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Implementation of Wide Area Measurement System in Slovenian Transmission System

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SUMMARY

Maintaining a reliability of power supply is essential for each utility. Therefore events leading to outages in power systems have to be avoided. Blackouts, voltage collapses and cascade tripping are mainly caused by wide area disturbances, such us voltage instability, frequency instability, etc. Phasor measurement units enable real-time monitoring of the power system. Real-time collection of phasor measurements from the power system into a central unit together with complex analysis offer a possibility for wide-area monitoring, protection and control.

This paper presents a developed complex wide area monitoring and protection system. The system includes high-speed data concentrator, multi-user Web SCADA, and programmable logic controller together with wide set of functions for real-time power flow and stability analysis as well as protection functions. Moreover, the system enables exchange of selected data with other companies. Additionally, some examples of obtained measurements are presented. At the end guidelines for future development of wide area protection and control system are given.

KEYWORDS

Synchronized phasor measurements, wide-area system, wide area monitoring, wide area protection, phasor data concentrator, multi-user Web SCADA, virtual PMU, stability calculation, post-mortem analysis.

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1. INTRODUCTION

Electrical power systems are constantly exposed to faults and disturbances. If a faulty power system element e.g. line, transformer or generator is not quickly isolated from the system, it may lead to element damage or it may pose a treat to reliable power system operation. Therefore, protective relays and devices are installed in the power system, with the basic objective being to reduce the consequences of faults by disconnecting the faulty elements.

Cascading events due to protective relay action following severe overloads, voltage instability or violation of operating limits can lead to a regional or even total blackout [1-2]. Wide area disturbances are rare events, however when they occur the effects on industries, commerce and the everyday life of the general population, can be quit severe.

In order to prevent or mitigate consequences of wide-area disturbances monitoring of dynamic of the power system is required. Phasor measurement units (PMU) enable current and voltage measurements for dynamic monitoring of the power system [3-5]. By a real-time collection of phasor measurements from the power system into a central unit it is possible to set up wide area monitoring, control and protection platform for a real-time procedures.

This paper briefly introduces the Slovenian transmission system equipped with phasor measurements units. The main part is focused on the first phase of developed Wide Area Monitoring System (WAMS). The emphasis is on the system architecture and functionalities. Moreover, measurements gathered from the WAMS implemented in the Slovenian transmission system are presented. The paper will conclude with the advantages of described system and future trends.

2. SLOVENIAN TRANSMISSION SYSTEM

The Slovenian transmission system is made up nearly 100 substations interconnected with 400, 220 and 110 kV power lines. The electric power system is connected to the electric power systems of the neighbouring countries as follows: two 400 kV power lines and one 220 kV power line with Austria, a 400 kV and a 220 kV power line with Italy, three 400 kV power lines, two 220 kV power lines and three 110 kV power lines with Croatia.

The demand of electric power as well as the power transfer in Slovenia transmission system is increasing every year. Increased power transfers raise concerns about steady-state overloads, increased risks of voltage collapses, and potential stability problems. Therefore, the decision was taken to implement the wide area measurement, control and protection system into Slovenian transmission system. At the fist stage five 400 kV substations are going to be equipped by PMUs as given in Figure1.

3. OVERVIEW OF THE WIDE AREA MONITORING SYSTEM

The basic hardware structure of the WAMS is given in Figure 2. The complex device WAProtector^{TM} gathers phasor data from PMUs via the standard intranet communication network. Different users, i.e. system operator, analysis engineers or engineers in protection centre have the access to the WAProtector^{TM} by Ethernet and thus can observe data using Web SCADA system which is the integrated part of the WAProtector^{TM}. Moreover, PMU data can be exchanged between different companies through WAN communication network. The WAProtector^{TM} consists of two main parts, real time system and visualisation system.

4. REAL TIME SYSTEM

The heart of the WAProtector^{TM} is the complex real-time device given in Figure 3. It has the functionality of:

- programmable logic controller with wide set of functions for real-time power flow analysis and protection functions,

- multi-user Web SCADA,
- phasor data concentrator (PDC).

