# Electromagnetic compatibility of receivers in the power supply system with induction heating units

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**Abstract**. The problem of electromagnetic compatibility of users that have a mutual supply center is examined. On the basis of field studies, the levels of higher harmonic components of current and voltage were determined at an operating steel plant with induction heating electrical installations. Simulation model of steel plant with electrical installations of induction heating is presented, which includes controlled filter-compensating devices and fuzzy logic controller, for which product rules of fuzzy interference are formulated. It is shown that the use of a fuzzy logic controller allows limiting the level of higher harmonics of current and voltage during operation of the induction furnace.

## 1. Introduction

At present, electric induction heating installations (EIHI) are widely used in modern industrial enterprises for surface hardening, bending and heat treatment of machine parts, quenching of complex-shaped parts, etc. High-frequency generators based on thyristor converters consuming nonlinear current from the network and distorting sinusoidality of supply voltage are used to create electromagnetic field.

The nonsinusoidal modes adversely affect operation of power electric equipment, the systems of automatic equipment, telemechanics and communication. During the operation of synchronous, asynchronous motors and other electric units in the conditions of nonsinusoidal tension, additional power losses caused by the higher temporary harmonics of current appear.

Electromagnetic Compatibility (EMC) studies in Industrial Power Supply System (IPSS) with EIHI are relevant, as the works of I.V. Zhezhelenko [1-3], J.S. Zhelezko [4], M.P. Bader [5], Dovgun [6-7], etc., are devoted the problem of EMC in IPSS. In these works, the nature of generation of higher harmonics into the power line, their influence on the network elements are revealed, and control systems of filter compensating devices are developed to limit higher harmonics of current and voltage of nonlinear electric receivers with a wide range of loads.

## 2. Methods

In an electrical supply system of the steel plant (Figure 1) the receivers forming linear and nonlinear loadings are presented. Besides, the responsible receiver having the high-precision medical equipment, crucially sensitive to changes of the parameters of quality of electrical energy (PQE) regulated by IEC60601-1[8] is connected to section of buses. The existing scheme of power supply essentially

(without installation of additional specialized equipment) does not allow to provide the stated requirements of PQE.
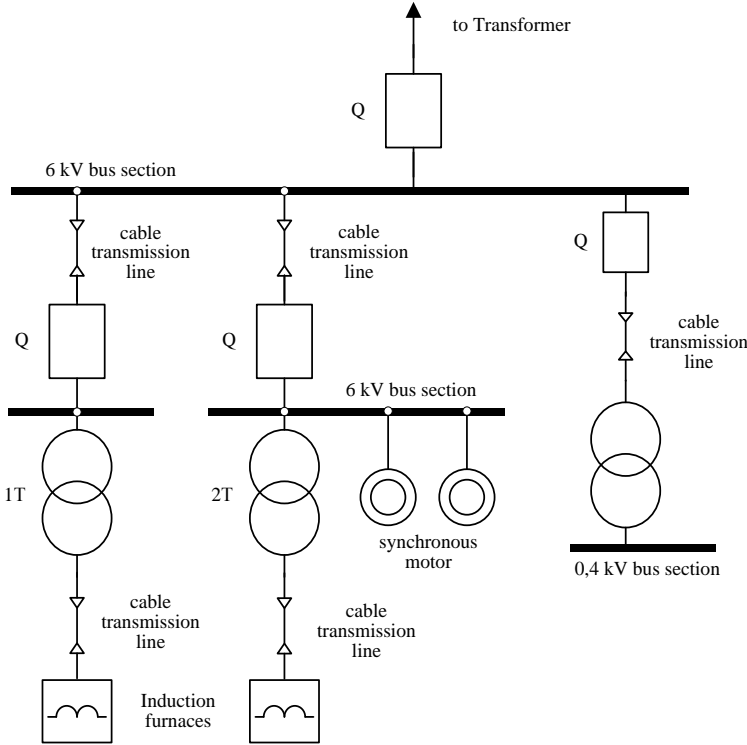


**Figure 1.** Schematic diagram of the equipment of the power supply system of the steel plant

Installation of controlled filter compensaing devices (PKU) will solve this problem. Determination of installation sites, power and other parameters of PKU should be carried out on the basis of simulation modeling and field studies, which are necessary to assess the adequacy of the model.

