



Estonian WAMS System – Implementation and Experiences

Jako KILTER¹, Alexei N. GOLOSHCHAPOV², Bojan MAHKOVEC³
Elering OÜ¹, PARMA Ltd.², ELPROS³
Estonia¹, Russia², Slovenia³
edlund@parma.spb.ru

KEYWORDS

WAMS, WAProtector, PMU.

1 INTRODUCTION

Reliable and secure operation of electric power systems is a fundamental requirement for the modern societies. The increasing complex of interconnected electric power systems introduces considerable challenges to the automation, control and operation management systems for maintaining reliable, secure and stable operation of large-scale power systems.

Monitoring of dynamic of the power system can prevent or mitigate consequences of wide-area disturbances. Phasor measurement units (*PMU*) enable current and voltage measurements for dynamic monitoring of the power system [1]. 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. Overviews of wide area monitoring system (*WAMS*) and different implementations are available in the literature [2], [3], [7].

In order to monitor the operation of Estonian power system in different conditions and obtain more reliable information Estonian Transmission System Operator decided to implement wide-area monitoring system. The objective was to measure the basic state variable from all interconnectors to Russia, Latvia and Finland and from some important lines inside Estonia. Currently used *SCADA* system alone could not provide adequate information with sufficient rate of measurement data. Moreover, the need to understand the behavior of possible inter-area oscillations and voltage stability phenomenon's, but also to obtain information for verification of the Estonian power system dynamical model were sufficient to justify the purchase of *WAMS*. For longer perspective the studies for system protection including *WAMS* were planned.

This paper presents an overview of the *WAMS* implemented by Estonian TSO. *PMU* devices, placed at different locations at 330kV grid, serve as acquisition units. The complex *PDC* (Phasor Data Concentrator) device is used for:

- continuous phasor data acquisition from *PMU* devices,
- monitoring and detection functions,
- storage of measured and calculated values in a database,
- multi-user Web *SCADA* for real-time and post-mortem data visualisation.

The paper also describes the experiences that Estonian TSO (*Elering*) has obtained with the system and also some examples of captured events, e.g. outage of large generation unit in Russia and its influence to system frequency, some of the interesting effects of system contingencies both in Russia and Estonia and their effect on Estonian power system and its interconnections; are presented.

At the end guidelines for future use of *WAMS* are given. The emphasis will be on verification of the dynamic model, increasing the monitoring system, international co-operation and integration of *WAMS* and *SCADA* state estimator.

2 ESTONIAN POWER SYSTEM

Estonian power system is a part of the Baltic power system that is located at a crossroad between three large synchronous networks – former *UCTE*, Nordic and *IPS/UPS* (Fig. 1). Estonian power system is located at the Northern-Western part of the so-called power loop and it is connected with other systems by five 330 kV overhead lines (three lines to Russia and two to Latvia) and by one *HVDC* link to Finland. Currently, second interconnection to Finland (650 MW *HVDC LCC*) is at its building stage and it will be in operation 2014. The distinctive characteristic of Estonian power system is its configuration. Basically all production is located at the Northern-Eastern part of Estonia, but at the same time over 60% of consumption is located at the Northern region. Estonian *HVDC* connection to Nordic is also located at Northern region. Therefore, there are large energy flows between Northern and Northern-Eastern parts of Estonian power system. Additionally, there are rather big energy flows, depending on loop operation, at Northern-Southern corridor of Estonian power system due to the power transfer from St. Petersburg region to Lithuania and Belarus and vice versa.

Estonian TSO operates 110 kV and 330 kV network. There are ten 330 kV substations with 1514 km overhead lines and 133 110 kV substations with 3415 km overhead and cable lines. Installed capacity is ca. 2,2 GW (80% oil shale, 7% wind, 7% natural gas, 6% others), peak load ca 1,5 GW and yearly consumption ca 8 TWh.

