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Analysis and Simulation of Shunt Active Power Filter For Harmonic Cancellation of Non Linear Loads

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Abstract

Use of nonlinear loads, such as power converters, power sources, uninterruptible power supply (UPS) units, and arc devices like electric furnaces and fluorescent lamps and large adjustable speed motor drives, is expected to grow rapidly. All of these loads inject harmonic currents and reactive power into the power system. This paper presents a study and simulation of a three phase active power filter. A multilevel PWM inverter is used with current control technique. The proposed control system is very simple and therefore practical implementation of active power filters is available. The presented system is able to compensating current harmonics, reactive power and unbalance current of non linear loads. The total harmonic distortion is calculated for deferent load before and after filtering with deferent type of filter. A comparison is made between passive filter and active.

The results have been obtained using software called PSIM, which has demonstrated its reliability for almost 10 years of simulations, which have been approved with real experimental results.

Keywords: current source, multilevel, PWM, inverter, active filter, harmonics.

تحليل ومحاكاة المرشحات الفعالة المربوطة على التوازي لالغاء التوافقيات المتولدة من الاحمال الغير خطية

الخلاصة

ان كثرة استخدام الاحمال الغير خطية في حياتنا العامة مثل دوائر توحيد الموجة, مصادر الطاقة الاحتياطية ودوائر السيطرة على سرعة المحركات الكهربائية... الخ, قد ادى الى كثرة التوافقيات في التيار المسحوب من منظومة الشبكة الكهربائية الوطنية. وعلى هذا الاساس اصبح من الضروري استخدام مرشحات نشيطة بدلا من المرشحات التقليدية التي كانت تستخدم سابقا للتخلص من هذه التوافقيات. في هذا البحث تم تحليل ومحاكاة مرشح فعال باستخدام تقنية مولد موجات توافقية تساوي الموجات التوافقية المتولدة من الاحمال الغير خطية بالمقدار وتعاكسها بالاتجاه (اي فرق طور =180 درجة) وضخ هذه التوفقيات داخل منظومة الطاقة الوطنية لكي نتخلص من هذه التوافقيات وايضا تحسين عامل القدرة. في هذا البحث تم حساب التشويه الكلي للموجة بسبب التوافقيات (THD) لمجموعة من الاحمال الغير خطية قبل وبعد استخدام المرشح الفعال واجراء مقارنة بين عمل انواع المرشحات الفعالة والغير فعالة.

في هذا البحث تم استخدام برنامج (PSIM) في تحليل ومحاكات المرشح الفعال والحصول على النتائج المطلوبة حيث ان هذا البرنامج يعتبر من البرامج الموثوقة والمعتمدة على مدى 10 سنوات من المقارنات بين النتائج المستحصلة من البرنامج والنتائج العملية.

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1- Introduction

Ideally, an electricity supply should always show a perfectly sinusoidal current wave form at every customer location. However, for many reasons, utilities, it is difficult to keep such conditions. The deviation of the current waveforms from sinusoidal is described in terms of the waveform distortion, often expressed as harmonic distortion. [1]

The increasing in use of nonlinear loads in industry is keeping harmonic distortion in distribution networks to increase. The most used nonlinear device is perhaps the static power converter so widely used in industrial applications such as the steel, paper, and textile industries. [1,2]

A harmonic component in an AC power system is defined as a sinusoidal component of a periodic waveform that has a frequency equal to an integer multiple of the fundamental frequency of the system. [1]

$$f_h = h \times fundamental \quad frequancy$$

Where (h) is an integer.

Conventionally, passive filters were the choice for the elimination of harmonics and to improve power factor. These passive filters have the disadvantages such as large size, resonance and fixed compensation. Active filters avoid the disadvantages of passive filters by using a switch mode power electronic converter to supply harmonic currents equal to those in the load currents. [2]

2- Non linear load

Nonlinear loads are loads in which the current waveform does not take the shape of the applied voltage waveform due to a number of reasons, for example, the use of electronic switches that conduct load current only during a fraction of the power frequency period. Therefore, we can describe the nonlinear loads as those in which Ohm's law cannot describe the relation between V and I. There are many nonlinear loads drawing nonsinusoidal currents from electrical power systems as shown in figure (1). These non sinusoidal currents pass through different impedances in the power systems and produce voltage harmonics. These voltage harmonics propagate in power systems and affect all of the power system components. [1, 3, 4]

