

Algorithm for Selecting Cross-Capacitive Compensation Device Parameters with High Harmonics Accounted For

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Abstract

The article deals with the matters of reactive power compensation by means of capacitor banks with harmonic distortions in voltage and current, resulting from both their own nonlinear load and the same from third party consumers connected to the connection point shared by consumers. It is advised to reduce the capacitor bank currents overload by varying the reactive power compensation device parameters depending on the system resistance and the linear electric load parameters. Based on the characteristics obtained, capacitor bank parameters are selected in a manner that provides for their overload not exceeding planned values, and the maximum power factor would be provided. In addition, an algorithm is presented for compensation device parameters selection that accounts for minimum capacitors overload and the maximum network power factor.

Keywords: capacitor banks, high harmonics, reactive power, active power, electrical network, nonlinear electric load, linear electric load, system resistance.

INTRODUCTION

Currently, different approaches exist to paying electric power on the market, including the one, where reactive power is paid for [1, 2, 3]. The term of «reactive power» is used when calculating linear electric load networks. However, electric technical complexes at modern enterprises have most loads presented by nonlinear receivers [4, 5, 6]. That is why the relevant legislation in many countries does not fix rates, discounts and additional charges to pay for reactive power, leaving it for electricity supplies agreements between parties [7, 8, 9]. Charging for reactive power consumed may approach as much as 10% of the active power cost.

With high harmonics in the network at an enterprise, reactive power compensation devices work worse. [10, 11]. Capacitors in such units, in combination with the load inductance, may form resonance loops with the resonance frequencies close to those of one of the high harmonics. This may result in a stronger current in capacities, causing early damage.

Overloads, taking place at resonance on capacitor unit elements and on the load, may result in insulation failure. It may happen because capacitor reactance in reactive power compensation units weakens at high voltage frequencies. Therefore, if the feeding network voltage comprises high harmonics, the capacitor reactance at those harmonics will be much worse than at 50 Hz. In other words, even low voltage of the high harmonics results in substantial currents damaging the capacitors in the reactive power compensation devices. There have been situations, when advanced enterprises using 6-10 kV power lines, had their capacitor banks in resonance of currents (or close thereto) at a frequency of one of those harmonics, thus causing dangerous current overload. One of the consequences was the more costly bills for both active and reactive power consumed.

Reducing the influence by high harmonics onto capacitor bank operation may be possible by means of some dedicated means, which include filter compensating devices and active filters above others [12]. Each harmonic order needs its own power filter in the filter compensating device fit for this specific harmonic. Several filters are usually installed, making the equipment more expensive. Active filters reside on heavy-load semiconductor systems, which add much extra-cost, too.

Therefore, with financial viability criterion taken into account, the criterion that is critically important for industrial enterprise operation to take place normally, on day-to-day basis, just as planned by the higher management of any efficient enterprise, the studies focus on reducing capacitor bank overloading with high harmonics in a manner that would be the most cost efficient. The task formulated was to find, for specific harmonics spectrum in the feeding network voltage, the possibility to select such capacitor bank power that would eliminate the overload thereof by current, with power factor meeting the system requirements.

METHOD

In accordance with technical specifications for capacitor banks in most European countries and in Russia, the high harmonics current capacitor overloading ratio is defined by the value [13]:

$$F_{ovl} = \frac{\sqrt{\sum_{v=1}^n I_v^2}}{I_{CB}} \leq 1.3,$$

где I_v - rated value of v -harmonics; I_{CB} – rated current of condenser battery; n - index number of the last of relevant harmonics.

The principle diagram for the electric network typical for many industrial enterprises is presented with the Fig. 1, where X_S is the system resistance; L_1 is the equivalent low-voltage load in form of an asynchronous motor; L_2 is the equivalent high-voltage load in form of an asynchronous motor; CB is the capacitor bank; SHD is the source of harmonic distortion.

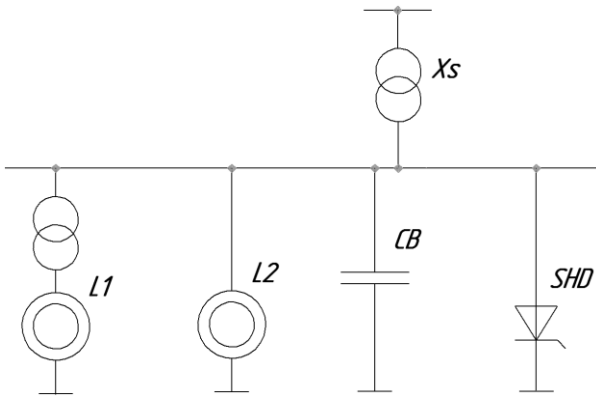


Figure 1. Single-line principle diagram of a network

The corresponding single-phase electric network substitution principle diagram may be as the Fig. 2 presents, where U_0 is the phase voltage of the source of the network discussed; R_{L1} , R_{L2} are active resistances of an asynchronous motor; $\nu \cdot X_L, \nu \cdot X_S, \tilde{O}_{CB} / \nu$ represent the reactance at the ν th harmonic of the asynchronous motor, the system and the capacitor bank, correspondingly; $R_{O1}, \nu \cdot \tilde{O}_{O1}$ represent the active resistance and the reactance of the transformer at the ν th harmonic.

