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ARCHITECTURE AND DESIGN PRINCIPLES OF UNINTERRUPTIBLE POWER SUPPLY (UPS) SYSTEMS

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Abstract: This paper examines the architecture and design principles of uninterruptible power supply (UPS) systems for local area networks (LANs), their types, as well as issues related to the integration of UPS systems into the network. The paper addresses ways to enhance the reliability of power supply through the application of modern technologies and to optimize energy efficiency. The main causes of power-related emergency situations in local area networks are analyzed, a comparative study of different UPS design options for LANs is conducted, and a schematic design of a high-efficiency power supply device is proposed.
Keywords: *uninterruptible power supply systems (UPS), inverter, rectifier block, On-line UPS system.*

Introduction.

During the operation of electrical networks, various technical and operational problems may arise. Such situations include, for example, prolonged disconnection of consumers from the power supply in emergency cases, or sudden drops or increases in voltage as a result of load changes when additional consumers are connected to the network. These types of malfunctions primarily lead to the failure of electronic and electrical equipment, loss of important data stored on computers and servers, as well as disruption of technological processes in industrial enterprises. In turn, these processes are accompanied by significant economic losses [1-5].

Even more dangerous consequences can occur when systems related to critical infrastructure- especially medical equipment, fire extinguishing installations, and ventilation systems -are stopped, even for a short period. Such cases pose a threat to human health and life and, in some instances, may lead to injuries or even fatalities.

Today, with the development of information technologies, the demand for high-speed data processing centers and reliable network systems is growing rapidly. However, it should be taken into account that no technological system can operate continuously under ideal conditions. Users must accept the possibility of certain deviations from the nominal parameters of the power grid. In this context, the correct design and efficient construction of uninterruptible power supply (UPS) systems for local area networks is of great importance. Uninterruptible Power Supply (UPS) systems are critical components in electrical and electronic infrastructure, ensuring continuous power delivery to essential equipment during utility outages or fluctuations. Their design must align with power quality, reliability, and system-specific needs. The main function of UPS systems is to protect local network equipment from power interruptions and malfunctions, as well as to ensure their uninterrupted and safe operation [6-11].

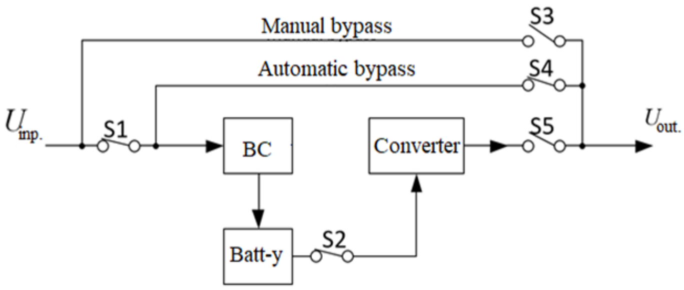
Research methods and investigations.

Currently, there is a steady demand for three types of uninterruptible power supply (UPS) systems:

- Switched UPS (off-line UPS);
- Network-interactive UPS (Line Interactive UPS);
- Double conversion UPS (On-line UPS).

This paper examines the architecture of uninterruptible power supply systems for local area networks (LANs), their functional elements and interactions between them, as well as identifies technical and technological solutions that should be considered when designing these systems. The aim of the work is to increase the reliability of power supply in local networks and ensure the stability of information flow [7].

Switched UPS (off-line UPS) are the simplest and most cost-effective uninterruptible power supply systems. These types of UPS are mainly used to power low-power devices, personal computers, and simple electronic equipment (*Fig.1).*



(BC-Battery charger, Converter-Converter–Inverter, Switching keys S1–S5)

Figure 1. Switched UPS (off-line UPS)

Such UPS systems start supplying power from the battery in the event of any problem in the electrical network. However, these power sources have a relatively long switching time, typically ranging from 4 to 12 ms. Due to this longer switching time, there is a brief voltage drop at the UPS output during the switchover process. Additionally, these devices lack a voltage stabilization function and only activate when there is a complete power outage or when the voltage reaches a critical level. This creates a small voltage dip, which is unacceptable for a local area network (LAN) [6].