Total harmonic distortion (THD) is an important index used to describe power quality in power system. It is define as the contribution of every individual harmonic component on the signal. THD is defining for current as follow: - [3]

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1}$$

This equation can be described as the ratio between the (r.m.s) values of signals including harmonics and signals considering only the fundamental frequency. [3]

The total harmonic distortion of two kinds of loads which are taken as examples are: -

THD of load figure (a) = 0

THD of load figure (b) = 0.37

3- Harmonics Source and Effects

Generally every device that uses power electronic components such as renewable electrical power generation systems, cycloconverters, electronic phase control loads, and pulse width modulation (PWM) drives produce harmonics. [1, 4]

Among the most common nonlinear loads in power systems are all types of rectifying devices like those found in power converters, power sources, uninterruptible power supply (UPS) units, and arc devices like electric furnaces and fluorescent lamps. Even linear loads like power transformers can act nonlinear under saturation conditions. Figures (2) & (3) represents the source current and its harmonics for different types of load (half wave rectifier and full wave rectifier) are taken as examples in this paper because these type of non linear loads are the most popular kind which are used in most electrical devices such as mobile cell charger, LCD, PC computer and monitors, and they are used in a very large range in life. [4]

Except devices such as ovens and furnaces, which produce heat, most of the other electrical loads are sensitive to harmonics. In fact, harmonics may lead to improper operation. The effects of harmonics in power systems and electrical loads are described as the disturbance to Electric and Electronic Devices, and higher losses. [4]

4- Basic Configuration of Shunt Active Filter

Active filters are categorized into two main groups: single-phase and three-phase. Three-phase active filters may be with or without neutral connection. Single phase active filters are used to compensate power quality problems caused by single phase load, and three phase active filters are used for high-power nonlinear loads. Also active filter can be classified according to the type of the utilized inverter to current source inverter or voltage source inverter. Generally; Shunt active power filters compensate current harmonics by injecting a compensating current harmonics equal in magnitude but opposite in direction, i.e. injecting the harmonic components generated by the load but phase shifted by 180. As a result, components of harmonic currents contained in the load current are cancelled by the effect of the active filter, and the source current remains sinusoidal and in phase with the respective phase to neutral voltage. This principle is applicable to any type of load considered as a harmonic source. Moreover, the active power filter can also compensate the load power factor. In this way, the power distribution system sees the non-linear load and the active power filter as an ideal resistor. The compensation characteristics of the shunt active power filter is shown in Figure. (4). [5]

The operation of an active power filter depends basically on the characteristics of the current controller, the method implemented to generate the reference signal and the modulation technique. Most of the modulation techniques used in active power filters are based on PWM strategies with hysteresis band control method. The Hysteresis Band method switches the transistors (Q1 and Q4) when the current error exceeds a fixed magnitude to force the output of the inverter to follow the reference signal as can be seen in Figure (5), this type of control needs a single comparator with hysteresis per phase. In this case the switching frequency is not determined, but it can be estimated because it is affected by the band of the hysteresis controller and the frequency is varying inversely with the bandwidth. . Under the limit condition of zero hysteresis bandwidth, the current error can be forced to zero, so that this condition implies an infinite frequency for the switch commutations, which is, of course, not practical. In real-life implementations, the hysteresis bandwidth is kept sufficiently small to minimize the tracking error without implying too high switching frequencies. [5]

Figure (5) shows that the status of the power transistors (Q1 and Q4) of phase (A) are changed whenever the actual current (i) goes beyond a given reference current (i^*) $\pm\ \Delta\ {}^{i}\!/_{2}$. And identical controllers are used in phase (B) and (C). [6]

