Analysis of a computer model of a power supply system for agricultural consumers in a single-phase ground fault mode

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Abstract. On the basis of the constructed computer model, the process of a single-phase earth fault in the power supply system of agricultural consumers with a dead-grounded neutral was studied. As a result of the analysis of the model of the power supply system in the single-phase short circuit mode, the phenomenon of a sharp-pointed voltage pulse of negative polarity, arising at the moment of protection operation, was revealed, which negatively affects the electrical equipment of agricultural consumers.

1. Introduction
The development of digital technologies in the agro-industrial complex of the Russian Federation is caused by the need to increase yields, labor productivity, and production profitability. In turn, in the existing power supply system, more and more problems arise related to the qualitative and quantitative supply of electrical energy to agricultural consumers, the reliability of which is estimated at 70-100 hours of breaks per year (for comparison: abroad this indicator is 7-10 hours / year). In this regard, the agricultural power supply system has the following tasks: providing consumers with a sufficient amount of high-quality electricity, minimizing the costs of production, transmission and distribution of energy, prompt response to any changes in the network, and the use of renewable energy sources in the process of economic activity. At the moment, a self-regulating power supply system has been developed that allows solving the tasks.

2. Materials and methods
A self-regulating power supply system is an automated system that independently monitors the distribution of electrical energy flows. The existing structure is able to monitor the quality of electrical energy and automatically maintain the parameters of electrical energy of agricultural consumers in accordance with GOST 32144-2013 [1-3]. The introduction of modern information and communication technologies allows the equipment to interact with each other, forming a single system. The information received from the elements of the system is processed, and the result of the processing helps to optimize energy use, reduce costs, increase the reliability and efficiency of the system [4].
3. Results and Discussion

The implementation of a self-regulating system is closely related to technical development in the field of communications, the use of alternative sources of electrical energy, the development of models and algorithms for the functioning of the power system based on artificial intelligence methods: the theory of fuzzy sets and fuzzy logic, neural network technologies, genetic algorithms (figure 1).

![Figure 1. The structure of a self-regulating power supply system.](image)

The structure allows: to carry out timely localization of emergency situations; promptly make decisions in case of emergency situations; analyze the operation of equipment; increase the service life of equipment due to continuous monitoring of system parameters; reduce equipment operating costs.

One of the factors affecting the reliability of the power supply system is an event consisting in a malfunction of the equipment, which is caused by short-circuit currents. Single-phase short circuits occur more often, while the frequency of occurrence increases with an increase in the voltage class of the network. This is due to the increase in the distance between the phases. Short-circuit currents are usually several times higher than rated currents [5]. The short circuit process leads to an increase in electrical energy losses, causes increased heating of contact joints, destroys the insulating layer, and is also accompanied by significant electrodynamic forces between the conductors. A sharp drop in bus voltage for consumers can lead to negative consequences. For example, to a violation of the stability of parallel operation of generators and to a systemic accident with large national economic damage.

Using the Electronics Workbench software, we will build a model of the power supply system (figure 2).

Accepted designations: transformer - power source (TP, KTP); 3P - three-phase wattmeter; DPS - Diesel Power Plant; WPS - wind power station; CNDF - cetane number of diesel fuel; frsd, frws - rotational speed of the diesel engine shaft, wind turbine, respectively; nrsd is the number of revolutions of the diesel shaft; Pdps, Pwps - power of diesel power plant, wind generator, respectively; 3Pdps, Pwps - power delivered by diesel engine, wind generator to the system; B - battery; PL - power line; inverter– DC to three-phase converter; QA - microcontroller (quality analyzer); GLONAS - communication line, SC - short circuit, Isc - short circuit current [6-7].

A sequential consumer equivalent circuit is adopted. When constructing the model, the following assumptions were made: neglect of active resistances, phase shift of EMF vectors is not taken into account, resistances of network elements are constant.

The model allows you to set the required values and analyze the behavior of the system when all operating modes of the system change: emergency modes - transients, voltage drops, pulses, fluctuations (flicker), voltage deviation, frequency deviation.
Figure 2. Computer model of the power supply system for agricultural consumers in the single-phase short circuit mode.

In accordance with the requirements of the PUE, in electrical installations with voltages up to 1000 V with a solidly grounded neutral, a reliable disconnection of a single-phase short circuit to earth must be ensured by a protective device.

The design points for determining the current of a single-phase short circuit to earth are the most distant points of the network, since it is these points that correspond to the highest value of the current of a single-phase short circuit:

$$I_{K.Z} = \frac{U_F}{Z_{TP} + Z_{PL}}$$  \hspace{1cm} (1)

Where: $U_F$ is the phase voltage of the network, $Z_{TP}$ is the resistance of the supply transformer in a single-phase short circuit; $Z_{PL}$ is the impedance of the supply line (phase-zero circuit) from the supply transformer to the short-circuit point.

Let us analyze the behavior of the current and voltage curves relative to our model (figure 3).

Figure 3. Oscillogram of a single-phase short circuit.

Red vertical line 1 - the beginning of the transient during a short circuit.

Blue vertical line 2 - the moment of protection operation, the end of the short-circuit to earth process, but not the end of the transient process from the short-circuit.

3 - the short-circuit current decreases exponentially to the steady-state value. However, it does not reach the steady-state value, since the protection is triggered.

4 - sharp-pointed voltage pulse of negative polarity.

Consider the behavior of the current and voltage curve after a single-phase short circuit with a protection response time of 0.01s-0.05s (figure 4).
Figure 4. Behavior of the current and voltage curve depending on the protection response time.

We will transfer the obtained values of the surge current and voltage impulse from the protection operation time to table 1.

| Protection operation, ms | 1  | 2   | 3  | 4   | 5   |
|--------------------------|----|-----|----|-----|-----|
| kA                       | 0  | 1.45| 3.5| 6.64| 6.63|
| % of phase               | 0  | 5708.7| 13779.5| 26102| 26102|
| kV                       | 0  | -0.19| -1.8| -5.8| -1.6|
| % of phase               | 0  | -86.4| -818.2| -2636| -727.3|

Based on the data obtained, we will build a graph of the dependence of the surge current and voltage pulse on the protection response time (figure 5).

Figure 5. Dependence of surge current and voltage impulse on protection response time.

As a result of the protection operation, a sharp-pointed voltage pulse of negative polarity with a duration of several microseconds occurs, with an amplitude approximately five times higher than the amplitude of the phase voltage (figure 5).
4. Conclusion
The use of a self-regulating power supply system allows you to: optimize the use of electrical energy; reduce the cost of servicing electrical equipment, extend its service life through constant monitoring of system parameters; perform timely localization of emergency situations; promptly make decisions in case of emergency and emergency situations.

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