The Study of Transition to the Isolated Operation of Power Supply Systems with Distributed Generation Plants and High Power Energy Storage Units

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Abstract: The development of power engineering, under current conditions, is aimed at the use of distributed generation plants in power supply systems located in immediate proximity from power consumers. The article deals with power supply system with turbo generator plant and high power energy storage unit. Description of a power supply system model with turbo generator plant, energy storage unit and asynchronous load is provided, and modeling results of power supply system transition to the isolated operating mode. The model of the power supply system under study was carried out in the MATLAB environment using the Simulink and SimPowerSystems simulation packages. In work is a description of the PSS model used with DG plant and ESU, as well as the simulation results. Based on the computer simulation results the conclusion, that use of prognostic controllers turbo generator plant allows improving the damping properties of the system when switching to an isolated mode of operation.

1 INTRODUCTION

Currently, it is expedient to use distributed generation (DG) plants located in immediate vicinity from power consumers (Ackermann et al., 2001), for power supply systems (PSS) development and modernization. This approach enhances the consumers power supply reliability and reduce losses associated with power transfer (Rugthaicharoencheep and Auchariyamet, 2012). The use of DG plants affects the PSS power quality in a positively (Sikorski and Rezmer, 2015), (Hariri and Faruque, 2014).

The PSS parallel operation with DG plants and high-capacity electrical energy system (EES) allows to stabilize voltage and frequency at various disturbances. At the same time, such parallel operation mode results in short circuit currents increase, sophistication of relay protection devices and modes control. In emergency situations it is expedient to use the island (isolated) mode when DG plants are separated in clusters to supply the part of essential consumers (Martinez-Cid and O'Neill-Carrillo, 2010), (Saleh et al., 2015). To enhance the PSS functional reliability, a number of tasks shall be solved, which includes DG plants optimal control at the transition to the isolated mode (Arai et al., 2009). In this case, it is necessary to consider the types of DG plants and their generators used, restrictions on the consumers maximum load, the nature of the load, as well as the effect of a sharp increase or decrease in load on generating plants.

DG plants, operating on the basis of synchronous turbo- and hydrogenerators, provide a sufficiently large power to supply industrial consumers. Automatic excitation controllers (AEC) and automatic speed controllers (ASC) of rotor rotation allow to increase the stability of synchronous generators operation in PSS.

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The tasks of constructing and adjusting regulators of DG plants operating in PSS under various operating modes, can be solved using energy storage units (Lombardi et al., 2014) and intelligent control technologies (Magdi and Fouad, 2015), (Wang et al., 2018).

The studies carried out indicate that the use of fuzzy controllers (Voropai and Etingov, 2001), (Kryukov et al., 2017) and predictive algorithms (Camacho and Bordons, 2007), (Bulatov et al., 2018) is an effective way to control synchronous generators. This approach makes it possible to create adaptive systems. However, the practical application of such systems requires laborious research on complex models, while taking into account a large number of possible operating modes in order to determine their influence on the control parameters and quality indicators of the control process.

The purpose of this work is to study the behaviour of the proposed prognostic AEC and ASC of synchronous generators during the transition of a PSS with a powerful asynchronous load to the island (isolated) mode. The studies were carried out for PSS of an industrial enterprise with a turbogenerator plant (TGP) and a high-power electric energy storage unit (ESU). The simulation was performed in MATLAB using Simulink and SimPowerSystems packages. Below is a description of the PSS model used with DG plant and ESU, as well as the simulation results.

2 DESCRIPTION OF PSS MODEL USED WITH DG PLANT AND ENERGY STORAGE UNIT

The diagram of the PSS under study, provided in Figure 1, had links with EES via two 110/10 kV transformers (T-1 and T-2) each having power of 6300 kVA. The main power consumers of the PSS under study are asynchronous motors (AM): two high-voltage AMs with a power of 670 kW each, as well as a large number of low-voltage AMs which are taken into account in the model in the form of equivalent units with transformers and cable lines with a power of 930 kW and 1485 kW, respectively, powered from different bus sections (Figure 1). The PSS includes a TGP with a power of 3125 kVA and a high power ESU.

The model of the PSS under study was carried out in the MATLAB environment using the Simulink and SimPowerSystems simulation packages.

