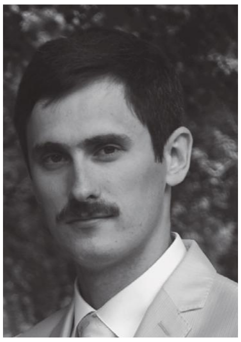
ЭЛЕКТРОТЕХНИЧЕСКИЕ КОМПЛЕКСЫ И СИСТЕМЫ
ELECTRICAL FACILITIES AND SYSTEMS

Антанс Саухатс
Antans Sauhats
Dr. habil. sc. ing, Professor
Director of Power Engineering
Institute Riga Technical University
Riga, Latvia



Дмитрий Антонов
Dmitrijs Antonovs
Mg. sc. ing.
Researcher, Power Engineering
Institute Riga Technical University
Riga, Latvia

Диана Жалостиба
Diana Zalostiba
Dr. sc. ing.
Docent, Power Engineering Institute
Riga Technical University
Riga, Latvia

Александр Долгицер
Aleksandrs Dolgicers
Dr. sc. ing.
Asoc.professor, Power Engineering
Institute Riga Technical University
Riga, Latvia

Эдите Биела-Даилидовича
Edite Biela-Dailidovicha
Mg. sc. ing.
Researcher Power Engineering Institute
Riga Technical University
Riga, Latvia

УДК 621.313.2:537.6/.8

APPLICATION OF POWER SYSTEM MODELLING SOFTWARE FOR EDUCATIONAL AND RESEARCH PURPOSE

To ensure the success of the personnel of power systems are required not only deep theoretical knowledge, but also practical skills, the acquisition of which in modern universities is associated with considerable difficulties and problems. The paper provides an overview of opportunities to overcome part of these difficulties by creating automation and protective relaying testing educational and research scientific base. For generating of test signals, power system emergency processes records and simulation software are used. For research purposes special algorithm of terminal settings verification and evaluation is created and results are presented with corresponding examples of case study.

Key words: educational technologies, power engineering, modelling, out-of-step regime, testing, software, terminal setting, GPS synchronization.

ПРИМЕНЕНИЕ ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ МОДЕЛИРОВАНИЯ ЭНЕРГОСИСТЕМ В ОБУЧАЮЩИХ И НАУЧНЫХ ЦЕЛЯХ

Для обеспечения успешной работы персонала необходимы не только глубокие теоретические знания об энергосистеме, но и практические навыки, получение которых в современных университетах связано с определенными трудностями и проблемами. Данная статья включает в себя обзор возможностей, которые позволяют преодолеть часть трудностей при помощи создания научной и исследовательской базы тестирования автоматики и релейной защиты. Для формирования тестовых сигналов используются записи аварийных процессов энергосистемы и программное обеспечение моделирования. Для исследовательских целей создан специальный алгоритм верификации и оценивания уставок терминалов, также представлены результаты с соответствующими примерами для конкретного случая.

Ключевые слова: технические средства обучения, энергетика, моделирование, асинхронный режим, тестирование, программное обеспечение, уставки терминала, GPS-синхронизация.

I. Introduction

For hundreds of years, energy has been at the basis of the development of human society and technical progress. Electric energy, due to its characteristic features, has advantages in industrial, production, transport and communication applications. The rising welfare level and life standard stimulates the necessity for energy services. Energy consumption is steadily growing; this tendency is expected to persist in foreseeable future and to promote further development of electric power systems.

The world's growing population, the scarcity of energy resources and striving after the benefits offered by modern civilization have resulted in power systems of grandiose dimensions. Power systems are arguably among the most complicated artificial technical systems created as a result of human activities. They consist of thousands of generators, transformers, hundreds of thousands of kilometres of transmission lines and millions of consumers. The maintenance and development of a power system in any country requires significant investments and qualitative personnel. The consumers, independently from the generators, change their energy demand in accordance with their needs. All the elements of the power system function as a unified system. The operation of the power system is strongly influenced by a number of natural factors. Changes in the operating conditions also make it necessary to change the operating mode of power facilities.

The rise in energy consumption, the growing dimensions of power systems, their degree of complication and significance, the increase in the prices of energy carriers, the influence of occasional factors and uncertainty – all of the aforementioned has sharpened a number of serious energy-related problems [1].

Efficiency and availability of power supply is critically important in modern world. Unfortunately, the standards of living for different layers of population differ even in developed countries that are well provided with energy. Still larger are the differences in living standards between industrially developed countries and developing countries. Provision with energy resources is very inhomogeneous at various places of the world. As a result of this, one fourth of the world's population still has no access to electric energy sources and, consequently, to most of the benefits offered by modern civilisation. The main reason for this is the energy price, which is inaccessible to the poorer layers of population. The growth in the energy prices hampers the development of industrial production and consequently limits the opportunities to solve many social and environmental problems.

