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Application of Intelligent Technologies for Control of Generator Sets in Power Supply Systems for Non-Traction Consumers

Yuri Bulatov[1,*] Andrey Kryukov[2,3] Konstantin Suslov[3,4]
Pio Lombardi[5] Przemysław Komarnicki[5,6]

[1] *Department of Energy, Bratsk State University, Bratsk, Russia*
[2] *Department of Transport Electric Power, Irkutsk State Transport University, Irkutsk, Russia*
[3] *Department of Power Supply and Electrical Engineering, Irkutsk National Research Technical University, Irkutsk, Russia*
[4] *Department of Energy, Transbaikal State University, Chita, Russia*
[5] *Fraunhofer Institute for Factory Operation and Automation IFF, Magdeburg, Germany*
[6] *Department of Engineering and Industrial Design, Magdeburg-Stendal University of Applied Sciences, Magdeburg, Germany*
[*] *Corresponding author. Email: bulatovyura@yandex.ru*

ABSTRACT
One of the key features of the current transition of the electric power industry to the smart grid technological platform is a large-scale application of distributed generation (DG) plants. The efficient operation of such plants is not possible without the development of new approaches to the control of their generators. In modern conditions, these approaches are based on intelligent technologies. This article discusses intelligent control technologies for DG plants used in power supply systems for non-traction consumers. The purpose of this research is to assess possible effects produced by intelligent technologies in the control of DG plants. The research simulation and calculations were carried out in MATLAB. Using the fuzzy logic system, we demonstrated the operation the proposed control system for the settings of the automatic regulators of the DG plants. Determination of optimal settings of the regulators was carried out using a genetic algorithm. The results of simulating neural network regulators of DG plants are presented. The simulation results revealed that the use of intelligent control technologies for DG plants increases the control accuracy and improves control quality indicators.

Keywords: *Railways, Power supply systems, Distributed generation plants, Intelligent control technologies, Fuzzy logic, Genetic algorithm, Neural network regulator.*

1. INTRODUCTION

In recent years, smart grid technologies have been actively developed and implemented [1–3], which implies large-scale use of intelligent control algorithms in electric power systems (EPS). Therefore, the problems of developing such algorithms are of particular relevance. These algorithms can be used as a basis for building cyber-physical EPS [4–6] characterized by deep integration of power elements and information technologies. The implementation of a cyber-physical approach to the creation of intelligent EPS with active-adaptive grids provides for the large-scale use of distributed generation (DG) plants of relatively low power. As a rule, DG plants are located near power consumers [7–12] and provide ample opportunities for reducing peak loads, stabilizing voltage levels, reducing losses and improving quality of electric power [11, 13].

DG plants implemented on the basis of synchronous generators (SGs) help generate sufficiently large amounts of electric power and can be effectively used to supply it to stationary objects of railway transport. The control of SGs is performed via automatic voltage regulators (AVRs) and automatic speed regulators (ASRs) that usually employ proportional-integral-derivative (PID) control laws.

Quite a lot of works have addressed application of intelligent technologies in the problems of determining the settings of PID regulators, for example, see [14–17]. A significant number of works explore how to use intelligent regulators to control generators of DG plants [18–22]. The practical application of intelligent algorithms requires taking into account both the features of the DG plants and EPS in which they operate. Handling the issues of using these regulators in cyber-physical EPS requires additional research and computer simulations.

This paper presents a description of intelligent control systems for AVRs and ASRs of a DG plant designed to work in the power supply system (PSS) of non-traction consumers. The proposed control systems used the following intelligent components: genetic algorithm (GA); fuzzy logic system; neural networks. The goal of the present research is to assess effectiveness of intelligent technologies in the control of DG plants.

2. FUZZY LOGIC SYSTEM FOR CONTROL OF REGULATORS OF THE DG PLANT

Improving the quality of regulation of AVRs and ASRs is possible by adapting their adjustment coefficients to changes in the operating modes of the PSS. This approach can be implemented using a regulator with a fuzzy logic system (Figure 1).

