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Tutorial Part 2

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Methods of Processing Provided Information and Use of Monitoring Results for Power System Dynamic Characteristic Analysis
Monitoring of Power System Dynamic Performance

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SUMMARY

Power system operation is becoming more and more complex. The number of links between different system areas is permanently increasing and the increased number of participants in the global electricity market requires a corresponding adaptation and expansion of the classical tools in use for ensuring a stable high-quality electricity supply.

This document represents an overview over a half-day tutorial, focussing on practical experiences in the Swiss transmission system operating in the middle of the interconnected central European power system - UCTE.

As an introduction, the system structure of the UCTE power system is presented and the main control loops affecting the overall system behaviour are described. Based on timely high-resolution measurements and associated time-domain simulation results the main topics of power system control are discussed.

First results of the implementation of a Wide Area Monitoring system capable to extract system dynamic information on-line and to deliver clear signals to the control room are presented.

KEYWORDS

UCTE power system – Dynamic characteristics – High-resolution measurements – Primary control – Secondary control – UCTE Operation Handbook – Dynamic system modelling – On-line monitoring of dynamic system behaviour

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1. CHARACTERISICS OF THE CENTRAL EUROPEAN INTERCONNECTED POWER SYSTEM UCTE

Since the first synchronous interconnection of the three power systems of France, Germany and Switzerland in 1958 the system size and load has been increasing continuously. Currently 450 million people are interconnected from Greece to the Iberic peninsula to Denmark and Poland up to the border of the Black Sea. This system has a peak load of 300-370 GW and operates in a decentralised way. Only for a better matching of scheduling and accounting there are two coordination centres (North - RWE in Brauweiler, Germany and South – ETRANS in Laufenburg, Switzerland), which are able to get a higher level system overview.

In addition, all the coordination work is shared in the framework of working groups and technical committees where all European TSOs participate actively. Since the opening of the market and subsequently increased electric energy flows between the individual areas the old “UCTE Ground Rules” were replaced by the “UCTE Operation Handbook” followed by the “Multilateral Agreement” signed by all TSOs [1] . A compliance monitoring process as well as an enforcement process are being prepared and performed, in order to close the loop.

For a better understanding of the dynamic characteristics of this huge and highly meshed system, the historical development in terms of size and load is shown in **Fig. 1**.

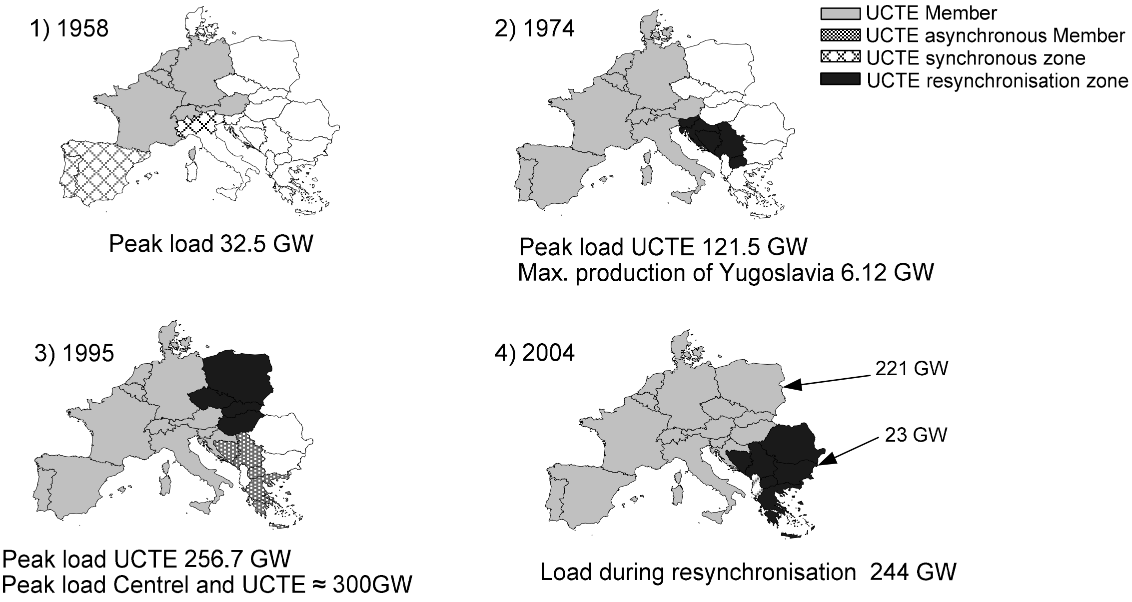


Fig. 1: UCTE Expansion Stages

Some of the main technical standards and their vital importance for the whole secure interconnected operation are subject of this tutorial. First wide area data exchange was required after the implementation of the load-frequency control characteristic applied for the secondary control within the UCTE system.

