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The Influence of Disturbances Generated by Arc Furnaces on the Power Quality

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***Abstract*—**The paper presents the impact of work on the electric arc furnace. Arc equipment is one of the largest receivers powered by the power system. Electric arc disturbances arising during melting process occurring in these furnaces are the cause of an abrupt change of the passive power of furnaces. Currents drawn by these devices undergo an abrupt change, which in turn cause voltage fluctuations and light flicker. The quantitative evaluation of the voltage fluctuations is now the basic criterion of assessment of an influence of unquiet receiver on the supplying net. The paper presents the method of determination of range of voltage fluctuations and light flicker at parallel operation of arc devices. The results of measurements of voltage fluctuations and light flicker indicators recorded in power supply networks of steelworks were presented, with different number of parallel arc devices. Measurements of energy quality parameters were aimed at verifying the proposed method in practice. It was also analyzed changes in other parameters of electricity: the content of higher harmonics, asymmetry, voltage dips.

***Keywords*—**Power quality, arc furnaces, propagation of voltage fluctuations.

I. Introduction

THE following article constitutes continuation of the issues related to power quality of electricity presented at the 19th International Conference on Power Quality Management, Measurement, Analysis and Monitoring, 21-22 September London 2017 [6]. Article introduces problems related to disruptions in networks supplying arc furnaces.

Arc furnaces belong to rather loud electric power receivers. Electric arc disturbances rising during melting process occurring in these furnaces are the cause of an abrupt change of the passive power of furnaces. Currents drawn by these devices undergo an abrupt change, which in turn cause voltage fluctuations and light flicker [1], [2], [4], [6], [15], [16].

As a result of voltage fluctuations, there are changes in the current consumed by the lighting receiver, which results in changes in the luminous flux. At a given amplitude and frequency of changes, the flickering of light causes nervousness in people reaching the level of irritation, beyond which most people are unable to perform any work related to the perception of small objects, slightly contrasting with the surrounding background. Flickering of light could also be dangerous for people who suffer from epilepsy [1], [15].

In Fig. 1, arising, perception, and measure of flicker of light was presented.

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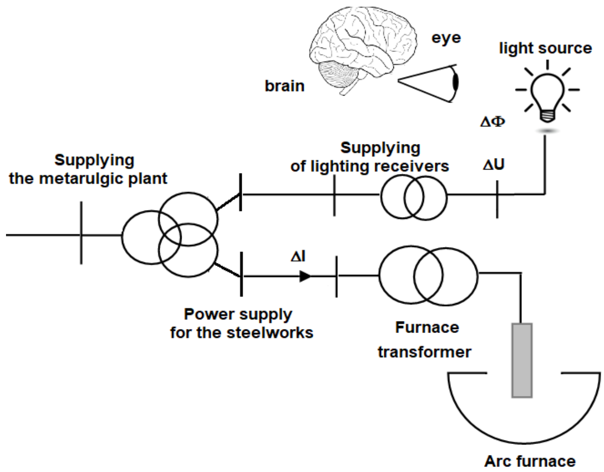


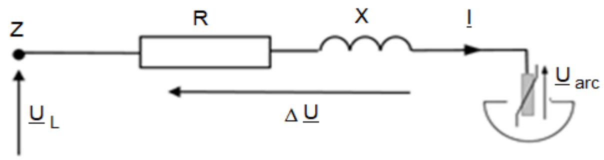
Fig. 1 Arising, perception, and measure of flicker of lightning

II. Voltage Fluctuations and Flickering of Light

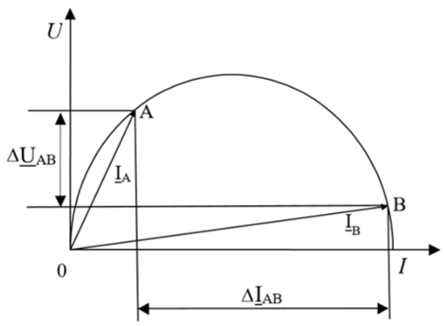
Fast-changing voltage fluctuations are defined as changes in the effective value or voltage wave envelope [13].