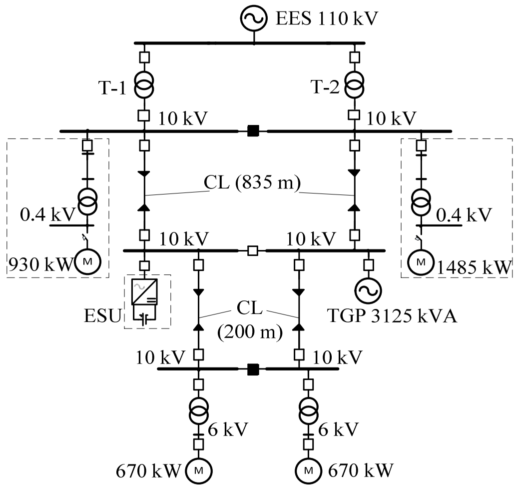


Figure 1: The diagram of the PSS under study of an industrial facility: CL – cable line.

The model of the used TGP steam turbine was described by the following differential equation:

$$T_T \cdot \frac{dP_T}{dt} + P_T = \mu\,, \qquad (1)$$

where P_T – turbine power; μ – opening of a controlling element; T_T – turbine time constant (was taken for practical reasons equal to 0.2 s).

The TGP generator excitation system was modeled using the first-order aperiodic link with transfer function $\frac{1}{0.025s+1}$ (Anderson and Fouad, 2003), and a series-connected amplifier with transfer function $\frac{1}{0.001s+1}$, where s – Laplasian operator.

To stabilize the voltage on the TGP generator terminals and the rotor speed, as well as to increase stability, the model uses AEC and ASC, which are proportional-integral-differential (PID) controllers with or without prognostic links.

It is proposed to use a prognostic AEC as an excitation regulator for TGP synchronous generator, whose Simulink-model block diagram is shown in Figure 2. The diagram of the used Simulink-model of prognostic ASC is shown in Figure 3 (Bulatov et al., 2018). The proposed AEC and ASC models differ from the known ones in that a linear prognostic link with a transfer function $T_p\mathrm{s}+1$ with a series-connected electronic amplifier having transfer function is used at the controller output $\frac{K_a}{T_a\mathrm{s}+1}$. The following numerical values of the parameters were accepted in modelling: K_a=1; T_a=0.001 s.

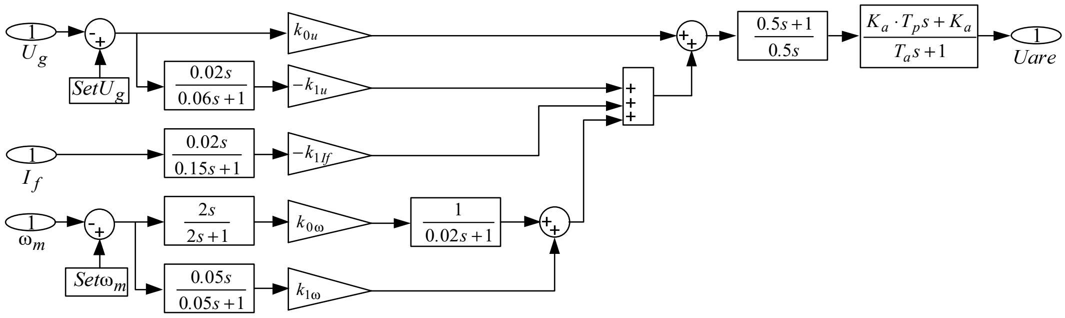


Figure 2: A structural model diagram of the prognostic AEC: U_g – an instantaneous value of generator voltage; $SetU_g$ – a set value of generator voltage; I_f – generator excitation current; ω_m – a generator rotor speed instantaneous value; $Set\omega_m$ – a generator rotor speed set value; k_{0u}, k_{1u}, k_{1If}, $k_{0\omega}$, $k_{1\omega}$ – tuning coefficients of AEC; T_p – the prognostic link time constant.