Today’s high resolution measurement techniques and corresponding reliable high speed telecommunication have opened the door to implementation of additional monitoring and control possibilities by including enhanced dynamic information into the classical SCADA environment.

By discussing the contents of **Fig. 2** the whole range of observations with respect to dynamic system performance can be shown in a very simple and comprehensive way:

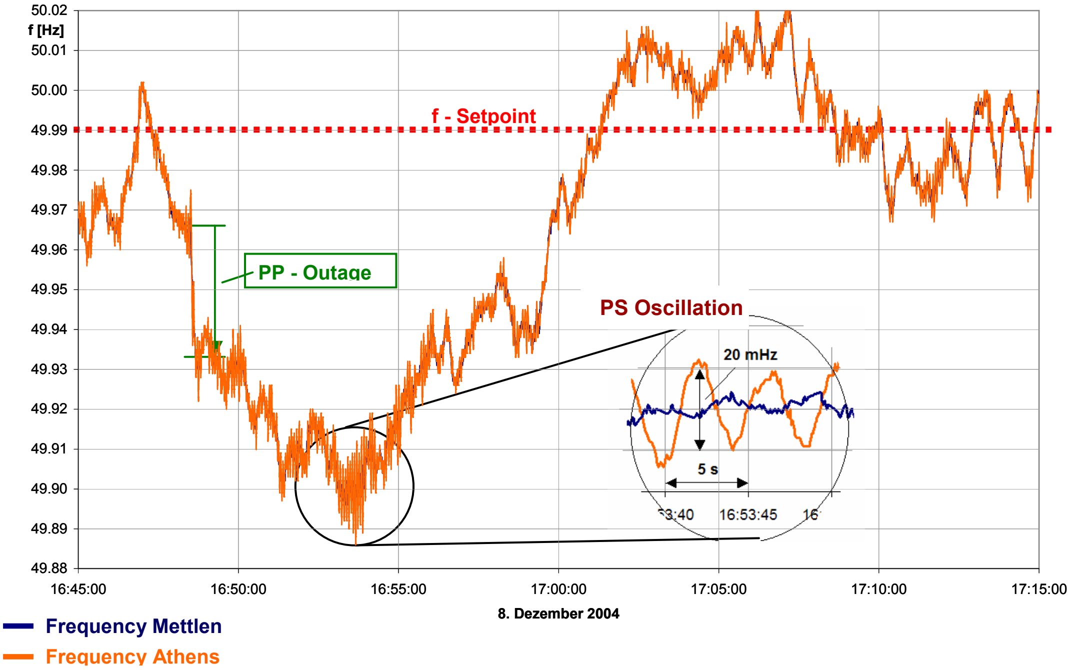


Fig. 2: System Frequency – Mirror of System Behaviour

Based on the fact that the system frequency is in steady-state condition unique for the whole system and that the individual differences extracted from timely high resolution measurements reflect the dynamic transient response, the detailed analysis of this measurand enables us to describe the whole system behaviour.

The recording presented above reflects the UCTE system frequency in a time window of half an hour on a December afternoon, Wednesday 8th in 2004. Due to time correction on that day the frequency setpoint for the whole system was 10 ms below the rated value of 50 Hz. At about 16:48 a forced outage of one unit (1000 MW) of a nuclear power plant occurred. At that time due to the available spinning reserve of the complete system the related frequency drop was 40 mHz. However, only after another additional 30 mHz of frequency drop a stabilisation of the frequency decay took place.

Subsequently the secondary control of the disturbed area started to take the lead and brought the frequency back to the setpoint after another 6 minutes. After a short overshot system frequency recovered to the setpoint followed by some minor secondary controller oscillations of about one minute time period.

