USING THE RTDS® SIMULATOR FOR THE ANALYSIS OF AUTOMATIC EXCITATION CONTROLLER

Development of Test Circuits

J.L. Artsyshevsky, T.G. Klimova, National Research University "MPEI"
A.V. Zhukov, E.I. Satsuk, A.I. Rasscheplyaev, JSC "SO UPS"

The use of advanced digital modeling tools for technical systems and processes in power systems engineering significantly extends the capabilities of various studies. In particular, the emergence of digital systems for simulation of complex power systems in real time allows testing of Relay Protection and Automation (RPA) in near real circuit-operation conditions of their behaviour in the power system. These tests ensure the stability of the operating parameters during repeated experiments, which is particularly important for the certification testing of RPA. This article discusses the use the combined hardware and software of a Real-Time Digital Simulator (RTDS®) to test the operation of automatic excitation controllers for compliance with the JSC "SO UPS" standard [1].

Figure 1. RTDS and the tested AEC.

Figure 1 shows the RTDS Simulator, established by the Scientific and Educational Center "The reliability and efficiency of the Relay Protection (RP), Substation Automation (SA) and telecommunications in the intellectual power system with active - adaptive grids" (Department of relay protection and automation of power systems of National Research University "MPEI"). The RTDS Simulator includes:

1. A workstation connected to Ethernet LAN, using a special software package, RSCAD, which allows the creation of different circuits to simulate various circuit-mode situations, monitor calculations and manage modeling in real-time;
2. The RTDS Simulator hardware, consisting of custom computing boards, digital and analog input/output boards, and various interface boards (Figure 1, (1));
3. Power amplifiers, designed to step up the low level analog signals from the RTDS Simulator to secondary voltage and current levels. Each panel contains different sets of gain blocks which are used to provide current and voltage signals for the RPA terminals being tested. The input signals are amplified to the level required for normal operation of RP terminals (Fig. 1 (2));

Figure 1 also shows the Automatic Excitation Control (AEC) terminal for synchronous generators (Fig. 1 (3)).

RSCAD is used to create specific digital models to run on the RTDS Simulator hardware. The power systems circuit is drawn and parameters of its elements are defined in the graphical user interface called Draft. The same editor contains models to generate control signals and the circuits necessary to implement data processing algorithms. For AEC analysis, the methodology presented in the Standard of JSC "SO UPS" was used [1]. 6 circuit diagrams with 16 operating modes were developed as part of this standard. An example of one of the circuit diagrams can be seen below in Figure 2.

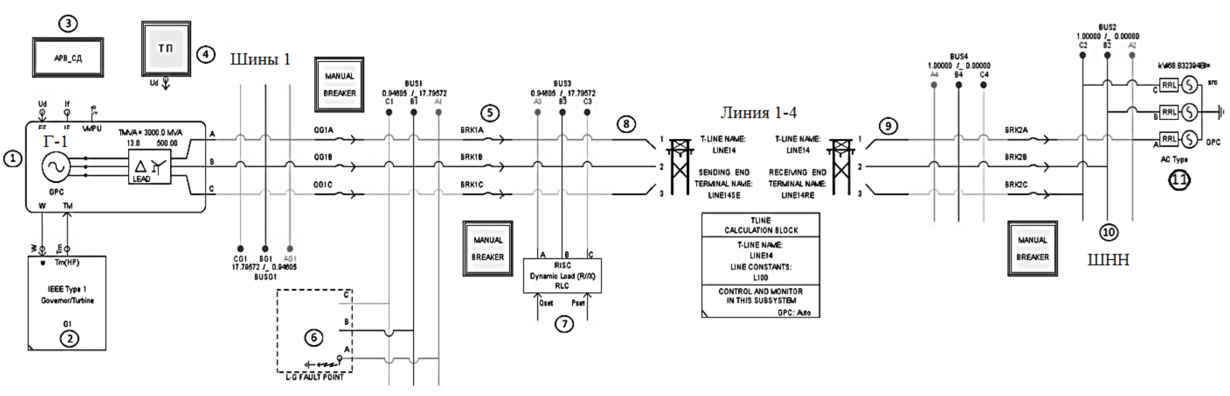

Figure 2. Power System diagram.