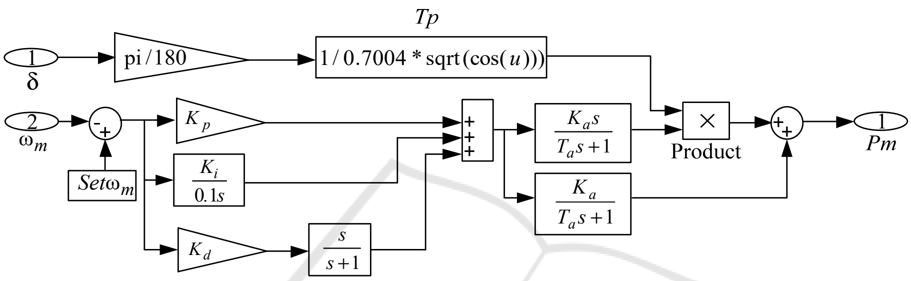


Figure 3: A structural model diagram of the prognostic ASC: K_p, K_i, K_d – tuning coefficients of ASC.

AEC and ASC tuning coefficients were determined based on practical considerations and were assumed to be the same for classical PID controllers and devices with a prognostic link. The prognostic time constant for ASC was determined automatically (Bulatov et al., 2018) and changed subject to the generator load angle δ according to the following function:

$$T_p^{ASC} = \frac{1{,}428}{\sqrt{\cos\delta}} .$$

The time constant of the prognostic link was determined for AEC T_p^{AEC} in accordance with the method described in (Bulatov et al., 2018), and was assumed to be equal to 0.125 s. It should be noted, that the method used for determining the time constants of AEC and ASC prognostic links is universal and can be used in schemes with any number of generators and power consumers.

The use of ESU based on large capacity accumulator batteries is a promising development line for use in smart EES. The work uses lithium-ion storage batteries due to their advantage over other ESU types (Nishi, 2001). The Battery unit of the SimPowerSystems package of the MATLAB system was used as a model of lithium-ion accumulator batteries. The ESU, the power of which was 3 MW in the course of simulation, can be charged from the EES or from the TGP during the minimum loads periods.

3 SIMULATION RESULTS

The studies were carried out during the PSS transition to an isolated operation mode with the following technical equipment of the DG plants:

- the use of TGP with prognostic AEC and ASC or with classical controllers;
- the use of high power ESU, in which case, the ESU is permanently connected or automatically connected when the voltage drops.

The initial load of the TGP was 80%, and when switching to the island operation mode, the generator was found to overloaded. Such a mode cannot exist continuously, therefore, to compensate for the generating capacity shortage in the PSS, a ESU was used, the power and capacity of which were sufficient for a continuous consumer supply. The simulation results of the PSS transition to the isolated operation mode in the form of time dependences of the power on the TGP turbine shaft, the rotor speed and the generator voltage are provided in Figure 4. Figure 5 shows the time dependences of the PSS frequency in the specified operation mode. The time dependences presented in Figures 4 and 5, indicate that the use of a high-power ESU in PSS allows the generator load shedding and more efficient stabilization of frequency at PSS transition to the isolated mode. However, at the same time, there is an increase in overshoot, oscillation, and transient time for the rotor speed and voltage of the TGP generator.

It can also be noted that the use of prognostic AEC and ASC of the TGP generator makes it possible to improve the system damper properties without employing the optimization procedures for controller settings: the value of overshoot, oscillation, and transient time for the speed of the generator rotor speed, the turbine shaft power, and the frequency of the mains voltage, are reduced. At the same time, in the mode under study, the prognostic link in the AEC has virtually no effect on the voltage at the terminals of the TGP generator.