During the lowest frequency period the beginning of inter-area oscillations can be observed. Synchronised measurements of the system frequency in the middle of the system (Mettlen/Switzerland) and on the periphery of the system (Ag. Stefanos /Greece) reflect the permanent synchronising forces of an interconnected system. Due to the fact that the oscillations amplitude increases together with the absolute frequency deviation, it can be concluded that the primary control currently participates in an active way on the damping of inter-area oscillations.

2. CONTROL PRINCIPLES USED IN THE CONTROL OF THE UCTE POWER SYSTEM

For secondary control the network characteristic control principle is in use in the central European system either in hierarchical or pluralistic mode, see **Fig 3**.

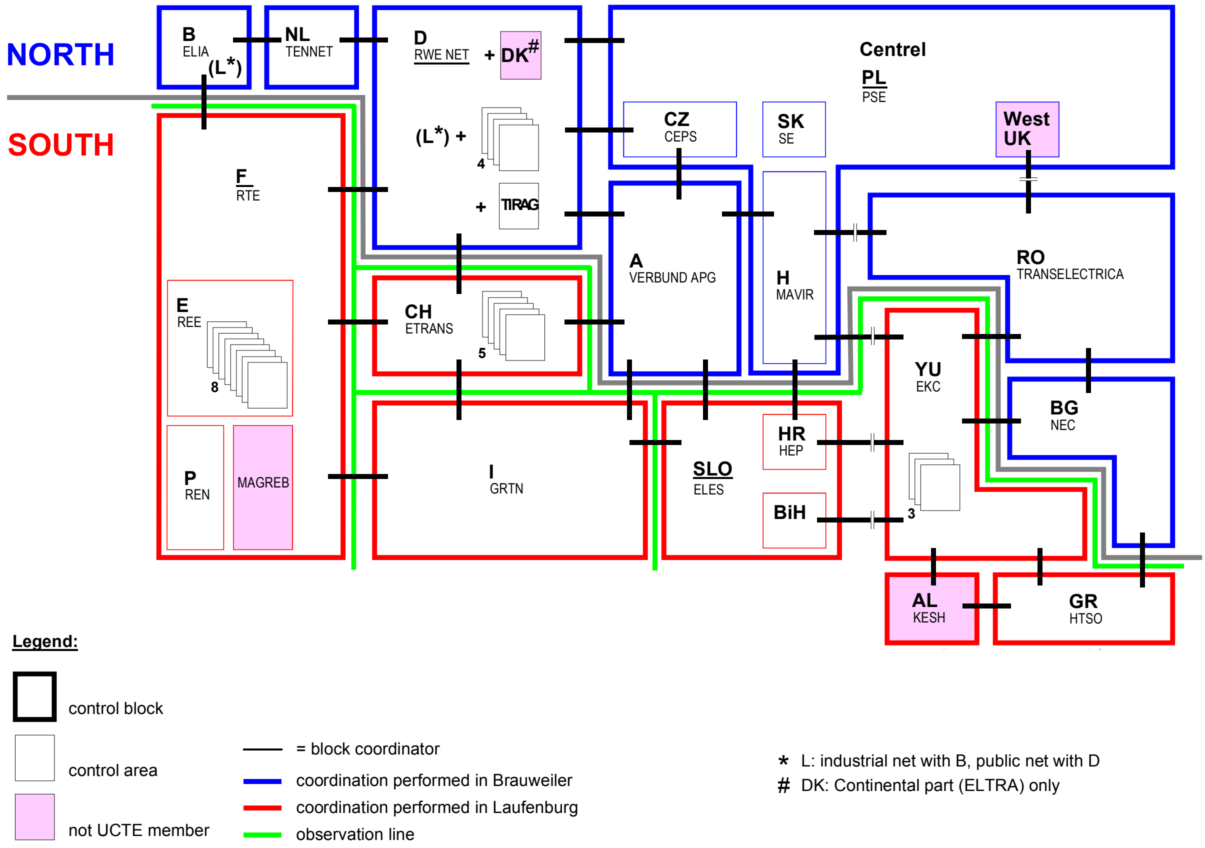


Fig. 3: UCTE Control Block Structure

This control principle enables the system to automatically adapt the balance between load and generation as well as to compensate deviations from the pre-defined schedules between the different system areas. The corresponding settings of the individual area control blocks are defined according to the yearly generated energy amount by each control area. These settings have a direct impact on the primary control requirements and the correlated secondary controller settings for each control block.

