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The influence of power quality on the operational modes of industrial power supply systems

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Abstract. About 90% of distortions involving power quality analysis value are caused by the operation of industrial power supply systems. Thus, not only do gradual changes of voltage and harmonic distortions appear, but also disturbances caused by voltage dips and interruptions, which lead to technological equipment malfunctioning as well as serious damage to power quality. However, despite the possible damage from voltage dips and short interruptions in power supply systems, there is no standardization in power quality requirements, and power quality requirements are often not taken into consideration in the design and operation of power supply systems. On the basis of the research conducted on power quality value and analysis of current regulatory documents, the author of the article feels that it is crucial to take into consideration voltage dips and interruptions in the operation of industrial power supply systems.

1 Introduction

The issue of building industrial power supply systems in which power quality is taken into consideration is intrinsic to ensure the effective and trouble-free operation of these power supply systems [1].

As a rule, the issue of increasing power quality is relevant for power grids which are connected to a large number of consumers having sharply variable, unbalanced and non-sinusoidal operational modes.

Electrical interference has a random character of voltage distortion; and when affecting the technological equipment of industrial enterprises, the interference results in breaking the technological cycle of production caused by:

- automation systems malfunction;
- the error in determining the operating parameters of power grid;
- the breakdown in operating modes of industrial equipment.

In power supply systems nearly 60% of defects and breakdowns in industrial power supply systems are related to poor power quality including failures caused by voltage dips and interruptions. The mentioned above troubles can be the reasons for failures in control and protection systems of electric consumers, technical errors in the operation of microprocessor technology, equipment damage and emergence of abnormal operating modes of the main industrial equipment.

Despite the possible damage, the regulatory documents do not contain a number of indicators concerning power quality, which seems quite important for designing power supply systems. Transition to smart power grids will contribute to an even greater number of failures in operating modes because of voltage dips and interruptions. The latter is connected with the susceptibility of digital elements of power grids to these types of interference.

2 Electromagnetic interference levels in industrial power supply systems

In connection with the development of the industrial sector of Russia's economy in current market conditions, the following issues are being addressed:

- minimizing the damage caused by a decrease in power quality;
- increasing the reliability of industrial equipment power supply;
- increasing the capacity of power sources when connecting to new consumers.

The findings in terms of power quality [2] show that for industrial facilities the indicators of power quality, in average 30% cases under their supervision, do not meet the requirements of GOST 32144-2013:

- under- and overestimated voltage 60% of measurements;
- total harmonic distortions 2% of measurements;
- n-harmonic voltage factor 20% of measurements;

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- unbalance factor of return voltage sequence 2% of measurements;
- unbalance of zero sequence of voltage 24% of measurements.

It should be noted that about 90% of distortions of power quality analysis value are the result of the operation of industrial electric receivers.

In most cases, technical problems related to the functioning of electrical receptors in the Russian Federation due to power quality disturbances are caused by:

- voltage harmonics 18% of disturbances;
- voltage dips or interruptions 52% of disturbances.

In the European Union countries, the main causes of technological equipment malfunctioning are:

- harmonic components - 5.4%;
- voltage sags - 23.6%;
- pulsed voltages - 29%.

In the USA, according to the statistics, equipment shutdown can be caused by:

- voltage sags and pulsed voltages - 48%;
- harmonic distortions - 22%.

Based on the data presented, it should be noted that the most frequent causes of breakdowns in industrial power supply systems are brownouts and pulsed voltages.

These disturbances occur during normal operation of industrial equipment including the following manufacturing equipment: electric arc furnaces (EAF), various rolling mills, welding machines, electrical receivers with motor load. The Figure 1 shows a voltage-dip graph based on measurements on one of the 0,4 kV feeders of the welding areas of JSC "Zavod Trud" (Nizhny Novgorod).

