Testing the software and hardware complex for managing the power supply system of stationary consumers of railways

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Abstract. A prototype of an intelligent electronic device in the form of a software and hardware complex has been developed and tested, which provides identification of modes, automatic maintenance of optimal (quasi-optimal) voltage levels in the distribution network of the controlled area, automatic coordinated control of voltage regulation means and reactive power compensation means, FACTS devices, storage devices, generation, active consumers based on the involved components of the concepts of "virtual power plant" and "Internet of energy", automatic reconfiguration of the electrical network in normal mode. The results of numerical experiments on simulation models and physical measurements at operating facilities of the electric power industry confirm the reliability of the scientific and practical provisions presented in the article.

1. Introduction

Digital modeling of electric power systems in real time with physical connection of relay protection devices to the model is the most effective method used in the development of equipment, the study of transient and emergency modes. A power system simulator for real-time simulation (Real Time Digital Simulator, RTDS) allows you to combine real devices with a virtual model of their operating environment and conduct complex tests of relay protection and automation devices, including those operating under the IEC-61850 protocol with full feedback and response to change their state [1-3].

The study of the stability of the power system when changing modes of generating and consuming electrical equipment requires testing using digital simulators in a closed loop mode [4-6]. The software of the test devices includes specialized programs that provide selection, playback and viewing of pre-prepared oscillograms of emergency processes in the COMTRADE format [7-10].

To test the performance of relay protection devices without taking into account the instantaneous response of the electric power system, tests can be carried out in an open loop mode using hardware and software test complexes [11-12].

2. Materials and methods

The developed prototype of the software and hardware complex of the intelligent system for automatic control of transport and distribution of electrical energy in the power supply system of stationary consumers of railways [13] is a superstructure (addition) to the existing (prospective) automated control system of the power grid infrastructure, providing the following main functions:

- Automatic maintenance of optimal (quasi-optimal) voltage levels in the controlled area of the distribution network;
• Automatic coordinated intelligent control of distributed voltage regulation and reactive power compensation devices, FACTS devices, storage devices, generation, demand of active consumers based on the involved components of the concepts of "Virtual Power Plant" and "Internet of Energy" for voltage stabilization, elimination of overload (increased throughput) power facilities of the electrical network, reducing electricity losses and costs;
• Automatic reconfiguration of the electrical network.

The information support of the PTK includes:
• Description of input analog and discrete signals;
• Description of output discrete signals;
• Description of digital input and output signals;
• Description of the organization of information exchange with separate substation systems.

The IED of the substation level is designed to implement the algorithms under consideration as a control controller and can be performed on the basis of an industrial computer due to the absence of strict requirements for the development time of control actions and rather complex optimization calculations and data processing methods that require significant computing resources.

The IED of the bay level has freely programmable logic; it can be implemented on the basis of the controller and is designed to implement the automation algorithms for the elements of the power supply system, i.e. acts as a local controller of executive devices (power facilities).

The communication architecture of the software and hardware complex (PTC) for the supply substation and the controlled section of the electrical distribution network includes an automated place (AWP) with servers, switches, communication and control controllers, network switches, intelligent electronic devices (substation level), intelligent electronic devices (connection level), control objects, interface devices with measuring devices (field level).

The enlarged structural and functional diagram of the PTC is shown in figure 1.

![Figure 1. Simplified structural and functional diagram of the PTC.](image-url)
The developed software (SW) of the PTC prototype for the substation-level IED is designed to determine the optimal coordinated control actions of generation sources, storage devices, reactive power compensation devices, FACTS devices, energy routers for voltage stabilization, reduction of overload in the electric power system based on a multi-agent approach.

Testing the PTC to check the developed algorithms is performed on the basis of a mathematical (digital) model of the power supply system (parameters of lines, transformers and other elements, their mathematical models, a system of equations of states of the electric power system for calculating the steady state, etc.) [14].

The mathematical algorithm of the program based on the assessment of the state of the electric power system (topology, mode parameters, including the results of measurements), taking into account the ontology (knowledge base), which contains process models, criteria and constraints, determines, according to the voltage stabilization condition, the value of control actions for implementation by executive devices based on a multi-agent approach.

The program for the electric network model provides the following functions: input and receipt of initial data from external measuring devices; output of solution results on the monitor screen and data transfer to external devices, including executive ones.

The main stages of simulation based on the developed algorithms [14] can be conventionally represented in the form of the following enlarged steps:

- Determination of control actions for voltage stabilization, optimization of power flows based on a multi-agent approach by performing sensor analysis of the electrical network (in normal and post-emergency modes) by determining the sensitivity of the electrical network nodes to assess the boundaries of the influence of linear and centralized regulators on the voltage mode and determine the actual and permissible power flows through lines limiting the throughput;
- Description of local agents and coordinating agents, knowledge base in the power supply system;
- Simulation of electrical network modes with the calculated settings of the regulators, the calculated topology of the electrical network for the purpose of voltage regulation and
overload limitation in the power supply system of stationary railway consumers in Matlab Simulink.

For research and approbation of the developed scientific and technical solutions and methods of intelligent control of transport and distribution of electricity in the power supply system of stationary consumers of railways, a prototype of a software and hardware complex of an intelligent electronic device based on an industrial computer tested using physical signals of currents and voltages was created.

The PTC test procedure included the following stages:

- Development of a mathematical model of a given section of power supply systems in normal mode from 12 buses with a full description;
- Setting the module for calculating the steady state of the electrical network based on nonlinear equations of state to simulate the response of the mode parameters to external disturbances;
- Setting the database module required for the operation of the software package;
- Connection to a software package that simulates the external environment via Ethernet of an industrial computer with an installed PTC;
- Connection to an industrial computer to a parallel port through a verified measuring transducer of three analog signals from the Retom 41M software and hardware complex;
- Adaptation of the software and hardware complex for the mathematical model of the electrical network;
- Software simulation with a step of 1-5 seconds of changing the parameters of the power supply system by loads and in the form of calculated voltages, power flows, etc. based on the mathematical model of the network;
- PTC reading of mode parameters, network topology state and determination of control actions (voltage in three nodes of the electrical network is simulated by analog signals with Retom 41M) according to the condition of voltage stabilization;
- Transfer of control actions from the PTC to a software package with a mathematical model of the network and obtaining new mode parameters.

3. Results and Discussion
In figure 3-5 shows the test results of a prototype of a PTC based on an industrial computer in the form of the obtained increments of the active and reactive power of regulators, voltages without control and with control based on a given network circuit for voltage stabilization (figure 4).

Figure 3. Voltage 1 ssh TP 16 without (2) and with control (1) voltage.
4. Conclusion

The research results have shown the practical feasibility and effectiveness of the presented algorithms for coordinated voltage control in the power supply system of stationary railroad consumers. Integration in one software product of the components of system dynamics and agent behavior makes it possible to holistically simulate the behavior of a multi-agent voltage control system in electric distribution networks of railways.

The results of numerical experiments on simulation models and physical measurements at operating facilities of the electric power industry confirm the reliability of the scientific and practical provisions presented.

The presented studies create a theoretical and practical foundation for the development of a software platform with an open architecture for intelligent control of the railway power supply system as a whole, which is the topic of further research by the author.

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Figure 4. Increment of active generation of TS 1.

Figure 5. Reactive power l ssh TS 16.
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