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ANALYSIS OF CAUSES AND CONSEQUENCES OF VOLTAGE SAGS IN INDUSTRIAL POWER SUPPLY SYSTEMS

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Abstract. *The article analyzes the main causes and consequences of voltage sags in industrial power supply systems. The study highlights the most typical sources of voltage disturbances, such as motor starting, short circuits, load changes, and equipment failures. The direct and indirect effects of voltage sags on industrial processes and equipment reliability are examined. Technical solutions for preventing and minimizing voltage sags, including the use of soft starters, frequency converters, reactive power compensation, and proper network design, are discussed. A systematic approach to monitoring and analyzing power quality parameters is proposed to enhance the resilience and efficiency of industrial enterprises.*

Keywords: *Voltage sag, industrial power systems, power quality, soft starters, frequency converters, short circuits, reactive power compensation, energy efficiency, equipment reliability, network design.*

Introduction. Voltage sags in industrial networks are among the most common types of power quality disturbances, significantly impacting the stability of electrical systems and the economic performance of enterprises. A voltage sag is generally understood as a short-term reduction of the root mean square voltage value to between 10% and 90% of its nominal level, lasting from a few milliseconds up to several seconds. The frequency of occurrence, duration, and amplitude of voltage sags depend directly both on the internal operating conditions of the enterprise's network and on the parameters of external power supply systems.

Research results. One of the main causes of voltage sags is the starting of powerful asynchronous motors, particularly those not equipped with soft-start systems. The starting current of such motors can exceed the nominal current by several times, immediately causing a significant voltage drop in the local network and, depending on the configuration of the electrical system, even affecting neighboring consumption areas. The simultaneous starting of several large consumers further complicates the situation, causing deeper and prolonged sags. These phenomena are particularly critical in systems with insufficient short-circuit capacity, where the network is unable to effectively compensate for such current impulses.

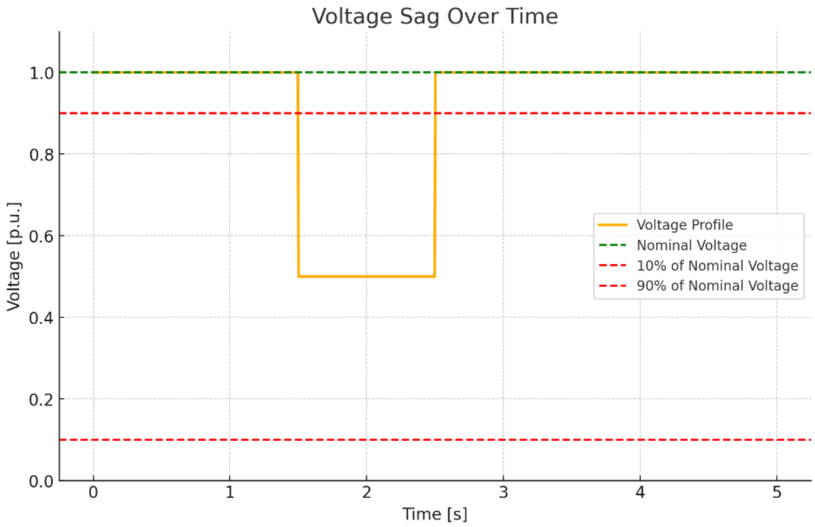

Figure 1 - Voltage Sag Profile During Short-Term Disturbance

Another common cause is short circuits in networks, even if they are transient or quickly eliminated by automatic disconnection devices. During a short circuit, a sharp increase in current occurs, accompanied by a voltage drop over a wide area of the electrical network. The consequences of such events depend on the distance to the fault location, the structure of the system, and its operating mode. It is worth noting that even a short-duration short circuit lasting only fractions of a second can cause a voltage sag capable of disabling sensitive equipment.

Load changes also frequently lead to voltage sags. The sudden connection of a powerful consumer or a sharp increase in the consumption of active or reactive power in an industrial system disturbs the balance of the network, resulting in a decrease in voltage levels. This phenomenon is particularly typical for enterprises with a large number of electrothermal devices, where switching on furnaces or heaters leads to a steep rise in load.

Emergency situations related to the failure of power network elements, such as damage to transformers, cable lines, or automatic circuit breakers, can also cause significant voltage sags. Such events are usually accompanied by deeper and longer-lasting disturbances in power quality parameters.

The consequences of voltage sags are diverse in nature and have both direct and indirect effects. The direct impact is seen in the malfunctioning of electronic devices, computer systems, automation, and control systems, all of which require stable voltage to maintain normal operation. Even short-term voltage drops can cause device reboots, disruption of technological processes, data loss in computer systems, and control algorithm failures.

