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A new optimal approach for improvement of active power filter using FPSO for enhancing power quality

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ABSTRACT

In the recent years, development of industry cause to increase nonlinear and time variant loads in power systems. These loads bring about power quality phenomena such as voltage and current harmonics, current unbalance and flicker in power systems. In this paper, an optimal method for active power filter is proposed to improve power quality. The control system of APF is based on combination of the synchronous detection method, instantaneous power theory, and output of DC capacitor voltage regulator. To stabilize the DC voltage and improvement of reference currents, PID controller is suggested. Regarding to intense changes of load in power system due to nonlinear load, PID controller with fixed parameters could not adequate for the APF control. Therefore, Fuzzy Particle Swarm Optimization method is proposed for optimizing of PID controller. This method is found on PSO and Fuzzy algorithm. To evaluate the proposed method, the APF is modeled in the worst conditions with a power system loaded with two electric arc furnace. In addition, in order to make good use of frequency changes in the power system, the power frequency estimation is put to use.

Introduction

Nowadays, power electronic application in various industrial due to advantages of these devices such as speed performance is increasing. Different converters, dimmers, drives, inverters and similar application are some applications of power electronic devices. Most important problems related to power electronic are quality of electric power supply because they are very sensitive to voltage and current harmonics, voltage fluctuations, unbalances, and disturbances. Hence, utilities and costumers try to enhance power quality in power system by means of different compensators such as passive filters, and static compensators.

One of best compensators that have shown good ability in harmonic elimination is the active power filter (APF). The APFs can compensate most power quality phenomena such current harmonics, voltage fluctuations, unbalances in the event that they are adequately controlled. These filters generally generate similar signals to the system but in opposite directions for compensating any disturbance. So far, many various methods have been suggested to control the APF [1–12]. Some methods are founded on the instantaneous power theory in order to generate the reference current. However, the disadvantage of these procedures is that APF cannot properly compensate destructive effects heavy loads with intense changes. Also, it is not possible to improve all harmonics and voltage unbalances. Surely, simplicity in implementation and the ability to define different explanation for calculating the reference current are the advantages of these methods [1–4]. Some other methods of calculating the reference current are synchronous procedures [5–8] that the reference computation current is based on the solution the d–q equations using low-pass filters. Other procedures are based on the active current components in which there is an access to three states of equal active powers, currents, and resistances [9–11]. Therefore, the three-phase current source must be without any reactive current produced by an APF.

There are two difficulty of utilizing this method: First, it necessitates many converters; second, the filter response has also a time delay. On top of this method is not able to properly compensate the harmonics when the heavy loads have intense changes and they have non-sinusoidal mode. Another method to generate the reference current uses the frequency domain [12–15]. There are two disadvantages to this method: first, it requires many cycles to estimate the current; and second, it is not able to produce suitable reference currents in the transient mode with heavy load changes. Most of these methods are not able to optimize the compensation of disturbances in the system. They are also not suitable for nonlinear and time varying loads such as EAFs; and they cannot compensate the generated disturbances in a proper manner. Anyway, by means of planning a suitable control system for the

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Nomenclature

APF	active power filter
DC	direct current
PID	controller proportional-integral-derivative controller
PSO	particle swarm optimization
FPSO	Fuzzy Particle Swarm Optimization
EAF	electric arc furnace
IGBT	insulated-gate bipolar transistors
SLD	single line diagram
PCC	point of common coupling
HV, MV, and LV	high, medium and low voltage
I_m	peak of current after compensation
V_m	peak of voltage
v_{dca}	dc voltage
T_x	sampling time
Δe_{dc}	required energy to achieve the reference voltage
I_{cp}	current peak in phase with voltage
n	number of particles in the group
m	number of members in the particle
$k_{\max}$	maximum of iteration
k	current number of iteration
PBPE	present best performance evaluation
NPBPE	normalized present best performance evaluation
$V_{aS,average}$	network voltage averaging

APF, it can be compensate the harmonics and other power quality indices.