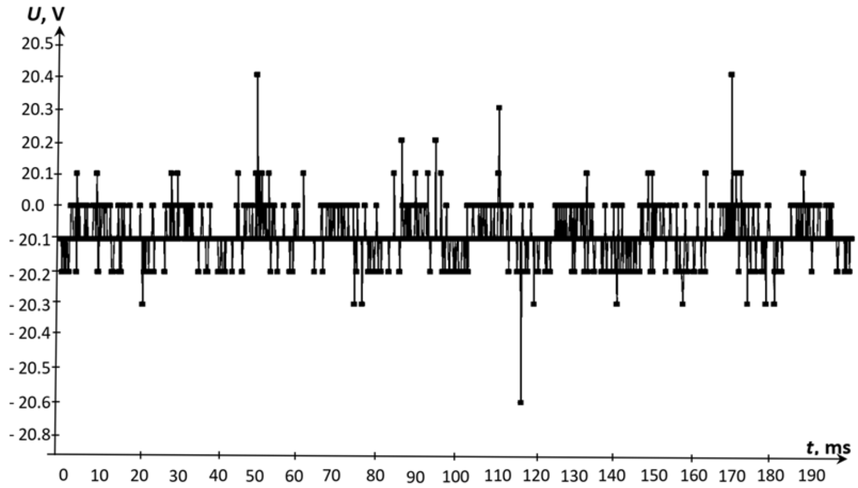

Fig. 1. Diagram of voltage dips (0.4 kV feeder of the welding area).

Let us consider the electromagnetic interference levels (EML), in particular voltage dips, introduced into power grid with industrial electrical consumers [3-5].

While operating electric arc furnaces produce irregular voltage dips with a frequency of up to 1Hz and regular voltage dips with a frequency of up to 10Hz.

When electric arc furnaces work, regular voltage dips usually have a depth not exceeding 5% of the supply voltage value, whereas irregular voltage dips have the depth up to 100%. The causes of irregular voltage dips are unfavorable arc ignition conditions during the melting of metal, arc unstable combustion, electrode short circuits with charge at furnace startup and charge collapse.

Working welding machines create a voltage sag, the value of which depends on the capacity of the machine and power supply [6]. Projection and spot welding create voltage dip up to 7% deep. Butt and multiple-spot welding create voltage dip up to 19% deep. In this case, voltage dip duration for spot, projection, multi-spot and seam welding machines is 0.02-1.0s., while for butt welding machines - 0.2-20s.

The voltage sag value created by rolling mills depends on their types. Synchronous and asynchronous direct current motors are exploited as the drivers of rolling mills. Rolling mills with drives from synchronous and asynchronous DC motors are the reason for voltage fluctuations and dips. Thus blooming and slabbing mills in 6, 10kV grid create voltage dips up to 20% in depth over 1-5s. and the average frequency of 20-40 dips per minute. Hot strip mills create voltage dips from 2 to 10% in depth over 1-5s. and an average frequency of 2 to 20 dips per minute. In the case of cold rolling mills, voltage dips are between 2 and 20% in depth for 2 to 20s. and average frequencies of 4 to 20 dips per hour.

Presses and automatic press lines during their operation create voltage dips from 1 to 5% with a frequency of occurrence of 0.17-0.2Hz.

Conveyors, fans, and compressors at equipment startup are the reason for dips not exceeding for transporters and conveyors 1.2%; fans 3-5%; compressors 4-6% in depth.

Asynchronous and synchronous DC motors create voltage dips from 1 to 20% in depth for 3-10s. The frequency of voltage sags depends on the electric motor operation modes. The highest frequency is observed in the intermittent mode of equipment operation.

3 The effect of voltage dips and interruptions on industrial electrical equipment

The influence of voltage dips and voltage interruptions on the industrial electrical consumers depends on the factors that determine the depth of voltage dips, their duration and the frequency of their occurrence. Interestingly, control and protection systems industrial electric consumers [4, 5, 7] built on the basis of microprocessor technology are the most sensitive to these types of interference. Figure 2 shows the maximum allowable voltage dips and interruptions causing the failure of microprocessor-based control systems [8].

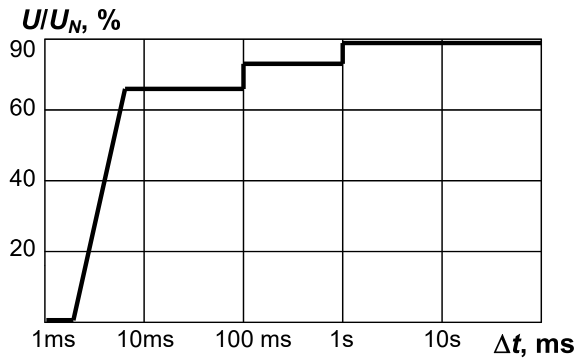

Fig. 2. The graph of allowable voltage dips for microprocessors.