The technological process associated with steel melting is characterized by rapid changes in the current drawn by the furnace: from the interruption in the power supply circuit to the short-circuit in the initial phase of the melt. After the electric arc has been initiated, the current changes are still violent, mainly due to the varying arc length. The changing current of the furnace causes, in the power supply network of arcing devices, rapid voltage changes in the frequency of changes of several per second.

Fig. 2 presents a simplified one-phase diagram of the substitute power supply for the arc furnace (a) and pie chart (b) illustrating the generation of voltage ΔU_{AB} caused by the current changes ΔI_{AB}.



(a)



(b)

Fig. 2 Single-phase equivalent circuit (a) and circular plot of the network powering the arched device (b)

For U_A arc voltage, the current consumed by the furnace is I_A. The voltage drop on the grid impedance in relation to the U_L supply voltage can be determined from:

$$\frac{U_L - U_{LA}}{U_L} = \frac{\Delta U_A}{U_L} = \frac{RP_A + XQ_A}{U_L^2} \qquad (1)$$

when changing the arc length, the arc voltage changes from U_A to U_B and current from I_A to I_B. The voltage drop on the network impedance with the I_B current flow is:

$$\frac{U_L - U_{LB}}{U_L} = \frac{\Delta U_B}{U_L} = \frac{RP_B + XQ_B}{U_L^2} \qquad (2)$$

In order to determine voltage fluctuation levels and indicators of flickering and other indicators of electric power quality in metallurgical plant networks, the author measured at three points: A - power supply, B - power steelworks, C - low voltage light circuits as shown in Fig. 3. For measurements, the Memobox 800 analyzers and a computer measuring system were used to measure high-speed currents and voltages [11].

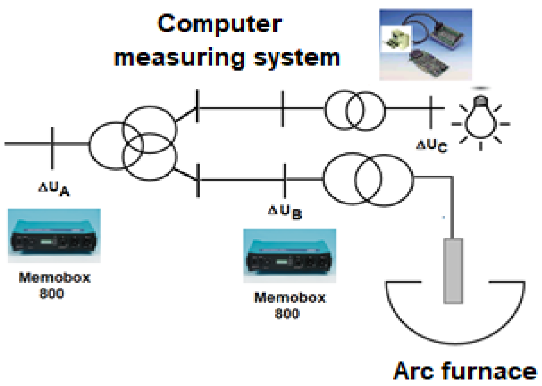


Fig. 3 Places of measurement of electricity quality parameters

Fig. 4 presents the voltage changes between the maximum and minimum value recorded in the power supply network of the smelter (110 kV line) at the time of smelting in the arc furnace. The voltage parameters were recorded at five-second measuring intervals and referred to the rated voltage, adopted as 100%. It can be assumed that the voltage in the network varies between 98% and 101.5% of the nominal voltage of the network.

