Implementation for Power Quality Improvement of Industrial Loads by Active Harmonic Filter

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***Abstract*— Most of the power electronics equipment are nonlinear nature; the harmonic distortion in the power system according to this is appeared. It has become to decrease the power quality. The harmonic resonant may become unpredictable and variable in a renewable generated electric power system due to a large number of household capacitors and inverter output capacitors. So, the harmonic filters for power system are considered to reduce the harmonic effects. There are two types of harmonic filters as passive and active filter. In this thesis, the design and application of active harmonic filter is presented for industrial application. This paper is studied the application of active harmonic filter at industries to suppress power system harmonics and to improve power quality. The active harmonic filter is designed in detail with hysteresis control for industries. The principal of operation, theoretical analysis, simulation results with the designed active harmonic filter are presented. The designed circuit is intended to provide nearly zero THD at industrial application. The complete design calculations and the simulation model construction are done with the international standards and regulations. The necessary theory and equations are also described. The performance analysis of the designed circuit is executed by Matlab software.**

***Keywords*—Non-linear, harmonic distortion, THD, Active Filter, Matlab**

I. INTRODUCTION

Harmonics have existed in power systems for many years. In the past, balance linear load was used in most electrical equipment. A linear load in a power system distribution is a component in which the current and voltage are perfect sinusoidal. Examples of linear loads are induction motor, heaters and incandescent lamps. But the rapid increase in the electronics device technology such as diode, thyristors, etc cause industrial loads to become non-linear. These components are called solid state electronic or non-linear load. The non-linear load connected to the power system distribution will generate harmonics current and voltage. Harmonics in power distribution system are current or voltage that are integer multiples of fundamental frequency. For example, if the fundamental frequency 50 Hz, then the 2nd harmonics is 100Hz, the 3rd is 150Hz, etc. A pure voltage or current sine wave has no distortion and no harmonics but non-sinusoidal wave has distortion and harmonics. To quantify the distortion, the term total harmonics distortion (THD) is used. The THD value is the effective value of all the harmonics current added together, compared with the value of the fundamental current. Wave form distortion can be analyzed using Fourier analysis as a periodical oscillation at different frequency [2].

The harmonics current injected on power distribution system caused by nonlinear load, and they can damage equipment overtime by sustained overheating or cause sudden failures due to resonant conditions. Some of non-linear load connected to the power system distribution is the three phase power electronics equipment. Generally, non-linear load using three phase-six pulse diode rectifier is used to covert alternating current (ac) become direct current (dc) need for power electronics equipment operation. Due to three phase-six pulse diode rectifiers are non-linear load, so the current waveform of power system distribution is distorted. Therefore, line current system is much containing 5th and 7th harmonics current order. In power distribution systems with more than 15%-20% of harmonic loads, a harmonic survey should be performed to indicate potential problem areas. Readings taken over changing load conditions at potential capacitor locations are most useful in determining the types of systems best employed to accomplish the ultimate harmonic suppression, power factor improvement, kVA reduction and other goals. A number of methods have been proposed to address this phenomenon. One conventional method is the application of LC passive filter. The designing form is large and weight to filter low frequency harmonic current order. The LC filters which to filter harmonic current needs specific value of LC for each order harmonic. Beside this, the LC filter has a problem formulation due to the system impedance variation and resonance condition. The other method in reducing harmonic is Active Power Filter (AFP). The active power filter is a PWM inverter current source. Therefore, it is very difficult used for high capacity and more expensive.

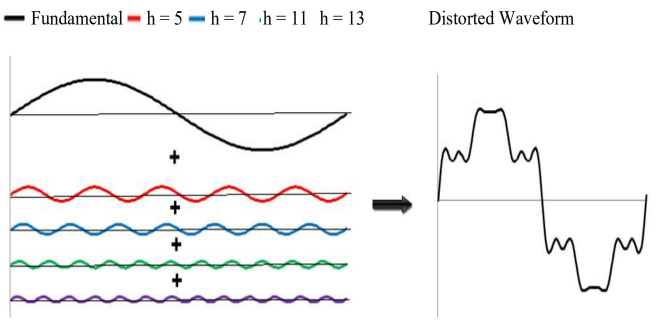

Fig. 1Fourier Series Representation of a Distorted Waveform

II. EFFECTS OF HARMONIC DISTORTION

The effect of current distortion on power distribution systems can be serious, primarily because of the increased current flowing in the system. The harmonic current doesn't deliver any power; its presence simply uses up system capacity and reduces the number of loads that can be powered. Harmonic current occur in a facility's electrical system can cause equipment malfunction, data distortion, transformer and motor insulation failure, overheating of neutral buses, tripping of circuit breakers, and solid-state component breakdown. Harmonic currents also increase heat losses in transformers and wiring. Since transformer impedance is frequency dependent, increasing with harmonic number, the impedance at the 5th harmonic is five times that of the fundamental frequency. So each ampere of 5th harmonic current cause five times as much heating as an ampere of fundamental current. More specifically, the effects of the harmonics can be observed in many sections of electrical equipment and a lot machines and motors. These effects can be described in more details as follows [1].