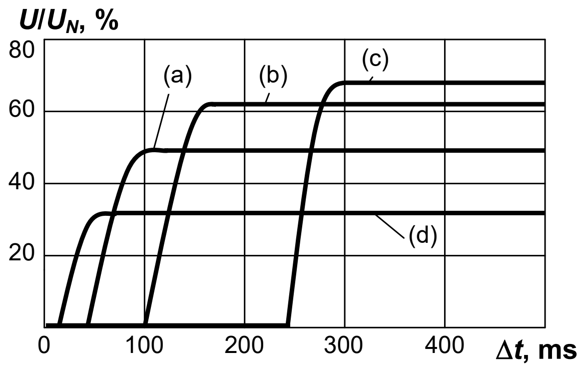

Fig. 3. The graph of allowable voltage dips: a) magnetic starters; b) variable speed drives; c) programmable controllers; d) relays.

Figure 3 shows the allowable voltage dips and interruptions which have been discovered in automatic systems including control relays, magnetic starters, programmable controllers and elements of variable speed drives.

Thus, technical failures in equipment operation will be observed at the following values of voltage dips:

- magnetic starters $\Delta U_{п} \geq 50\%$;
- variable speed drives $\Delta U_{п} \geq 60\%$;
- programmable controllers $\Delta U_{п} \geq 70\%$;
- microprocessors $\Delta U_{п} \geq 65\%$;
- relays $\Delta U_{п} \geq 30\%$.

Failures of these devices will be observed if the duration of voltage dips is:

$\Delta t_{п} \geq 40$ms for magnetic starters;

$\Delta t_{п} \geq 100$ms for variable speed drives;

$\Delta t_{п} \geq 240$ms for programmable controllers;

$\Delta t_{п} \geq 100$ms for microprocessors;

$\Delta t_{п} \geq 40$ms for relays.

For industrial power consumers with rectifier and inverter units the limits of allowable values of voltage dips and interruptions are shown in Figure 4 [9]. It should be noted that inverters have greater sensitivity to voltage dips in comparison with rectifiers. If the duration of voltage dip is more than 6-9ms and the value of sag is more than 20%, the rectifier fails to work.

If a voltage sag is not more than 15% and its duration is not more than 3ms, rectifier and inverter units shut down.

To assess the possibility of uninterrupted operation of personal computers in the context of existing voltage dips and interruptions, ITIC (Information Technology Industry Council) curves have been developed, Figure 5 [10]. According to these curves voltage interruptions with A duration not exceeding 20ms. are allowed. Voltage dips up to 10% in depth of any duration, up to 20% in depth with a duration not exceeding 10s. and up to 30% in depth with a duration of less than 0.5s are allowed too.

When assessing the reliability of industrial manufacturing equipment in the context of THE occurrence of voltage dips and interruptions, it is necessary to evaluate of damage extent caused by these dips and interruptions.

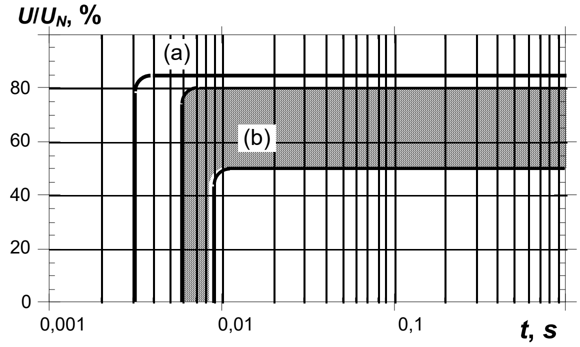

Fig. 4. Characteristics of noise immunity: a) inverter; b) rectifier.

Determination of damages from power supply interruptions should classifies into two types of damages – main and unforeseeable [11]. The main damage is associated with the damage caused by voltage dips and interruptions in the power supply of industrial enterprises, but the equipment is preserved, manufacturing process is ongoing and there is no wasted produce. In other words, the main damage is caused by the failure to implement the plan for production output. The unforeseeable damage is associated with the element of surprise, as a result of which there may be manufacturing process disturbance, equipment failure and, as a consequence, waste is produced. This damage depends on the type of consumer, the amount of electricity shortfall, the availability of the consumer's generation reserves and the possibility of changing industrial manufacturing process. If consumer's reserves is sufficient to compensate for the shortfall in production during its energy limitation, the shortfall in electricity during that time is compensated by the backup power supply system of the enterprise, thereby ensuring the continuity of the manufacturing process.