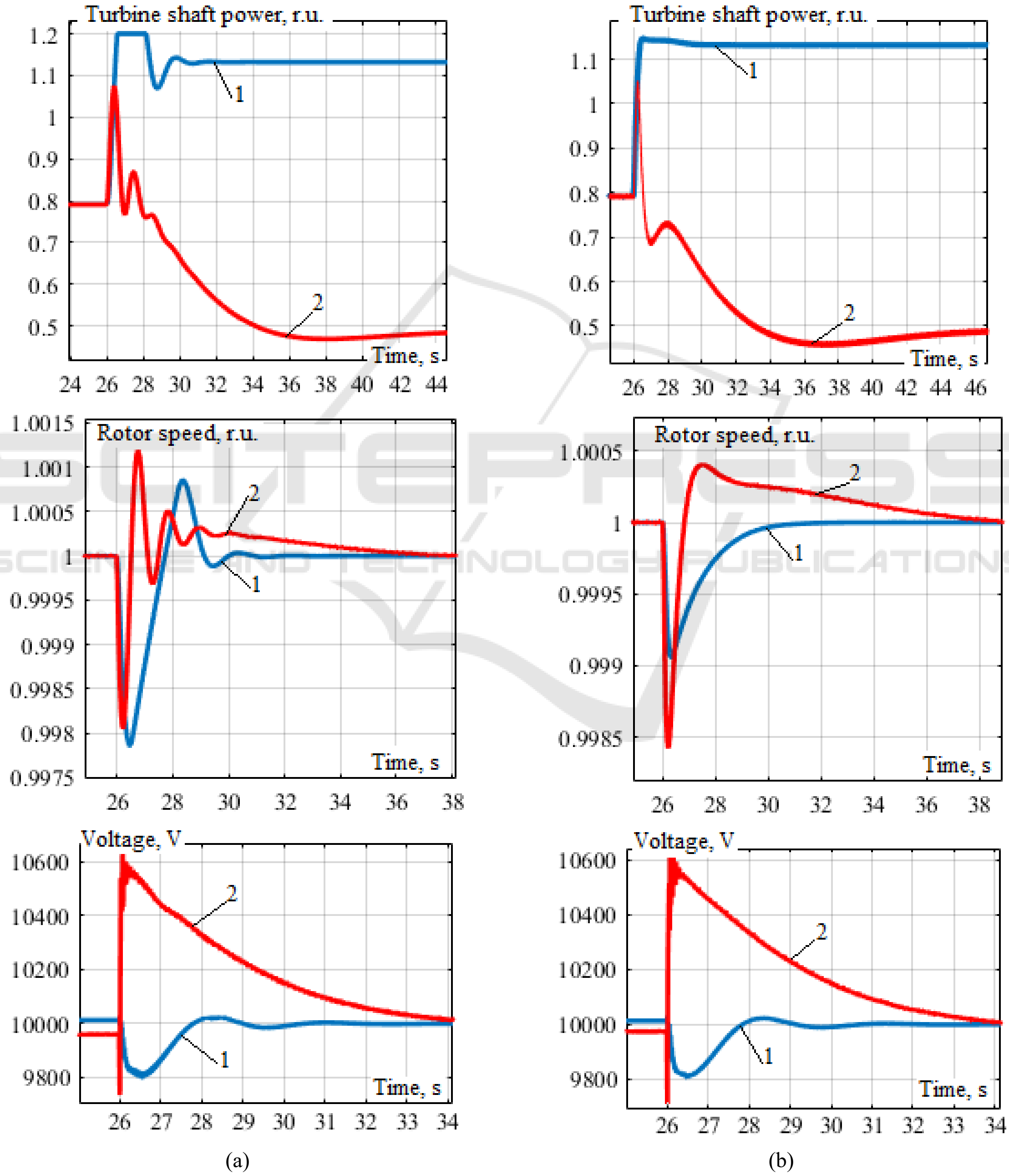
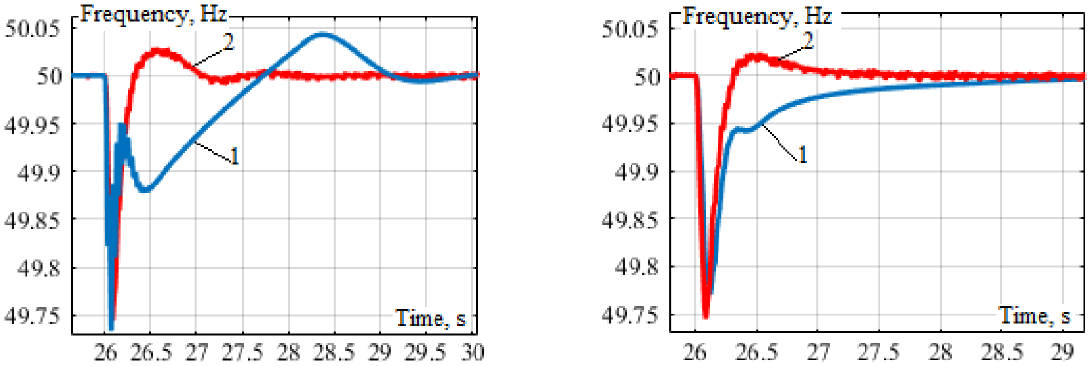
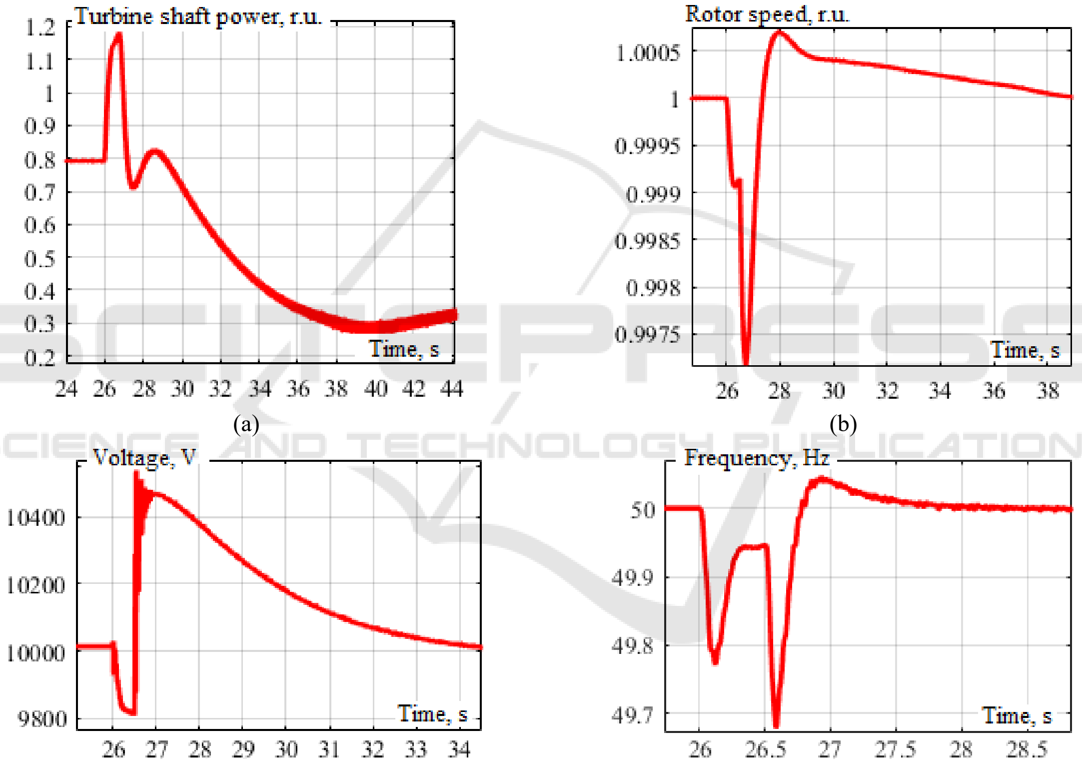