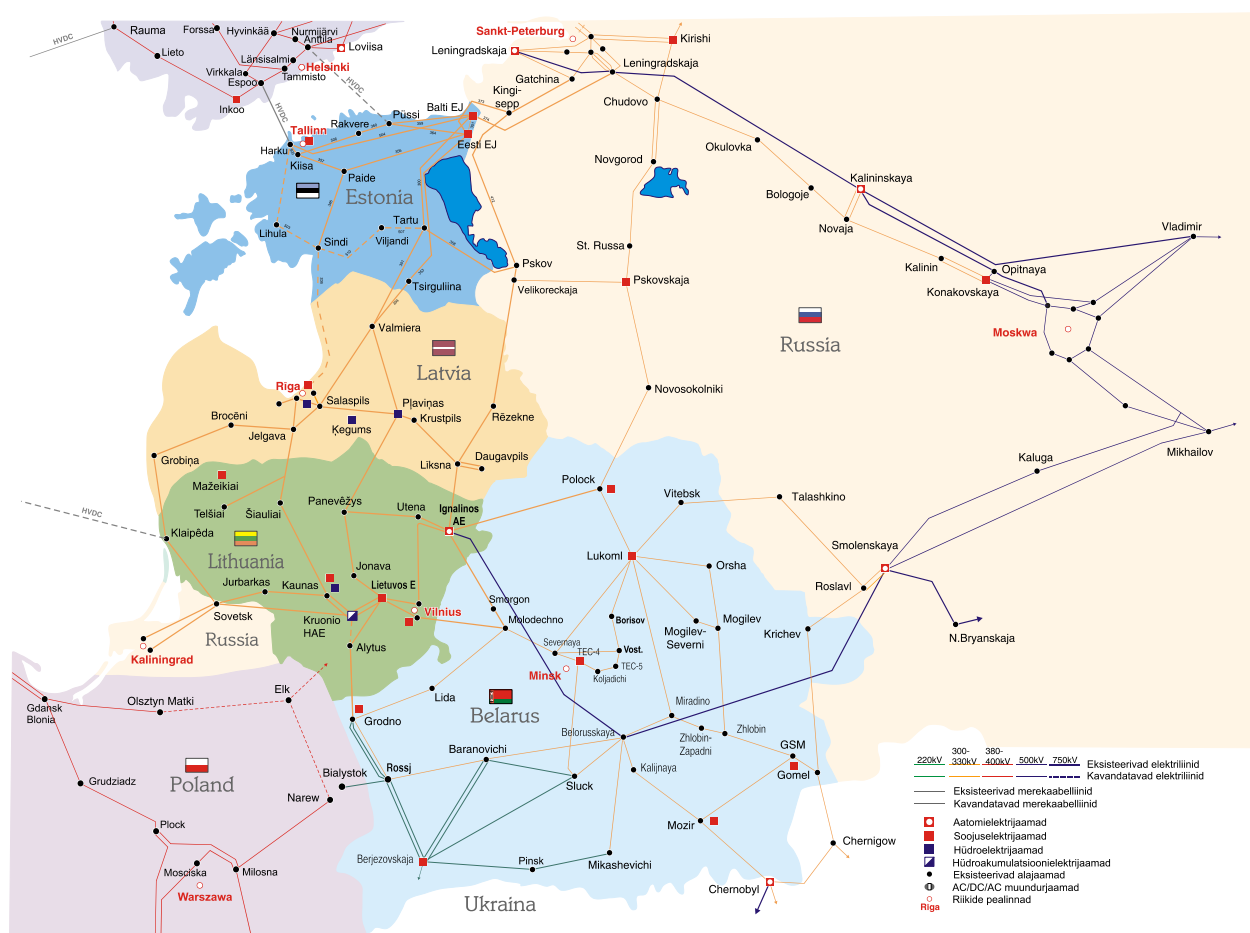


Fig. 1: Baltic Power System

3 ESTONIAN WAMS

Estonian *WAMS* consists of central data concentrator and ten *PMU* devices. The *PMU* devices are installed at five 330 kV substations, Harku, Tartu, Püssi, Eesti and Balti, covering ten transmission lines as shown in Figure 2. The *WAProtector* as phasor data concentrator is installed at Estonian TSO Control Center. The implemented *WAMS* architecture is given in Figure 3.

