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Main Sources of Higher Harmonic Components and Assessment of Their Impact on Power Quality

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ABSTRACT: In the power supply systems of mining enterprises, non-linear loads are widely used. In such enterprises, the load current is non-sinusoidal and, in many cases, also non-linear, which leads to the generation of higher harmonic components. In these facilities, sources such as induction furnaces, converters, power transformers, single-phase and three-phase welding equipment, and controlled semiconductor devices-including thermistor power regulators and thermistor-controlled reactors-serve as primary sources of harmonics. The emergence of higher-order harmonics due to induction furnaces primarily occurs during the melting process of materials. During this period, the most significant voltage fluctuations appear in the network and the intensity of harmonic distortions is greater compared to other stages of the melting cycle. [1,2].

I. INTRODUCTION

Phase imbalance or overloading of power transformers generates higher harmonics in electrical networks. In addition, electrical equipment with non-linear volt-ampere characteristics is also a source of higher harmonic distortions. During short-circuit conditions; the amplitude of harmonics can increase significantly. Based on the above considerations, an analysis was carried out to evaluate the power of harmonic-generating electrical equipment in the power supply systems of each workshop of the enterprise. The results of this analysis are presented in Table 1. [3,4].

Table 1. **The main electrical loads generating higher harmonics in the enterprise**

	Names of Electrical Equipment	Power rating, kW	Quantity
1	Asynchronous motors	Less than 100	64
2	Synchronous motors	630 to 4000	58
3	Welding equipment	40-130	30
4	TMZ-type transformer	1000	19
5	Thyristor-based converter	Up to 500	17
6	ZNOM-type voltage transformer	25	4
7	RDTSNK-type transformer	63000	2
8	Induction furnace	320 350	1 2

There are various methods for presenting the results of electric power quality measurements, which enable a reduction in the amount of information regarding power quality at designated control points. However, these methods do not fully meet the requirements of comprehensive monitoring and analysis. According to the results of the study, a power quality measurement report is prepared based on the measured quality indicators. This report allows for drawing conclusions regarding the compliance of power quality indicators with the requirements of the control center, based on a comparison between the measured values and the normative standards. Although this approach provides a quantitative assessment of the degree of deviation from the required power quality, it does not identify the root causes of such disturbances. The

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spectrum of higher harmonic components of voltage serves as a compact and, at the same time, informative form of describing a non-sinusoidal mode. It contains detailed information about all harmonic components of the measured signal. In most cases, amplitude spectra are used in power quality analysis, where the harmonic order is plotted along the x-axis (abscissa) and the amplitude of the harmonics along the y-axis (ordinate), usually expressed in percentage [3-6]. The amplitudes of the fundamental frequencies are not shown, since they are always considered to be 100%.

II. RESULTS AND DISCUSSIONS.

In high-power networks with multiple sources of higher harmonics, it is not possible to make a definitive conclusion about the causes of power quality deterioration solely by analyzing the voltage spectrum. The analytical evaluation becomes even more complex when voltage asymmetry is present alongside waveform distortion. When higher current harmonics are generated, especially during the operation of both controlled and uncontrolled converters, unusual harmonic components can emerge within the asymmetrical voltage waveform. The graphical method is considered one of the most effective approaches for identifying and assessing the causes of power quality degradation. If additional information is available regarding changes in the network scheme, the operating modes of regulating and compensating devices, or the time-varying nature of load composition, it becomes possible to apply laws and patterns related to power quality variations figure 1.

