# RESULTS FROM AN EXPERIMENTAL STUDY AT *''STOMANA INDUSTRY" SA* OF THE POWER QUALITY AT THE LEVEL OF 220 kV WHEN OPERATING ELECTRIC ARC FURNACES

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ABSTRACT. The report presents the results from the experimental studies of the impact of the electric arc furnaces operation on the electric power quality indicators at the 220 kV side. The voltage deviation and the higher harmonics in the voltage curve under different operating modes of the electric arc furnaces and of the ladle furnaces have been studied. The results of the registered current loads of the 220/35 kV transformers, the active and reactive power, and the values of the power factor have also been given. Conclusions have been made on the influence of the operating modes of the furnace transformers upon the "pollution" (deterioration) of the 220 kV system voltage.

Keywords: electric power quality indicators, electric arc furnaces

**ЕКСПЕРИМЕНТАЛНИ ИЗСЛЕДВАНИЯ НА КАЧЕСТВОТО НА НАПРЕЖЕНИЕТО НА НИВО** 220 kV **ПРИ РАБОТА НА ЕЛЕКТРОДЪГОВИ ПЕЩИ В „СТОМАНА ИНДЪСТРИ" АД**

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**РЕЗЮМЕ**: В доклада са представени резултатите от експериментални изследвания на влиянието на работата на електродъговите пещи върху показателите на качеството на електрическата енергия на страна 220kV. Изследвани са отклонението на напрежението и висшите хармоници в кривата на напрежението при различни работни режими на електродъговите пещи и кофъчно-пещните инсталации. Дадени са и резултатите от регистрираните токови натоварвания на трансформаторите 220/35 kV, активната и реактивната мощност и стойностите на фактора на мощността. Направени са изводи относно влиянието на работните режими на пещните трансформатори върху „замърсяването" на системното напрежение 220 kV.

**Ключови думи**: показатели за качеството на електрическата енергия, електродъгови пещи.

## Introduction

By its very nature, the electric power is a commercial product that should possess an inherent adequate quality. The widely used concept "Power Quality" (PQ) means uninterrupted power delivery to the consumers, and the parameters of the supply-line (mains) voltage shall be within a specified range, allowing for the normal functioning of the net-connected power loads. A perfect power supply implies that the mains voltage should never be interrupted, its value and the frequency shall be within the allowable range specified by the applicable standards and have a perfectly/pure sinusoidal (wave) form without superimposed noises. The meaning of PQ has always been seriously paid attention to since the very creation of the power grids, but today, it is much more important due to two basic reasons. The latter can be said to be closely related to the existence of a great number of state-of-the-art types of loads, which, on one hand, need a high/good PQ, but on the other - they deteriorate it because of their inherent action. As an example, it will be enough to mention the electric arc furnaces in the metallurgical plants. There are plenty of human activities where the deterioration of the PQ is related to considerable financial losses, mainly, in the uninterrupted production processes. Another example is the short-time interruptions of the network voltage that can bring about substantial losses in glass-making and steel-making industries, as well as in telecommunications.

It is well known, each non-sinusoidal current is a sum of sinusoidal current with a mains frequency f (basic harmonic), as well as sinusoidal currents with frequencies nf, where n is a random positive integer (n-th harmonic). The flow of the harmonic currents in the network creates voltages with their frequency, i.e., the mains voltage also stops being sinusoidal. According to the studies cited in (Chobanov S., 2015), the harmful consequences caused by the presence of higher harmonics in the electrical networks are as follows:

- The existence of harmonics in the mains voltage leads to additional energy losses in the furnace transformers and to overheating of their windings (due to the impedance increase) and of the core (due to Foucault currents). The losses are roughly proportional to the square of the harmonics frequency and may be up to ten times greater than is the case with a mains voltage with a purely sinusoidal shape. The harmonics cause additional heating of the power cables too, but apart from this, they create unwanted vibrations that cause faster wear, resulting in cable breakdowns and reduced insulation resistance of the wires themselves.

- There are also changes that may set in in the cosø correction devices (17% probability). Because of the harmonics, the performance of the furnace transformers is deteriorated, and the correction is not effective enough. Damage to the coils can also occur when the harmonics frequency coincides with its resonant frequency.
- Switching on and off of heavy loads linked to the electric arc furnaces is associated with large pulse currents that generate significant voltage jumps up and down, especially for long connecting wires. The probability of disturbing the normal operation of the grid is 12.3%, while the reduction of this phenomenon needs resizing of the wires.
- If there are harmonics, the sum of their amplitudes may reach an order of magnitude equal to that of the fundamental harmonic/component and accidentally trigger protective relays or switches (probability 7.5%).
- The probability for the harmonics to interfere with the optimal use of the current-carrying networks is 3.6%, and a harmonics control should also be established on top of that of the reactive energy.

