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Analysis of methods for increasing the reliability of power supply systems for lighting and automation devices in mines

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Abstract. This article analyzes modern approaches aimed at increasing the reliability of power supply systems for lighting and automation devices in mines. In mine conditions, it is important to ensure the uninterrupted operation of lighting and automatic control systems and the stable operation of the production process. The study shows that the overall stability of the system increases significantly when using backup energy sources and automatic reconnection systems. Also, the stability indicators of the power supply system are analyzed in depth using the Mikhailov and Nyquist criteria. The results show that the integration of power supply with digital monitoring methods expands the possibility of early detection of accidents, and the introduction of backup and automated control measures can increase the reliability of the system. This approach is considered a promising and effective solution for high-risk technological processes in mines.

INTRODUCTION

Over the past decade, increasing the reliability of power supply systems for lighting and automation devices in mines has become of great importance and plays a significant role in ensuring the continuity of energy supply in many mines; at the same time, the efficiency and stability of the system are significantly increased by using installed power and backup sources. [1-6].

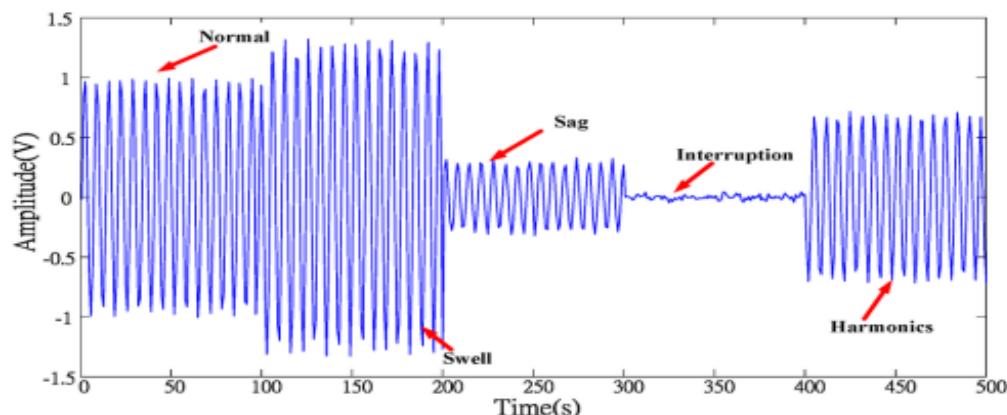


FIGURE 1. Power Quality problems In the figure 1 it shows the graph of time vs various Power Quality problems. The commonly used terms those describe the parameters of electrical power that describe or measure power quality are sags, swells, interruptions, harmonics etc. are shown in figure 1.

Development of power supply for lighting and automation devices in mines. In 2025–2035, special attention will be paid to ensuring uninterrupted and reliable power supply for lighting and automation devices in mines. [7-10]. These projects will be implemented mainly at the expense of mining enterprises and investors. In order to increase the reliability of the power supply system in mines, it is planned to introduce backup sources, UPS systems and automated control tools. Through annual modernization and upgrades, stable operation of lighting and automation systems in mines will be guaranteed. [11-14].

EXPERIMENTAL RESEARCH

The uninterrupted operation of lighting systems and automation devices used in the mining industry is one of the main factors of production safety and labor productivity. These devices cannot operate without a reliable power supply, since in mining conditions, power outages or changes in parameters can lead to accidents, shutdowns of technological processes, and a threat to the lives of workers. Therefore, increasing the reliability of power supply systems in mines is one of the important scientific and practical directions of modern energy. The quality indicators of electricity - voltage stability, frequency and phase stability - ensure the normal operation of lighting and automation devices operating in mining conditions. GOST and other current standards impose strict requirements on the quality indicators of electricity. In mines, voltage drops or fluctuations can be observed due to frequent changes in loads, the length of cable routes, sudden changes in humidity and temperature. Compensation for these factors and the organization of stable supply are considered one of the main directions of increasing reliability. The uninterrupted operation of lighting systems and automation devices in mining conditions directly depends on the stability of the power supply system. Voltage fluctuations, frequency fluctuations or short-term interruptions lead to the cessation of technological processes and a decrease in safety. Therefore, stabilizing the quality indicators of electricity within the framework of regulatory requirements is one of the main tasks of the mining power system. Power supply systems used in mines are usually characterized by complex load dynamics, long cable routes, high humidity and environmental variability. These factors can cause voltage drops, fluctuations and accidents. Several technical solutions for power supply systems are used to eliminate these problems. [15-18].