5- Control system of active power filter

The model of the proposed three phase multi-level PWM active filter is simulated by using PSIM simulation tool. Figure (6) shows a complete system diagram. The three phase source (3-Φ) of 220 volt (r.m.s), 50Hz is feeding a contaminating load, such as a power rectifier. The parameter of the load are R=5Ω, C=470µf, L=0.3mH, this value give a sufficient distorted load current. Figure (7a, 7b) shows the load current wave form and harmonics spectrum respectively with THD equal to (46.68%). The instantaneous load current is measured using current sensor and filtered by a second order band-stop filter (notch filter) with center frequency equals to (50) Hz and stopping band equal to (20) Hz. Figure (8) shows the amplitude response of Band Stop Filter. If this center frequency were selected to be equal to 50Hz, the filter circuit shows infinite impedance to 50-Hz currents. Therefore, the band stop filter will block the fundamental frequency, while passing most of the other frequency components. The center frequency is the cut off frequency, and the different between the low cutoff frequency and high cutoff frequency is called the stopping band frequency. Generally the band stop filter must be tuned to eliminate the fundamental frequency of the load current and allow other components of the current to passing through it, i.e. the output of the band-stop filter is the harmonics of the current except the fundamental frequency as shown in Figure (9). The output of the band-stop filter is considered to be the reference current signal (control signal) of the hysteresis band current controller which is forced the multi-level inverter. Table (1) shows the transistor state for one cycle in all phases, figure (10) shows the wave form of all transistors state. [5]

Now it is clearly that the output waveform of the inverter is similar to harmonics waveform and this is the advantages of the hysteresis current control as shown in Figure (11). [1, 5]

The output of the inverter must be filtered to eliminate the switching frequency; passive filter is more suitable for this stage by tuning the cutoff frequency of the passive filter equal to switching frequency and injecting to the source line current to cancel the harmonics and only the fundamental current is drain from the source. Figure (12a and 12b) shows the source current and harmonic spectrum respectively. [5]

6- Conclusions

In this paper a three phase active power filter is proposed using multilevel PWM inverter with hysteresis current control. The active power filter is very effective and flexible and also has lower cost comparing with passive filter, because the passive filter is tuned to eliminate a single frequency, but the active filter is suitable for all frequencies. Also the multilevel PWM technique gives the active filter a good performance comparing with passive filter. Table (2) shows the total harmonic distortion (THD) for different loads with different types of filters, in this paper we chose passive filter, two-level and multilevel PWM active power filter.

7- References

[1] Muhammad H. Rashid, ***Power Electronics Handbook***, Academic Press, 2001.

[2] Francisco De la Rosa, ***Harmonics and Power System***, Taylor & Francis Group, 2006.

[3] Bimal K. Bose, ***Power Electronics and Motor Drives***, Elsevier Inc.2006.

[4] Ali E., Abdolhosein N. and Stoyan B. Bekiarov, ***Uninterrutible Power Supplies and Active Filters***, CRC Press LLC, 2005.

[5] Fraidoon Mazda, ***Power Electronics Handbook,*** Third edition, Anthony Rowe Ltd, Eastbourne, 1997.

[6] Simone Buso and Paolo Mattavelli, ***Digital Control in Power Electronics***, Morgan & Claypool Publishers, 2006.

Table (1)
3-Φ Transistor state of one cycle

Phase	Q1	Q2	Q3	Q4
Phase A *Phase shift = 0*	1	0	0	1
	1	1	0	0
	0	1	1	0
	0	0	1	1
Phase B *Phase shift = 120*	1	0	0	1
	1	1	0	0
	0	1	1	0
	0	0	1	1
Phase C *Phase shift = 240*	1	0	0	1
	1	1	0	0
	0	1	1	0
	0	0	1	1

Table (2)
THD Comparison between different loads

Non linear load	THD		
	Without active filter	With two level active filter	With Multilevel active filter
Full wave rectifier	0.327	0.152	0.048
Dc power supply	0.94	.0074	0.0042
Ac power supply	5.34	0.088	0.173