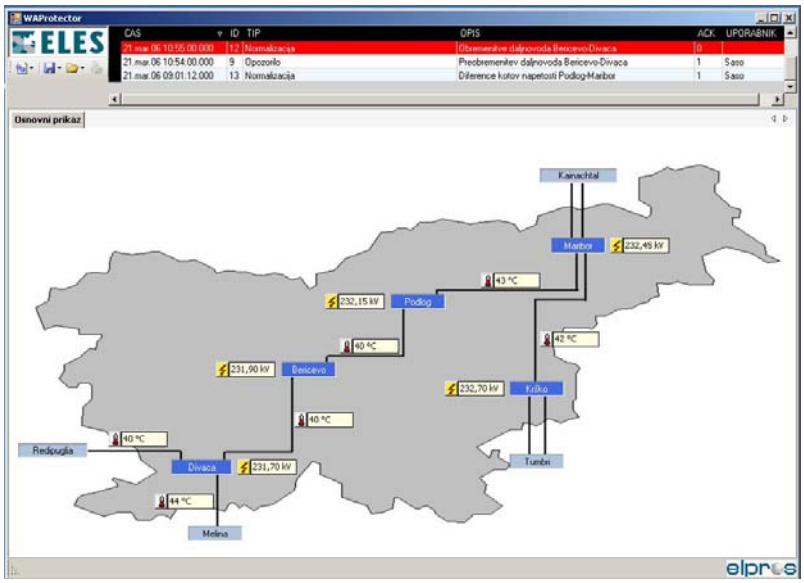

Figure 1: The first phase of PMUs placement in the Slovenian transmission system

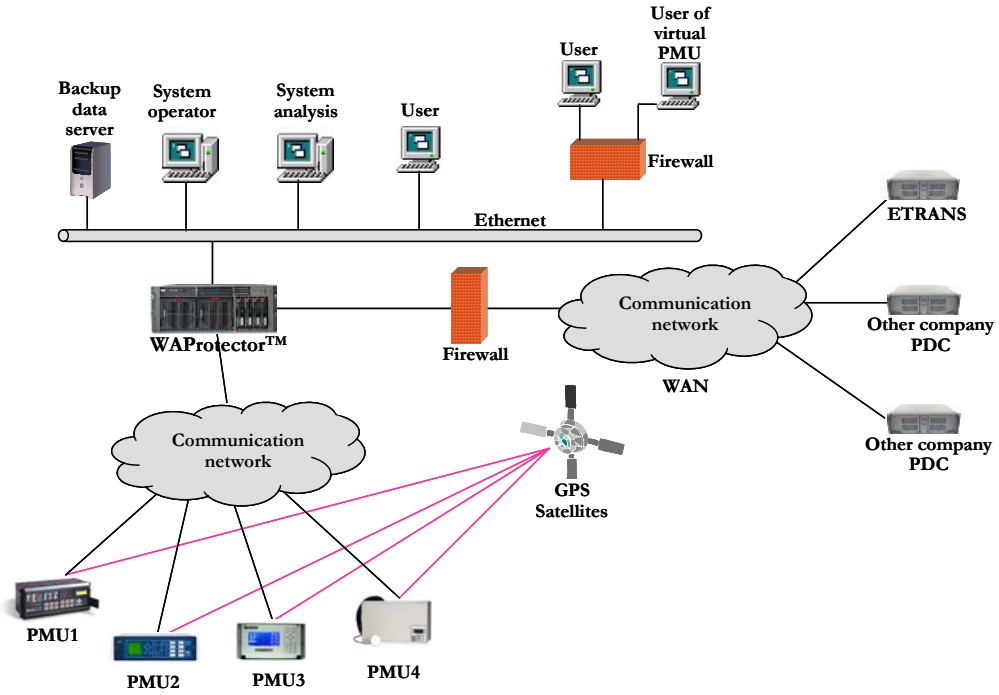

Figure 2: The hardware structure of wide area measurement system

4.1. Functionality of phasor data concentrator

The system acquires measurements at the sampling rate depend on the applied PMU. The server hardware performance determines the limits of the number of supported PMUs and applied algorithms. The hardware capability can be adjusted to the customer requirements. The system is modular and enables easy upgrade and adaptation to the customer needs.

The real-time database enables up to the last 14 days of measured and calculated values (i.e. currents, voltages, power, different stability indices, etc.) with maximal sample rate in normal condition.

When a disturbance occurs, the system enables disturbance recording, i.e. the certain time before and after the event is stored for post-mortem analysis. If a disturbance is still present after the predefined

time, the system automatically extends the duration of capturing. The length of disturbance recording can be up to 30 minutes for user selected data values.

WAProtector™ provides a wide range of communications protocols to collect and yield synchrophasor data. PMU client drives acquire data from PMUs. They support IEEE 1344 and C37.118 synchrophasor data format, IEC 60870-5-101/104, and DNP protocols. The IEC 61850 protocol is going to be available soon.

