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Asst VP Global Product Management

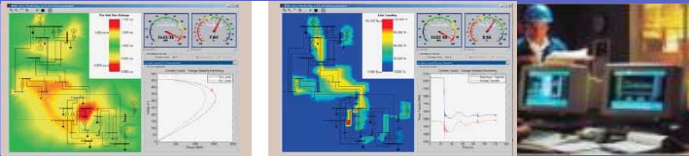
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Acknowledgement: A. Leirbukt, R. Nuqui, M. Larsson, P. Korba



## ABB WAMS Capabilities



North American SynchroPhasor Initiative  
June 10-12, 2008 | Bellevue-Seattle, Washington



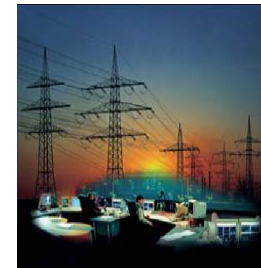
# Outline

- **ABB WAMS Portfolio**
  - PMU: ABB RES 521
  - PDC: PCU400
  - System: NM WAM
  - PMU-Assisted State Estimation
- **WAMS Pilot at Norwegian TSO**
  - Collaboration Description
  - Power Oscillation Monitoring
  - Small Signal Stability Event

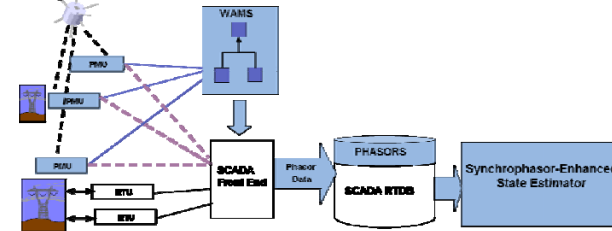
RES 521



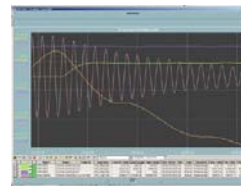
WAMS in NM



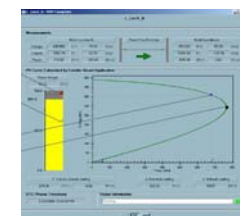
Synchrophasor Enhanced State Estimator



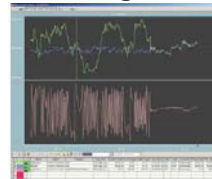
Oscillations Monitoring



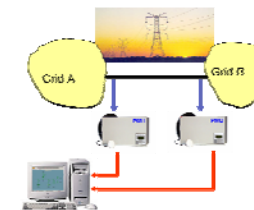
Corridor Voltage Stability Monitoring



Phase Angle Monitoring



Line Thermal Monitoring



# Where is WAMS Positioned?

Many Points  
Wide Area

Number of Devices

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

Few Points  
Local Area

Object Protection  
Direct local actions by  
on-line status information

Dynamic

<1 mS

20-1000 mS

> 1 S

Static

# ABB's WAMS Portfolio

## ■ PMU RES 521

- IEEE 1344 and PC37.118 compliant
- Installed base in North America, Europe, Thailand, South Africa, ...

## ■ PSGuard

- Standalone WAMS solution focused on Corridor Applications
- Phasor Data Concentrator (PDC) hosting subset of WAMS Applications

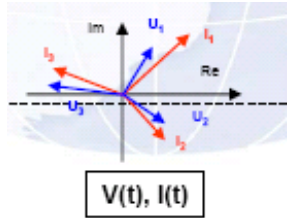
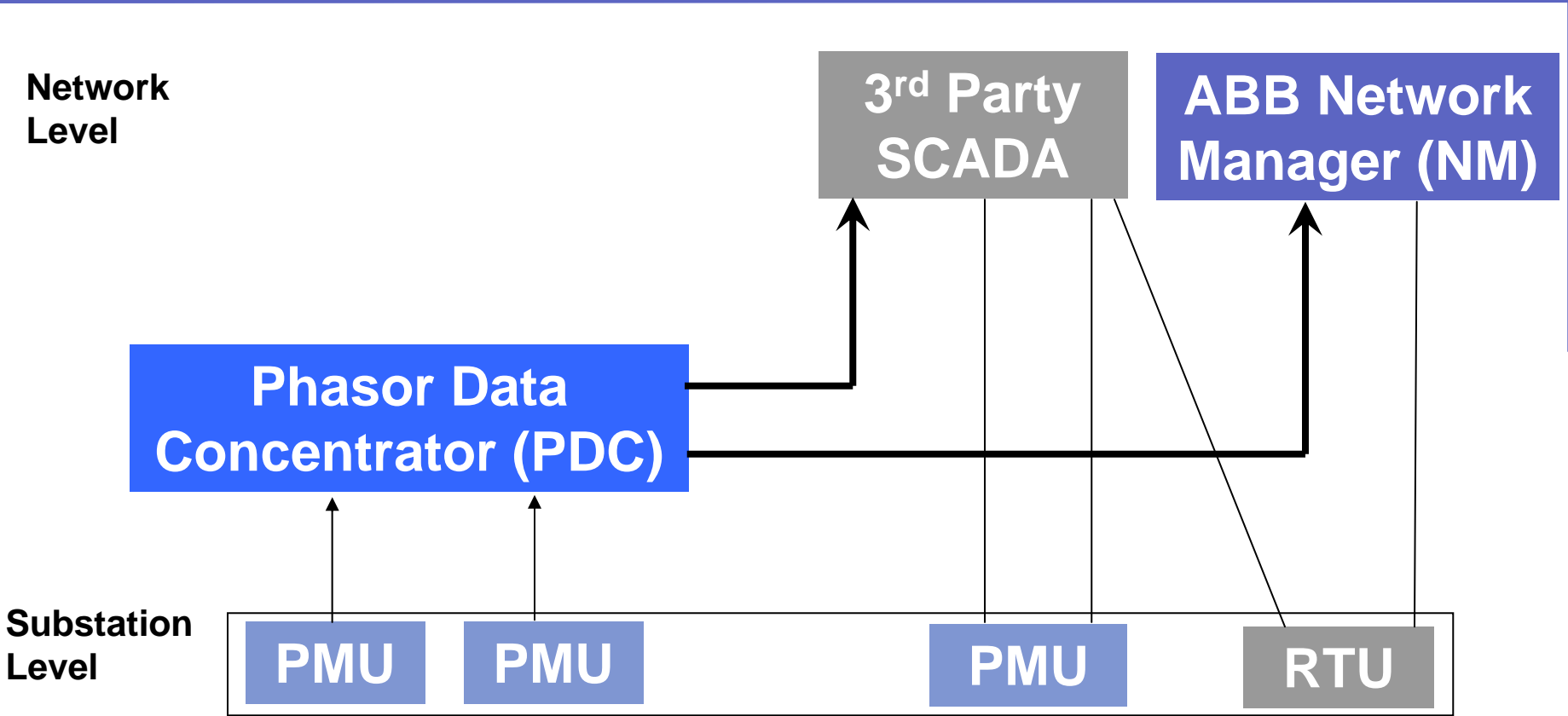
## ■ Network Manager (NM) WAM

- Seamless integration of PMUs and WAMS Applications into ABB Network Manager
- Interfaced with 3rd party software for historic archiving, analysis applications

## ■ WAMS Applications

- PMU-assisted State Estimation (PMUinSE)
- Power oscillations monitoring (POM)
- Phase angle monitoring (PAM)
- Line thermal monitoring (LTM)
- Voltage Stability Monitoring (VSM)
- User defined signal processing

# ABB WAMS Solutions Overview



\* NM is ABB's SCADA/EMS system



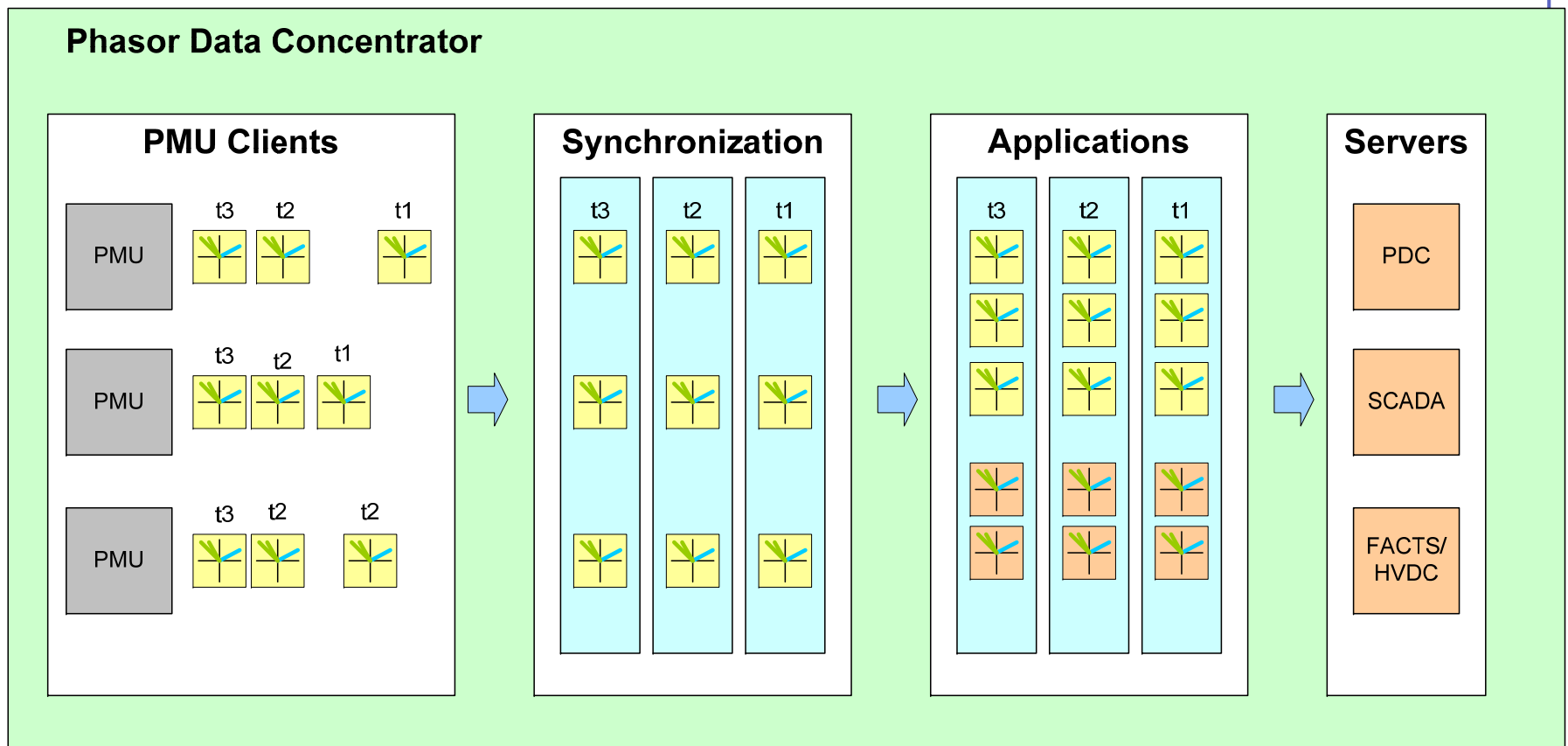
# ABB RES 521 – Phasor Measurement Unit



- Based on Protective Relay technology
- 18 Analog Inputs (4 x 3ph CTs, 2 x 3ph VTs)
- Selectable transfer rates up to 1 phasor/cycle
- Built-in GPS -Synchronized sampling in different substations
- High measurement accuracy when connected to metering CTs
- Accurate frequency measurement  $< 5$  mHz
- Time tagged AC voltage and current phasors with accuracy better than  $1 \mu\text{s}$
- Local functions such as frequency,  $df/dt$
- Trigger functions for:
  - Abnormal frequency
  - Abnormal  $df/dt$
  - Overcurrent
  - Undervoltage
- Supports Synchrophasor data format (IEEE 1344, IEEE PC37.118)