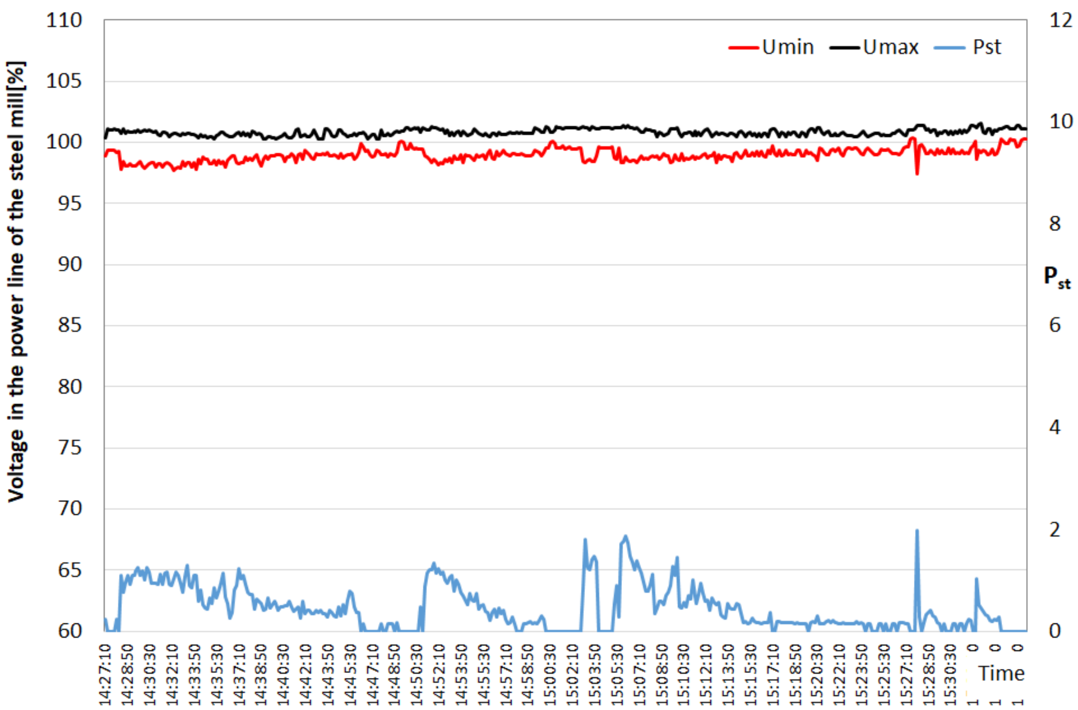


Fig. 4 Changes in voltage and short-term flicker factor P_{st} under the time of smelting in an arc furnace - power supply line for the steelworks

Measurements of voltage changes were also carried out in the steel supply network at the 30-kV voltage level as shown in Fig. 5. At a much lower short-circuit power on the MV side, in relation to the short-circuit power of the mains power supply network of about 1:6, a significant increase in voltage fluctuations was recorded. The voltage in the power supply network of mills varies between 90% and 104% of the rated voltage. The biggest voltage fluctuations are in the initial phase of the melting.

Assuming that the voltage fluctuation range in the HV network is 3.5%, and in the MV network 15%, with a damping ratio between HV and MV of 0.8, it can be assumed that the voltage fluctuation is available -circuit power [15].