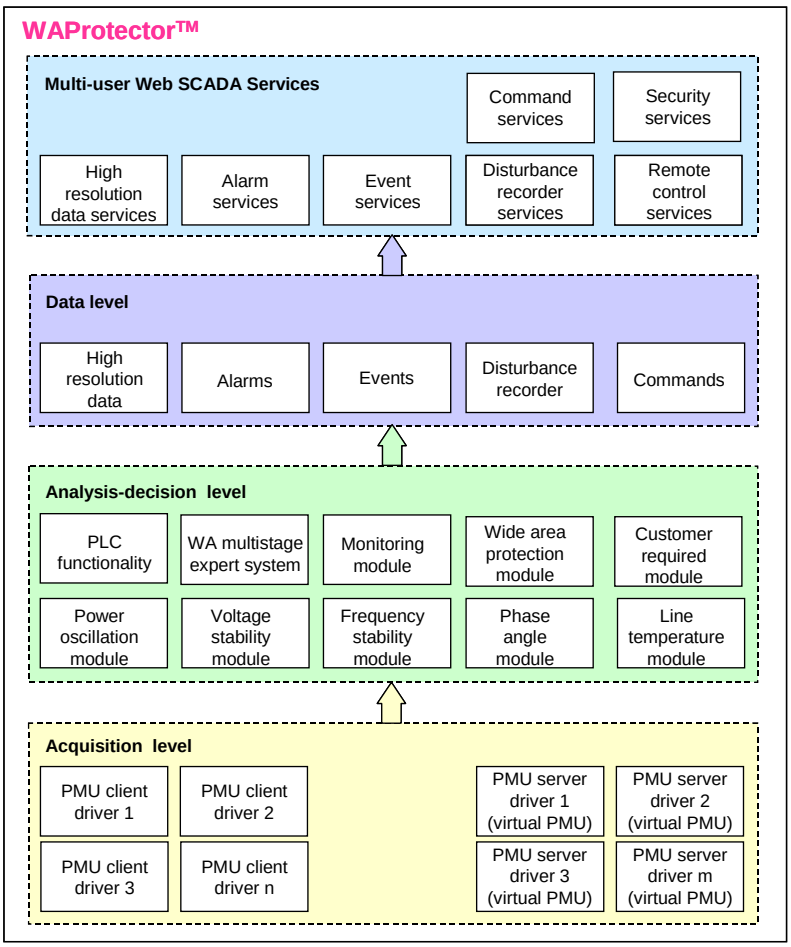

Figure 3:The structure of real-time WAMS

4.1.1. Virtual PMU

The purpose of the virtual PMU is to present selected data, obtained from physical devices, for exchange with other users. Two or more companies can share selected data from one or more PMUs, for example, lines connecting two substations, one in Slovenia (Beričevo) and one in Italy (Redipuglia), Figure 1. The line has two PMUs at each end one, one belonging to ELES and another to Terna.

Moreover, the virtual PMU enables exchange of data via different communication network. This way the access to the company intranet, which is closed for the other companies, is not required. The main advantage of the virtual PMU is that the user (client) is connected to it on the same manner as on the physical PMU, i.e. the same protocol, without access to the local intranet.

The trend in Union for the Co-ordination of Transmission of Electricity (UCTE) is going to have one international centre for monitoring the whole interconnection system. Virtual PMUs gives the possibility to exchange only important or required phasors.

4.2. Data Analysis

Data analysis part performs extensive complex real-time calculations important for reliable power system operation:

- Voltage stability calculation for monitoring the power transfer on a certain line or corridor.
- Frequency stability calculation detects frequency changes as a result of a sudden large generation deficit or sudden loss of load.
- Power oscillation function is used for identification of power swings on power lines. This function calculates the oscillation dominant frequency, its magnitude and damping coefficient.
- Phase angle function monitors the differences in the phase angles between two busbars in the network.
- Line temperature function monitors the thermal limits of the line. Based on the on-line temperature calculation this module enables higher loading of the power line without exceeds the maximum line temperature.

Wide area protection modules enable:

- wide area differential protection,
- wide area level detection protection.

Wide area differential protection serves for detection of difference between two values, e.g., phase angle difference between two nodes or frequency difference between two nodes. The alarm or warning is trigged when the set difference between two quantities is reached.

Wide area level detection protection detects violations of selected quantity, e.g., over/under voltage, over/under frequency, or calculated indices. Each alarm can have two or more levels.

Wide area multistage expert system protection is an expert system, which combines different status of protections, described above and gives the possibility for more sophisticated decision-making.