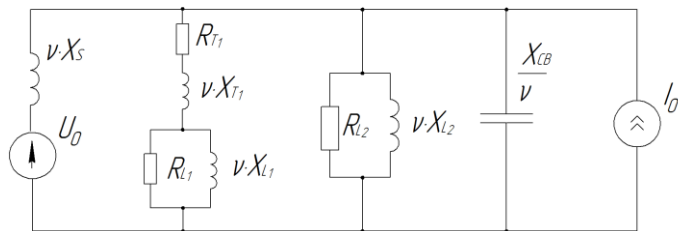


Figure 2. Network substitution diagram

The overlay method is used to calculate the said substitution diagram, and the inductive resistance on ν th harmonic increases in ν -times, and the capacitive resistance decreases in ν -times. When calculating, the capacitor bank overloading factor (F_{OVL}) is determined by the load power ($S1,2,3,4,5$), the system resistance (X_S) and the compensated reactive power value (Q_{CB}).

RESULTS AND DISCUSSION

Let us consider the case, when the source of high harmonics is its own non-linear load at the enterprise. Data of the current harmonic composition at the buses of the converting substation is presented in Table 1 [14], where ν – index of high harmonics, I_v – current value of ν -harmonics, line voltage is 10 kV.

Table 1. Harmonic composition of the current

ν	1	5	7	11	13	17	19	23	25
$I_v, \%$	100	4.1	1.5	2.8	2.1	0.75	0.8	0.68	0.7

When calculating the following assumption is accepted - non-linear load consists of a drive with the same frequency converters, i.e., the ratio of current harmonics for each drive is the same. Full load power changes from S1 to S5 upward:

- S1 - $P_{L1}=1$ MW, $Q_{L1}=0.7$ MVar, $P_{L2}=0.75$ MW, $Q_{L2}=0.5$ MVar;
- S2 - $P_{L1}=0.5$ MW, $Q_{L1}=0.35$ MVar, $P_{L2}=1.5$ MW, $Q_{L2}=1$ MVar;
- S3 - $P_{L1}=1$ MW, $Q_{L1}=0.7$ MVar, $P_{L2}=1.5$ MW, $Q_{L2}=1$ MVar;
- S4 - $P_{L1}=4$ MW, $Q_{L1}=2.8$ MVar, $P_{L2}=1.5$ MW, $Q_{L2}=1$ MVar;
- S5 - $P_{L1}=1$ MW, $Q_{L1}=0.7$ MVar, $P_{L2}=6$ MW, $Q_{L2}=4$ MVar.

Limit of the allowed the capacitor bank overload, equal to 1.3, is specified on the schedule as well. As the result, a family of characteristics is obtained, as Fig. 3, 4 present.

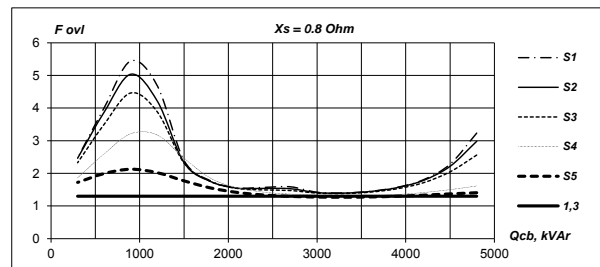


Figure 3. Dependence of F_{OVL} from Q_{cb} , where $X_s = 0.8$ Ohm

The graphs show that under a certain combination of load, network and the capacitor bank parameters, the capacitor bank operation mode can be achieved without overloading the capacitors. Moreover, the results of studies show that not all combinations of the abovementioned parameters satisfy the conditions of safe operation of the capacitor bank.

The peaks obtained when constructing of the above dependencies, are none other than the resonance at different harmonics. It's worth noting that resistance decrease in the resonance system at different harmonics becomes greater and, therefore increases the current flowing through the capacitor bank at these harmonics.

Also, resulting from the family of characteristics obtained, it is evident that reducing the power load in the electric network and the corresponding change in the capacitor banks power increases the capacitor bank overload by current.

Based on the dependencies obtained, one can determine in which capacity area of the capacitor banks it's operation is ensured without overload. This is true both for non-regulated and regulated capacitor bank. In the latter case, one can select the range for changing the capacitor bank, where no overload arises, due to high harmonics currents.