The main areas of increasing the reliability of power supply are: Creating a stable power supply. Modernization of transformer stations, proper load distribution and optimization of protective devices increase the overall stability of the system. Voltage stabilization. Automatic voltage stabilizers, inverters and compensators quickly eliminate voltage fluctuations, ensuring uninterrupted operation of lighting and automation devices. Backup power sources. The main safety requirement of lighting and control systems is continuity. Therefore, batteries, diesel generators and UPS systems provide uninterrupted power to the main consumers in case of an emergency. Automatic reconnection and control systems. Intelligent systems that monitor electrical parameters (voltage, current, frequency) in real time detect faults, isolate and restore supply. A specific feature of the mine power supply is the need to compensate for instability caused by rain, gas, dust, vibration and high loads. Therefore, it is especially important to control voltage, frequency and phase changes for the stable operation of automation devices. By applying the above methods, it is possible to significantly increase the reliability of power supply for lighting and automation systems in mines. This ensures safety, uninterrupted continuation of technological processes and reduces the risk of accidents. [19-23].

RESEARCH RESULTS

Studies on ensuring reliable power supply of lighting and automation devices in mines show that existing power supply systems often operate unstable due to voltage drops, uneven load distribution, and severe conditions. To eliminate these problems, solutions were proposed aimed at real-time control of electricity quality indicators. [24-25,26,27]. During the study, a hybrid lighting and automation power supply model adapted to mine conditions was created. This model is based on an optimized combination of standard transformer points, backup power sources (UPS, battery packs), voltage stabilizers, and automatic disconnection devices. The advantage of the proposed hybrid system is that its technical indicators are more stable compared to existing alternative schemes, and changes in electrical parameters (voltage, frequency, phase asymmetry) are minimized. In addition, the voltage recovery time in lighting circuits is significantly reduced. Analyses have shown that the hybrid power supply system increases the uninterrupted operation of lighting and automation devices, reduces accidents, and ensures a high level of mine safety. [28-29,30].

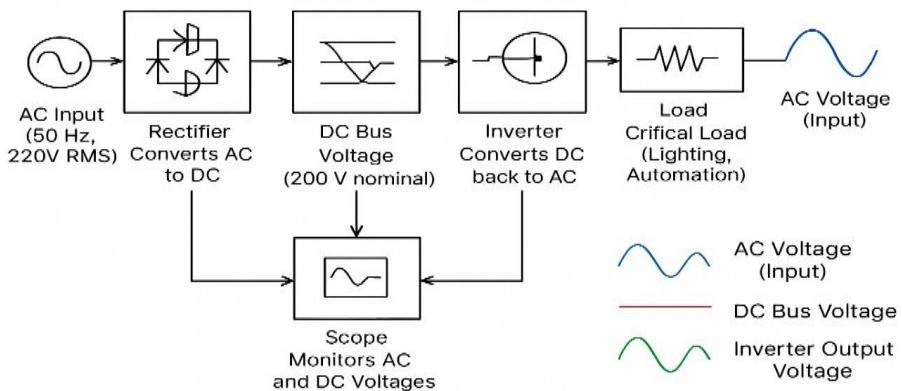


FIGURE 2. Single-phase UPS block diagram illustrating the AC input, rectifier, DC bus with battery, inverter, and load. Voltage waveforms: blue – AC input, red – DC bus, green – inverter output.