*3. Field studies*

Field studies were conducted by passive experiment using a fleet of certified PECYPC-UF2M PKU analyzers in accordance with IEEE Std. 519-1992 IEEE "Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems" [9]. Connection diagram of the device is shown in Figure 2.
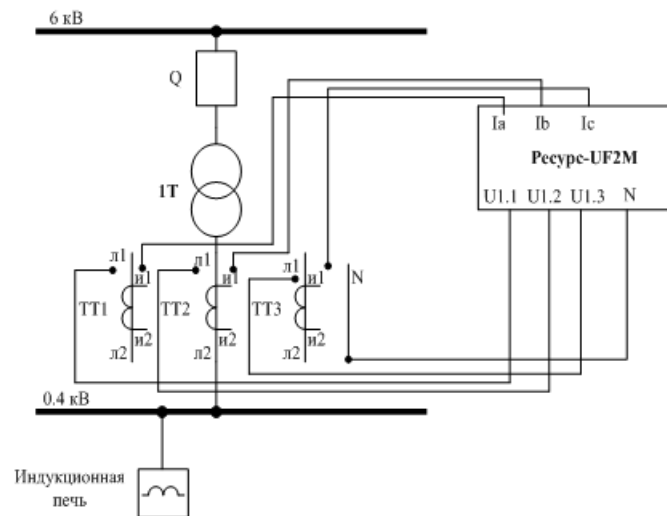
**Figure 2.** Device connection diagram

*4. Simulation modeling*
Simulation modeling is performed in a software package MatlabSimulink using a SimPowerSystems library. A model of power supply system of steel plant with EIHI is obtained, which includes PKU tuned to 5 and 7 harmonics and using fuzzy logic regulator (1) (Fig. 3), operation of which is based on Mamdani algorithm.

For management of logic of operation of the controller, taking into account features of system operation of power supply, the array of rules was created:

1. If total coefficient of non-sinusoidality - min, coefficient of nth harmonic component by 5-th harmonic - min, then distortion level - low, Control PKU — Disable all.

2. If coefficient of the nth harmonic component by the 5-th harmonic is - middle, the distortion level - medium, Control of PKU - Switch PKU to the 5-th harmonic.

3. If coefficient of the nth harmonic component by the 5-th harmonic is - middle, the distortion level - medium, Control of PKU - Switch PKU to the 5-th harmonic.

4. If the total coefficient of non-sinusoidality - middle, coefficient of the nth harmonic component by the 5-th harmonic - min, then the distortion level - medium.

5. If the total coefficient of non-sinusoidality - max, coefficient of the nth harmonic component by the 5-th harmonic is - mid, then distortion level - high, Control of PKU - Enable all.