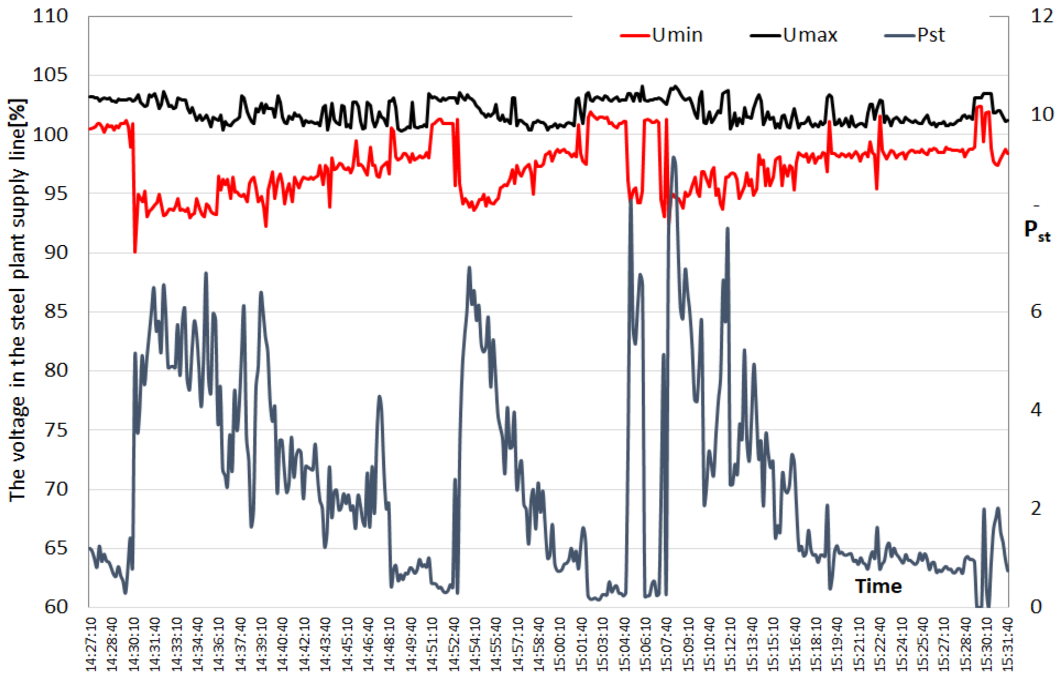


Fig. 5 Changes in voltage and short-term flicker factor P_{st} under the melting time in an arc furnace - power supply line for steelworks

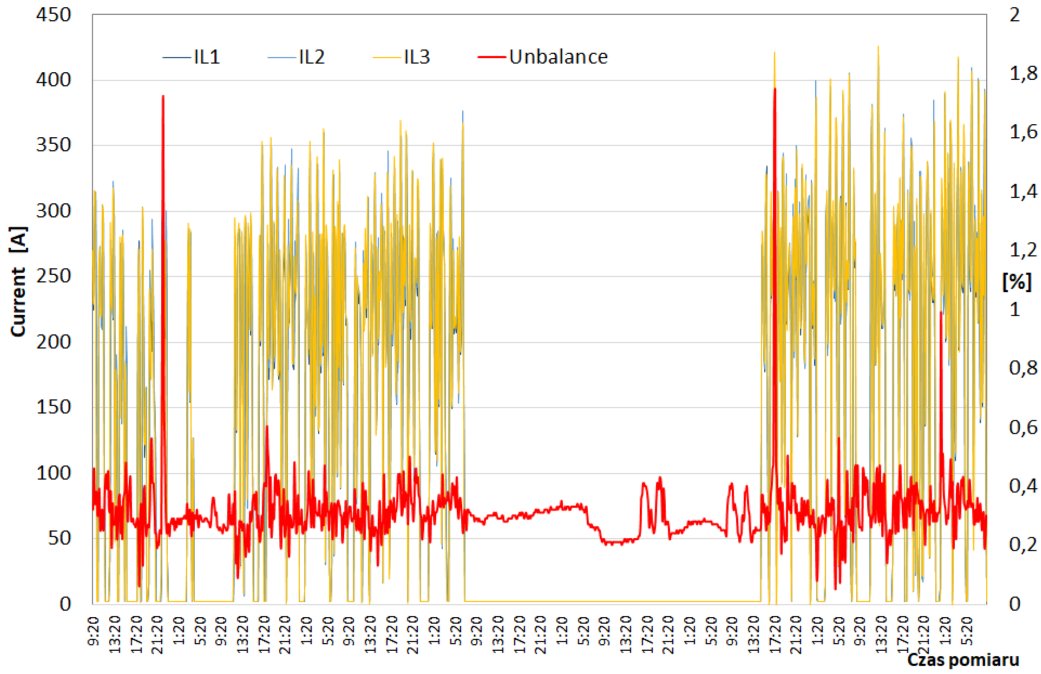


Fig. 6 Current waveforms and unbalance coefficient recorded during one week of measurements

Fluctuations caused by the arc furnace are discussed in detail in [7], [8], [10].

III. Unbalance in Network Supplying Arc Furnaces

The asymmetry of voltages (currents) occurs in a three-phase power supply in the case when the vectors of voltages (currents) have different sizes or angles of displacement between particular vectors are different from 120°. The impact of asymmetry on the power grid and the operation of equipment is presented in publications [5], [9], [16].

In the case of three-phase arcing furnaces, there are two main reasons (types) of asymmetry: constructional and operational.

