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Implementation of the shunt harmonic voltages compensation approach

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ABSTRACT

Instead of injecting harmonic currents to compensate those drawn by distorting loads, in this paper a shunt active filter is used for generating harmonic voltages to compensate harmonic voltages at the point of common coupling; the main advantage in using such a compensation approach is that, when the aim is to reduce or eliminate the harmonic voltages at the point of common coupling only one active filter is required. For determining the harmonic voltages such a filter must generate, two simple and practical methods are proposed in this paper; the effectiveness of these methods was evaluated using a 1-kW prototype of an active filter operating according to the shunt harmonic voltage compensation approach. In addition, the laboratory results were comparable to those obtained with the ATP-EMTP simulation software.

1. Introduction

Shunt active filters have been proposed as a means to alleviate harmonic pollution in transmission/distribution systems. This use of shunt active filters (SAFs) is based on the principle underlying the shunt harmonic currents compensation approach (SHCCA) whereby harmonic currents are injected into the AC system through a current-controlled voltage source inverter so to compensate for harmonic currents drawn by a distorting load [1–7]. However, to compensate for harmonic voltages at a bus through SHCCA requires the use of an SAF for each distorting load or for each group of distorting loads connected at the same bus, a process which significantly increases overall costs and thus limiting the widespread use of shunt active filters as a means to reduce harmonic pollution.

In this paper an alternative approach to the SHCCA is discussed which, rather than injecting harmonic currents, uses an SAF to generate harmonic voltages to compensate harmonic voltages at the point of common coupling. Such a shunt harmonic voltage compensation approach (SHVCA), with an SAF operating as a harmonic voltage compensator (HVC), provides not only an efficient way to eliminate harmonic voltages at the point of common coupling, but is also highly cost-effective. In fact, the great advantage eliminating harmonic voltages via a voltage-compensation approach is that only one HVC is required to reduce or eliminate harmonic voltages at the point of common coupling since the HVC filters out all harmonic voltages detected at this junction; within the SHVCA, the HVC operates as a passive filter since HVC compensates all harmonic voltages, including those due to the distorting loads connected to the point of common coupling (PCC) as well as those arising from other loads that could influence the voltage at the PCC.

The advantage of compensating the harmonic voltages at the PCC via the SHVCA rather than the SHCCA can be illustrated using the radial distribution system shown in Fig. 1 whereby two distorting loads (connected at load buses 1 and 2) cause harmonic currents to flow through the feeders, thus distorting voltages at all the buses, including bus 3 where a sensitive and un-distorting load is connected. In order to safeguard the quality of power supplied to a sensitive load, a corrective measure must be implemented. With the traditional harmonic currents compensation approach, elimination of the harmonic voltage distortion at bus 3 requires a SAF for each distorting load, significantly increasing overall costs. Indeed, if only one SAF is installed at bus 2, this SAF compensates for only the harmonic currents drawn by Load-2 but the uncompensated current drawn by the Load-1 causes harmonic voltage drops on feeder-1 and, as a result, voltages at buses 2 and 3 remain distorted since the voltage at bus 1 is distorted. By analogy, if only one SAF installed at bus 1, this SAF compensates for only the harmonic currents drawn by Load-1 but the uncompensated current drawn by Load-2 causes harmonic voltage drops on feeder-1 and feeder-2, thus distorting voltages at buses 2 and 3. Depending on the network configuration and the responsibility of system operators and customers, installing only one SAF at bus 1 would compensate for both current harmonics of Load-1 and Load-2 but only for the current provided by the power system since the low quality of power supplied to the sensitive load would persist because the voltages at buses 2 and 3 would remain distorted due to the harmonic voltage drops on feeder-2. In the radial distribution system illustrated, an SHCCA would thus require two SAFs.

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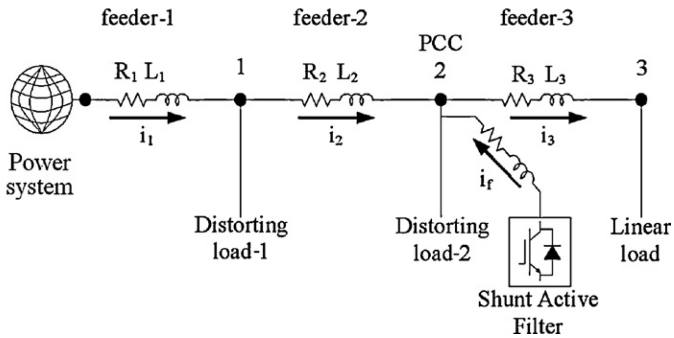

Fig. 1. A radial distribution system.

