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DESIGN OF C-TYPE PASSIVE FILTER FOR ARC FURNACES

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The article presents an example of power supply system modernization in one of Polish steelworks. For the existing power system containing 3rd harmonics filters it was necessary to design a C-type filter for the 2nd harmonics. Two design methods have been presented. The first method is based on the assumption concerning the desired harmonic current flow of filter adjustment between the filter and power grid. The second method was based on using a genetic algorithm, searching for the R_T resistance value of the filter. Applying the genetic algorithm makes it possible to take into account the broad spectrum of the electrical environment where the filter will be working.

Key words: steelworks, arc furnace, electrical energy, filters, genetic algorithm

INTRODUCTION

One of the important factors affecting the production costs is the cost of electric power. Hence the need for rational electric power management and attention to energy efficiency [1]. Basic parameters of electrical power are defined by PN-EN 50160 [2] standard.

In large, non-linear loads of electrical power, namely steelworks arc furnaces, it is essential to compensate reactive power and reduce voltage distortion represented by a voltage harmonic content factor (THD_U) and individual harmonic content below values provided in the standard. The simplest method to improve power quality parameters is the use of passive power filters[3].

In order to increase production capacity, one of arc furnaces was replaced with a new 140 Mg / 30 kV one. It was necessary to re-design the power system in particular, because reactive power in the system increased and voltage harmonic contents changed.

THE FURNACE POWER SUPPLY SYSTEM

Table 1 presents voltage harmonics in the system at the PCC during operation of the furnace itself and the furnace with two filters of the 3rd harmonic.

On the basis of data in table, THD_U factors were determined for operation of the furnace itself (10,54 %) and in the case of the furnace with filters of the 3rd harmonic (7,68 %).

A significant reduction in the 3rd harmonic and consecutive harmonics is seen. However, attention should be paid to the 2nd harmonic. Its amplitude is enhanced above the limit value given in the standard.

Table 1 **Voltage harmonics in % at the 30 kV side**

n	2	3	4	5	6	7	8	9	10
Furnace	1,74	6,35	1,64	6,3	1,12	4,29	0,99	2,25	1,24
Furnace +2xF3	2,44	0,57	0,94	4,15	0,77	3,04	0,71	1,63	0,91
n	11	12	13	14	15	16	17	18	19
Furnace	2,23	0,75	2,1	0,87	1,62	0	0,95	0	0,96
Furnace +2xF3	1,63	0,55	1,55	0,64	1,20	0	0,70	0	0,71

Two 3rd harmonic filters compensate reactive power of 40 Mvar completely. In the system with the new furnace, it was insufficient. Additional reactive power of 20 Mvar appeared in the system and the new filter will have to compensate it.

Figure 1 presents the power supply system of the new arc furnace along with the designed additional 2nd harmonic filter.

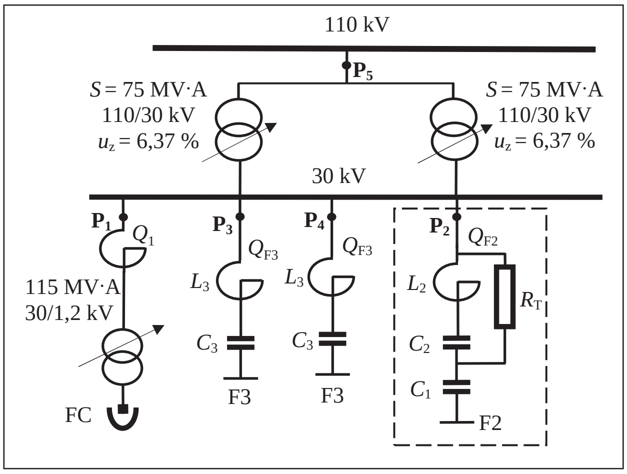

Figure 1 Diagram of arc furnace power supply system

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DETERMINATION OF THE C-TYPE FILTER PARAMETERS

In [4, 5] a method of designing the C-type filter is proposed, based on the assumption about the harmonic current flow of filter adjustment between the filter and power grid (1).

$$C_1 = \frac{-Q}{\omega_1 U^2}, \qquad C_2 = C_1\left(n^2 - 1\right),$$
$$L_2 = \frac{1}{\omega_1^2 C_2}, \qquad k = \frac{I_S(n)}{I_F(n)} \tag{1}$$
$$R_T = \frac{U^2}{\omega_1 L_S k\, n^3 Q^2}\sqrt{\left(U^4 - \omega_1^2 L_S^2 k^2 n^4 Q^2\right)} \qquad 1$$

where:
ω_1 – the basic harmonic pulsation,
U – filter operation voltage,
n – harmonic order of filter tuning
k – the assumed harmonic flow ratio,
Q – the C-type filter reactive power,
L_S –the equivalent inductance of the power grid,

Table 2 presents information of power supply system and the design requirements:

Table 2 **Power supply system requirements**

Network	3rd harmonic filters	C-type filter
U = 30 kV S_z = 916 MV×A L_s = 3,129 mH	Q_3 = -20 Mvar L_3 = 18,48 mH C_3 = 63 μF n_r = 2,95	Q = -20 Mvar n = 1,95 k = 1

The C-type filter parameters determined from (1) are: C_1 = 70,736 μF, C_2 = 198,24 μF, L_2 = 51,11 mH, R_T = 276,86 Ω.