Constructional asymmetry is related to the construction of multi-current tracks supplying the arc furnace. At different track lengths in individual phases, depending on the distance between the electrodes and the furnace transformer and the different distances between the individual phases of the track, resistances and own and mutual reactances have different values. Operational asymmetry results from the change of arc resistance caused by different arc length during the melting process. In the book [16], this asymmetry was called the operational asymmetry.

Fig. 6 presents the changes of the asymmetry coefficient and currents taken by the arc furnace registered during one week.

Arc furnace, in terms of uniformity of load, is a symmetrical receiver. The symmetrical load of individual phases is ensured by electrode position adjustment system. The electrodes position adjustment system, due to its inertia, however, is not able to eliminate fast-changing current changes resulting from the change in the length of the electric arc.

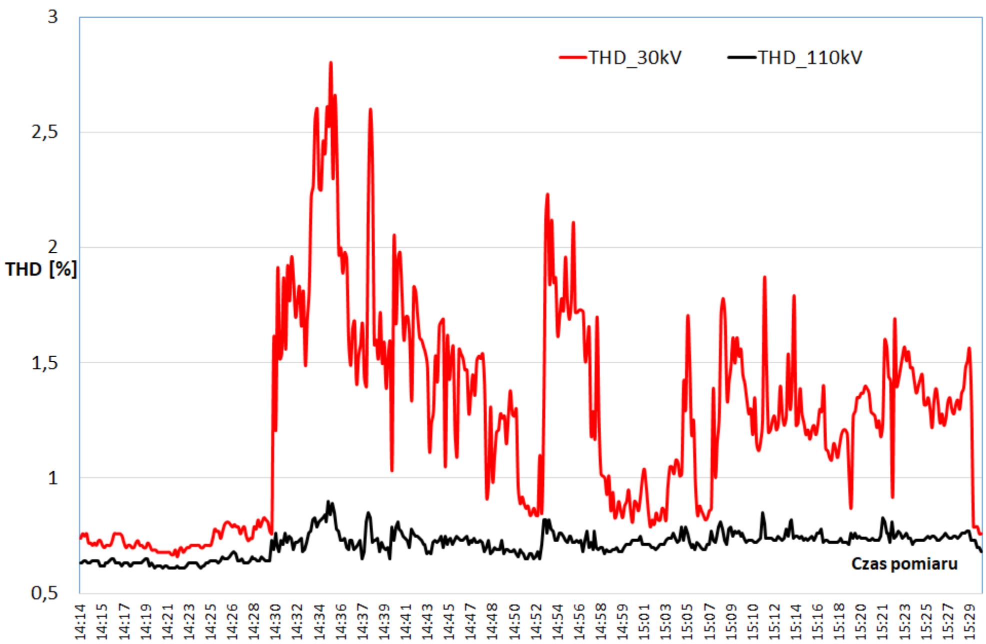
IV. Voltage Deformation Caused by Arc Furnaces

Non-linear receivers supplied with voltage of a specific shape (eg sinusoidal) cause that the currents of these receivers have a different shape than the voltage supplying them. The constantly increasing number of such devices causes a deterioration of the quality of electricity in the power system and has a negative effect on the operation of other devices. These issues have been described, among others, in publications [5], [10], [16].