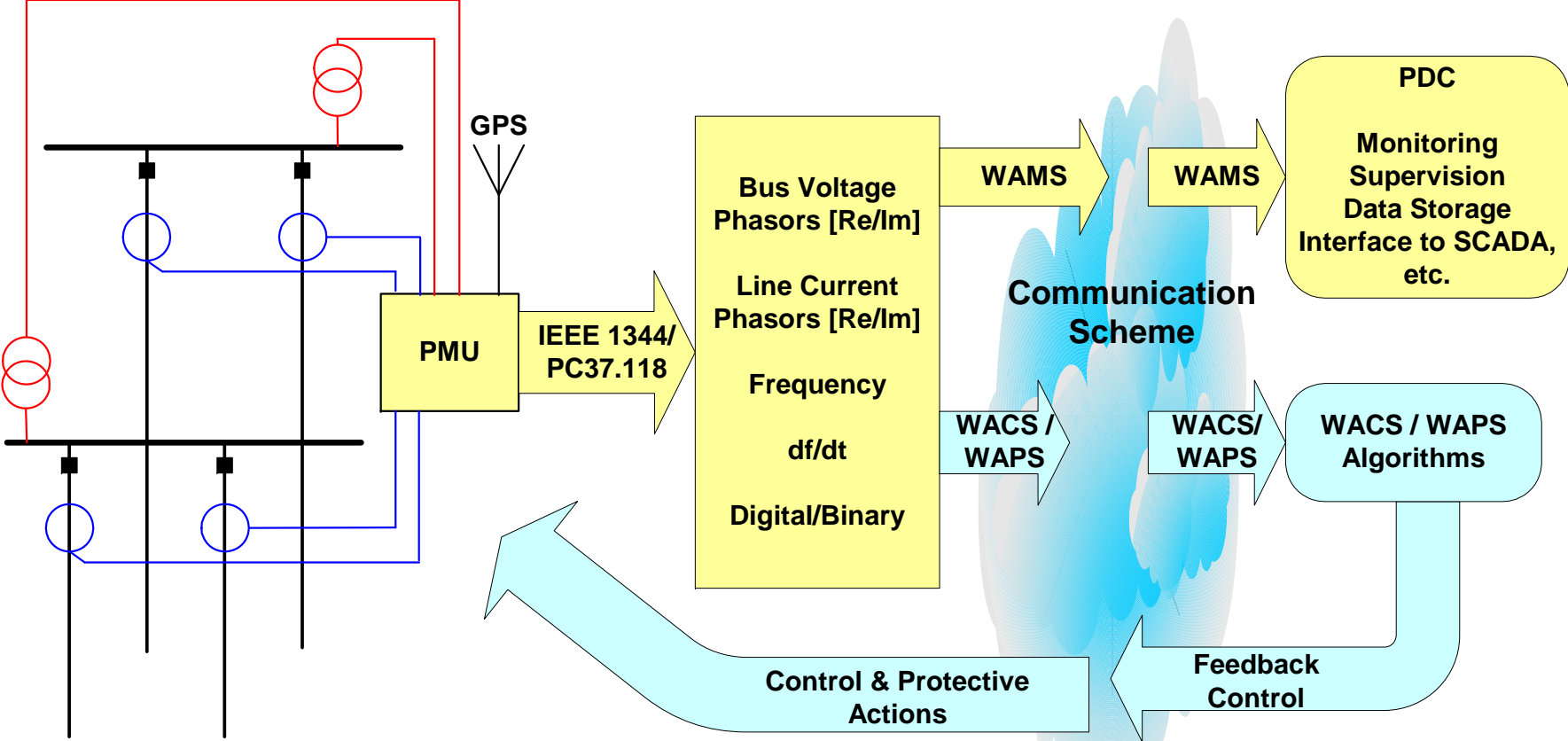
# ABB PCU400 Phasor Data Concentrator

- PCU400 module handles PMU protocol, synchronization and WAMS applications
- PCU 400 is an Enhanced SCADA Front End → interacts with RTUs and PMUs



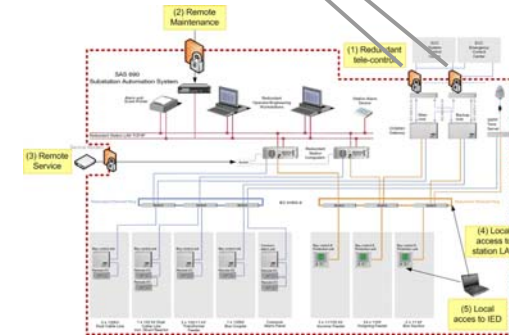
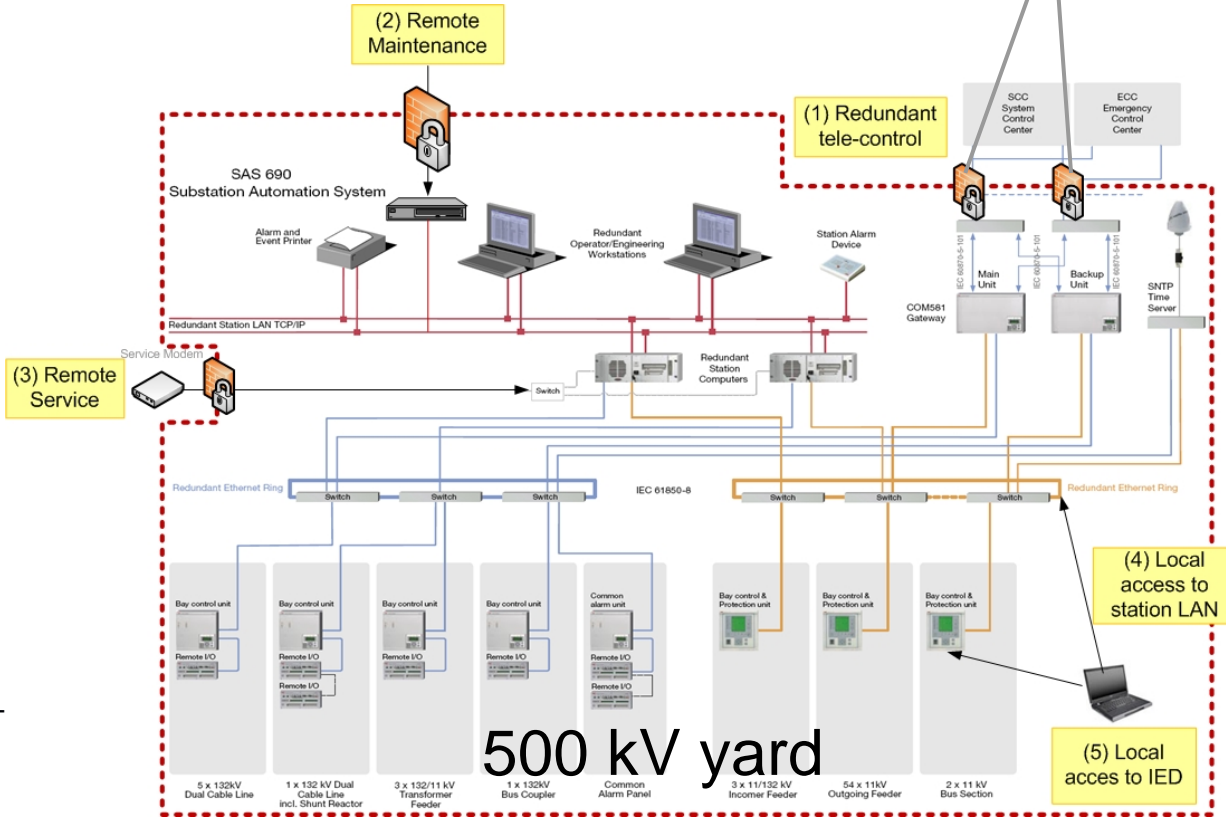
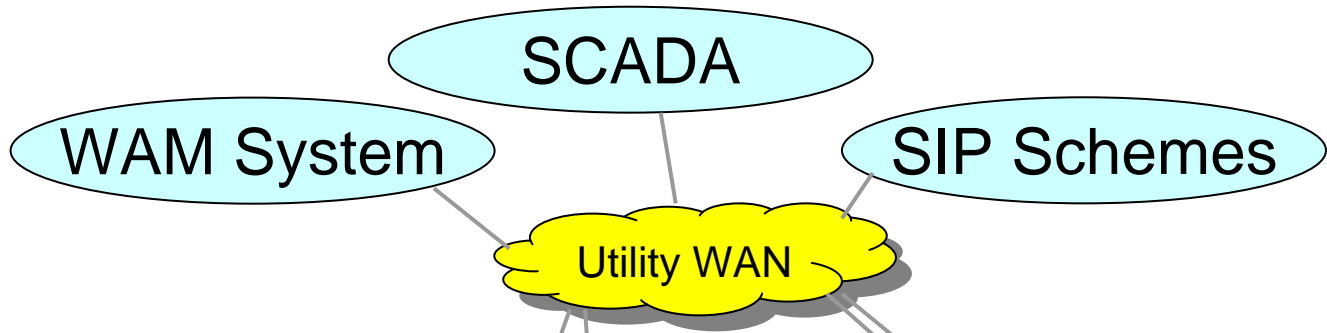
# Phasor Measurement System Architecture

