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Utility experiences with Phasor Measurement Units in Wide Area Monitoring Systems

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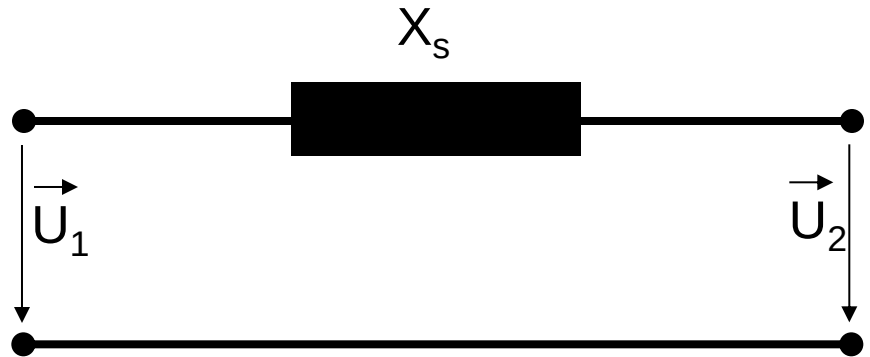


- Introduction
- PMU installation TenneT TSO
- Presentation of Phasor Data Processing (PDP) system SIGUARD
- Examples of data evaluation during events
- Lessons learned

Introduction

Why should we measure phasors?

$$P_2 = \frac{U_1 \cdot U_2}{X_s} \sin(\delta)$$

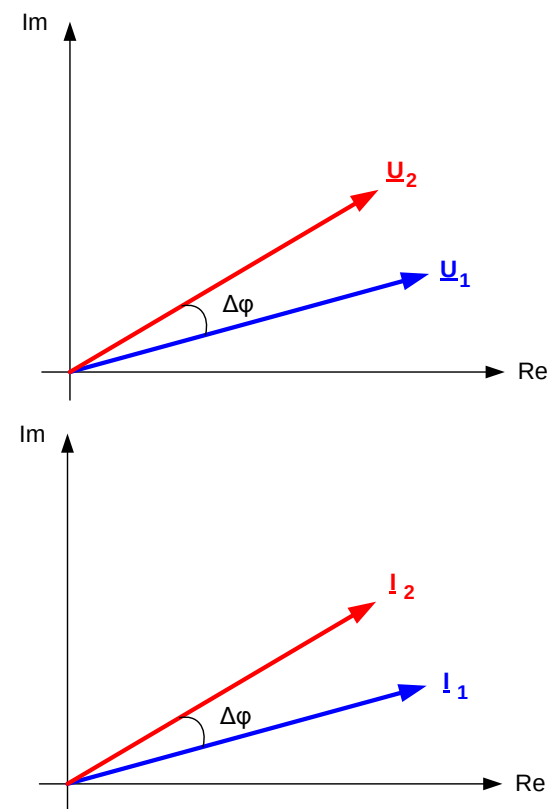
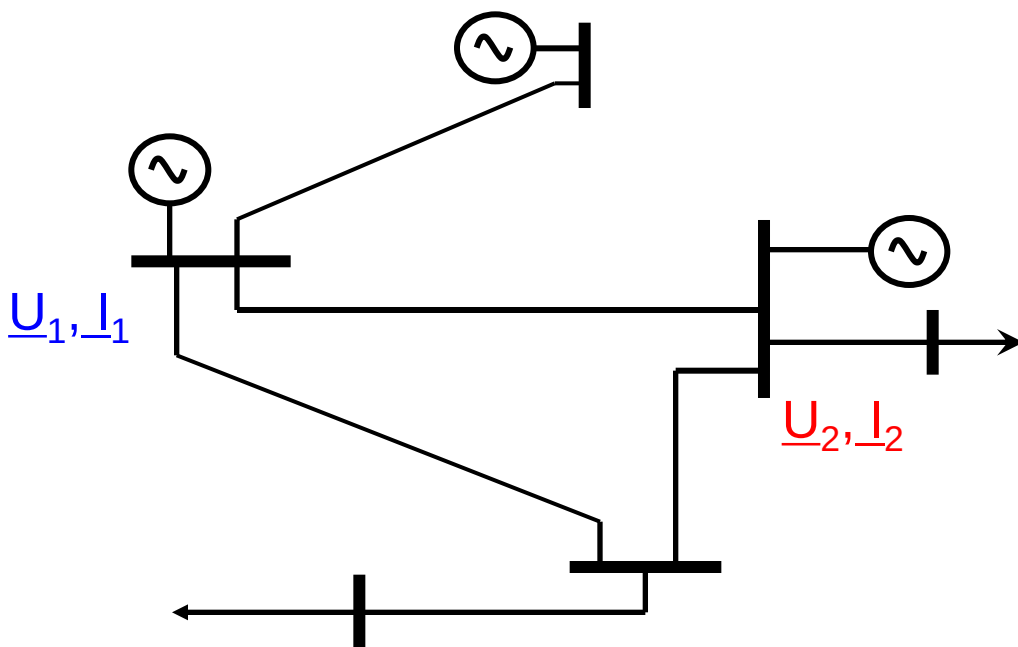