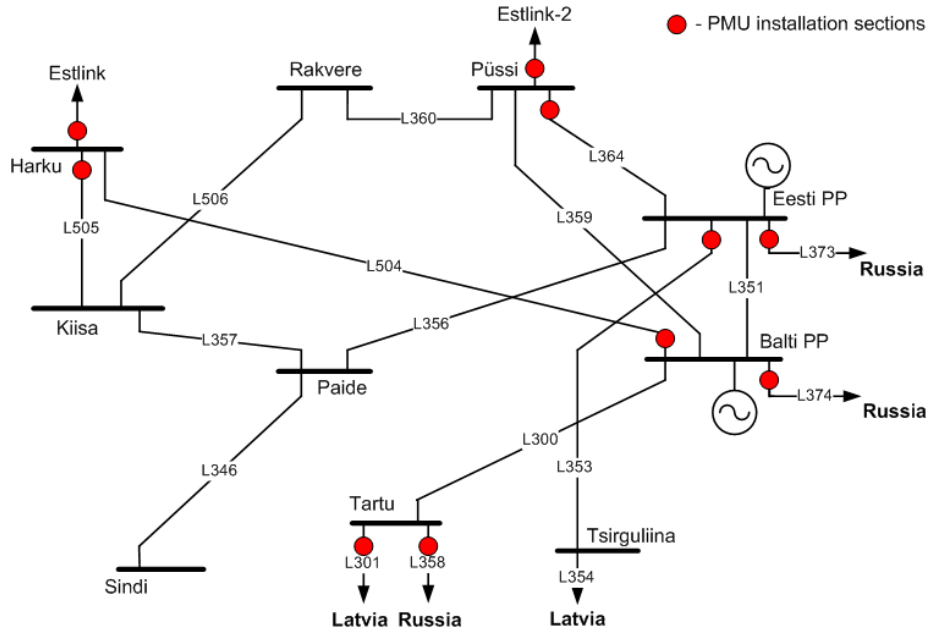


Fig. 2: PMU locations in Estonian Power System.

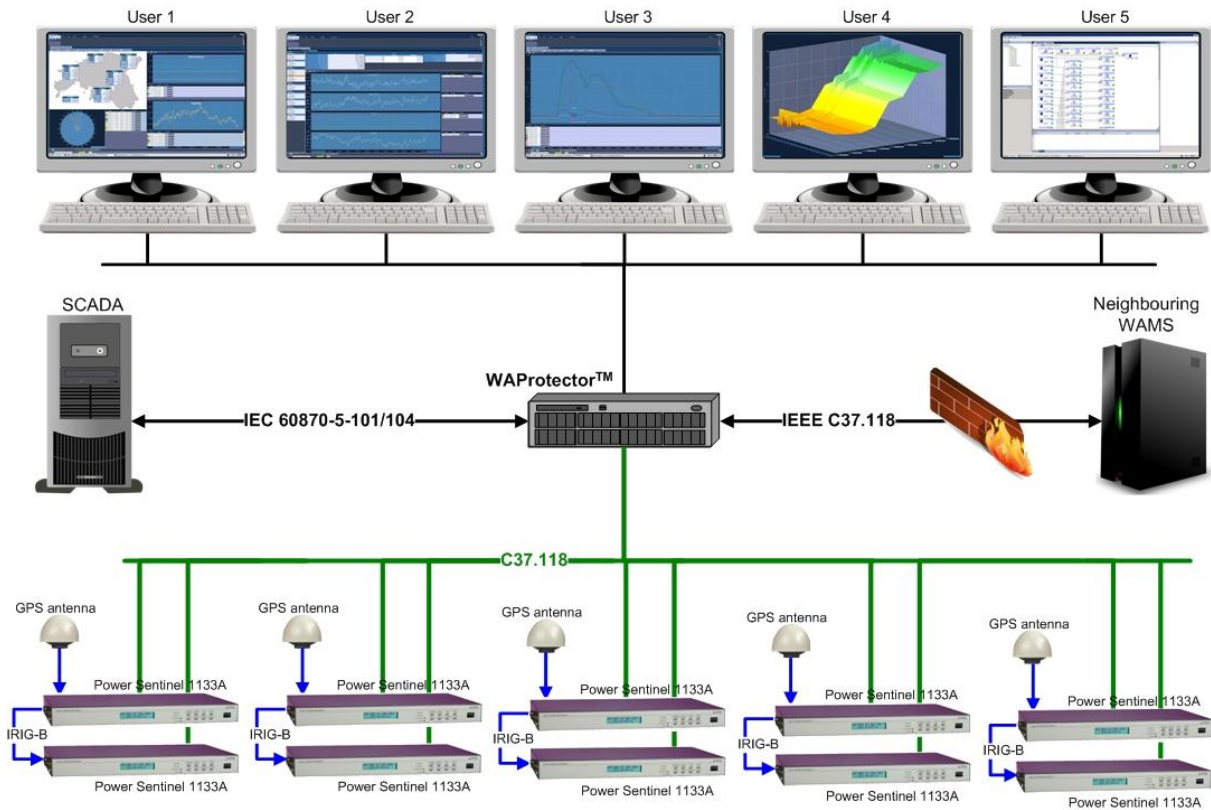


Fig. 3: Estonian WAMS architecture.

