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Large Scale Wide Area Measurement System

Tadeja BABNIK¹, Kay GÖRNER², Bojan MAHKOVEC¹, Christian REHTANZ²
ELPROS¹, TU Dortmund University²
Slovenia¹, Germany²
tadeja.babnik@elpros.si

KEYWORDS

LS-WAMS, PMU, large scale wide area monitoring system.

1 INTRODUCTION

The majority of electric power systems were built in 1960s and 1970s. The main purpose of interstate transmission lines was to exchange power reserves and to assure better frequency response, voltage conditions and consequently higher quality of energy supply.

Electricity market and possibility to buy energy in the Eastern part of Europe cause that transmission lines, inside European interconnection ENTSO-E, are much more loaded as they were designed.

Beside electricity market more and more renewable energy sources like wind power and photovoltaic are included in the power system. Renewable energy sources present un-deterministic power sources and they bring new challenges for stable power system operation.

Electricity market and desire for maximum utilization of the power system brought the power system on the edge of its safe operation. Recent power system blackouts showed that operation of interconnected power systems with high level on operation security and stability is not achievable with limited system knowledge and monitoring only of separate interconnection patches. Secure operation of the power system can be achieved if transmission system operators (TSOs) have reliable information of the total system state.

Conventional SCADA (Supervisory Control and Data Acquisition) systems provide steady, non-synchronous information of the power system with time resolution between 1 and 10 s. Conventional SCADA systems are limited to steady-state measurements and cannot be used for observing system dynamics. The use of WAMS (Wide Area Monitoring System) enables system dynamic behavior to be permanently monitored. WAMS provides time-synchronized information every 20 ms (in 50 Hz system); each data sample is equipped with a Coordinated Universal Time (UTC) stamp. Moreover, data is synchronized with accuracy up to one μ s.

For big interconnected systems like ENTSO-E RG Continental Europe and IPS/UPS reliable operation of interconnections is important. Each interconnected system consists of several TSOs. To observe the current state of the interconnected system the real-time information from all TSO is required. Interconnected systems require large scale (LS) WAMS.

This paper presents the work done within the ICOEUR project (Intelligent coordination of operation and emergency control of EU and Russian power grids) [1] related to large scale wide area power system monitoring system under use of shared phasor data concentrator (PDC).

The first part of the paper briefly describes the concept of LS-WAMS. The second part of the paper concentrates on presentation of 230 V WAMS (Since TSOs' communication network is closed for external users and therefore the access to TSOs PMUs is not possible, the low voltage (230 V) WAMS was built for testing purpose.) based on phasor measurement units located in several countries

across Europe and the complex phasor data concentrator located in Slovenia. The third part of the paper is focused on detected events by 230 V WAMS. The fourth part of the paper deals with correlation of data from low voltage (230V) and high voltage (400 kV) grid through events. The paper will give conclusions related to comparison of low voltage and high voltage data related to the power system frequency and low-frequency oscillations observing on voltage phase angle differences.

2 LARGE SCALE WAMS CONCEPT

2.1 Centralized LS-WAMS

Centralized LS-WAMS contains only one PDC collecting data from all other sources. Data sources can be:

- PMU devices
- Local PDC WAMS from individual TSO.

Advantages

- All data can be accessed from one place. It is possible to perform stability analysis in a great extend.
- Coordinated alarming and remedial actions in case of detection event (abnormal operation)
- Easier administration coordination for data exchange since data exchange between TSO and centralised LS-WAMS should be formalised only once.

Disadvantages

- In case of the PDC fault, the whole system is out of operation (This can be improved by redundancy).
- In case of communication fault, the whole system is out of operation.

2.2 Distributed LS-WAMS

Distributed LS –WAMS contains several PDCs which can operate on following levels:

- TSO
- Region of several countries

Data sources can be:

- PMU devices
- Local PDC WAMS from individual TSO.

Advantages

- More reliable in terms of a failure of individual unit since all other units can still operate with limited number of data.

Disadvantages

- Smaller extend of data enables limited extend of stability analysis.
- Higher communication data transfer since the same data is sending to several distributed LS-WAMS.
- Coordination in case of event is more complex.
- Higher implementation cost.