This equation means that active power flow is proportional to the phase angle difference between U_1 and U_2 .

Thus it is possible to measure power flow without complicated algorithms as state estimator, power flow etc.

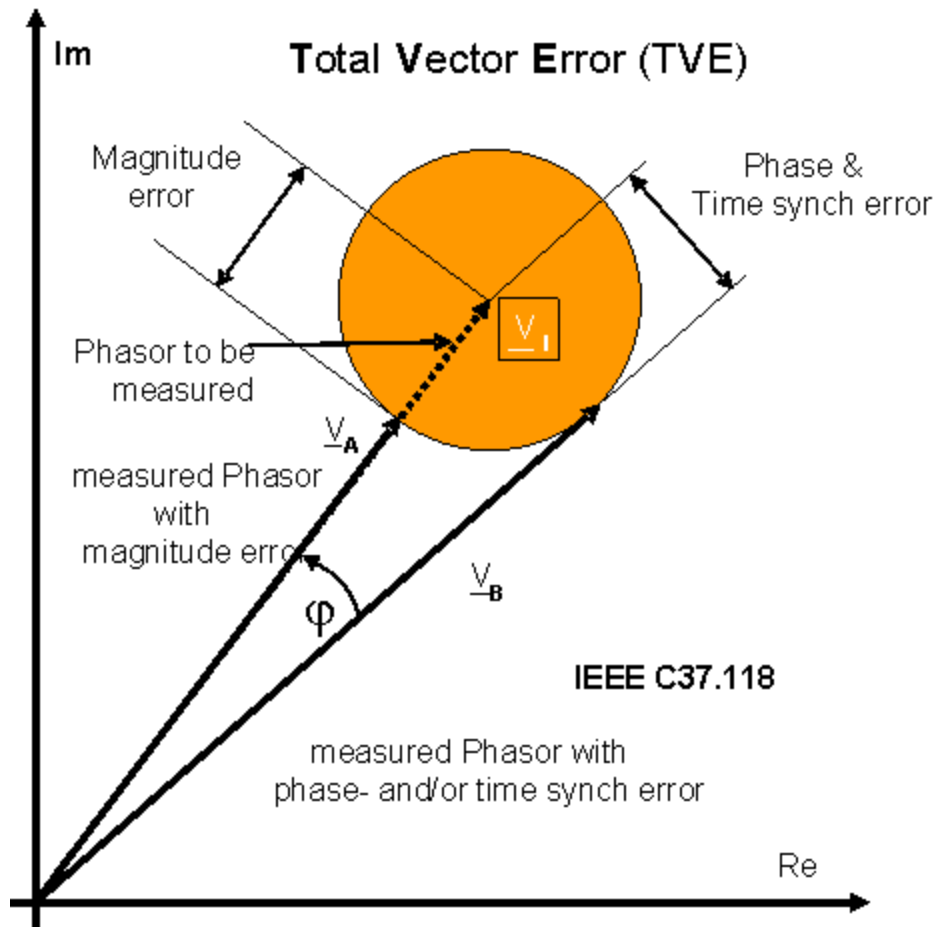
Phasor Measurement Unit

Idea: Increase awareness for dynamic behaviour of transmission and distribution network by timestamped phasor measurements in realtime.