Power supply reliability is another important direction in power system. Humanity has gradually got accustomed to conditions that are unthinkable without guaranteed energy supply and has adapted its way of living accordingly. Even in case of short-term power cuts, modern-day cities, industrial enterprises and transportation systems suffer damage and large-scale economic loss, emergency and catastrophe threats arise, possibly even with large casualties.

Environmental impact is relatively new field of science, but not least important, that mentioned earlier. Energy production is practically impossible without influence on climate, the air and water basin, natural sceneries and, as a result, the human living environment.

Sustainability is included in different development strategies for achieving better results in future. This concept is linked to the limited amount of basic resources available to modern society. Although the amount of energy produced from renewable sources has increased considerably over the last decade, yet it is expected that almost 85 % of the increase in the energy production amount will be related to an increase in the consumption of fossil fuel.

The acuity of the above problems has resulted in decisions on an international scale regarding the restructuring of power systems and the use of market conditions and mechanisms in the management of the development and operation of power systems. The power system is divided into a number of legally independent parts that compete with one another. Competition is the main factor that can ensure rational development of power systems.

Division of a system into a number of parts diminishes the dimensions of the objects to be managed. It seems that the models and algorithms for management and decision-making are simplified, yet at the same time, new problems emerge. To solve the problems described above are generally recognized two main ways:

- Distributed generation usage.
- The Smart Grids technologies application, which uses information and communications technology to gather and act on information about suppliers and consumers behaviours, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.

Nowadays tendency of necessity of skilled engineers persist. In summary it is possible to assert that the management and operation of modern power systems requires the use of a large number of well-trained engineers. It can be expected that the trend of growth of requirements for qualified personnel have to be continued in the future. Areas of personnel activity, management, operation and maintenance of energy supply process can be divided into the following groups:

1. Development of equipment and apparatus. Much of the effort in this group focused on the development of automation and control systems.
2. Designing of power system objects (development of new or reconstruction and modernization of existing power stations, substations, transmission lines).
3. Operational control of power plants, substations and network areas.
4. Operation of transmission and distribution grids, power plants and substations.
5. Management and operation of consumer's energy demand.

Activity in any of the above-mentioned areas is related to the complex and dangerous equipment state changes. Errors in making or implementing decisions can cause serious consequences. In some cases there are enormous economic and social losses or even human victims [2-5]. The major blackouts in different parts of the world can serve as example of errors, which was made in different stages of process management or operation. The significant cost of possible errors determines the high demands on the staff, which ensures the development and operation of power systems. Much of the staff should have higher education and scientific degrees including doctoral level.

To ensure the success of the personnel are required not only deep theoretical knowledge but also practical skills, the acquisition of which in modern universities is associated with considerable difficulties. This statement may be explained by the variety of instruments and the conditions of their operation, by the high cost of equipment in the teaching and research laboratories Encountered difficulties, the desire to reduce costs leads to the use of various simulators, allowing to obtain the necessary skills in conditions which are near to real [6].

Three types of simulators currently are used:

- Engineering software dedicated to the accurate simulation of the dynamics (including arc flash, load flow, short circuit, transient stability, relay coordination) of all electric power systems [7-9]. Even complete virtual laboratories can be created, like for example, Virtual laboratory based on LabView software package [10]. Such simulators can't be used for direct testing of real devices.
- The equipment, which can generate processes in real time and is specifically designed for basic testing of real protection and measurement devices [11].
- Real-time large power systems process simulators [12, 13], which can generate processes in real time.

It should be noted that the last two groups of equipment are expensive, while the first group of simulators, are not appropriate for obtaining the sufficient practical skills.

This paper is devoted to the description of one of the possible approaches to create algorithm with purposes of its use in teaching and research on the development of automation and protection areas.

II. The Power System Processes Simulation System

The proposed power system processes simulation system scheme that takes the advantages of digital technology utilization is shown in Fig. 1 [6].

Presented in Fig. 1 structure has the following features and properties:

- Laboratory server forms the library of processes in two ways:
  - Applying special programs [7, 8] and user defined scenarios of accidents provides modelling and

recording of emergency processes (Section V).

▪ Collects records of real processes which were registered by power system automation devices.

• For automation and protection system algorithms and software testing purposes specialized micro-controller based terminals (see the description. below) was developed. These terminals allow to record multiple automation devices operating software and they may be tested using both analog and a digital signals.

Here (Fig. 1), the currents and voltages are fed to the tested device by the Digital-Analog Converters (DAC) and power amplifiers [12]. Thus, for real time software and device hardware testing it becomes necessary and sufficient: to write in memory and hold there waveform data of the input signals; to ignore input signals in testing mode, instead using the stored in memory data; to compare the responses of the ideal and the tested device, using computer simulation of device performance as ideal characteristic.