Example: High Voltage Substation double line / double busbar





# Challenge: Security for Ethernet based Systems



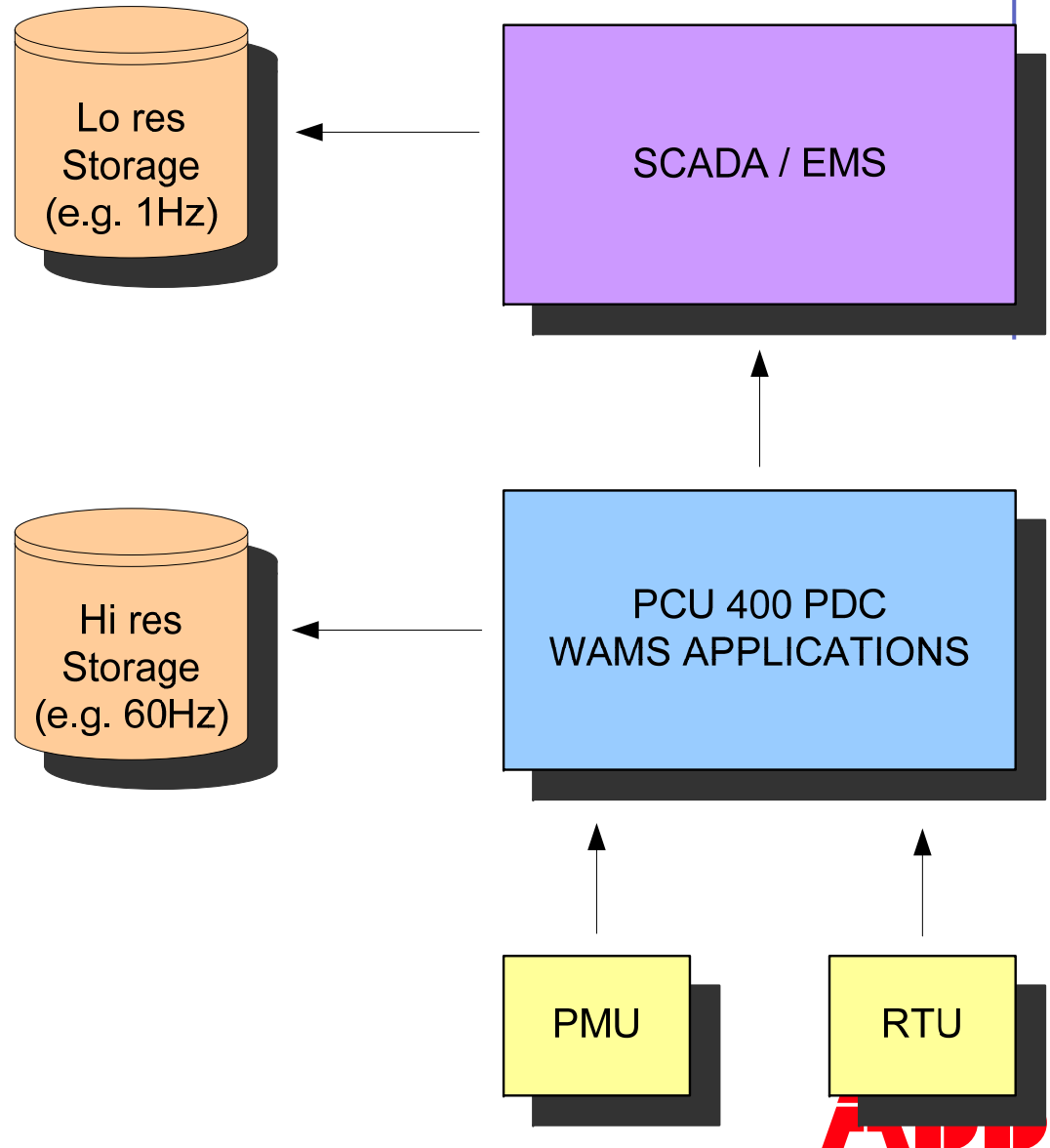
69 kV yard

**Electronic Security Perimeter**

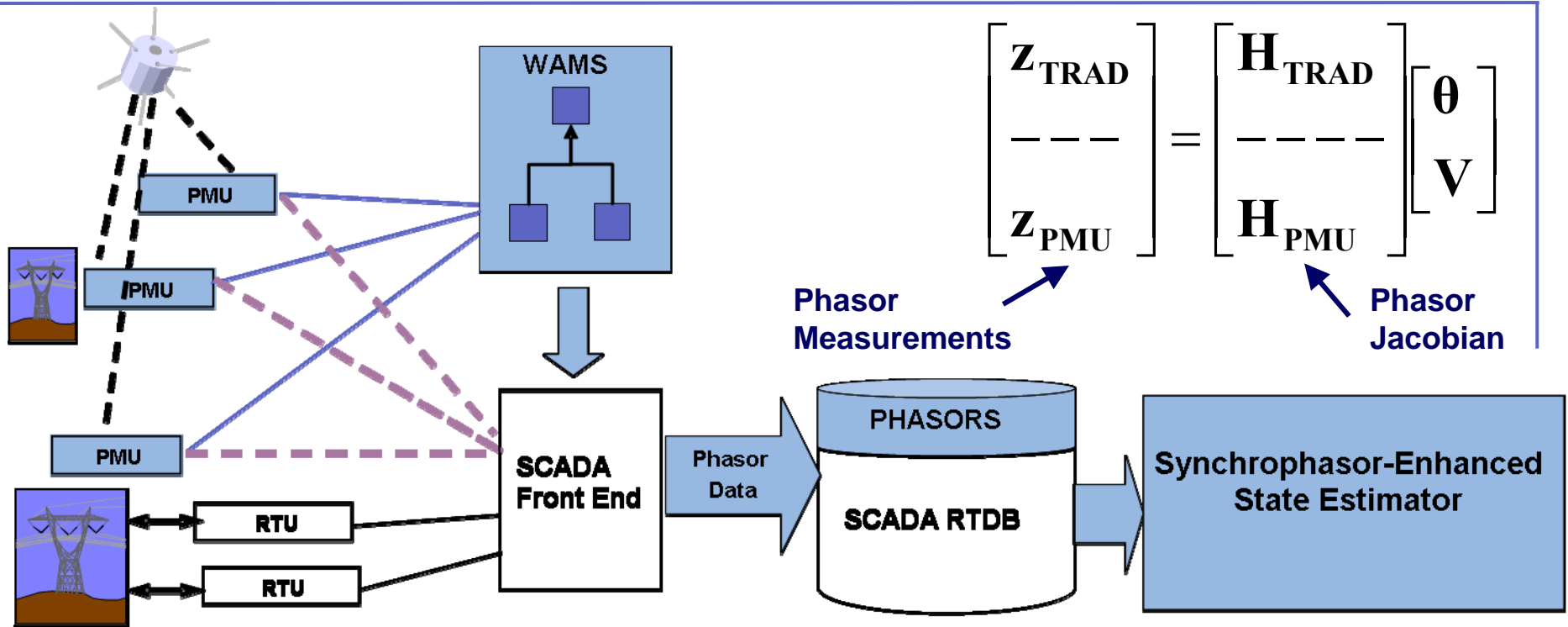


# ABB NM WAM – Alarms, Events and Archiving

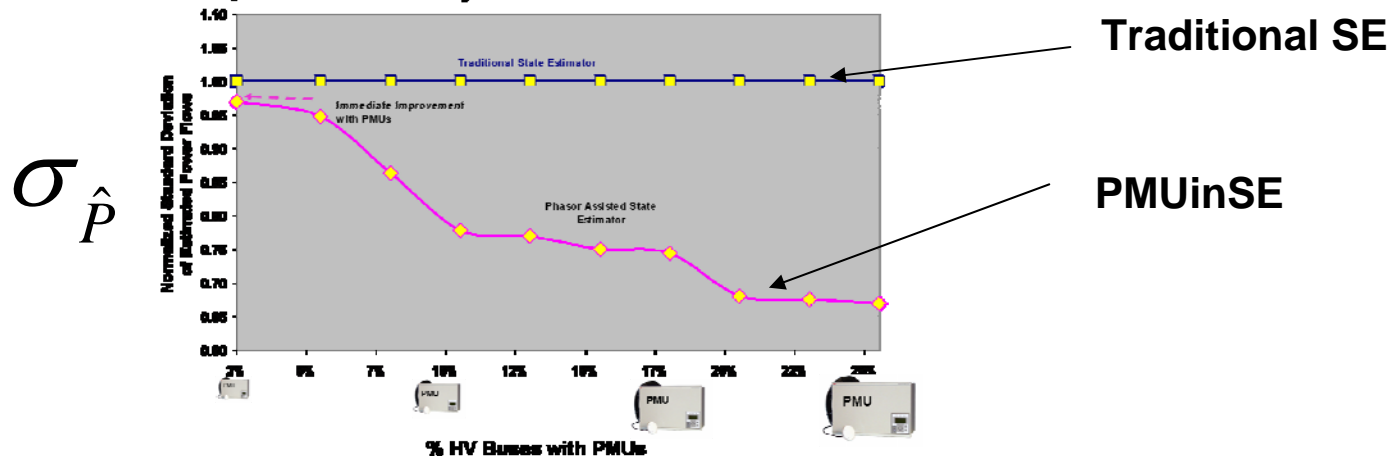
- All WAMS alarms and events in SCADA
- UDW (Utility Data Warehouse) or PI-Historian used for historic archive purpose
- Interconnections of PDCs employed as PMU penetration increase



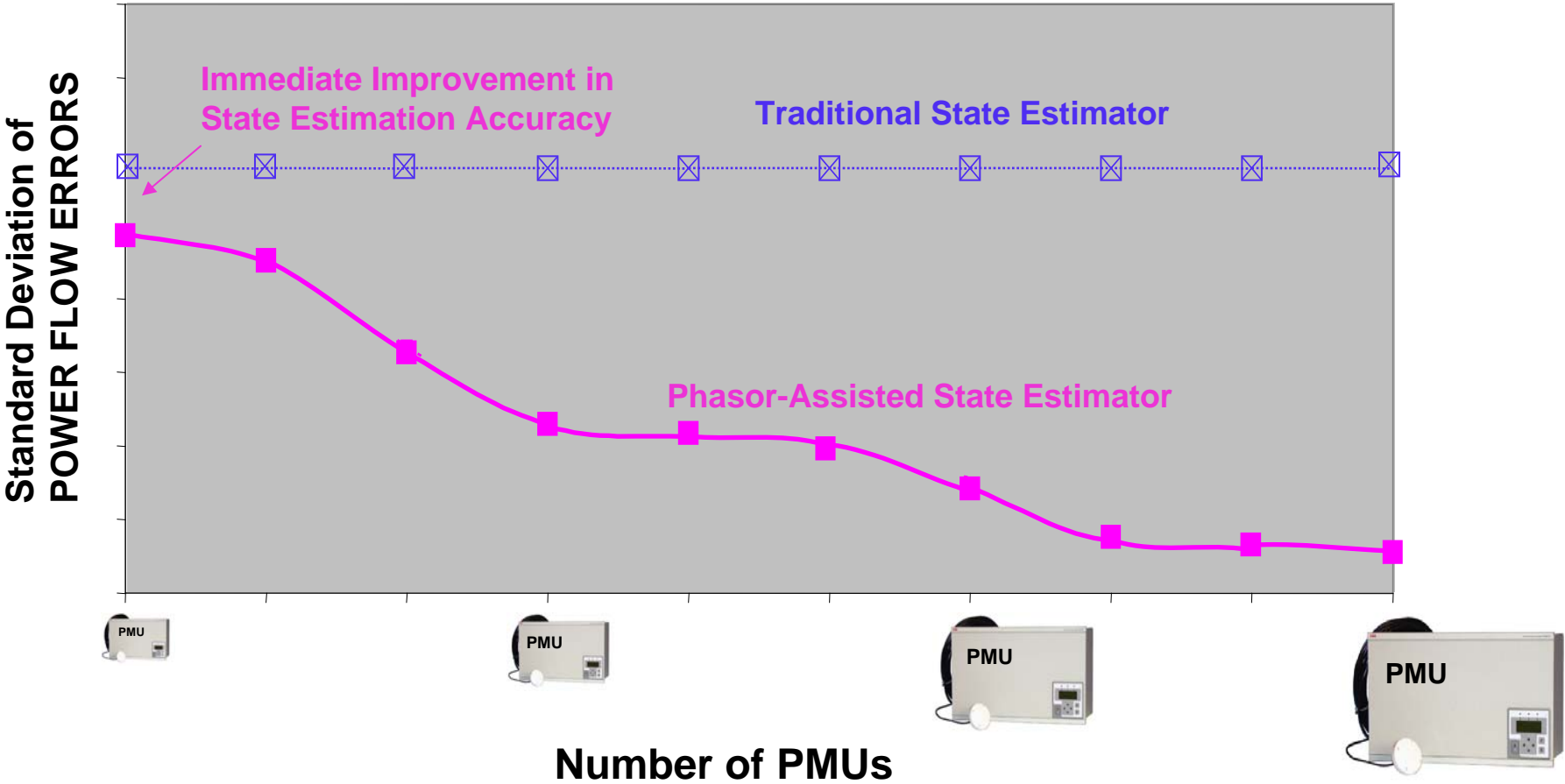
# Synchrophasor Enhanced State Estimator (PMUinSE)



