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Power quality improvement in 3-phase 3-wire distribution systems using modular active power filter

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Abstract

Active power filters have been introduced for the purpose of power quality improvement. The power converter used as an active filter is rated based on the magnitude of the injected current and is operated at the switching frequency required to perform the filtering job successfully. Excessive losses are expected if the converter's power rating and switching frequency are both high. In this paper, an efficient and reliable active filter system for the power quality enhancement is proposed. The proposed filter is based on 3-phase PWM-controlled current–source converter (CSC) modules, where each filter module is dedicated to eliminate a specific harmonic and/or balance the line currents. Based on the information extracted from the line by the ADALINE, each leg of every CSC module is independently controlled to perform the balancing or/and harmonic filtering in a 3-phase 3-wire distribution system. As the harmonic order increases, the magnitudes of the harmonics decrease and their frequencies increase. Therefore, the power rating of the active filter modules will decrease and their switching frequency (bandwidth) will increase with the harmonic order. As a result, the overall switching losses are minimized due to balanced 'power rating-switching frequency' product. An economic study shows that the modular approach is superior to the conventional one converter scheme. Furthermore, the modular approach offers higher reliability, as the failure of one converter does not jeopardize the whole filtering mission. Speed and accuracy of ADALINE, self-synchronizing harmonic tracking, optimized dc-side current values and minimal converter losses are additional features of the proposed filter. The theoretical expectations are verified by digital simulation using EMTDC simulation package.

Keywords: Active power filter; ADALINE; CSC; EMTDC

1. Introduction

In AC distribution systems, active power filters have been used to improve electric power quality through harmonic mitigation [1–4], correction of voltage sags [4] and balancing the unbalanced line currents [5]. Almost all of the existing active power filters are realized by one single-phase or three-phase bridge converter [4]. The power rating and the switching frequency of the converter are determined by the magnitude of the distortion current and the desired bandwidth of the filter, respectively. The combination of high power and high switching frequency results in excessive amounts of power losses. Furthermore, the reliability of the existing active filters is a major concern, as the failure of the converter results in no compensation at all.

This paper proposes a novel active filtering scheme based on 3-phase PWM current-source converter (CSC) modules to mitigate the harmonic currents and to correct the line currents imbalance in 3-phase 3-wire distribution system. The proposed active filter system is composed of the extraction, computation and mitigation stages. First, the information on the line currents and voltages are extracted very accurately by adaptive linear neurons (ADALINEs) from the power-line signals. Then, the required corrective signals are calculated and finally, the compensating currents are produced by the CSC modules and injected into the 3-phase 3-wire system. Fig. 1 shows the block diagram of the operating stages of the proposed system. The proposed filter consists of several filter modules, each dedicated to eliminate a specific harmonic of choice. One filter mod-

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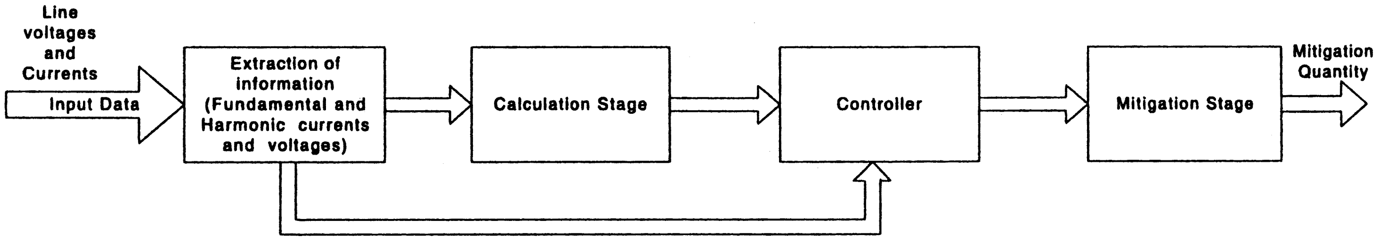

Fig. 1. The block diagram of the compensation principle of the proposed active filter system.

ule may be used to balance the unbalanced currents. Low conduction and switching losses, high reliability and flexibility, fast response, self-synchronization and accuracy of ADALINE and fast response and high efficiency of CSC are the main advantages of the proposed system. The performance of the proposed active power filter is found to be excellent in eliminating the line harmonics as well as balancing the line currents. The theoretical expectations are verified by digital simulation using EMTDC simulation package.

In the following sections, first, the principle of operation of the proposed filtering scheme is given. Then, a brief review of tri-logic PWM CSC will be presented followed by the system configuration. The method of harmonic extraction using an ADALINE is explained next followed by the evaluation of the proposed active filter. Finally, some digital simulation results from EMTDC simulation package are presented to verify the theoretical expectations.

2. The principle of operation of the proposed filtering technique

The operation of the proposed filtering method is based on:

1. the extraction of the fundamental and individual harmonic current components of interest using an ADALINE and estimating the fundamental components of the line voltages by another ADALINE,
2. calculation of the negative-sequence components of the fundamental line current, for each phase, and injecting equal-but-opposite of this component into the corresponding line using one CSC unit (for balancing the system), and
3. injecting equal-but-opposite of each harmonic component of each phase into the corresponding phase using a CSC module dedicated to that specific harmonic (for eliminating the harmonics).

The magnitudes of the harmonic currents decrease and their frequencies increase with harmonic order. Therefore, the converters dedicated to lower-order harmonics have higher ratings but are switched at lower rates, while those dedicated to higher-order harmonics are of lower ratings but are switched at higher rates. As a result, the overall switching losses are considerably reduced due to balanced 'power rating'–'switching frequency product and selected harmonic elimination. The control system utilizes two (ADALINEs) to process the signals obtained from the power-line. The ADALINEs' outputs are used to construct the modulating signals of the filter modules. The output current of each phase of each filter module can be independently controlled using the tri-logic PWM switching strategy [6] provided that the instantaneous currents in the three phases add up to zero. For each phase, the two ADALINEs continuously track the line current harmonics and line bus voltage as well as the system frequency and turn over this information to the controller of the CSC modules [9]. The ADALINEs have the ability to predict accurately the fundamental and harmonics of the distorted signal in case of frequency drifting. In this method, a sophisticated software (the ADALINE-based controller) is developed to reduce the operating cost and increase the flexibility of the proposed filter system. The current and voltage ADALINEs are realized by calling a common subroutine, the ADALINE algorithm which is explained in Section 5.

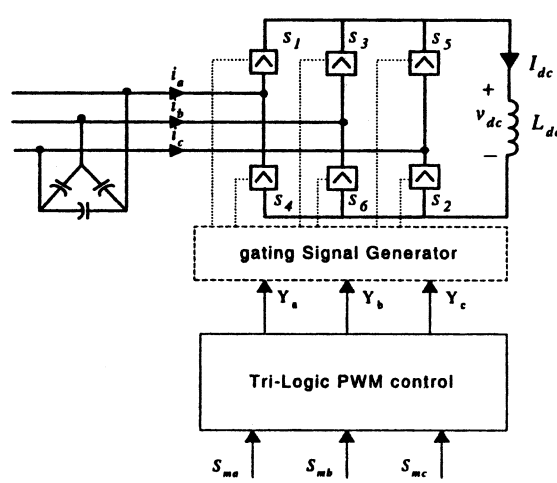

Fig. 2. Current source converter with tri-logic PWM control.