The development of simulation complex of isolated power supply system functioning under principles of «microgrid»

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Abstract. It is necessary, while designing new and modernizing existing electricity supply system (SS), both to seek to improve uniformity of electricity load and to increase the generation of electricity due to an alternative energy source. These facts are contradictory in terms of practical implementation because of stochastic nature of wind power plant, solar panels etc. The only solution is the transition from centralized to decentralized development of power industry, which is based on aggregation of distributed energy resources (including renewable energy sources (RES) and the applying the principles of «Internet of Energy», «Virtual power plant », «Microgrid » etc.) The using of this approach for designing isolated power system could reduce high energy cost which was caused by transport component. Pilot operation of the same energy systems without preliminary studies has high technical and economic risks. For that reason, it required a developing of simulation complex modelling system's work. The article includes scientific and technological solutions for designing simulation complex of isolated power system, which function in "microgrid" and consist of models of sources and energy storage devices. Dependence of energetic parameters for different input parameter have been obtained. The concept of hardware/software solution, which provide opportunity for testing and researching algorithms of control system, have been presented also.

1. Introduction

Today basic trend of development of the power industry is the transition to distributed generation simultaneously with increasing electricity generation by renewable energy sources. At the same time distributed energy resources and consumers are grouped and use concepts like «Internet of Energy», «Virtual power plan», «Microgrid» to enhance the effectiveness of generating capacities [1], [11], [3]. These concepts are based on principle of free exchanging of energy between all system’s members [16], [9].

This approach could be the solution of a number of problems for Russian electric power system, which were enshrined in federal strategy for different industry development. The supply of reliable electricity for isolated from United Power Grid areas is one of the most important challenges [2]. The use of renewable energy in isolated power system allowing reduction of the transport costs of fossil fuel and, as a result, reduce final electricity cost. Moreover principle of free exchanging of energy obviate the need for maintance of additional generating capacities. All of this have the positive economic benefit [12]. Today Russian practical experience in introducing and operating such systems is almost non-existent.
Pilot operating power systems, operating on the principle «Internet of Energy», «Virtual power plant», «Microgrid» etc. without sufficient science and technology base might lead to significant costs because of high technical and economic risks.

Because of this there are a need for model of real isolated electricity supply system, that will allow:

- to conduct study of systems operating under principles of «Internet of Energy», «Virtual power plant», «Microgrid» etc.;
- to develop and test algorithms of control system which ensure efficient use each power plant and the system as a whole thanks to energy enterchange;
- to analyse and assess technical and economic indicators measuring the system when using principles of «Internet of Energy», «Virtual power plant», «Microgrid» etc.;

The purpose of article is to develop scientific and technological solutions for designing simulation complex of isolated power system, which include wind power plant (WPP), gas piston power plant (GPPP), diesel power plant (DPP) and electric power storage as well as to research energy signatures obtained through models.

2. A description of the structure of isolated SS and its operational principles
Simulated isolated SS consist of two segments. Structure of the segments is reported in Figure 1. A presence of DPP in the segment №1 is essential to increasing flexibility and reliable generating in case of load fluctuations and because of stochastic nature of functioning of WPP [13].

![Figure 1](image)

Figure 1. Structure diagram of isolated supply system. CS – control system, DPP – diesel power plant, WPP – wind power plant, battery – electric power storage, GPPP – gas piston power plant.

Originally, segments of the SS are stand-alone. If there is imbalance, power flows should be distributed by control system (CS) and, as a result, ensuring the most optimal mode of SS [14], [10]. This is done by minimising the use of DPP by using RES [6]. Regime changes call for consistent implementation of the terms of rationality starting/ending inter-segment power flows [7], [8]. The terms of rationality are presented in table 1, which: \( P_{\text{DPP}} \) – active power of DPP, kW; \( P_{\text{WPP}} \) – active power of WPP, kW; \( P_{\text{bat}} \) – active power of battery, kW; \( P_{\text{GPPP}} \) – active power of GPPP, kW; \( P_{\text{cons,1}} \) –
active power of consumer in the segment №1, kW; \( P_{\text{cons,2}} \) – active power of consumer in the segment №2, kW; \( V_{\text{bio}} \) – level of biogas in the gas holder, m\(^3\); \( V_{\text{min}} \) – the lowest possible level of biogas in the gas, m\(^3\); \( V_{\text{max}} \) – the highest possible level of biogas in the gas hold, m\(^3\); \( C_{\text{segm,1}} \) – cost of kilowatt hour of electrical energy in the segment №1, rub; \( C_{\text{segm,2}} \) – cost of kilowatt hour of electrical energy in the segment №2, rub.