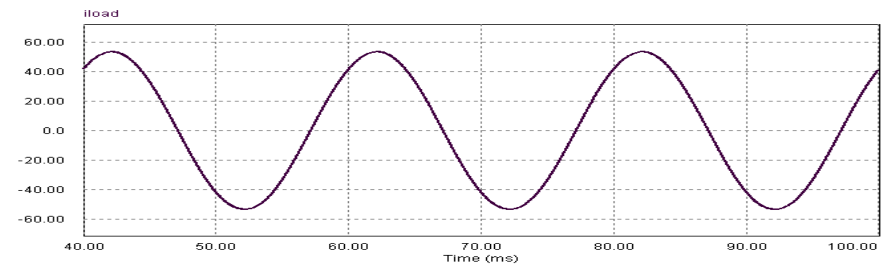

Figure (1-a)
Linear Load Current

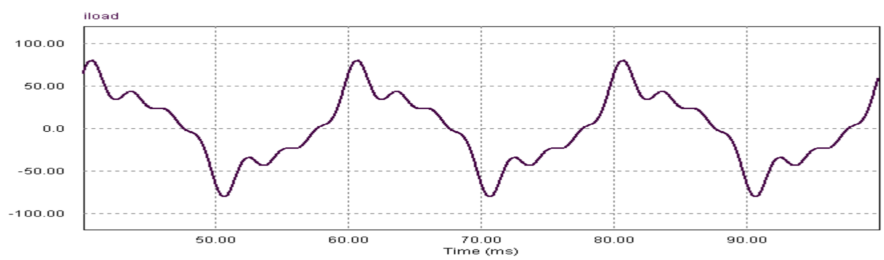

Figure (1-b)
Non linear load current distorted with third and 5^{th}, 7^{th} harmonics

