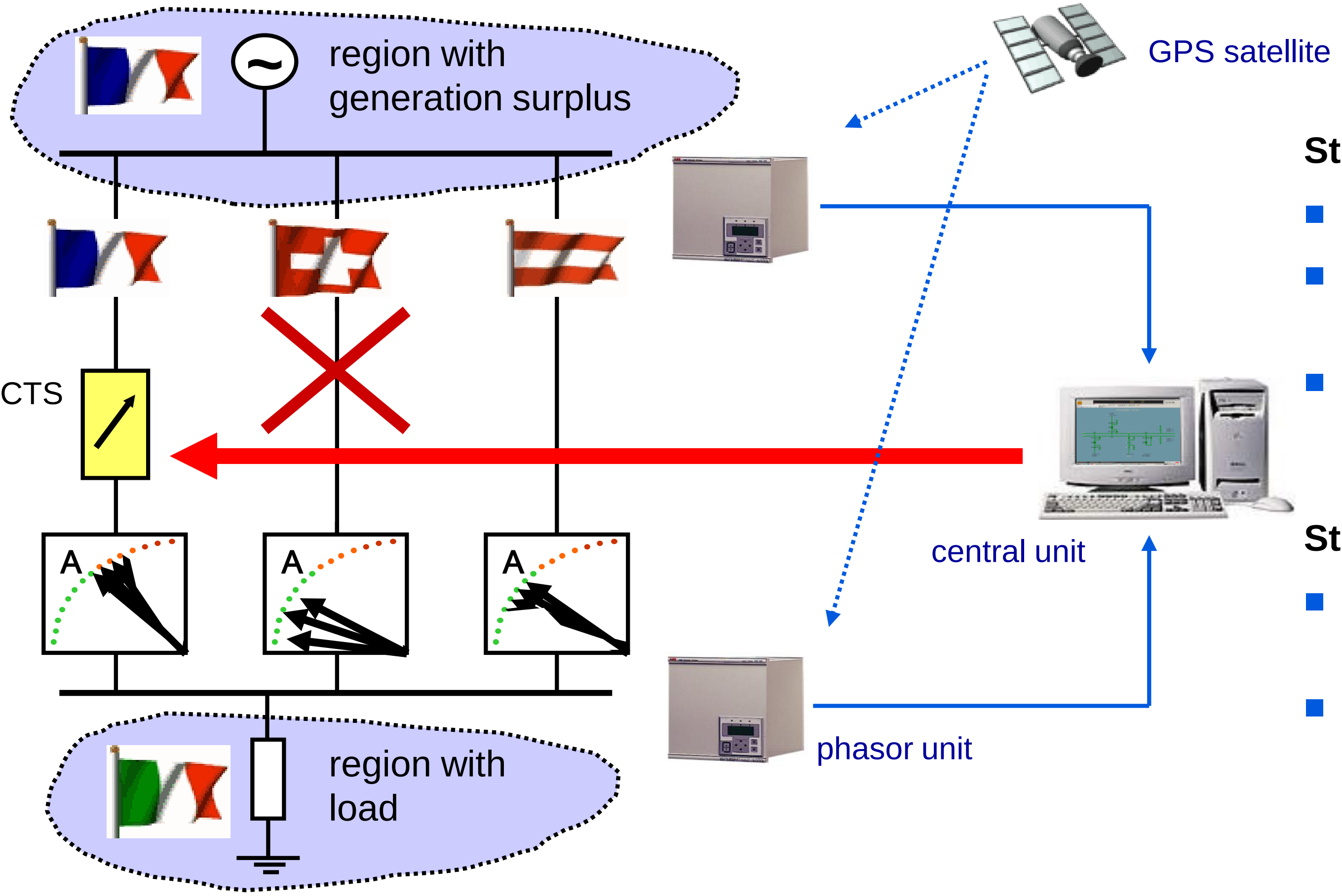
2004: FACTs for Power Flow Control



- 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

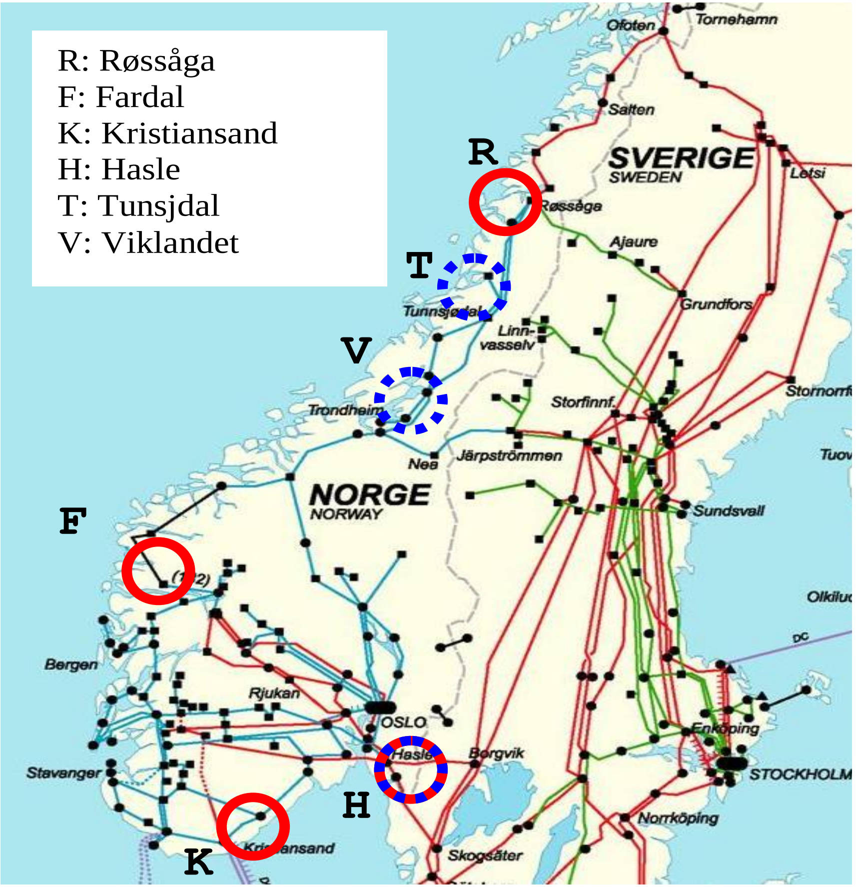
Step 2:

- increase reactance of overloaded line
- stable situation

Nordic Power System

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

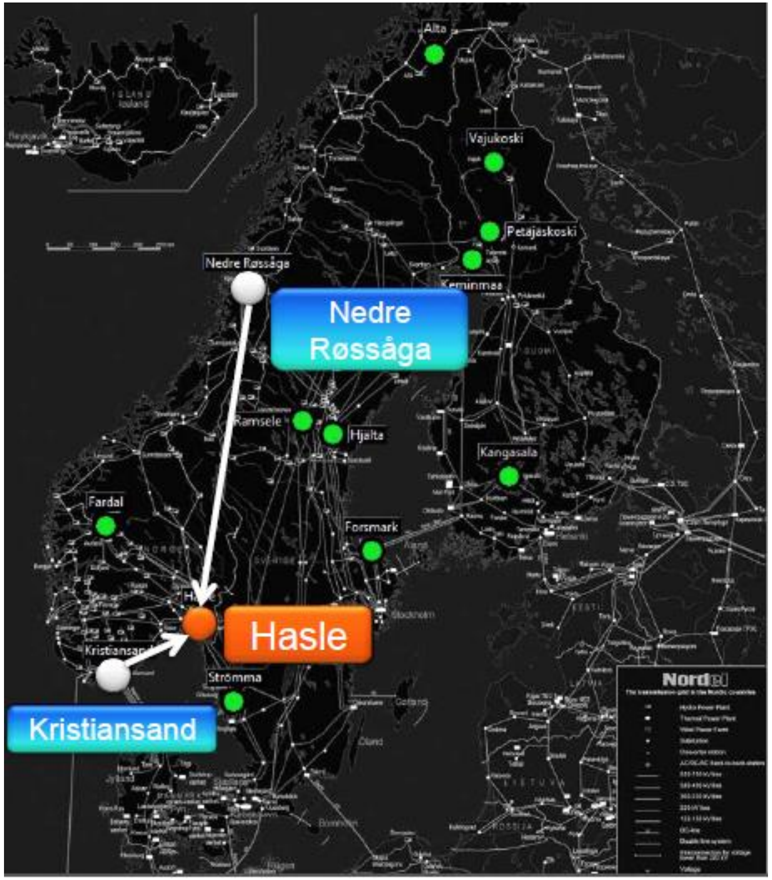
- Recently installed in Norway
  - PMUs (locations R, F, K, H)
  - SVCs (locations H, T, V)



R: Røssåga
F: Fardal
K: Kristiansand
H: Hasle
T: Tunsjdal
V: Viklandet

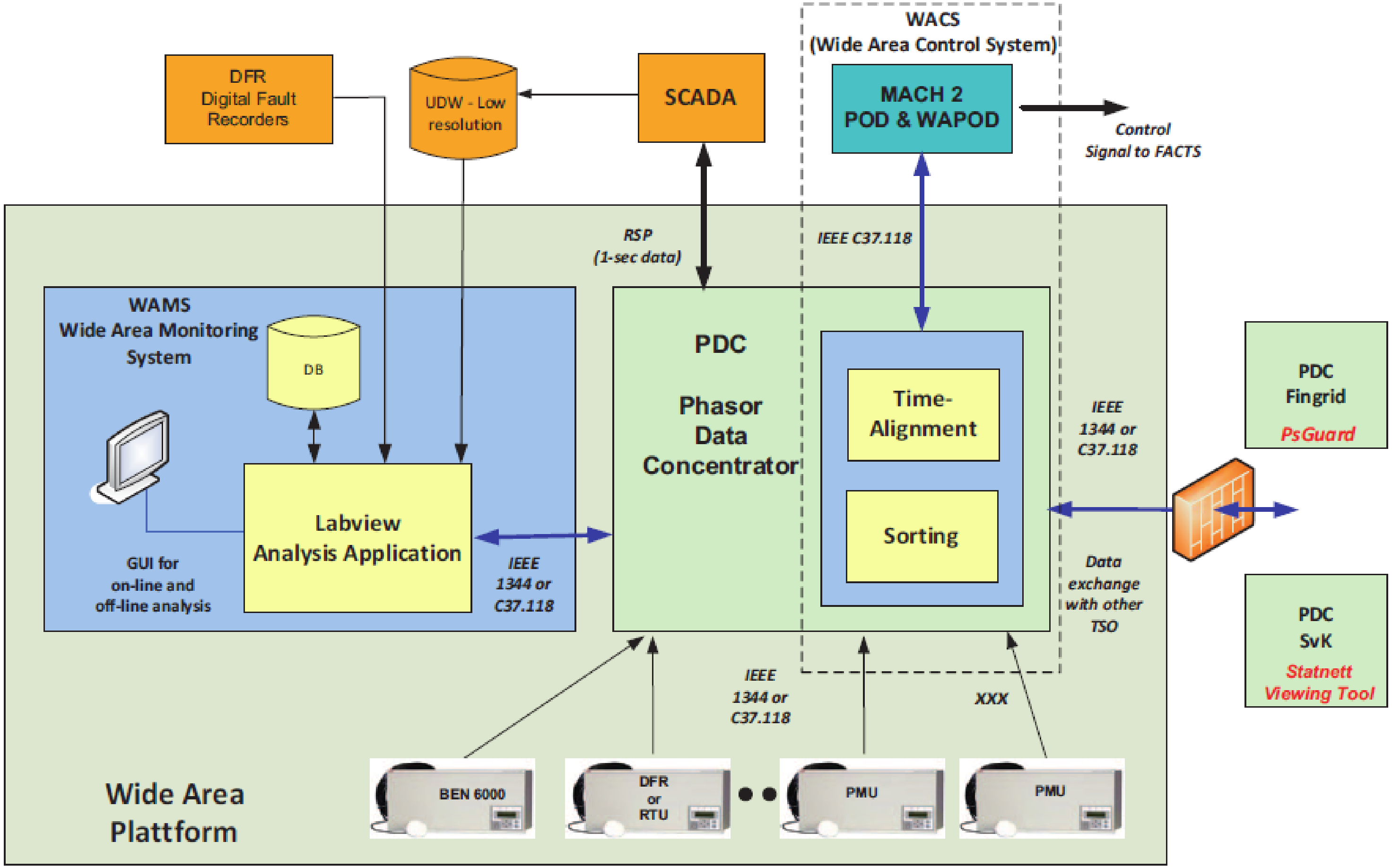
Wide-area Power Oscillation Damper Control