The principle of the secondary control is shown in **Fig. 4**. It is important to understand that the primary control is based on a decentralised pure proportional control scheme (droop control) and that the secondary controller has to be timely decoupled from the primary control (time constants of minutes) and that the integral control structure ensures the restoring of the frequency to the setpoint. The secondary control for each area is a centralised controller with input from all the cross-area tie-lines and generates an output via contribution factors only to dedicated generation units. The network controller or AGC (automatic generation controller) is under permanent supervision of the TSOs control room dispatchers. It is within their job to ensure that the related primary and secondary control reserve is permanently fulfilled.

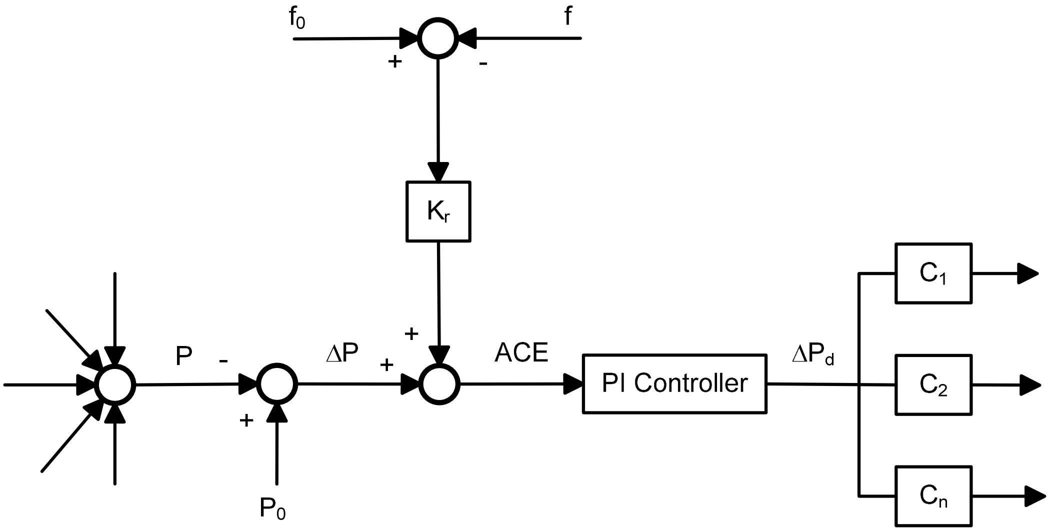


Fig. 4: Secondary (Network Characteristic) Control Principle

3. DYNAMIC MODELLING AND STABILITY CALCULATIONS APPROACH

As a consequence of recent major events in power systems all over the world, dynamic aspects of system behaviour have come more and more to the foreground of discussion. At the same time, the available tools for dynamic system analysis have improved in terms of user-friendliness, computation power and interfacing capabilities with data acquisition equipment. Thus, the interchange of dynamic models between the highly meshed interconnected TSOs has become a must. Each study for future system expansion is currently accompanied by detailed dynamic system calculations.

However, the most time-consuming and therefore cost-critical point in this field is the accurate calibration of such dynamic models. Reliable tuning of these models can only be ensured by intensive comparisons between measurement and simulation. If finally the models are well-tuned they can be of crucial importance to analyse and understand the complex system behaviour either in the planning stage or in post-mortem analysis for preventing to have recognised problems in the future again.

Fig. 5 gives an example of a decomposition of the individual contributions during the electromechanically transients after a frequency drop of 30 mHz in the UCTE system. The transient analysis results presented are based on dynamic system calculations reflecting a post-mortem calculation of a forced unit outage (1200 MW) [2]. The individual portions correspond to:

$\Delta P_{G.,f}$	inertia of generators
$\Delta P_{V.,f}$	inertia of motor driven machines
$\Delta P_{G,f}$	spinning reserve activation of the generation units
$\Delta P_{V,uf}$	steady-state load voltage and frequency dependency
P_Z	total disturbed power

It can be clearly observed that before the spinning reserve of generating units can be activated the system inertia together with the load frequency and voltage dependency are the main contribution factors for stabilising the system frequency.

The individual curves are obtained by summing up the related contributions of all the loads and generators of the system model.

