Energy Efficiency Improving of Reactive Power Compensation Devices

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***Abstract*— The article describes a method for reducing the influence of the high harmonics on the operation of reactive power compensation devices. This method based on the variation of the power system resistance and the separation of linear and nonlinear loads. The resistance of the power system within the considered plant is proposed to change by replacing the double-winding transformer to split-winding one. Current harmonic composition data are obtained by measurements at an aluminum plant. In this work calculations of the necessary extent of the system resistance have been made to reach allowed current values on capacitors. The constructed graphs allow to determine the zone of the possible system resistance variation in which the capacitor batteries operate without overloads. Algorithm of methods to reduce high harmonics is used by means of the given criterion.**

Keywords*— Power system resistance, high harmonics, energy saving, energy efficiency, reactive power compensation, transformer, power supply network, nonlinear load.

I. Introduction

At present nonlinear receiving terminals are a major part of electric load of industrial enterprises among which a frequency-controlled drive, loads controlled by thyristors and nonlinear single-phase receiving terminals could be given accent to [1, 2, 3]. The watt consumption of this type is comparable to the total power demand of the enterprise. Metallurgical plants are a shining example of such kind of enterprises where the ratio of nonlinear load is as much as 50%. Nonlinear load exploitation is accompanied by high harmonics generation, which results in voltage and current curves distortion. Reactive power compensation devices are used to reduce power losses in electrical networks of industrial enterprises. A bank of capacitors, intended for reactive power compensation, are known to be the most vulnerable receiving terminal concerning high harmonics. Condenser batteries operation is violated in the presence of high harmonics and the requirements for saving energy are not fulfilled.

Reduction of the high harmonics level in the enterprise network leads to energy savings, which consists not only in reducing active power losses due to the decrease of the rms value of the current, but also by increasing the efficiency of reactive power compensation devices. A capacitor banks downtime due to their damage by high harmonics leads to increased power losses and increased payment for reactive power [4, 5].

There are different kinds of facility which render possible minimizing generated high harmonics among which mention should be made of: the application of filter compensating devices and active filters; effective flowcharting of electric supply, the use of series compensation devices [6, 7, 8].

Filter compensating device is a simple enough device which is composed of a series-connected reactor and condensers. It is not an automatically controlled device, consequently when there is a change of load configuration and, as a consequence, the change of harmonic configuration of voltage and current curves, it is impossible to secure automatic neutralization of high harmonics in a necessary volume with the help of this device.

Active filters are the most modern devices aimed not only at improving electric energy quality from the point of view of high harmonics, but at increasing capacity ratio of electric circuits as well. The filters possess two main disadvantages, viz a high price and absence of constructions meeting their operating conditions in circuits of 6-10 kV.

Apart from these methods minimization of high harmonics is possible due to a decrease of the precircuit resistance (as a rule, it is a power system resistance). It is known, that high harmonics in the bus sections appear as a consequence of the tension drop in the system resistance in the mains of industrial enterprises including metallurgical ones. It follows thence, that a decrease of the system resistance results in a decrease of the influence of high harmonics on the electric equipment operation. It should be noted that this conclusion is valid, if the source of the high harmonics is not the feeding network [3].

As we can see, each of mentioned means possesses its pros and cons. To choose the most rational of them is a complicated enough task, as besides the economic efficiency there is no other criterion, which could be put into grounds of such a choice. We propose an option and argumentation of the criterion selection, by which a rational means to decrease a high harmonics effect on electric-technical complex operation of the industrial enterprise can be defined.

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II. METHOD

According to technical conditions of the duty of the capacitor banks, adopted in the majority of European countries (Russia is among them), the overloading ratio of the condenser by the high harmonics current is found by the value:

$$F_{ovl} = \sqrt{\sum_{\nu=1}^{n} I_{\nu}^{2}} / I_{dcb} \leq 1.3\,, \quad (1)$$

where I_ν – rms current of ν-harmonics; I_{dcb} – design current of the battery; n – index number of the last of relevant harmonics.

The power quality is defined by the grade of correspondence of parameters of electric power to their values, established by standards. So, one of indicators of the power quality is a total harmonic distortion THD and its value for the 10 kV mains under examination can not exceed 5%. The THD is found according to the formula:

$$THD_U = 100 \cdot \sqrt{\sum_{\nu=2}^{n} {U_\nu}^2} / U_{dvm}\,, \quad (2)$$

where U_ν – rms value of voltage of ν-harmonics; U_{dvm} – design voltage of the mains; n – index number of the last relevant harmonics.

The investigation was carried out at an electrical installation of the aluminum production plant, its simplified circuit being given in Fig. 1, where PTL is a power transmission line; Tp1 is a double-wound transformer; CB is high-voltage bank of capacitors; AE is an equivalent linear load of the enterprise; SH is an equivalent nonlinear load (a source of high harmonics).

