

# Analysis of nonlinear load influence on operation of compensating devices

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**Abstract.** The paper presents the results of studies to detect the location of the high harmonics distortion source relative to the connection point shared by consumers. The developed method is rather simple to use at an industrial enterprise, since it does not require the connection of additional measuring devices and is based on the assessment of the capacitor banks overload with antiharmonic reactors depending on the system resistance. The change of the system resistance can be carried out by switching branches on the windings of transformers and assessment of capacitor banks overload via using built-in reactive power controllers.

## 1. Introduction

Currently, the electric power quality parameters have a significant impact on the operating conditions of electrical grid and technological equipment [1, 2, 3]. When such parameters are beyond the acceptable limits, it results in a reduction of manufacturing products quality, increase of power losses, and a decrease of the equipment lifespan and performance. It is known that distortion of power quality parameters can be caused both by the consumer's operation and by operation of third party power facilities, connected to the connection point shared by consumers [4, 5]. In this case, it is difficult to determine accurately the location of the source of electric power quality distortion and its contribution to the normalized parameters, for example, to the total harmonic distortion. There are different ways, varying by complexity, to identify and detect the source of high harmonics using the method of active two-pole, high harmonics active powers flow, etc. [6, 7, 8, 9], based on which it is possible to perform a rational economically viable choice of methods and technical means of excluding their influence on electric technical complex of an enterprise.

The task to be solved in the present work is to develop a method for identifying the source of high harmonics under conditions of an operating industrial enterprise without introducing additional electric technical devices.

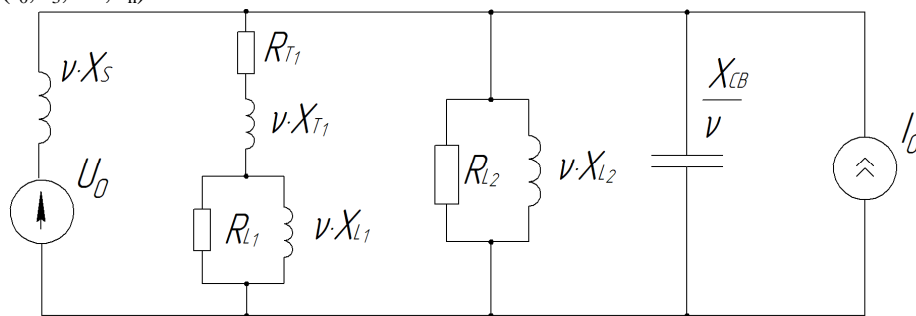
## 2. Methods

Virtually all large industrial enterprises in Russia and abroad apply measures to compensate reactive power, as set forth by regulatory documents in this field [10, 11]. In addition, during construction of new industrial facilities, measures to compensate reactive power must be stipulated by the project documentation. At most enterprises, capacitor units are used as the main electric technical devices, designed to reduce reactive power consumed from the electrical grid. Such units can be equipped with anti-harmonic reactors designed to protect them from overload by high harmonics currents, which is determined by the ratio between linear and nonlinear electric loads at an enterprise.



In this paper it was important to determine whether it is possible to determine the location of the source of high harmonics relatively to the consumers shared power connection point, using measured currents on the capacitors. Such parameters are measured in real time by means of reactive power controllers, which constitute a part of capacitor units. An electric installation operator, at any time when needed, can display these readings on the screen, without using additional expensive electric measuring equipment, for example, electric power quality analyzers. To solve this problem a substitution diagram with capacitor units for reactive power compensation, asynchronous motors, as a linear load, and 6-pulse rectifiers, as a nonlinear load, was applied. Such rectifiers constitute a part of frequency converters, widely used at industrial enterprises.

In his paper Y. E. Shklayrskiy [12] has revealed variable parameters, and determined significance thereof, which directly affect the performance of capacitor banks in the presence of high harmonics. These parameters include the system resistance, the electric load, power of capacitor banks, power of transformers, location data and power of nonlinear load. As a result, the single-phase substitution diagram of an industrial enterprise was developed (Figure 1), where  $U_0$  is the phase voltage of the power source;  $R_{L1}$ ,  $R_{L2}$  are active resistances of an asynchronous motor;  $\nu X_L$ ,  $\nu X_S$ ,  $X_{CB}/\nu$  represent the reactance at the  $\nu^{\text{th}}$  harmonic of the asynchronous motor, the system and the capacitor bank, correspondingly;  $R_{T1}$ ,  $\nu X_{T1}$ , represent the active resistance and the reactance of the transformer at the  $\nu^{\text{th}}$  harmonic;  $I_0$  is the current of the nonlinear loads. At the network substitution diagram, the external source of high harmonics is represented by a set of voltage sources with frequencies from 1 to  $n$  ( $U_0$ ,  $U_3$ , ...,  $U_n$ ), and current sources substitute the enterprise nonlinear load, which operation results in distortions ( $I_0$ ,  $I_3$ , ...,  $I_n$ ).



