Analysis of the voltage drop of a drilling rig connected to a local energy network

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Abstract. The article discusses and analyzes the operation of an autonomous electrical complex of a drilling rig in an emergency mode, namely when the supply voltage drops. The concept of voltage drop is also described, a comparative characteristic of technical devices and methods of overcoming voltage drops, indicating the disadvantages and advantages, is given. Modeling of an autonomous electrical complex of a drilling rig is performed in the MATLAB Simulink software package with a description of the parameters of the main elements. The voltage drop is achieved by a sharp increase in the load power consumption, which in reality is achieved by the drilling rig head getting stuck in the hard layers of the earth's surface. As a result, there are graphs of changes in the voltage value at the terminals of the electric motor of the drilling rig, depending on the magnitude of the load. Based on these graphs, we can conclude that with an increase in load, the autonomous system does not have its own reserves and power reserves (and according to regulatory documents, this margin is 20%) in order to overcome the voltage drop and return it to acceptable values for further uninterrupted operation. As a conclusion, we can say that today the only optimal option in terms of material costs and technical features is to connect a backup diesel generator connected in parallel to the main one and having a comparative power.

1. Introduction

Local energy systems, or autonomous power supply systems, are widely used in many sectors of the national economy. Especially often they are used in power supply systems of industrial facilities in the oil and gas industry [1]. This is connected with development of oil and gas deposits that are especially remote from electric grids in various regions of the world, including in our country: in Siberia, the Far East and other regions.

High-power autonomous power supply systems, remote from high-voltage electric networks, are mainly powered by autonomous power plants with two diesel generator sets, one of which is the main one and the other is the backup one. In systems with low load power, the backup power source is usually a rechargeable battery. In such isolated systems, particular attention must be paid to power quality indicators. Indeed, the operability, reliability and efficiency of equipment operation depend on the quality of electricity.

2. Voltage drop study

The most significant indicator of the quality of electricity that occurs when a sudden decrease in the voltage of the electric network below 0.9 Unom is a voltage drop [2]. After the failure, the voltage is
restored to the initial or close to it level after a certain period of time from 10 ms to several tens of seconds. Its decrease changes by 10 ... 100% of the nominal. A voltage drop of 100% for a period of time according to [2] can be considered as a short-term power interruption. Failures are the most critical emergency violations. They lead to blackouts and overloading of electrical equipment and electricity consumers [3].

In isolated power supply systems, technical, technological, economic, geographical, climatic factors influence the choice of types (technologies) of electric energy storage devices [4].

There are the following devices that protect electrical equipment of industrial enterprises from voltage drops: flywheel, static uninterruptible power supply (UPS), dynamic voltage distortion compensator, static compensator (STATCOM), boost converter, active filter, and transformerless serial amplifier [5,6,7].

| Device name                          | Advantages                                                                 | Disadvantages                                                                 |
|--------------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Flywheel                             | - disturbance protection main power supply;                                 | - significant mechanical losses;                                              |
|                                      | - high efficiency;                                                          |                                                                                |
| Static UPS                           | - operating speed;                                                          | - high cost;                                                                  |
|                                      | - short power output time;                                                  |                                                                                |
| Static compensator                   | - active regulation of reactive power;                                     | - high cost;                                                                  |
|                                      |                                                                            | - need for high power frequency converters;                                  |
|                                      |                                                                            | - compensation of voltage drops only up to 50% of Unom;                      |
| Boost converter                      | - operating speed;                                                          | - the need to use batteries to overcome deep drops;                          |
|                                      |                                                                            |                                                                                |
| Active filter                        | - along with the voltage drop, the negative influence of higher harmonics is also compensated; | - increased power to compensate for deep drops;                              |
| Transformerless serial amplifier     | - operating speed;                                                          | - compensation of voltage drops only small power;                            |
|                                      | - unbalanced failure compensation;                                         | - compensation of voltage drops only up to 50% of Unom;                      |
| Supercapacitor                       | - operating speed;                                                          |                                                                                |
| Superconducting magnetic coils       | - the ability to send a large amount of energy to the network in a short time; | - compensation for voltage drops of only small power;                        |
|                                      | - large life cycle.                                                        | - expensive service.                                                          |

Having analyzed table 1 and some sources [8,9], we can conclude that autonomous power sources are most effective for reducing the effect of voltage drops. Of these, diesel generator blocks, voltage stabilizers can be distinguished [10]. However, the use of voltage stabilizers is limited in view of their
small capacity for an industrial scale. Therefore, this article presents an analysis of the voltage drop of a drilling rig in a local electrical complex based on a model (Fig. 1) in the MatLab Simulink environment [11,12,13].

