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Application of mixed integer distributed ant colony optimization to the design of undamped single-tuned passive filters based harmonics mitigation

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ABSTRACT

The purpose of this study is to find the optimum sizing parameters of the undamped single tuned filter in the nonsinusoidal system by using a new method called Mixed Integer Distributed Ant Colony Optimization. The inductance and capacitance values of the filter are obtained for each criterion where the power factor is maximized, the losses power in Thevenin's resistor is minimized or the transmission efficiency is maximized complying with the technical and practical constraints based on IEEE Std. 519-2014 and IEEE Std. 18-2012. A detailed study has been performed and discussed where global minimum and maximum are achieved after considering the loads being nonlinear, the value of the filter that would introduce resonance, voltage total harmonic distortion, the consequence of the Thevenin's impedance on the load voltage and the practical values of the capacitor. The obtained optimum value of a single tuned filter is used to explain the system performance by evaluating other functions. The effectiveness of the proposed method is proved by comparison with previous publication and other evolutionary computation techniques which are genetic algorithm and particle swarm optimization.

1. Introduction

Power system harmonics are the steady-state power quality problem that has existed in the power system since the early development of alternating current system where the distorted waveforms were observed. Recently, nonlinear loads such as rectifiers, power supplies and other devices using solid state switching, have increased, which also increased the concern to the power quality problem [1]. These nonlinear loads produce currents and voltages with a frequency greater than the fundamental frequency, up to a multiple of the fundamental frequency, which is known as the power system harmonics. All of the addressing issues in the power system problem have been very important to pay attention to the power quality problems and the concerns to harmonic distortion problems.

There are several harmonic mitigation techniques to reduce or eliminate the effect of harmonics such as K-factor transformer [2], tuned harmonic filter [3], active filter [4] and shifting transformer [5]. Generally, single tuned filters are the most common passive filters in use due to their simplicity and cost. It has been recommended for nonlinear loads because of its dual purposes of mitigating harmonics and improving power factor. However, the disadvantage of the filter is that it may introduce series or parallel resonance into the system, which needs to be safely away from any significant harmonics [6].

Different approaches optimal filter design for harmonic mitigations have been developed using an Adaptive Carrier Frequency Optimization [7], Non-Dominated Sorting Genetic Algorithm (NSGA-II) [8], Artificial Bee Colony [9], Adaptive Bacterial Foraging Optimization [10], Differential Evolution [11], Cuckoo Search Algorithm [12], Crow Search Algorithm [13] and Bat Algorithm [14].

The first application of Mixed Integer Distributed Ant Colony Optimization (MIDACO) to find the optimal value of single tuned passive filters is presented in this paper taking into consideration the different criteria including different technical and practical constraints using IEEE Std. 519-2014 [15] and IEEE Std. 18-2012 [16]. The proposed method has generally considered the loads being nonlinear, voltage total harmonic distortion, the value of the passive filter that would introduce resonance, the effect of the Thevenin's impedance, and the standard value of capacitor. The major contribution of this methodology is the guarantee of the fast convergence capability to the ideal solution where the results is proved by comparing the results with other effective published techniques which are genetic algorithm (GA) and particle swarm optimization (PSO). Finally, the effectiveness of this proposed technique is demonstrated in examples adopted from IEEE Std. 519-1992.

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2. Single-tuned passive filter

A single tuned filter consists of series passive elements, Resistor (R), Inductor (L) and Capacitor (C). Fig. 1 illustrates the filter configuration $R-X$, and $Z-\omega$ plot for single tuned filter.

