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Development Of Software–Hardware System for Real Time Simulation of Electric Power System with Smart Grids

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Abstract

The design and research of electric power system (EPS) with smart grids (SG), which are the current world trend of modern electric power industry, requires solving a large number of non-trivial tasks. The developed technical solutions and used equipment are novel for the world practice. Therefore, their implementation requires careful analysis and an individual approach to research that provides an assessment of the impact of new network elements on the power system. All of this puts requirements on the tools and methods of research used to solve such problems. At present, digital systems for modelling EPS with SG based on the application of numerical methods are used as such tools. However, despite the high level of these developments, it has drawbacks. The use of incomplete and invalid information obtained by digital tools can lead to the wrong design and operational decision in real power system, which can cause blackouts. The alternative approach for solving the problem of detailed simulation of EPS with SG is the creation of hybrid system based on the principle of combining different modelling methods. Hybrid Real-Time Power System Simulator (HRTSim) is developed based on this approach and presented in the paper.

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1. Introduction

Generators, transformers (autotransformers), power transmission lines and another equipment of the electric power systems (EPS) are continuously connected in the processes of production, transmission, distribution and consumption of electrical energy in all possible normal, emergency and post-emergency operational regimes. Due to the unity, continuity and high speed of the mentioned processes, the reliability and efficiency of power distribution grids depend on the level and the quality of their automation. Therefore, one of the main trends of the modern EPS development and improvement is their enhanced automatic controllability [1, 2]. Since the last automated

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components of the EPS are electrical networks, the key solution to the challenging requirement are Flexible Alternative Current Transmission Systems (FACTS) [3]. The FACTS, together with the microprocessor automation and data management systems transform the existing electrical networks, mostly passive, into the active-adaptive networks, called Smart Grids (SG). However, achieving this goal requires to solve complex and non-trivial tasks of the design, research and operation of the EPS with SG.

Obtaining the most complete and valid information about the processes in the equipment working under all normal and emergency regimes is vitally important for the solution of non-trivial tasks, but it may be realized only by the EPS with SG modelling, predominantly with mathematical modelling.

Most of currently used computational digital tools [4-6] for real-life EPS simulation often use simplifications and restrictions unacceptable for complex tasks. The main reason for the simplifications and restrictions is a stiff non-linear system of differential equations of higher order, which describes any complete and reliable three-phase mathematical model of the EPS. A satisfactory solution of the differential equations by numerical methods used in modern digital tools is possible only by the reduction of the stiffness, differential order, nonlinearity of an equation system, as well as a solution interval. However, it is only possible by the decomposition of the regimes and processes of the EPS with SG, the simplification of the mathematical models of the equipment and EPS as a whole, and by reducing the interval of the process simulation [7, 8].

Due to the methodological reasons, the mentioned negative consequences arise in any numerical modelling of the large dynamic systems, regardless the computer hardware. These consequences are fundamentally irremovable. An alternative radical solution to the problem of an adequate large dynamical system simulation is a hybrid simulation. This approach enables choosing and creating the most effective ways of solving the problem satisfactorily. At present, one of the most advanced and developed solution to the hybrid power systems simulation is the Hybrid Real-Time Power System Simulator (HRTSim) developed in Tomsk Polytechnic University.

2. Hybrid simulation of electric power systems

Limiting factors and constraints regarding an adequate simulation of the EPS with SG, determining the conditions necessary for their implementation, which are the main points of hybrid approach, are as follows:

- The full mathematical models for each type of main and auxiliary power equipment are synthesized and used, such model allow to fully and accurately describe a continuous spectrum of quasi-steady-state and transient processes in the equipment and EPS as a whole for all possible normal, emergency and post-emergency conditions.

- Methodically accurate method of continuous implicit integration is used to solve such mathematical models with guaranteed instrumental accuracy.

- Management parameters of mathematical models and simulation in general, view, conversion and display the simulation results is carried out by using an analog-to-digital and digital-to-analog conversion of information.

- For realization of any kinds of longitudinal and transverse switching, natural interaction and formation of a simulated power system is carried out conversion of mathematical values into equivalent physical currents and voltages using voltage current converters. To implement the switching are used digitally controlled analog switches.

- The implementation of the preceding claims is carried out on the basis of the modern achievements of microprocessor engineering and IT-technologies to provide the required performance.

3. Hybrid Real-Time Power System Simulator

The above mentioned hybrid simulation approach lies in achieving the reference properties and capabilities of the developed simulator. Therefore, a practical implementation of the simulation provides the ultimate level of reliability and efficiency of solving the problems of the EPS design and their subsequent usage.