Figure 4: Parameters of the TGP during the transition to the island (isolated) operation mode of the PSS: (a) – classic AEC and ASC were used; (b) – prognostic AEC and ASC were used; 1 – ESU is disabled; 2 – ESU is always on.



(a) (b)

Figure 5: The frequency in the mains during the PSS transition to the island (isolated) operation mode: (a) – classic AEC and ASC were used; (b) – prognostic AEC and ASC were used; 1 – ESU is disabled; 2 – ESU is always on.



(a) (b)

Figure 6: TGP parameters with auto prognostic ASC and prognostic AEC (a, b, c) and frequency in the mains (d) when the PSS transition to an isolated operation mode: ESU is connected automatically when the voltage drops.

Also, a simulation was carried out for the transition of the PSS to an isolated operation mode when the ESU is disconnected, and which was connected automatically when the voltage on the 10 kV buses dropped. Figure 6 shows the simulation results in the form of TGP parameters and frequency in the PSS.

A comparative analysis of the simulation results for the PSS transition to the isolated operation mode allows us to make a conclusion that it is effective to use high power ESU to increase the reliability of consumers power supply and to prevent the overload mode of the used distributed generation plant.

At the same time, in comparison with the PSS operation mode, when the ESU is disabled, slightly larger deviations and fluctuations in the voltage and rotor speed of the generator of the DG plant are observed, which can be minimized due to the use of the prognostic AEC and ASC.

4 CONCLUSIONS

Based on the computer simulation results of the PSS operation modes with the DG plants and ESU when the links with the high-power EES are disabled, the following conclusions can be drawn:

1. The use of high power ESU in PSS allows to deload the TGP generator without disconnecting important consumers, which is especially important for the PSS with a shortage of generating plants.