PMU

Calculation of Total Vector Error



Both amplitude and phase angle error have to be considered for synchrophasor accuracy.

Basics of Phasor Measurement

Measurements via RTU / Substation Automation	Synchrophasors via PMU
Update slowly (for example every 5 s)	Continuous update (measurement stream) with for example 10 values per second (= reporting rate)
No time correlation for measurements	Every measurement has a timestamp
RMS values without phase angles	Phasor values (Amplitude and phase angle) for voltage and current



Dynamic View on Power Swings
and other dynamic phenomena

Advice for PMU location

For angle dynamics/ power oscillations:

- At each or **near** (inside the influencing area) **relevant power plants**, to monitor stress of a line corridor.

For frequency:

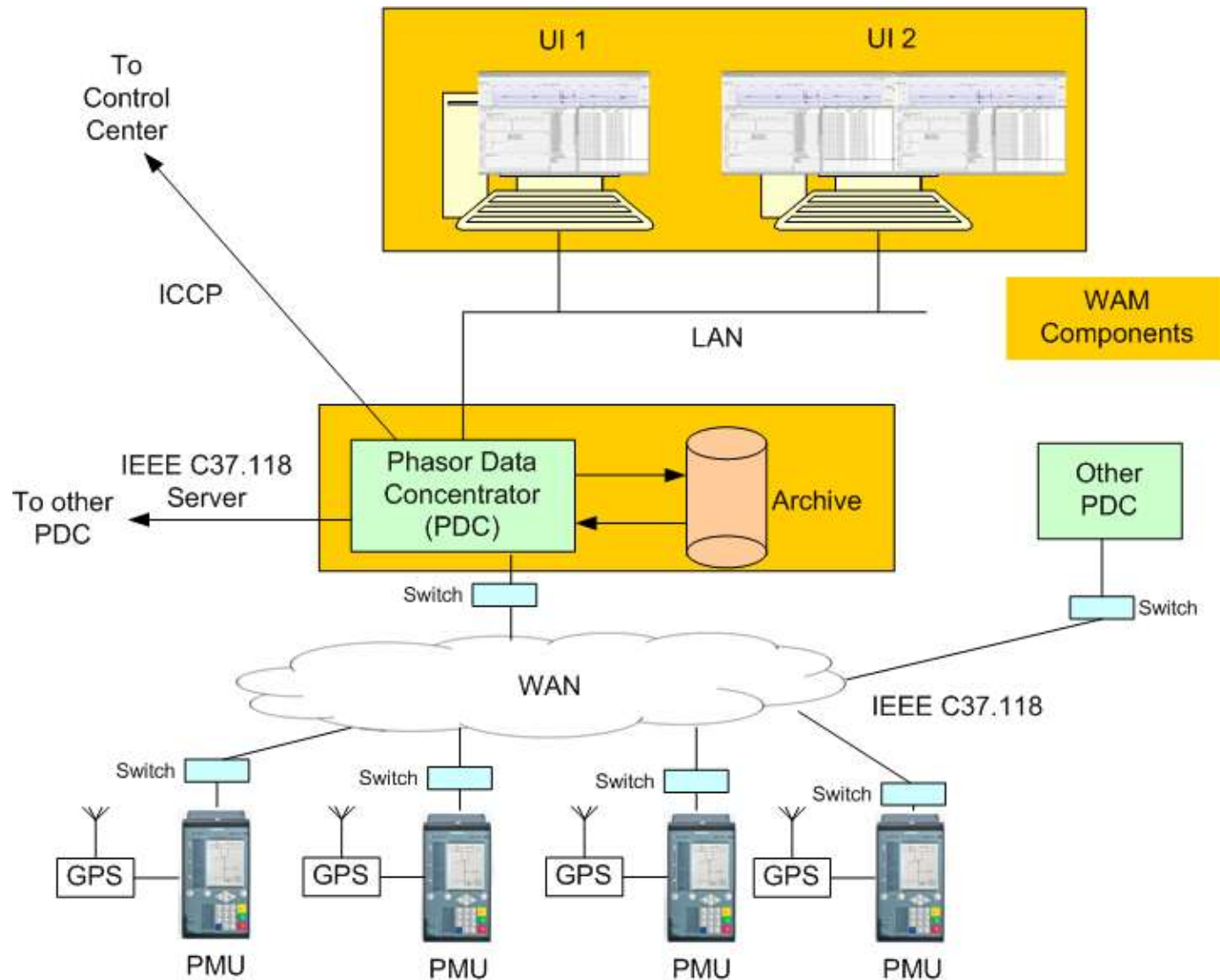
- Close to the **power plant** with the **largest inertia**, e.g. >500MW.
- **Near heavily loaded tie-lines** (e.g. tie-lines presenting higher sensitivity to generation variation)