Figure 2 contains the following:

1. A synchronous generator (Г-1) with a Y-Δ transformer (transformer can optionally be excluded);
    - Park-Gorev equations are used for this synchronous generator model;
2. turbine and governor;
3. exciter;
4. thyristor converter (TC);
5. circuit breaker;
6. fault branch;
7. dynamic load model, allowing load parameters to be changed during the simulation
8. transmission line;
    - Different transmission line models are available (ie. Bergeron and Frequency Dependent);
9. transmission line;
10. infinite buses. Bus 2 (element 10) is the fixed reference point for operation of the circuit.
11. infinite bus
    - A required voltage value, characterizing the infinite power system (11), is created at this point using the software. The interface device between the RTDS Simulator operating at 0.4 kV was developed at the RPA Department of National Research University "MPEI". This device can, if desired, use the busbars of "Mosenergo" electrical grid as the infinite power busbars.

The control window below (Figure 3) is captured from the RunTime module of RSCAD and is used to control the simulation process in real time, including adjusting the operating point of the models, creation of necessary disturbances, short-circuits, breaker operation, etc. In addition, RunTime allows the user to observe the parameters of the simulation (measure voltages, currents and other quantities), and to view a graphical representation of the results.

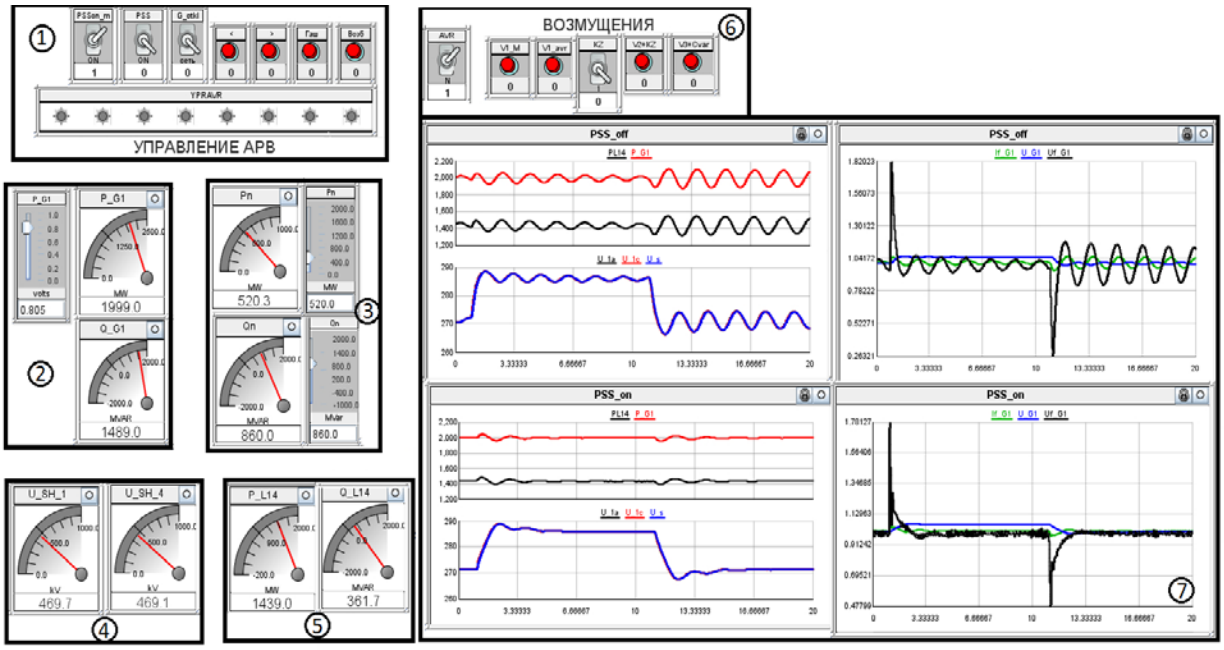

Figure 3. RunTime window with control of operating points, disturbances and recording of results.

Control, monitoring and recording (Figure 3) can be accomplished in RunTime to carry out all of the tests specified for certification according to the Standard of JSC "SO UPS" [1]. Test reproduction and calculated emergency disturbances are made at the software level.