The main loads in the oil and gas and mining industries are asynchronous motors that drive various technological mechanisms. Usually, except in special cases, voltage drops of up to 30% of the rated voltage do not significantly affect asynchronous motors [14]. At the same time, voltage drops with an amplitude greater than 30% of the rated voltage usually cause the motor's torque to drop below the load resistance level and stop the system [15,16]. Motor-load systems are sensitive to voltage drops and this sensitivity depends on the depth, duration of the voltage drops, and the moment of inertia of the load [17]. If asynchronous loads are a significant part of the electrical system, the starting currents during acceleration of engines after braking can reach the following values: 3 Inom for drops lasting from 400 MS to 500 MS; 4-5 Inom for drops lasting from 600 MS to 700 MS; 6 Inom for drops lasting about one second. These values are the worst-case scenarios, but they also depend on the moment of inertia of the engine and the load.

3. Description of the simulated autonomous complex

![Figure 1. Scheme of the local power network of the drilling rig.](image)

The electrical complex of a modern drilling rig with an electric drive of the main mechanisms is a set of subsystems that provide generation, distribution, conversion and use of electrical energy, as well as control of all these subsystems. It includes:
- high voltage switchgears;
- power and converter transformers [18];
- AC electric machines;
- complete thyristor devices;
- complete devices for control, protection and distribution of low-voltage electrical energy;
- cables and wires [19];
The structures of electrical complexes, despite the variety of drilling rig schemes predetermined by a wide range of requirements for drilling depths, purpose and operating conditions, can be reduced to two typical schemes - AC and DC systems, the use of which on installations of various designs is reduced to a quantitative change in the parameters of the electrical equipment used.

Compared to a DC drive, a variable frequency drive offers the following advantages:
- reduction in the mass and dimensions of electrical equipment;
- easier to solve the problem of providing explosion protection of the electric motor;
- higher accuracy of speed control;
- due to direct control of the moment, the required performance indicators of the functioning of the electric drive in dynamic modes are achieved;
- increases the reliability and durability of an electric drive operating in harsh operating conditions;
- thanks to the integrated diagnostic system, maintenance costs and downtime of technological equipment are reduced;
- higher value of efficiency [20].

The structure of the AC electric drive for installations with autonomous power supply is focused on the use of partially adjustable electric drives of the main mechanisms, which allow to form a starting characteristic and provide cost-effective speed control in a limited range.

The drilling rig is powered by a group of AC diesel generators [21], the number of which is determined by the unit power of the diesel generators and the total one - time power of the actuators, if the necessary reserve is available. In the scheme of autonomous high-voltage power supply, a corresponding step-down transformer is installed between the common buses and the converter, so from the point of view of building the structure, the level of primary voltage is not of fundamental importance. The power of diesel generators is summed up on the common busbars of the switchgear.

Gen1 and Gen2 blocks simulate the operation of the diesel generator block $P = 550$ kW, BU1 and BU2 - asynchronous motors of drilling rigs (the Asynchronous machine block from the Simulink library was used in the presented model) $P = 310$ kW. The additional electrical load is represented as a replacement circuit, which contains the following blocks: Load1 and Load2. In these blocks, the active and reactive power of the additional electrical load of the drilling rig's electrical complex is set. This method allows you to obtain comparative data, which are shown in figures 2 and 3.

![Figure 2. The value of the voltage at the terminals of the drilling rig motor in normal mode.](image-url)
Figure 3. The value of the voltage at the terminals of the drilling rig motor in emergency mode.

Figures 2 and 3 show the changes that occur in the network when an additional load is turned on or the equipment is "stuck" - the voltage at the drilling rig's terminals drops below 0.5 Unom. Currently, in the oil and gas mining industry, there is one way to deal with this emergency mode – emergency lifting of the drilling tool. However, this method leads to economic and technological losses.

4. Conclusion
Summarizing the results of the study, we can conclude from Table 1 that the most popular technical devices today will not be able to overcome the drop in value below 0.5 Unom and return the system to normal operation. Figures 2 and 3 show that own reserves and power reserves (according to regulatory documents 20%) are not enough to overcome the voltage drop. The solution to this emergency mode is to use a backup power source (diesel generator) connected in parallel with the main one. Further work should be considered in the study of transient processes during voltage drop and the connection of backup power, as well as in the development of recommendations.

5. Acknowledgements
The reported study was funded by RFBR, project number 20-38-90038.

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