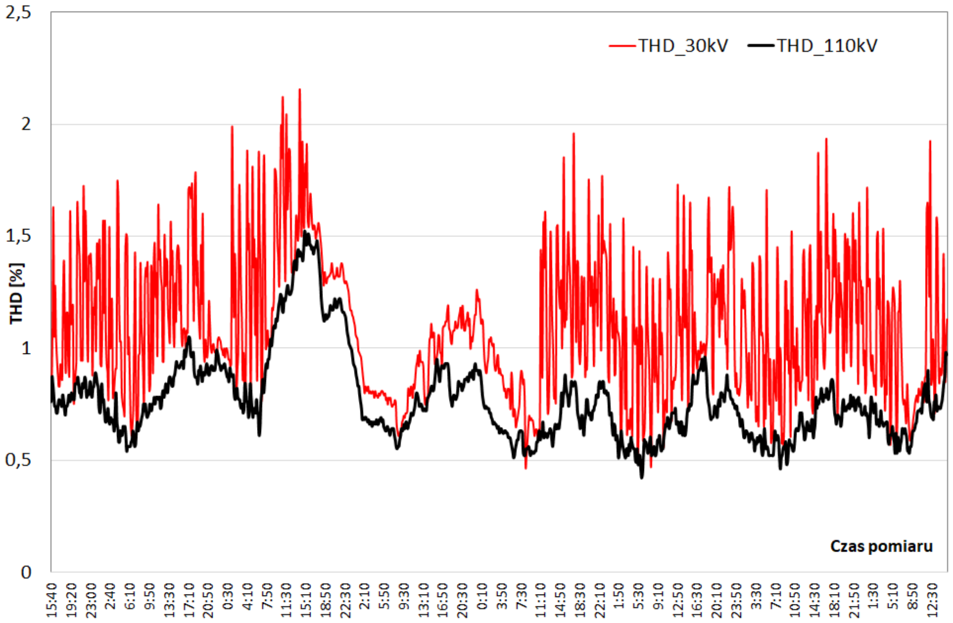
The influence of arc devices on voltage distortion depends on the short-circuit power of the network. Hanzelka, in [2], describes the small impact of arc furnaces on the voltage distortion in the mains power supply network (110-kV voltage level).

Fig. 7 presents the changes of the THD harmonic distortion recorded in the mains power supply network and the steelworks supplying line during one smelting (a) and during one week of measurements (b).

The influence of the arc furnace on the voltage deformation in the mains power supply network is small as shown in Fig. 7 (a). The THD waveform corresponds to the typical course of load changes in the power system. The arc furnace has a greater influence on the voltage in the power supply network of the steelworks, which depends on the melting phase as shown in Fig. 7 (a) and the daily load of the power system as shown in Fig. 7 (b).



(a)



(b)

Fig. 7 Changes in the deformation coefficient THD harmonics recorded during one cast (a) and during the measurement week (b)

V. Conclusion

Arc furnaces are electrothermal devices used to manufacture steel. Furnaces of this type are mainly used for obtaining steel from recycled scrap. Many types of arc furnaces for melting steel are used. The three-phase Heroulte arc furnaces are the most popular in the world [4], [15]. In 1996, 31% steel was produced in arc furnaces and 39% in 2007. It is planned that in 2030, more than 50% of steel will be produced in arc furnaces. Along with the development of the steelmaking industry, there were also changes in the construction of furnaces. The average melting time has been reduced from 4-6 hours in first generation furnaces to 50-60 minutes - fourth generation. Therefore, arc furnaces for most of the time of melting cause interference in the supply network.

On the basis of performed measurements at asymmetry coefficient below acceptable value [12], [14], it is possible to notice that flicker indicator changes in all phases in the similar range.

In modern arc devices, high-current triangular secondary lines (phase wires connected in vertexes of equilateral triangle) are applied. This approach allows containing the asymmetry phenomena [4]. In publications concerning voltage fluctuations, it is possible to assume that the influence of asymmetry is negligible and can be omitted. An equivalent one-phase circuit is useful in analysis of chosen aspects of unquiet receiver action on the supplying net. In the case of majority of receivers including arc devices into it, none of phases are distinguished with respect to the character and the value of the voltage and current waveforms [3].

Analysis presented in this article includes following factors: short-circuit power, the ratio of the resistance to the reactance of supplying net, the choice of working point of the arc device (the arc current at which the melting process is performed), interaction among remaining arc furnaces and ladle furnaces working parallel. This analysis has shown the crucial influence of short-circuit power on voltage fluctuations. Higher value of short-circuit power causes weaker interaction among furnaces and higher increase of voltage fluctuations and flicker of lightning at simultaneous work of several furnaces [10].

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