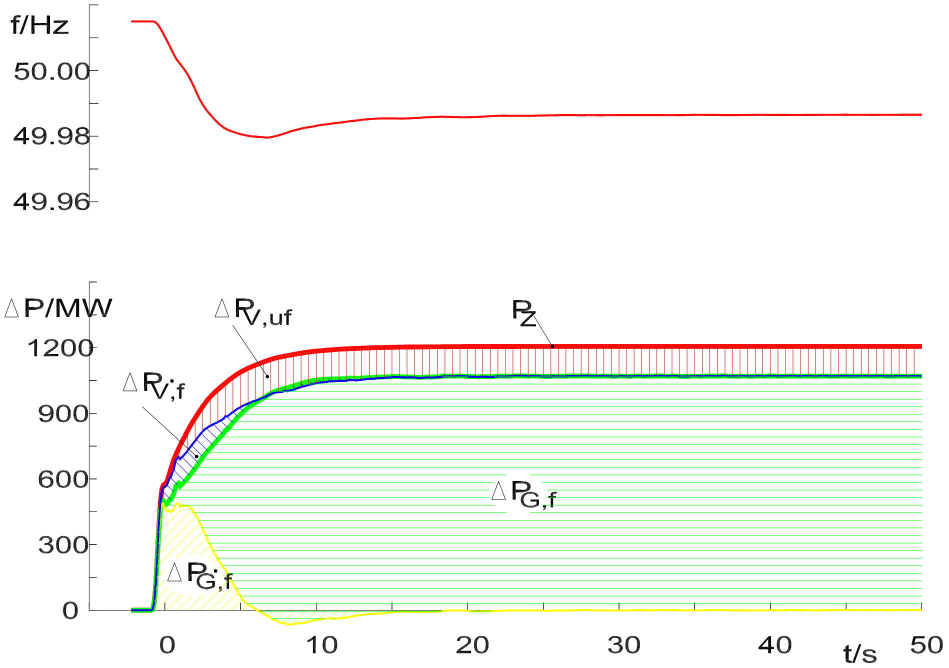


Fig. 5: Active Power Components Participating on the Frequency Stabilisation

In order to get the parameter for a detailed dynamic model for the power system of Switzerland dedicated dynamic tests in important hydro power plants were performed [3]. During these tests the power plant prepared for measurements was switched from interconnected operation to island operation in different exchange power scenarios (import/export).

By the subsequent identification of gains and time constants for controller equipment (AVR, governor) as well as for the penstock dynamics, accurate models have been set up.

Fig. 6 gives a comprehensive overview of the first stages required to come out with valid dynamic models. Experience shows that only a good and fruitful interaction between power generating company, system operator and manufacturer guarantees valuable results. Again, the main part of the work is to be done by well-skilled dynamic experts with a deep analytical background required for overcoming all stability details. For example it is of crucial importance to know how to divide the complex dynamic system into sections, which can then be identified step-wise. Therefore the used interfaces should be measurable quantities with a physical background (e.g. pressure, mass flow, voltages, currents, valve position, speed etc.).

Currently the models obtained for the Swiss power system are used for examination of the existing system restoration plans. Developments in the direction of dispatcher training simulators as well as dynamic modelling in the case of system expansion studies are two other fields of application for the existing models.