An ideal single-tuned filter is when the inductor and capacitor of the filter have equivalent reactance and pure resistance at the tuned harmonic. The total filter impedance in Fig. 1(a) is given in Eq. (1) where X_L and X_C in Eq. (2) is inductance and capacitance of the filter, respectively.

$$Z_f = R + j(X_L - X_C) \tag{1}$$

where,

$$X_L = \omega L$$
$$X_C = \frac{1}{\omega C} \tag{2}$$

For single tuned filter, the sharpness of the tuning is determined from the ratio of reactance or capacitance to the resistance at the tuned angular frequency given in Eq. (3) and expressed as

$$f_n = \frac{1}{2\pi\sqrt{LC}} \tag{3}$$

If X_0 is the capacitor's reactance at its tuned frequency

$$X_0 = \omega_n L = \frac{1}{\omega_n C} \tag{4}$$

where the tuned frequency in rad is given by $\omega_n = \sqrt{1/LC}$. Then, substituting Eq. (4) into Eq. (5) gives the value of quality factor QF.

$$QF = \frac{X_0}{R} = \frac{1}{R}\sqrt{\frac{L}{C}} \tag{5}$$

In industrial filter design, the typical value of the QF is in the range of 20–100. The filter that has small QF is sharply tuned to lower frequency while high QF results in expensive cost of reactor. Therefore, there are standard limitations to limit QF for the reactor.

On the other hand, resonant in the power system is the most important effect when adding a single tuned filter in the power system. The series and parallel resonant occur at a frequency below the tuned frequency and expressed as

$$h = \sqrt{\frac{X_C}{X_L}} \tag{6}$$

In theory, maximum efficiency can be achieved if the filter is tuned exactly equivalent to the harmonics that need to be eliminated. However, the filter usually is tuned 3%–10% of the harmonic frequency in Eq. (6) to consider detuning effects. Also, it will provide a margin of safety in case of any changes in temperature or failure with either capacitance or inductance [17].

3. Optimization problem

3.1. Objective functions

A single-phase equivalent circuit consists of an undamped single-tuned filter is shown in Fig. 2. It is ideal to gain understanding of the filter by oscillate with minimal damping. Therefore, LC filter is obtained by considering no dissipation energy due to resistance by removing of resistor R from RLC filter.

The utility supply is represented using Thevenin's voltage source in Eq. (7) and the nonlinear load is represented by using the harmonic current source in Eq. (8).

$$v_{th}(t) = \sum_K v_{thk}(t) \tag{7}$$

and

$$i_{lk}(t) = \sum_K i_{lk}(t) \tag{8}$$

where K refers to the present harmonic order.

In the compensated system, the Thevenin's impedance for Kth harmonic is

$$Z_{THK} = R_{THK} + jX_{THK} \tag{9}$$

and the load impedance for the Kth harmonic is

$$Z_{LK} = R_{LK} + jX_{LK} \tag{10}$$

The undamped single tuned filter impedance is denoted by Z_{CK} wherein

$$Z_{CK} = j\left(KX_L - \frac{X_C}{K}\right) \tag{11}$$

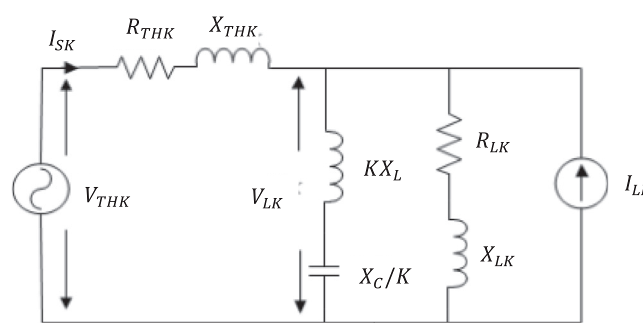

Fig. 2. Single-phase equivalent circuit for Kth harmonic with undamped single tuned filter.

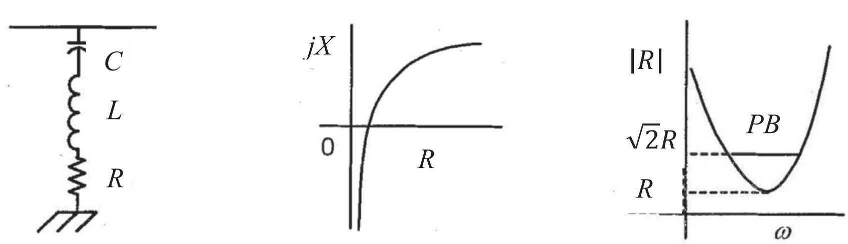

Fig. 1. The filter a) configuration, b) $R-X$ Plot and c) $Z-\omega$ Plot for single tuned filter.