For voltage stability:

- **Near critical load areas** (busbar with lower load ability margin)
- **Near generation** (if reaching reactive injection or absorption limit)
- **Nodes equipped with FACTS** (e.g. SVCs)

System Structure

SIGUARD Phasor Data Processor

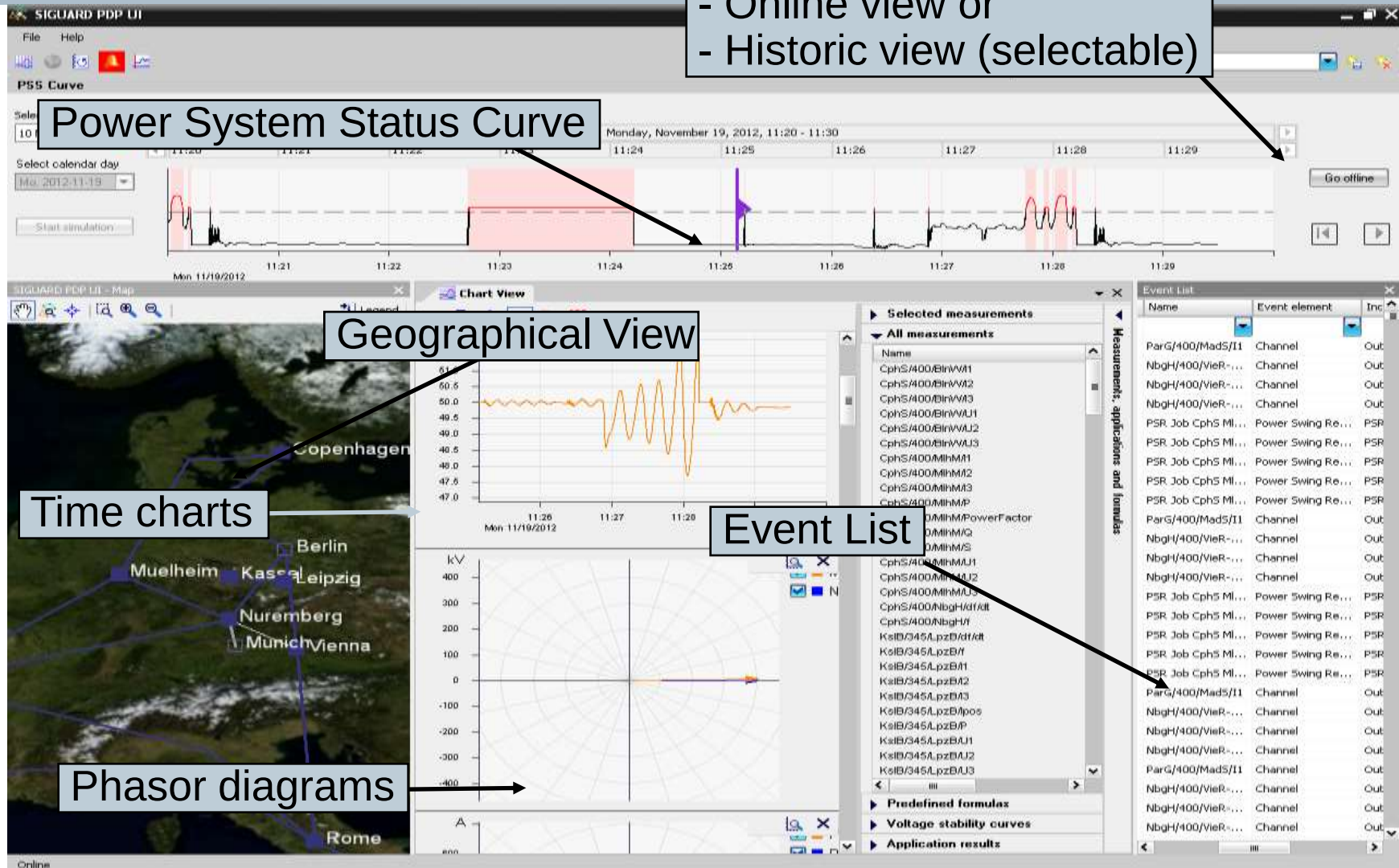