Several methods of determining the C-type filter parameters were described in literature [6 – 9]. They differ primarily in the method of calculating the resistance value R_T. Increasing the resistance value results in better filtration of the tuning harmonic, but high harmonics attenuation is deteriorating. Thus, it is necessary to find a compromise between the effectiveness of a selected harmonic and high harmonics attenuation.

Genetic algorithms as an optimization method are applied including passive filters [10, 11], production planning [12] and predicting mechanical properties of the casts [13].

OPTIMISATION OF R_T USING GENETIC ALGORITHM

One of the possibilities to obtain a compromise described above is to use a genetic algorithm (GA) whose purpose is to determine the resistance value R_T.

The purpose of the GA is to continuously improve the population of potential solutions through the use of operators modeled on nature – selection, crossing and mutation. Each successive generation produces individuals for whom the value of the objective function determines the better usability of an individual.

In the presented example, the purpose is to reduce the 2nd voltage harmonic to the relative value of 1,22 %.

The value of the 2nd voltage harmonic after connecting C-Filter and two 3rd harmonic filters is determined by the dependence:

$$U_2 = \left|\frac{\underline{Z}_{X(2)}}{\underline{Z}_{S(2)} + \underline{Z}_{X(2)}}\right| U_1 \tag{2}$$

where:
U_2 – the 2nd voltage harmonic after connecting all filters
U_1 – the 2nd voltage harmonic without filters
$\underline{Z}_{S(2)}$ – the equivalent impedance of the grid for the 2nd harmonic
$\underline{Z}_{X(2)}$ – the equivalent impedance of all filters combined in parallel.

The filter C_1, C_2 and L_2 parameters are specified by formulas (1), while the resistance value R_T will be sought with the use of the GA. The objective function for the GA is (3):

$$f_{goal} = |\,1{,}2 - U_2\,| \tag{3}$$

Range of variation of decision variables under the terms of the task: R_T = (0 - 10^3).

Genetic Algorithm parameters [14]:

- parameter is coded in a string of 30 bits,
- populations of 100 individuals,
- crossing probability p_k = 0,7,
- mutation probability p_m = 0,01,
- condition of termination - 100 generations,
- ranking with the factors: C_{min} = 0, C_{max} = 2,
- selection - stochastic universal sampling SUS,
- crossing the shuffle.

The GA constructed in such a way obtained the resistance value R_T = 328,86 Ω. The obtained resistance value is greater than in the case of using formula (1), because AG was based on real measured values of the voltage harmonics made before designing the C-type filter.

Figure 2 shows frequency characteristics of: the network, the resultant impedance of the network and two 3rd harmonic filters, and the resultant impedance of the network, two 3rd harmonic filters and the C-type filter.

Data listed in Table 3 demonstrate that connecting the C-type filter results in the expected reduction of the 2nd voltage harmonic in the supply system, whereas other harmonics are reduced to a small extent.

Table 3 **Voltage harmonics without and with filters**

n	2	3	4	5	6	7	8	9	10
Furnace +2xF3+FC	1,22	0,56	0,90	3,96	0,74	2,90	0,68	1,56	0,87
n	11	12	13	14	15	16	17	18	19
Furnace +2xF3+FC	1,56	0,53	1,48	0,61	1,15	0	0,67	0	0,68

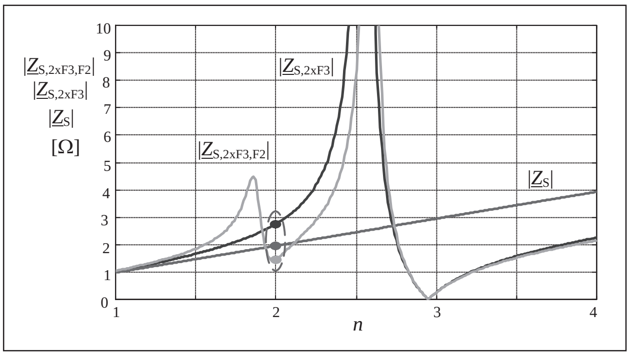

Figure 2 Frequency-impedance characteristics seen from the load side

CONCLUSIONS

The article presents the method of the C-type filter parameters determination, considering the equivalent impedance of the power grid and with the assumed degree of the filter tuning harmonic reduction and an alternative method using Genetic Algorithms, whose purpose is selection of resistance R_T. The advantage of the second method is the possibility to take electrical environment, in which the designed filter is to operate, into account. The obtained resistance value is greater than in the first method due to the measured real values of voltage harmonics in the system.

The measurements which have been carried out after the installation of the C-type filter show that the C-type filter performance has met the requirements, i.e. it attains the expected reduction of reactive power, ensures the second harmonic reduction in the power system and harmonic distortion THD_U reduction by means of high harmonics mitigation.

The obtained reactive power and high harmonics reductions result in lower production costs due to lower electrical power costs. Also the load of the power line and devices connected to it undergoes reduction. It is also important to lower the risk of failure occurrence due to the poor quality of electrical power, that is the possibility of an emergency interruption in production and bearing the costs of repairs.

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Note: The responsible translator for English language is Marcin Zimny, Krakow, Poland