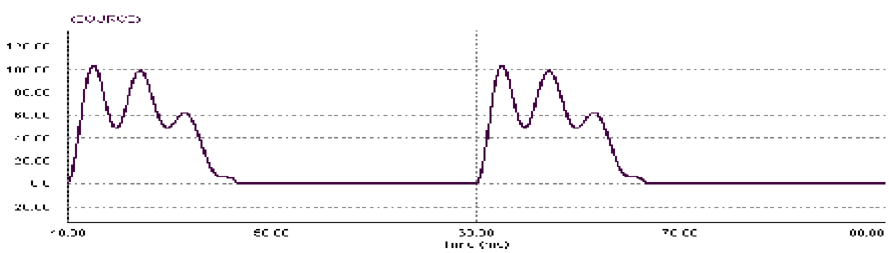

Figure (2–a)
Source Current with Half wave rectifier load

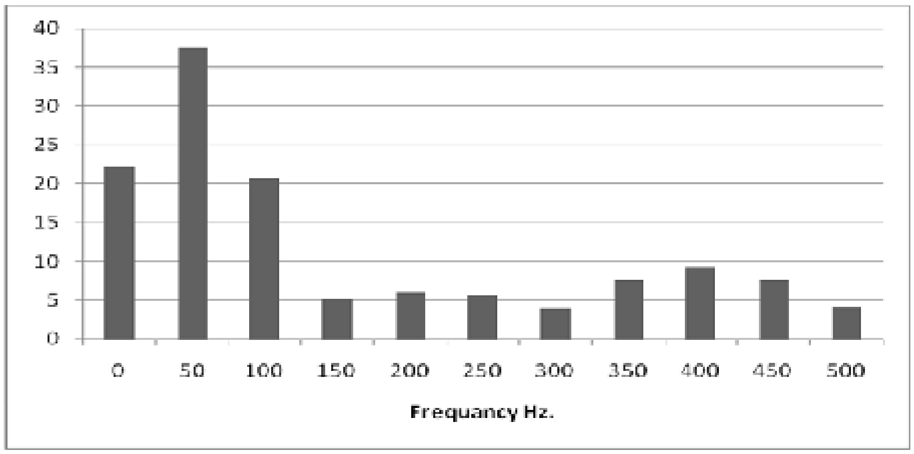

Figure (2-b)
Harmonics spectrum of Source Current with Half wave rectifier load

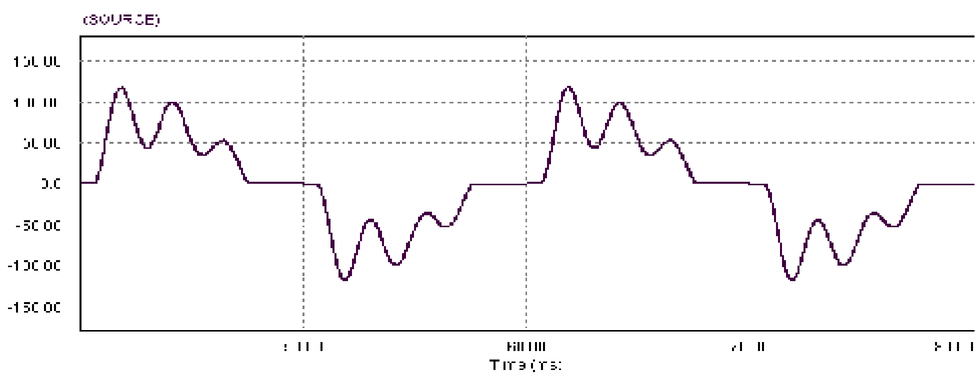

Figure (3-a)
Source Current with Full wave rectifier load