The voltage and current higher harmonics cause specific losses that, according to Kirov and Iliev (2017), can be examined from the following points of view:
- Additional power and electricity losses in case of higher harmonics;
- Additional cost of increased electrical equipment failure as a result of the accelerated aging of the insulation;
- Additional costs of disturbing the operation of the relay protections by reverse sequence currents and unbalanced capacitive currents in earth connections;
- Additional costs due to the negative influence of the higher harmonics on the operation of the communication and automation media.

In the metallurgical plant of *"Stomana Industry" SA*, there are currently two electric arc furnaces (EAF) and two ladle-furnace installations (LF). The electric capacity of the furnaces is respectively: EAF1 - 120 MW, EAF3 - 75 MW, and that of LF No. 1 – 18 MW and LF No.2 – 18 MW. The furnace transformers are supplied by a voltage of 35 kV from two power transformers 220/35 kV with power respectively 200 MVA and 180 MVA.

The main purpose of the experimental research carried out was to determine how the operation of the EAF and the LF influences the electric power quality parameters of the power transformers on the 35 kV and the 220 kV side. The results from the 35 kV network research are given in (Stoilov Iv., K. Dzhustrov, T. Nikolov, 2015). The results from the experimental studies on the 220 kV side are examined here.

## Experimental Studies

1. All experimental research has been performed with modern digital network analyzers FLUKE 437-II and FLUKE 435-II. The devices are connected to the secondary circuits of the measuring transformers.

Measurement accuracy class of the instruments:
- in terms of voltage - 0.1% of the nominal (1000V);
- in terms of current for the corresponding ammeter jaws - 2.0%
- voltage harmonics - 0.1% ± n. 0.1%, where n is the number of the respective harmonic;
- voltage THD (the voltage curve sinusoidality distortion factor) - ± 2.5%.

2. The measurements have been carried out simultaneously on the 220 kV and 35 kV side in the following technological modes:
- idle operation of the transformer 220/35 kV;- simultaneous operation of EAF No. 1 and LF-1.

All measurements of the electricity quality indicators have been performed according to the methodology formulated in IEC 61000-4-30:2008.

3. Cumulative results of the 220 kV side measurements under the simultaneous operation of EAF No. 1 and LF-1 for one heat processing period.

*3.1. Voltages in the three phases (Fig.1).*

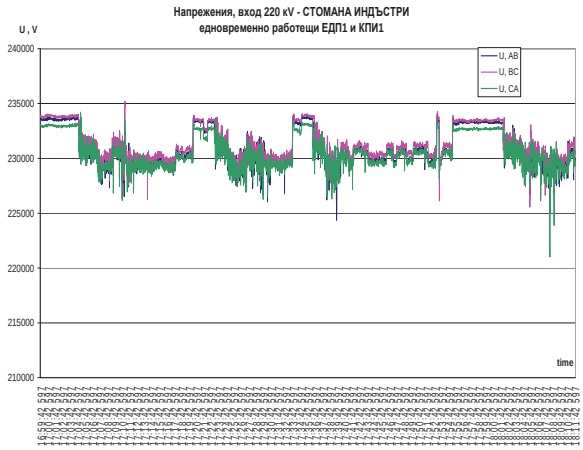


Fig.1. Voltages, 220kV input – STOMANA INDUSTRY, EAF1 and LF1 operating in parallel

The registered idle voltage of the transformer in the individual phases is in the range of 233 to 234 kV, the difference not exceeding 0.5%. During the operation of the electric arc furnaces, the voltage is relatively constant and with a value of about 230 kV. There have been registered short-term voltage peaks only at the moments of a sharp drop in current. The maximum registered value is 235.2 kV. The minimum recorded instantaneous voltage value during the heat process has been 221 kV. When both the electric arc furnace EAF No. 1 and LF-1 are in operation, the voltage quality indicators defined in EN 50160:2010 are not disturbed.

*3.2. Current loading (Figure 2)*

The records attached herein show the transformer current load on the 220kV side.