Based on these requirements, the following components were created in RunTime (Figure 3):

1. signals generated in the control system for the AEC: switches (signals of constant value) and buttons (intermittent signals) are used;
2. synchronous generator operating point control (a slider allows control the of the mechanical torque) and a measurement of generated power;
3. controls for the parameters of the dynamic load (sliders specify active and reactive power) and measurement of this power;
4. voltage measurement at the system busbars;
5. measurement for the power flow through the line;
6. control of disturbances which can be programmed and selection of the AEC (physical device or its software model);
7. graphical representation of power system signals

Testing of the AEC of synchronous generators is carried out by the simulated implementation of the following disturbances:

1. Test disturbances with the parameters:

- A step change of the tested AEC by +5% of the rated value;
- Single-phase short circuit (duration of 0.03s) at Bus 1;
- A stepwise voltage change by connecting capacitance C3 to Bus 1;

2. disturbances in accordance with [2] with the following parameters:

    - Duration of the short circuit is 0.12s;
    - Single-phase reclosing time is 1s;
    - Three-phase reclosing time is 2s;
    - Switch-off time of one phase caused by mis-operation of the breaker failure protection is 0.35s;
    - Input lag on the control action of the AEC is 0.4s from when a short circuit takes place

Software implementation of the necessary disturbance requires the creation of control impulses. An example of the control impulses (the implementation of a single-phase fault near Bus 1 with successful single-phase reclosing of the line) is shown in Figure 4. These impulses are sent to the fault block (6) and the circuit breaker (5) from Figure 2.

Figure 4. The control pulses for the implementation of a single-phase fault near Bus 1 with a successful single-phase reclosing of the line. The short circuit impulse duration is determined by the need of successful single-phase reclosing of the line, while the reclosing time is given in [2].

The tests are aimed at:

- setting of stabilization channels or system stabilizer;
- provision of angular stability and stabilization of normal, maintenance and post-fault modes;
- checking lack of intragroup instability;
- provision of transient stability during emergency disturbances in the power system;

- ensuring the accuracy and efficiency of the regulator during emergency operating conditions

In order to connect the tested AEC to the RTDS Simulator, an interface controller has been designed. This controller contains a model of thyristor converter, controlled by a standard 6 pulse output from the AEC. It also includes a circuit which converts the signal from the output of the thyristor converter into a digital signal to be connected to the RTDS Simulator. The result of the thyristor converter operation is shown in Figure 5.

Figure 5. Illustration of the thyristor converter for the excitation system.

The dashed line in Figure 5 shows the signal generated by the AEC before its conversion to control impulses for the thyristor converter. This signal, after level limiting, is submitted to the field winding of the synchronous generator model. The solid line shows the corresponding signal, obtained in the RTDS Simulator software model. A good correlation of the original signal and the result of the conversion can be noted.

The RTDS Simulator has the ability to model different complex loads. Comparison of the effects of different loads is made by applying a test disturbance - a single-phase short circuit (duration of 0.03s) at the Bus 1. The following terms are used in the analysis of different loads:

- Dynamic load (DL) in the RTDS Simulator is a load which consumes constant power under voltage variations, i.e. has a varying impedance, where the voltage regulatory effect factors equal to zero [5]. Both active and reactive dynamic loads are used. Static load (SL) in the RTDS Simulator has fixed values of resistance and reactance, i.e. its power consumption varies with voltage and frequency, so that the regulatory effect will come out.

- g - logarithmic damping ratio, which shows how many times the magnitude of the oscillations is reduced in one period T [4].The value of 1 / g defines the number of periods, after which the magnitude is reduced by e (i.e. approximately by 1/3 of the initial value).

- t_{tr} - transient time, time during which the free components of the transient are reduced by 95%. The process is stable if all the roots of the characteristic equation have a negative real part.
- $t_{tr} \approx 3 / |\tau|$, s, where τ – is the real part of the root of the characteristic equation closest to the imaginary axis of the complex plane of the roots, decay constant.

Figure 6 shows different effects of active dynamic and static loads with stabilization enabled on generated and transmitted power.