A structural scheme of HRTSim is shown in Figure 1. The created and operated HRTSim prototype in Tomsk polytechnic university includes the following three-phase elements: 279 bus bars, 69 electrical machines (synchronous generators, synchronous motors and asynchronous motors), 126 power transmission lines, 58 transformers and autotransformers, 138 dynamic loads.

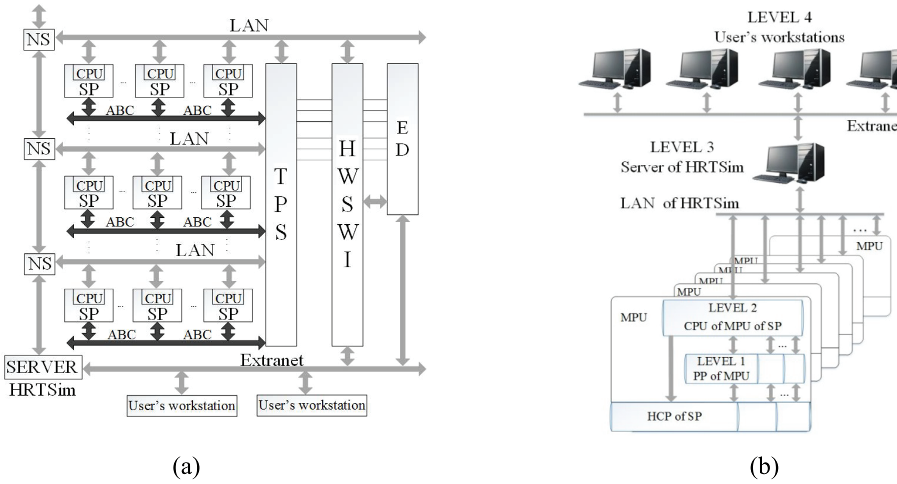

Figure 1: Hybrid Real-Time Power System Simulator (HRTSim). (a) HRTSim structure: TPS – three-phase switch; HWSWI – hardware and software interface; SP – specialized processor; CPU – central processing unit; LAN – local area network; NS – network switches; ED – external device; ABC – physical three-phase inputs-outputs. (b) Informational and control levels of HRTSim: HCP – hybrid coprocessors; PP – peripheral processor.

3.1. Specialized processors

Each element of the power system requires developing a specialized processor (SP). According to the designated approach and structure of the HRTSim all SPs have a common structure. As example describes the specialized processors of synchronous and asynchronous electrical machines (SPM). The SPM block diagram is shown in Figure 2a. An external view of SPM is shown in Figure 2b.

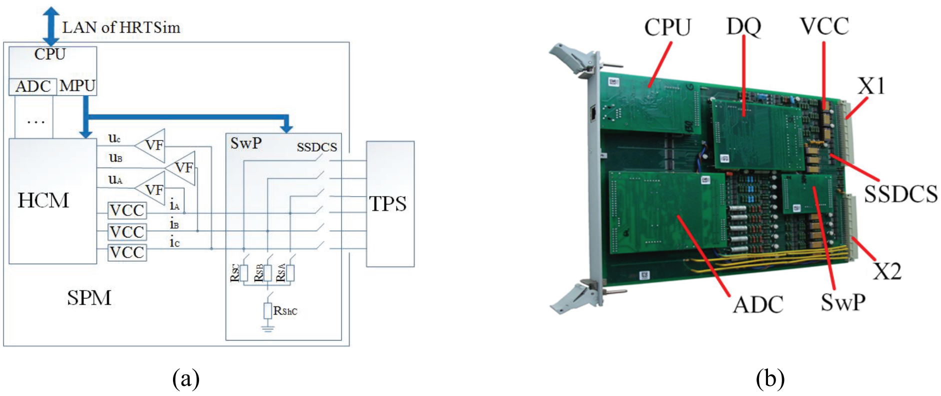

Figure 2: Specialized processor of synchronous and asynchronous electrical machines (SPM). (a) Structure of SPM: LAN – local area network; CPU – central processing unit; HCM – hybrid co-processor of electric machines; SwP – switching processor; ADC – analogue-to-digital converter; TPS – three-phase switch; ABC – physical three-phase inputs-outputs of SPM; SSDCS – series and shunt digitally controlled three phase switches; VCC – voltage-current converter; VF – voltage follower. (b) External view of SPM.

3.2. Cross-board for interaction of specialized processors

A three-phase switch (TPS) cross-board (see Figure 3) is designed to interconnect SP three-phase inputs-outputs in accordance with the topology of the simulated EPS with SG. It organizes SP power supply, as well. This constructive solution allows replacing a cross-board conveniently and expeditiously, if it is necessary.