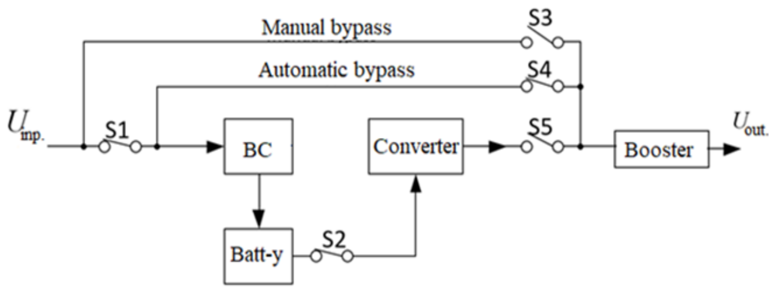


Figure 2. Network-interactive UPS (Line Interactive UPS)

The block diagram of a network-interactive uninterruptible power supply is shown in Figure 2. This device is an uninterruptible power supply system that operates in direct interaction with the network and automatically compensates for voltage fluctuations. This type of UPS is more functional compared to off-line UPS systems. Under normal conditions, a line-interactive UPS stabilizes the alternating current (AC) coming from the network and directly delivers it to the output. At the same time, the batteries are charged. If there are sharp voltage drops or surges in the network, the automatic voltage regulator (AVR) built into the UPS compensates for these changes and ensures stable output voltage. In the event of a complete power outage, the system switches to battery → inverter mode within 2÷4 ms and continues uninterrupted power supply.

A line-interactive UPS offers a balanced solution for both energy stabilization and short-term backup power supply. It creates an intelligent interaction with the network by performing filtering and voltage regulation functions. For this reason, such a UPS is often considered the most optimal choice both economically and technically [1,6,12].

However, these devices also have some disadvantages. For instance, when there is a complete power outage in the network, there is still a switching delay within the range of 2÷4 ms, and if the voltage fluctuations are very large, the compensation may not be sufficiently effective.

As a result of the conducted research, these shortcomings of the previously described devices were analyzed, and a solution with higher energy efficiency — a double conversion UPS (On-line UPS) -was proposed (Figure 3)

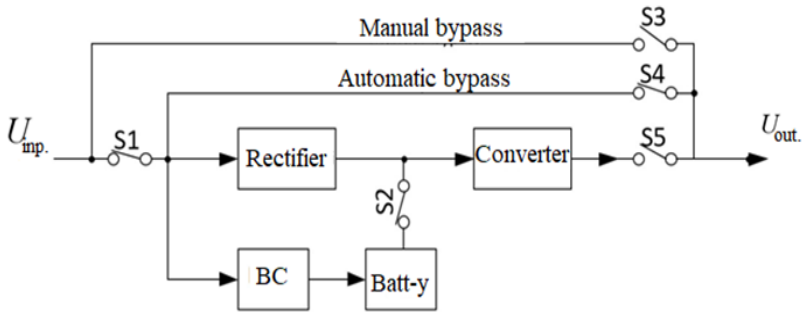


Figure 3. Double Conversion UPS (Uninterruptible Power Supply)

The rectifier of this UPS is very powerful. It not only charges the battery but also provides stable voltage to the continuously operating inverter. The On-line UPS works as follows: the input AC mains voltage first passes through the rectifier and is converted to DC voltage, which is then converted back to AC voltage by the inverter. During this time, the battery is continuously connected between the rectifier and the inverter. The schematic of such a UPS is shown in Figure 3. The On-line UPS scheme ensures a perfect output voltage even if there are any problems in the electrical network. This system is characterized by a "zero" transfer time, meaning that during the transition from normal mode to autonomous mode and vice versa, there is no switching process, and the output voltage does not change.

Modern improvements in the inverter and rectifier blocks of double conversion UPS systems allow achieving higher power quality, lower risks, greater reliability, long-term stability, and stable operation under critical loads. This requires advancements in high-frequency and high-power electronic switches and their control systems. Unlike traditional transistor switches, this work uses transistors from leading global manufacturers — IGBT modules (EconoDUAL, EasyPACK, PrimePACK, etc.) from Infineon Technologies (Germany) with high frequency and industrial-grade specifications, such as IKW75N65ES5 (650V, 75A), as well as compact and high-speed IGBT modules CM300DY-24H (1200V, 300A) from Fuji Electric (Japan), primarily designed for UPS and inverters. Additionally, improving the energy efficiency of these devices directly depends on the choice of control methods for the rectifier and inverter [7,13,14].

There are many methods for inverter control: SPWM (Sinusoidal Pulse Width Modulation), SVPWM (Space Vector PWM), FOC (Field Oriented Control), MPPT (Maximum Power Point Tracking), as well as ARM and FPGA-based control, among others. Analysis of these methods showed that the work applies a combined approach — ARM and FPGA control together with SPWM modulation — for inverter control. The joint use of ARM and FPGA control with SPWM modulation is very effective and forms the basis of modern inverter technologies.