Industrial equipment such as ventilation systems, compressors, and pumps operating in continuous mode is also vulnerable to voltage sags. In the event of a voltage reduction, overload protections may activate, equipment may switch to emergency modes, or mechanical failures may occur due to loss of rotational stability.

Indirect consequences of voltage sags manifest through increased production losses, a rise in the amount of defective products, and higher costs for maintenance and repair of equipment. These consequences are particularly serious in industries with continuous technological processes, where even a brief shutdown may require a long time to restart and stabilize parameters.

From a technical perspective, repeated voltage sags contribute to premature wear of electrical equipment. Frequent short-term reductions in voltage create additional thermal and mechanical stresses on motors, power supplies, and electronic control systems. In the long term, this reduces the reliability of equipment and accelerates its physical aging.

Given the potentially serious consequences of voltage sags, enterprises implement measures for their prevention and minimization. One of the most effective methods is the use of soft starters and frequency converters for electric motors, which help limit starting currents.

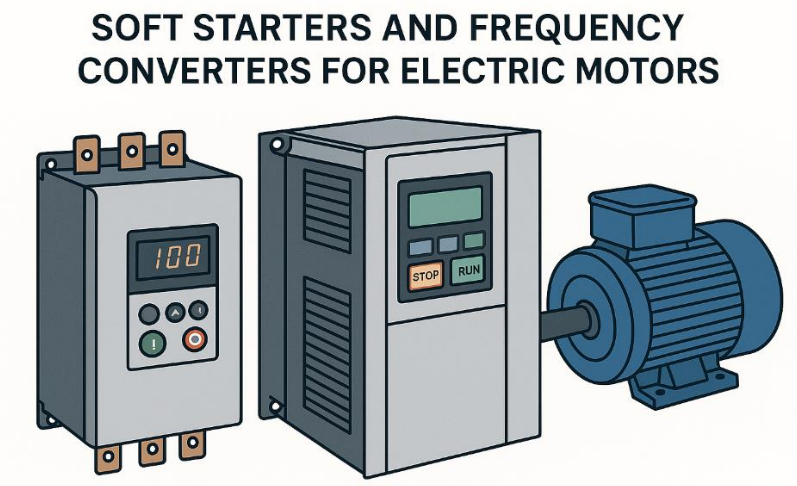

Figure 2 - Soft starters and frequency converters for electric motors

Reactive power compensation systems assist in stabilizing voltage levels under varying loads. Uninterruptible power supplies (UPS) for critical systems ensure the functionality of electronics during short-term voltage disturbances.

Equally important is the proper planning of electrical network architecture, considering possible emergency operating modes. Designing with sufficient power reserves, applying automatic transfer switches to backup power sources, correctly sizing transformers, and network sectioning all contribute to enhancing the resilience of the system against voltage sags.

For a systematic assessment of the problem, it is necessary to implement power quality monitoring systems capable of recording short-term events and accumulating statistical data. Data analysis makes it possible to identify typical sag scenarios, evaluate their depth, duration, and frequency, and detect the most vulnerable points in the power supply system, thus enabling the development of well-grounded solutions for system improvement.

Conclusion. In conclusion, it can be stated that the causes of voltage sags are multifactorial and may be associated with both internal characteristics of enterprises and external influences. The consequences of these phenomena affect not only the technical condition of equipment but also have a direct impact on production economic indicators. Therefore, minimizing the frequency and duration of voltage sags is a crucial component of the overall strategy to enhance the reliability of power supply and the efficiency of industrial enterprises.

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АНАЛІЗ ПРИЧИН І НАСЛІДКІВ ПРОСАДОК НАПРУГИ В СИСТЕМАХ ЕЛЕКТРОПОСТАЧАННЯ ПРОМИСЛОВИХ ОБ'ЄКТІВ

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Анотація. *У статті проаналізовано основні причини та наслідки просадок напруги в системах електропостачання промислових об'єктів. У дослідженні висвітлено найбільш типові джерела порушень напруги, такі як пуски двигунів, короткі замикання, зміни навантаження та відмови обладнання. Розглянуто прямі та опосередковані наслідки просадок напруги для промислових процесів та надійності обладнання. Обговорено технічні рішення для запобігання та мінімізації просадок, зокрема застосування пристроїв плавного пуску, перетворювачів частоти, компенсації реактивної потужності та правильного проєктування мережі. Запропоновано системний підхід до моніторингу та аналізу параметрів якості електроенергії для підвищення стійкості та ефективності роботи промислових підприємств.*

Ключові слова: *просадка напруги, промислові енергосистеми, якість електроенергії, пристрої плавного пуску, перетворювачі частоти, короткі замикання, компенсація реактивної потужності, енергоефективність, надійність обладнання, проєктування мереж.*