SIGUARD PDP

User Interface, Example

Monitoring of

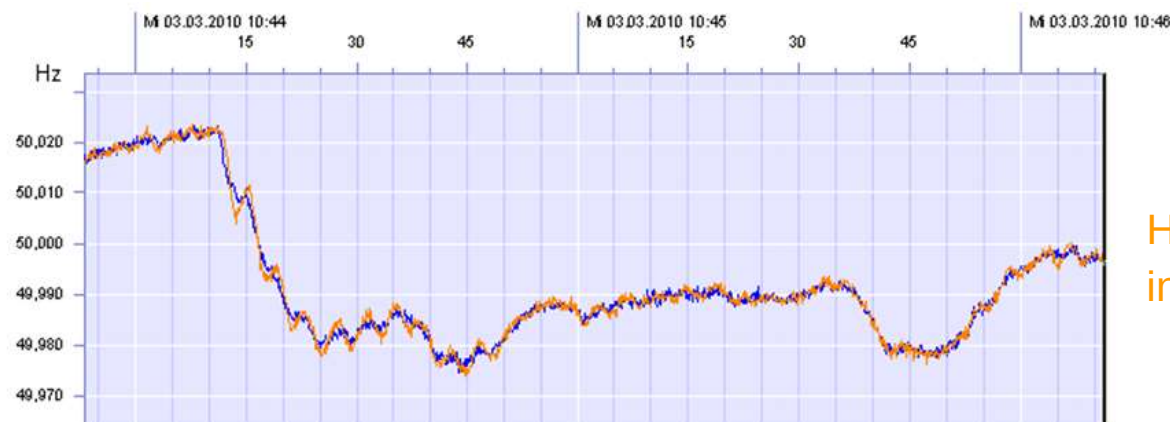
- Online view or
- Historic view (selectable)



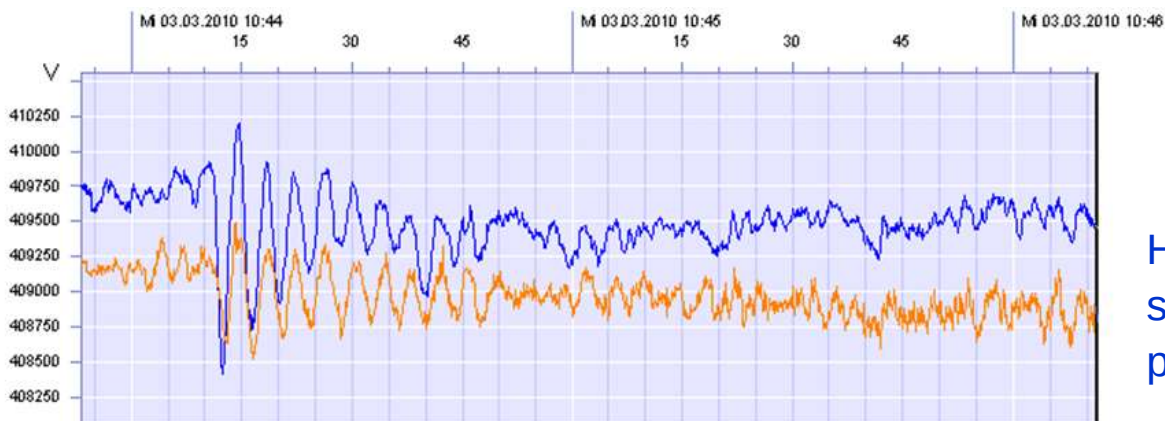
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Example 1: Generation loss