**Figure 1.** A substitution diagram of an industrial enterprise

The values of the substitution diagram parameters are common to enterprises of the mineral resources sector of Russia and are presented in the paper [12]. Simulation was carried out using the SimPowerSystems and Simulink software and included the following steps: drawing up an electric power supply system substitution diagram in the presence of high harmonics; calculating the substitution diagram elements resistances for frequencies of the considered spectrum of high harmonics; determining the spectral composition of high harmonics currents, generated into the electric network by a nonlinear load; calculating the network modes with each of the considered high harmonics accounted for. The simulation of the following operation modes of the electric technical complex was carried out:

1. Nonlinear electric load is located outside the considered enterprise and is not included into its electric technical complex. This nonlinear load generates harmonics in the grid voltage and has a negative impact on capacitor units. The capacitor units are not equipped with anti-harmonic reactors.
2. Nonlinear electric load is included into the electric technical complex of the considered enterprise. The said load consumes nonlinear current from the grid and generates harmonics in the grid voltage. The capacitor units are not equipped with anti-harmonic reactors.
3. The first mode with capacitor units equipped with anti-harmonic reactors.
4. The second mode with capacitor units equipped with anti-harmonic reactors.

The degree of capacitor banks overload by high harmonics currents was calculated under all operation modes, depending on the system resistance. The capacitor banks overload degree is

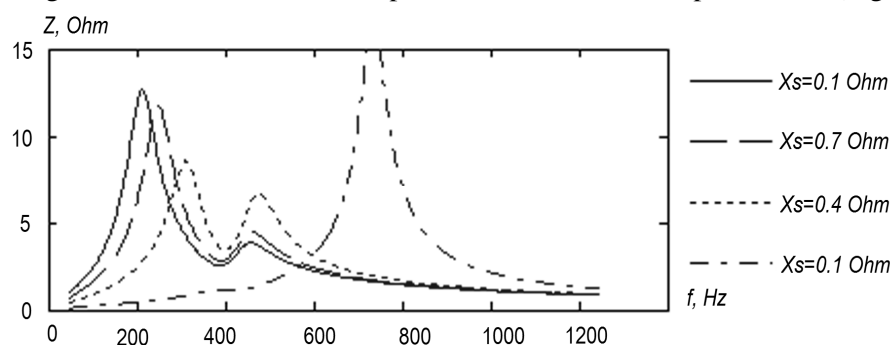
determined by the following formula, deriving from calculation of the network operation modes at frequencies of high harmonics.

- $Z_E jX_S / (Z_E + jX_S)$  for mode with nonlinear load located in an internal grid of industrial enterprise;
- $Z_E / (Z_E + jX_S)$  for mode with nonlinear load located in an external grid of industrial enterprise.

### 3. Results and discussion

Under all operation modes, the capacitor banks overload degree can be estimated based upon the network amplitude-frequency relatively to the capacitors terminals. Analysis of such dependences will reveal the value of resonant frequencies, when maximum overload of capacitors by high harmonics currents and possible shift of these frequencies upon change in the system resistance take place.

For the selected grid and load parameters, according to modes 1 and 2, the amplitude-frequency characteristic of a grid was constructed with respect to terminals of the capacitor unit (Figure 2).