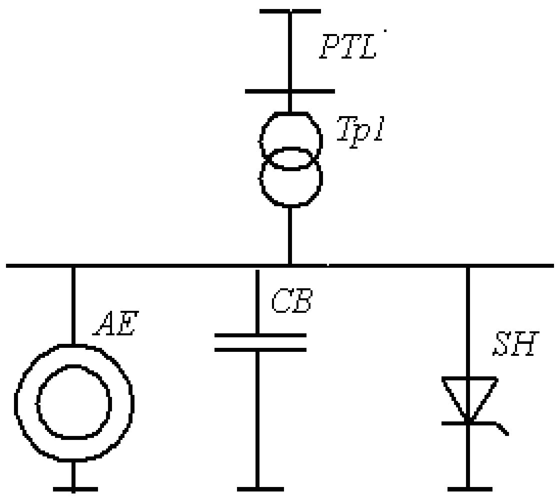

Fig. 1. Single-line schematic circuit diagram

Sources of high harmonics are converter thyristor systems which covert alternative current into direct one for electrolytic furnaces for the production of aluminum. Current harmonic composition data in the buses of the converter substation are given in Table 1, where v is harmonic number, and I_v – current of the relevant harmonic. The active power of linear load P_E =5500 kW, the reactive power Q_E = 4100 kVAr; the capacity of capacitor banks Q_{CB} = 4100 kVAr.

TABLE I. CURRENT HARMONIC COMPOSITION DATA

v	1	5	7	11	13	17	19	23	25
Iv, A	1857	75.9	25	52	37.1	14	15	14	14.3

The relevant single-phase schematic circuit diagram of the equivalent circuit is shown in Fig. 2, where U_0 – phase voltage of the source of the involved circuit; R_E – active resistance; $\nu{\cdot}X_E$, $\nu{\cdot}X_S$, X_{CB}/ν – reactive resistances on ν-harmonic AE of the system and capacitor bank respectively; $I_0(\nu)$ – current component of ν-harmonic. The parameters of I_0 are given in Table 1. The parameters of the equivalent circuit were determined as follows:

$$X_{CB} = U_{dv}^{2} / Q_{CB}; \quad X_S = X_{Tr} + X_{PTL}\,. \quad (3)$$

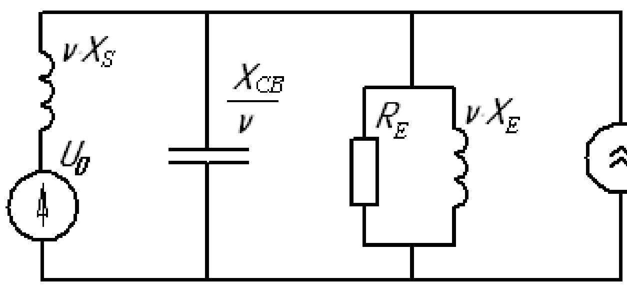

Fig. 2. Equivalent circuit diagram

For the equivalent circuit calculations the superposition method is applied, in this context inductive resistances on v-harmonic increase by in v-times, and capacitive impedances decrease by v-times. As a result of calculations currents through CB and the voltage with regard of each harmonic are determined.

III. RESULTS AND DISCUSSION

The calculations have shown, that condenser batteries face a problem of overloading in current that arise from unilateral load for its accepted parameters which is equal to 41% the latter exceeding significantly the allowed value of 30%. The THDU amounts as much as 5.25%, which exceeds the value of this parameter allowed by the Russian Government Standard as well.

While comparing harmonic currents on capacitor banks with different values of resistance of the system (XS) it was established, that when the given resistance decreased harmonic currents on CB considerably diminished, and when the former increased the latter grew too. Such conclusion is valid, if the source of the high harmonics is not the feeding network [3].

One of the means to decrease the system resistance is separation of linear and nonlinear loads according to sections by replacing of a double-winding transformer for a triple-winding one as is shown in Fig. 3, where Tp2 – triple-winding transformer.

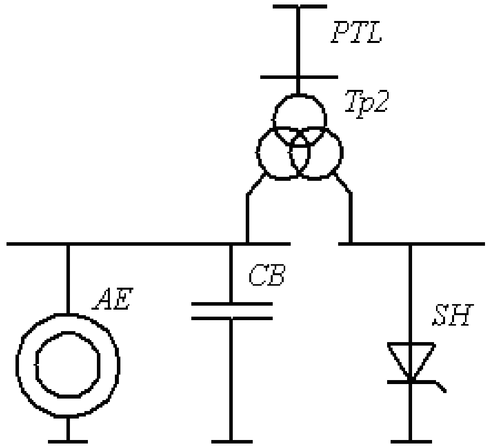

Fig. 3. Single-line schematic circuit diagram with load separation

The resistance of the secondary transformer winding Tp2, into which nonlinear load is tapped is not taken into consideration when calculating eventual results as it does not influence on the harmonic composition of the voltage in the section with linear load. Thus, the system resistance decreases and therefore decreases the voltage drop on Xs from high harmonic, which in its turn induces a current overloading in capacitors.

