DEVELOPMENT OF A LESS COMPLEX SINGLE PHASE ACTIVE HARMONIC FILTER

S. M. Bashi, N. Marun, M. A. M. Radzi and E. S. Ling
Department of Electrical Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor

ABSTRACT

Harmonic pollution has become a serious problem in recent years. Harmonic is introduced into power systems due to non-linear loads or system components presenting non-linear behavior. An active power filter is one of the important methods of minimising the effects of the harmonic. However, active harmonic filter usually requires some complicated algorithm for implementation. Therefore, this paper presents the work on design and development of a new approach of active harmonic filter. The designed active harmonic filter is less complex compared to other conventional active harmonic filters. It works by injecting the inversion form of the harmonic into the main line, this result to a lower value of harmonic content. In other words, the harmonic component needed by the non-linear load is provided by the active filter rather than the AC source.

Keywords : *Active Filter, Current, Harmonic, Non-Linear Load, Voltage*

1.0 INTRODUCTION

The power quality issue is becoming increasingly important to electrical utilities as well as to industrial and domestic consumers and this has drawn increased attention over the past few years [1]. This is due to the fact in recent years, there is an increase in the number of system loads and controls that are sensitive to power quality, as well as an increase in the number of system loads that are themselves a source of poor power quality. Due to the energy conservation efforts and the need for continuous control of certain industrial processes have led to an increase in the number of electrical or electronic equipment and motor drives. Process automation involving the extensive use of electronic and digital control systems is also common in modern industrial plants. The increasing usage of power electronic devices to provide more precise control of electrical power has brought about an increase in the distortion of voltage and current waveforms in many plants. Power quality refers to the degree in which voltages and currents in a system represent sinusoidal waveforms. In other words, power quality can also be referred to as the consistent flow of power to the electrical equipment.

A major issue in the power quality area is supply voltage variations. Poor voltage wave forms, due to harmonics or transients, low voltage or over voltage conditions and unbalanced load in the network can lead to unnecessary and costly disruptions in production. Distortions to voltage and current waveforms may be caused by either transient or continuous disturbances. Transient disturbances include voltage spikes due to lightning and switching surges, and voltage dips due to motor starting. These transient disturbances typically last for only a few cycles.

On the other hand, concern over harmonic distortion being generated by non-linear loads has been on the increase. It is estimated that more than 60 percent of electricity now passes through non-linear loads. These loads are highly nonlinear and they inject harmonic and reactive current to the grid, resulting in lower power factor, lower transmission efficiency, and harmful disturbance to other appliances. Ironically, the equipment used to boost productivity and efficiency is generating a tremendous increase in non-productive power consumption, power pollution and low-power factor. In addition, the same equipment that produces the resultant harmonic distortion is also the most susceptible to damages from it.

This paper covers the design of an active harmonic filter by using the idea of measuring the current that is flowing to the load and extracts the harmonic signals. These signals are then inverted and amplified before they are injected back into the power supply to cancel the harmonics, which results in cleaner sinusoidal currents being drawn from the power supply. The designed active filter has been tested to reduce the harmonic content in the DC load. It managed to reduce the harmonic content to lower level, where the lower level is determined by the efficiency of the filtering process in sampling the harmonic signals. This designed active harmonic filter is working as desired for input source voltage less than 20V. However, it still needs to be improved for working at higher rating.

2.0 THE ACTIVE FILTER IN VARIETY OF APPLICATIONS

In the real applications, there are a lot of active filters developed due to their requirement and need in order to solve harmonics problem. Several active filter systems have been proposed to mitigate harmonic current of industrial loads. Pure series and shunt filters are suitable for small-rating nonlinear loads.

In order to develop a low rating and low bandwidth requirements of the active filter inverter, the Dominant Harmonic Active Filter (DHAF) prototype has been developed. The DHAF system achieves harmonic isolation at the dominant harmonics using square-wave active filter inverters [2].

Hybrid series and hybrid shunt active filters, which are characterised by a combination of passive L-C filters and active filters, are cost effective and practical for large-rated non-linear loads. The trend seems to be using combined active filter and passive filter rather than passive filter alone. Such a system reduces initial costs and improves efficiency [3]. The hybrid filters are attractive from both practical and economical points of view, in particular, for high-power applications [4].