Improved Accuracy in State Estimation



# Impact of PMUs in State Estimation



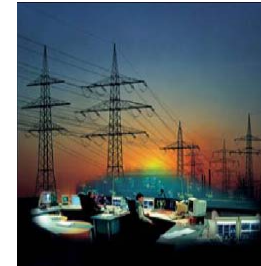
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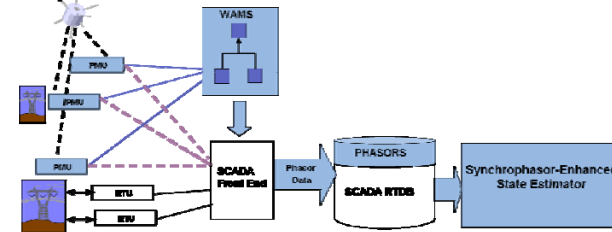
RES 521



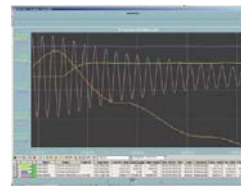
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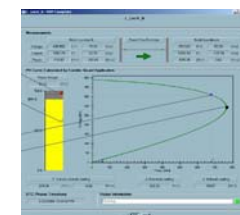
Synchrophasor Enhanced State Estimator



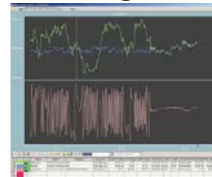
Oscillations Monitoring



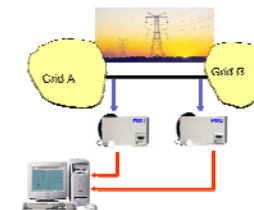
Corridor Voltage Stability Monitoring



Phase Angle Monitoring

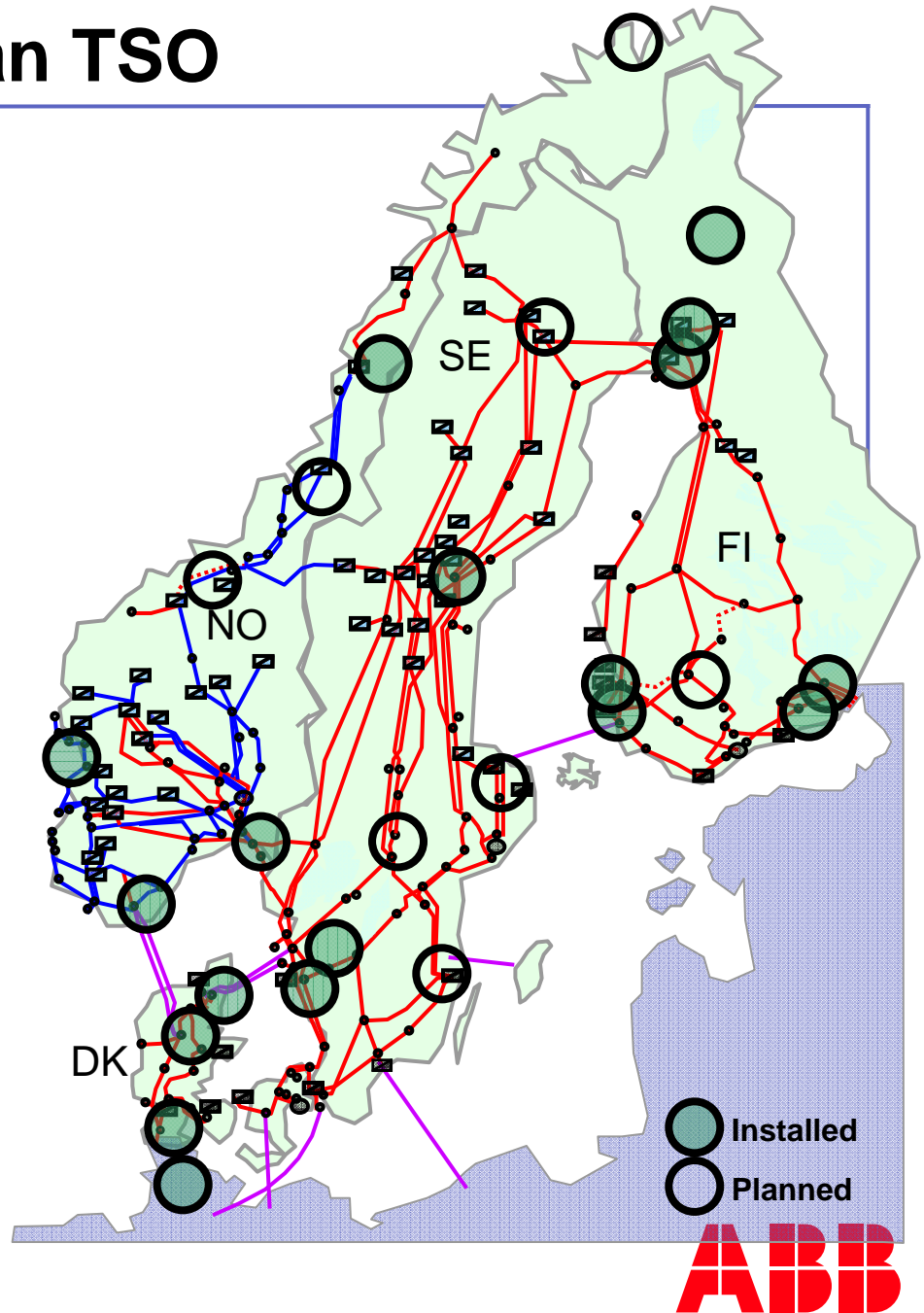


Line Thermal Monitoring

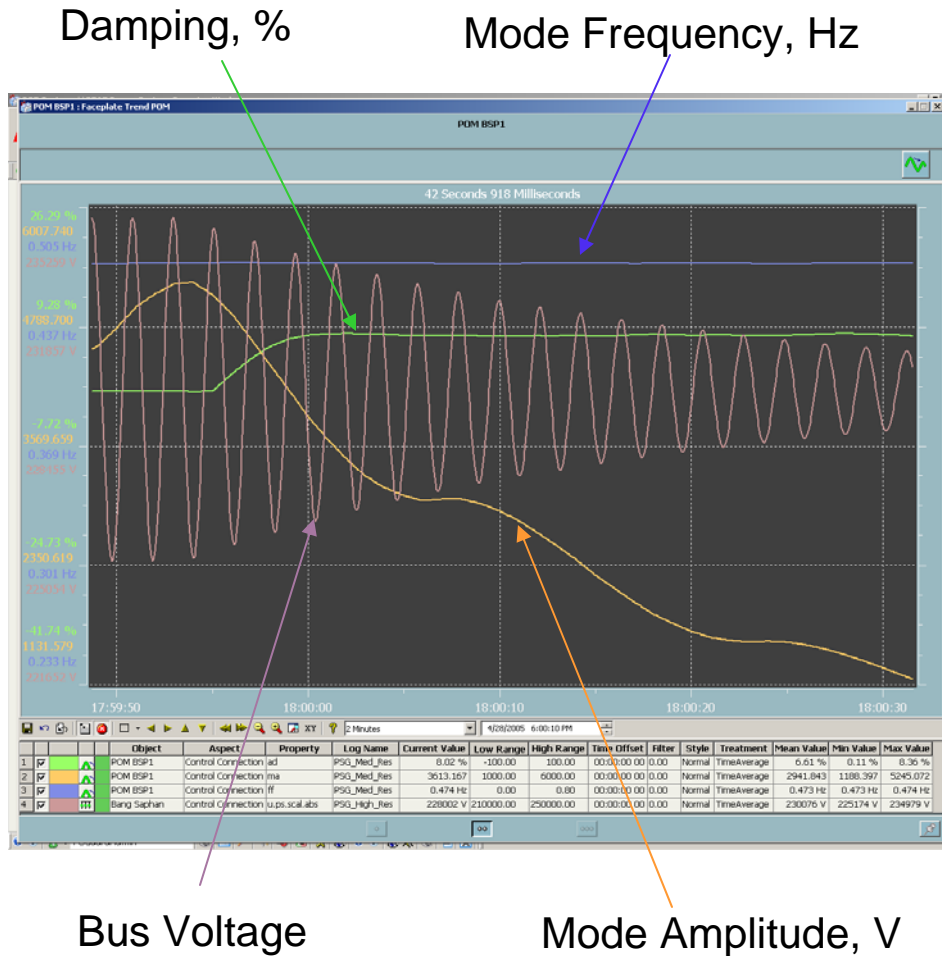


# WAMS Pilot at Norwegian TSO

- Statnett (TSO) owns and operates 220-420kV bulk transmission grid in Norway
- ABB, TSO and Sintef in WAMS R&D Collaboration since 2000
- *Key issue: small-signal stability transfer limits*
- WAMS in Norway
  - 4 PMUs
  - PDC Pilot with POM application
  - Real time WAMS data exchange with Finland PDC
- WAMS in Nordel (DK, FI, NO, SE)
  - 20 PMUs
  - 3 PDCs
  - Data streaming between PDCs
  - IEEE 1344-1995 and IEEE PC37.118 protocols in use



# Power Oscillations Monitoring (POM)



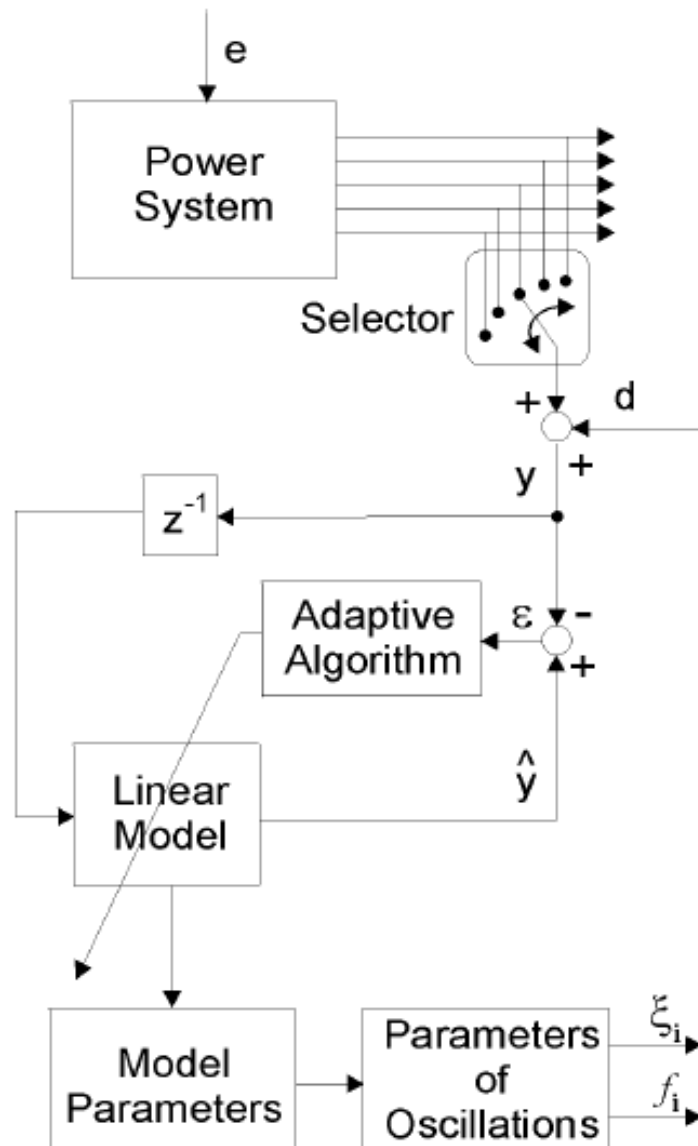
## Principle:

- Real-time detection of power swings
- For the dominant swing mode, POM identifies:
  - amplitude
  - frequency
  - damping
- Algorithm is fed with select voltage and current phasors

## Field Experience:

- POM running in PDC since 2007
- Response time is in order of seconds, sufficient for operator warning
- When power oscillations are present the input signals are persistently exciting
- Small signal stability event  
Aug 14 2007

# POM Algorithm – More Detail

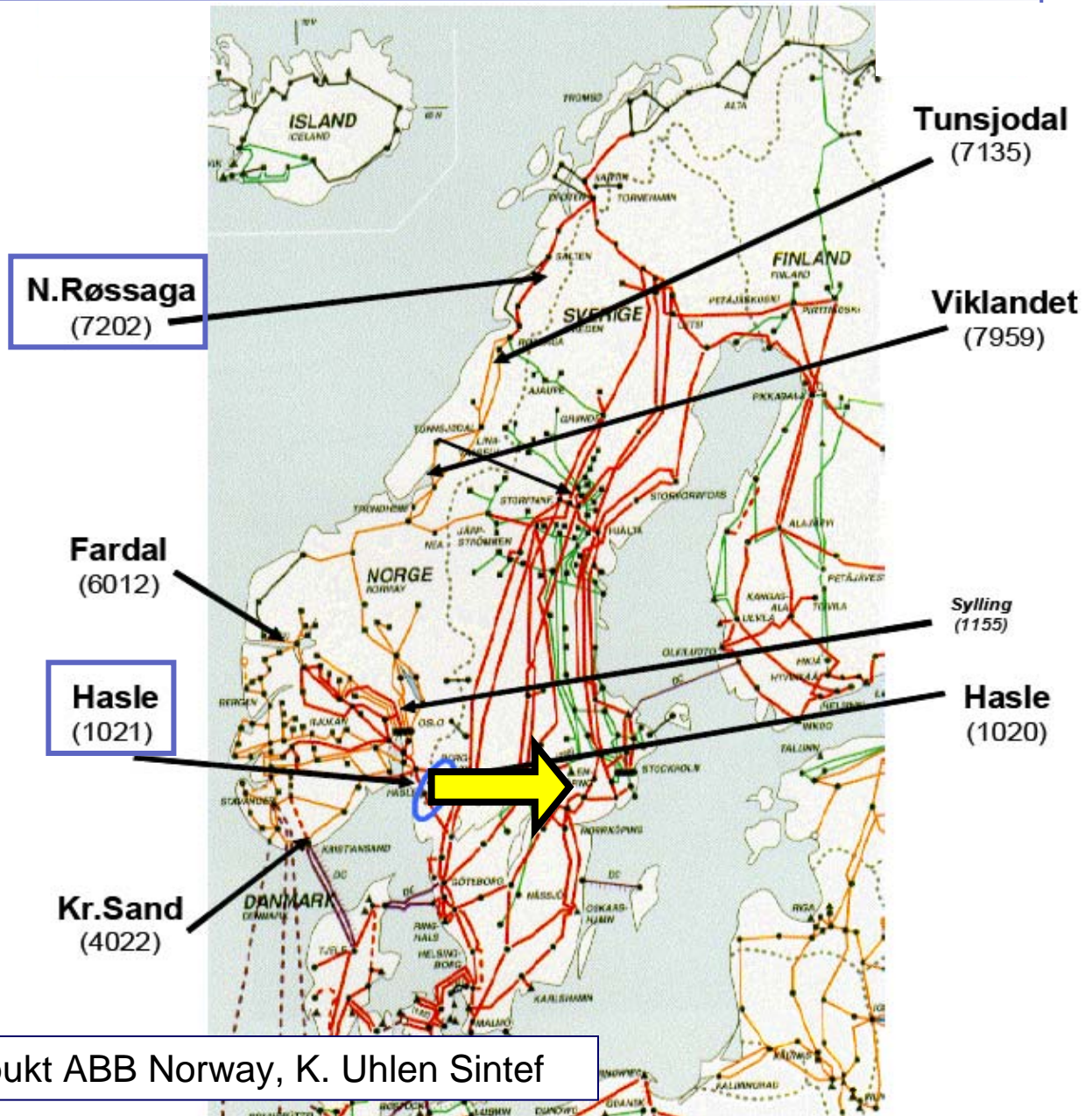


- Autoregressive model: Fix the model order, but model parameters are to be estimated
- Kalman Filtering is used to estimate the parameters of the model
- Calculate the describing parameters (frequency, damping ratio) of the dominant swing mode



# August 14, 2007 Disturbance – Background

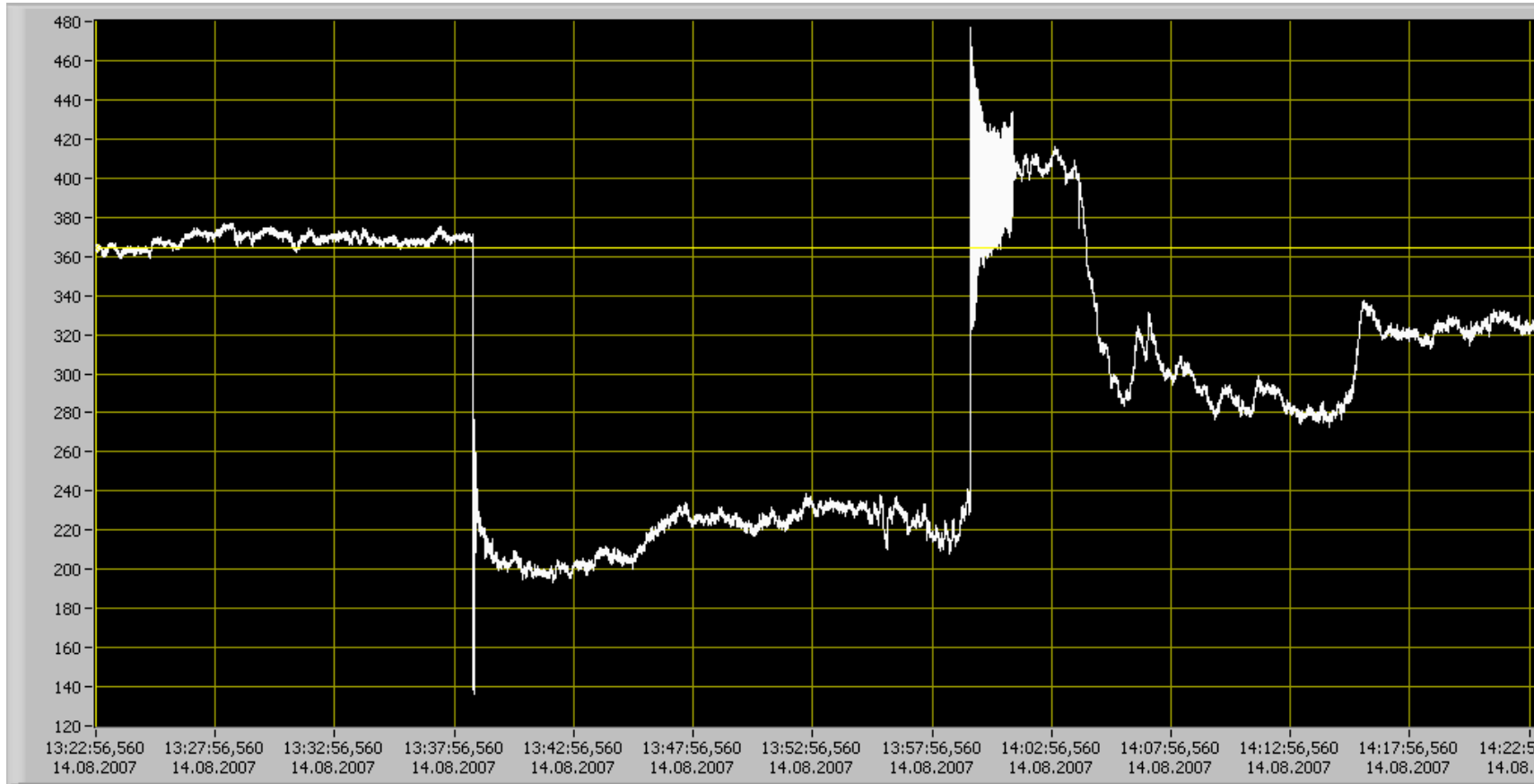
- Light summer load
- High generation from hydro power plants in western and northern parts of Norway
- Event:
  - Event occurred at 14h00
  - Resulting in un-anticipated flow patterns
  - PSS for SVC at N. Rossaga not tuned for this unfamiliar operating point
  - SVC helped sustain the oscillation



