Available online at www.sciencedirect.com
SCIENCE DIRECT®
Electric Power Systems Research 71 (2004) 41–49
ELECTRIC POWER SYSTEMS RESEARCH
www.elsevier.com/locate/epsr

Genetic based algorithm for active power filter allocation and sizing

Reza Keypour, Hossein Seifi*, Ali Yazdian-Varjani

Department of Electrical Engineering, P.O. Box 14155-4838, Tarbiat Modares University, Tehran, Iran

Received 20 July 2003; received in revised form 14 November 2003; accepted 17 January 2004

Abstract

Active power filters (APF) can be employed for harmonic compensation in power systems. In this paper two algorithms are proposed for optimum allocation and sizing of APFs. In the first algorithm, the aim is to minimize the voltage harmonic distortion while in the second; the aim is to meet the harmonic standard levels by minimum injection of APF currents. Both algorithms are solved using genetic algorithm (GA) as the optimization tool. The performance of the proposed approaches are assessed and appreciated by various case studies on an 18-bus test system.

Keywords: Power quality; Harmonics; Active power filters; Optimization; Genetic algorithm

1. Introduction

The harmonic distortion levels in power system networks are raised due to high utilization of power electronic based equipments. This results in higher losses, decreasing the life age of devices and interference with the loads and protection devices. Nowadays, most of the problems caused by harmonics are attributed to the large sources, such as adjustable speed drives and rectifiers, while in future, large number of similar but small sources may cause the same problems. The conventional solutions include network reconfiguration, capacitor switching and passive filtering.

Widespread increase in number of small power electronics based apparatus causes a higher level of harmonic distortions in power systems. In this case, the above-mentioned solutions for large sources of harmonics may become inappropriate or ineffective. Therefore, the need for a better and effective solution, such as active power filter (APF) is essential which could control the harmonic levels in the presence of wide-variation of harmonic sources and system impedances [1].

The installation of an APF in an appropriate place and proper size is one of the recent research topics [2–9]. The important factors to be considered for APF applications are: existing harmonic pollution levels, harmonic standard constraints, locations and sizes of APFs and finally network topology. The size of an APF is normally defined as its maximum effective injection current.

Regardless of any solution procedure, allocation and sizing of APFs are normally found based on optimization process in which various objective functions may be employed. Total harmonic distortion (THD), telephone interference factor (TIF), total injected currents, etc. are a few among others [8]. The allocation and sizing of a single APF are proposed in [2–4], extended to multiple APFs in [7], assuming APF sizes as continuous variables. In [5,9], APF sizes are considered as discrete variables, assuming that APF capacitors and inductors are available in standard and discrete sizes. In these papers, in each stage, the smallest possible size of an APF is found using a series of indices until the harmonic standard constraints are met. However, the optimum solution is not guaranteed. Assuming that APF sizes are discrete, optimum allocation and sizing of APF is in fact a non-linear mixed integer programming problem (NLMIP). A conventional method, such as generalized benders decomposition theory (GBDT) may be used to solve the problem [8].

In this paper, two algorithms for allocation and sizing of APFs are proposed. In the first algorithm, the harmonic voltage distortion level is minimized while in the second one

* Corresponding author. Tel.: +98-21-8006544.
E-mail address: seifi_ho@modares.ac.ir (H. Seifi).

0378-7796/$ – see front matter © 2004 Published by Elsevier B.V.
doi:10.1016/j.epsr.2004.01.004

the aim is to meet the harmonic standard levels by minimum injection of APF currents (in other words, the APF cost). To find an optimum solution, a genetic based algorithm (GA) is employed which is not trapped in a local minimum and searches the global minimum in solving the resulting complex optimization problem. By appropriate modifications of GA operators, the speed and the accuracy are improved noticeably.

The algorithms from modeling viewpoints are described in Section 2. GA implementation as solution tool is discussed in Section 3. In Section 4, the results are demonstrated. Some concluding remarks are, finally, provided in Section 5.