This approach combines precise pulse control and intelligent management functions, creating a fast, stable, and energy-efficient system [13, 15, 16].

As a result of the conducted analysis and research, a simulation model of the double-conversion UPS was developed in the Matlab/Simulink environment (Figure 4), and an oscillographic analysis of the output voltage and current under fault conditions, as well as their FFT (Fast Fourier Transform) analysis, were performed [15,17,18].

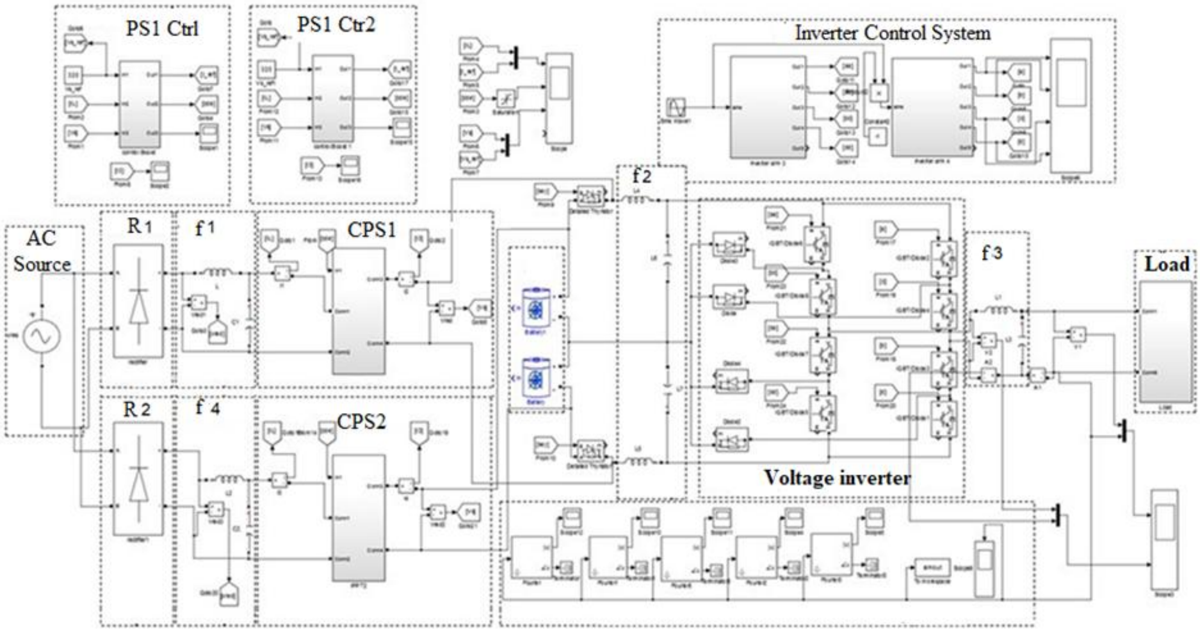


Figure 4. UPS simulation model in Matlab Simulink environment

The simulation of the uninterrupted power supply system operation in fault mode is performed by setting the voltage value to 0 V in the AC Source block. The load used has an active-inductive characteristic. The load with the UPS nominal power S=15 kVA is continuously loaded at 80%. At 0.2 seconds, an additional 20% (3 kVA) load is connected to the system. Oscillograms of voltage and current obtained under active-inductive load conditions are shown in Figure 5.