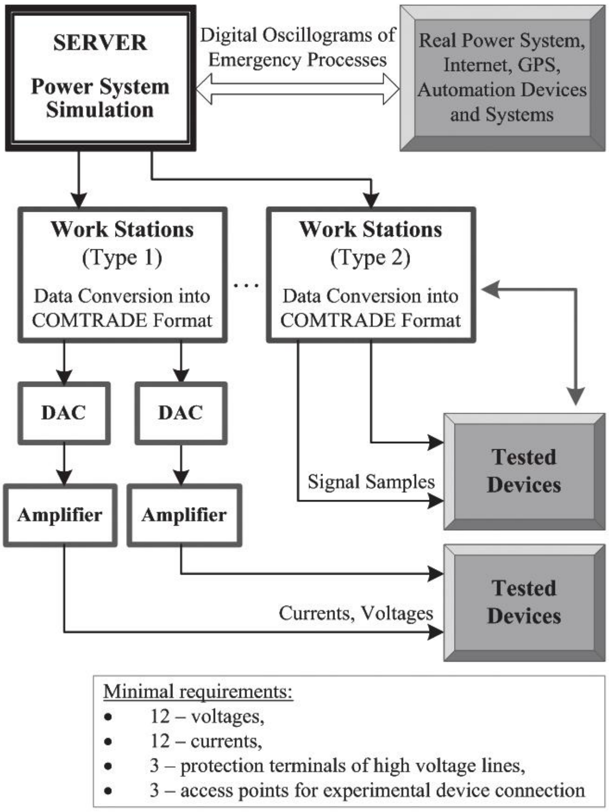


Fig. 1. Power Systems Simulator structure

For the new technology application, the automation devices should be designed to accept the digital format of testing waveform data and to support the ability to ignore the analog-digital conversion results in testing mode. For this purpose special software has been developed and installed both to computer and to micro-controller of the tested device.

In order to analyse and evaluate the operation of automation and relay protection testing signals are needed. These signals may be generated by following tree methods:

1. Performing power system numerical simulation.
2. Registering and applying for testing procedure a real power system emergency processes.
3. Describing processes in the form of a mathematical formula.

The modern software allows dynamic simulation of large power system [7-9]. Currents and voltages obtained during simulation can be saved in external file and can be used (after conversion into analog or digital form) for automation device testing. However, output signals of power system dynamic simulation software are represented with signal effective value and phase angle, but automation test system accept signals in COMTRADE format (instantaneous values), the converter program is required. Such conversion program has been made and it converts the EUROSTAG and ETAP output file into COMTRADE format. As soon as the COMTRADE data file is obtained it can be used by simulation system for setting verification, terminal (relay) operation evaluation, etc.

III. Out-of-Step Protection Types and Algorithms

Normally out-of-step systems installed throughout the world monitor voltages and currents at PTLs' terminals. More recent technology incorporates Global Positioning System (GPS) receivers providing for synchronized phasor measurements [14] over multiple grid locations.

For local systems a number of algorithms are accepted as good practice in this field:

- Angle-based algorithms.
- U cosφ algorithm.
- Energy function-based methods.
- Incorporation into the differential protection technology.
- Distance algorithms, and others.

Wide-area systems with remote synchronized measurements may be realized using measurement of phasors [15]. Measurement of phasors (i.e. complex of fundamental frequency AC system voltages and currents) is a critical element of many computer based monitoring, protection and wide area control systems.

The configuration consists of two or more phasor measurement units (PMU), which provide synchronized real time information regarding the state of the system. Synchronization of measurements can be made on basis of the GPS or Navstar Satellite system. It permits accuracy of better then 1 microsecond. The data provided by the PMUs is sent to an appropriate control unit, where it is analysed. The platform is based on powerful digital processor, and is capable of receiving data from a large number of PMUs and verifying the data integrity.

In this paper is described the automation that uses elements of both the above mentioned methods. The implementation of algorithms for recognizing the asynchronous mode is carried out by local devices, but to increase their efficiency are used high-speed communication channels, synchronized measurements and information from remote substations.

A selection between two asynchronous operation (AO) detection algorithms is possible for currently used applications of AO protection A (AOP-A) to power systems [16]. The unstable power swings are detected based on continuous monitoring of angle φ between two simulated voltages U_1 and U_2 [17]. To simulate these voltages two-machine circuit - an equivalent of the real system - is used, as Fig. 2 and (1) show.