During the electric-arc melting, peak currents are recorded in one of the phases exceeding 350 A. Most of the time, the current ranges from 200 to 250 A.

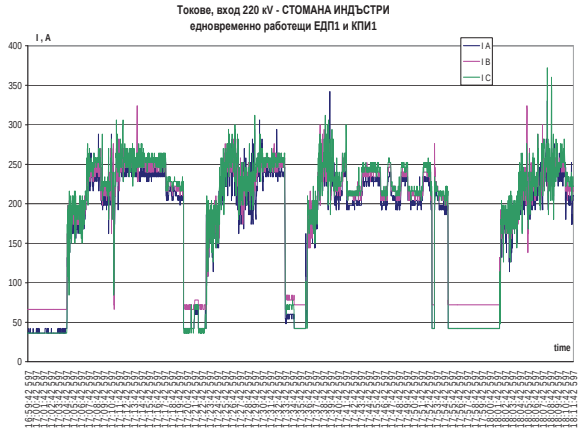


Fig. 2. Currents, 220 kV input – STOMANA INDUSTRY, EAF1 and LF1 operating in parallel

*3.3. Active and reactive power (Fig. 3).*

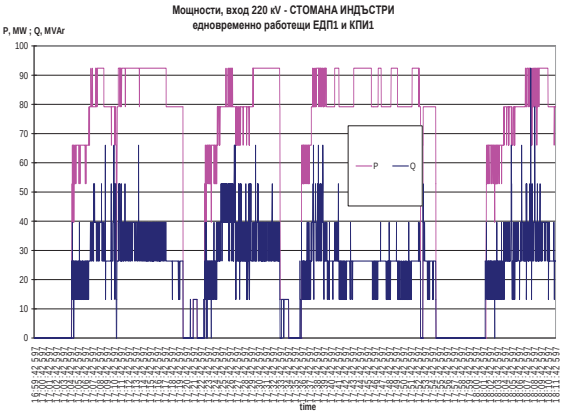


Fig. 3. Power values, 220 kV input – STOMANA INDUSTRY, EAF1 and LF1 operating in parallel

The change in the active and reactive power during the liquid bath smelting characterizes the variable power loads of the production facilities during the process. The maximum active power values do not exceed 93 MW.

*3.4. Power factor (Fig. 4).*

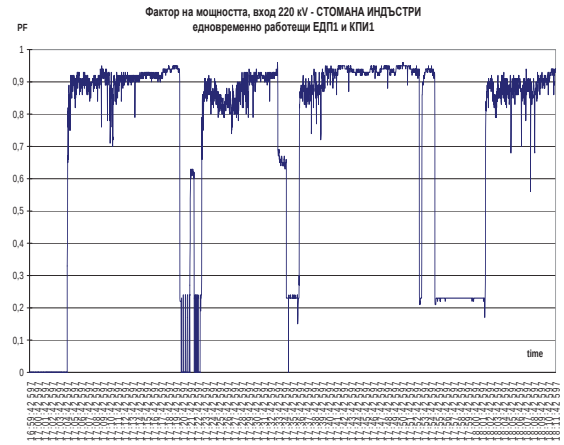


Fig. 4. Power factor, 220 kV input – STOMANA INDUSTRY, EAF1 and LF1 operating in parallel

The figure shows the operation of the compensating devices. There are time intervals in which the power factor is below the standard (normative) value of 0.9.

*3.5. Total factor of non-sinusoidality – THD (total harmonic distortion factor in %) (Fig. 5).*

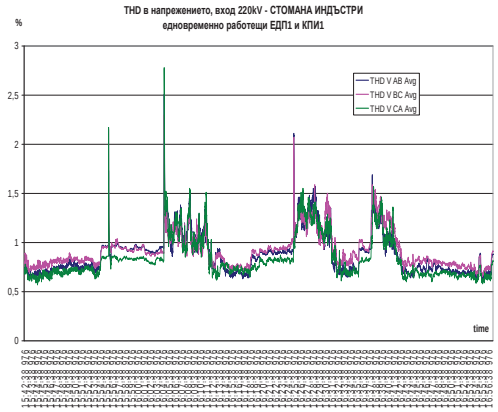


Fig. 5. Voltage THD, 220 kV input – STOMANA INDUSTRY, EAF1 and LF1 operating in parallel.