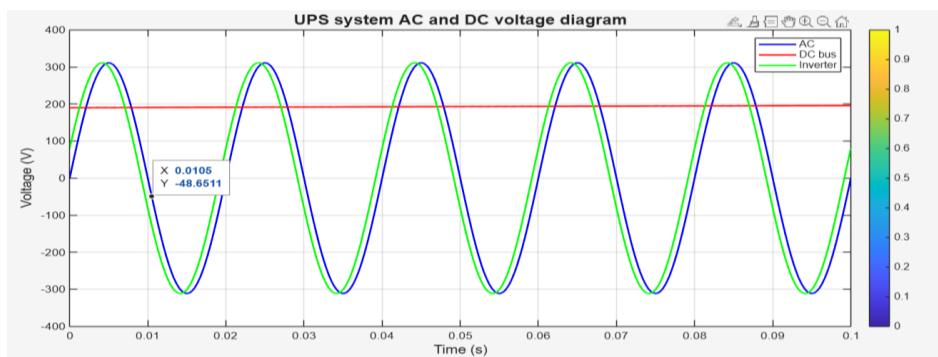


FIGURE 3. AC and DC Voltage Diagram of UPS System

The diagram provides a visual representation of how a UPS system works: AC input → Rectifier → DC bus + Battery → Inverter → Load. It clearly shows how the AC input, DC bus, and inverter output voltages change over time. This graph is used to analyze the performance and voltage stability of a UPS system. [31-34]. Electrical data has been collected from GDK-10A underground mine and based on the data collected, power system model has been developed in MATLAB / SIMULINK. The simulations are performed for the cases: (i) without compensation and (ii) with compensation. The system performance is analyzed. These cases are summarized below: [35-36].

Case (1): Without compensation Model has been simulated for one second and load 1 (375 KW) is switched on between 0.3 to 0.5 sec and load 2 (250KW) is switched on between 0 to 1 sec. After switching ON the load, the voltage was falling down and decreased to a certain level. Simulation results are shown in Figure 4. The Total Harmonic Distortion (THD) without compensation observed is 28 % at 50 Hz fundamental frequency which is high.

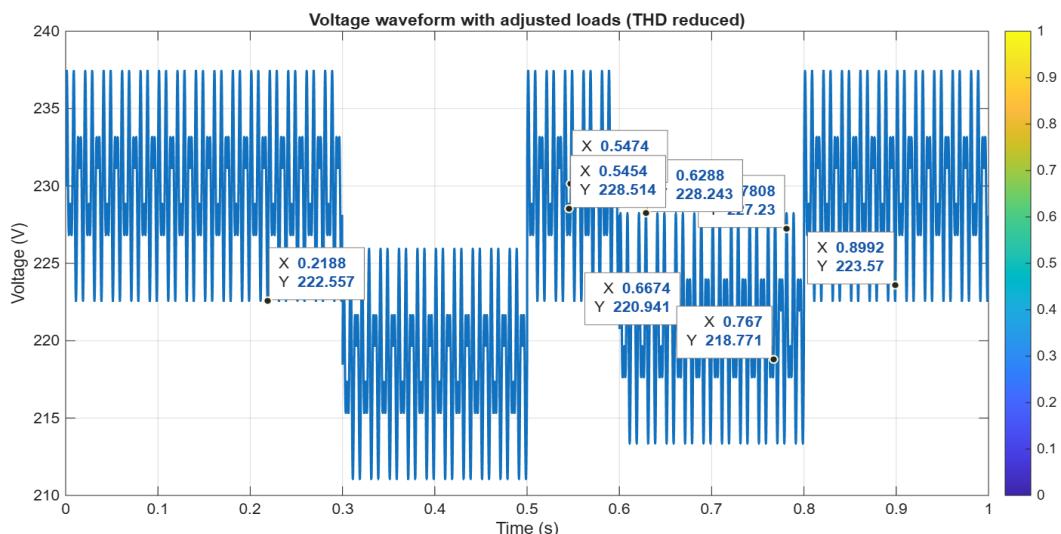


FIGURE 4. Load voltage Magnitude

CONCLUSIONS

As can be seen from the above analysis, the stable operation of lighting and automation devices in mines is directly dependent on the reliability of the power supply system. The changing requirements of various loads and electrical devices can lead to voltage drops in the system, the appearance of harmonics, and additional losses [37-66].

The results of the analysis show that the following methods are effective for increasing the reliability of power supply systems:

1. Reducing voltage drops in the system through time monitoring of loads and dynamic control.
2. Improving the quality of operation of lighting and automation devices by reducing harmonics and using filters, reducing torque pulses.
3. Ensuring uninterrupted operation of the system during any malfunction by introducing backup (reserve) power sources.
4. Optimizing transformer and cable networks, as well as reducing losses by using high-quality windings and cables.
5. Predicting and optimizing system operation under different load conditions through energy monitoring and simulation systems.

Methods used in this way make it possible to increase the stability of lighting and automation systems in mines, improve energy quality, and increase their resilience to emergency situations.

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