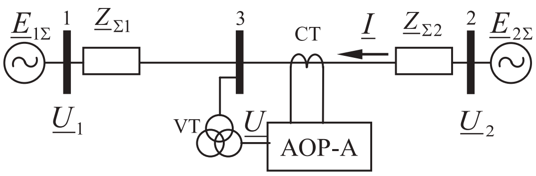


Fig. 2. Equivalent circuit of the power system

$$\begin{cases} \underline{U}_1 = \underline{U} \pm \underline{Z}_{\Sigma1} \cdot \underline{I} \\ \underline{U}_2 = \underline{U} - \underline{Z}_{\Sigma2} \cdot \underline{I} \end{cases}, \qquad (1)$$

where $\underline{U}$ and $\underline{I}$ are local voltage and current values measured by protection in the point of installation (an additional current input may be activated for improved precision), $\underline{Z}_{\Sigma1}$ and $\underline{Z}_{\Sigma2}$ are the settings chosen depending on the equivalent parameters of the power system.

Depending on the location of electric centre of swings (ECS), the modelled voltages $\underline{U}_1$ and $\underline{U}_2$ can be located either side of ECS (the angle φ does not exceed 90º) or on the opposite sides of ECS (angle φ increases until it reaches 180º).

The protection operates when the following requirements will be met:

1) angle φ has reached its limit value;
2) angle changes with a sufficiently high rate ($d\varphi/dt$);
3) currents and voltages are symmetrical.

Application and operation of the currently accepted AOP-A approach holds a number of drawbacks analysed below.

First, setting values are derived from system studies. As AO is a very un-common and rare event in system practice, its modelling considers extreme grid outage scenarios applied to an integrated and interconnected network. This type of modelling is a complex process and prediction of those scenarios plays a vital role in providing AOP-A efficiency. Any significant difference between pre-analysed and actual AO scenarios might lead to incorrect device response. The extensive system modelling phase would be eliminated.

Additionally, any significant amount of demand supplied from buses 1, 2 and 3 (Fig. 2) might influence particularities of the unstable swing processes. As a result, those modelling bus voltages might reproduce generator angles incorrectly. A new approach is introduced in the next section aiming to overcome drawbacks outlined above.

The new proposed solution is based on a combination of synchronised phasor measurements with local-based approaches, referred to as AOP-B. Its application would be beneficial for those power utilities that have limited PMU coverage currently as well as at interconnections between systems with different PMU application policies.

The real-time synchronised measurements of voltage phasors are compared between two key substations (Bus 1 and Bus 2 in Fig. 3) located within a transmission corridor in question. Additionally, two remote voltage phasors are simulated in the same timeframe reaching for relevant locations (Gen 1 and Gen 2 in Fig. 3) not covered by PMU and communication technology presently.

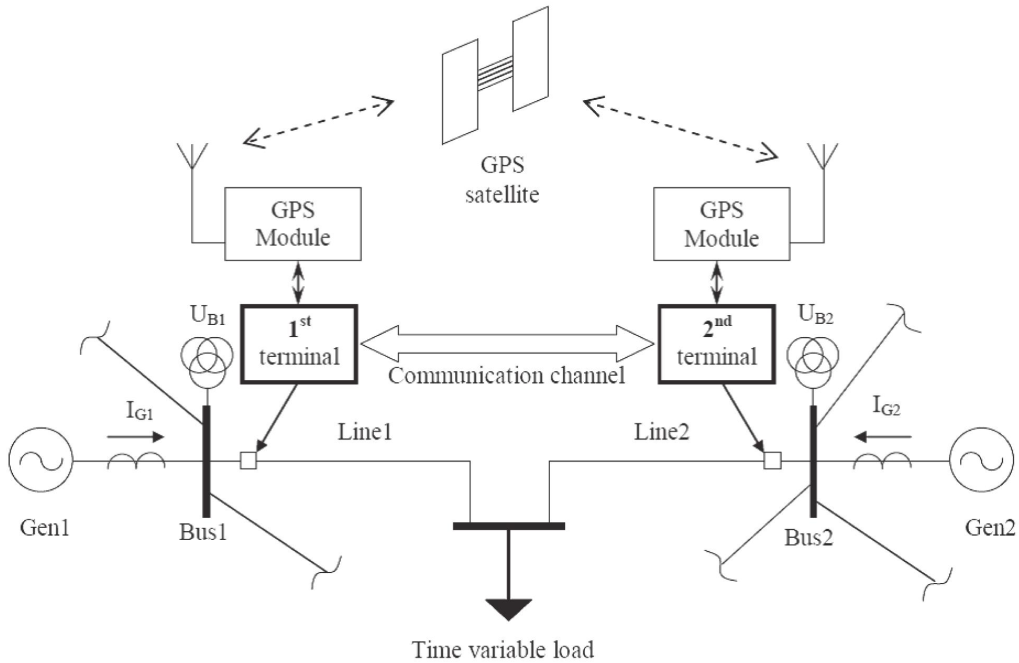


Fig. 3. Simplified diagram of terminals connection in power system

The proposed structure and associated modelling is free from the above mentioned drawback. The modelling phasors are processed in accordance with formulas (2) [18].