- 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



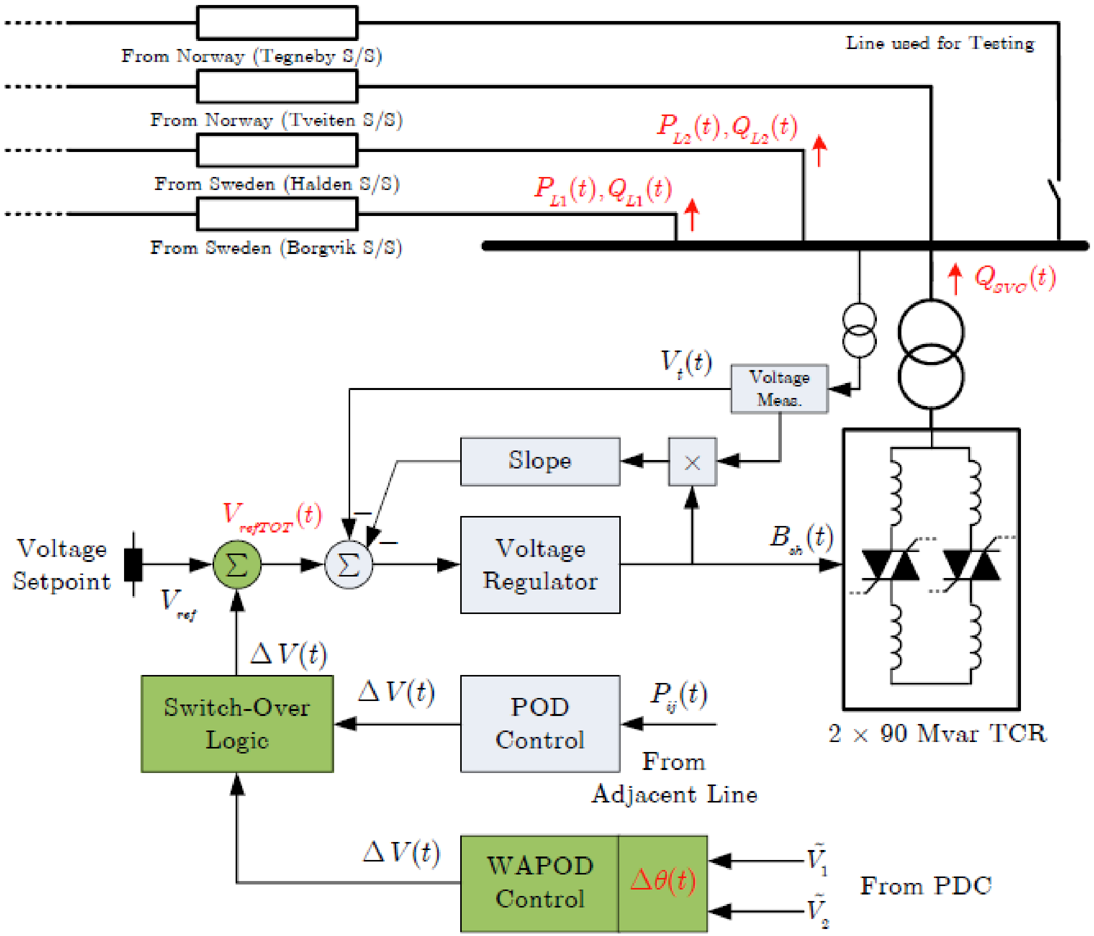
Source: K. Uhlen, etc Wide-Area Power Oscillation Damper Implementation and Testing in the Norwegian Transmission Network, IEEE PES 2012.