3.1 Phasor measurement units

Installed PMU devices, model 1133A Power Sentinel by Arbiter Systems Inc [4], provide the time synchronised precise measurements of power system state parameters according to IEEE C37.118 standard requirements: phase angles and magnitudes of voltages and currents, frequency, real and reactive power etc. All data from PMU-s is transmitted to the WAMS server through fiber-optic communication lines by IEEE C37.118 protocol format. Time synchronization of measurements is

provided by *GPS* receiver built in one of *PMU* on each substation. Through this *PMU* the second *PMU* in the substation is synchronized by *IRIG-B* interface.

3.2 *Data concentrator - WAprotector*

WAProtector [5] is a multifunctional system for power system wide area monitoring, protection and control. The system contains following functionalities:

- Complex phasor data concentrator
- Real-time data analysis
- Detection of abnormal power system operation states
- Data archiving
- Data visualization
- Real-time data exchange

In Estonian *WAMS* system the following functionalities are implemented.

3.2.1 *Communication connectivity*

WAProtector provides a wide range of communications protocols to acquire and transfer synchrophasor data. The system supports:

- Data connectivity with *PMU* devices over IEEE c37.118/IEEE 1344 communication standard (client driver).
- Communication connectivity with other *PDC*-s over IEEE c37.118/IEEE 1344 communication standard (server driver).
- Communication connectivity with other systems like *SCADA/EMS* through standard protocols like IEC 60870-5-101/104, etc.

3.2.2 *Real-time data analysis*

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

Stability detection functions:

- Phase angle difference detection, for detection of phase angle differences between two substations
- Low frequency oscillation detection, for detection of un-damped low-frequency oscillations detected on power, frequency or phase angle difference.
- Over/under value detection, for detection when observed quantity exceeds (fall) the threshold value.

Signal processing functions:

- Fast Fourier Transformation, for detection of permanent oscillation phenomena

User programmable functions are used for design of user own functions and include:

- Logical functions (and, or,...),
- Arithmetic operations (+, -, *, /,...),
- Comparison functions (>,<, =, ...),
- etc.

3.2.3 *Data archiving*

Data archiving contains real-time circular database, event database and disturbance recordings (oscillography) database. The real-time circular database enables data storage of measured and calculated values (i.e. currents, voltages, power, different stability indices, etc.) with maximum sample rate 1 sample per cycle (50 samples per second). The real-time circular database has 14 days of data storage. The event database is used for archiving of events and alarms. Disturbance recording is separately recorded data storage activated when an event occurs. It is used for post-mortem analysis.

Actual Trends in Development of Power System Protection and Automation 30 May – 3 June 2011, Saint Petersburg

