Combinatorial method for optimal sizing and placement of active power filters

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***Abstract*—Combinatorial method for optimal sizing and placement of active power filters (APFs) has been presented in the paper. The main idea is to separate the sizing and placement parts of the algorithm to avoid calling the cost function during the APF sizing part of the algorithm, what allows to overcome some problems associated with nonlinearity and discontinuity of the APF cost function. The results confirm a high effectiveness of the method in comparison with the traditional approach. The main disadvantage of the method is a relatively large amount of computation caused by the combinatorial testing of all possible APF connection nodes.**

Keywords*—*power quality, active power filters, optimization of sizing and placement of APF

I. Introduction

A growing number of nonlinear loads in contemporary power networks can lead to a significant increase in the level of voltage and current harmonic distortion [1]. In many cases the existing distortion must be reduced to a level that ensures correct operation of the entire network and meet the imposed standards [4]. Among many methods of harmonic distortion reduction, one of the most effective is the use of APFs (active power filters) [5]. This method is still relatively reluctant to apply because of the significant total cost associated with the price of the APFs. Another issue is the proper selection of the optimal number, size and placement of the APFs to ensure that the distortion will fall below the required level at the lowest possible cost. Solutions available in the literature are often based on the frequency model of the considered power system and various optimization algorithms [2]. One of the biggest problems is a fact, that the cost of APF as a function of its RMS current is usually discontinuous and nonlinear [3]. An example of such a function is shown in Fig.1.

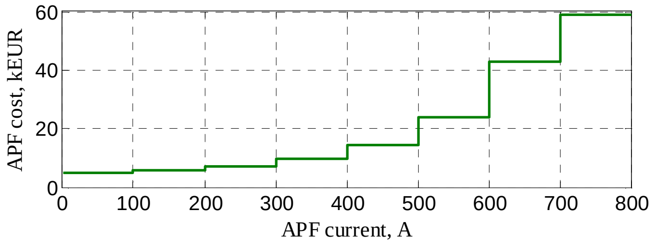

FIGURE 1. Exemplary APF cost as a function of RMS current

The second issue is the combinatorial nature of APF placement problem. Theoretically, all possible APF connection points should be considered resulting in a rapid increase in the number of APF connection combinations as the number of nodes in the power system increases. In connection with the discontinuous and nonlinear APF cost function it leads to a nonlinear and discontinuous combinatorial problem which solution might be a challenging task [3].

II. Combinatorial Method for Optimal Sizing and Placement of APF

The proposed algorithm of APF sizing and placement is shown in Fig.2.

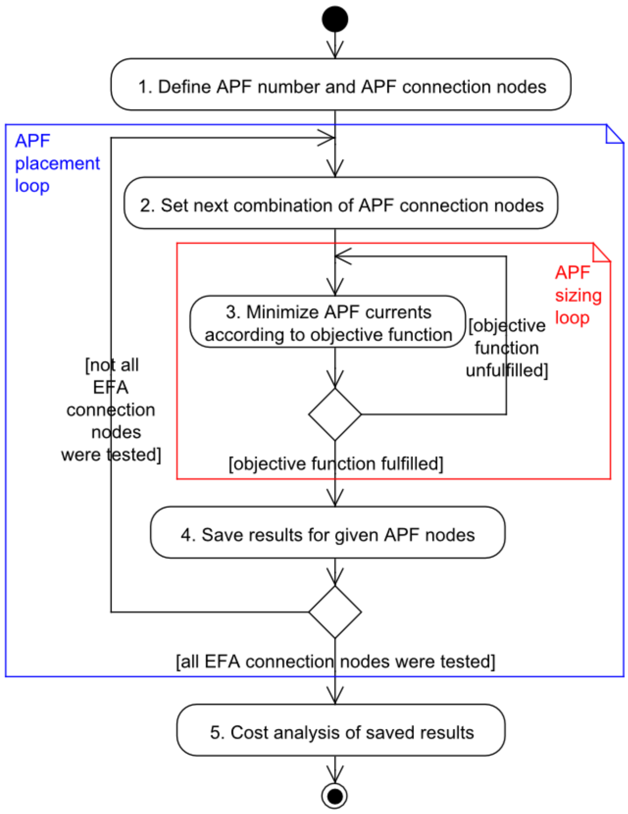

Figure 2. APF sizing and placement algorithm

First, the APF number and placement nodes are defined (Fig.2). In the next step, the algorithm enters the APF placement loop where all possible combinations of APF placement are tested. The third step is the APF sizing optimization loop, where all currents of the connected APFs are minimized according to the specified objective function. In particular, the objective function can be defined as follows:

