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An active resonance damper which avoids the estimation of the line characteristic impedance

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ABSTRACT

The authors propose an active power filter as a means to damp the harmonic resonance along the power distribution line. The main advantage of the proposed damper is that of avoiding the estimation of the characteristic impedance of the distribution line. The effectiveness and the robustness of the proposed damper are verified by computer simulation with Simplorer. A comparison with a well-designed damper proposed by others is also provided.

1. Introduction

In electric power systems, harmonic propagation indicates the amplification of voltage harmonics at buses of a power distribution system and transmission links; such a phenomenon is due to the harmonic resonance between the line impedance (usually inductive) and the capacitors used to compensate low power factor [1,2]. Harmonic propagation may deeply compromise power quality since the harmonic voltage distortion measured at the end of the distribution feeder, illustrated in Fig. 1, can be much more than the one measured in the beginning. So, due to the resonance phenomenon, all consumers connected to Buses 2–4 of Fig. 1 will suffer a low quality voltage, even though distorting loads are absent.Fig. 2

Modern active power filters used as a means to alleviate or eliminate harmonic propagation are called active resonance dampers (ARDs) [1–14]. ARDs inject harmonic currents so as to damp the harmonic propagation along the entire line and also reduce the overall harmonic pollution; such a reduction is a welcome by-product due to the fact that the amplitude of some harmonic bus voltages may worsen.

The main disadvantage in using ARDs is the necessity of estimating the characteristic impedance of the distribution line. Such an impedance might rapidly change due to the connection/disconnection of loads or shunt capacitors so its value must be calculated adaptively; the estimation of the characteristic impedance is not an easy task and it may give inaccurate values, so prejudicing the effectiveness of the ARD damping.

In [12–14] a high performing ARIMAX estimator has been proposed and tested; such an estimator requires only 5 cycles of the fundamental to give a valid estimation of the characteristic impedance of the distribution line.

In this paper the authors propose a new active resonance damper which avoids the estimation of the characteristic impedance of the distribution line; such a new damper is named harmonic voltage compensator (HVC) as it is designed to damp harmonic propagation by generating harmonic voltages instead of injecting harmonic currents (as the ARD does).

Two algorithms, which are useful in determining the harmonic voltages generated by the HVC, are also presented.

Section 2 presents a brief insight to previous active resonance dampers. Section 3 illustrates the HVC and both algorithms in detail. Section 4 concludes the paper providing computer simulation results which verify the effectiveness, the limits and satisfactory performance of the HVC.

2. The active resonance damper

In order to damp the harmonic propagation, i.e. the amplification of harmonic voltages due to the resonance between the series inductance and the shunt capacitance, the ARD is optimally placed at the end of power line [1,2] and operated as well as a 50 Ω-terminator in a signal transmission line. Thus the ARD must be designed to represent a resistor with a high resistance at the fundamental frequency and controlled resistance at the resonant frequencies.

The ARD injects harmonic currents determined as follows:

$$I^h_{\mathrm{ARD}} = kv * V^h_{\mathrm{PCC}} \quad (1)$$

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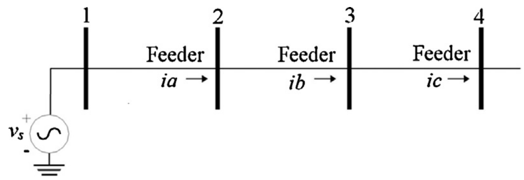

Fig. 1. A power distribution line.

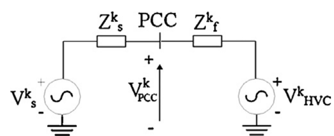

Fig. 2. Thevenin equivalent circuits at kth harmonic of the power distribution line and the HVC.

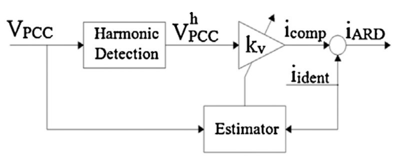

Fig. 3. The ARD control scheme.

where

- I^h_{ARD} is the current injected at the hth harmonic,
- k_v is a control gain,
- V^h_{PCC} is the voltage measured at PCC at the h harmonic,
- PCC is the point of common coupling,
- h indicates the resonance harmonic order.