$$\begin{cases} \underline{E_1} = \underline{U_{B1}} + \underline{I_{G1}} \cdot \underline{Z_{G1}} \\ \underline{E_2} = \underline{U_{B2}} + \underline{I_{G2}} \cdot \underline{Z_{G2}} \end{cases}, \tag{2}$$

where $\underline{I}_{G1}$ and $\underline{I}_{G2}$ are currents of transmission branches linked to equivalent generators, $\underline{E}_1$ and $\underline{E}_2$ are voltage phasors associated with EMFs of equivalent generators, $\underline{Z}_{G1}$ and $\underline{Z}_{G2}$ are corresponding modelling impedances (settings), $\underline{U}_1$ and $\underline{U}_2$ are bus voltage phasors measured by two terminals at their locations in real time.

In case of AO in power system, the angle δ between simulated voltages increases till 180º and voltage at the ECS is equal to zero. The terminal operates when the following requirements are met:

1) angle δ has reached its limit value;
2) angle changes with a sufficiently high rate ($d\delta/dt$);
3) voltage circuits are in serviceable condition;
4) currents and voltages are symmetrical;
5) communication channels is in operation condition.

The communication channel plays an important role in the proposed structure and its arrangement is described in the next section.

Nowadays, the communication channels are more and more becoming a part of the power system operation. In regards to this, an important issue is any communication network time delays. Power systems widely use the Synchronous / Plesiosynchronous Digital Hierarchy (SDH/PDH) telecommunication equipment both for dispatching information data transfer and for data exchange between remote terminals [19]. The PDH and SDH technologies uses time division multiplexed technique and allow the client to be connected to the network throw the communication multiplexors.

The practical usage of fiber optic channels with multiplexors technology realization showed, that different types of glitches occurs during data transferring process [20]. Communication channels reliability becomes a crucial factor for a whole protection system correct operation.

IV. Study Case

The comparison of existing AO protection relays, namely AOP-A and the proposed two terminals methods based on synchronized measurements is presented and analysed.

The analysis was established based on the high-voltage transmission grid of the Latvian power system including all relevant power plants [21]. The power plant models are structured as per actual arrangement, e.g. Plavinu HPP consists of multiple hydro-generators with every two units sharing a single step-up transformer.

The Latvian power system is interconnected with neighbouring networks of Lithuania, Estonia and Russia. The Lithuanian power system representation is based on four external nodes. Both Estonian and Russian systems are modelled as power grids, i.e. two links with the Estonian system up to Tsirguliina and Tartu buses and a single Velikoreckaja bus in the Russian network.

Comparison between AOP-A and AOP-B devices is developed analysing a selected portion of the Latvian system (Fig. 4) using the following assumptions. The AOP-A device monitors the angular difference between phasors associated with Plavinu HPP generators (Bus 3) and the Russian power system (Bus 4) derived from the local measurements – line L2 at Bus 2.

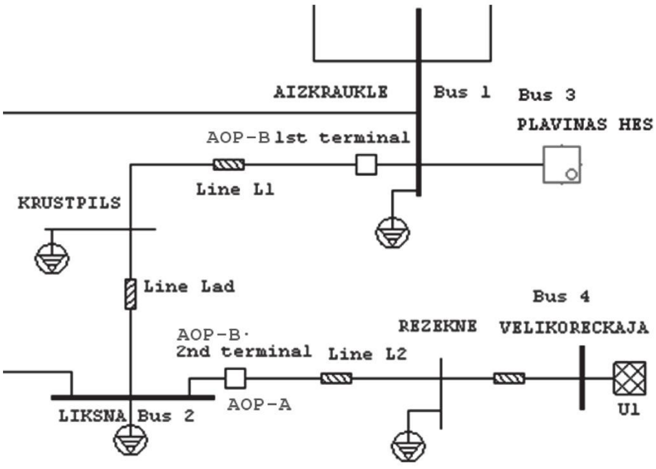


Fig. 4. Studied part of the Latvian power system

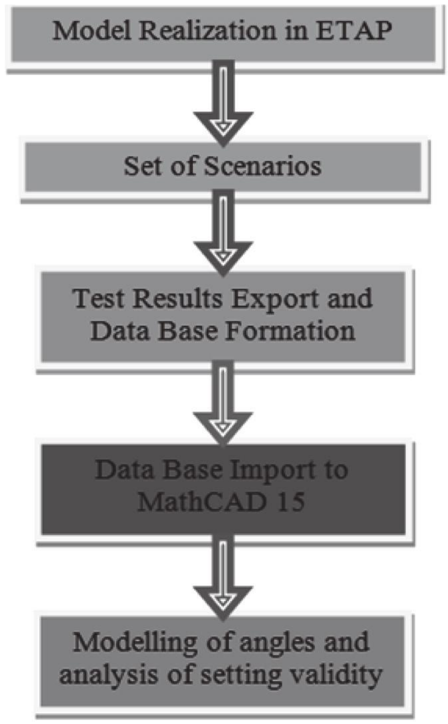


Fig. 5. Generalized algorithm of case study

The AOP-B solution employs two terminals: the first one is installed at Bus 1 and additionally measures the current associated with the Plavinu HPP generators. The second terminal is located identically with AOP-A. The examined system includes a number of concentrated demand nodes, for example Bus 1, etc.

