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Optimal harmonic filters design of the Taiwan high speed rail traction system of distributer generation system with specially connected transformers

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ABSTRACT

This paper presents a method for combining a particle swarm optimization with nonlinear time-varying evolution and orthogonal arrays (PSO-NTVEOA) in the planning of harmonic filters for the high speed railway traction system of Distributed Generation (DG) system with specially connected transformers in unbalanced three-phase power systems. The objective is to minimize the cost of the filter, the filters loss, the total harmonic distortion of currents and voltages at each bus simultaneously. An orthogonal array is first conducted to obtain the initial solution set. The set is then treated as the initial training sample. Next, the PSO-NTVEOA method parameters are determined by using matrix experiments with an orthogonal array, in which a minimal number of experiments would have an effect that approximates the full factorial experiments. This PSO-NTVEOA method is then applied to design optimal harmonic filters in Taiwan HSR traction system, where both rectifiers and inverters with IGBT are used. From the results of the illustrative examples, the feasibility of the PSO-NTVEOA to design an optimal passive harmonic filter of Taiwan HSR system is verified and the design approach can greatly reduce the harmonic distortion. Three design schemes are compared that V–V connection suppressing the 3rd order harmonic and Scott connection for the harmonic improvement is better than those of V–V and Le Blanc connection.

1. Introduction

The harmonic distortion is one of indexes of power quality for power systems [1,2]. For Taiwan High Speed Railway System (HSR), the traction motor loads are provided by single-phase power supply. The great amount of power electronics application to the motor driving circuits such as rectifiers and inverters resulted in the harmonic current flow to the railway catenary system [3]. The IEEE Standard 519-1992 provides a solution for the limitation and mitigation of harmonics [4]. Both passive and active filters can be used to reduce harmonic currents. While passive filters provide low impedance paths to absorb harmonic currents, active filters give countervail harmonic components to purify load currents [5,6]. However, passive filters are usually a better choice for customers considering cost. The capacitors of passive filter also provide reactive power compensation to improve power factor.

Some special electrical systems usually require strong single-phase power sources to reduce the voltage unbalance disturbances of the three-phase sources. Therefore some specially connected transformers are used, such as V–V, Scott, and Le Blanc connection schemes. These have been employed in the railway electrification systems. The power quality issues in railway electrification systems today include the studies on the influence of traction loads on three-phase utility systems. For example, simplified models of specially connected transformers have been given in three-phase power flow studies [5]. The harmonic current of the Le Blanc transformer of the Taiwan railway system is measured to determine how it reduces the power supply capacity to the trolley. Improvements to the harmonic current in point-of-common-coupling (PCC) after adding the double-tuned filter to the load side [7]. Voltage regulation of railway systems was improved by using thyristor switched capacitor [8].

In recent years, many researchers have appeared in literature involving optimal planning. For example, an advanced computer code technique was used for single-tuned harmonic filter design [9]. The genetic algorithms have also been applied to locating and sizing of passive filters [10]. The PSO-NTVEOA has been applied to the optimal passive filter design [11]. This paper presents a positive approach in an optimized design of a combinatory unified power-quality conditioner (UPQC) and superconducting fault current limiters (SFCLs) based on a normalized simulated annealing algorithm compared with analytic hierarchy process

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objective optimization recently [12]. Distributed Generation (DG) based on renewable green energy is expected to grow at an unexpected rate. However increasing penetration of DG to the power grid has issued power quality of power system. A novel selective harmonic suppression method based on a robust PLL Algorithm is proposed and 10 kW prototype active power filter is set and verification experiment will be conducted with the nonlinear load [13].

There are rectifiers and inverters in the traction motor driving system on the train, and so the train produces harmonic current during operation. If there is no improvement for harmonic elimination, the harmonic current will flow to the utility system through traction substation, and influence the power quality. With regard to power factor and harmonic for railway system the passive filters are usually used to solve the problem. This paper investigates the harmonic filters planning of a power system of distributed generation system with three-phase to two-phase specially connected transformers using PSO-NTVEOA method to solve the harmonic problem due to nonlinear loads. First of all, an orthogonal array is first conducted to obtain the initial solution set. Second, this stochastic method of PSO-NTVEOA is then applied to design optimal harmonic filters in Taiwan HSR traction system considering various types of the traction transformers for single phase V–V, Scott and Le Blanc connection. Finally, the computation results show that the PSO-NTVEOA is a good method for filter design to mitigate harmonic distortions of the DG system with specially connected transformer.