Wide-area Monitoring and Control System



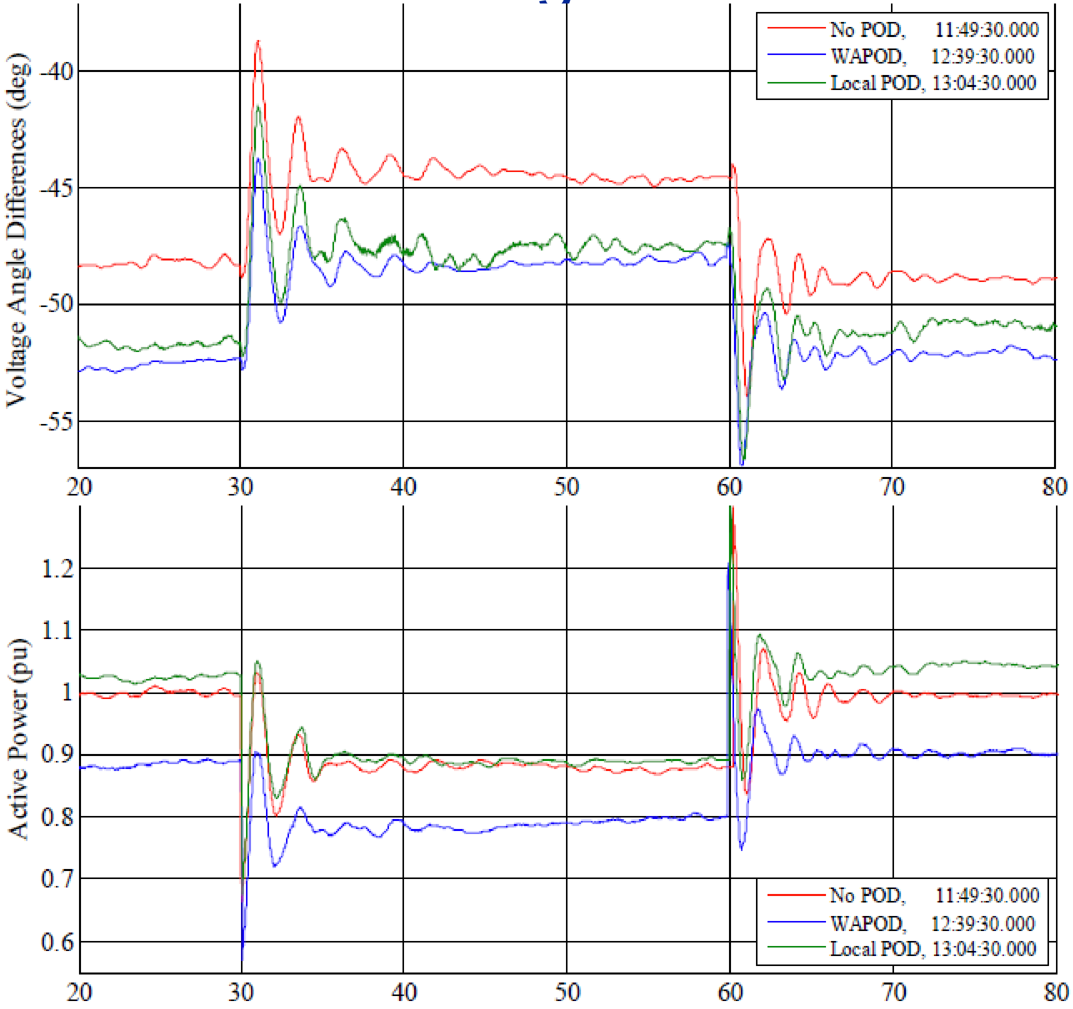
Source: K. Uhlen, etc Wide-Area Power Oscillation Damper Implementation and Testing in the Norwegian Transmission Network, IEEE PES 2012.

SVC Control Implementation



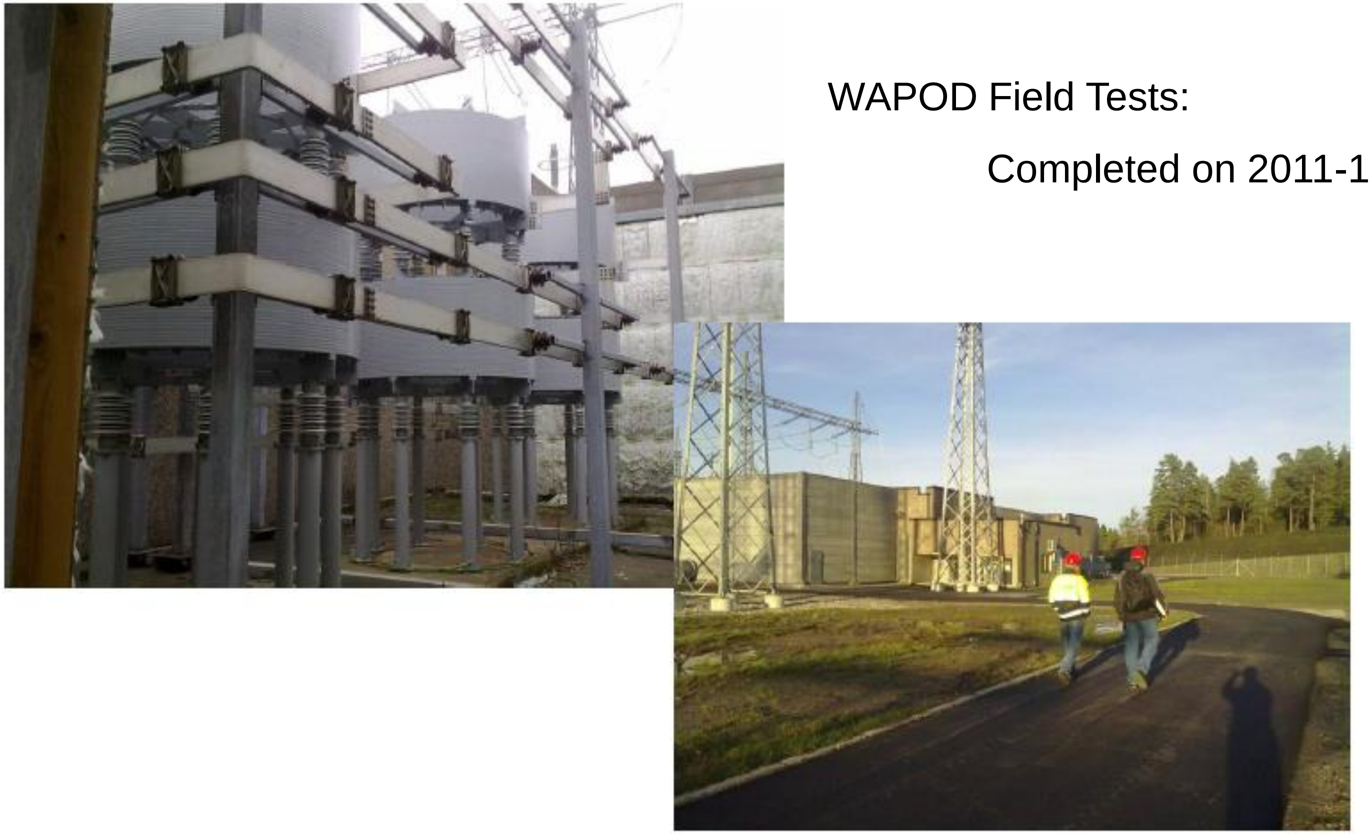
Source: K. Uhlen, etc Wide-Area Power Oscillation Damper Implementation and Testing in the Norwegian Transmission Network, IEEE PES 2012.