According to the requirements of standard EN 50160:2010, the total harmonic distortion factor (THD) in the 220 kV voltage supply networks shall not exceed 2,0%. From the recordings carried out, it can be seen that during the smelting process the THD ranges from 0.6% to 1.5%. Three cases were registered during the recording, in which short-term (about 5 s) THD values exceeded the normative ones: 2.77%, 2.17% and 2.11%. Since the standard EN 50160:2010 specifies the THD values as average within a 10-minute interval, one can positively claim that the parallel operation of EAF No. 1 and LF-1 does not disturb the 220 kV system voltage with higher harmonics.

*3.6. Mean values of the harmonics up to No. 50 for the entire period of the heat process (Fig.6).*

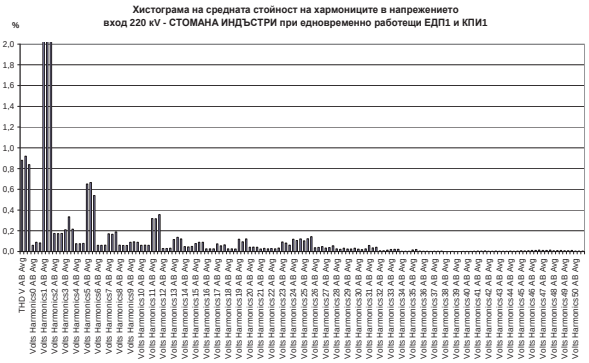


Fig. 6. Bar chart of the mean value of the voltage harmonics - 220 kV input – STOMANA INDUSTRY, EAF1 and LF1 operating in parallel

From the histogram (bar graph) attached herein, the values of the higher harmonics are recorded as averaged for each single phase of the heat-processing period. The total harmonic distortion factor THD (also called the voltage waveform distortion factor) for the three phases has values of 0.88, 0.92,

and 0.84. The highest values belong to the 5th harmonic - 0.66%, followed by the 11th - with 0.36%, the 3rd - with 0.33%, the 7th - with 0.19% and the 2nd - with 0.17%. All registered values of the higher harmonics are significantly lower than those specified as acceptable in the EN 50160:2010 standard.

*3.7. Phase A harmonics from the second to the seventh for the entire measurement period (Figure 7).*

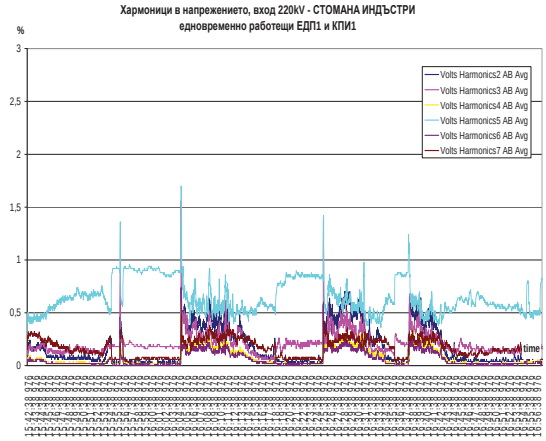


Fig. 7. Voltage harmonics - 220 kV input – STOMANA INDUSTRY, EAF1 and LF1 operating in parallel

It is evident from the record attached herein, that, for the heat-processing period, the momentary values of the quoted harmonics do not exceed the individual coefficients specified in EN 50160:2010. There are two moments recorded, in which the 3rd and 5th harmonic exceed the factor of 1.5% as allowed by the standard above. These unit values have a duration of less than 6 seconds and reach: the 5th - 1.7% and the 3rd - 1.56%. Since the standard specifies the individual coefficients of non-sinusoidality as mean values within a 10-minute interval, apparently, the individual harmonic factors can also be deemed as not infringing the normative requirements.

## Conclusion

1. Experimental data have been obtained for the voltage quality indicators at the level of 220 kV during the heat processes conducted in the electric arc furnaces (EAF) and the ladle-furnace installations (LF) at *"Stomana Industry" SA*, involving different modes of operation of the furnace transformers;
2. The nature of the current load in the three phases during the smelting process of one heat has been determined;
3. The loading diagram has been registered in terms of active and reactive power at 220kV for a single smelting process.

The main conclusion from the research conducted is that the simultaneous operation of the electric arc furnace (EAF) and the ladle furnaces (LF) in "*Stomana Industry" SA* does not generate unacceptable values in the quality parameters of the electrical energy in the system voltage of 220 kV. On the basis of these results, the entity "*Stomana Industry" SA* has been designated for the so-called "tertiary" production facilities control in the electric power system of the country.

## References

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