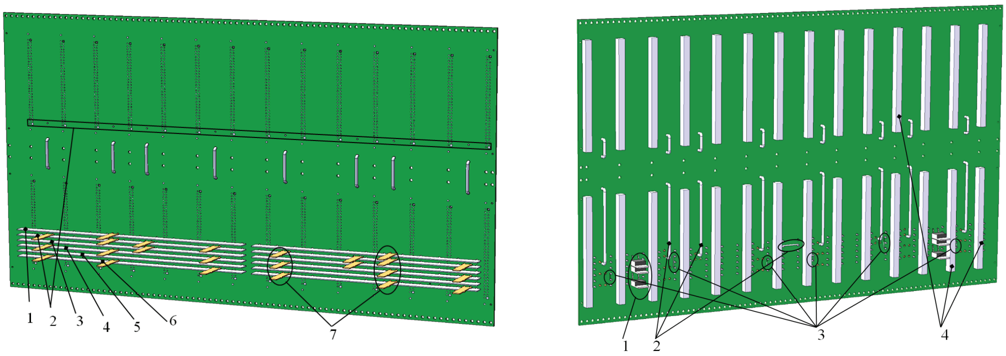

Figure 3: External view of a TPS cross-board. (a) From the side of power supply: 1 – power bus -15V; 2 – operating analogue ground bus; 3 – power bus +15V; 4 – ADC' ground bus; 5 – microprocessors' ground bus; 6 – power bus +5V; 7 – knife switches. (b) From the side of connectors for connecting SPs: 1 – protective diodes; 2 – combinations of operating SP analogue grounds; 3 – combinations of ADC power buses grounds, microprocessors and a cross-board operating analogue ground; 4 – SP connectors.

4. Example of task solved with Hybrid Real-Time Power System Simulator

The application of HRTSim is considered using the example of research results obtained during the Russian pilot project of the creation of EPS with SG - the Elgaugol project. The large coal processing plant is included in the Elgaugol energy cluster. Shutdown the responsible motors at such plant is unacceptable, because the all production process may be disrupted. Therefore it is necessary to provide the self-starting motors. The under-voltage protection (UVP) serves the function of switching off the non-critical electric motors with the aim to provide the self-starting responsible motors and to maintain the operability of the industrial plant. It is very important to setting the UVP. Traditional methods of calculation thresholds by known formulas do not always allow to correctly setting this protection, since they are very approximate. The most reliable setting is based on the field data, but it is practically impossible on real equipment for obvious reasons. Developed HRTSim allows to solve a similar problem successfully. This system can detailed simulate the operating modes of any power system and conduct appropriate experiments to obtain the required data.

Oscillograms of self-starting asynchronous motor AM-4 of 110/6 kV substation (SS) “Promploschadka” of the Elgaugol energy cluster are presented in Figure 4. There is three-phase short-circuit (SC) on the line 220 kV VL-204 and subsequent switch off this line by relay protection (RP) without time delay. The motors start to stopping because of reducing the voltage. The most responsible on this SS is AM-4. When the monitored voltage falls below the threshold of UVP, the non-critical motor of SS “Promploschadka” AM-3 is switched off. Thus, it is possible to operation AM-4.