6. If total coefficient of non-sinusoidality - max, coefficient of nth harmonic component by 5-th harmonic is - max, then distortion level - high, Control of PKU - Enable all.
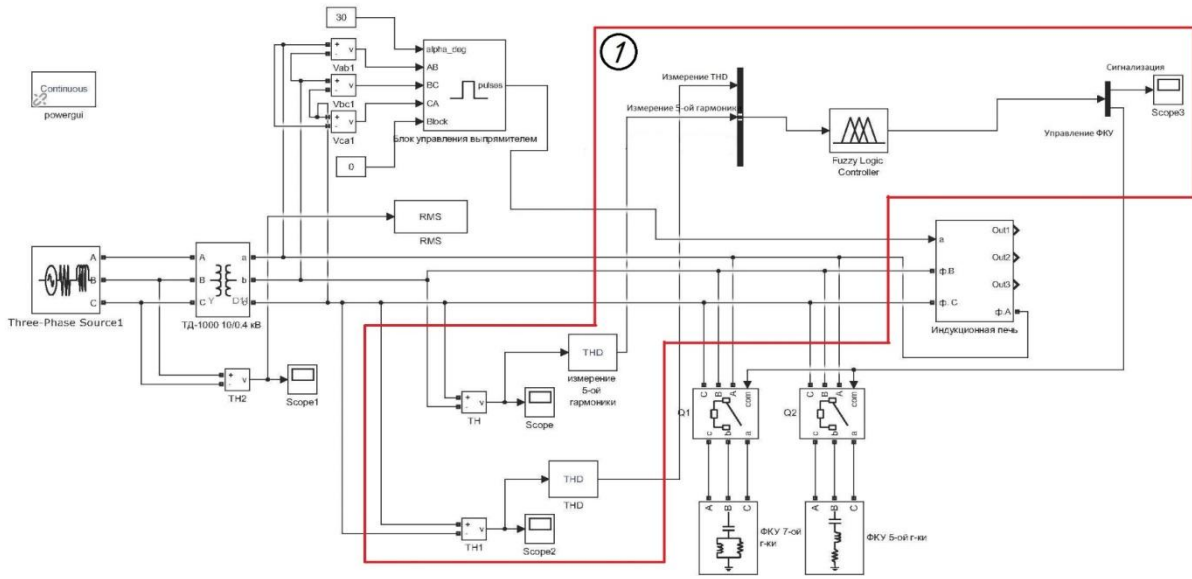
**Figure 3.** Simulation model of the power supply system of a steel plant.

## 3 Results and Discussion

As a result of the field studies, the dependancies of short-term dose of flicker on the time for each phase are acquired (Fig.4), the coefficient of the nth harmonic component at the connection point of the device (Fig.5).
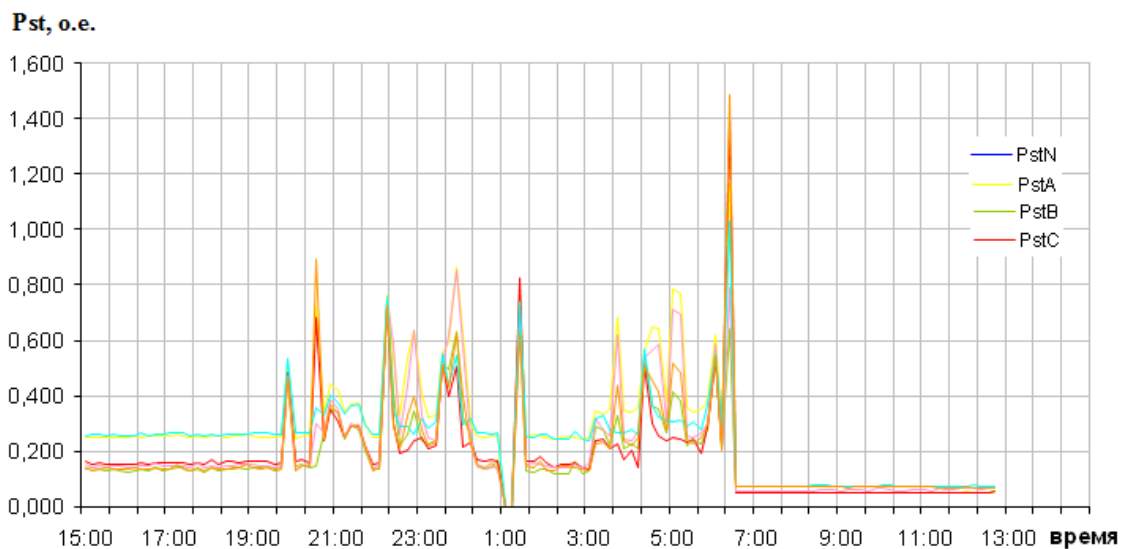