In HVDC systems, the limits for harmonics are continuously decreasing and it is anticipated that in the future this system will not be feasible without active filters. The use of DC active filters offers essential advantages in performance and costs, especially if the required performance limits are low [5].

A novel hybrid filter topology and its control have been developed to prevent such harmonic currents from entering the power system [6]. The system consist of a passive filter network, a power electronic converter operating in a current-controlled mode, a static switch consisting of two back-to-back connected thyristors and an MOV for protection.

Active AC filter has been also designed to be used in HVDC converter stations [7]. In this technology, the active filter decouples the reactive-power supplying and filtering tasks that have been characterising the traditional HVDC passive AC filters.

An alternative control strategy using a number of notch filters has been introduced into the active DC filter in the Lindom Converter Station [8]. These filters can be tuned at those frequencies that need to be damped. This controller gives shorter system response time and improved stability margin.

Most active filter topologies are complicated and require active switches and control algorithms, which are implemented using IGBT or Digital Signal Processing (DSP) chips. The active filter topology also needs current and voltage sensors and corresponding Analog to Digital (A/D) converters. This extra hardware increases the cost and component counts, reducing the overall reliability and robustness of the design.

Based on the conventional active harmonic filter and the latest development of the active filter, the research on the harmonic filter is mainly on the algorithm of the active filter, harmonic extraction method and current injection method. Similarly, in this work, the designed active harmonic's topology is similar to the conventional active harmonic filter but the difference is the method used by injecting the current into the main line. The method of extracting the harmonic signal from the load current used in this project is by using a current transducer, which acts as a source voltage for RLC filter. Thus the harmonic signal is across the resistor R in the RLC circuit. Meanwhile, the injection method adopted in this project is a Class A amplifier. No complicated algorithms is used to implement this filter. However it also bears a number of disadvantages compared to other method.

3.0 DESIGN SPECIFICATION

In order to start the designing process of this filter, the specifications of the filter were determined. First, it works like other conventional active harmonic filter where it introduces the harmonic current into the main current to cancel the harmonic created by the nonlinear load. However, it does not require complicated algorithm, only a few formulas are involved for filtering, voltage regulation, amplification and current injection. As it does not require a complicated algorithm so the complexity of the entire circuit is reduced.

The general idea of the designed filter is shown in the Figure 1. At first, the current in the main line is measured instantaneously using a current transducer with its output in the form of voltage proportional to the current in the main line. The voltage is then utilised to extract the sample of the harmonic component in the main current by using a RLC filter where the circuit is tuned to 150Hz or equivalent to third harmonic. The reason of reducing the third harmonic is because it has the highest magnitude in a single-phase load. In the RLC filter, circuit sample of the harmonic is available across the resistor R. The signal is then fed into an inverting amplifier for voltage regulation and inversion of the signal or in other words 180 degree phase shift.

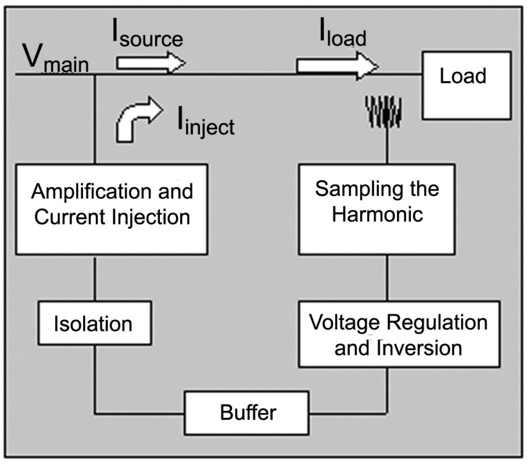

Figure 1: General block diagram of the designed active filter

The following stage is buffering, where before the signal is fed into the class A amplifier, the signal needs to be buffered so that it will be capable of supplying the input signal to the class A amplifier. Isolation circuit is required in order to isolate the control circuit from the power circuit and also to isolate the DC bias of the transistor in the next stage from affecting the operation of the amplifier.