Example: Generation loss in southern Europe



Higher frequency deviation
in the north (distant from fault)



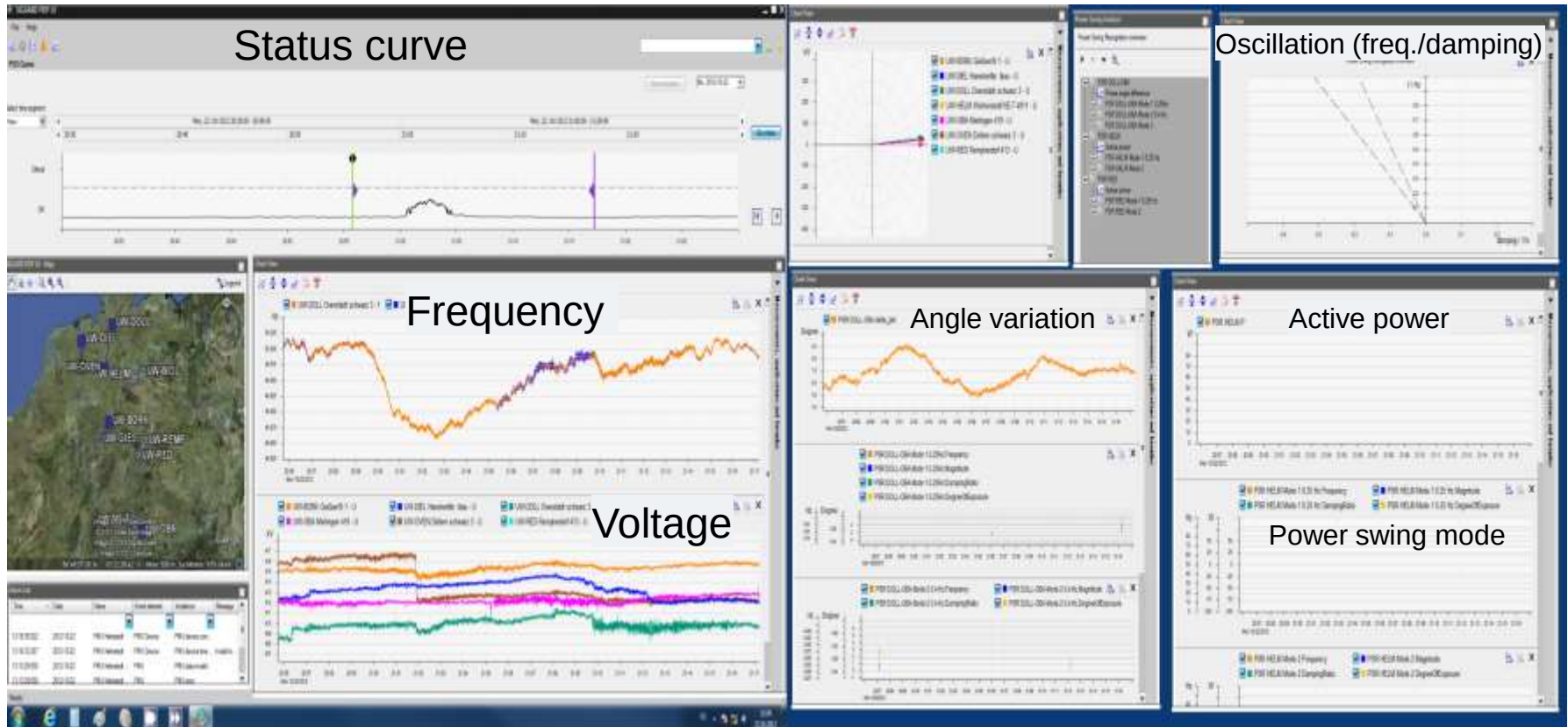
Higher voltage deviation in the
south (closer to the fault)
power swing of appr. 0,25 Hz