2. The use of ESU in all considered modes allows to better stabilize the mains frequency, however, in this case, there is an increase in overshoot, oscillation and transient process time for the rotor speed and TGP generator voltage. The overvoltage arising on the generator terminals during the transition to the island operation mode is accounted for an abrupt drop in the TGP load during the redistribution of consumer supply from the ESU.

3. The use of the TGP generator auto prognostic ASC allows to improve the damping properties of the system without using the controllers settings optimization procedures: the amount of overshoot, oscillation and transition process time for the generator rotor speed, power on the turbine shaft and the mains voltage frequency are reduced. The prognostic AEC has virtually no effect on the voltage on the TGP generator terminals in the mode under consideration.

4. The use of the ESU, which is automatically connected to the 10 kV PSS buses when the voltage drops, makes it possible to somewhat reduce the overvoltage on the generator terminals during its load shedding, as well as to further reduce the required mechanical power on the TGP turbine shaft in comparison with the permanently connected ESU.

5. The proposed prognostic controllers of synchronous generators can be recommended to increase the DG plants stability in PSS during the transition to an isolated mode. It is expedient to conduct further research based on more complex computer models, as well as on PSS physical models with DG plants. It is advisable to conduct further research with respect to coordinated operation of DG plant controllers and the energy storage unit.

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REFERENCES

Ackermann, T., Anderson, G., and Söder, L., 2001. Distributed generation: a definition. *Electric Power Systems Research*, 57, 195–204.

Rugthaicharoencheep, N., Auchariyamet, S., 2012. Technical and Economic Impacts of Distributed Generation on Distribution System. *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, 6, 385–389.

Sikorski, T., Rezmer, J., 2015. *Distributed Generation and Its Impact on Power Quality in Low-Voltage Distribution Networks*, Power Quality Issues in Distributed Generation, Dr. Jaroslaw Luszcz (Ed.), InTech, DOI: 10.5772/61172.

Hariri, A., Faruque, M.O., 2014. Impacts of distributed generation on power quality, *North American Power Symposium (NAPS)*, 1-6.

Martinez-Cid, R., O'Neill-Carrillo, E., 2010. Sustainable microgrids for isolated systems, *Transmission and Distribution Conference and Exposition*, IEEE PES New Orleans, LA, USA 19-22 April 2010

Saleh, M.S., Althaibani, A., Esa, Y., Mhandi, Y., 2015. Impact of clustering microgrids on their stability and resilience during blackouts, *Proc. on Int. Conf. on Smart Grid and Clean Energy Technologies*, 195–200.

Arai, J., Yamazaki, S., Ishikawa, M., Ito, T., 2009. Study on a new power control of distributed generation in an isolated microgrid, *Power & Energy Society General Meeting*, PES '09. IEEE 26-30 July 2009, Calgary, Canada.

Lombardi, P., Styczynski, Z.A., Sokolnikova, T., Suslov, K., 2014. Use of energy storage in isolated micro grids, *Power Systems Computation Conference (PSCC)*, 1-6.

Magdi, S., Fouad, M., 2015. *Control and Optimization of Distributed Generation Systems*. Cham: Springer International Publishing: Imprint: Springer.

Wang, R., Wang P., Xiao, G., 2018. *Intelligent Microgrid Management and EV Control Under Uncertainties in Smart Grid*, Springer.

Voropai, N.I., Etingov, P.V., 2001. Two-Stage Adaptive Fuzzy PSS Application to Power Systems, *Proc. of International Conference on Electrical Engineering ICEE'2001*, July 22-26, Xi'an, China, 1, 314-318.

Kryukov, A.V., Kargapol'cev, S.K., Bulatov, Yu.N., Skrypnik, O.N., Kuznetsov, B.F., 2017. Intelligent control of the regulators adjustment of the distributed generation installation, *Far East Journal of Electronics and Communications*, 17(5), 1127-1140.

Camacho, E.F., Bordons, C., 2007. *Model Predictive Control*, 2nd edition Springer.

Bulatov, Yu.N., Kryukov, A.V., Nguyen, V.H., 2018. Automatic prognostic regulators of distributed generators. *International Multi-Conference on Industrial Engineering and Modern Technologies*, Vladivostok, 1–4.

Anderson, P.M., Fouad, A.A., 2003. *Power System Control and Stability*, Second Edition. IEEE Press.

Nishi, Y., 2001. Lithium ion secondary batteries; past 10 years and the future. *Journal of Power Sources*, 100, 101–106.