**Figure 4.** Graph of a short-term dose of flicker for each phase

It can be seen from the graph (Figure 4) that at the moment of furnace shutdown - the moment of metal melting stop - (time 6:20-7:00 in Figure 4) the short-term dose of flicker does not comply with the standard values.
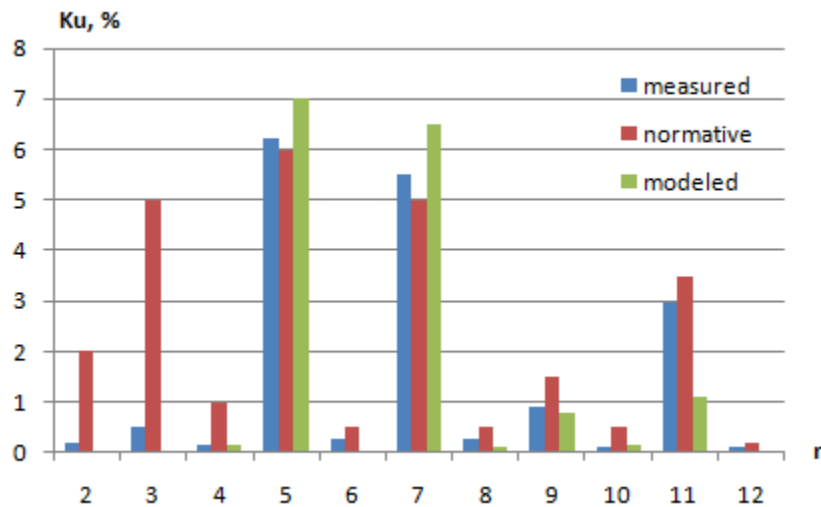
**Figure 5.** Histogram of the nth harmonic component of the voltage at the connection point of the device

It can be seen from the histogram (Fig.5) that at the moment of induction furnace operation, in the power supply system the coefficient of n-th harmonic component of voltage on 5-th and 7-th harmonics goes beyond the permissible limits. Apart from odd harmonics not multiple of three, even harmonics are present. This is due to the interference generated by adjacent electric receivers, which causes additional losses and heating, as well as accelerated aging of insulation of electrical equipment, and also has a negative impact on the operation of various types of electrical equipment.

Thus, the presence of higher harmonic components of currents and voltages in the power supply system of the steel plant has been experimentally confirmed. It has been established that the 5th and 7th harmonics of stresses are the most pronounced. The total coefficient of harmonic components of voltages reaches on average, respectively THD = 11%.

PKU parameters for 5 and 7 harmonics were calculated, the results are summarized in Table 1.

**Table 1.** Parameters harmonic filter

| Harmonica number | Power of PKU, kVAr | Power of PKU, taking into account decrease of mains voltage, kVAr | Capacitive resistance of PKU on nth harmonic, microfarad | Capacitor resistance, Ohm | Inductance of a throttle, H |
|---|---|---|---|---|---|
| 7 | 57,363 | 47,611 | 15 | 30,33 | 0,014 |
| 5 | 90,85 | 75,41 | 33,26 | 19,15 | 0,012 |

As a result of simulation the oscillogram of linear stress on the party of 0.4 kV of the oven transformer (Fig. 6) and harmonic network analysis of tension (Fig. 7) is received.

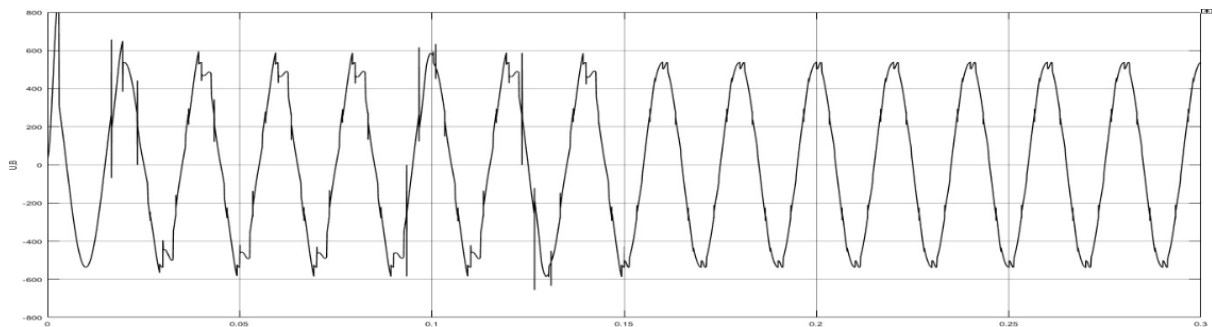In timepoint 0.15 sec., the fuzzy logic controller gives a command for inclusion of PKU on 5th and 7th harmonics.