# August 14, 2007 Disturbance – SCADA

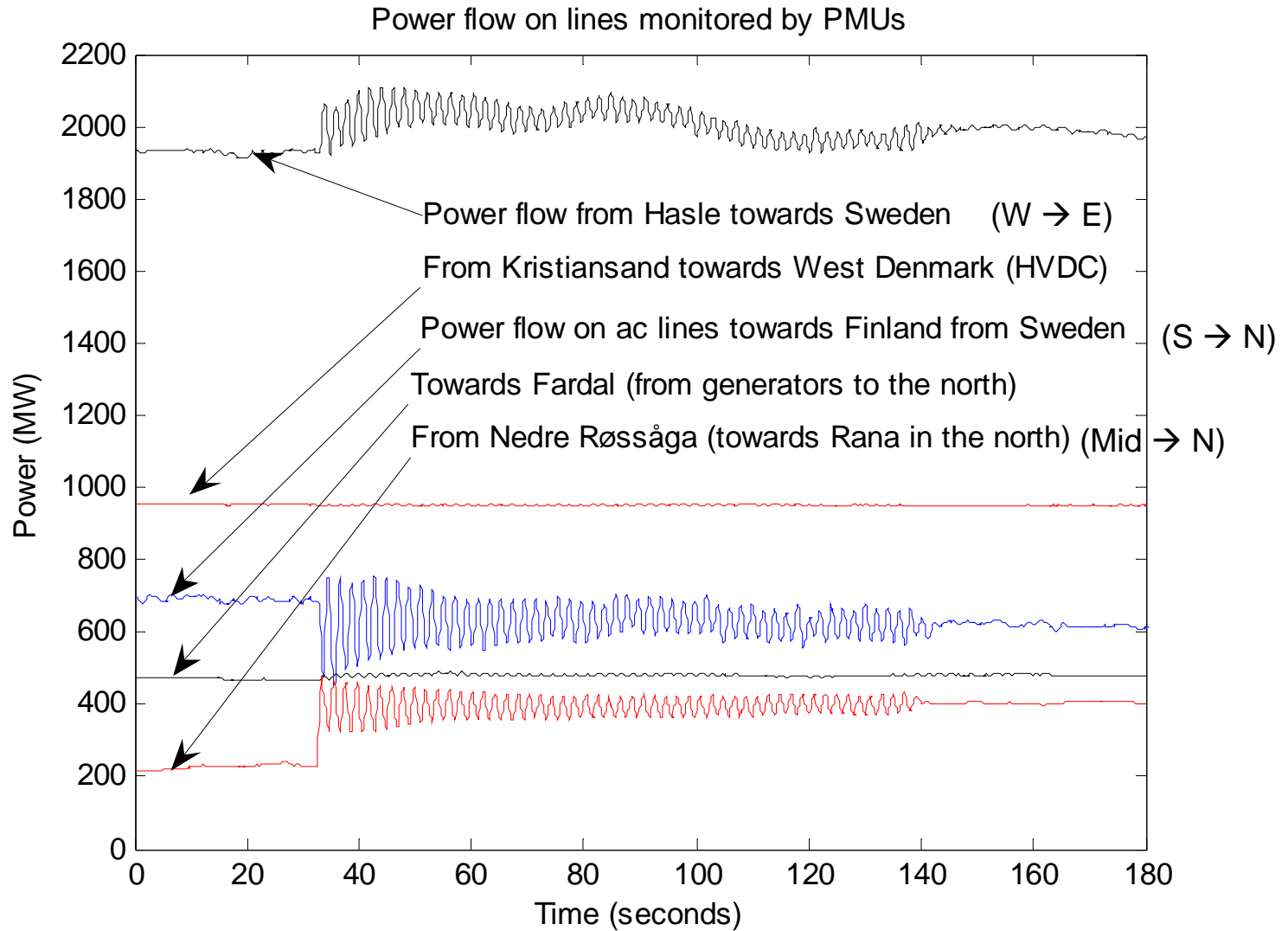
## Power flow between Røssoga & Rana

3 min.  
↔

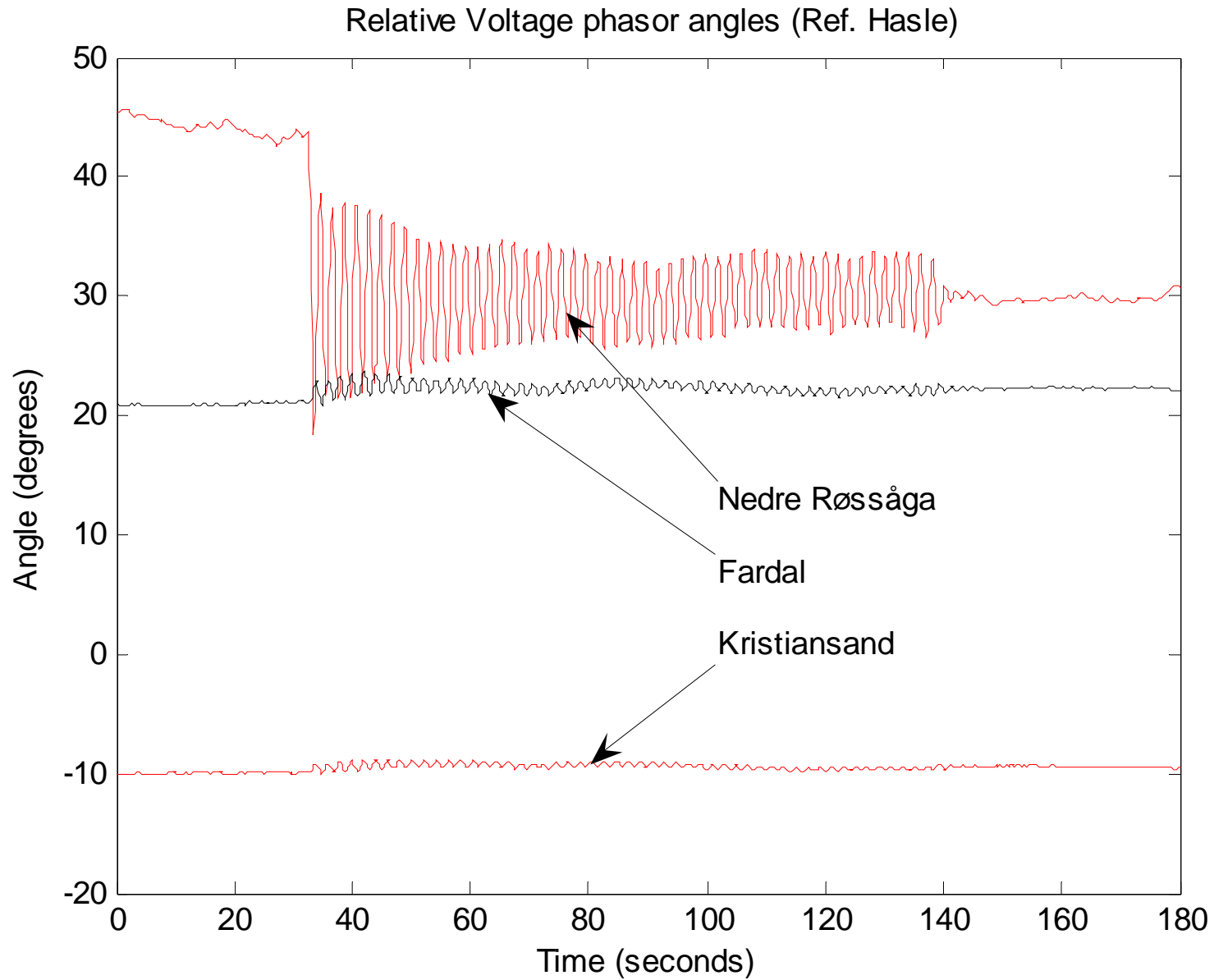


↔ 1 hour

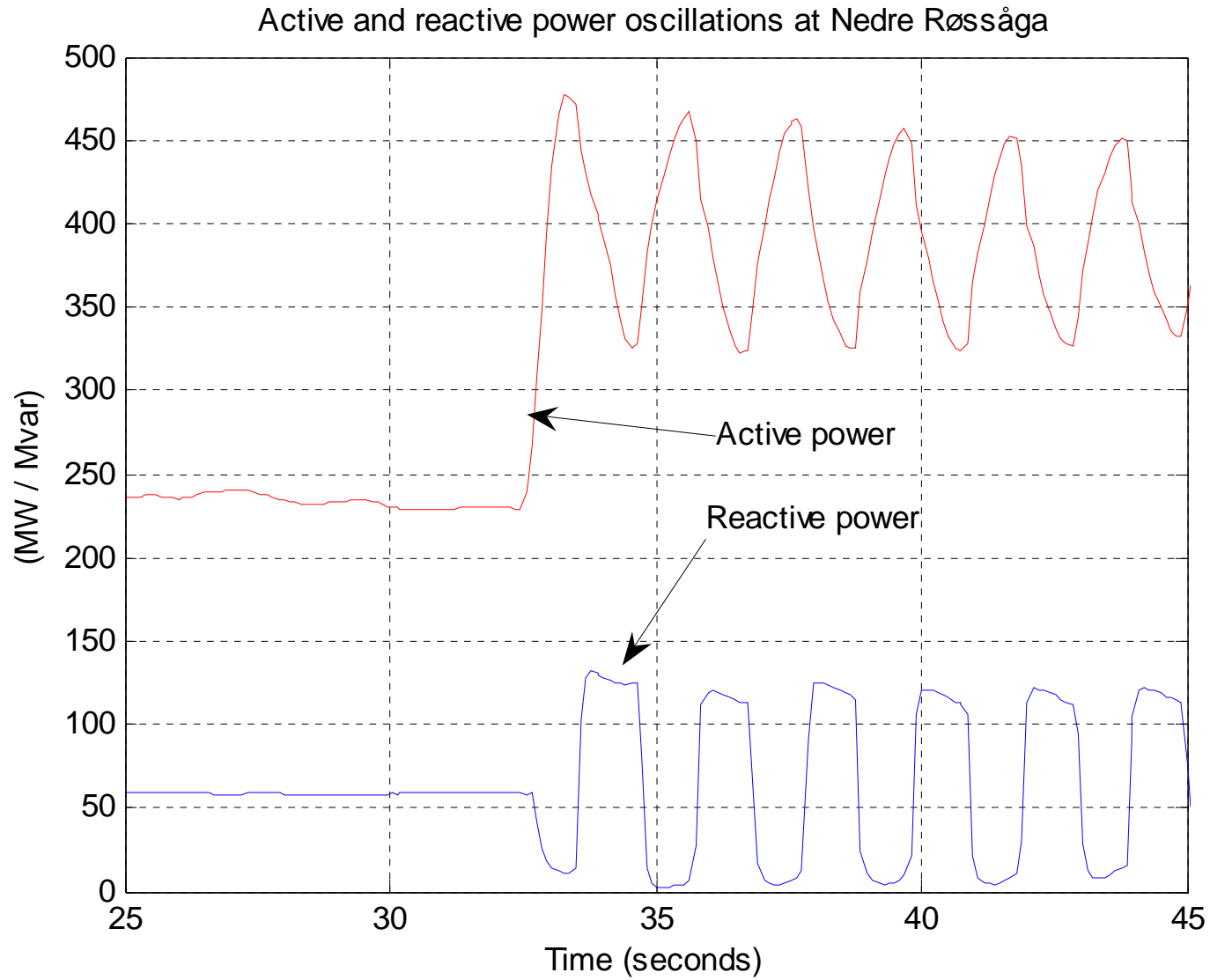
# Power Flow on Main Transmission Lines



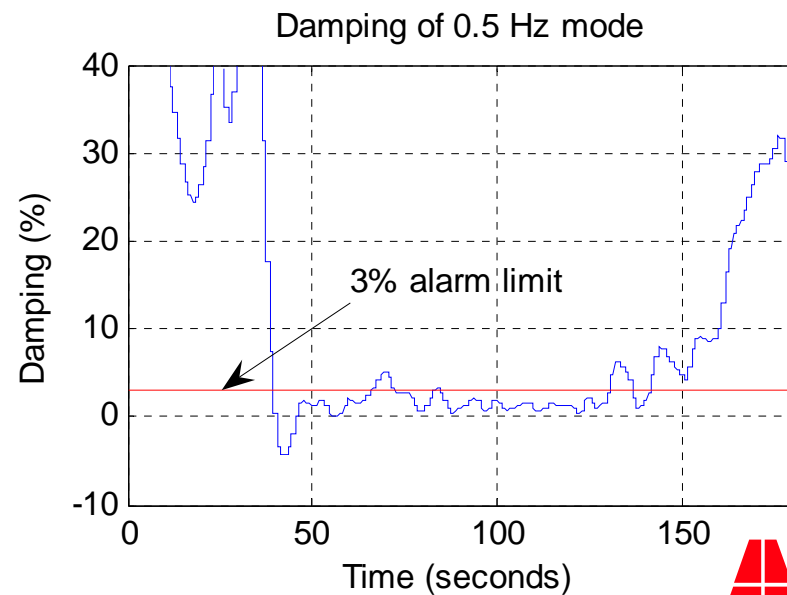
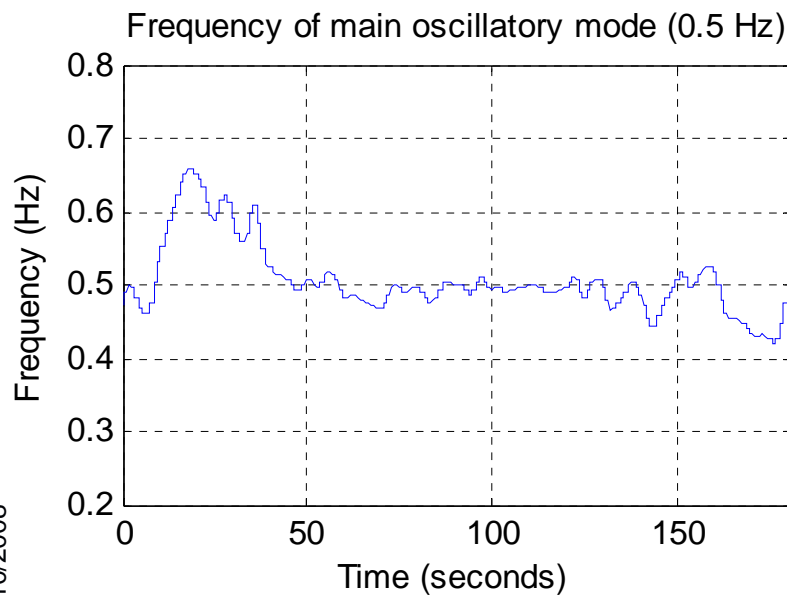
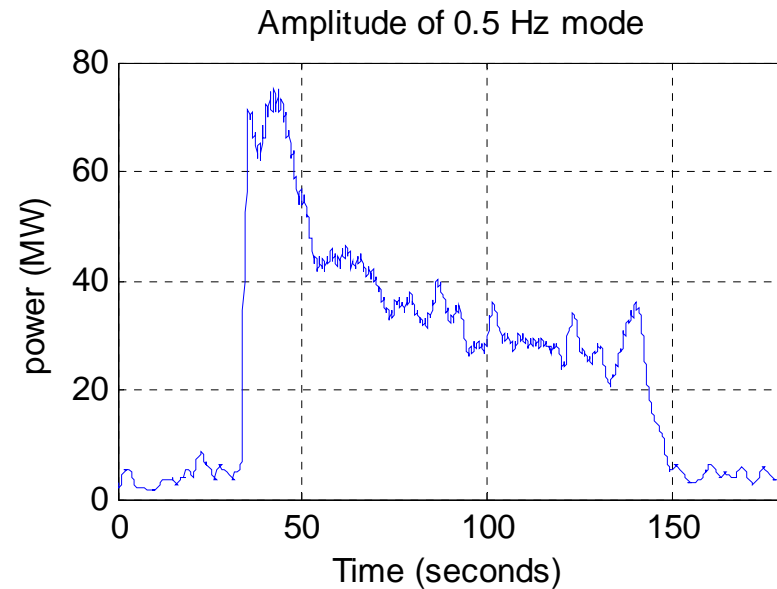
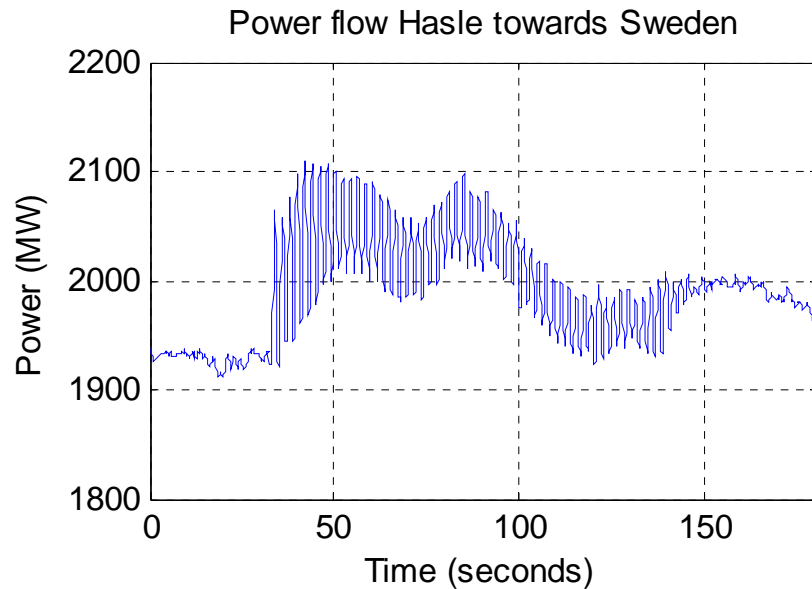
# PMU-monitored Voltage Angles



# Large Power Oscillations Measured



# Power Oscillation Monitoring (POM) Results



# Further Activities

- ABB, Sintef, Statnett to continue Norwegian R&D collaboration
- Projects:
  - Phase 1 (2000–2004): WAMS Infrastructure and Voltage Instability Monitoring
  - Phase 2 (2005–2007): Power Oscillation Monitoring
  - Phase 3 (2008-2010) ...
- Main objectives of Phase 3:
  - Deploy more PMUs
  - Study Wide Area Control for FACTS/HVDC
  - Design and deploy WACS for FACTS/HVDC