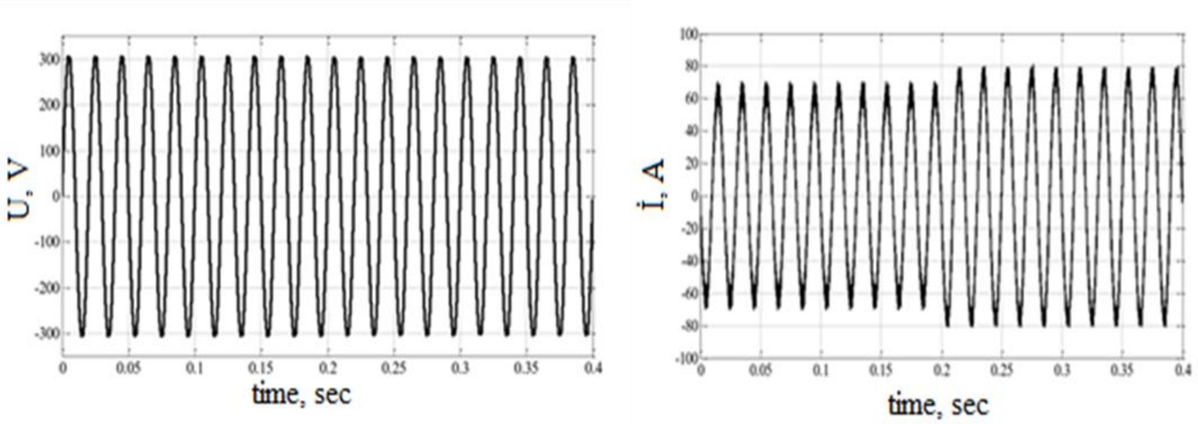


Figure 5. Oscillograms of voltage (a) and current (b) under active-inductive load conditions

From the presented oscillograms, it can be seen that when an additional load is connected, the voltage remains stable, while the current increases significantly. The results obtained from the UPS operation modeling in fault mode are almost identical to those obtained during operation in grid-connected mode.

Harmonic analysis

The harmonic content of the output current under active-inductive load, obtained using the FFT Analysis function, is shown in Figure 6.

The sinusoidal waveform of the current was analyzed over one cycle after an additional load was connected at 0.2 seconds. Based on the Fourier series shown in Figure 6, the analysis concludes that the parameters of the input and output filters are properly selected, and the levels of higher harmonics do not exceed the permissible limits.

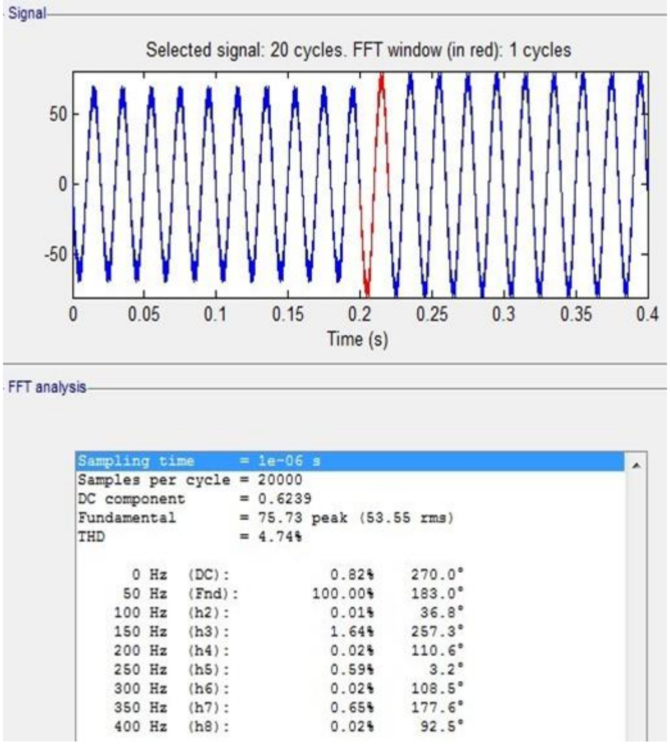


Figure 6. Harmonic content of the output current under active-inductive load

Conclusion.

As a result of the conducted study, modern architectures and control principles ensuring reliable and efficient operation of uninterruptible power supply systems (FETS/UPS) in local networks were analyzed. The structural features, advantages, and disadvantages of various types of UPS — commutated (off-line), line-interactive, and double-conversion (on-line) — were comparatively studied.

Special attention was given to the double-conversion UPS, which is characterized by high energy efficiency and reliability. A simulation model of this UPS was created in the Matlab/Simulink environment, and an analysis of the output voltage and current oscillograms under active-inductive load conditions was performed, as well as a harmonic composition study using FFT (Fast Fourier Transform). The analyses showed that even when an additional load was connected, the output voltage remained stable and the current increased; however, the system as a whole operated steadily, and the level of high harmonics did not exceed permissible limits.

Furthermore, the use of ARM and FPGA-based control combined with SPWM modulation ensured precise, fast, and energy-efficient inverter operation. This approach creates important advantages for modern UPS systems, providing both energy savings and high-quality power supply to critical loads.

Overall, the conducted work demonstrates that proper design of uninterruptible power supply systems in local networks, the use of modern control methods, and high-quality electronic components allow ensuring reliable and continuous equipment operation, which contributes to the stability of information flows and enhances the security of critical infrastructure.

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