III. HARMONICFILTERS

Filtering the dominant harmonics can reduce the effect of harmonics. There are several filters available to perform this function. There are:

- Passive filters
- Tuned filters
- High-pass (damped) filters
- Active filters.

The single tuned filter and the high-pass (damped) filer are two commonly used devices [3].

A. Passive Filters

The passive harmonic filters are such that they are used for different voltage levels. In case of passive harmonic filters, the harmonics are reduced by using series or parallel resonant filters. The way these passive harmonic filters works is, a filter connected in parallel with the load and in series with inductance and capacitance is a current acceptor. A current acceptor is a parallel filter which is in parallel with the load and is in series with the inductance and capacitance. The filter which is near the resonant frequency of the parallel array provides maximum attenuation. The filter passes as much current as the harmonic voltage nears the filter resonant point. The passive filters thus eliminate the harmonics. If the individual load requirement is more than that of the input load, the harmonic current should be eliminated. A capacitor in series with an inductance is a passive filter. The reduced harmonic frequency must be equal to the resonant frequency of the circuit. The impedance of the network and the low impedance of the filter thus eliminate the harmonic current. Fig. 2 shows a single phase representation of distribution system with the nonlinear load and passive shunt filter [4].

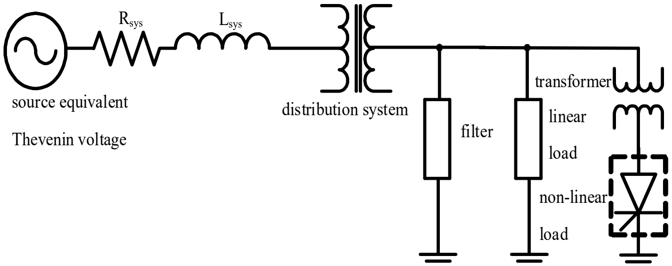

Fig. 2 Single Phase Representation of Non Linear load and Passive Shunt filter

B. Active Filters

The active power filter (AFP) is a device that is connected in system to cancels the reactive and harmonic currents from a group of nonlinear loads so that the resulting total current drawn from the ac main is sinusoidal. Ideally, the APF needs to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line, thus it handles only a fraction of the total power to the load. The performance of this active power filter depends on the inverter topologies and the PWM control method. Therefore, the suitable device in developing the AFP is "Pulse Width Modulated (PWM)" inverter by using IGBT or MOSFET devices. The active harmonic filters are used for low voltages where reactive power requirement is low. The way this filter works is, the output load with the voltage waveform is obtained by boosting the voltage throughout each half cycle by the filter. The voltage which is thus produced tends to rectifiers in the power supply to gain current. The duty cycle and power factor are thus improved. Depending on the active harmonic filter used, the output distortion is reduced. Also, current that is produced due to load is monitored by the harmonic filter and generates a waveform which coincides with the exact shape of the nonlinear portion of the load current [5].

The active filters are used in a condition where the harmonic orders change in terms of magnitudes and the phase angles. In such conditions it is feasible to use the active elements instead of passive ones in order to provide dynamic compensation. The active filters are used in nonlinear load conditions where the harmonics are dependent on the time.

IV. ADVANTAGES OF ACTIVE FILTER OVER PASSIVE FILTER

- One of the main advantages of using an active filter over the passive filter is that it can be used to reduce the effects of harmonics of more than one order.
- Active filters are also useful in flickering problems that are caused in the power system.

V. CONTROL TECHNIQUES FOR ACTIVE HARMONIC FILTER

A. Peak Current Control

The basic scheme of the peak current controller is shown in Fig. 3, together with a typical input current waveform. The switch is turned on at constant frequency by a clock signal, and is turned off when the sum of the positive ramp of the inductor current (i.e. the switch current) and an external ramp (compensating ramp) reaches the sinusoidal current reference.