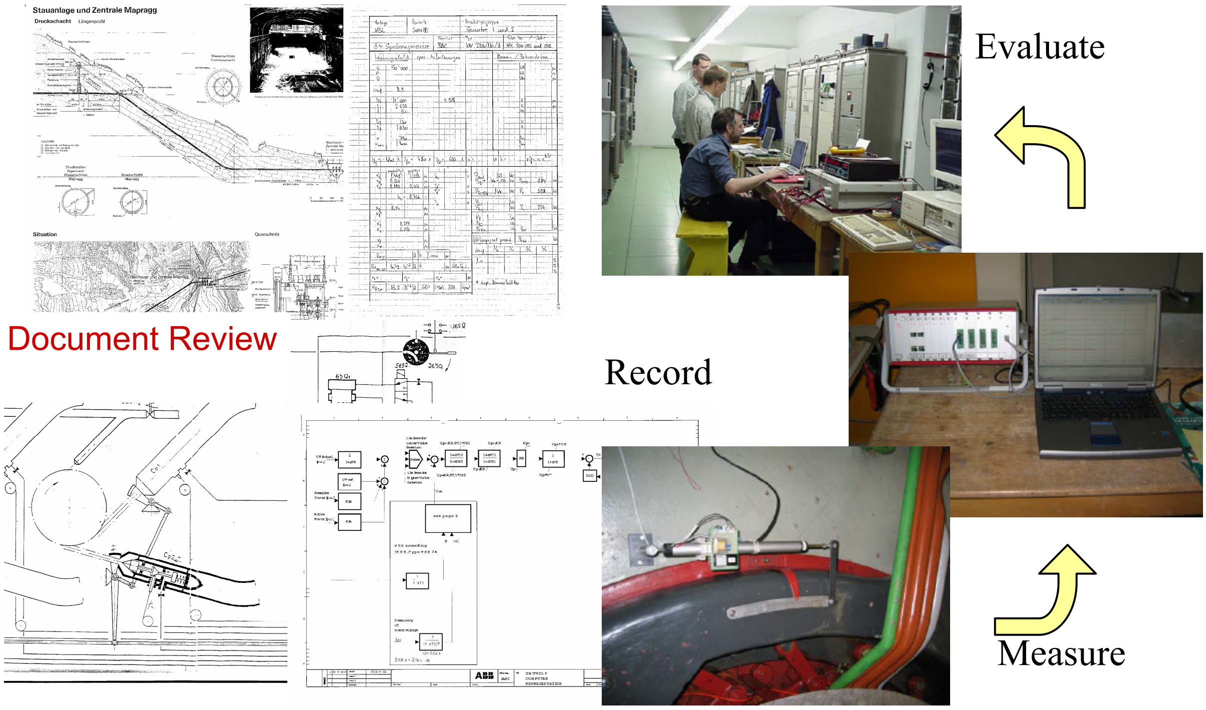


Fig. 6: First loop for setting up system dynamic models

4. ON-LINE MONITORING OF DYNAMIC SYSTEM BEHAVIOUR

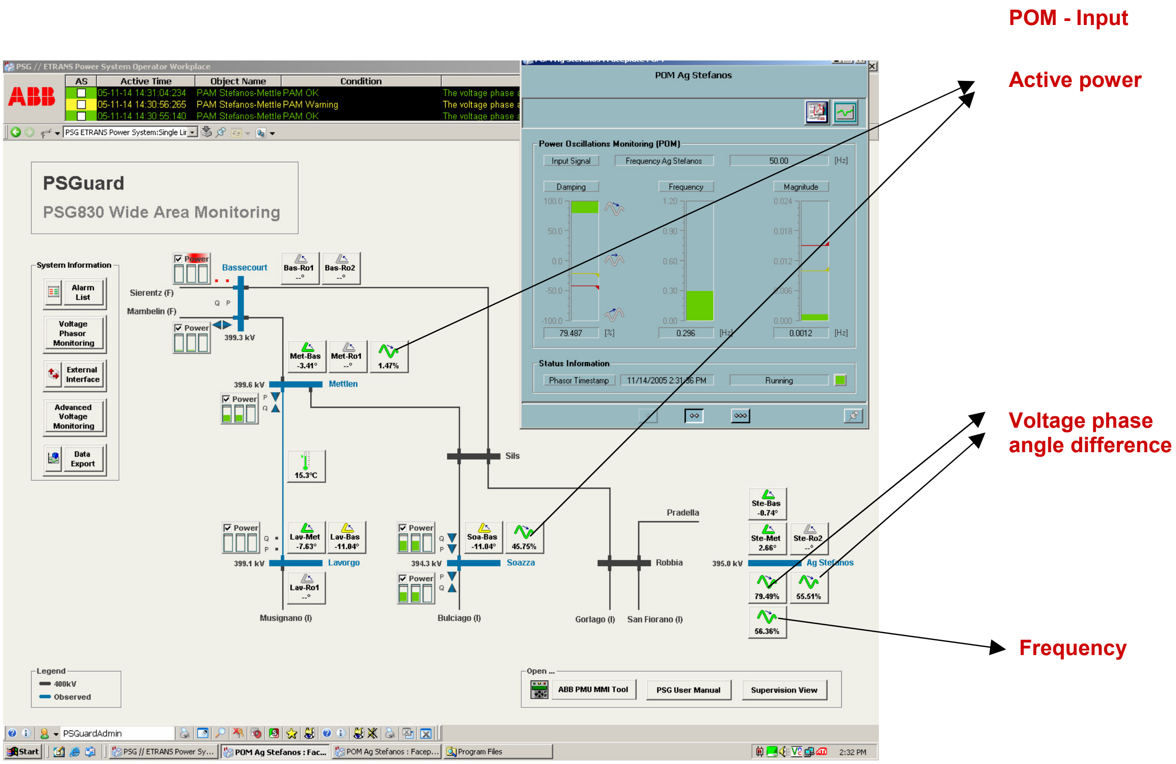
Wide area monitoring enables system operators to permanently dispose of stability indices, in order to receive warning signals in the case of poor system damping. Secondly by permanent recording of stability indices a correlation between dangerous operating conditions and related system loading or topology configuration can be deduced.

