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Direct neural method for harmonic currents estimation using adaptive linear element

L. Merabet[a], S. Saad[a,*], D. Ould Abdeslam[b], J. Merckle[b]

[a] Laboratoire Systèmes Electromécaniques Badji-Mokhtar University, BP 12, Annaba 23000, Algeria
[b] MIPS laboratory, Université de Haute Alsace, 4 rue des frères lumière, 68093 Mulhouse, France

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ABSTRACT

The use of nonlinear loads has increased in power systems consequently the harmonic currents have also increased causing detrimental effects to the supply system and user equipment. The aim of the present paper is to identify harmonics in order to obtain a perfect compensation by active power filter (APF). A study of harmonic currents identification by two different methods is conducted in this work. The instantaneous power (PQ) theory method requires two low-pass filters for the extraction of direct power components from total power components. However the direct neural method based on ADALINE neural network method estimates total harmonic current as well as harmonic components separately. Moreover, the identification of each component separately enables the selective compensation of harmonics by the active filter if the objective is to minimize the cost. The method is easy to implement in real time compared to PQ method.

In present paper two algorithms based on conventional PQ method and direct neural method were developed in order to identify the harmonic currents. These developed algorithms are confirmed by experimental tests by implementing these techniques in a dSPACE controller in order to show their effectiveness. The obtained results are compared, discussed and analyzed.

1. Introduction

The development of power electronics, the rising powers involved and the flexibility of using semiconductors, have encouraged electrical engineers to undertake significant associations of static power converters with electric machines. These devices are non-linear loads, producing non-sinusoidal current and behave as harmonic generators. Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency. If the fundamental frequency is 50 Hz, the third harmonic is 150 Hz, the fifth 250 Hz, etc.

Some examples of harmonic producing loads are rectifiers, electric arc furnaces, static VAR compensators, inverters, DC converters, switch-mode power supplies, printers, Fluorescent lighting, battery chargers and also variable-speed drives. The voltage provided by the source will be distorted by harmonic currents due to the source impedance. If the source impedance of the voltage source is low, harmonic currents will cause only small voltage harmonics. Therefore, the voltage in the point of common coupling will contain harmonic components. The distorted voltage can than affect other loads that share a transformer or branch circuit with the original harmonic load.

Furthermore, harmonic voltages and currents propagate into the supply system, increase losses, generate measurement errors, interfere with other consumers, and cause serious problems of electromagnetic compatibility [1]. One of the major effects of harmonics is the increase of the current in the power system. This is particularly the case for the third harmonic, which causes a sharp increase in the zero sequence current, and therefore rises the current in the neutral conductor.

IEEE Std. 519-1992 titled “IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems”, is the main document for harmonics limitations in North America. This standard serves as an excellent tutorial on harmonics. It puts limits on individual and total distortion for harmonic currents. The Point of Common Coupling (PCC) is generally defined as the utility/customer connection point. It is at this point that the current distortion limits are applied. These harmonic current limits change depending on the ratio of short circuit current to maximum demand load current at the PCC.

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* Corresponding author. Fax: +213 38871168.
E-mail addresses: lei_elt@yahoo.fr (L. Merabet), saadsalah2006@yahoo.fr (S. Saad), djaffar.ould-abdeslam@uha.fr (D.O. Abdeslam), jean.merckle@uha.fr (J. Merckle).

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A deterioration of the current waveform implies the presence of harmonics thus several solutions were studied and proposed to solve this issue. The use of passive filters is the most common solution, but the effectiveness of this technique depends on the network impedance, which itself is subject to change. Moreover, the passive filter forms with the inductance of the source, a resonant circuit that produces amplification of any harmonic having a frequency close to the resonance frequency. Therefore the solution of active power filter is the most used technique for harmonic suppression. At the moment, many active filter topologies are used such as series, shunt, hybrid filters and Unified Power Quality Conditioner UPQC [2].

Pulse Width Modulated (PWM) rectifier is another mean to reduce harmonic currents in the power system. Implementing PWM control of the inverter switching devices allows the elimination of a number of harmonics and respecting the IEEE Std. 519-1992 recommendations.

Several control methods such as sliding mode control [3], fuzzy control [4,5], adaptive neural network control [6], neuro-fuzzy control [7], and fundamental magnetic flux compensation [8], have been proposed and used to control harmonic currents and dc voltage of power filters. These controllers are also employed to improve active power filter performances and replace the conventional PID controllers.