Example 2: Loss of a power plant in 2012

Power swing recognition

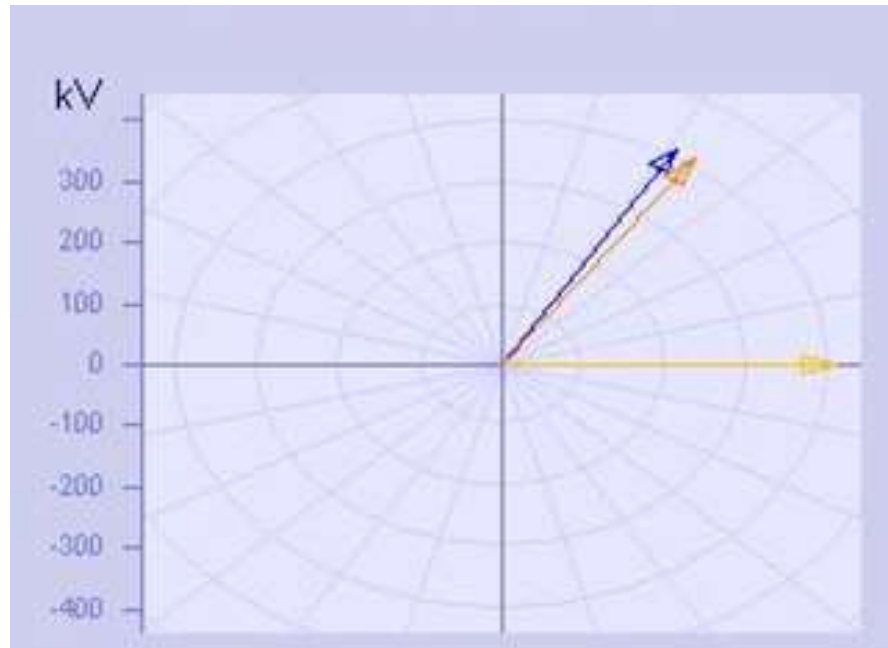
Angle evaluation between PMU

Local power evaluation



Example 3: Maximum load

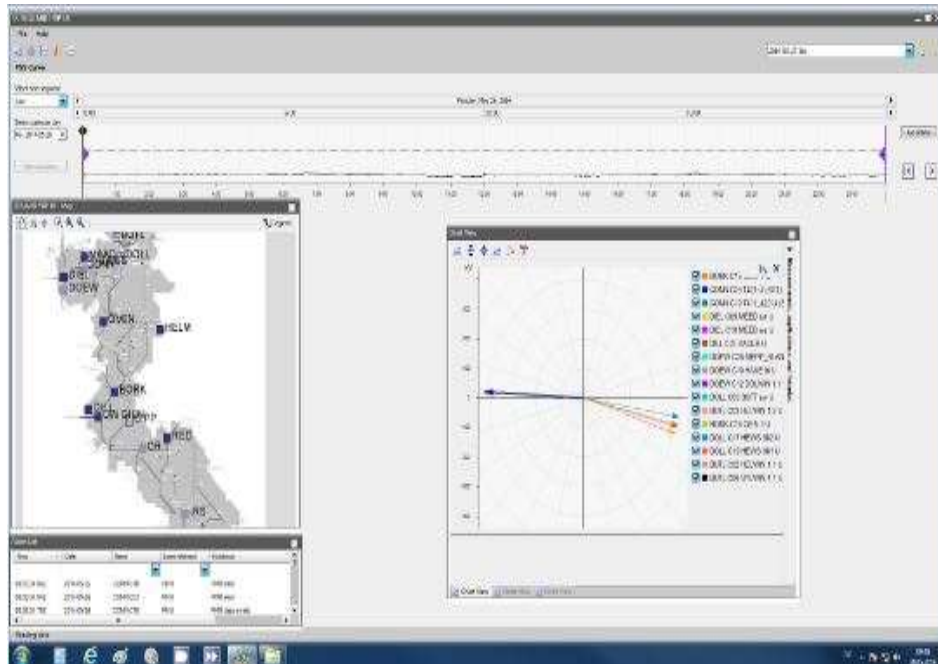
Example: Strong Windpower in the North



Voltage Phasor
— PMU North1
— PMU North 2
— PMU South (reference)