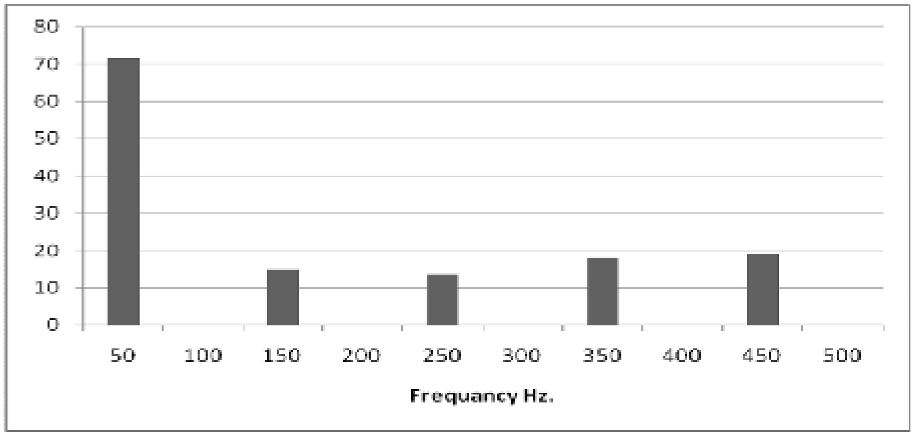

Figure (3-b)
Harmonics spectrum of Source Current with Full wave rectifier load

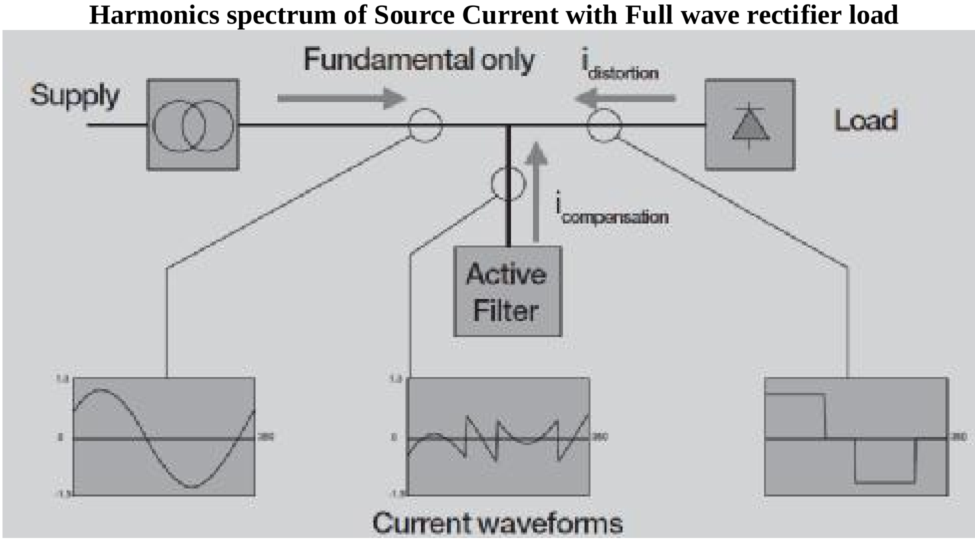

Figure (4)
Shunt Active Power Filter

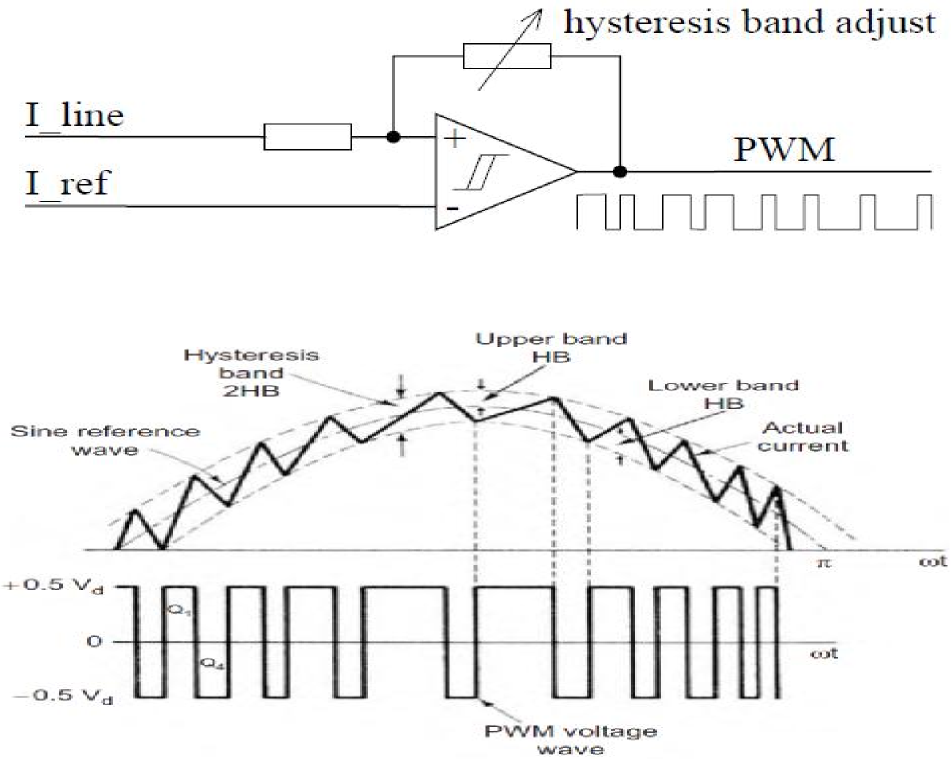

Figure (5)
Hysteresis current controller

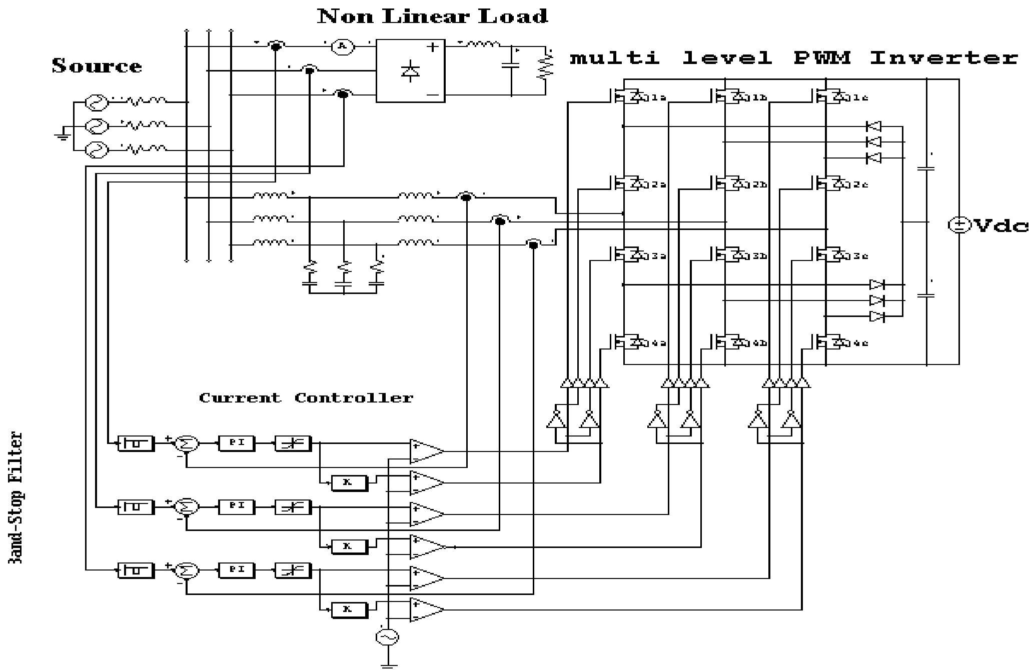