The transformed design circuit is presented in Fig. 4, where $\nu \cdot X_{T1}$, $\nu \cdot X_{T2}$ is reactive resistance of the secondary winding on ν-harmonic of Tp2 transformer.

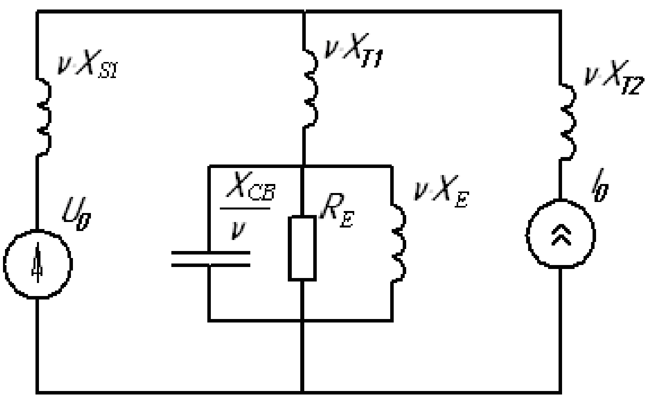

Fig. 4. Equivalent circuit diagram with triple-winding transformer

While designing the given circuit by the superposition method the values of harmonic currents have been found on CB and voltage on the buses of the enterprise. From the obtained data it follows, that when of the double-winding transformer is replaced for the triple-winding one of the equivalent power and if loads are separated the current on the capacitor banks decreases and doesn't achieve a maximum permissible value. In conditions of the enterprise under examination the overloading in current make up a magnitude of 23% and the THDU is 3.56%. Thus, the proposed method can be effectively used to suppress high harmonics in the electric circuit.

When calculating the overloading factor of capacitor banks should be noted the possibility of a voltage resonance between the capacitor resistance and the system resistance. To avoid such processes it is necessary to use antiharmonic reactors to protect capacitors.

For conditions to be examined in the paper there have been made calculations of the necessary extent of the system resistance decrease (Xs) to reach allowed values of current on capacitors. With this object in mind we have constructed a dependence of the capacitor`s overloading factor from the system resistance, presented in Fig. 5.

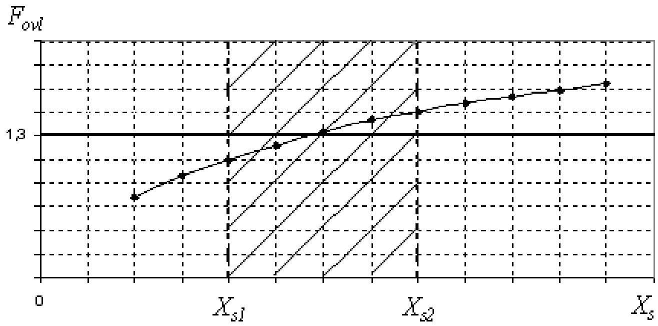

Fig. 5. Dependence of the capacitor`s overloading factor from the system resistance

From the obtained dependence it is seen that when the system resistance decreases the overloading factor in the current of CB decreases practically according to linear law. On the grounds of the obtained dependence it is impossible to draw a generalized conclusion about the regularity of overload factor changes from the system resistance. For that we need additional theoretical and practical investigations. Nevertheless, it is evident, that when one has such kind of dependence we can determine the expediency of application of one or another method of reducing the high harmonics influence on the electric equipment of the industrial enterprise with capacitors.

The criterion in this case is positioning of the dependence zone $F_{ovl} = f(X_s)$, limited by allowed overloading into the zone of possible system resistance changes. The illustration of the application of the mentioned criterion is given in Fig. 5.

IV. CONCLUSIONS

In this case as applied to the metallurgical enterprise having evaluated due to the proposed criterion the necessary reduction of the system resistance, it is possible to select a method to secure the necessary quality of electric energy. According to the logic of the disposed material the choice of these methods are to correspond to the following algorithm:

1. Define the dependence $F_{ovl} = f(X_s)$.
2. Determine the zone of the possible change of the system resistance with the help of separation of linear and nonlinear loads, having replaced the transformer at the electric circuit terminal.

3. In the case of insufficiency of the obtained zone at the transformer replacement define the possible zone with application of series compensation devices.

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