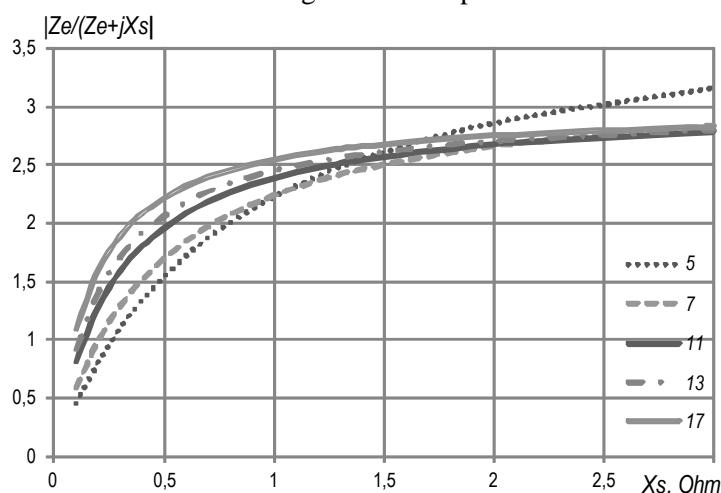


**Figure 2.** Amplitude-frequency characteristic of a grid relatively to the capacitors terminals

Such dependencies were constructed for two modes under different values of load power, capacitor units power, and system resistance. However, the dependencies in determining the location of high harmonics source were not revealed.

Then, in modes 3 and 4, the degree of capacitor banks overload by high harmonics currents was calculated. At the same time, the impedance of the network  $Z_E$  and the degree of overload are calculated using an anti-harmonic reactor for different harmonics ( $v = 5 \div 17$ ).

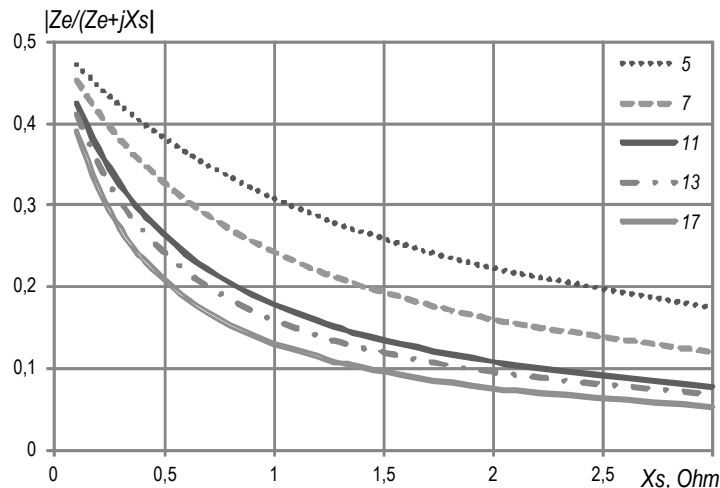
Figure 3 shows the dependence of the degree of capacitors overload for mode 3. The amplitude-frequency characteristic is represented by the ratio at different voltage harmonics on the capacitor banks to nonlinear load current in the presence of a nonlinear load on the side of the enterprise. It is obvious that this ratio will characterize the degree of the capacitor banks overload.



**Figure 3.** Capacitor banks overload depending on  $X_S$  with the use of an antiharmonic reactor

(mode 3)

Figure 4 shows the dependence of the degree of capacitors overload for mode 4. The degree of the capacitor banks overload in the presence of the nonlinear load on the side of the grid will be characterized by the ratio of voltage on the capacitor banks to the network input voltage on different harmonics.



**Figure 4.** Capacitor banks overload depending on  $X_s$  with the use of an antiharmonic reactor (mode 4)

It can be derived from the graphs that decrease in  $X_s$  in the presence of harmonics on the side of nonlinear load of the enterprise, as well as increase in  $X_s$  in the presence of harmonics on side of the grid, results in a reduction of overload on the capacitor banks. At the same time, there are no resonance phenomena on harmonics generated by nonlinear load.

#### 4. Conclusion

From the studies given above one can conclude that an increase or decrease of the system resistance with simultaneous assessment of capacitor banks overload by high harmonics currents does not allow detecting the location of the source of high harmonics. However, the presence of anti-harmonic reactors in the chain of capacitor banks makes it possible to reveal the following dependencies:

- in the presence of nonlinear load in the external grid, the system resistance should be increased to reduce capacitors overload by high harmonics currents;
- in the presence of nonlinear load in the internal enterprise network, the system resistance should be decreased to reduce capacitors overload by high harmonics currents.

Thus, change in the system resistance with simultaneous assessment of capacitor banks overload by high harmonics currents makes it possible to detect the location of nonlinear load relatively to the power connection point shared by consumers. This method is easy to implement due to the fact that change in the system resistance can be carried out by switching branches on the windings of transformers and assessment of capacitor banks overload via using built-in reactive power controllers.

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