Figure (6)
Multi-level PWM power active filter

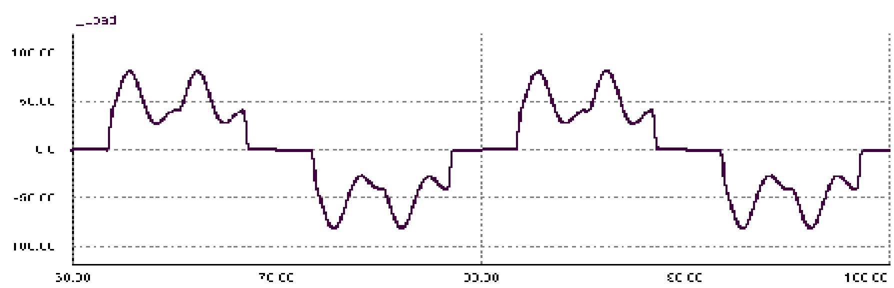

Figure (7a)
Load current wave form

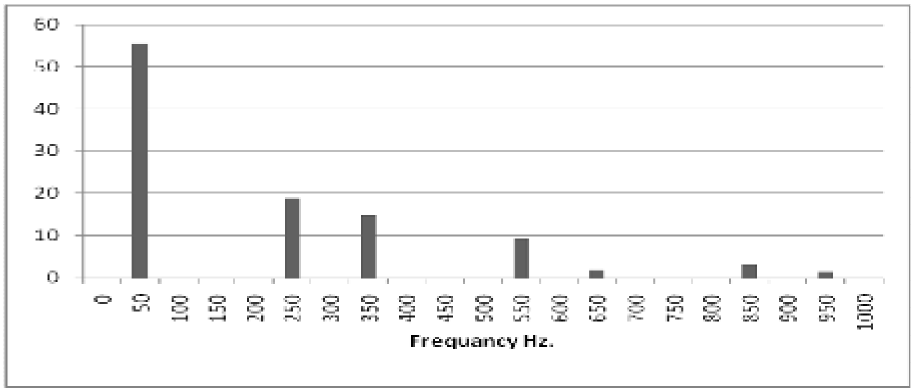

Figure (7b)
Harmonic spectrum of load current

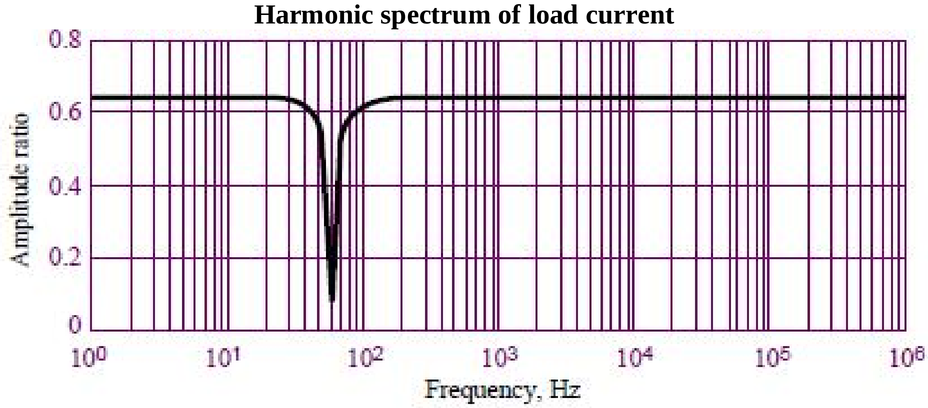

Figure (8)
The Amplitude Response of Band Stop Filter (Notch Filter)