The signal is amplified in the last stage while injecting the current in the inversion form of the existing harmonic order into the main line. So the resultant of the current in the main line is the sum up of these two current components. In other words, the harmonic component needed by the non-linear load is provided by the active filter rather than the AC source. The expected result of the current injection is that magnitude of third harmonic current will be lower.

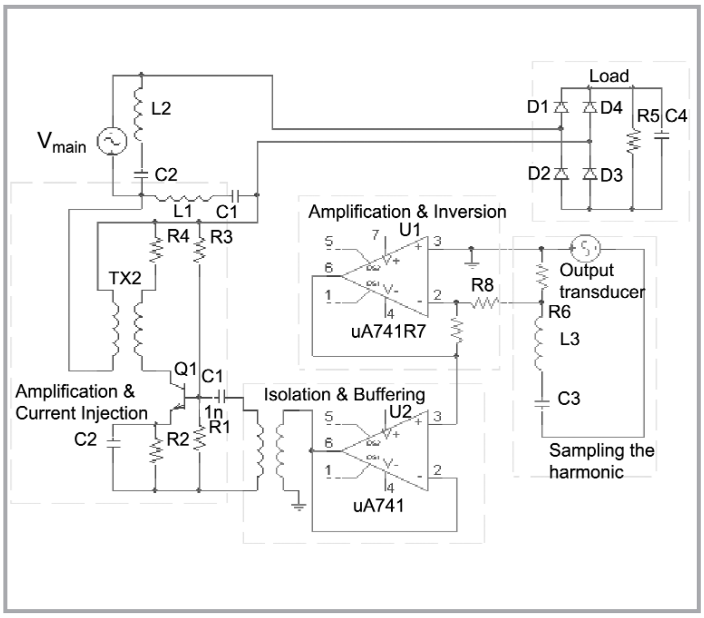

Figure 2: Schematic of the entire designed circuit

4.0 EXPERIMENTAL SETUP

The entire circuit of the active harmonic filter is shown as in Figure 2. The first step is to measure the current of the main line so that the sample of the harmonic content is measured instantaneously. The Hall effect current transducer PCB mounting is used, where it provides output voltage option that is proportional to the current measured. A narrow band pass filter is designed based on the quantitative analysis for determination of the appropriate component values.

For the purpose of inverting and amplifying of the harmonic signal, amplifier model mA741 is used. This amplifier is used for two functions; as an inverting operation amplifier and a voltage follower operation. After filtering out the harmonic content of the desired order, the harmonic signal sample is then fed into an inverting operation amplifier where the signal is inversed or shifted 180 degree and in the meantime the amplitude of the signal is then amplified to a desired level.

After the amplification, the signal is then buffered using a voltage-follower where the three buffers are connected in parallel to increase the maximum current. In this work, the three parallel buffer connected in parallel still do not meet the requirement of the input signal range 0.05-0.1A as an input signal current to the class A amplifier. So, a high-voltage/high-current OPA544 operational amplifier is added as a non-inverting operation amplifier in order to amplify the signal to higher amplitude since a step-down transformer is used to isolate the control circuit from the power circuit and also to isolate the DC bias of the transistor from affecting the operation of the non-inverting amplifier.

In the last stage, the amplification of the input signal is done by using a class A amplifier configuration. The amplified voltage is induced in series with the input voltage by using a series transformer by connecting the secondary winding in series with the input voltage.

HARMONIC CURRENT

The result is yielded by measuring the load current and input voltage of the circuit with voltage source of 10V that is connected to a DC load of 15 ohm by using the 3166 Clamp-On Power Hitester. The results of the harmonic current and voltage of the nonlinear load contain all the waveform of the current and lists of the harmonics in odd order for voltage and current.

The data is analysed by using Harmonic Data Analysis Utility Program. The data is listed up to 13th order of harmonic and the rest order that is not shown is due to the value of these orders is negligible. As the filter is designed to reduce the third order harmonic, only the value of the third order will be highlighted during the discussion.

