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An Efficient Control Method of Shunt Active Power Filter Using ADALINE

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Abstract: This paper deals with the problem of reference signal generation for Shunt Active Power Filter (SAPF) capable of reducing the Total Harmonic Distortion (THD) in power system using Adaptive Linear Neuron (ADALINE). The important issues associated with adaptive control methods are convergence speed, steady state error, stability, and computational resource requirements. These issues will be addressed in the paper. The reference signal generation (simulations using real data) is based on virtual instrumentation using the LabVIEW developmental environment and its associated data acquisition measurement cards (DAQmx). The results revealed that control method of SAPF using ADALINE work properly in the dynamic condition and moreover among which the ADALINE works slightly better than other commonly used methods (LMS - Least Mean Squares and RLS - Recursive Least Squares).

Keywords: Adaptive Linear Neuron Shunt; Active Power Filter; Total Harmonic Distortion; Virtual Instrumentation; LabVIEW.

1. INTRODUCTION

In modern low voltage network (Rahmani et al., 2010), non-linear consumers (Massoud et al., 2014) are being increasingly used, so the network does not have sinusoidal current. This waveform is formed by a sinusoidal current whose frequency corresponds to the network frequency, and higher harmonic currents whose frequencies are multiples of the network frequency. Network impedance causes voltage outages at these frequencies, all harmonic or higher harmonic cause network supply load. These unwanted harmonics cause (Ghosh et al., 2012):

- *Interference* – harmonic generating devices significantly reduce the quality of the network. Electronically controlled devices may then be interfered by the harmonics, leading to their outages or reporting inexplicable errors.
- *Retroactive effects on the purity of the network* – if the higher harmonic currents in the network increase the currents of weakened supply middle voltage network, then the harmonic interference can also influence the surrounding network which itself does not have non-linear consumers.
- *Overloaded neutral conductor* – direct power supply for electronic devices, TVs, PCs, PC peripherals, and energy-saving lights is the source of the highest proportion of currents of the 3rd and 9th higher harmonics, the risk represents overloading the neutral conductor e.g. at large office buildings; see (Agrawal, et al., 2014).
- *Warming* – transformers, motors and generators by the vibrations of iron core, thus substantially increasing power dissipation. The effect of flickering computer screens due to voltage drop in the neutral conductor of four-conductor network.
- *Worsening of power factor l*; see (Bartnikas, et al., 2011).
- *Overloaded cables by skin-effect;* see (Agrawal, et al., 2000).

This article deals with Active Harmonic Compensation (AHC) while being primarily focused on SAPF adaptive control methods; see (Martinek, et al., 2013a); (Martinek, et al., 2015a), (Martinek, et al., 2015b), (Martinek, et al., 2015a). Thus controlled systems are designed to improve power quality. The paper deals with the problem of reference signal generation for SAPF capable of reducing THD (Jang, et al., 2004) in power system using ADALINE (Bhattacharya, et al., 2011). The system examined by the authors can be used for non-linear loads for appliances with rapid fluctuations of the reactive and active power consumption. The pro-posed system adaptively reduces distortion, falls (dip) and changes in a supply voltage (flicker). Real signals for measurement were obtained at a sophisticated, three-phase experimental workplace (6834B AC Power Source/Analyzer, 4500/1500VA, 150/300V, 30/15A, see (Agilent 6834B Specifications)).

The results revealed that control method of SAPF using ADALINE work properly in the dynamic condition and moreover among which the ADALINE works slightly better than other commonly used methods (LMS - Least Mean

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Squares and RLS – Recursive Least Squares, see (Martinek, et al., 2015b).

Results of experiments with ADALINE are compared to the results of studies see (Martinek, et al., 2015b) and (Martinek, et al., 2013a), where the results of SAPF adaptive control using adaptive algorithms LMS and RLS were presented. The achieved results are evaluated both in terms of the implementation of adaptive control methods (convergence speed, steady state error, stability, and computational resource requirements), and in terms of THD.

This article does not address the own SAPF hardware implementation in more detail, this issue is very comprehensive and is dedicated numerous publications to, such as (Rahmani, et al., 2010), (Asiminoaei, et al., 2008), and (Tang, et al., 2012). The article primarily focuses on Adaptive Control Method (ACM), (Martinek, et al., 2015a) and (Martinek, et al., 2015d) particularly from the perspective of examining the performance of used adaptive methods.