The algorithm of the proposed fuzzy logic control system is based on identification of the operating mode of the SG and deviations in the adjustment coefficients of the AVRs and ASRs caused by significant variations in the operating mode. A fuzzy logic controller, implemented on the basis of a fuzzy logic system, is equipped with an autotuning unit (Figure 1) and also includes modules for identifying an object and adjusting AVRs and ASRs. The following parameters are supplied to the device inputs: voltage U_g, rotor speed ω_g, active and reactive powers P_g, Q_g of the generator, power quality indicators (PQI) of the non-traction consumer's network. As a result, the optimal for the current mode adjustment coefficients of the AVRs and ASRs are determined.

The algorithm for adjusting and creating a knowledge base of a fuzzy logic controller for various modes of operation of the power supply system includes the following stages described in detail in [9, 15]: identification of the SG model; optimization of AVRs and ASRs settings using a GA; calculation of the gain margin. Performing the listed tasks using a specialized software package [9] helps create a base of rules for a fuzzy logic controller that implements a search using a GA for optimal adjustment coefficients.

Approbation of the proposed fuzzy logic system was carried out on the basis of a computer model of the railway power supply system (RPSS) developed in MATLAB. When building this model, the main attention was paid to the power supply area (PSA) of non-traction consumers, the networks of which were connected to the 6 kV buses of the traction substation (TS) (Figure 2).

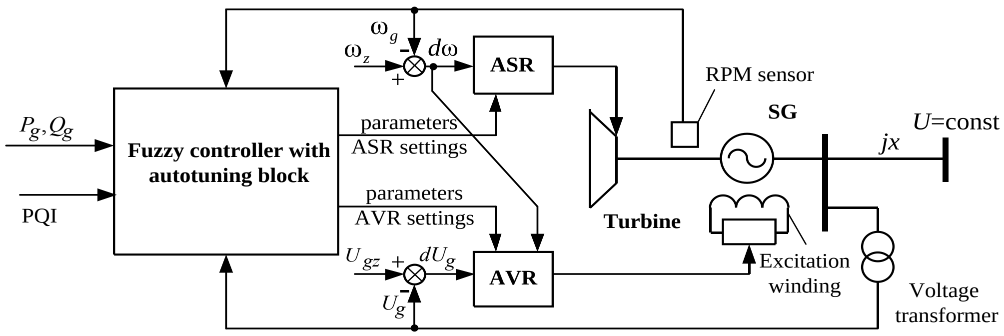

Figure 1 Diagram of the fuzzy logic control system for adjusting AVRs and ASRs.

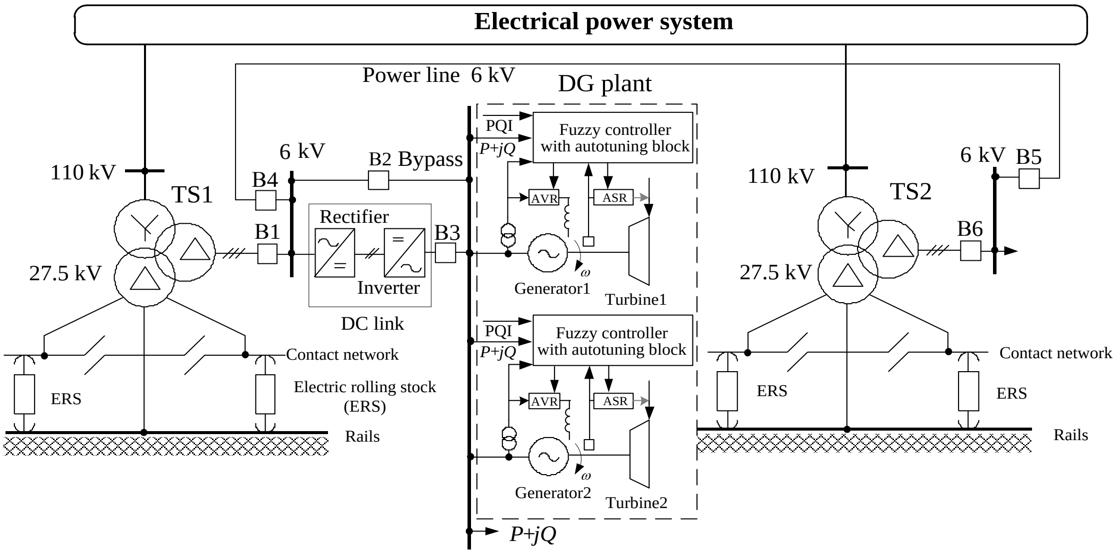

Figure 2 A fragment of the RPSS.

