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Optimal control of shunt active power filters in multibus industrial power systems for harmonic voltage mitigation

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Abstract

The bus voltage and branch current detection control strategies of the active power filters used in industrial multibus power systems for harmonic voltage mitigation are analyzed and compared in the paper. The effectiveness of both the methods with real control gains is assessed in terms of the harmonic bus voltage mitigation and of the demanded current spectrum injected by the active power filters.

Keywords: Active power filter; Harmonic distortion; Optimization; Industrial network

1. Introduction

Active power filters (APF) have been analysed mainly in terms of operation principles, control algorithms, and performance characteristics [5]. Some analyses have been related with active filter compensation performance in power distribution systems [1–4]. The performance and effectiveness of the active power filter depends on the point of its connection.

The problem of an optimal location of active power filters and of current spectra injected by them and demanded for minimum harmonic voltage distortion has been formulated either as unconstrained or constrain optimization problem solved by analytical procedures [1], graphic methods [2], or by using some techniques suitable for very large scale optimization problems [3]. A strategy enabling us to exactly determine the most effective points of connections of active power filters in multibus power systems with distributed harmonic sources has been presented in Ref. [4]. Nevertheless, the question how to control active power filters to attain desirable effects of harmonic voltage mitigation remains still open.

The bus voltage and branch current detection control strategies of the active power filters used in multibus power systems for harmonic voltage mitigation are analyzed and compared in the paper. The steady state analysis of a power system configuration composed of a large number of buses where active current harmonics compensation performance

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should be optimized is done in the frequency domain. The analysis of basic principles of both the control methods applied in a multibus industrial power system is focused on the effectiveness of the methods in terms of the harmonic bus voltage mitigation and of the demanded current spectrum injected by the active power filters.

2. Circuit representation

Let us suppose that a circuit has n nodes and b branches. The voltages $V_N(i)$ at nodes are related to a reference node 0, which voltage $V_N(0)$ is set to zero ($V_N(0) = 0$). The vectors $\boldsymbol{V}_I$ and $\boldsymbol{I}_I$ represent voltage and current sources (injected voltages and currents).

We will analyse steady states in the frequency domain, so the following equations will be algebraic equations for voltage and current vectors (phasors) with frequency dependent matrix elements.

The whole circuit may be described by:

- $(n-1)$ equations (first Kirchhoff's law) for $(n-1)$ nodes

$$\boldsymbol{A}^T\boldsymbol{I} + \boldsymbol{A}_I^T\boldsymbol{I}_I = 0, \tag{1}$$

- b equations (Ohm's law) for b branches

$$\boldsymbol{I} = \boldsymbol{Y}(\boldsymbol{V} - \boldsymbol{V}_I), \tag{2}$$

- b equations reflecting the incidence among the branch and node voltages

$$\boldsymbol{V} = \boldsymbol{A}\boldsymbol{V}_N, \tag{3}$$

where $\boldsymbol{V}$ and $\boldsymbol{I}$ are vectors of the branch voltages and currents, $\boldsymbol{V}_N$ the vectors of the node voltages, $\boldsymbol{Y}$ the branch admittance matrix and $\boldsymbol{A}$ and $\boldsymbol{A}_I$ are the incidence matrices. The matrix $\boldsymbol{A}_I^T$ describes the distribution of the m currents $\boldsymbol{I}_I$ injected into individual nodes.

On the basis of Eqs. (1)–(3) we can obtain the matrix relation between $\boldsymbol{V}_N$ and the injected voltages $\boldsymbol{V}_I$ and currents $\boldsymbol{I}_I$. Let us suppose that the vector $\boldsymbol{I}_I$ of the m currents injected consists of the vector $\boldsymbol{I}_{IL}$ of m_L load currents and the vector $\boldsymbol{I}_{IF}$ of m_F APF currents. The APF currents should compensate the node voltages $V_N(i)$, $i = 1, \ldots, n$ induced by the injected currents $\boldsymbol{I}_{IL}$ and voltages $\boldsymbol{V}_I$

$$\boldsymbol{V}_N = \boldsymbol{Z}_{NIL}\boldsymbol{I}_{IL} + \boldsymbol{Z}_{NIF}\boldsymbol{I}_{IF} + \boldsymbol{H}_{NI}\boldsymbol{V}_I, \tag{4}$$

where $\boldsymbol{H}_{NI}$, $\boldsymbol{Z}_{NI}$ are the transfer matrices of the injected voltages and currents, $\boldsymbol{I}_I = (\boldsymbol{I}_{IL}, \boldsymbol{I}_{IF})^T$, $\boldsymbol{Z}_{NI} = (\boldsymbol{Z}_{NIL}, \boldsymbol{Z}_{NIF})$, $m_L + m_F = m$.

3. Control strategies

The control aim is to generate such a vector $\boldsymbol{I}_{IF}$ that eliminates, or at least decreases, the node voltages $\boldsymbol{V}_N$ at selected nodes ($\leq n-1$). For the full elimination of the harmonic voltages at all $(n-1)$ nodes we should apply $m_F = n-1$ APF currents, which values could be found by solving Eq. (4).

We need to compensate usually harmonic voltages in a few nodes only. In some cases we need to mitigate the harmonic voltage at one node (e.g. at an input bar of a distribution system) so that it could be compliant with standards, and to hold voltage harmonic spectra at remaining system nodes as low as possible.

3.1. Voltage detection feedback control strategy

The voltage detection feedback control strategy belongs among control strategies very often used for parallel APF applied in simple power distribution systems. We will analyse an application of this strategy in multibus power distribution systems with a few harmonic power sources.