Let us consider another case, where the feeding network voltage (Fig. 5) is the source of high harmonics. In this case the load at the enterprise is linear.

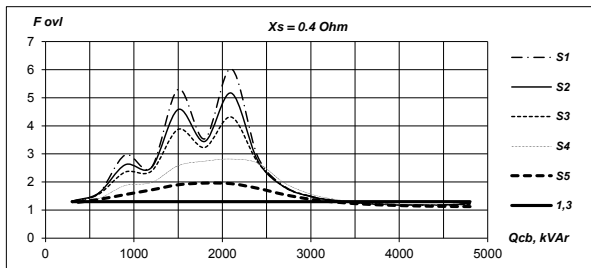


Figure 4. Dependence of F_{OVL} from Q_{cb} , where $X_s = 0.4$ Ohm

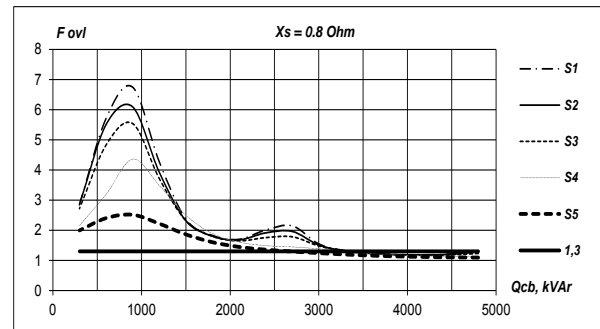


Figure 6. Dependence of F_{OVL} from Q_{cb} , where $X_s = 0.8$ Ohm

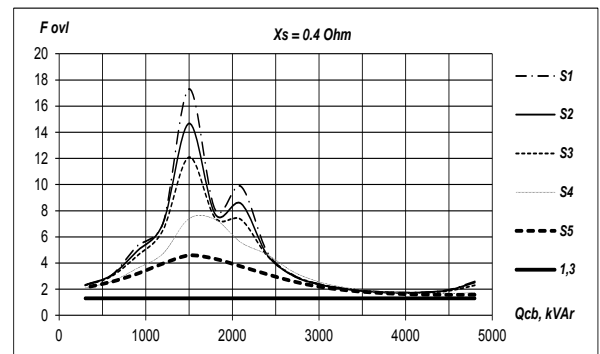


Figure 7. Dependence of F_{OVL} from Q_{cb} , where $X_s = 0.4$ Ohm

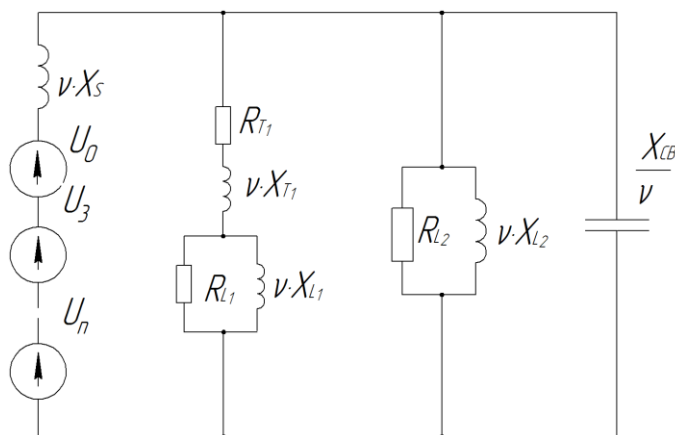


Figure 5. Network substitution diagram in the presence of distortion from the feeding network

Similar to the previously considered case, the capacitor bank overload coefficient is determined by the load power ($S_{1,2,3,4,5}$), the system resistance (X_s) and the compensated reactive power value (Q_{CB}). The feeding network voltage waveform distortion coefficient for this case, equal to about 12%, is determined on the basis of the Table 1 by finding the stress of v^{th} harmonics at the buses of the substation.

As the result, a family of characteristics is obtained, as Fig. 6, 7 present.

As in the case of high harmonics caused by nonlinear load of the enterprise, the graphs show that the operation mode can be achieved, without overloading the capacitors, under a certain combination of load, network and capacitor banks parameters.

However, increasing the system resistance in the presence of distortion from the feeding network results in decrease of capacitor banks overload by high harmonics currents. This means that:

- if the feeding network is the source of high harmonics, the system resistance should be increased to reduce the capacitor bank overload;
- if a load of enterprises is the source of high harmonics, the system resistance should be decreased to reduce the capacitor bank overload.

It is obvious that change in the system resistance must meet the electromagnetic compatibility of the power supply system at the highest possible power coefficient.

Thus, calculations carried out showed that by means of selecting the capacitor banks power, depending on parameters of the electric network, load capacity and the current spectral composition and voltage, the capacitor bank operation mode to be achieved without overloading.