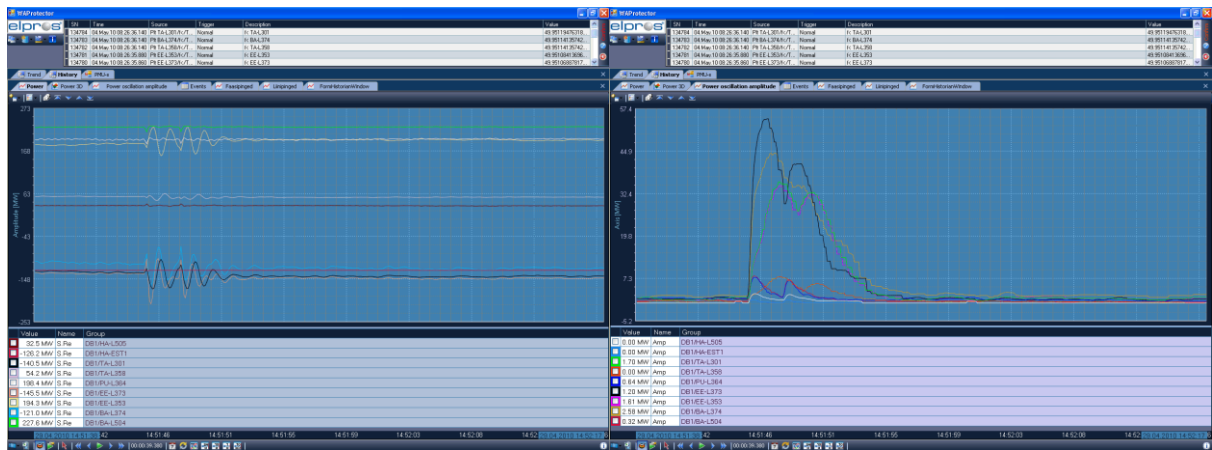


Fig. 5: Oscillations on the interconnectors after a contingency outside Estonia

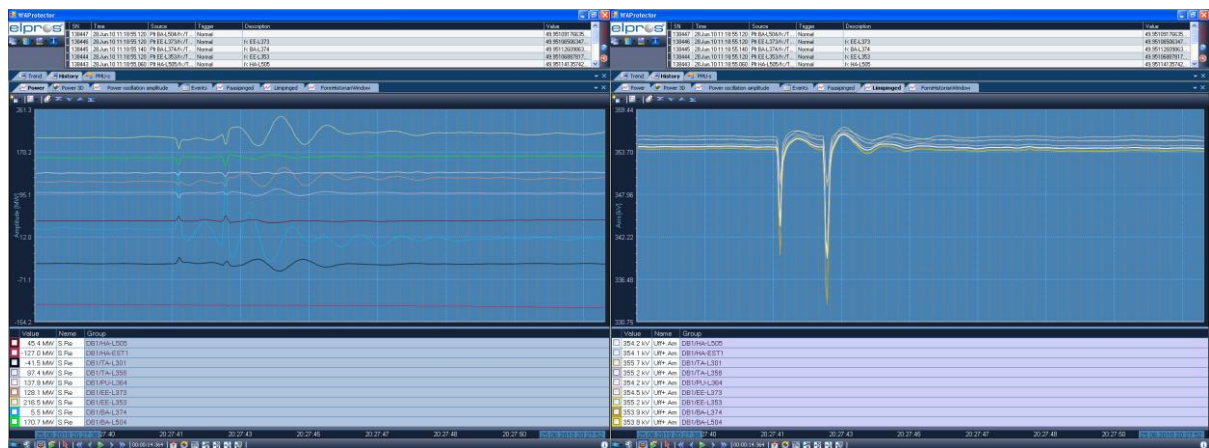


Fig. 6: Estonian power system operation after line L372 outage in Russia

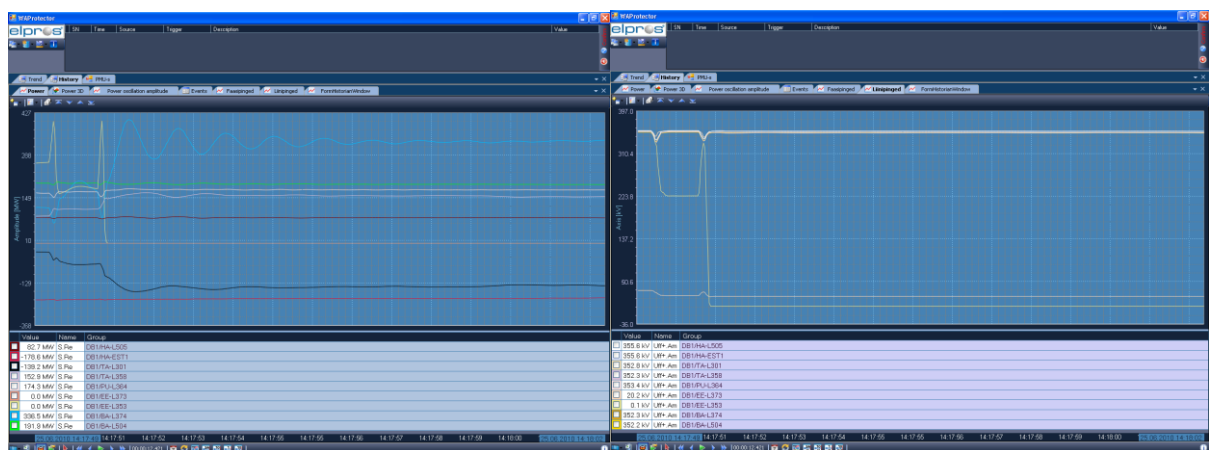


Fig. 7: Estonian power system operation after line L373 outage

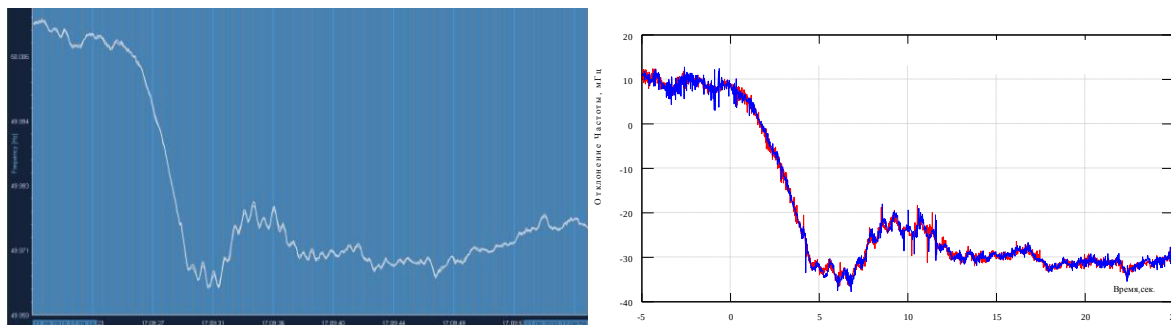


Fig. 8: System frequency deviation in case of power plant outage

5 FUTURE WORKS

Currently the WAMS system is used only for measurement and for system analysis purposes. Based on the information, it is possible to assess the system operation and analyse the effects of different contingencies to system operation purposes. This approach gives good base to continue the development of WAMS. To increase the effectiveness of the monitoring system data exchange between neighboring countries is planned. With Latvia and Lithuania it could be handled online and with Russia the data could be exchanged offline.

The next phase in the project would be to integrate the WAMS measurements into SCADA state estimator in order to improve its accuracy and as a consequence to increase the effectiveness of system operational planning. The important step is also use the available data for the development and verification of the power system dynamical model. Preliminary studies in this field have already been performed and the results have shown that tuning of models is necessary.

When looking to the future one must also consider the possibility of using the WAMS system for system protection purposes. This includes (i) preventive and remedial action procedures involving control activates of tap-changers, reactive shunt device, control of HVDC links power flow, frequency control and (ii) system back-up protection for classical protection schemes. This is especially interesting in Estonian context considering the system operation and possibility to handle system contingencies after the installation of second HVDC connection to Nordic [6]. Due to that, the existing protection schemes have to be refurbished and WAMS is one promising solution. Nevertheless, before system protection functions could be implemented, the issues regarding, redundancy, communication, data latency, system reliability etc., have to be resolved.

6 CONCLUSION