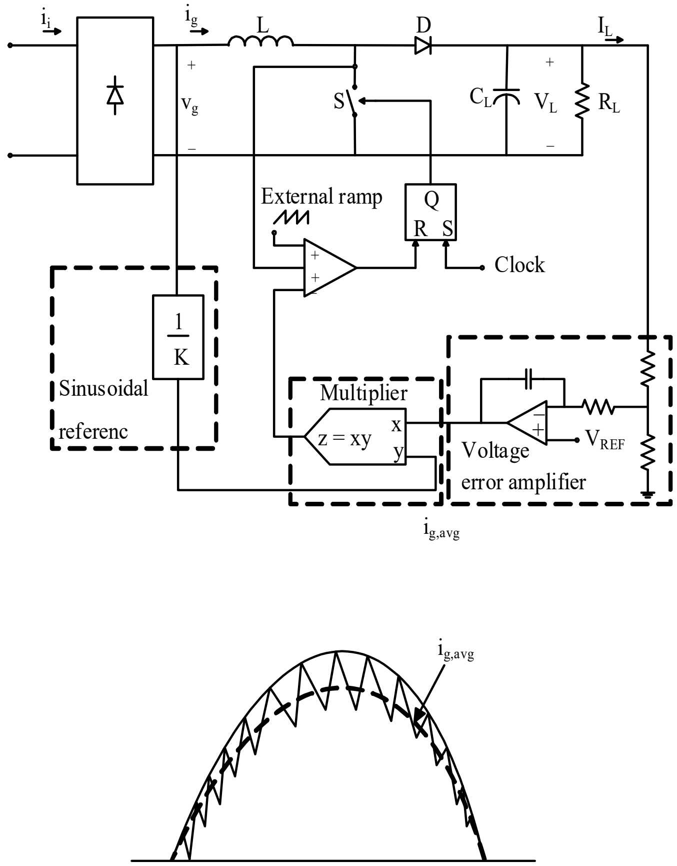

Fig. 3 Peak Current Control Scheme

This reference is usually obtained by multiplying a scaled replica of the rectified line voltage v_g times the output of the voltage error amplifier, which sets the current reference amplitude. In this way, the reference signal is naturally synchronized and always proportional to the line voltage, which is the condition to obtain unity power factor.As Fig. 3 reveals, the converter operates in Continuous Inductor Current Mode (CICM); this means that devices current stress as well as input filter requirements are reduced. Moreover, with continuous input current, the diodes of the bridge can be slow devices (they operate at line frequency). On the other hand, the hard turn-off of the freewheeling diode increases losses and switching noise, calling for a fast device. Advantages and disadvantages of the solution are summarized hereafter.

B. Average Current Control

Another control method, which allows a better input current waveform, is the average current control represented in Fig. 4. The inductor current is sensed and filtered by a current error amplifier whose output drives a PWM modulator. In this way the inner current loop tends to minimize the error between the average input current i_g and its reference. This latter is obtained in the same way as in the peak current control. The converter works in CICM, so the same considerations done with regard to the peak current control can be applied.

C. Hysteresis Control

Fig. 4 shows this type of control in which two sinusoidal current references $I_{P,ref}$, $I_{V,ref}$ are generated, one for the peak and the other for the valley of the inductor current. According to this control technique, the switch is turned on when the inductor current goes below the lower reference $I_{V,ref}$ and is turned off when the inductor current goes above the upper reference $I_{P,ref}$, giving rise to a variable frequency control. Also with this control technique the converter works in CICM.

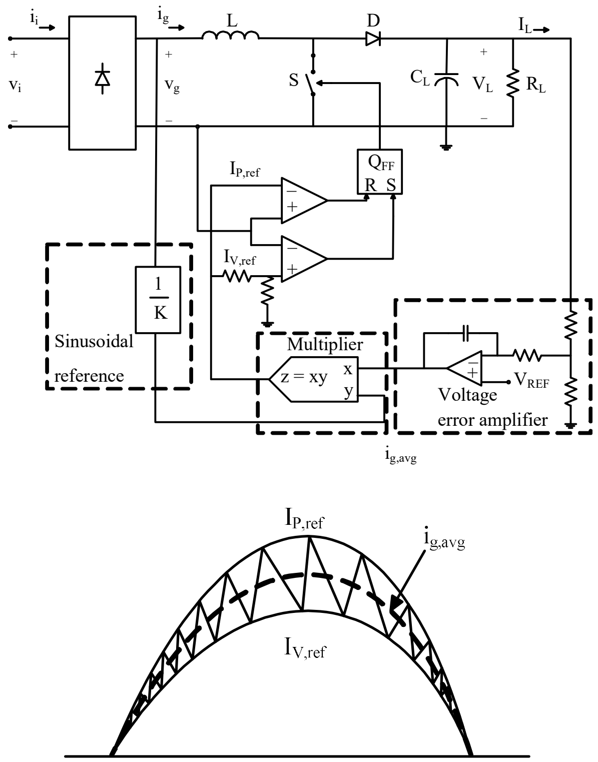

Fig. 4 Hysteresis Control Scheme

VI. STUDY OF INDUSTRIAL LOADS

For the implementation of power quality improvement at industrial loads, a field study is executed at Hlaing Thar Yar Industrial Zone. This industrial zone is located at Hlaing Thar Yar Township, Yangon, Myanmar. Hlaing Thar Yar Industrial

Zone is the largest one in Myanmar. Total power demand is about 50 MW and they are supplied from Hlaing Thar Yar Substation No (1) and No (2) by 11 kV and 33 kV feeders. This industrial zone is the most developed one in Myanmar and production technology is also high. All types of industries can be found there as: textiles, food and beverages, machining, heavy machinery, pharmaceutical, domestic appliances, plastic, metals, electrical, electronics and IT, cool storage, etc.