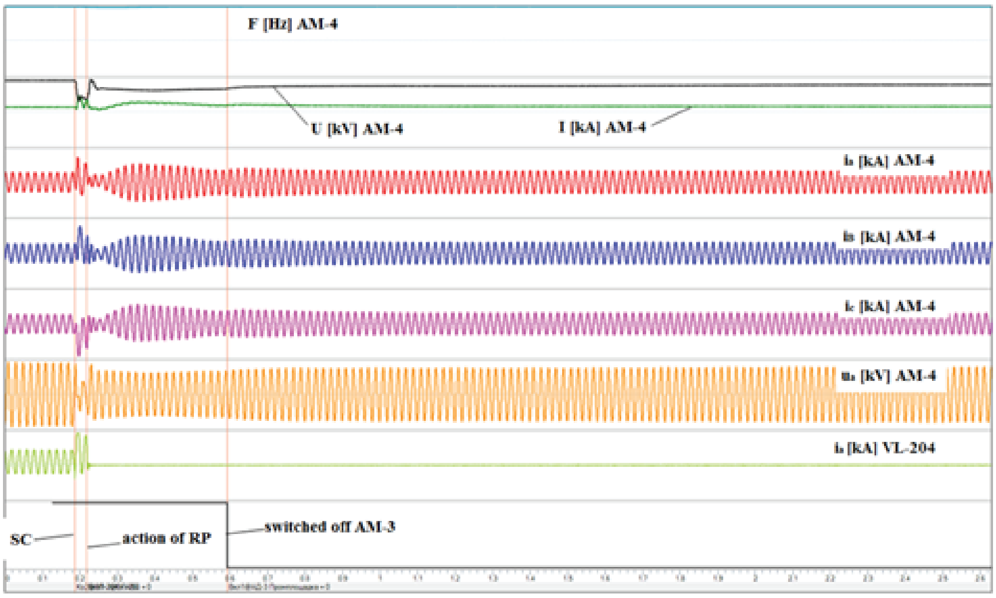

Figure 4: Oscillograms of self-starting asynchronous motor AM-4of 110/6 kV SS “Promploschadka” during 3 phase short-circuiton the line 220 kV VL-204 (UVP enabled). The time interval t=0-2.6 sec.

Oscillograms of self-starting asynchronous motor AM-4 of 110/6 kV SS “Promploschadka” during SC on the line VL-204 are presented in Figure 5, too. However, in this case, UVP was blocked and there is no switched off AM-3. But as can be seen from the curve of frequency (the first curve in Figure 5) AM-4 starts to slow down, which led to stopping.

It is obvious that the role of UVP as an instrument for maintaining the continuous power supply of industrial plant is very high. As a result of the research, the optimal setting of UVP is determined and the processes of self-starting asynchronous motors are investigated during the operation of UVP in real power system with Smart Grids.

5. Conclusion

The main advantage of the digital simulators is the flexibility of the used mathematical models of equipment and modelled EPS network topology. However, it is not a

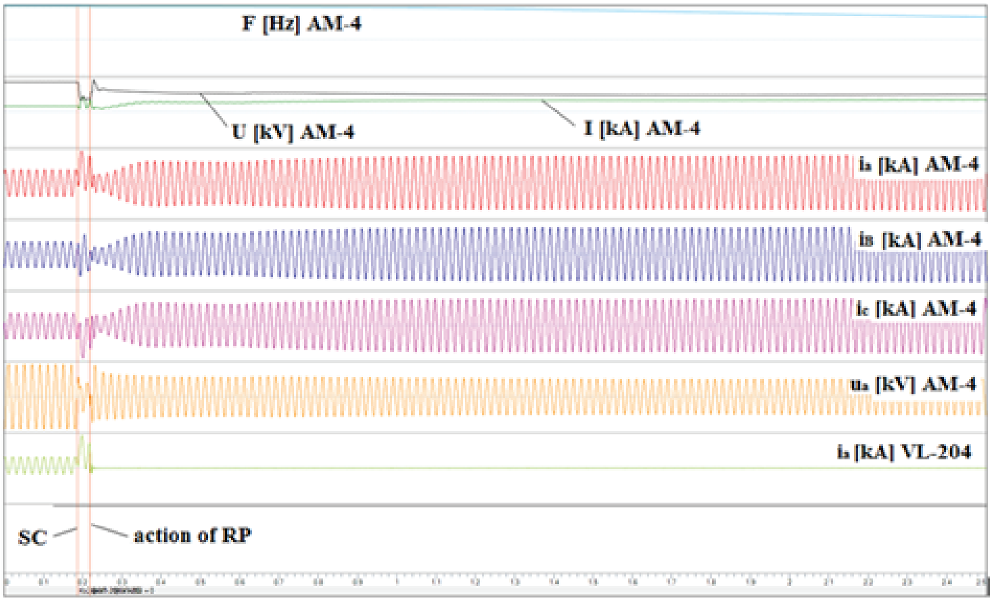

Figure 5: Oscillograms of self-starting asynchronous motor AM-4of 110/6 kV SS "Promploschadka" during 3 phase short-circuiton the line 220 kV VL-204 (UVP disabled). The time interval t=0-2.6 sec.

significant drawback of the HRTSim. First, the cross-boards are easily manufactured and replaced, if it is necessary to make some significant changes in the topology of the power system. Secondly, currently existing technologies [9] allows creating a cross-board with the possibility of interactive changes in the topology of a simulated power system. With regard to the flexibility of mathematical models of the equipment, as mentioned earlier, we create universal models, considering all key features of a particular type of equipment. The specification of the model for specific equipment can be done by setting certain parameters. The HRTSim allow minimizing the drawbacks of analogue simulators, such as, for example, zero-drift, at the same time, observing their advantages. The most important advantage is the exclusion of the methodological error of integration of differential equations, irrespective to a differential order, stiffness and duration of the simulated processes. The solution accuracy is guaranteed and depends on the component errors that are affected by the components quality. Components of higher quality should be used to achieve better accuracy. Thanks to its features, the HRTSim can be used as a testbed for various kinds of projects. The fragments of the studies carried out by the authors are described in [10].

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