Phase Angle reaches 60 Degree

Example 4: Event on Wednesday 28.05.214

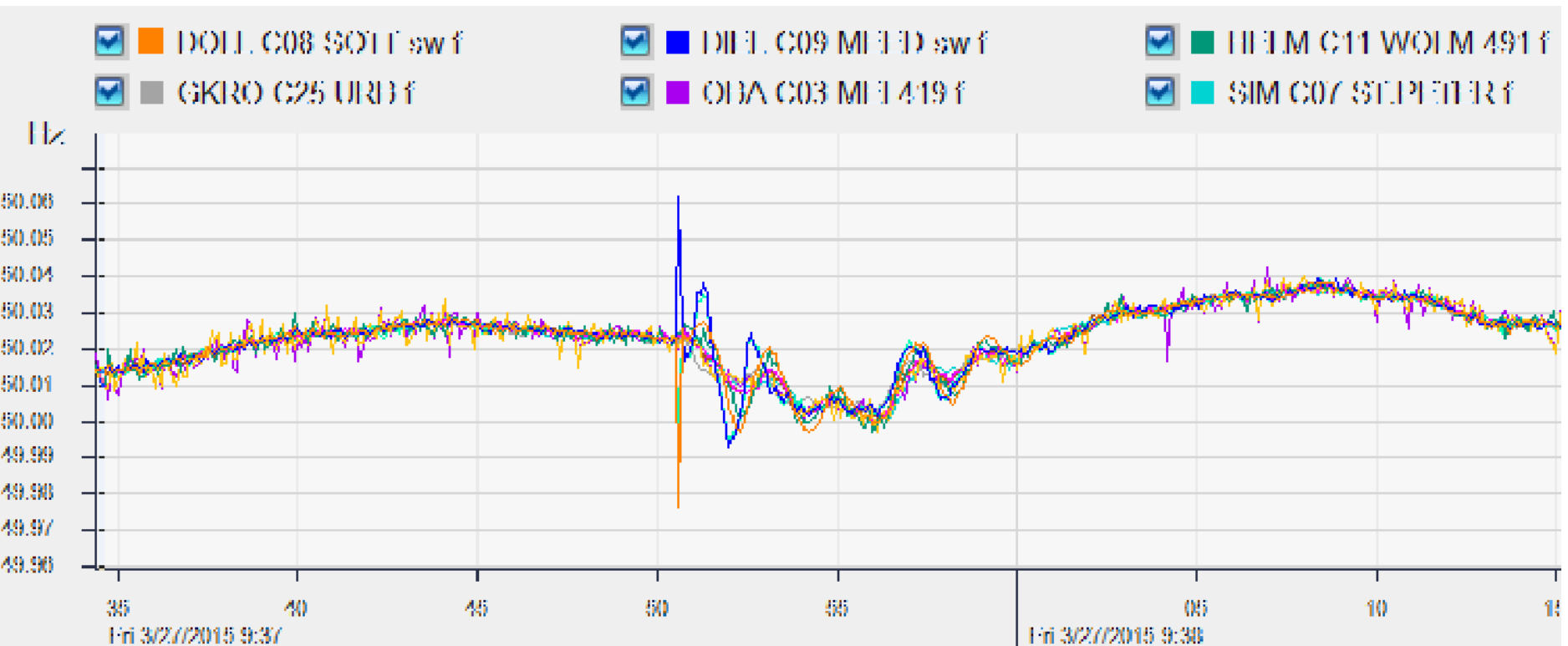


Angle differences



Frequency variations

Example 5: Amsterdam Blackout 27.03.2015



Frequency Measurements from German PMUs on 27.3.2015

Blackout in Amsterdam and surroundings (Busbar fault and loss of power generation)

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Lessons Learned

- Improvement in recognition of critical power network situations for reasonable investment.
- Need of reliable communication channels and security of data transmission are very important
- PMU-integration in system operations, would offer a new level of performance; e.g. verification of network data compared to the network model.
- Comprehensive training of operators on dynamics is necessary

Thank you for your attention!



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