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)

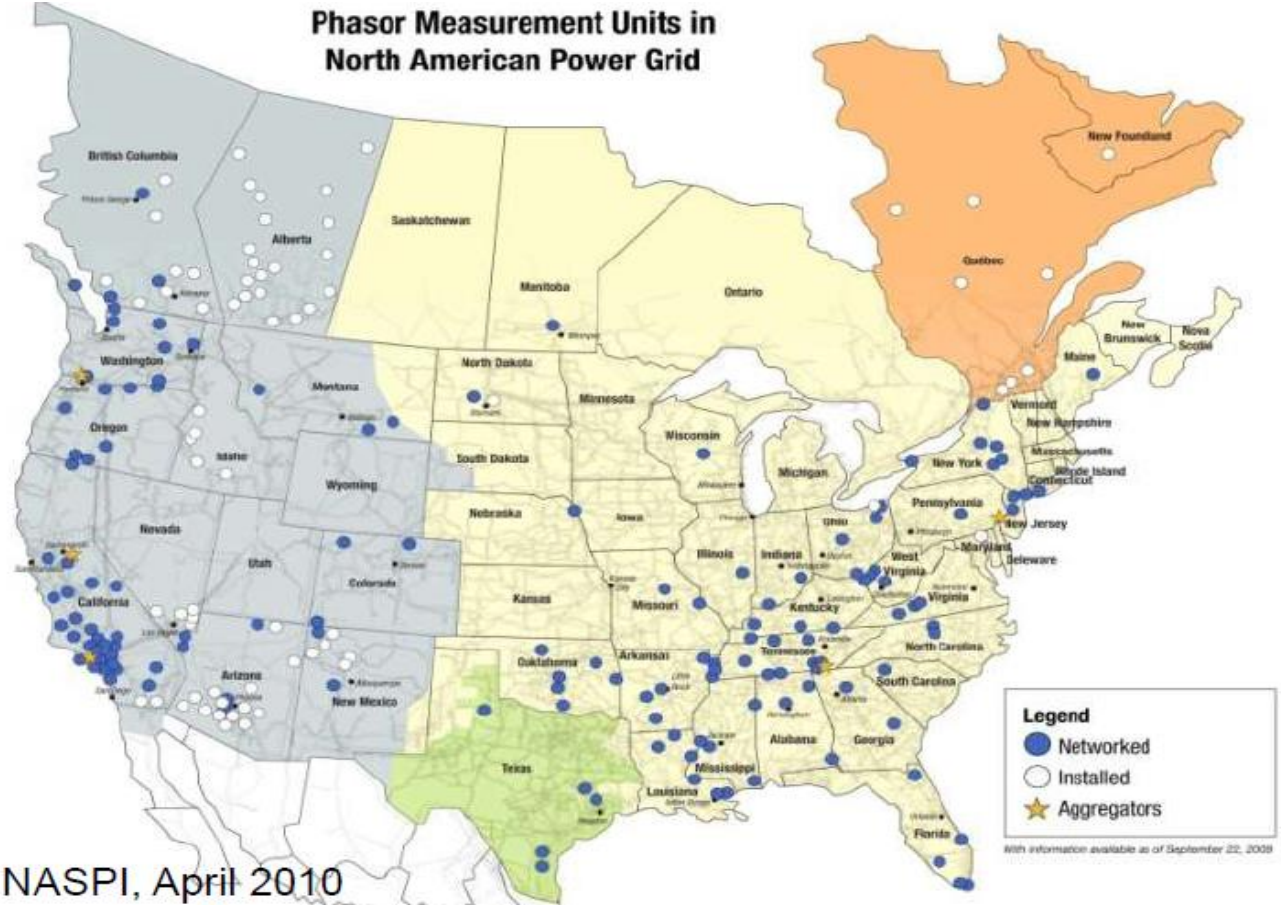


WAPOD Field Tests:

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.