The total loads of the PSA were 5 MV·A. It was assumed that the DG plant was implemented on the basis of two synchronous generators with a capacity of 2.5 MV·A. A fragment of the model developed in MATLAB is shown in Figure 3.

The model of the RPSS under study was build using standard units of the MATLAB Simulink and SimPowerSystems libraries. The parameters for models of synchronous generators (Synchronous Machine pu Fundamental in Figure 3) of the DG plant are shown in Figure 4.

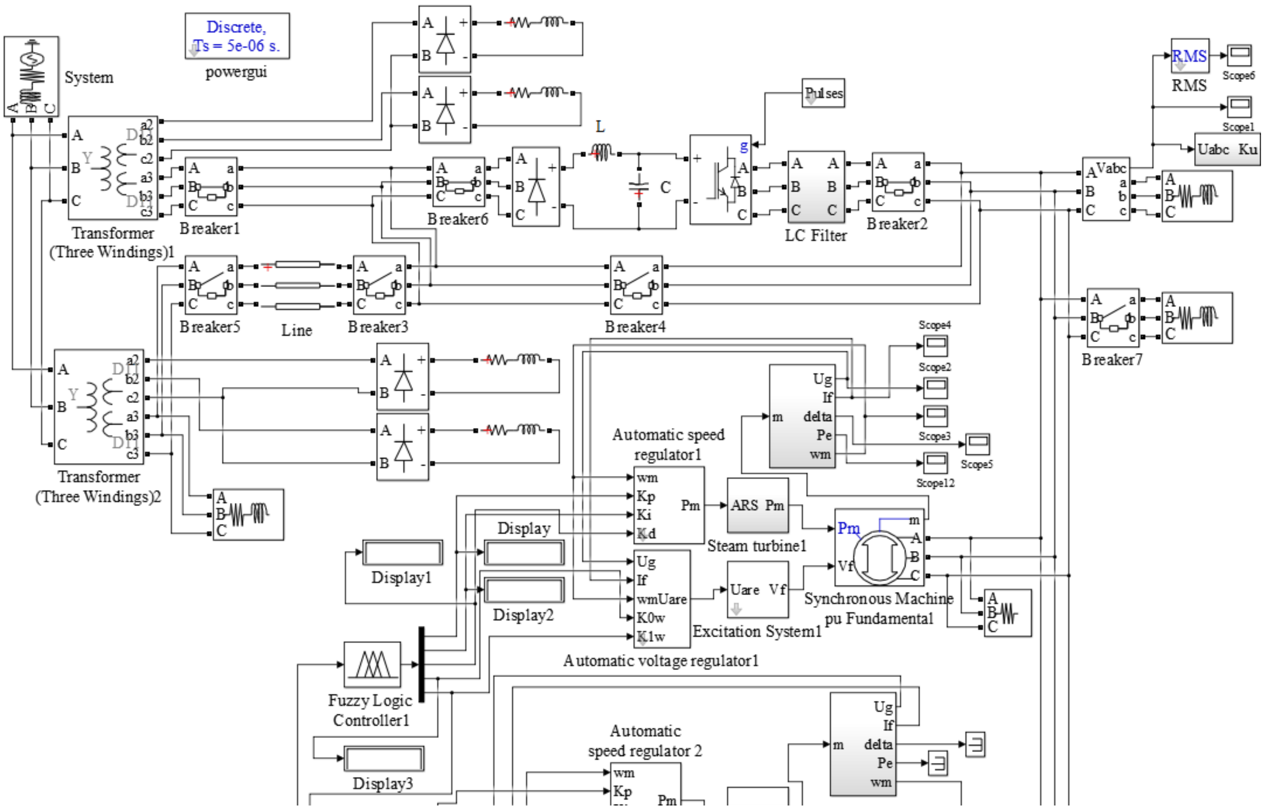

Figure 3 A fragment of the RPSS model in MALAB.