Power system security depends on different criterions e.g. system configuration, equipment used, monitoring system etc. Power flow changes over the years in transmission system have changed and mostly we are moving closer to operational limits. Commonly used SCADA systems do not offer possibility to monitor fast system process and therefore more advanced monitoring system is needed. In order to comprehensively monitor and control system operation wide area monitoring and control system offers many possibilities.

In this paper an overview and examples of WAMS system development in Estonian power system have been showed. The obtained, modern and powerful, on-line wide-area measurement system, provides accurate measurements of power system state variables, acquisition of all information, data processing, visualization and archiving – all spectrum of WAMS functionality.

The WAMS system implemented in Estonian power system consists of data concentrator and ten PMU devices with possible future connections to neighboring WAMS systems and also data exchange with SCADA state estimator. Currently the main objective of the system is to monitor the operation of interconnectors and use the available data for system analysis. This has already given reasonable amount of information and understanding of system processes. Verification of system dynamical model has provided understanding that additional tuning of the models is necessary. In the future, other functionalities and possibilities of WAMS, e.g. information exchange with SCADA and other neighboring WAMS systems, system protection, voltage stability etc., are planned to be implemented.

Especially, the field of system protection offers many challenges and it is important due to system development (second interconnector to Finland, load increase etc.) and requirements for higher system security.

REFERENCES

- [1] Phadke, A. G. Synchronized Phasor Measurements – A Historical Overview”. In. *Proc. IEEE PES T&D Conf. Asia Pacific*. Yokohama, Japan, Oct. 2002. Vol. 1, pp 476-479.
- [2] Sattinger, W., Bertsch, J., Reinhardt, P. Operational Experience with Wide Area Monitoring Systems. In *Proc. CIGRE 2006 Session*, Paris, 27 August – 1 September 2006, paper no. SC B5-216.
- [3] CIGRE Technical Brochure nr 330. “Wide Area Monitoring and Control for Transmission Capability Enhancement”. 2007, 116 pp.
- [4] Model 1133A Power Sentinel™ operation manual, Arbiter Systems.
- [5] WAProtector user manual, Elpros.
- [6] Kilter, J., Reinson, A., Kraav, R. Influence of system protection to Estonian power system security. *Proc. of 2010 Power Quality and Supply Reliability Conference PQ2010*, Estonia. 2010, 6 pp.
- [7] 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