**Figure 6**. Oscillogram of the line voltage of 0.4 kV furnace transformer after installing the PKU

From the given harmonic network analysis (Fig, 7) it is obvious that after inclusion of PKU the total coefficient of non-sinusoidality decreased to THD=3.87% which justifies use of the fuzzy logic controller.
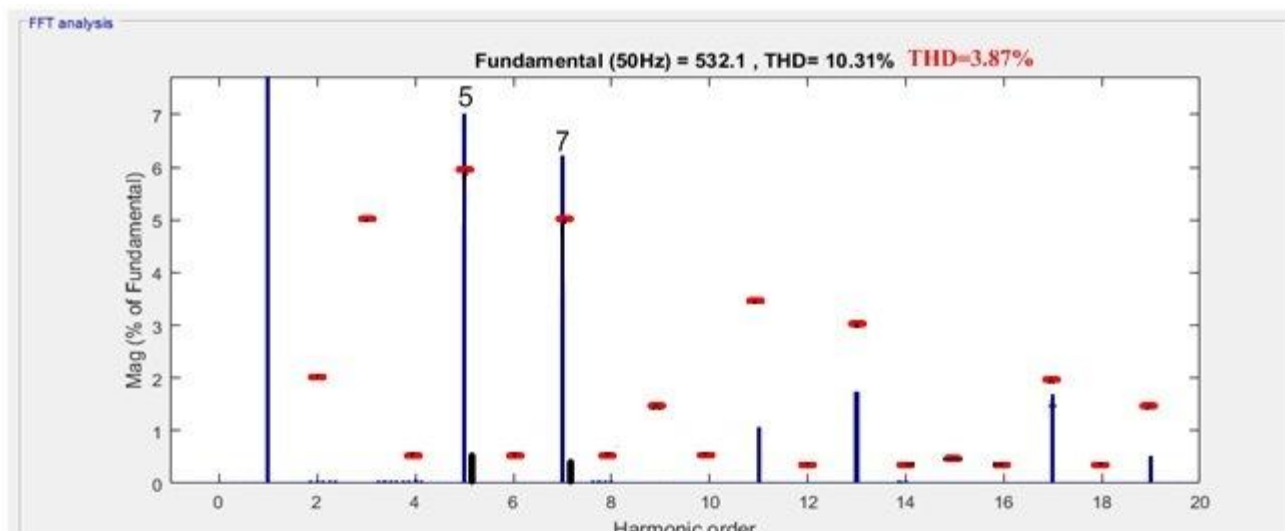

**Figure 7.** Harmonic network analysis after installing PKU

## 4. Conclusions

Analysis of electromagnetic situation showed that non-sinusoidal modes of operation in power supply systems of steel-industrial enterprises with EIHI, caused by powerful non-linear electric receivers, lead to significant negative consequences, the main of which are accelerated wear and failure of electrical equipment and networks, additional power and electric power losses in the elements of the power supply system.

The field study confirmed that during the work of EIHI with thyristor frequency converters, the sinusoidalnost of power voltage is considerably distorted.

The obtained simulation model of the power supply system of the industrial enterprise with EIHI included into MatlabSimulink allowed to estimate the level of distortion of voltage sinusoidality.

The created base of productional rules for the fuzzy logical regulator allowed to carry out decision-making support by the controller about control action.

It is established that use of the developed indistinct logical regulator in SES of the steel plant with electric units of induction heating allows to connect timely PKU configured on the frequency of 5 and 7 harmonics for restriction of the negative effects arising during the operation of the induction furnace.

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