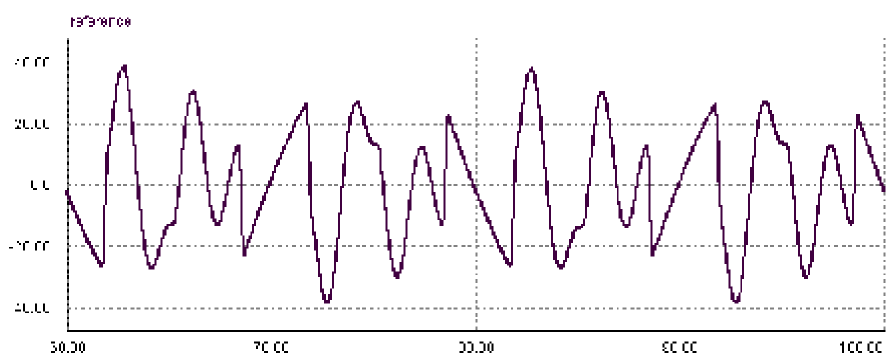

Figure (9)
Reference signal of Hysteresis current control

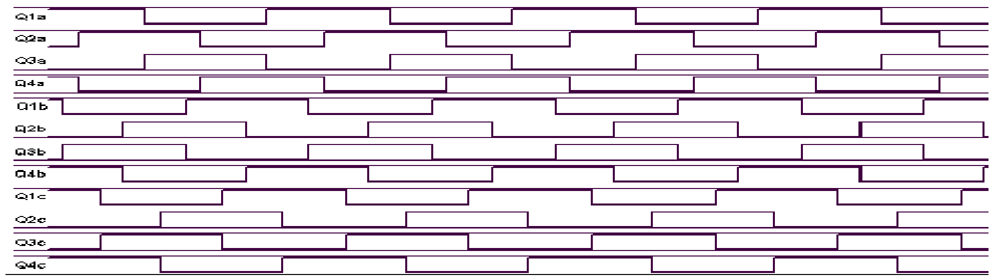

Figure (10)Transistors Switching State

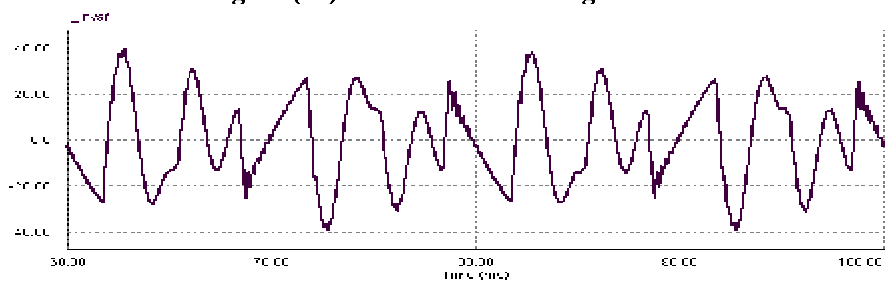

Figure (11) Output current of multilevel inverter

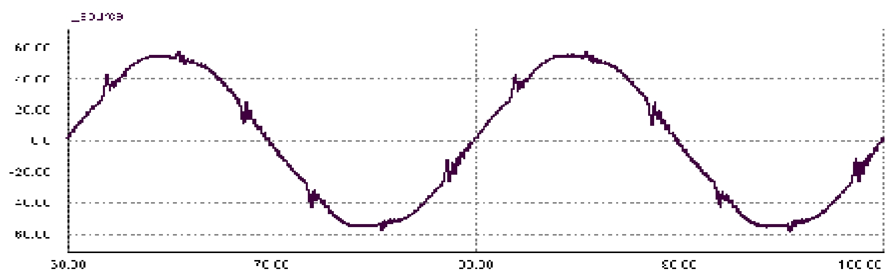

Figure (12a)Source current with active power filter

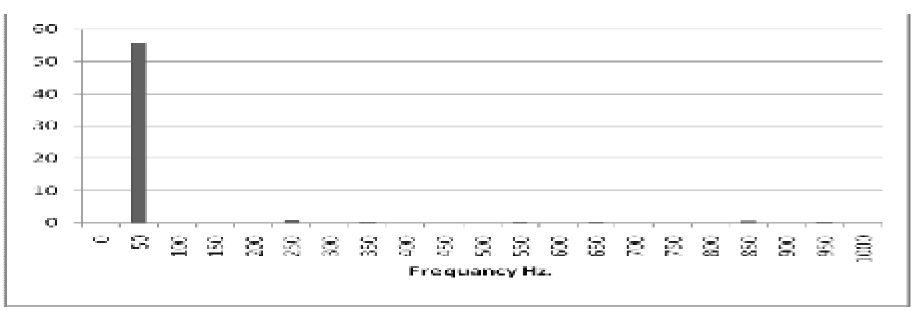

Figure (12b) Harmonic spectrum of source current with active power filter