The optimal value of the control gain k_{v} is given by the inverse of the characteristic impedance of the distribution line:

$$k_{\text{v}} = \frac{1}{Z_0} = \sqrt{\frac{C}{L}} \tag{2}$$

where L and C are the inductance and capacitance of the distribution line respectively [8].

Such a characteristic impedance may vary over time so the value of k_{v} should be estimated adaptively; obviously, this is not a trivial task.

Several on-line estimators of the optimal value of the control gain have been proposed in literature, among them in [12–14] an ARIMAX Least based parameter estimator, is presented and tested. Such an estimator demonstrated good performance as it requires only 5 cycles of the fundamental to return a satisfactory estimation of the distribution feeder parameters.

The ARD control scheme using the ARIMAX estimator for the adaptive control gain is illustrated in Fig. 3; a white noise (i_{ident}) is added to the compensating current i_{comp} for a better estimation of k_{v}.

3. The proposed active resonance damper

In order to avoid the calculation of the characteristic impedance of the distribution line, the proposed active resonance damper operates representing a resistor with a high resistance at the fundamental frequency and null resistance at the resonant frequencies.

So, the harmonic resonance damping is performed by eliminating the harmonic voltages at the PCC, i.e. the point of common coupling; hence, the damper proposed by the authors is a harmonic voltage compensator (HVC). The HVC eliminates the harmonic voltage distortion at the PCC by detecting only the PCC voltage and by generating harmonic voltages, (rather than injecting harmonic currents). These harmonic voltages are determined by using one of the two algorithms described in the following.

3.1. The iterative algorithm

Let us consider the two Thevenin equivalent circuits illustrated in Fig. 2 representing, on the left, the power distribution line at terminals of Bus 4 while, on the right, the proposed HVC. In order to eliminate the kth voltage harmonic at the point of common coupling, the voltage generated by the HVC is updated by using the following iterative algorithm:

```
1 Harmonic detection function: THD(V_PCC)
2 i: = 1
3 WHILE THD(V_pcc) > THD_ref DO
4     FOR each harmonic must be compensated DO
5         V^k_HVC_{i+1} := V^k_HVC_i − V^k_PCC_i
6     ENDFOR
7 ENDWHILE
8 i: = i + 1
```

where

- i is the iteration index;
- k is the harmonic order;
- $V^k_{\text{HVC}_i}$ is the voltage generated by the HVC;
- $V^k_{\text{PCC}_i}$ is the voltage detected at the PCC.

In this iterative algorithm, the statements at Step 1 detect the voltage harmonics at the PCC. The condition at Step 3 proves to be true when the measured harmonic content (e.g. the THD of VPCC) is greater than a reference value (THDref), so that all the statements from Step 4 to Step 8 are repeatedly executed. The FOR statement of Step 4 iterates all the harmonics determined at Step 1; the values of harmonic voltages that the HVC must generate are determined at Step 5 by subtracting the harmonic voltages measured at the PCC. This iterative algorithm is appealing and feasible for practical purposes as it is extremely simple and easy to be implemented; unfortunately, this algorithm should be time-consuming and convergence is not completely guaranteed [15].

To attain convergence, the amplitudes of V_{PCC} harmonics must decrease at each iteration:

$$\left|V^k_{\text{PCC}_{i+1}}\right| < \left|V^k_{\text{PCC}_i}\right| \forall i \tag{3}$$

Such a constrain, with easy mathematical calculations, can be re-written as:

$$\left|z^k_f\right| < \left|z^k_s + z^k_f\right| \tag{4}$$

so concluding that convergence of this iterative method depends on the value of Zs, i.e. the parameters of the power distribution line. Hence, the authors designed a more robust and faster algorithm illustrated below.

3.2. The sensitive algorithm

In order to provide a rapid and reliable algorithm, the authors designed a *sensitive* algorithm which updates the harmonic voltages generated by the HVC taking into account the variation of the voltage at the PCC between two consecutive iterations. This sensitive algorithm, as demonstrated in [15], requires only three cycles of the fundamental frequency to completely annul the total harmonic distortion (THD) of the voltage at the PCC when electrical