The study employs comprehensive electrical engineering software ETAP covering design, simulation, operation, and automation of generation, transmission, distribution, and industrial power systems. Special attention is paid to the Transient Stability Analysis module dedicated to various types of disturbances and emergency scenarios.

For modelling purposes, the outcomes of the grid simulations were transferred and analysed using an external data base (DB). The next step was creation of a tool, which processes data and provides the required results for comparison of two approaches under analysis. For this task, the Mathcad 15 software was chosen as the most appropriate one. Thus all necessary modelling data sets were built including appropriate simulation parameters, e.g. U1, U2, E1 and E2, etc. Fig. 5 summarises the software in use.

It is well known that for stability considerations a three phase short circuit is the most severe single fault. In study scenarios a three-phase fault occurs at a transmission line connecting Viskali and Bisuciems buses at 95% of its length [21]. The short-circuit lasts for 0.53 seconds being longer than any relay protection operation time.

However, for the purpose of the study this fault is assumed to be a simplified representation of more complex cascading events within the grid. The complex unstable conditions are shown in Fig. 6.

Instability develops both between Latvian and external systems as well as within Latvian system itself. Generators connected to the grid loss their stability and various transient groups are formed. Each unstable group will require either controllable splitting of the grid or tripping of unstable machines. However, further analysis is concentrated on inter-system observations under this complex instability pattern, in particular Latvia to Russia connection – line L2.

Suitability of AOP-A settings under the observed case conditions is confirmed by a verification study performed in ETAP. Fig. 7 compares phasor angle values for corresponding system locations as modelled by AOP-A (changes in time during AO) versus ETAP simulation results for the same buses (generators). The comparison of presented graphs brings to the conclusion that settings are chosen properly. Similar results were obtained for AOP-B.

Generally, identification of correct settings for AO protection devices requires a difficult and extended calculation procedure involving significant expert and computational resources. This is due to the fact that the power system is a complex structure with its parameters being variable in time. For example, a comprehensive setting verification/validation would involve a range of scenarios for devices purely based on pre-selected settings.