### Table 1. The terms of rationality of starting and ending inter-segment power flows.

| From segment №1 to segment №2 | From segment №2 to segment №1 |
|-------------------------------|-------------------------------|
| Starting                      | Ending                        | Starting                      | Ending                        |
| \( P_{\text{DPP}} = 0 \)     | \( P_{\text{WPP}} + P_{\text{bat}} < P_{\text{cons,1}} \) | \( P_{\text{DPP}} \neq 0 \) | \( P_{\text{GPPP}} + P_{\text{WPP}} + P_{\text{bat}} < P_{\text{cons,1}} + P_{\text{cons,2}} \) |
| \( P_{\text{cons,2}} > 0 \)   | \( P_{\text{GPPP}} - P_{\text{cons,2}} \geq P_{\text{DPP}} \) | \( P_{\text{WPP}} + P_{\text{bat}} \geq P_{\text{cons,1}} \) |
| \( V_{\text{bio}} < V_{\text{max}} \) | \( V_{\text{bio}} = V_{\text{max}} \) | \( V_{\text{bio}} > V_{\text{min}} \) | \( V_{\text{bio}} \leq V_{\text{min}} \) |
| \( C_{\text{segm,1}} \leq C_{\text{segm,2}} \) | \( C_{\text{segm,2}} \leq C_{\text{segm,1}} \) |

### 3. Development of models of sources and energy storage devices

Simulation complex of isolated electricity supply system is based on models of its components implemented in software package LabVIEW using «G» programming language [17].

Operation algorithms for power plants (wind power plant, gas piston power plant, diesel power plant and electric power storage) have been developed.

Simulation complex consist of front panel and block diagram [15], [5].

A front panel informs users about parameters of the current model’s mode and block or allow entering parameters. A block diagram is program code reflecting sequence of calculations and logical operations.

Appearance of front panel for wind power plant model (at wind speed of 20 meters per second) is reported in Figure 2 as an example.
4. Results from the simulation complex

Dependencies of different energy parameters of the plants on input data have been obtained by using the developed models.

Dependency of generated by wind power plant active power on wind speed can be seen in Figure 3. As the wind speed increases wind rotor is moved and generation starts with optimal wind use coefficient. With intense wind speeds of between 11 and 25 meters per second a wind wheel is braked. In this case generated power equal nominal value. Wind power plant is automatically power down for wind speed above 25 meters per second.

Dependencies of excitation system utilization and phase voltage level of generator (when load is changed) are presented in Figure 4 and 5. If load increase, automation increase exciting current to maintain a fixed voltage (230 V) and, as a result, increase utilization rate of excitation system. Having phase power above 5000 W, generator go into standby. If load is above 5500 W, voltage at terminals is reduced.
Result from electric power storage model is charge and discharge characteristics. Charging consists of two steps as shown in Figure 6: constant current charging and following constant voltage charging. An increase of charging current reduce processing time, but at the same time decrease the highest possible battery charge level. With an increase in discharging current battery delivers its energy faster, as illustrated in Figure 7.

5. The concept of hardware/software solution of isolated SS, which function in «microgrid»

Hardware implementation has to be accomplished for visualizing function of simulation complex. Hardware/software solution consist of microcontrollers, which keep in memory operation algorithms of real power plants and algorithms of control system. Hardware/software solution makes it possible to study an infinite number of modes minimize risks as much as possible.

The transition from real power plants to hardware/software solution is presented schematically in Figure 8.
6. Conclusion

Scientific and technological solutions for designing simulation complex of isolated power system, which function in "microgrid" were represented in the paper.

Models of sources and energy storage devices that formed simulation complex were developed in software package LabVIEW. Dependencies generated through simulation complex were in line with the relevant analytical dependencies. This indicate that work of simulation complex is correct.

The simulation complex will be further used in studying and testing concepts «Internet of Energy», «Virtual power plant », «Microgrid » etc. Using models instead of real power plant minimize the technical and economic risks.

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