Currently ETRANS has implemented a Power Oscillation Monitoring (POM) system under development in test operation, see **Fig. 7**, which makes it possible to detect the excitation of one of the two major inter-area oscillation modes existent in the UCTE power system.

The most visible mode is the east-west mode reflected by active power swings in east-west direction which can be measured on tie-lines connecting areas on this axis or the frequency at the Eastern system margin. As input for recording this mode the comparison between the frequency in Switzerland and Greece is used. The same results could be obtained by using the voltage phase angle difference between Greece and Switzerland. The second mode, which reflects the north-south inter-area oscillation, is monitored by ETRANS by using as input the active power flows of two 380 kV tie-lines oriented in north-south direction as part of the import corridor from North to Italy.

The timely high resolution measurements (each 100 milliseconds one measurement set) are subsequently processed in such a way that as a result of an on-line parameter estimation together with a modal analysis three main parameters describing the system damping are calculated and stored in the measurement database:

- Damping factor
- Oscillation amplitude
- Oscillation frequency



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AS  Active Time              Object Name            Condition
    05-11-14 14:31:04:234   PAM Stefanos-Mettle    PAM OK        The voltage phase a
    05-11-14 14:30:56:265   PAM Stefanos-Mettle    PAM Warning   The voltage phase a
    05-11-14 14:30:55:140   PAM Stefanos-Mettle    PAM OK        The voltage phase a