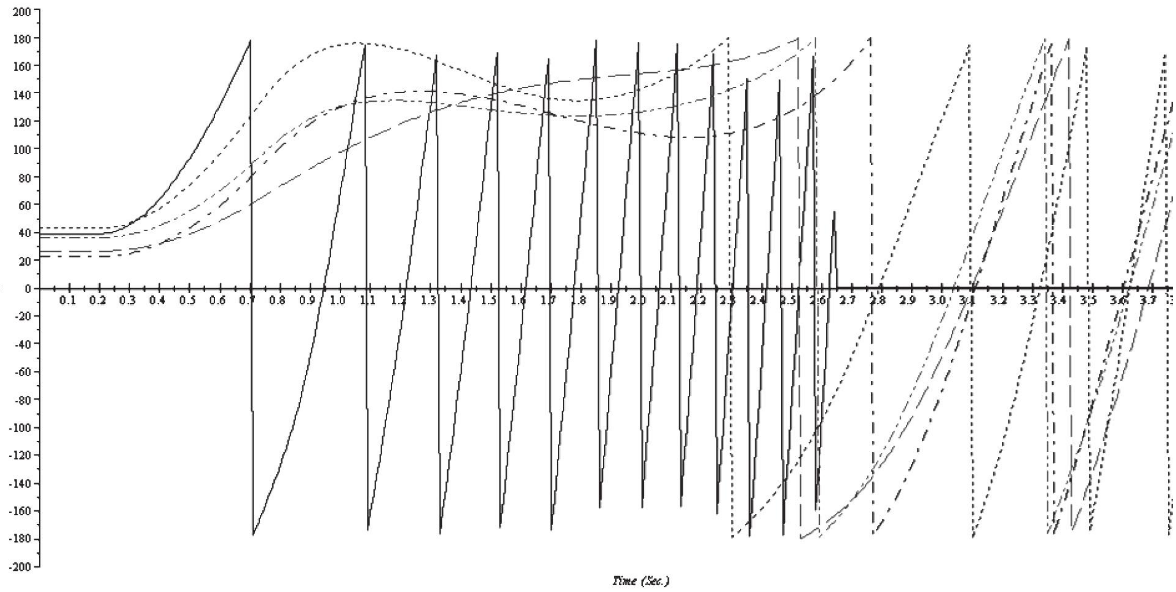


Fig. 6. Generator rotor angles (deg.) following three-phase fault

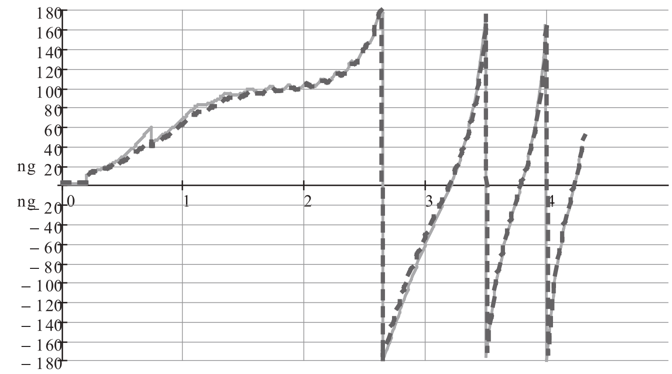


Fig. 7. AOP-A device modelled (solid) and ETAP calculated (dotted) phasor angles

Generally, identification of correct settings for AO protection devices requires a difficult and extended calculation procedure involving significant expert and computational resources. This is due to the fact that the power system is a complex structure with its parameters being variable in time. For example, a comprehensive setting verification/validation would involve a range of scenarios for devices purely based on pre-selected settings.

To compare operation of AOP-A and AOP-B devices, special attention was paid to the system parameters change influence on expected responses, i.e. used impedance settings didn't represent actual system parameters due to changes in power system structure.

Two specific cases were observed. The first one represents the night minimum conditions in the system with reduced amount of generation units in operation. For instance, only two Plavinas HPP units are in service. Assume, the impedance settings for AOP-A were changed based on a part of influencing factors only. In that case, it would operate with a significant difference comparing to the actual stability performance. It means that AOP-A will respond incorrectly, and this can lead to more severe consequences (losses). Analysing AOP-B operation, it is possible to conclude that it will operate very close to real regime data.

Fig. 8. compares AOP-A (red-coloured curve) versus AOP-B (green-coloured curve) responses as well as shows the phasor angle difference between corresponding system locations (black-coloured curve).

The second case is related to the grid maintenance, when a power transmission line is being taken out of service and AOP-A settings must be updated properly when evaluating the corresponding network structure changes. Consider an outage of the "Salaspils – Valmiera" line was addressed incorrectly in AOP-A settings leading to its missed operation – non-operation, when required. The modelling results are depicted in Fig. 9 (colouring as above).

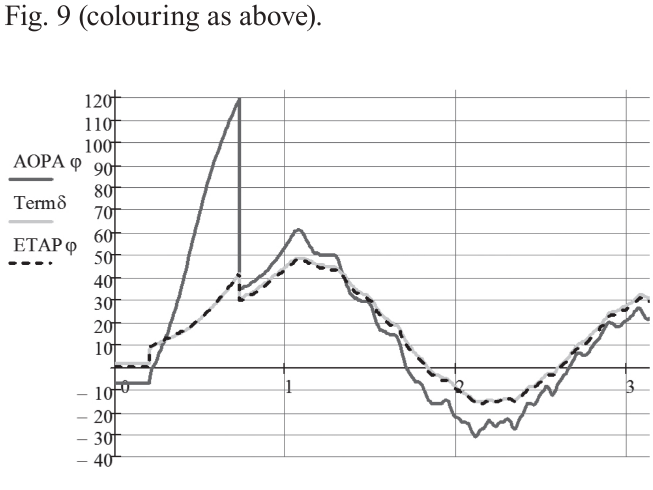


Fig. 8. AOP-A and AOP-B angles (deg.) in time (sec) – system night minimum case

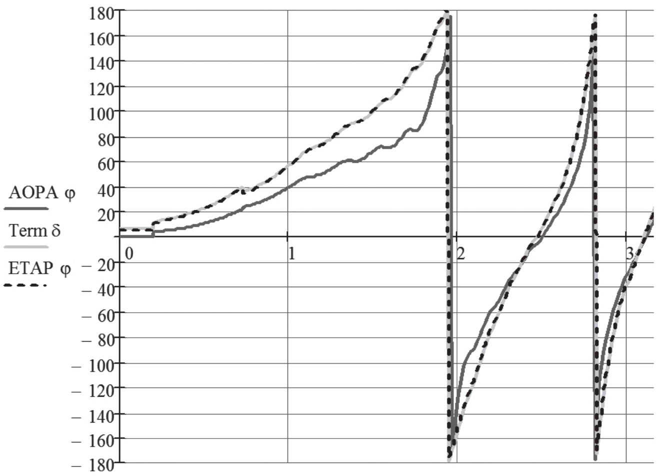


Fig. 9. AOP-A and AOP-B modelled angles (deg.) in comparison with system instability – grid maintenance case

As on comparison of AOP-A and AOP-B angle curves, it is possible to evaluate that AOP-A will not operate when required demonstrating potential unacceptable performance due to inadequately chosen settings. Performance of the new proposed AOP-B device is in line with requirements.