5. VISUALISATION SYSTEM

User-friendly designed graphical interfaces are the most important tool for power system operators and analysts. WAProtector^{TM} is based on the latest advanced Internet .NET technologies. The visualisation system enables multi-user Web SCADA presentation of:

- real-time measurements and calculated values,
- statuses,
- historical database for the last 14 days,
- events and alarms,
- event disturbance recordings,
- historical data stored on the local user computer.

The user can choose between:

- two and three-dimension time-base curves,
- the polar coordinate phasor diagrams,
- bars,
- the single-line diagram,
- PV curve,
- voltage stability indicator,
- line thermal monitoring.

Multiple windows as shown in Figure 4 based on complete user interoperability and adjustment give operators and engineers the flexibility to create customized visualizations. This way it is possible to optimise their ability to monitor and analyse the power system. The example of multiple windows illustrated in Figure 4 displays voltage and current phasors given in the polar diagram, 2-D trend of voltages and currents flowing into the node Divača and bar presentation of currents.

Moreover, the visualisation system makes possible allocation of windows on more monitors that lead to better view of the data, Figure 5. The system also enables the animation of historical data. This way

the event or selected time period can be reviewing. The user can choose the speed of animation moving between the data (fast or slow).

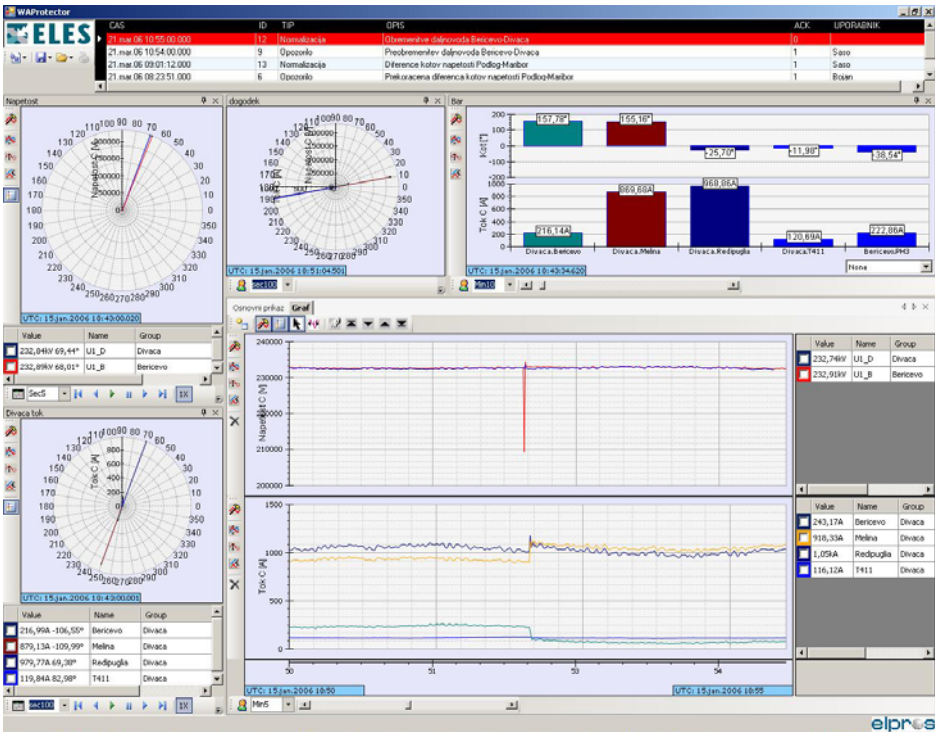

Figure 4: Multiple windows enables customized visualization

6. POST-MORTEM ANALYSIS TOOL

Post-mortem analysis of captured measurements enables post-mortem analysis tool. It makes complex arithmetic operations on time series measurements. Advances functions like different type of filters, spectral analysis and statistics are also provided. The user can also build complex user-defined functions. The tool is user-friendly and is based on a drag and drop principle. It enables synchronised presentation of measured and calculated values. An example of post mortem analysis is shown in Figure 6.