$$\min_x f_g(x) = \min_{\{A_w^h, B_w^h\}} \sum_{w=1}^{W} |I_w|, \quad THDV \le 5\% \qquad (1)$$

where $I_w^h = A_w^h + jB_w^h$ is a phasor of APF current in node w for the h^{th} harmonic and $|I_w|$ is the RMS value of APF current in node w for number of APFs equal W. The presented objective function is minimized under the constraint that all THDV (total voltage harmonic distortion) in the system are less or equal 5%. Other objective functions are also possible, what has been discussed in [3]. When the APF size is determined by the optimization algorithm, the result is saved and the algorithm returns to point 2. When all APF connection combinations are tested, the saved results are analyzed using the APF cost function, what allows to specify the optimal solution in terms of the total cost of the APFs installation. As one can notice, the process of determining the optimal solution is divided into two stages: APF sizing and APF placement. The optimization algorithm is used only during the first stage, while the discontinuous and nonlinear cost function is involved only during the second stage, what is the main advantage of the proposed method.

III. TEST POWER SYSTEM

For further consideration, a ski station power system consisting of 17 nodes has been chosen [6] (Fig. 2).

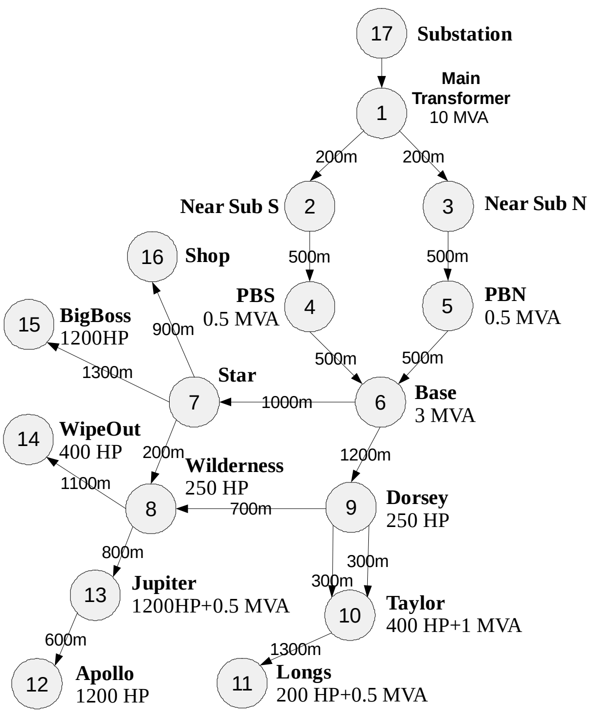

Figure 3. Test power system

The system includes 8 six-pulse rectifiers powering the ski lift motors (nodes with the HP label, which denotes the power of the motors in horse power). They are sources of harmonic currents, which affect the voltage distortion (THDV) at all system nodes. The maximal THDV in the system is equal 13.1% (node Apollo). Frequency model of the system has been implemented in PCFLO environment that provides the harmonic flow analysis [7].

IV. SIMULATION RESULTS

The algorithm presented in Fig.2 has been tested using the power system shown in Fig.3 and the objective function (1) with the given THDV constraint. Step 3 of the algorithm has been implemented in PCFLO and all other steps in Matlab. Simulation results in comparison with a classic APF placement method are shown in Fig.4. The classic method is based on connecting the APFs only to nodes with nonlinear loads to compensate the load current to a sinusoidal shape (all possible combinations with number of APFs from 1 to 8 were tested).

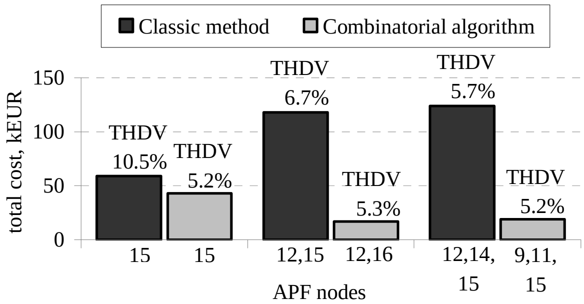

Figure 4. Minimal total APF cost and THDV for 1, 2 and 3 APFs installed in the system

As it can be seen in Fig.4, the results for the combinatorial algorithm are clearly better than those of the classic method. This applies to both, the cost of installation and the THDV. More detailed comparison of the results and details of both methods will be presented in the extended version of the paper.

V. SUMMARY

The combinatorial method presented in the paper can overcome some problems associated with nonlinearity and discontinuity of the APF cost function. The results confirm the high effectiveness of the method in comparison with the classic approach. The disadvantages of the method include the relatively large amount of computation that is connected with the full search of a set of possible solutions.

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