All calculations and modelling processes were made in specially designed simulator ("Analog-digital power system simulator" or VNPC) with remote connection possibility. This was very helpful and useful, because all necessary software was in one place and was available at any time. The simulator was realized within project "EVIIT" [22], what is directed to federal research centre foundation, and everyone can get access to this resources.

V. Conclusions

Laboratory, that is able to ensure the testing and verification of automation and relay protection algorithms, software and hardware, can serve as the basis to get for students practical skills which is necessary for the development and operation of power automation systems and transient stability studies.

Specialized terminals that are able to use digital input signals, provide the opportunity for a wide class of experiments based on the use of power systems simulation software.

Changes in power system topology and structure may lead to associated changes in AO protection zones and result in significant influence on correct recognition of unstable conditions. This will cause consequences dangerous for both power plant equipment and system integrity, if addressed incorrectly.

References

1. *Daniel Sadi Kirschen and Goran Strbac.* Fundamentals of Power System Economics, John Wiley and Sons, May 2004. – 296 p.

2. *Final* Report on the August 14, 2003 Blackout in the United States and Canada. U.S.-Canada Power System Outage Task Force, April 2004.

3. *RMS* Special Report "The 1998 Ice Storm: 10-Year Retrospective".

4. *Report* to the President on the Power Failure in the Northeastern United States and the Province of Ontario on November 9–10, 1965. – 57 p.

5. *Report* on the New York City Blackout July 13, 1977. State of New York Investigation, January 1978. – 63 p.

6. *Sauhats A., Žalostība D., Dolgicers A., Utāns A., Bočkarjova G., Bieļa-Dailidoviča E., Antonovs D.* Power System Simulation Laboratory as a Modern Educational Tool. Recent Advances in Education & Modern Educational Technologies: Educational Technologies Series 9: The 2013 International Conference on Education and Modern Educational Technologies (EMET'13), Italy, Venice, 28–30 Sept., 2013. – P. 103–110.

7. *Eurostag* Software [Electronic resource]. – URL: www.eurostag.be

8. *ETAP* Software [Electronic resource]. – URL: www.etap.com

9. *PowerWorld* Software [Electronic resource]. – URL: www.powerworld.com.

10. *R.A. JabbarKhan, A. Mohammed, M. Junaid, M.A. Masood, A. Iftkhar.* LabVIEW based Electrical Machines Laboratory for Engineering Education. WSEAS Transactions on Advances in Engineering Education Issue 5, Volume 7, May, 2010. – P. 161–171.

11. *Sauhats A., Bockarjova M., Dolgicers, A. Silarajs M.* "New method for complicated automation systems simulation test," 8th IEEE International Conference on Developments in Power System Protection, April 2004. – P. 280–283.

12. *Bose A., Clements K.A.* "Real-Time Modelling of Power Networks," Proceedings of the IEEE , vol. 75, no. 12, Dec. 1987. – P. 1607–1622.

13. *Real* Time Digital Simulator – RTDS [Electronic resource]. – URL: www.rtds.com.

14. *Phadke A.G.*, "Synchronized Phasor Measurements in Power Systems", IEEE Computer Applications in Power, vol. 6, no. 2, 1993. – P. 10–15.

15. *Power* Swing and Out-of-Step Considerations on Transmission Lines, IEEE PSRC WG D6, 2005.

16. *AGNA* technical description and operating manua [Electronic resource]. – URL: http://remi.eef.rtu.lv/.

17. *Sauhats A., Svalov A.*, Statistical Optimisation of a Complex of Local Devices for Prevention of Out-of-Step Conditions, 14th PSCC, Sevilla, 24–28 June 2002, Session 22. – P. 5.

18. *Antonovs D., Sauhats A., Utāns A., Bieļa E.*, "Out-of-Step Protection Terminal and Method", Latvia's

patent application Nr. P-13-91, July 5, 2013.

19. *Roland Kiefer*. Test Solutions for Digital Networks: Basic Principles & Measurement Techniques for Pdh, Sdh, Isdn & ATM, 1999.

20. *Utans A., Sauhats A., Leite L., Silarais M.* Experimental Testing of the Quality of Relay Protection Communication Channels // The 5th International Conference on Electrical and Control Technologies, Lithuania, Kaunas, 6–7 May, 2010, P. 253–256.

21. *Grid* Code of Latvia [Electronic resource]. – URL: http://likumi.lv/doc.php?id=257943.

22. *ERAF* project [Electronic resource]. – URL: http://www.rtu.lv/content/view/6834/2014/lang,lv/.