***Previous projects and the WAMS infrastructure has given an excellent basis for the next step:***

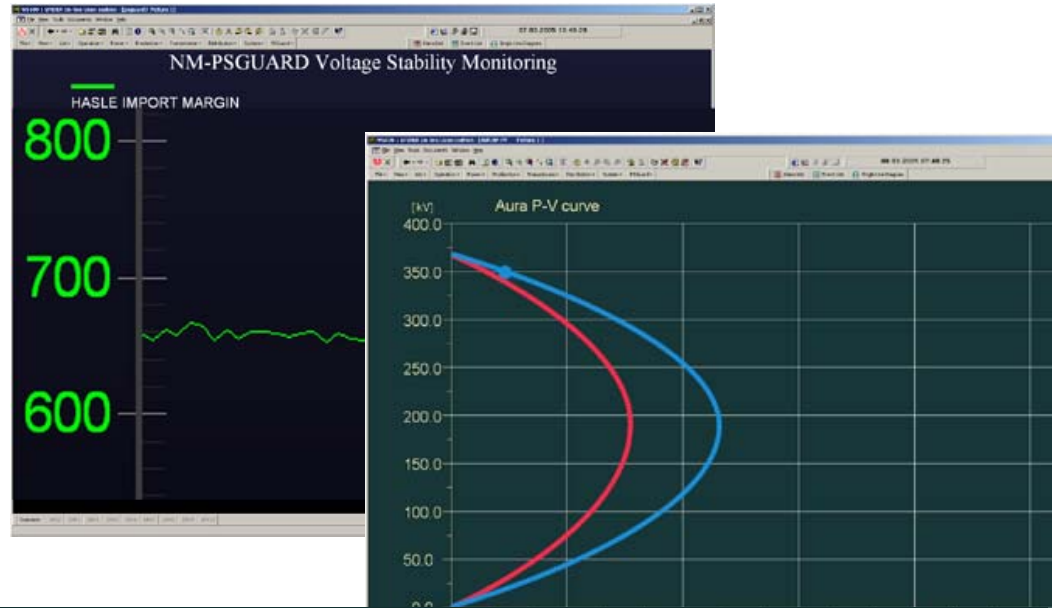
***WIDE AREA CONTROL***

**A A B B**



# WAMS in SCADA/EMS

- Increasing operator's situational awareness

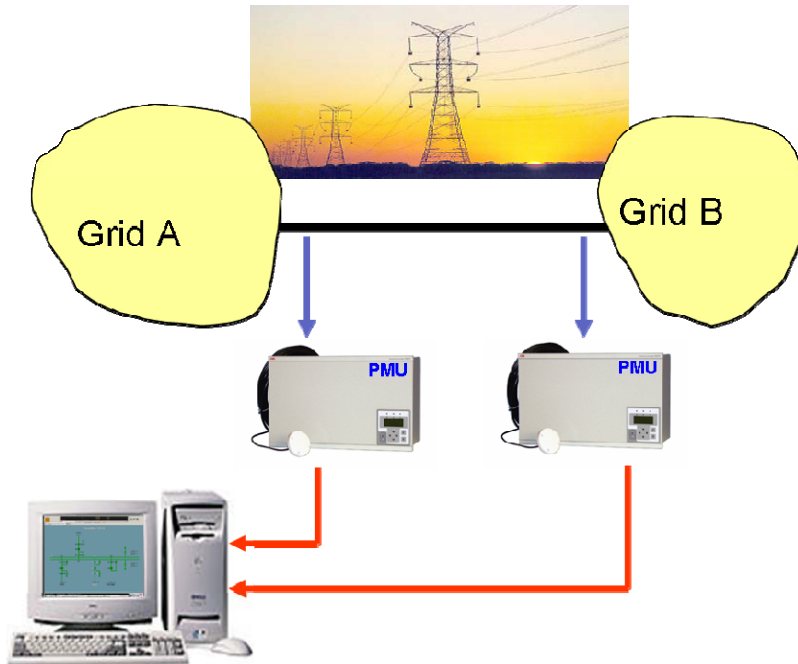


Alarms			Power System		
2005-02-23	17:17:18	Load Flow Calculation	stopped		
	17:27:29	BOWMANG1H_BUS	GEN_VOLTAGE	Into LIM4HI zone	15.94 KV
	17:27:29	COUNTAG1H_BUS	GEN_VOLTAGE	Into LIM4HI zone	15.94 KV
	17:27:29	NAES_G1H_BUS	GEN_VOLTAGE	Into LIM4HI zone	15.94 KV
	17:27:29	MAHISSG1H_BUS	GEN_VOLTAGE	Into LIM4HI zone	15.94 KV
	17:27:29	ICCP_G1H_BUS	GEN_VOLTAGE	Into LIM4HI zone	15.94 KV
	17:27:29	CLARK 220 BAY17	Reactive Power	Into LIM4HI zone	40.00 MVAR
	20:39:21	CERV SUM GEN P		Into LIM4HI zone	960.00 MW
				Into LIM4HI zone	130.00 MVAR
				Into LIM4HI zone	440.00 KV

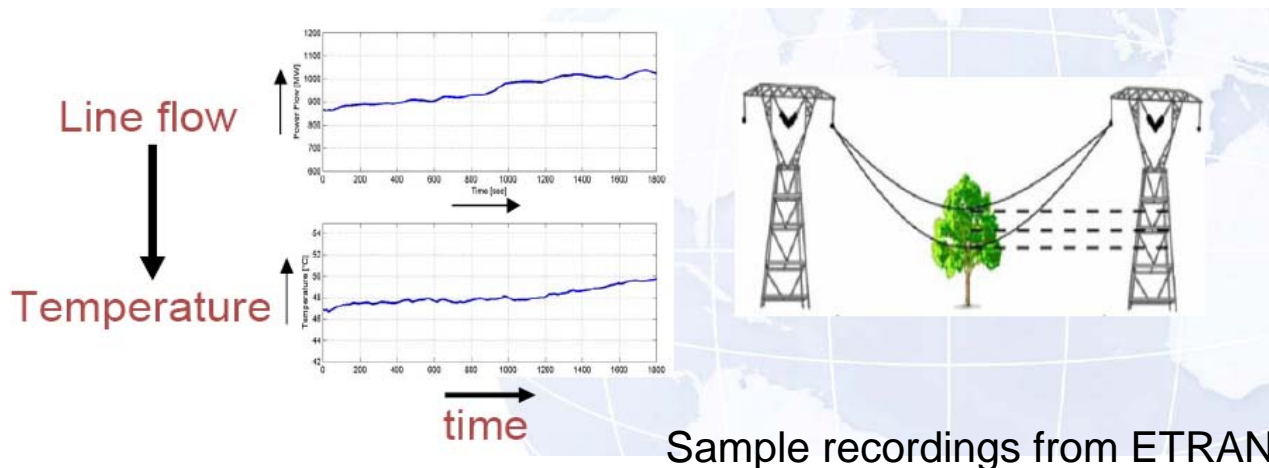
**Wide Area Alarms and Events in Network Manager.**