3 LOW VOLTAGE WAMS

Since TSOs' communication network is closed for external users and therefore the access to installed PMUs in transmission network is not possible, the low voltage (230 V) centralized LV-WAMS was built for testing purpose. PMUs are connected to an electrical socket (230 V) at universities and institutions. The concept of LV-WAMS is illustrated in Figure 1:

- Acquisition units-PMUs are installed at different locations across Europe. The PMUs belong to different regional groups (RG) according to Interconnection networks i.e. RG Continental Europe, RG Baltic and RG UK.
 - Continental Europe:
 - Dortmund (Germany)
 - Almelo (The Netherlands)
 - Ljubljana (Slovenia)
 - Bucharest (Romania)

- Baltic:
 - Riga (Latvia)
- United Kingdom:
 - Glasgow
 - Manchester
 - London
 - Birmingham
- The WAProtector as phasor data concentrator is installed in Ljubljana. It acquires data from PMUs by the standard Internet communication network. For the communication link between PMUs and PDC the public Internet is used.
- Data visualization is performed by web SCADA which is the integrated part of the WAProtector.

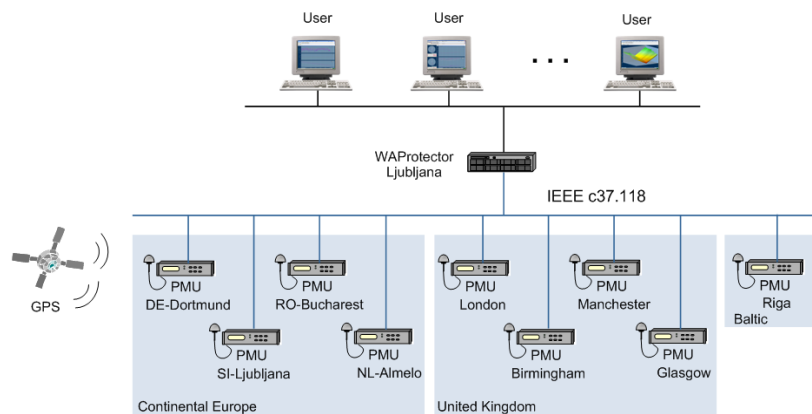


Fig. 1: Low-voltage WAMS configuration

WAProtector system beside PDC functionality performs:

- Data acquisition from PMUs,
- Phase angle difference monitoring,
- Low-frequency oscillation detection based on phase angle difference and frequency,
- Under/over frequency detection,
- Under/over voltage detection,
- Archiving of data into cycling data base. The storage is for the last 14-day with 20 ms sampling rate.
- Visualization for users with exporting capabilities. Example of visualization is given in Figure 2.

4 DETECTED EVENTS BY LV-WAMS

The project of LV-WAMS started in March 2009. From that time some smaller events have been detected. In the following three selected events are presented:

- Un-damped low-frequency oscillation.
- Reconnection of 400 kV line.
- Low-frequency oscillation caused by synchronisation of Turkish power system with the interconnected power systems of Continental Europe.

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30 May – 3 June 2011, Saint Petersburg



Fig. 2: Example of WAProtector vizualisation.

4.1 Recording of un-damped low-frequency oscillation

On September 22nd 2009 at 03:02:10 AM un-damped oscillations were detected on voltage phase angle difference between Dortmund and Ljubljana. The oscillation phenomenon was also present on the power system frequency. The dominant frequency of oscillation was around 0.5 Hz. The duration of un-damped oscillation was longer than 2 minutes. Recording of the event is given in Figure 3. It presents the voltage magnitude, voltage difference angle between Dortmund and Ljubljana, dominant frequency of oscillation, oscillation magnitude and frequency. Time window of recording is 3 minutes.



Fig. 3: Time window of recording is 3 minutes. The first chart presents voltage angle difference between Dortmund and Ljubljana. The second chart presents oscillation magnitude on voltage angle difference between Dortmund and Ljubljana. The third chart presents oscillation dominant frequency on voltage angle difference between Dortmund and Ljubljana. The fourth chart presents frequency captured in Dortmund (red curve) and Ljubljana (white curve).

According to some past experiences with un-dumped low-frequency oscillations [2] the reason for oscillation can be non-normal operation of generation unit. From figures above we can see that magnitude of dominant frequency oscillation of the power system frequency is higher in Dortmund (oscillation magnitude is approximately 10 mHz) than in Ljubljana (oscillation magnitude is

approximately 5 mHz). Therefore we can conclude that source of disturbance originated from the part of Europe which is closer to Dortmund.

Regarding on the recorded event we can conclude that event (low frequency oscillation) originated in one part of the transmission network affect to the whole power system and can be also well detected on the low voltage side.