```

Power Oscillations Monitoring (POM)

Input Signal: Frequency Ag Stefanos 50.00 [Hz]

Damping: 79.487 [%]

Frequency: 0.296 [Hz]

Magnitude: 0.0012 [Hz]

Status Information

Phasor Timestamp: 11/14/2005 2:31:36 PM Running

Fig. 7: Stability Monitoring Input Signals

The most recent inter-area oscillation observed in the UCTE power system is shown in **Fig. 8** and the corresponding oscillation monitoring tool output is presented in **Fig. 9**.

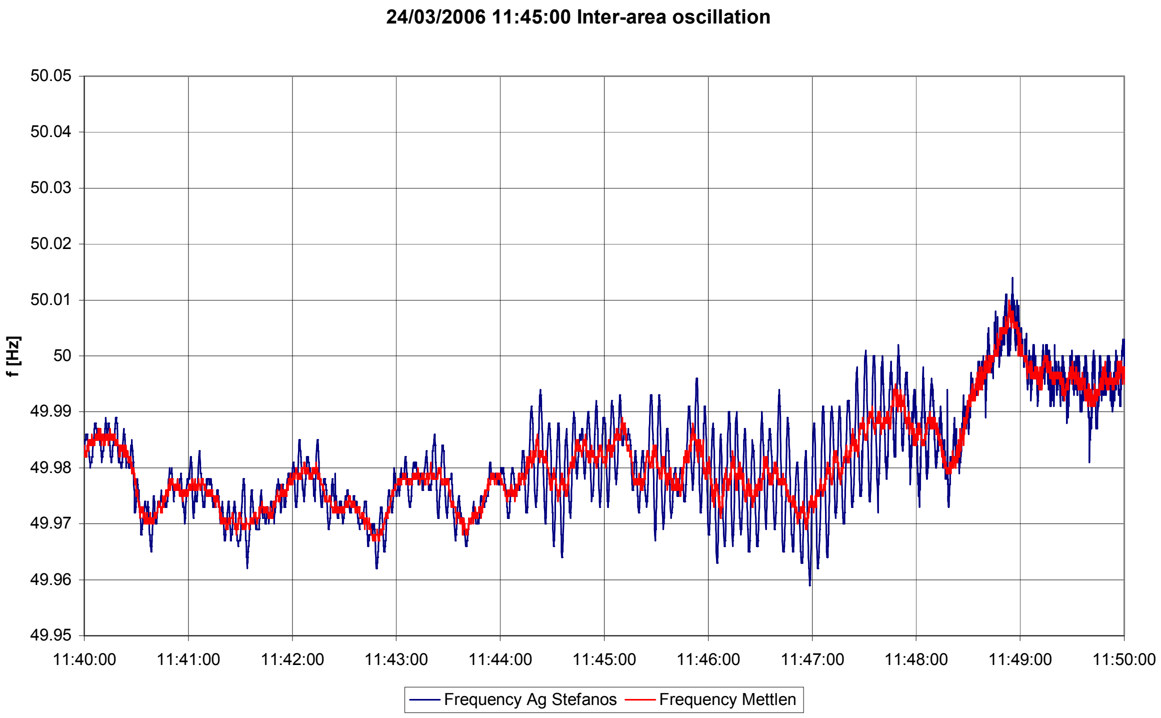

Fig. 8: UCTE Inter-area Oscillation Recordings

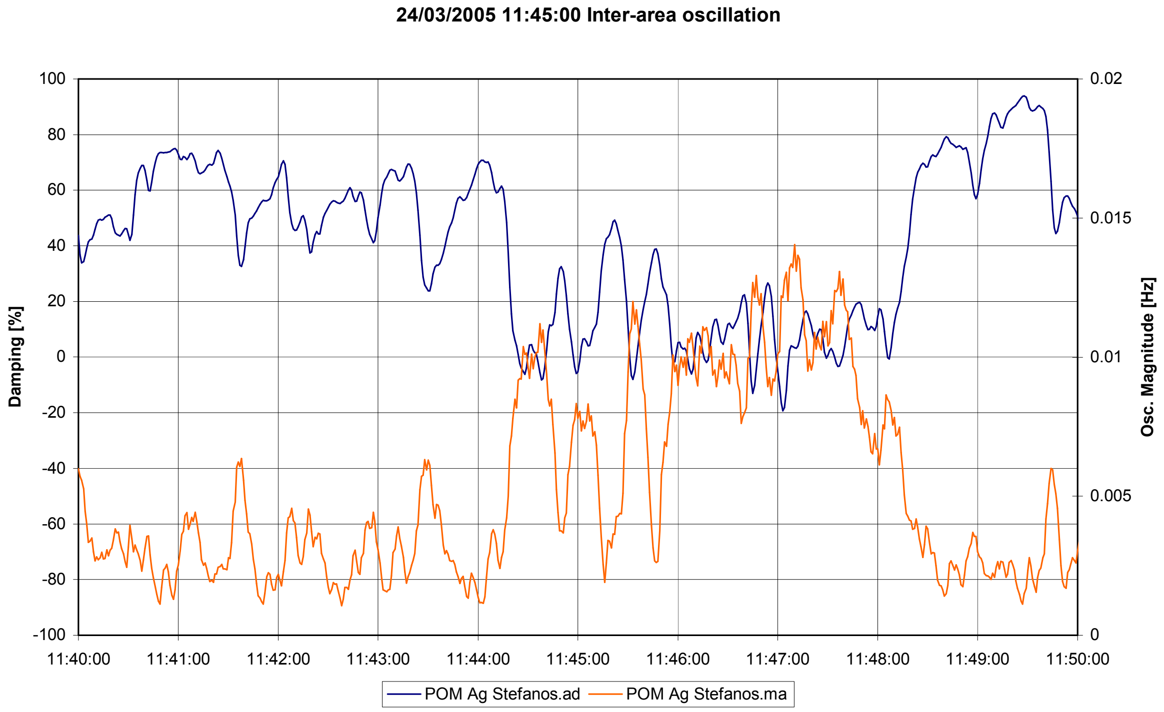

Fig. 9: Power Oscillation Monitoring Output Indices

By using both indices – the damping factor as well as the oscillation amplitude – together with a timer a reliable oscillation alarm will be created, in order to create a trigger signal for starting or acquiring additional recordings or for performing system topology improvements. Currently this signal is used only for monitoring purposes, but in the future it may be integrated in special protection schemes or enhanced control loops.

5. CONCLUSION

Current developments in data acquisition, reliable and fast telecommunication combined with increased computation power allows the power engineers to implement new comprehensive monitoring and control schemes in order to increase the security of power system operation. However, the most challenging process will be to combine the existing classical systems with the latest modern techniques with the aim of creating adequate tools for world-wide increasing power systems.

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