The power demand of each industry is ranging from 100 kW to 1 MW. The electric power is taken from 11 kV feeders in small industries and 33 kV feeders in large industries. The power transformers are located at each industry and 400 V three phase lines execute power distribution in industry. From the field study, three types of loads are found as follow:

- Normal AC Loads (induction motors, compressors, pumps, etc.)
- AC Loads with Power Electronic Drives and DC Loads (DC motors, Speed and Torque Controlled AC Motors)
- Dynamic Loads (Stamping, Metal Pressing, Cutting, etc)

In the mentioned loads, the first type of loads causes the displacement power factor and their contribution in current waveform distortion is small. But the second and third types are the sources of harmonics due to the power electronic switches used in their drives and converters. Generally, the loads provided via power electronic switch are about 5 to 15 percent of the total industry load according to the advancement of the industry. In the developed countries, the contributions of such loads in fully automated manufacturing processes are about 70 percent of total industry load. Therefore, the contribution of such loads in Myanmar Industries will increase to about 50 percent of total industry load in near future.

VII. CONSIDERATION OF TYPICAL INDUSTRIAL LOAD

For the implementation of power quality improvement by active harmonic filter (AHF), a typical industrial load is taken based on field study. In the typical system, total power consumption is taken as 500 kW and the load is distributed as 50 % for normal AC loads, 40 % for controlled AC motors and DC motors, and 10 % for dynamic load. The power is taken from 11 kV feeder with 1 MVA, 11/ 0.4 kV two winding transformer. The power distribution to all loads is with 400 V. The single line diagram of typical industrial load is illustrated in Fig. 5. For the harmonic reduction, 250 kVA capacity active harmonic filter is installed at 400 V bus as shown in Fig. 5.

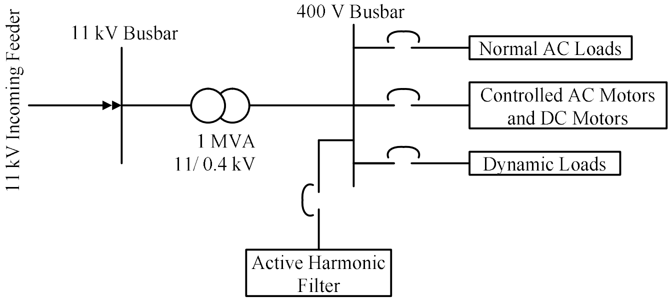

Fig. 5 Single Line Diagram for Typical Industrial Load

VIII. SIMULATION MODEL FOR ACTIVE HARMONIC FILTER

Table 1. Component and Rating for the Simulation Model

Sr. No.	Name	Qty	Rating	Remark
1	Generator	1	1000 kVA, 400 V, 50 Hz	Utility
2	**Load**			
	AC Load	1	250 kW, 0.8 PF (lag)	AC Motors
	DC Load	1	200 kW	Controlled AC
				and DC Motors
	Dynamic Load	1	50 kW	Dynamic Load
3	Transformer	1	1 MVA, 11/ 0.4 kV	-
4	Breakers	4	-	For switching
5	Scopes	9	-	For display
6	Active	1	250 kVA, 400 V, 50 Hz	For harmonic
	Harmonic Filter			cancellation

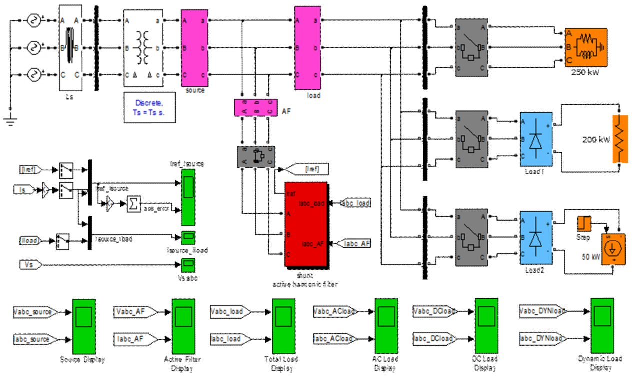

Fig. 6 Simulink Model of Active Harmonic Filter for Industrial Load

Three types of loads are selected so that it can represent the actual industrial loads. AC load represent the normal AC motor and other AC loads. Controlled AC motors and DC motors are grouped as DC load and represented by 200 kW DC load since the power consumption nature and the effect on harmonic distortion are resemblance. The dynamic loads are also represented by DC loads since they are also operated from DC drives. The difference in DC load and dynamic load is that the former are operate with continuous duty and the latter are operating with intermittence duty. The scheme to be performed for analysis of active harmonic filter is as follow:

- Operation of AC load without AFC
- Operation of DC Load without AFC
- Operation of Dynamic Load without AFC
- Operation of AC load with AFC
- Operation of AC load and DC load with AFC
- Operation of AC load, DC load and Dynamic load with AFC

The necessary switching of the system is done by 3 phase breaker. The harmonic content under various system conditions is observed by the scopes. In the Simulink model, most of the blocks are taken from Simulink Library Browser/ Sim Power System. At each operation, the waveform measurement is carried out at each load and AHF. For all the simulations, the simulation period is set to 0.3 second. With this time setting the waveform variation under various conditions can be observed clearly. Too little time setting will disturb the study on steady state performance and too large time setting will cause the longer execution period and blended waveform display. Thus 0.3 seconds is selected as the optimal one. The constructed Simulink block diagram is described in Fig. 6.The active harmonic filter with control scheme is shown in Fig. 7. This structure consists of capacitor, IGBT/diode switch and control system. For the continuous control and satisfactory output, hysteresis control is employed in this filter. The AHF is shunt connected at the 400 V bus at incoming of the industry. According to reference waveform, real time load current and active filter output current, hysteresis controller executes the necessary duty cycle and send to IGBT gate signals.

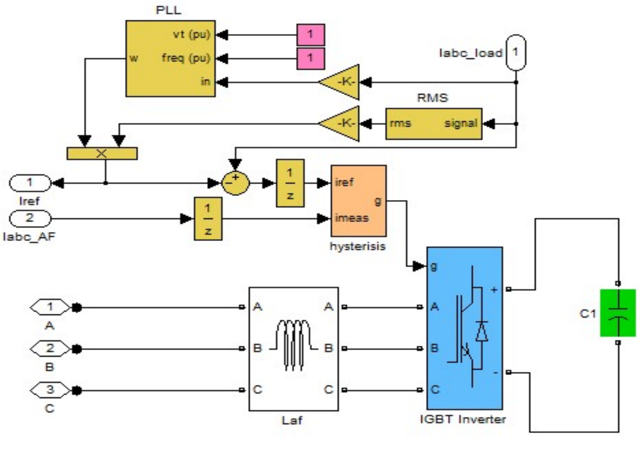

Fig. 7 Control Structure of Active Harmonic Filter

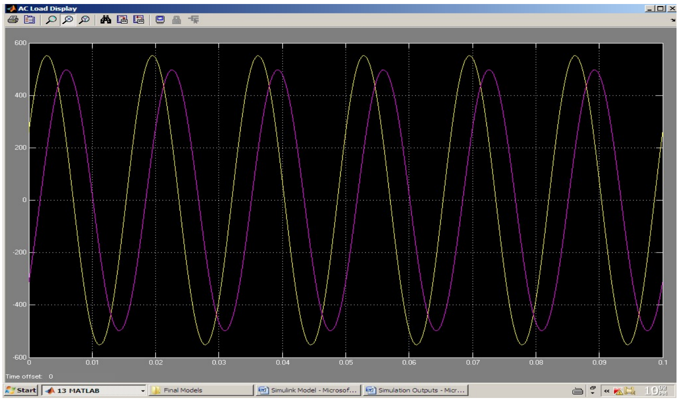

Fig. 8 Voltage and Current Waveforms for AC Load before Compensation

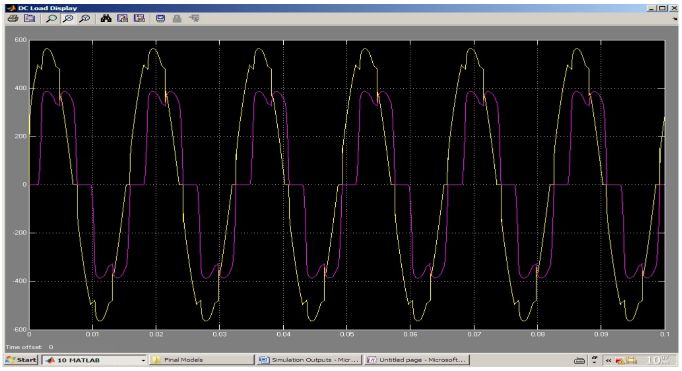

Fig. 9 Voltage and Current Waveforms for DC Load before Compensation

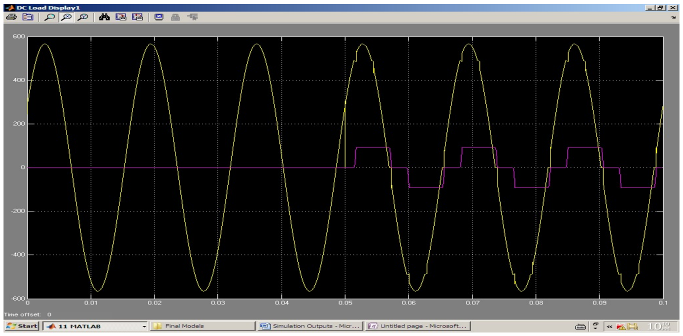

Fig. 10 Voltage and Current Waveforms for Dynamic Load before Compensation

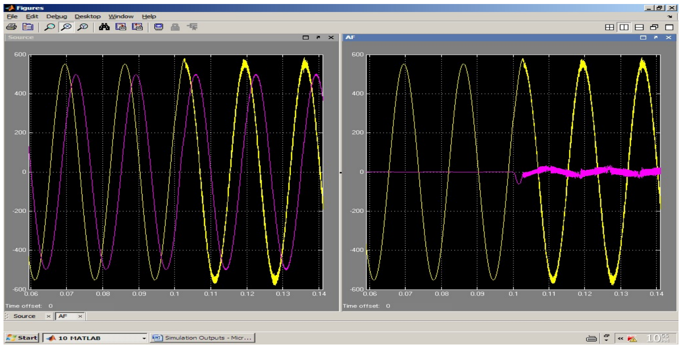

Fig. 11 AC Load Only with AHF (a) Source Display and (b) Active Filter Display

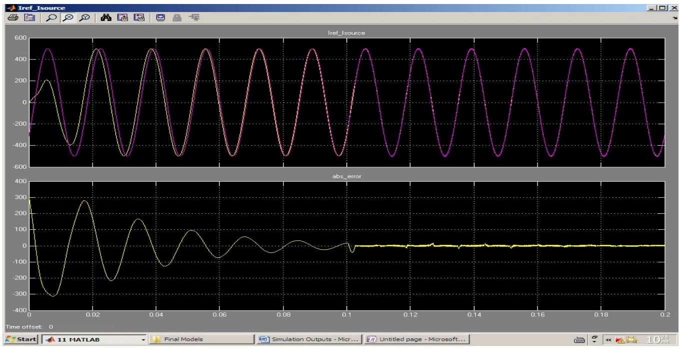

Fig. 12AC Load Only with AHF (a) Reference and Source current and (b) Error

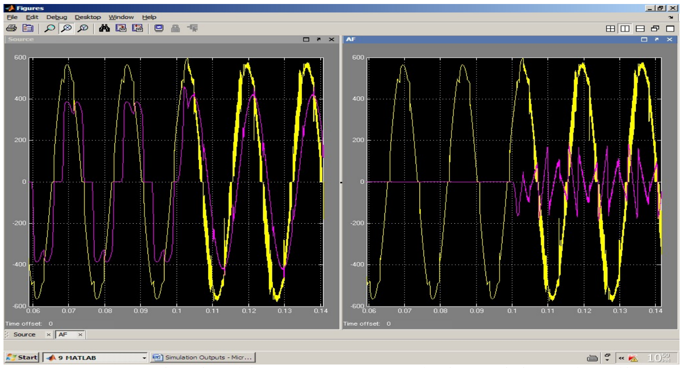

Fig. 13 DC Load Only with AHF (a) Source Display and (b) Active Filter Display

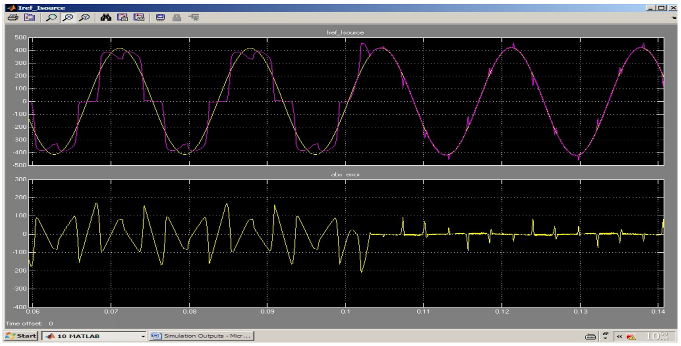

Fig. 14DC Load Only with AHF (a) Reference and Source current and (b) Error

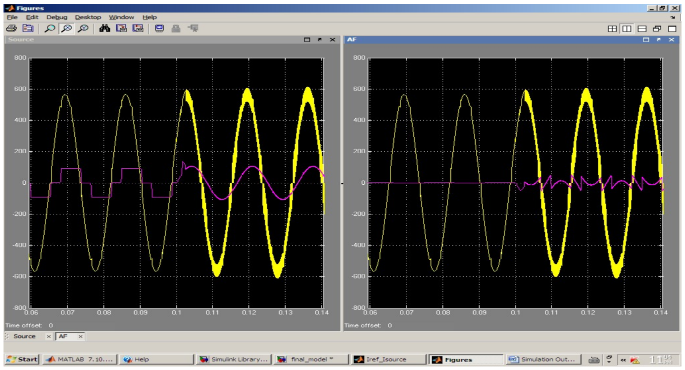

Fig. 15 Dynamic Load Only with AHF (a) Source Display and (b) Active Filter Display