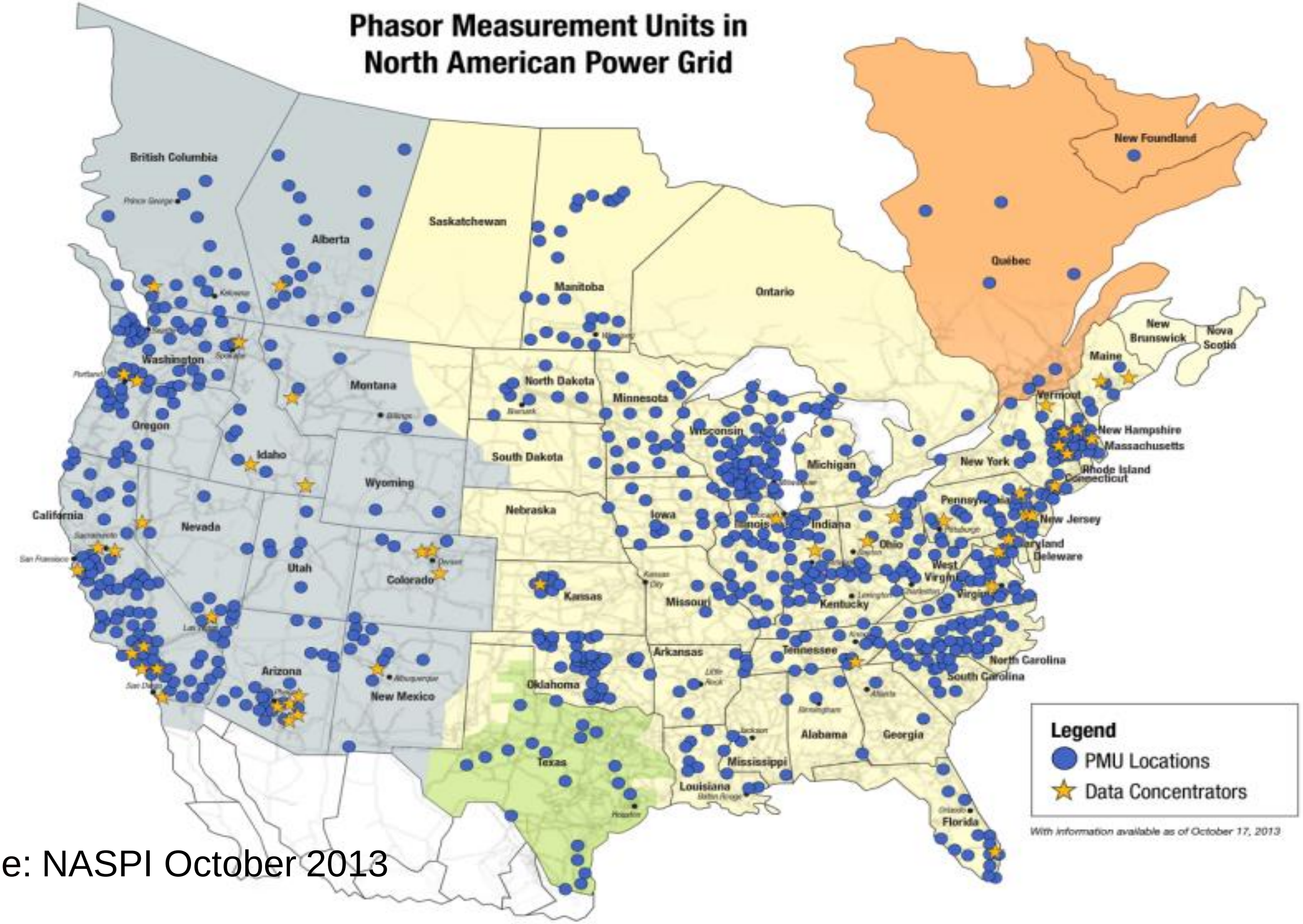
North American Synchrophasor Initiative



With information available as of September 22, 2009

Source: NASPI, April 2010

North American Synchrophasor Initiative



Source: NASPI October 2013

Western Interconnection Synchrophasor Program

PNM

SDGE connected

A Sempra Energy utility

BC hydro

FOR GENERATIONS

CFE

COMISIÓN FEDERAL DE ELECTRICIDAD

ESTADOS UNIDOS MEXICANOS

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 LA DWP Department of Water & Power

California ISO

Shaping a Renewed Future

PG&E

BONNEVILLE

POWER ADMINISTRATION

ROCKY MOUNTAIN POWER

aeso

ALBERTA ELECTRIC SYSTEM OPERATOR

aps

SRP

Delivering More Than Power.