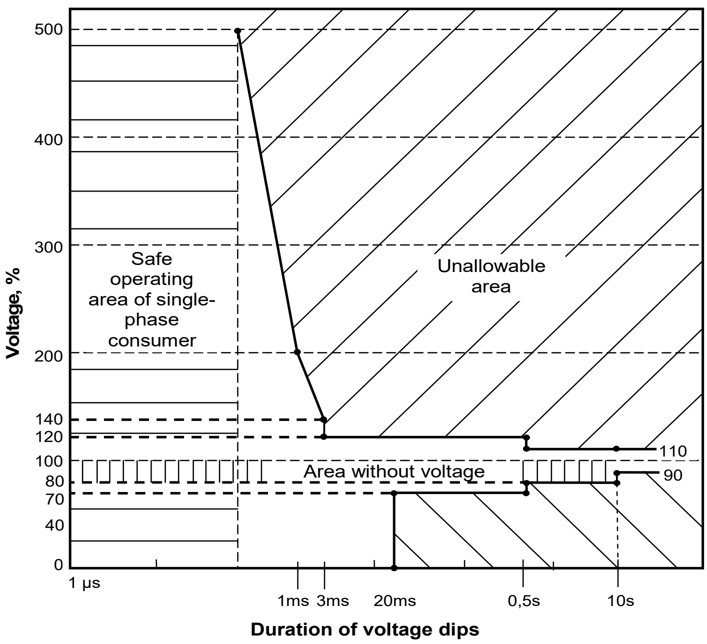

Fig. 5. Areas of allowable voltage dips and interruptions for personal computers, ITIC curves.

In the works [9, 12] the values of damages from poor quality of electric power defined in fractions from the total annual damage are given:

- voltage sags and short-term interruptions lasting less than 3 min - 57,7%;
- overvoltages - 34,4%;
- long voltage interruptions lasting more than 3min - 4,3%;
- flicker, voltage asymmetry - 2.7%;
- voltage non-sinusoidality - 0.9%.

As can be seen, the greatest damage is caused by voltage dips and interruptions. At the same time the complexity of modern manufacturing processes and high requirements to maintaining their stability lead to significant losses in various industries, which is clearly illustrated by Table 1 [5, 13]. In addition, it should be noted that GOST 32144-2014 [14] does not specify the requirements for these voltage dips and interruptions.

The presented information allows us to conclude that when power quality rationing and developing recommendations for its improvement, it is necessary to pay attention to the values that determine the depth and duration of voltage dips and interruptions.

Table 1. Damages from power outages in some industries

Industry	Damage, euro per an interruption
Semiconductor manufacture	3800000
Computer center	750000
Steel production	350000
Glass industry	250000
Pharmaceutical company	17000000

4 Recommendations for improvement of electromagnetic compatibility of industrial consumers

The methods for calculating certain types of electromagnetic disturbances are presented in the works [3-5]. Basically, the methods allow evaluating slow changes, oscillations, non-sinusoidal and asymmetric voltages. Taking into account the probabilistic nature of interference, it is better to exploit simulation modeling of power supply systems with the use of software products PSCAD and MatLab Simulink for interference calculation and prediction. Simulation modeling tools allow us to study the influence of any types of interference on industrial electrical equipment not only during normal operation, but also transient processes.

For industrial power supply systems, it is possible to ensure electromagnetic compatibility of mfanufacturing equipment by using schematic solutions as well as applying special devices in the grid. Schematic ways of ensuring electromagnetic compatibility are the most simple and economical. The following technical solutions can be recommended:

- separation of power supply to electrical consumers and manufacturing equipment, which create EMF and are sensitive to these types of interference;
- use of interlocks to limit the simultaneous work of large consumers creating voltage sags;
- increasing THE power source capacity of power supply systems;
- application of pulse-width modulation rectifiers.

In industrial power supply systems, special means can be used, including, for example, the use of [15, 16, 17]:

- uninterruptible power supplies;
- passive and active harmonic filters;
- static VAR compensators;
- transformer-thyristor voltage regulators;
- a motor soft starter;
- other devices.

Conclusions

In connection with the electric power industry transfering to intelligent technology systems in industrial power supply systems, it is possible to observe a tendency to increase the damage from voltage sags and interruptions, which must be taken into account when considering the noise immunity of industrial equipment to the effects of this kind of interference.

To increase the resistance of technological equipment to voltage sags and interruptions as well as to reduce damages, it is necessary to create the standards for voltage sags and interruptions as a part of GOST 32144-2013 and take these standards into account when considering the design and operation of industrial power supply systems.

As electrical consumers in industrial power supply systems create voltage sags and interruptions influencing other industrial consumers, it is necessary to separate consumer power supplies or to introduce uninterruptible power supply sources into the power supply system of responsible electric consumers.

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