4.2 Recording of reconnection of 400 kV line Slovenia Italy

Figure 4 illustrates recording during reconnection of 400 kV line between Slovenia and Italy. The observation window is one minute. The first chart presents voltage angle difference between Dortmund and Ljubljana. The second chart presents voltage magnitudes in Ljubljana, Dortmund, Almelo and Bucharest. The third chart presents frequencies at Ljubljana (white curve), Dortmund (red curve), Almelo (blue curve) and Bucharest (green curve).

The reconnection of the line has strong influence on voltage magnitude and frequency in Slovenia. Additionally it caused angle difference change between Dortmund and Ljubljana for approximately 7°.

Such recording of line reconnections can be interpreted as a step response and can be used for validation of power system elements models.

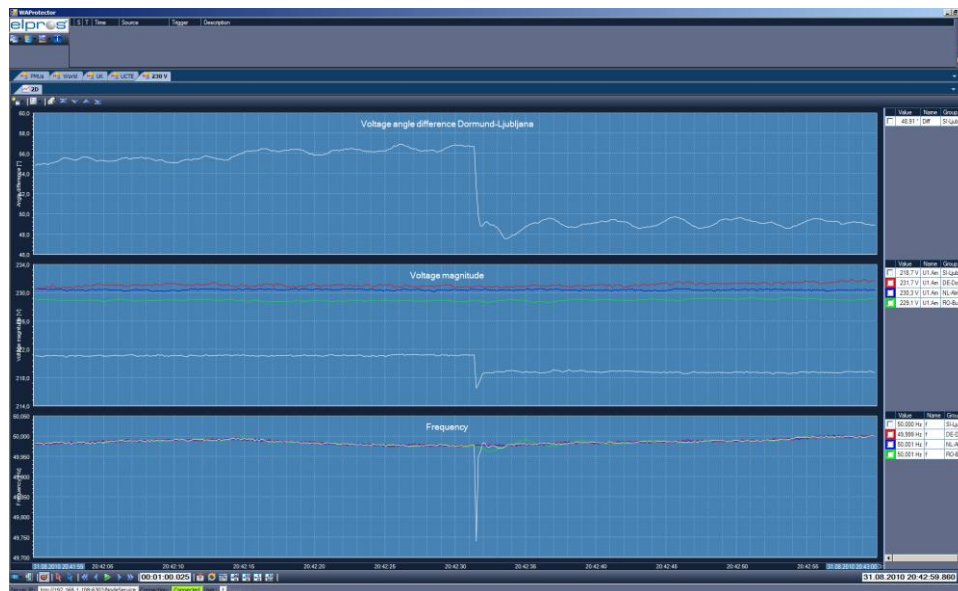


Fig. 4: Reconnection of 400 kV line Slovenia-Italy. Time window is 1 minute. The first chart is voltage angle difference between Dortmund and Ljubljana. The second chart is voltage magnitude at Dortmund, Ljubljana, Almelo and Bucharest. The third chart is the frequency at Dortmund, Ljubljana, Almelo and Bucharest.

4.3 Recording of synchronization of Turkish power system with the interconnected power systems of Continental Europe

Low frequency oscillations in the interconnected system of continental Europe can be divided into four dominant inter-area modes (global modes) in the low frequency range between 0.2 Hz to 0.5 Hz [3]. After the scheduled interconnection with Turkey a new Global mode (Turkish Mode) is expected with frequency around 0.15 Hz.

On 18th September 2010 at 9:25 AM the Turkish power system was synchronized with the interconnected power systems of Continental Europe [4]. After the interconnection of ENTSO-E with Turkey the new low-frequency oscillations occurred as shown in Figure 5 which presents FFT analysis performed on voltage angle difference between Dortmund and Ljubljana. The time window is 2 days. Before Turkey synchronization we can see permanent dominant frequencies in the range between 0.2 and 0.3 Hz and in the range between 0.3 and 0.4 Hz. After the synchronization new permanent oscillations in the range between 0.1 and 0.2 Hz occurred.