In this paper, a suitable control system based on time domain correction method for APF is proposed. The reference current of APF is generated by the combination of instantaneous power theory, the synchronous detection method, and output of DC capacitor voltage. For following the APF reference and actual current, the PID controller in DC voltage regulator is used. In power system with current intense changes, the constant of PID could not improve it. Therefore, to regulate the DC voltage and compensate the power system ideally, the FPSO method is presented. Then, the firing pulses of the APF are computed through the hysteresis method. By using the proposed control system, not only the harmonics are properly compensated, but also the other power quality indices in the system are adequately improved. Hence, presented method causes the APF is convert to multi-functional APF which can compensate most of power quality phenomena. To evaluate the operational accuracy of the proposed control system, the APF is modeled in the worst conditions with a power system loaded with EAF. The intended model for the furnace load is adopted from an actual arc at the MSC based on the statistical-probabilistic model and accurate-sampling process. The random flicker in arc voltage is also considered in the arc model. The simulation results indicate the high accuracy and correctness of the APF operation to improve the power quality indices. Also, performance speed of the proposed method is very significant than other methods.

Active power filter design

The electric single diagram of power system with the APF is illustrated in Fig. 1.

In this figure, nonlinear load inject harmonic and cause the power quality parameters in the power network. APF is composed of three-phase converter and DC capacitor. The different parts of APF control system including reference currents calculation, DC voltage regulator and firing pulses generation are shown in Fig. 2. According to this figure, at first, the reference currents computation is performed by combining the instantaneous power theory and synchronous procedure. Then current results of voltage DC regulator are added to pervious reference current and hence the final reference current is generated.

Now, for calculating the initial reference current based on instantaneous power, the voltage and current vectors are converted in $\alpha-\beta$ system as follows:

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = A_{\alpha-\beta} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

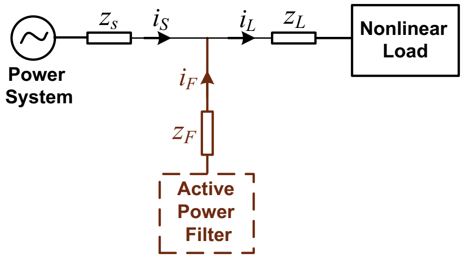

Fig. 1. Linear single diagram of power system with APF.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = A_{\alpha-\beta} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2}$$

where $A_{\alpha-\beta} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix}$

The calculation of instantaneous active and reactive powers is known as follows:

$$p = e_\alpha i_\alpha + e_\beta i_\beta = e_a i_a + e_b i_b + e_c i_c \tag{3}$$

$$q = -e_\beta i_\alpha + e_\alpha i_\beta = \frac{1}{\sqrt{3}}[e_a(i_b - i_c) + e_b(i_c - i_a) + e_c(i_a - i_b)] \tag{4}$$

For easier expression of instantaneous power, they are written in terms of matrix form as:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{5}$$

Therefore the $\alpha-\beta$ form of current can be indicated as:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \end{bmatrix} \tag{6}$$

For computing the final reference current, i_α and i_β, are divided into two components as follows:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ 0 \end{bmatrix} + \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ q \end{bmatrix} = \begin{bmatrix} i_{\alpha p} \\ i_{\beta p} \end{bmatrix} + \begin{bmatrix} i_{\alpha q} \\ i_{\beta q} \end{bmatrix} \tag{7}$$

where

$$i_{\alpha p} = \frac{e_\alpha}{e_\alpha^2 + e_\beta^2} p, \qquad i_{\alpha q} = \frac{-e_\beta}{e_\alpha^2 + e_\beta^2} q$$

$$i_{\beta p} = \frac{e_\beta}{e_\alpha^2 + e_\beta^2} p, \qquad i_{\beta q} = \frac{e_\alpha}{e_\alpha^2 + e_\beta^2} q$$