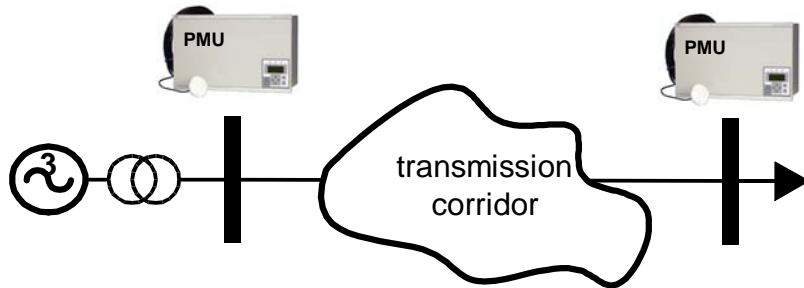
# Line Thermal Monitoring Application



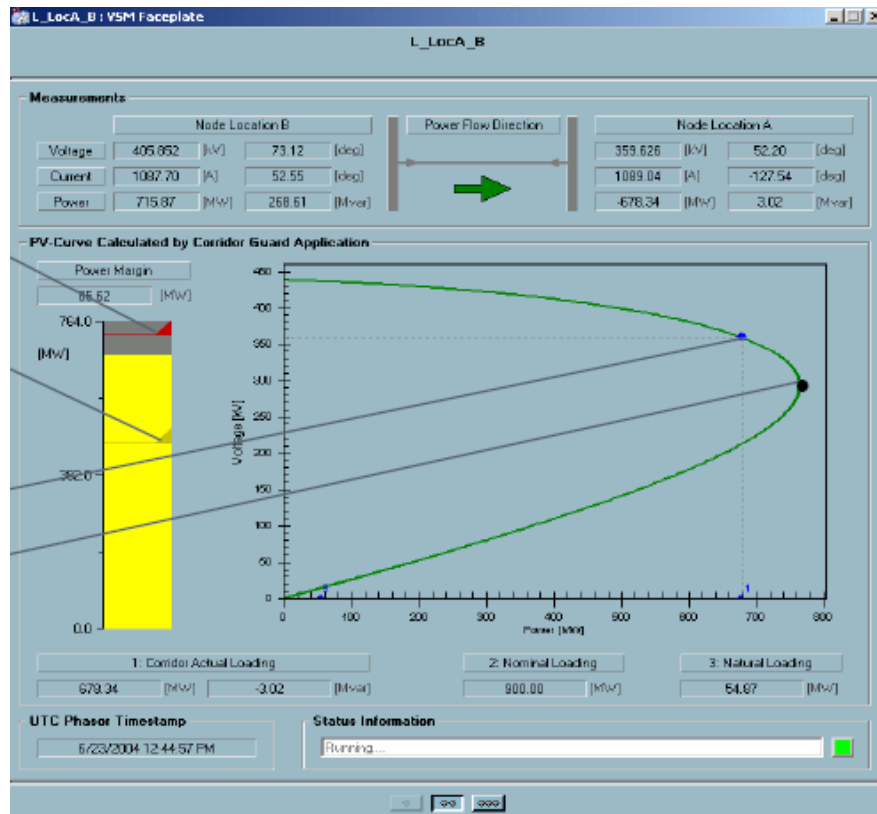
- Use PMU Measurement of V and I phasors
- On-line display of average temperature of conductor
- Initial field results correlate increased power transfer from 950 MW to 1150 MW leads to an average temperature increase from 46 degrees to 49 degrees over 30 min



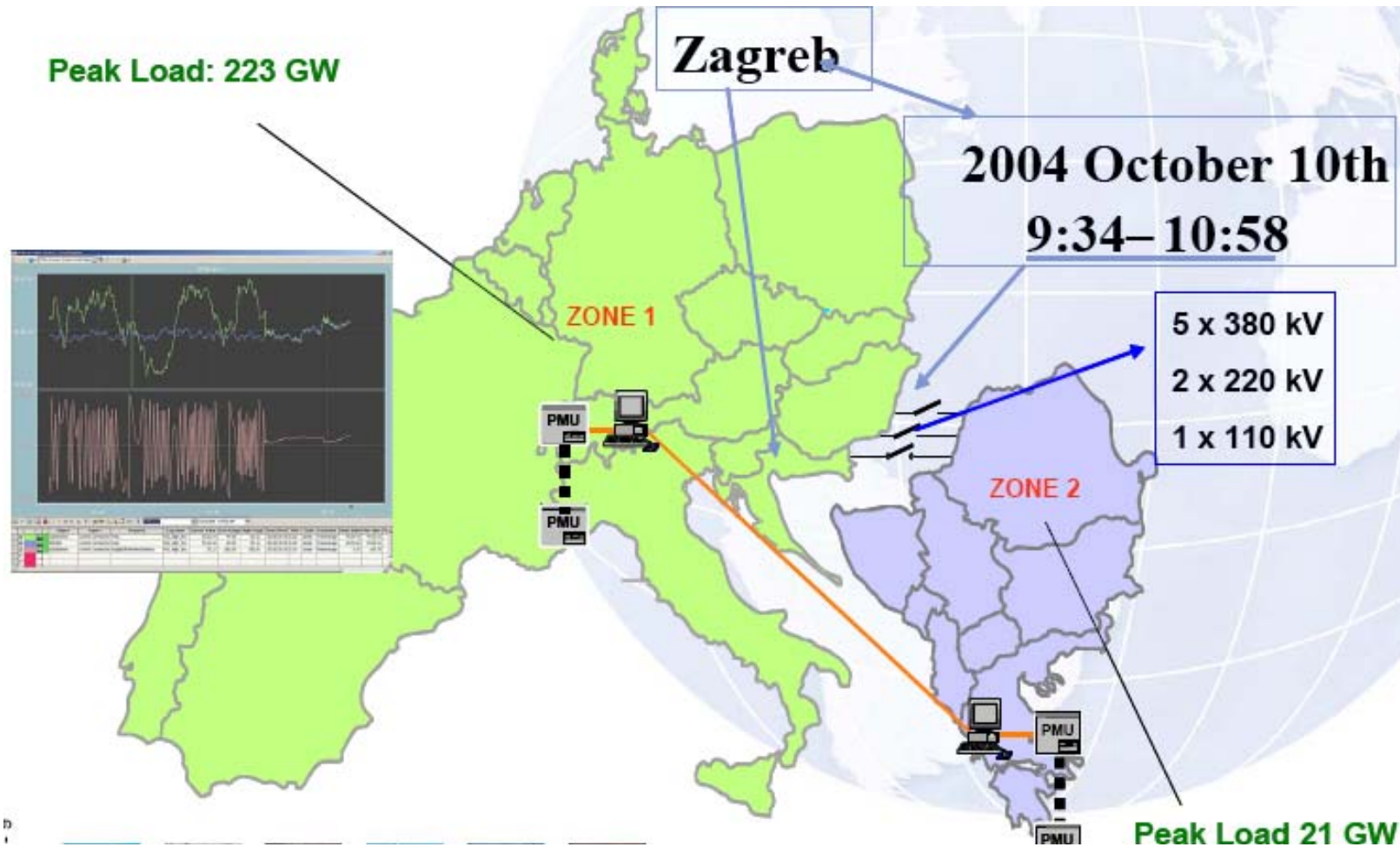
# Corridor Voltage Stability Monitoring



- Provides power margin to the point of maximum loadability of transmission corridors w.r.t. voltage stability
- High accuracy by using PMU data (dynamic data)
- Fast reaction (Usage of real-time data)
- Can be used to trigger emergency actions



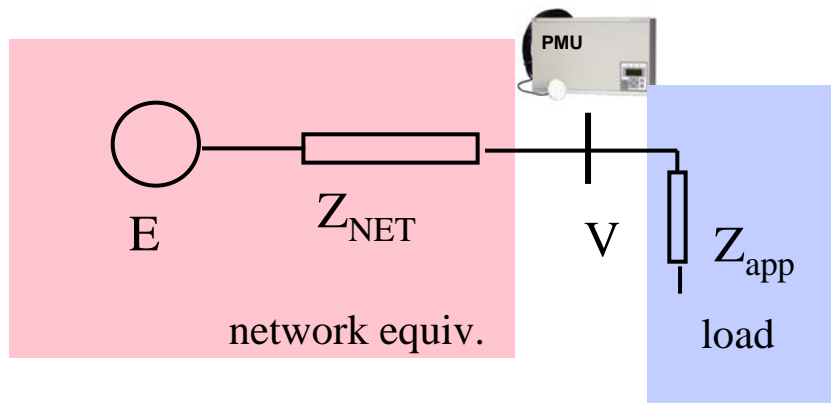
# Phase Angle Monitoring



UCTE grid reconnection

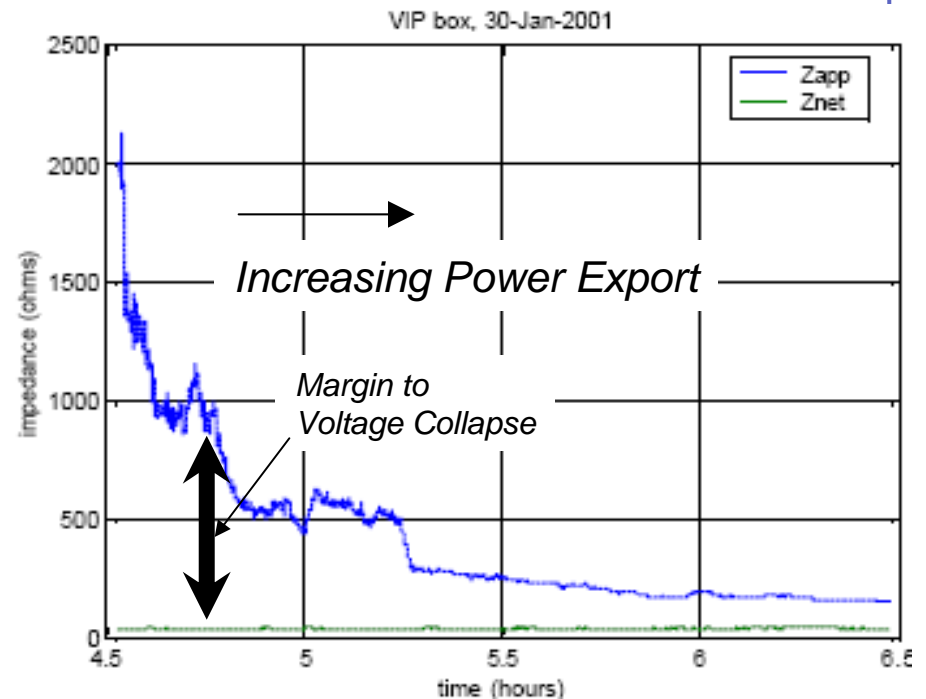
# Voltage Instability Predictor

- Predicts proximity to a voltage collapse by utilizing only local substation measurements.



Maximum power transfer

$$\Leftrightarrow Z_{NET} = (Z_{app})^*$$



Measured VIP response to an increase in power export to Sweden. Network impedance ( $Z_{net}$ ) and apparent load impedance ( $Z_{app}$ )