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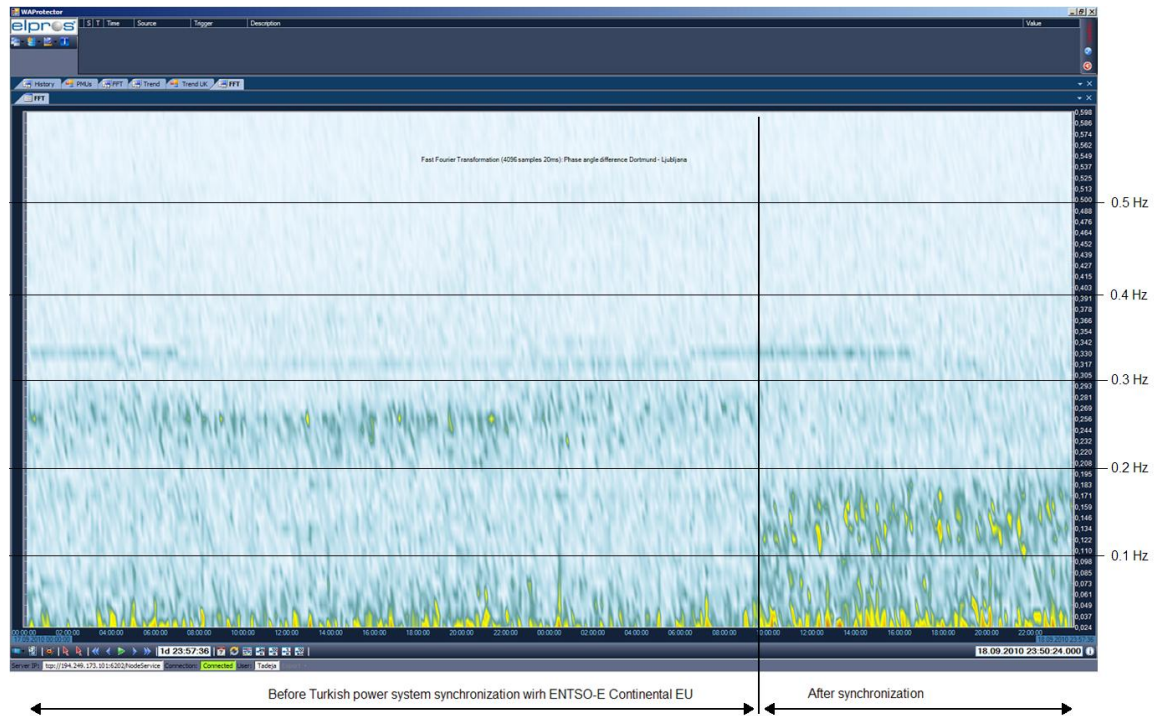


Fig. 5: Permanent dominant low frequencies before and after Turkish power system was synchronized with the interconnected power systems of Continental Europe. FFT is performed on voltage angle difference between Dortmund and Ljubljana.

One of examples of low-frequency (0.15 Hz) oscillations is given in Figure 6. It presents the voltage difference angle between Dortmund and Bucharest, oscillation magnitude and frequency at Dortmund (red curve), Ljubljana (white curve) and Bucharest (green curve). Time window of recording is one minute.



Fig. 6: Low frequency oscillation (~ 0.15 Hz) detected on voltage angle difference between Dortmund and Bucharest.

5 CORRELATION OF DATA FROM LOW VOLTAGE (230V) AND HIGH VOLTAGE (400 KV) GRID THROUGH EVENTS

5.1 Event: un-damped oscillation

An un-damped oscillation detected on frequencies is given in Figure 7. The first chart presents frequency in Dortmund and Ljubljana captured by 230 V WAMS and the second chart presents frequency at 400 kV substation Divača in Slovenia captured by 400 kV WAMS.

Conclusions: we can see that oscillation captured on 400 kV and 230 V in Slovenia is in strong correlation regarding oscillation magnitude and frequency.

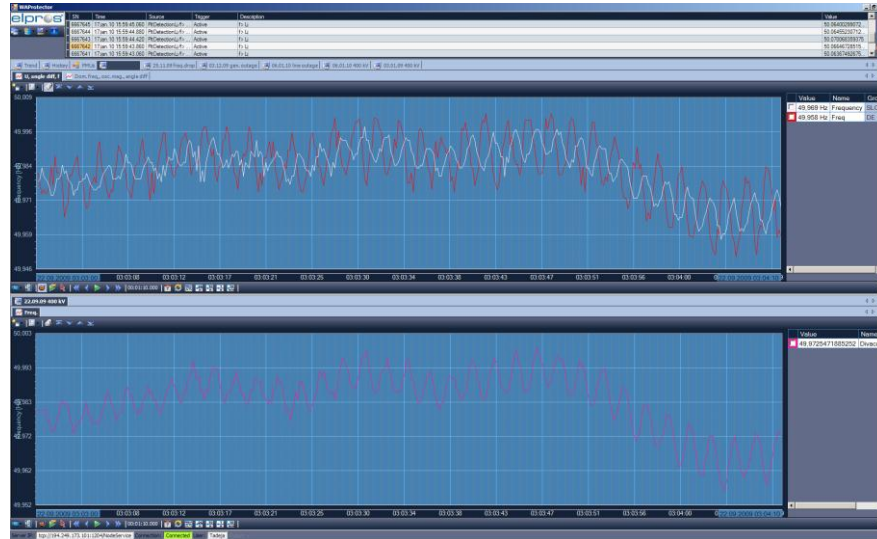


Fig. 7: Un-damped oscillation. Time window is one minute and 10 seconds. The first chart is frequency at Dortmund and Ljubljana captured by 230 V WAMS. The second chart is frequency at Divača substation (Slovenia) captured by 400 kV WAMS.