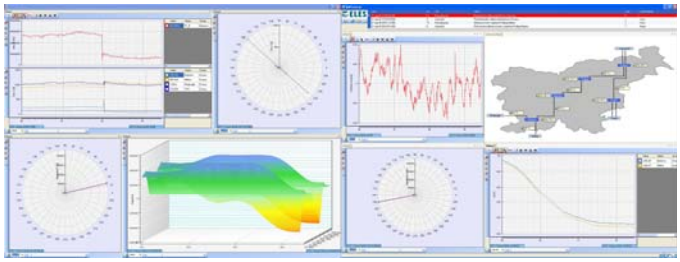

Figure 5: Visualisation on two monitors

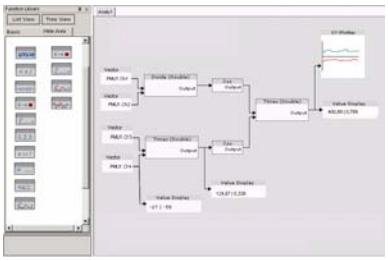

Figure 6: Post-mortem analysis tool

7. EXAMPLE OF RECORDINGS

The first stage, i.e. the functionality of wide area monitoring system has been implemented in the Slovenian transmission system in January 2006. One of the captured events by the WAProtector^{TM} is given in Figure 7. The event duration is 60 seconds. Outage of one of the transmission line caused change in power transfer, which is seen from diagram showing the active power. Beside the active power, also voltage magnitudes at Divača and Beričevo substation are presented. Additionally, voltage phase angles are given. The angle at the Beričevo substation is chosen as a reference angle, therefore it value is zero while the angle at the Divača substation oscillates. The evident oscillation was caused by the transient. The same event is taken under deeper look in Figure 8. The duration of observation

window is 10 seconds. The oscillation is well damped as it can be seen from active power given in the first graph.

Figure 7: Recordings obtained from PMUs at Divača and Beričevo substations

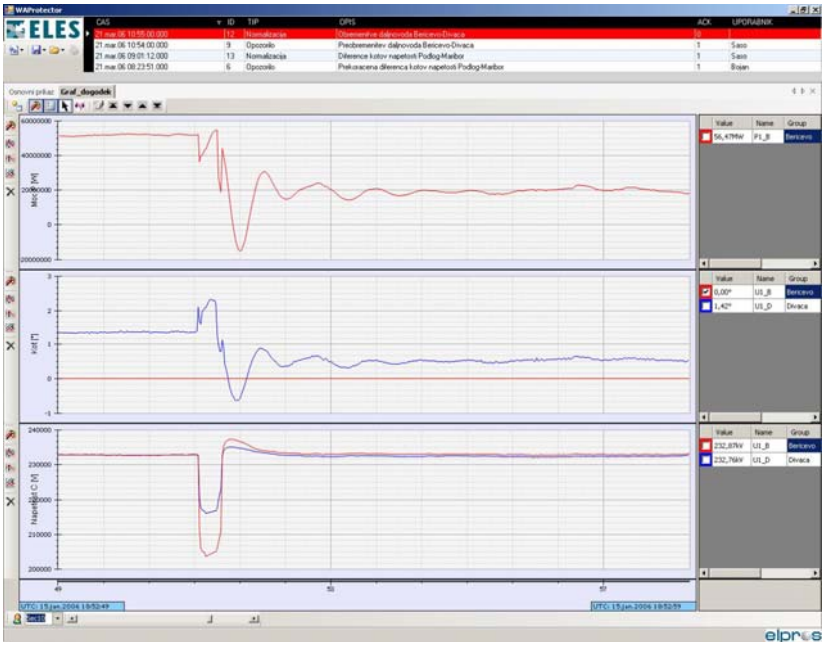

Figure 8: Real-time data display of active power, phase angle and voltage profile

8. FUTURE TRENDS

Wide area systems currently available on the market primarily serve as monitoring systems. Trends in the future are going to serve as a wide area protection and control systems. The main focus is in:

- wide area power system protection schemes,
- preventive and remedial action procedures involving control activates of tap-changers, reactive shunt device, frequency control, etc.,
- system back-up protection for classical protection schemes,

- new communication trends based on time-deterministic communications, which will enable deterministic operation time for actuators,
- complex state estimator functions.

9. CONCLUSIONS

The power flow in the transmission system might change very fast. Furthermore, the margins in transmission system and generation capacity are decreasing. The power system operates closer and closer to its limits. Therefore, the need for accurate fast and reliable monitoring and control systems is increasing.

A major component of the wide are protection is the ability to receive information from the entire power system in real-time together with taking decisions, actions and control in the real time. Very fast development of communication technologies gives the possibilities for realization of wide area protection. The strength of communication development will fully show its potential in the near future.

This paper presents the developed device WAProtector^{TM} and its implementation in the Slovenian transmission system. The primary goal of presented system is to monitor the power system in real-time and alert the system operator if the measured or calculate values exceed the setting values. Additionally, the system enables exchange of measured data with other international companies. WAProtector^{TM} potential lies in the real-time wide area protection and control system.

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