On the contrary, adopting the SHVCA where harmonic voltages are compensated via the generation of harmonic voltages instead of harmonic currents injection, only one SAF, operating as HVC and connected at bus 2, would be necessary since the elimination of harmonic voltages at bus 2 would also free the voltage at bus 3 of harmonics. While such an SHVCA approach is extremely advantageous, the optimal positioning of a single SAF requires calls for a systematic analysis as reported in [8]. In addition, only a few studies have investigated how to determine the intensity of the harmonic voltage which the HVC must generate in an SHVCA.

In this paper, the authors propose two methods which, using only the voltage detected at the PCC and independently by the SAF positioning, can determine the intensity of the harmonic voltages the HVC must generate to eliminate harmonic voltages at the PCC, rendering the single-SAF SHVC approach more efficient and cost-effective. The efficacy of the first method, an iterative method (Section 2.1), and the second, a voltage-sensitive method (Section 2.3), were evaluated using a 1-kW prototype of an HVC and results (Section 3) confirmed the effectiveness of both methods for implementing the shunt harmonic voltage compensation approach, with results comparable to those obtained with the ATP-EMTP simulation software.

2. Two methods for implementing the shunt harmonic voltage compensation approach

This section presents two methods for implementing the shunt harmonic voltage compensation approach, with both determining the harmonic voltages that the shunt harmonic voltage compensator must generate to compensate for disrupting harmonic voltages at the PCC. The first is an iterative method which uses the voltage measured at the PCC to iteratively update the amplitude and the phase of the voltage generated by the compensator. With this iterative method, convergence is not completely guaranteed and, when convergence is attained, the method could be is time-consuming depending on the network impedance. The second method is based on the sensitivity analysis of the voltage measured at the PCC with respect to the voltage generated by the HVC; this method is more complicated to implement than the iterative method but it is significantly faster and convergence is guaranteed.

2.1. The iterative method

An illustration of how the iterative method can compensate for the harmonic voltages at the PCC is illustrated in the linear electrical circuit shown in Fig. 2(a) whereby GRID A represents the electric power system subjected to harmonic pollution and GRID B represents the HVC used to compensate the harmonic voltages at the PCC; by referring to the Thevenin equivalent circuit at the kth harmonic (as shown in Fig. 2(b)) and by applying the Millmann theorem, the phasor representation of the voltage at the PCC can

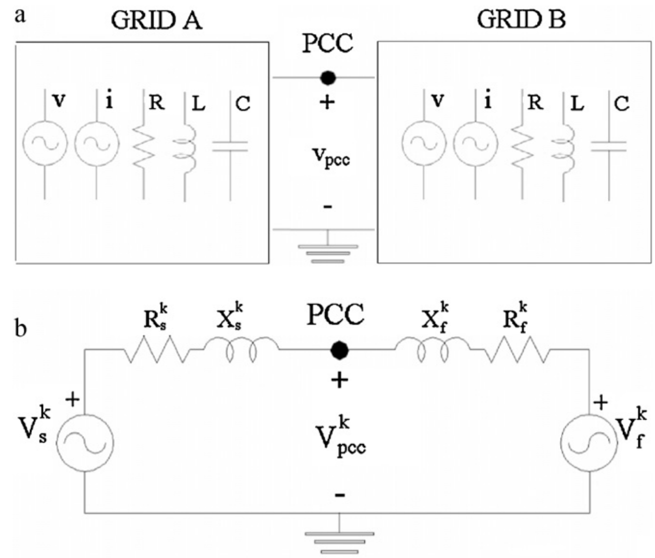

Fig. 2. (a) Two interconnected linear grids and (b) their Thevenin equivalent circuit at the kth harmonic.

be written as:

$$V_{pcc}^k = \beta^k V_f^k + \gamma^k V_s^k \tag{1}$$

where

$$\beta^k = \frac{Z_s^k}{Z_s^k + Z_f^k} \tag{1a}$$

$$\gamma^k = \frac{Z_f^k}{Z_s^k + Z_f^k} \tag{1b}$$

$$Z_s^k = R_s^k + jX_s^k \tag{1c}$$

$$Z_f^k = R_f^k + jX_f^k \tag{1d}$$

Eliminating harmonic voltages at the PCC bus means V_{pcc}^k must equal zero when $k \neq 1$. Therefore, in considering Eq. (1), the value of V_f^k must be set as:

$$V_f^k := -\frac{z_f^k}{z_s^k} V_s^k \tag{2a}$$

Unfortunately Eq. (2a) cannot be used to determine the voltage which the HVC must generate for harmonic compensation because V_s^k and z_s^k cannot be determined in practice [9]. On the contrary, since the voltage at the PCC can be easily detected, in place of Eq. (2a), the value of V_f^k can be set as:

$$V_f^k := V_f^k - V_{pcc}^k \tag{2b}$$

Obviously, the new value of the voltage at the PCC, corresponding to V_f^k as update in Eq. (2b), is not yet equal zero; by repetitively applying Eq. (2b), an iterative method which is able to annul V_{pcc}^k is thus obtained.