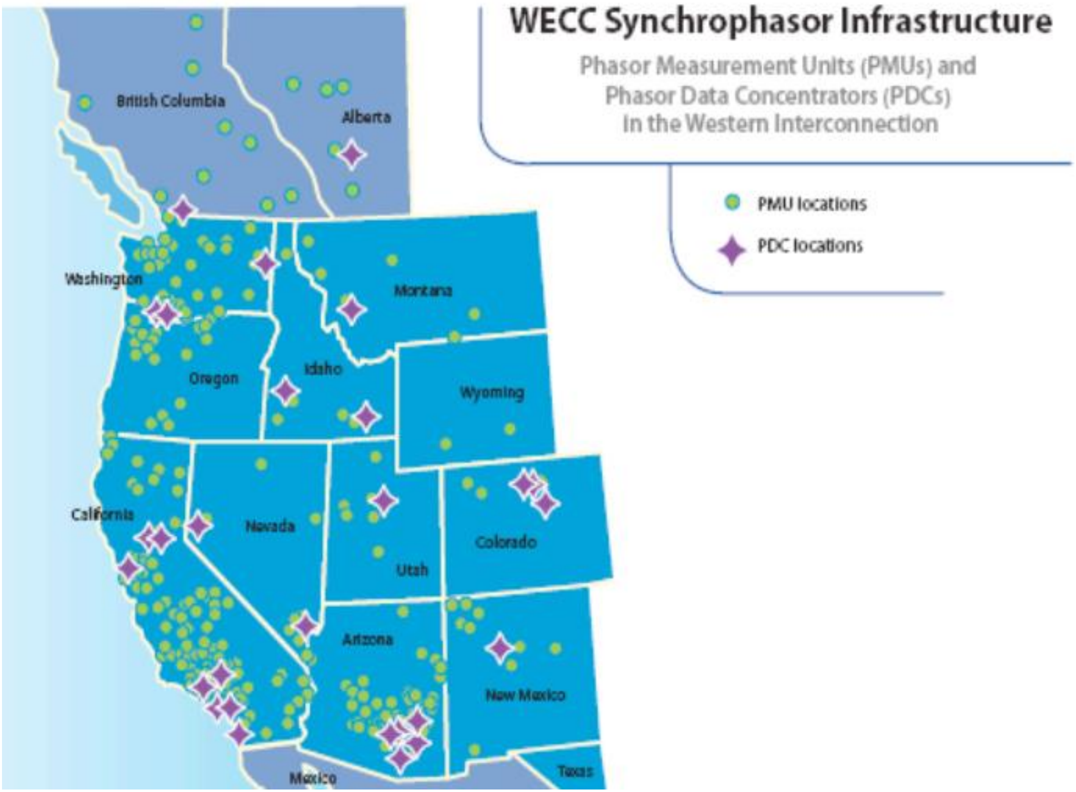
WECC

Western Electricity Coordinating Council

NVEnergy

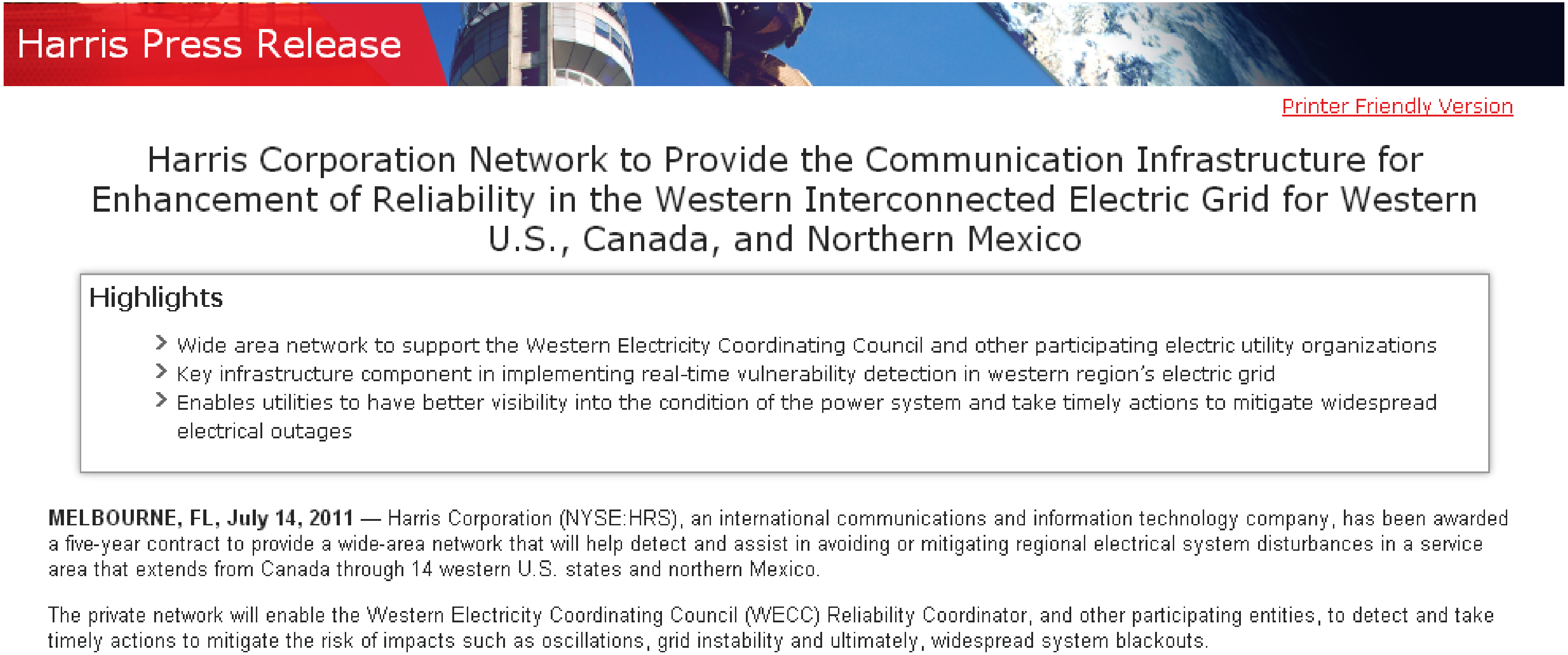
Western Interconnection Synchrophasor Program

- 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 12-13, 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