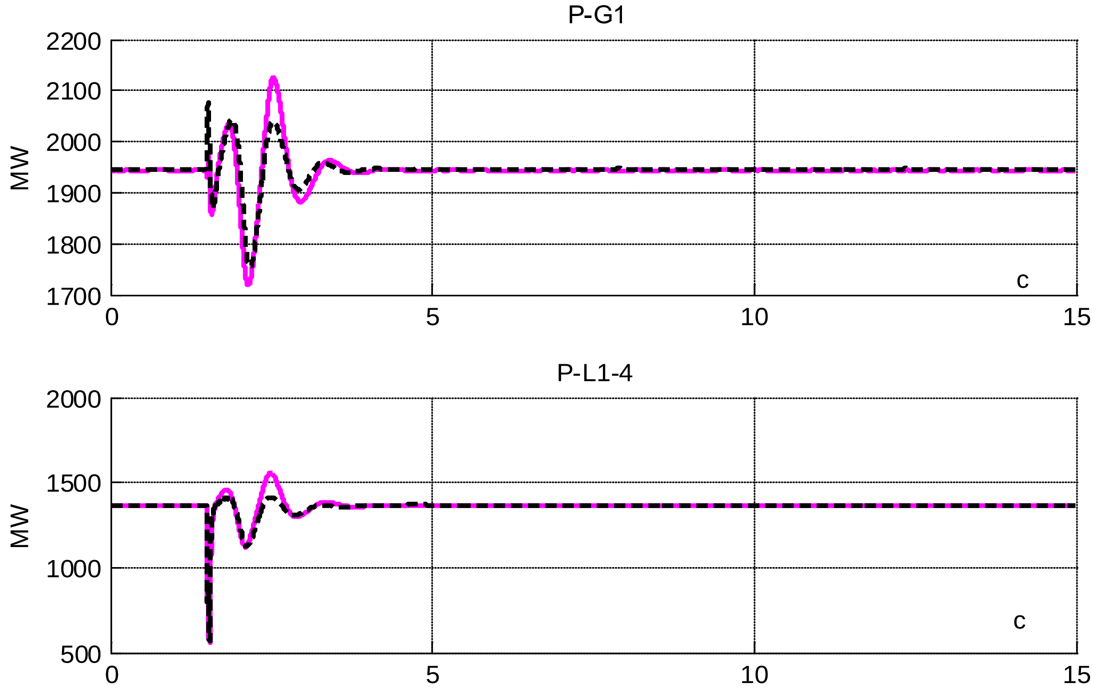

Figure. 6. Comparison of the effects of dynamic and static loads. Generated power P-G1 (generator G-1, Figure 2) , power flow through the line P-L1-4 (Line 1-4, Figure 2) under test disturbance (single-phase short circuit at Bus 1, Figure 2) are considered; dashed lines - static load, solid lines - dynamic load.

Table 1

Observed parameter	DL g_ DL	DL $t_{tr} \approx 3 / \|\tau\|$, s	SL g_ SL	SL $t_{tr} \approx 3 / \|\tau\|$, s	g_ДН / g_СН	tпп_ДН / tпп_СН
P_G1	1.5	1.7	1.46	1.53	1.03	1.11
PL_1-4	1.17	2.06	1.69	1.33	0.69	1.54

Table 1 shows the calculated damping constants and transient time under both static and dynamic loads. Analysis of the transient parameters shows that the

AEC performance in the test power circuit with the dynamic load are worse than those with the static load.

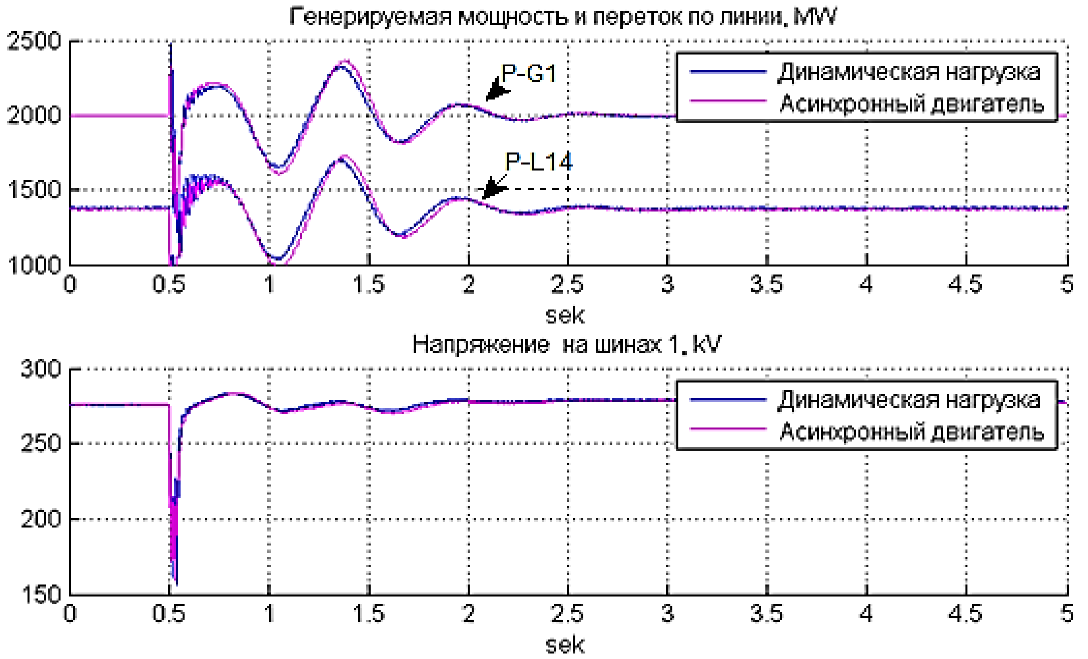

Figure 7. Comparison of the effects of dynamic loading and induction motor.