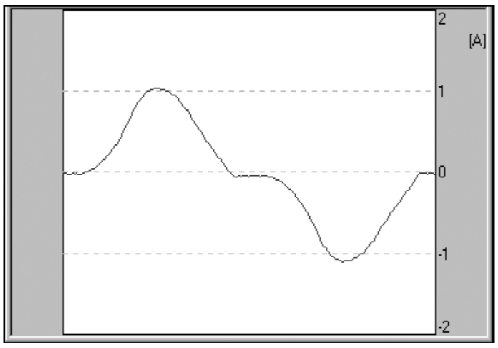

Figure 3: Waveform of the load current before turning on the active filter

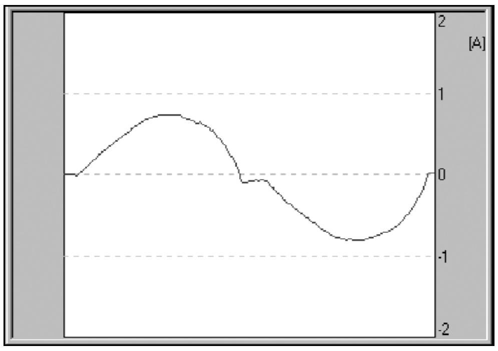

Figure 4: Waveform of the load current after turning on the active filter

The waveform of the load current also shows the difference before and after turning on the active filter. From the waveforms shown in Figures 3 and 4, the waveform of Figure 4 is improved into a better of shape of Figure 3 that is nearly to a sinusoidal waveform when the active filter is turned on.

HARMONIC VOLTAGE

The waveform of the voltage is also considered in the measurement as shown in Figures 5 and 6. From the observation of Figures 5 and 6, input voltage distortion becomes less when the active filter is turned on, since the waveform of the Figure 6 has a shape more linear than the Figure 5 although it is not obvious. The distortion can be found

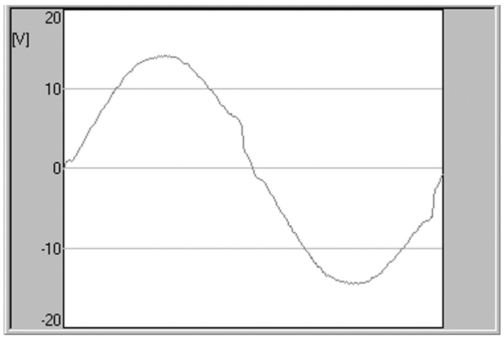

Figure 5: Waveform of the input voltage before turning on the active filter

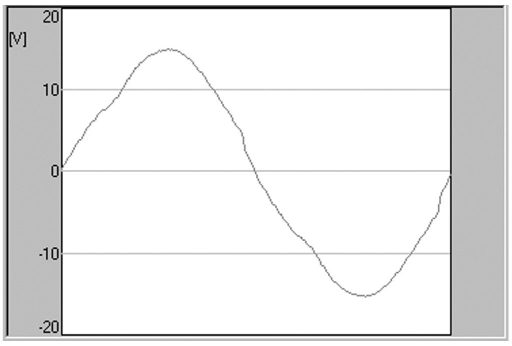

Figure 6: Waveform of the input voltage after turning on the active filter

from the following analysis.

6.0 CONCLUSIONS

This work is planned to design the harmonic active that minimise the harmonic content in main line by introducing the inversion form of the harmonic without using any complicated algorithm. In other words, it is working like other conventional active filter to minimise the harmonic but require a few simple calculation or simpler circuit.

According to the result, the objective of minimising the harmonic content is considered as a success but the section of the rating of the active harmonic filter has failed to increase to a higher voltage although the higher current with the same input voltage is still working well. One of the reasons for the filter to fail to work at the higher input voltage is the series winding voltage drop across it from the V_{main} appears to be very high on the primary side since transformer works to step up the voltage drop by the amount of the turn ratio in this way, which affects the operating amplifier. The second reason is the AC gain to the load is limited by the parameter (a *RL*/*re*) where the *RL* and *re* is fixed and the value of (*a*) cannot be too high.

Another weakness of this filter is that the LC circuit is added to bypass the tuned signal. However, it also appears as a load for the source of this circuit where it is connected across, contributing to the losses of energy. Nevertheless, this can be minimised. ■

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