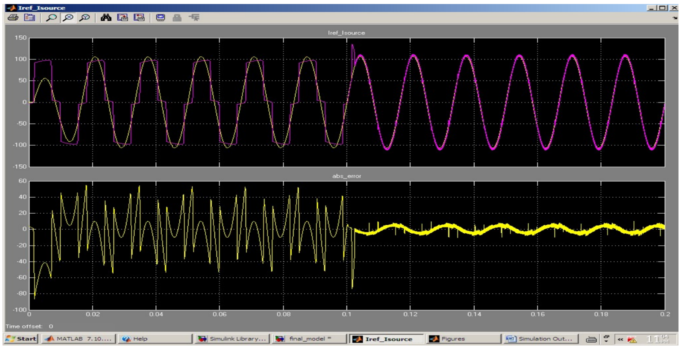

Fig. 16 Dynamic Load Only with AHF (a) Reference and Source current and (b) Error

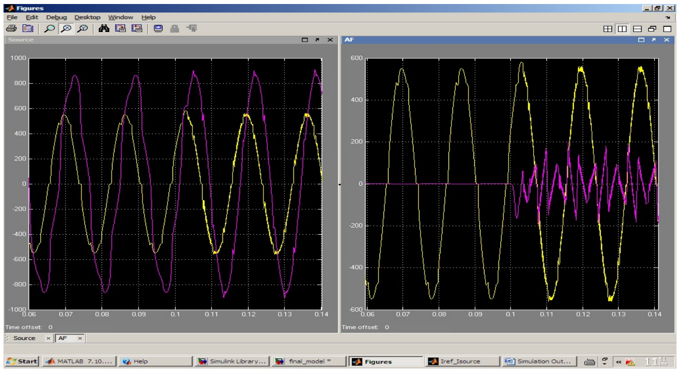

Fig. 17 Average Industrial Load with AHF (a) Source Display and (b) Active Filter Display

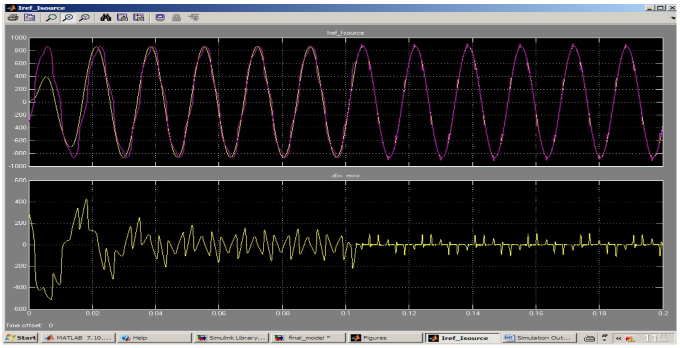

Fig. 18Average Industrial Load with AHF (a) Reference and Source current and (b) Error

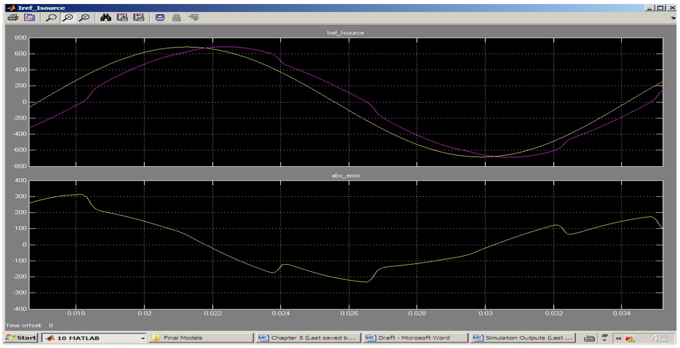

Fig. 19 One Cycle Illustration for Average Industrial Load Before AHF Compensation

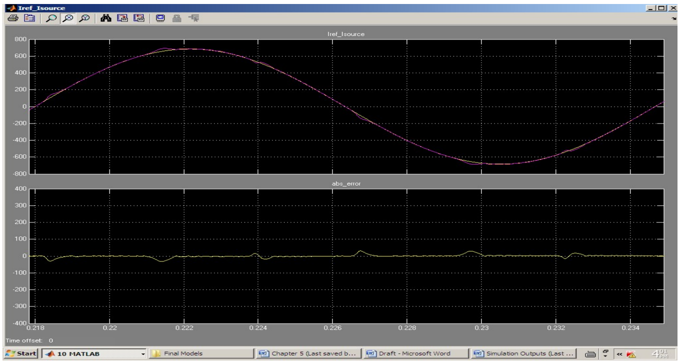

Fig. 20 One Cycle Illustration for Average Industrial Load After AHF Compensation