5.2 Event: reconnection of 400 kV line Slovenia-Italy

Comparison of LV in HV frequency data, when reconnection of 400 kV line Slovenia-Italy occurred, is given in Figure 8. The first chart is the frequency at Dortmund, Ljubljana, Almelo and Bucharest captured by 230 V WAMS. The second chart is frequency at three Slovenian 400 kV substations (Divāča, Beričevo, and Krško) captured by 400 kV WAMS.

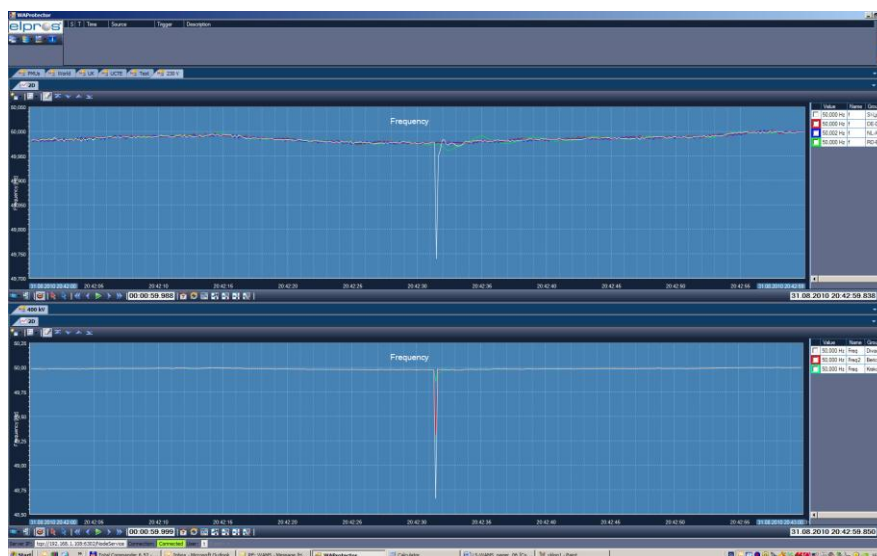


Fig. 8: Reconnection of 400 kV line Slovenia-Croatia. Time window is one minute. The first chart is frequency captured by 230 V WAMS. The second chart is the frequency at captured by 400 kV WAMS.

Similar to Figure 7, Figure 8 also shows a good correlation between measurements obtained by 230 V WAMS and 400 kV WAMS.

6 CONCLUSION

Based on the data obtained from 400 kV system and LV WAMS we can conclude:

- Some events can have a strong influence on the global or regional stability of the power system.
- Central system LS-WAMS inside interconnected networks like ENTSO-E can be very useful to improve the global stability of the whole network.
- For reliable operation of the LS-WAMS the communication network controlled by the TSOs is needed. Optional inside the ENTSO-E Electronic Highway can be used. Public network like Internet is not enough reliable for the LS-WAMS.
- The stability of power system stability can be increased by monitoring of the frequency and voltage angle difference. Based on that the inter-area power oscillation and islanding can be detected.
- Data measured on LV has strong correlation with data from HV. LV data like frequency and voltage phasors cannot be treated as confidential because such data are public available.

REFERENCES

- [1] ICOEUR (Intelligent coordination of operation and emergency control of EU and Russian power grids): <http://icoeur.eu/>
- [2] Babnik T., Gabrijel U., Mahkovec B., Perko M., Sitar G.: “The road from WAMS to WAPCS”, Paper PS3-304, CIGRE B5 Colloquium October 19-24, 2009, Jeju, Korea
- [3] Grebe E., Kabouris J., Lopez Barba S., Sattinger W., Winter W.: “Low frequency oscillations in the interconnected system of Continental Europe”, Power and Energy Society General Meeting, 2010 IEEE.
- [4] ENTSO (European Network of Transmission System Operators for Electricity): <https://www.entsoe.eu/>