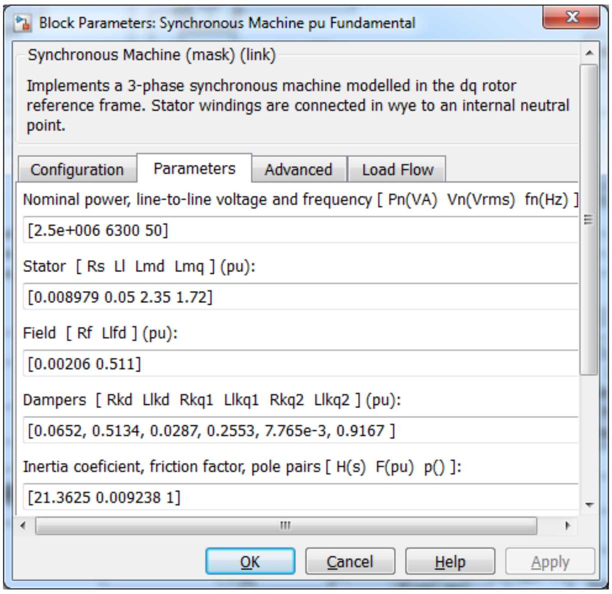

Figure 4 Parameter window the SG model.

The thyristor SG exciter (the Excitation System block in Figure 3) was modeled by a first-order aperiodic link with a coefficient $k_e = 1$ and a time constant $T_e = 0.025$ s. The description of the AVR and ASR models can be found in [11, 17]. The diagram of the steam turbine model (the Steam turbine block in Figure 3) is presented by the transfer function $\frac{1}{0.2s+1}$, where s is a Laplace operator.

The tuning of the fuzzy logic controller was limited only to the main operating modes of the presented RPSS and the DG plant, for which the corresponding IF-TO rules were created. The following operating modes of the DG plant were considered (Figure 2) as the basic ones:

- autonomous operation of the DG plant under a 5 MV·A load;
- parallel operation of the DG and EPS through the DC link and TS1;
- parallel operation of the DG and EPS through the DC link and TS2;
- parallel operation of the DG and EPS through bypass and TS1;
- parallel operation of the DG and EPS through the bypass and TS2.

When analyzing the control quality, the following commutations were simulated: disconnection of the DC link and activation of the bypass by the B2 switch in 0.5 s (Figure 2). Identification of the mode was carried out according to the following power quality indicators: harmonic coefficients and voltage unbalance on the 6 kV buses of a non-traction consumer. The simulation results showed the high efficiency of the proposed system; at the same time, a decrease in the transient time was observed; the voltage overshoot and rotation speed of the SG rotor decreased (Figures 5 and 6). The biggest effect was observed in the transient time for the deviation of the generator rotor speed (Figure 6), it decreased by a factor of 2.5.

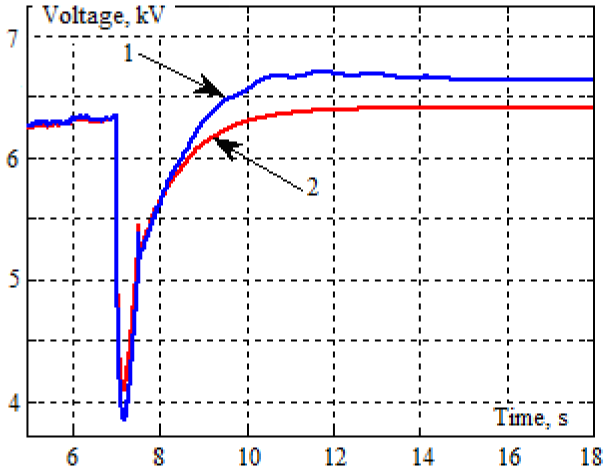

Figure 5 Effective voltage values on 6 kV buses: 1 – without varying the regulator settings; 2 – using a fuzzy logic controller.