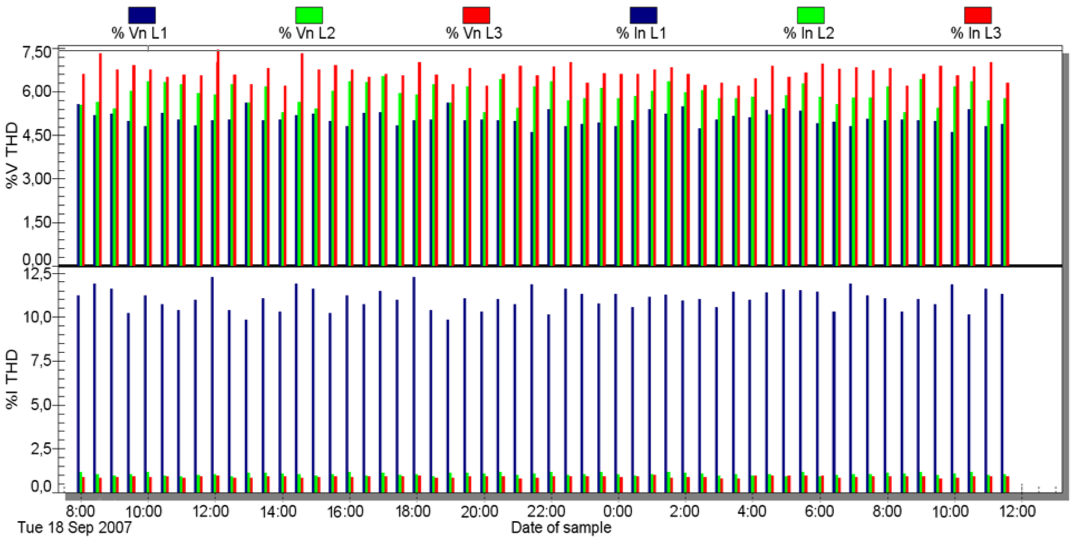

Figure 1. Total Harmonic Distortion at Point A

In Figure 2, The graphical method is considered one of the most effective approaches for assessing and identifying the causes of power quality deterioration. If additional information is available regarding changes in the network configuration, the operating modes of regulating and compensating devices, and time-dependent variations in load composition, it becomes possible to apply the regularities governing changes in power quality.

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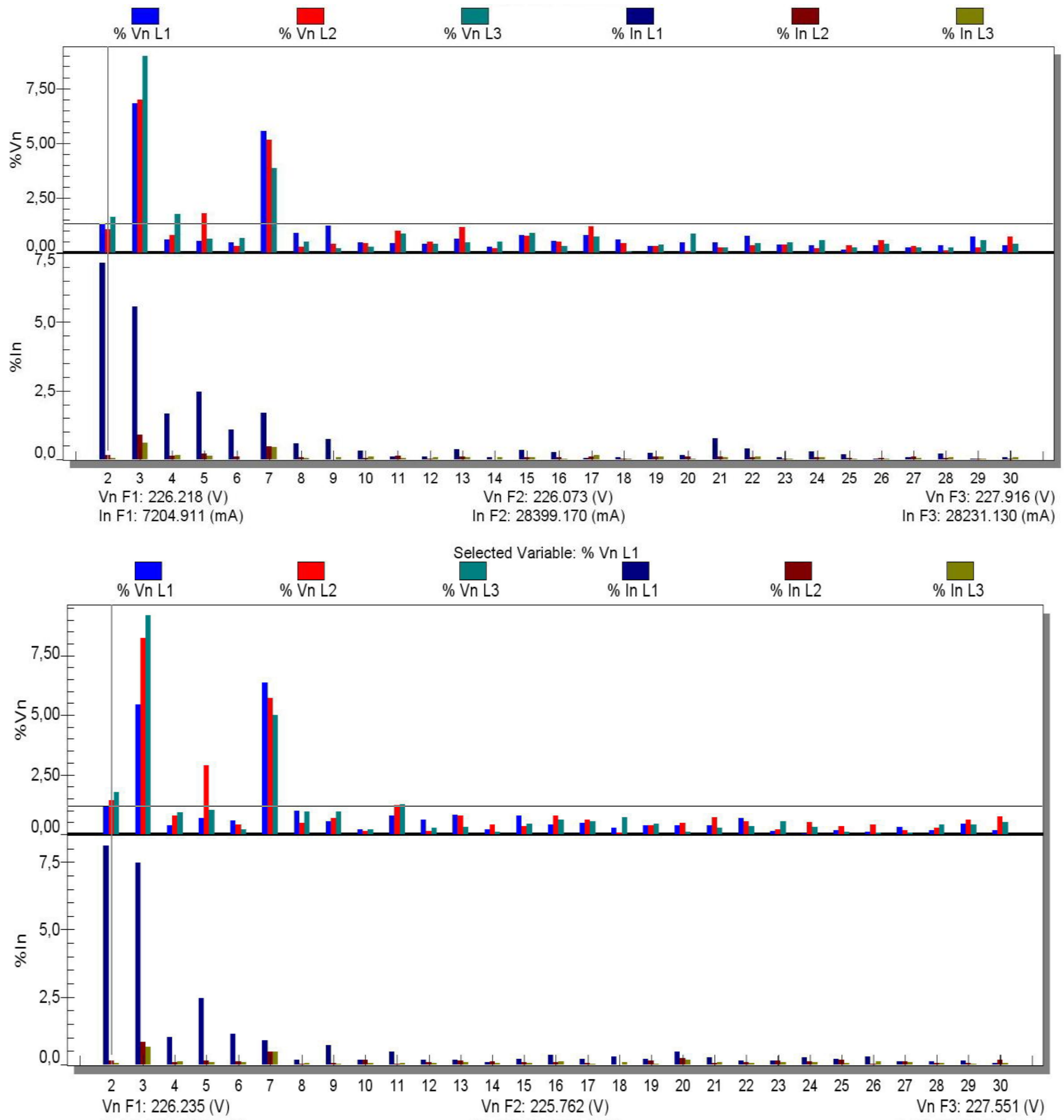