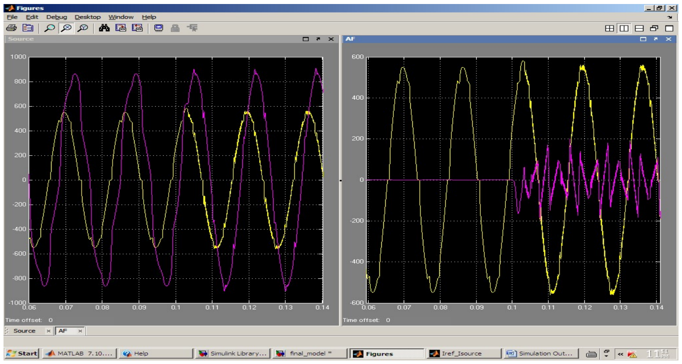

Fig. 21 Intermittent Industrial Load with AHF (a) Source Display and (b) Active Filter Display

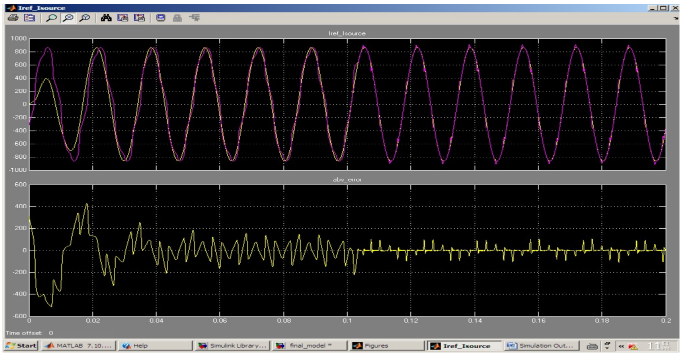

Fig. 22 Intermittent Industrial Load with AHF (a) Reference and Source current and (b) Error

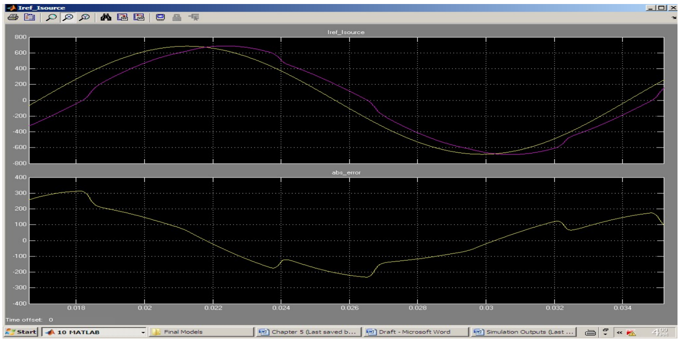

Fig. 23 One Cycle Illustration for Intermittent Industrial Load before AHF Compensation

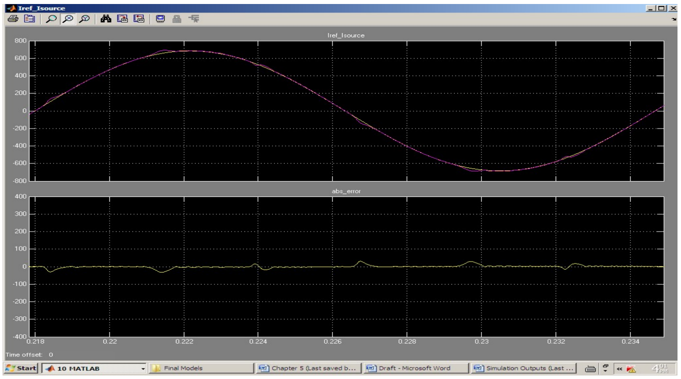

Fig. 24 One Cycle Illustration for Intermittent Industrial Load after AHF Compensation

IX.CONCLUSIONS

Proliferation of the power electronic equipment leads to an increasing harmonic contamination in power transmission or distribution systems. Many researchers from the field of the power systems and automation have searched for different approaches to solve the problem. One way was open by introducing the harmonic compensation by using active filters. This paper presents an automatic system based on active filtering for harmonic current reduction with direct applicability in the industrial electrical installations affected by harmonics. Simulation results were obtained before and after the use of the automatic system based on active filtering. From the analysis of the experimental data, in case of a nonlinear load of rectifier type, one may observe that there are different levels of current distortion produced depending on the load and its control mode, with high values of the total current harmonic distortion and low power factor. The use of simulation tools as MATLAB/ Simulink, allows reproducing the behaviour of the power systems in different situations, analysing how the system answers in these situations and choosing the solution that better fit with the particular problem without additional costs. Besides, active filters with different rated values can be simulated in order to analyse different reductions of the harmonic distortion.

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