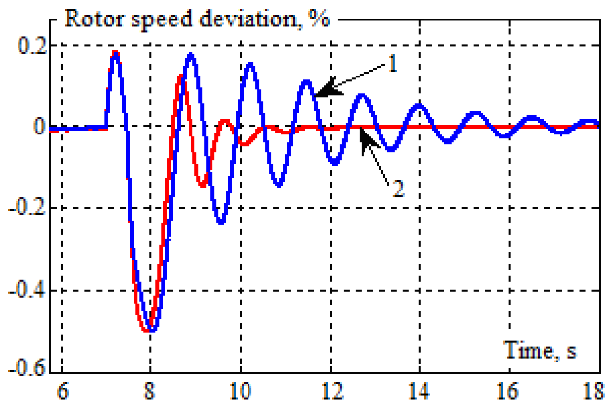

Figure 6 Deviation of the generator rotor speed: 1 – without variation of the regulator settings (transient time t_p=10 s); 2 – using a fuzzy logic controller (t_p=4 s).

In addition, we analyzed transient processes occurred due to a three-phase short circuit on 6 kV buses, which was turned off after 0.5 s following the relay protection signals. It was assumed that in the initial mode, the DC link was switched on and the non-traction consumers were powered by the TS1 and the DG plant (Figure 2). The obtained time dependences of the SG rotor speed are shown in Figure 7. It can be readily seen that changing the settings of regulators ensures stable operation in the emergency mode.

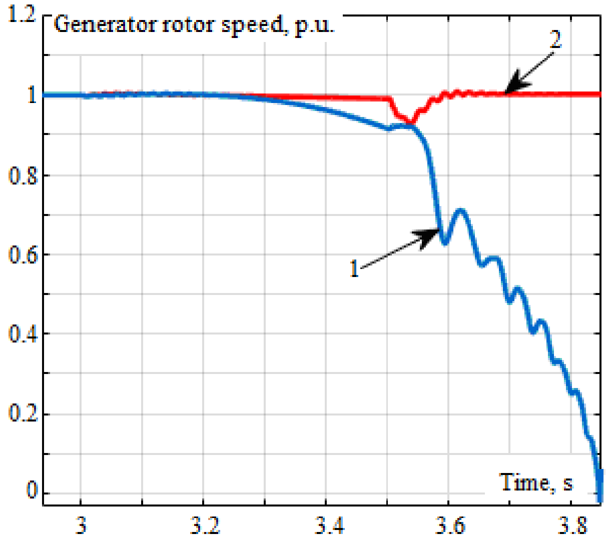

Figure 7 Oscillograms of the SG rotor speed under a momentary short-circuit: 1 – without variation of the AVR and ASR settings; 2 – using a fuzzy logic controller.

3. NEURAL NETWORK REGULATORS OF THE DG PLANT

The use of neural network regulators [18] makes it possible to take into account the specific features of the railroad power supply systems, namely: multimode and dynamism; risk of failures and accidents, as well as unique and non-standard situations; infeasibility to perform simultaneous control of all devices affecting the RPSS mode. These features can be taken into account on the basis of the following properties of artificial neural networks (ANNs): training enables them to make their own correct decisions; it is possible to predict the system behavior; adaptation to changes in properties of the control object and the external environment. ANNs are characterized by a high fault tolerance and fitness for the synthesis of effective regulators.

The RPSS model with neural network regulators that implement the functions of AVRs and ASRs for a circuit similar to the one shown in Figure 2 (but including one TS) was also designed in MATLAB. Figures 8 and 9 present the simulation results for operation under a remote momentary three-phase short circuit in comparison with typical PID regulators.

The simulation results showed a fairly high efficiency of the neural network AVRs and ASRs. Compared to typical regulators, the use of neural network devices provided the decrease in the voltage and rotor speed transient time; overshoot of the SG rotor speed decreased by 1.7 % under a remote momentary three-phase short circuit (Figures 8 and 9).