Figure 7 shows the generated power P-G1 (generator G-1, Figure 2) , power flow through the line P-L1-4 (Line 1-4, Figure 2) under test disturbance (single-phase short circuit at Bus 1, Figure 2) are considered. Stabilization features of the AEC are enabled. The difference in the effects of dynamic load and induction motor is about 2%.

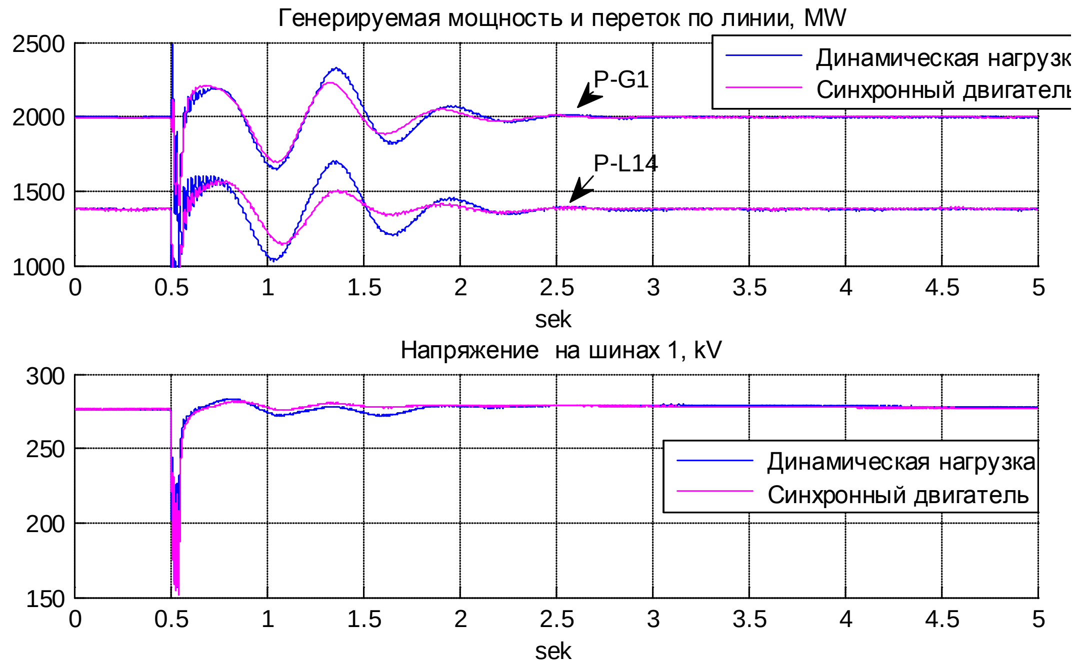

Figure 8. Comparison of the effects of dynamic load and a synchronous motor.

Figure 8 shows the generated power P-G1 (generator G-1, Figure 2) , power flow through the line P-L1-4 (Line 1-4, Figure 2) under test disturbance (single-phase short circuit at Bus 1) are considered. Stabilization features of the AEC are enabled.

The use of a dynamic load results in greater oscillation and less damping of transients compared to similar processes, obtained using a synchronous motor.

All the tests required by the JSC "SO UPS" Standard [1] were carried out. Methods to record the necessary parameters allows effective presentation of the results. In addition, it is possible to obtain the necessary numerical characteristics of the transient (transient time, damping constant, overshoot) by processing the results.

CONCLUSIONS:

1. The RTDS Simulator provides the opportunity to perform certification testing of the AEC required by the JSC "SO UPS" standard.
2. The RTDS Simulator provides the opportunity to model operating conditions of the generating equipment in the power system of varying complexity in order to verify the operation of the AEC. It also allows existing algorithmic or programming faults in the AEC to be rectified. Using real time digital simulation, the AEC can be adjusted for a particular power generating facility.
3. With the RTDS Simulator, information about the simulation can be recorded and then processed to measure and evaluate transients that take place during disturbances.

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