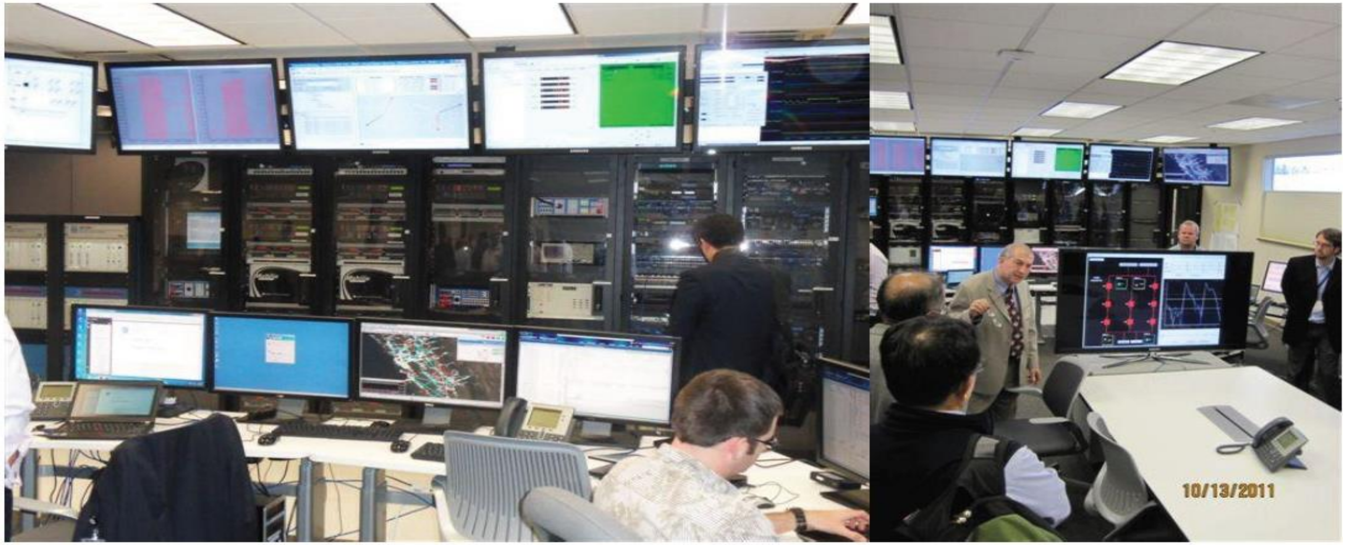
Highlights

- 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.

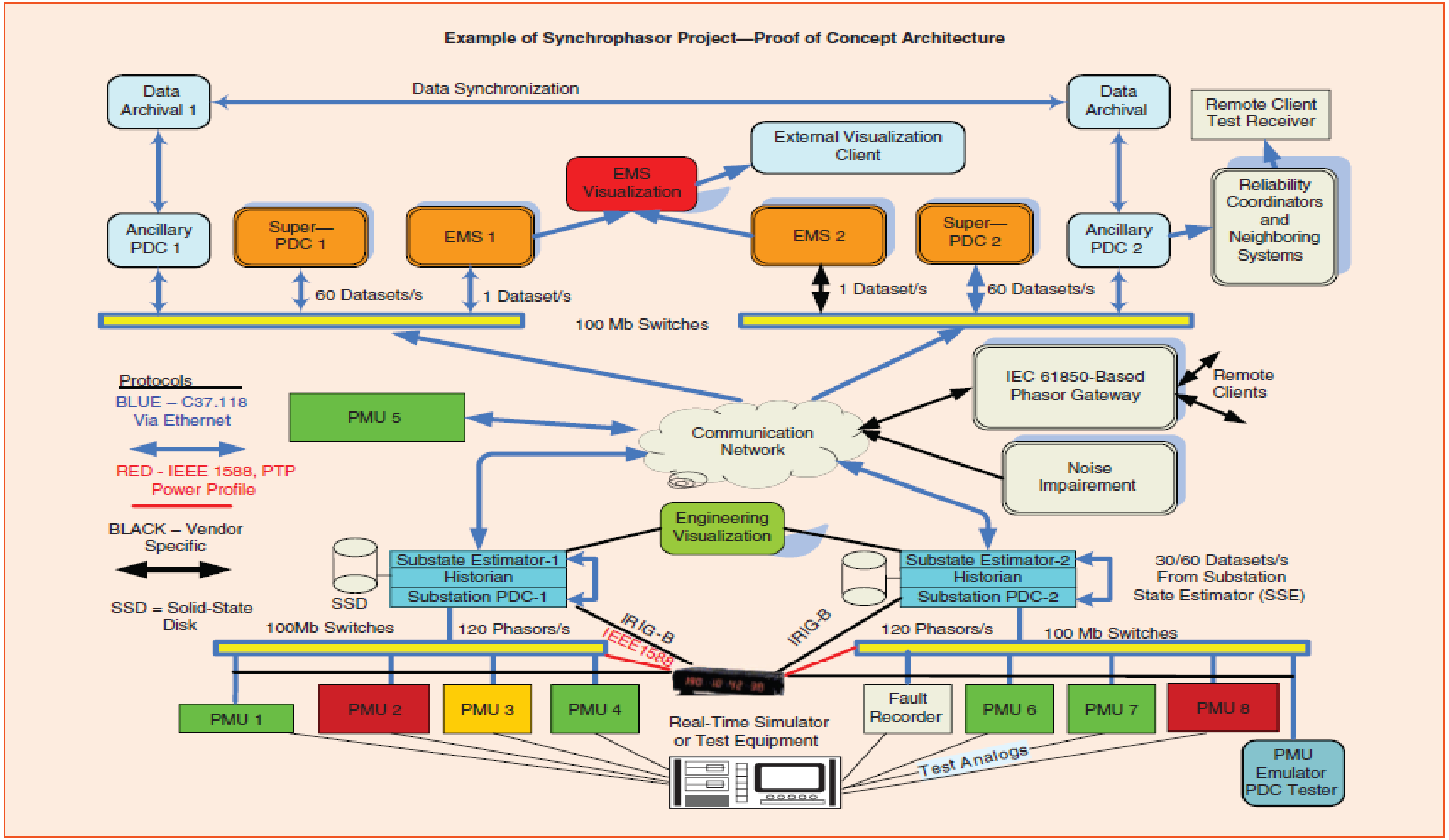
The private network will enable the Western Electricity Coordinating Council (WECC) Reliability Coordinator, and other participating entities, to detect and take timely actions to mitigate the risk of impacts such as oscillations, grid instability and ultimately, widespread system blackouts.

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

Conclusion

- Use of synchrophasor measurements can assist greatly in meeting strenuous reliability and power delivery requirements placed on power systems evolving today
- Synchrophasor measurements could be used for local and wide-area monitoring, control and protective relaying applications
- Active standardization (supported by smart grid developments) enables interoperability and faster adoption of the synchrophasor technology by the power industry

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