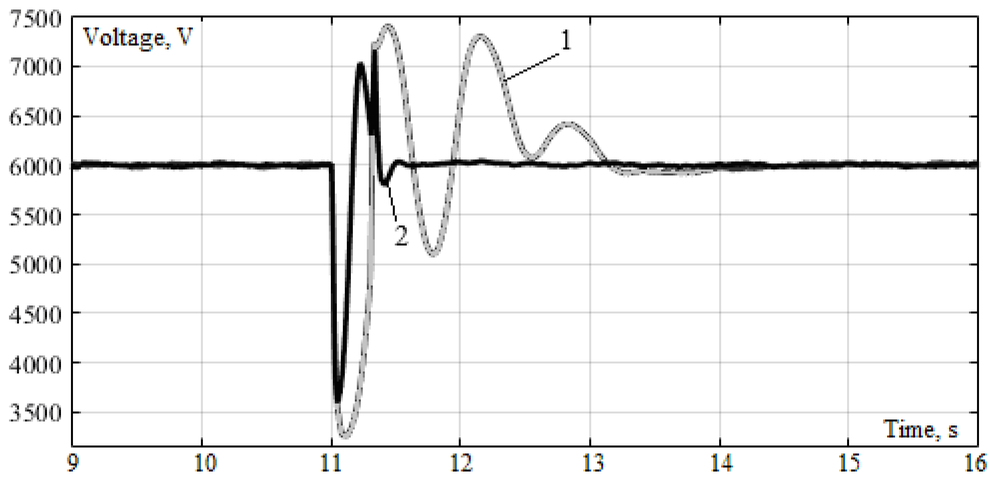

Figure 8 The effective values of the SG voltage under remote three-phase short circuit with a duration of 0.3 s: 1 – using standard AVRs and ASRs (t_p = 2.5 s); 2 – using neural network AVRs and ASRs (t_p = 0.5 s).

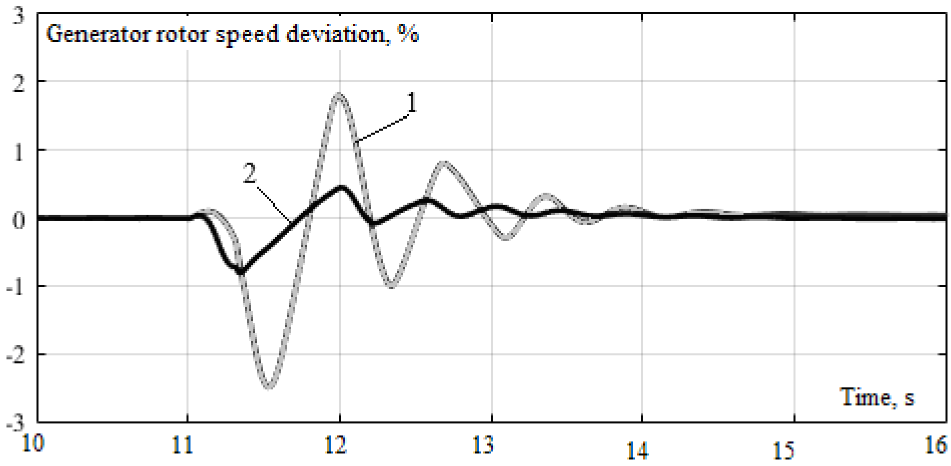

Figure 9 Deviation of the generator rotor speed under remote three-phase short circuit with a duration of 0.3 s: 1 – using standard AVRs and ASRs (overshoot σ=2.5 %, t_p=3 s); 2 – using neural network AVRs and ASRs (σ=0.8 %, t_p=2,5 s).

4. CONCLUSIONS

We considered intelligent technologies for the control of distributed generation plants intended for power supply to non-traction consumers. A fuzzy logic system for controlling the settings of automatic regulators of DG plants operating on the basis of SGs is proposed. A genetic algorithm was used to find optimal settings for AVRs and ASRs.

We presented the results of simulating neural network regulators that enable most adequate implementation of the specific features of railroad power supply systems.

The simulation results showed that using intelligent control technologies for DG plants provides the following positive outcomes:

- improvement of the regulation accuracy;
- improvement of the control quality indicators via reduction of the transient time and overshoot;
- increase in the stability of parallel operation of synchronous generators.

AUTHORS' CONTRIBUTIONS

Conceptualization: Y.B., A.K. and K.S.; methodology: Y.B. and A.K.; software: Y.B.; validation: Y.B., A.K. and K.S.; formal analysis: Y.B. and A.K.; investigation: Y.B., A.K. and K.S.; resources: K.S.; data curation: A.K.; writing original draft preparation: Y.B.; writing review and editing: Y.B., A.K. and K.S.; visualization: Y.B.; supervision: K.S.; project administration: Y.B. and A.K. All authors have read and agreed to the published version of the manuscript.

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