2. Proposed algorithms

2.1. Constraints and objective functions

Two types of constraints are observed in an APF allocation and sizing problem. First, are those due to APF itself, including the maximum current that an APF can produce, namely, APF size, and the discrete nature of APF sizes due to discrete sizes of capacitors and inductors employed in its structure. The second types of constraints are harmonic standards imposed on the level of voltage harmonics and total harmonic distortions in various locations. IEEE-519 standard is used in this regard [14].

For allocation and sizing of APFs, various objective functions have been proposed in literatures [2–9] which can be categorized into two groups; some of them try to minimize the voltage distortion in order to reduce the unwanted effects of harmonic distortions on the network while others have focused on employing harmonic standards on voltage harmonic distortion and total harmonic distortion (THD) levels in order to minimize the APF injected currents. As the cost of an APF is proportional to its maximum injecting current, this minimization will result in minimization of total cost. In this paper, two algorithms based on both objective functions are introduced.

In the first algorithm (*algorithm I*), the aim is to minimize the voltage distortion while APF current constraints are observed. The second algorithm (*algorithm II*) uses the minimization of injected currents as the objective function while harmonic standard levels and APF current constraints are simultaneously observed. Therefore, all constraints in published literature are considered in this algorithm.

2.2. APF model

The APF can be modeled as a current source as it is injecting harmonic currents to the system. The phasor presentation of each APF current is shown by I_m^h which m indicates the bus number connected to and h is the order of harmonic, i.e.

$$I_m^h = I_m^{h,r} + jI_m^{h,i} \tag{1}$$

The indices, r and i, represent the real and imaginary parts, respectively.The RMS current of each APF is determined as follows:

$$I_m = \left[\sum_{h=2}^{H}(I_m^{2^{h,r}} + I_m^{2^{h,i}})\right]^{1/2} \tag{2}$$

2.3. Power system model

For a linear frequency domain analysis, the power system network is linearized; and for each frequency, all non-linear loads are considered as current sources. Therefore, the network impedance matrix can be determined (calculated or measured) independently for each frequency.

2.4. Algorithm I

In this algorithm, the aim is minimization of voltage distortions. Thus, the objective function is considered as the squared sum of harmonic voltages. The only constraint considered is the maximum allowable APF size (observed as current constraint). Therefore

$$\text{Min} \sum_{h=2}^{H}\sum_{k=1}^{K}|V_k^h|^2 \tag{3}$$

$$\text{such that } I_m \leq \overline{I}_{\max}, \quad m = 1, 2, \dots, M \tag{4}$$

where $\overline{I}_{\max}$ is the APF maximum current, $|V_k^h|$ is the amplitude of harmonic voltage h in bus k and M is the number of APFs employed in the system. The decision making problem variables are $I_m^{h,r}$ and $I_m^{h,i}$ where V_k^h is a nonlinear function of them. Therefore, this is a non-linear programming (NLP) problem.

2.5. Algorithm II

In this algorithm, the aim is to meet the harmonic standard levels while the sum of APFs' sizes is minimized. The size of APFs can be considered either continuous or discrete. The resulting optimization problem can be presented as follows:

$$\text{Min} \sum_{m=1}^{M}\overline{I}_m \tag{5}$$

$$\text{such that } \overline{I}_m \leq \overline{I}_{\max}, \quad m = 1, 2, \dots, M \tag{6}$$

$$\overline{I}_m \in D \tag{7}$$

$$|V_k^h| \leq \overline{V}_k^h, \quad h = 2, \dots, H, \quad k = 1, \dots, K \tag{8}$$

$$\text{THD}_k \leq \overline{\text{THD}}_k, \quad k = 1, \dots, K \tag{9}$$

where $\overline{I}_m$ is the size of the APF in the candidate bus m, its value is equal to the smallest value of set D which is greater than I_m. If APF sizes are considered discrete, D is a set