A perfect compensation is necessary to avoid the consequences due to harmonics. Therefore the estimation of harmonic currents is an important part in the control of active power filters (APFs) used in power systems. During the last decays, many identification techniques and strategies have been developed such as methods based on FFT (Fast Fourier Transformation), wavelet method [9–11], and Kalman filter [12,13]. Instantaneous active and reactive powers (p–q theory) introduced by Akagi [14], is a well-known compensating strategy. This method requires the transformation of both supply voltages and load currents from the abc reference frame to the α–β reference frame. This method operates very well for harmonics cancellation and reactive power compensation, simultaneously, under balanced source voltages.

Artificial neural networks have emerged in 1943 during model testing the biological neuron Mcculloch and Walter Pitts. However, researchers from many scientific disciplines are developing and designing artificial neural networks (ANNs) to solve problems in pattern recognition, prediction, optimization, associative memory and control [15]. The application of intelligent techniques in the field of electrical systems is recent. Artificial neural networks are successfully applied to power systems [16,17], especially for harmonic extraction [18–22].

Neural networks can greatly reduce both the computation time and the response time which is an important gain. In addition, it does not need the system model for identification. The ADALINE (ADAptive LINeaire Element), which is a type of ANNs, and its new application for analysis of power quality, has the advantages of being simply built and easily implemented through hardware. The results of frequency tracking, [23–25] and especially harmonics detection, demonstrate that the ADALINE and its algorithm can be applied to the precise analysis for power quality. The learning capacity of the ANNs enables online adaptation to any change in electrical network parameters.

Many applications, such as harmonic monitoring may require the extraction of a limited number of individual harmonics as the 5th and the 7th harmonics because they are the most harmful. The ADALINE proposed by Widrow and Lehr [26], can estimate the harmonic terms individually as well as online.

The previous work conducted by the authors of the present paper [21] compares the classical PQ method with the diphase currents neural method. These two methods are applicable only for a three-phase network. Moreover, the PQ method requires a transformation of the currents and voltages from abc frame to $\alpha\beta$ frame. Whereas diphase currents neural method requires a transformation of the currents from abc frame to Park system.

In this paper the classical PQ method is compared to the direct neural method. This method identifies the harmonic content rejected by non-linear loads connected to a single-phase or three-phase network. The identification of the harmonics is done for each phase separately in the abc frame without going through another frame. This method can identify the harmonic content of all domestic loads connected to the network. The particularity of this work is the validation of three experimental tests carried out on three types of nonlinear loads:

- A three-phase diode bridge rectifier fed by a three-phase balanced network (three-phase load connected to three-phase network).
- A microcomputer (single-phase load connected to a single-phase network).
- A fluorescent lamp (single-phase load connected to a single-phase network).

The results demonstrate that the Direct Neural method is more efficient and easy to implement.

2. Principle of shunt APF

The shunt APF is a voltage source inverter connected in parallel to three-phase lines through the inductor (Fig. 1). This inverter injects an appropriate current into the system to compensate harmonic currents that are responsible for power network pollution. Shunt active power filter has two main parts. The first part generates the reference current deduced by harmonic current identification algorithm. The second part consists on providing the control signals in order to re-inject in opposite-phase the compensating currents, Fig. 1. When the PQ theory for harmonic current identification is used we must introduce a phase looked loop (PLL) to obtain the direct voltage components if the power system is unbalanced.

The rectifier can be thought as a harmonic current source and produces roughly the same amount of harmonic current over a wide range of power system impedances. The characteristic of harmonic currents that are produced by a rectifier are determined by the pulse number. The following equation allows the determination of the harmonics for a given pulse number:

$$h = kp \pm 1$$

where:

h: Is the harmonic order (integer multiple of the fundamental).
k: Is any positive integer.
p: Is the pulsation index of the rectifier.

This means that a 6-pulse (or 3-phase bridge) rectifier will exhibit harmonics at the 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, etc. multiples of the fundamental. As a rough rule of thumb, the magnitudes of the harmonic currents will be the magnitude of the fundamental current divided by the order of the harmonic (e.g. the magnitude of the 5th harmonic would be about 1/5 of the fundamental current).

3. Instantaneous power theory (p–q theory)

The compensation is accurate if we identify the harmonic current through the powers and specifying all the unwanted powers. Knowing that the active power consists of two components DC and AC, the direct component is useful because it contributes directly to the active energy consumption. On the other hand, alternative component is not useful and induces adverse effects such as heating