Figure 2. Voltage and Current Harmonic Components at Point A a) Total Harmonic Distortion at Point A b) Harmonic Spectrum of Voltage and Current

A comparison of the voltage and current waveforms allows the following conclusion to be drawn. Phase A is loaded more heavily on average than phases B and C. As a result, the voltage drop in phase B is approximately 1.3%, while in phase A it reaches 3%. Such an unbalanced voltage condition negatively affects three-phase consumers and leads to additional losses of electrical energy and voltage due to the zero-sequence current caused by the asymmetrical load. The operating parameters of the power supply system change randomly, which in turn is associated with fluctuations in load and corresponding stochastic variations in power quality indicators. During the measurements, various evaluation criteria were applied in accordance with the established requirements for power quality indicators. A total of 1500 measurement results were obtained over a 24-hour period. Using statistical analysis, the relative duration of exceedance beyond the permissible values was determined. The excess of currents in reactive impedances under total current flow is related to the activecomponents of the circuit's conductance.

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$$g < \omega_{vI} C = \frac{1}{\omega_{vI} C} = \sqrt{\frac{C}{L}} = \frac{1}{\rho}, \qquad (1)$$

Here, g denotes the active components of the circuit conductance. In a circuit with various reactive impedances connected in parallel, i.e., under current resonance conditions, the maximum current values flowing through the inductive and capacitive branches are not observed.

$$I_{IC\,max} = U \frac{1/\omega_{vIC} C}{r_C^2 + 1/(\omega_{vIC} C)^2}, \qquad (2)$$

The current frequency in this harmonic

$$\omega_{vIC} = \frac{1}{r_C C}. \qquad (3)$$

For a network with inductance, the maximum current value is given as follows::

$$I_{IC\,max} = U \frac{\omega_{vIL} L}{r_L^2 + (\omega_{vIL} L)^2}, \qquad (4)$$

The frequency corresponding to the harmonic of this current in the system is as follows:

$$\omega_{vIL} = \frac{r_L}{\sqrt{L(2-L)}}. \qquad (5)$$

Under near-ferroresonance conditions, maximum currents are observed in both the inductive and capacitive branches.

$$Z \approx \frac{\omega_{vI} r_L q^2}{\sqrt{\omega_{vI}^2 + 4q^2(\omega - \omega_{vI})^2}}. \qquad (6)$$

Moreover, in the case of parallel connection of branches, the relationship between voltages in the non-branched parts of the circuits and the current is as follows:

$$U = \frac{I \omega_{vI} r_L q^2}{\sqrt{\omega_{vI}^2 + 2q^2(\omega - \omega_{vI})^2}}. \qquad (7)$$

III. CONCLUSION

If voltages are replaced with currents, they correspond to the frequency characteristics obtained for the ferroresonance circuit. In the power supply systems of industrial enterprises, the areas represented by circuits with three or more branches connected in parallel with reactive elements are typically observed. In such circuits, ferroresonance phenomena can occur under various configurations of branch combinations. For example, in a system with three branches, there are six possible combinations in which ferroresonance may arise for a single harmonic. In the case of four branches, the number of such combinations increases to thirty-two. Moreover, the complexity of assessing the impact of harmonic components of ferroresonance phenomena on the reliability of electrical equipment is largely due to the presence of mixed reactive impedance combinations within the power supply system. It illustrates a part of the power supply system that includes a thyristor converter of an induction furnace.

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