2. CURRENT STATE OF THE TOPIC

Ideally, the best electrical supply would be a constant magnitude and frequency sinusoidal voltage waveform. However, because of the non-zero impedance of the supply system, of the large variety of loads that may be encountered and of other phenomena such as transients and outages, the reality is often different. The Power Quality of a system expresses to which degree a practical supply system resembles the ideal supply system (Schipman, et al. 2010):

- If the Power Quality of the network is good, then any loads connected to it will run satisfactory and efficiently. Installation running costs and carbon footprint will be minimal.
- If the Power Quality of the network is bad, then loads connected to it will fail or will have a reduced lifetime, and the efficiency of the electrical installation will reduce. Installation running costs and carbon footprint will be high and/or operation may not be possible at all.

Is a worldwide tendency to move away from passive filtering (Tang, at al., 2012) solutions in favour of active filtering solutions in LV and MV applications, see (Schipman, et al. 2010), (Rahmani, et al. 2010), and (Bhattacharya, et al. 2011). Most commonly found active filters are power electronics based electrical equipment that are installed in an installation on a parallel feeder to the polluting loads, see figure 3.

An active filter consists of a power stage and a control system:

- The power stage typically uses an IGBT-based PWM inverter (Schipman, et al. 2010), coupled to the network through a coupling circuit. The IGBT switches are controlled in such a way to amplify the control signals representing the compensating currents and voltages. The coupling circuit contains an output filter section, which acts as a low-pass filter absorbing the high frequency switching components created by the PWM inverter, leaving the compensating harmonic currents to flow.
- The control system relies on current measurements to obtain information on which harmonics are present in the network. The filter control system then calculates the control signals, which represent the compensating current to be injected into the network. These control signals are finally sent to the PWM inverter, which amplifies and couples them to the supply network (Konecny, et al., 2015).

3. ADAPTIVE LINEAR NEURON - ADALINE

Figure 1 shows an adaptive threshold element, a key component in adaptive pattern recognition systems. It consists of an adaptive linear combiner cascaded with a quantizer. The output of the Adaptive Linear Combiner – ALC (Widrow, at al. 1988) is quantized to produce a binary “decision.” Most often, the inputs are binary and the desired response is binary. As such, the adaptive threshold element is trainable and capable of implementing binary logic functions. The LMS algorithm (Martinek, et al., 2015e) was originally developed to train the adaptive threshold element of figure 1 (Widrow, at al. 1988). This element was called an adaptive linear neuron or Adaline (Widrow et al., 2015) and (Prauzek, et al., 2015), see figure 1. The adaptive threshold element was an early neuronal model. The adaptive weights were analogous to synapses. The input vector components related to the dendritic inputs. The quantized output was analogous to the axonal output. The output decision was determined by a weighted sum of the inputs, in much the same way real neurons were believed to behave (Martinek, et al., 2015c).

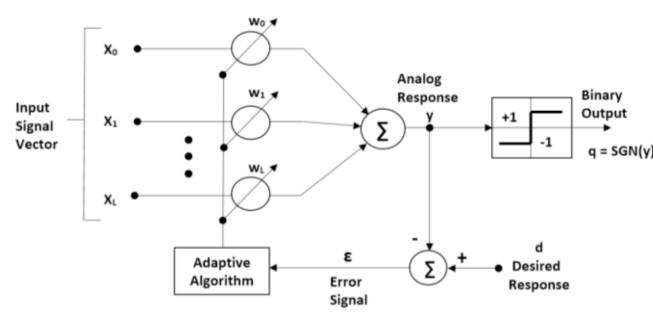

Fig. 1. Adaptive threshold element (Adaline).

Figure 2 shows an ADALINE system used in this paper, see (Jindapetch, at al., 2012) and (Han, at al., 2013). The measurable signal (input signal vector) is composed of signal (s) plus noise (n_0), i.e. ($s + n_0$). There is no need for external reference signal in the system because the delay version of measurable signal (n_1) is used as a reference. The output signal from the adaptive ADALINE filter is an estimation of the noise signal n_0. The error signal (e) is used for adjusting weight (w) and bias (b) of the adaptive filter based on LMS or RLS algorithm. When the algorithm converges, we can reduce the noise signal from the measurable signal, i.e., $a \cong n_0$ and $e \cong s$. This algorithm can work well when the noise signal is periodic and the signal is aperiodic (Jindapetch, at al., 2012).
The functions of a, e, w, and b are calculated as follows (Jindapetch, at al., 2012):

$$a(k) = w_1(k)p_1(k) + \cdots + w_{(N+1)}(k)p_{(N+1)}(k) + b. \quad (1)$$