Compensation device parameters, that ensure the capacitor bank operation mode without overload, need to be adjusted by the coefficient of the network capacity, as not all the values of the capacitor bank power, satisfying $F_{OVL} \leq 1.3$ condition, provide effective compensation of reactive power in the enterprise network.

Based on the abovementioned studies, the algorithm was introduced for selecting the capacitor bank power, which allows efficient reduction of the reactive power consumption and ensures absence of overloading within the network, caused by high harmonics (Fig. 8).

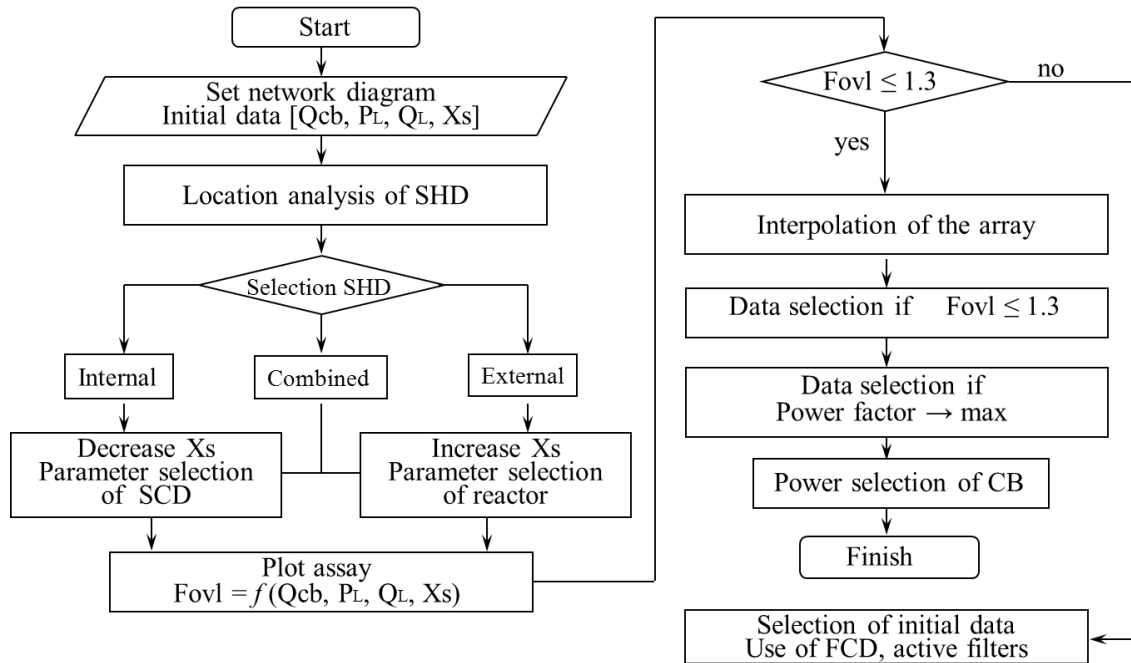


Figure 8. Algorithm for selecting the capacitor bank power in the presence of high harmonics, where SHD – source of high harmonics, SHD internal – own nonlinear load of enterprises, SHD external – feeding network is the source of high harmonics, SCD – series compensating device, FCD – filter compensating device

First, the generalized diagram for network substitution should be defined, based on which, the compensation device overload coefficients would be calculated. It is important to determine the range for changing the parameter of the network substitution, particularly, load power consumption, the system resistance and the compensation device power, and to analyze the high harmonics source and the nature thereof. The next stage would include building multifactor dependency of the capacitor bank overload coefficient on the variables selected. Provided there are capacitor bank power values keeping the capacitor overload within allowed range, the said multifactor dependency gets interpolated. Next variable values are to be selected out of the three-dimensional data array, for two conditions to be fulfilled: the network power factor should be at maximum, and the capacitor bank overload coefficient should not exceed the allowed value of 1.3. In accordance with the additional condition, when the power factor is at maximum, the capacity bank power is finally selected to provide the safe and efficient mode for reactive power compensation.

CONCLUSIONS

Based on the studies carried out, the algorithm for selecting the reactive power compensation device parameters was

developed for situations when high harmonics present. The algorithm allows operating capacitor banks with no overloading by high harmonics currents, with maximum network power factor. Lowering overloading of capacitor banks by current is carried out through varying the reactive power compensation devices depending on the system resistance and linear electric load parameters. Here, the system resistance should be modified depending on the location of the high harmonics source relatively the consumers shared connection point. Should there be harmonic distortions from the feeding network, lowering the overloading on capacitor banks needs increasing the system resistance; should there the own nonlinear load of enterprises be the high harmonics source, lowering the overloading on capacitor banks needs lowering the system resistance. If it is impossible to guarantee normal operation of the capacitor banks via the abovementioned methods, additional means, known in the art, should be used, such as active filters and filtering compensation devices.

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