2. Specially connected transformer scheme power system of Taiwan HSR

The single-phase electric supply of electrified railway is provided via single-phase or three-phase traction substations. The electric locomotives are basically considered single-phase loads in which the load conditions and speeds alter during every short span of time. Besides, non-linearity, asymmetrical, and non-sinusoidal are other characteristics of such single-phase loads. This results in an unbalance and harmonic load to the utility grid more than before. Special traction transformers, which are the V–V, Scott, and Le Blanc are usually applied to feed the traction loads and reduce the unbalance problem.

The V–V connection scheme is composed of two single-phase transformers. The transformer uses three-phase power on the primary side, and supplies two single-phase loads on the secondary side. Fig. 1 shows the circuit diagram of the V–V connected transformer. The voltages and currents relationships are got from Fig. 1 respectively, as follows:

$$\begin{bmatrix} V_T \\ V_M \end{bmatrix} = k_2 \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = k_2 \begin{bmatrix} 1 & 0 \\ -1 & 1 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} I_T \\ I_M \end{bmatrix} \tag{2}$$

where $k_1 = \frac{N_1}{N_2}$ and $k_2 = \frac{N_2}{N_1}$ denote the turn ratios of each phase. Fig. 2 shows the circuit diagram of the Scott connected transformer. It also transforms three-phase power to two-phase power. The main Transform (Phase M) has a middle-tapped winding on its primary side, and a single winding on its secondary side. The teaser transformer (Phase T) is a single-phase transformer. The voltages and currents relationships are, respectively:

$$\begin{bmatrix} V_T \\ V_M \end{bmatrix} = k_2 \begin{bmatrix} 2/\sqrt{3} & -1/\sqrt{3} & -1/\sqrt{3} \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = k_2 \begin{bmatrix} -2/\sqrt{3} & 0 \\ -1/\sqrt{3} & 1 \\ -1/\sqrt{3} & -1 \end{bmatrix} \begin{bmatrix} I_T \\ I_M \end{bmatrix} \tag{4}$$

The connection scheme of the Le Blanc transformer is shown in Fig. 3. The primary windings are the same as those of a common three-phase transformer in delta connection. The secondary side consists of five windings, which are separated into two phases. The voltages and currents relationships are, respectively.

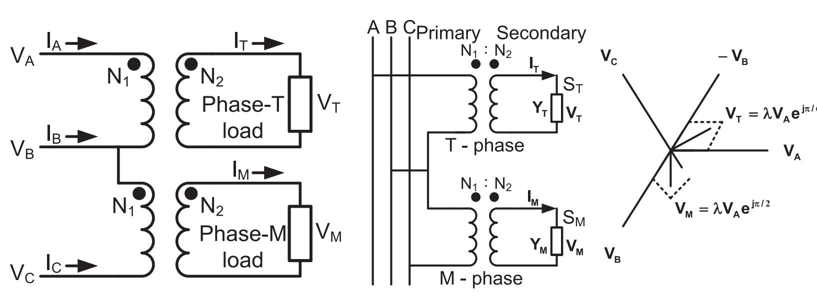

Fig. 1. V–V connection scheme.

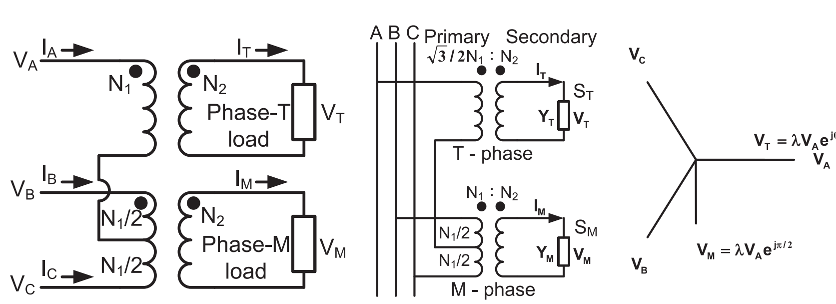

Fig. 2. Scott connection scheme.