A REVIEW OF UNITED STATE PATENT APPARATUSES FOR ACTIVE POWER FILTERS

S.Khalid, Lecturer — **Amity University, U.P.**
Bharti Dwivedi, Professor — **I.E.T, Lucknow**
N.Agrawal, Lecturer — **Amity University, U.P.**
N.Kumar, Lecturer — **BBDNITM, Lucknow**

ABSTRACT

This paper presents a review of the U.S. patent apparatuses for active power filters. The presentation is discussed in detail with their merits over the conventional active power filters. Latest patents in the field of controlling techniques have also been given. This is important for design engineers and researchers in Power Quality to know them to select the correct system for their specific applications.

INTRODUCTION

The wide use of nonlinear loads has increased the harmonic content of the voltage and current waveforms in alternating current (AC) power distribution systems. In many cases large numbers of such loads are operating, causing a corresponding increase in power line harmonics. Such harmonic currents in conjunction with their associated source impedances produce distortion of the line voltages which can cause equipment to malfunction.

To address the above problems, active power filters (APF) have been used for compensation of polluting harmonics on electricity distribution networks. An APF is a device that is connected to a power line and cancels the reactive and harmonic currents from a group of nonlinear loads so that the resulting a total current drawn from an AC source is sinusoidal. Ideally, the APF needs to generate just enough reactive e and harmonic current to compensate the nonlinear loads on the line, thus it handles only a fraction of the total power of the loads.

Active filters can generally be grouped into two different categories including pure shunt active filters and hybrid shunt active filters. U.S. Pat. No. 5,063,532 (hereinafter "the '532 patent") which issued on Nov. 5, 1991 and is entitled "Active Filter Device", describes an exemplary pure shunt active filter. The '532 patent filter senses coupling line current, compares compensating currents to the harmonic waveforms, adjusts pulse width modulating (PWM) firing signals as a function of the difference between the compensating and harmonic currents and controls a PWM inverter via the firing signals. PWM inverter output lines are linked to the three coupling lines to provide the compensating currents directly thereto thereby eliminating or substantially mitigating coupling line harmonics.

This paper gives a review of apparatuses of active power filters which are US patented with giving a brief description about the problems which these apparatuses remove.
The above said Patents are discussed below:

- **(1)** Current control method and apparatus for active power filters
- **(2)** Active power filter for isolating electrically noise load from low noise power supply
- **(3)** Control system for active power filter
- **(4)** Active power filter apparatus with reduced VA rating for neutral current suppression
- **(5)** Three phase three wire active power filter
- **(6)** Power converter for hybrid power filters

(1) Current Control Method and Apparatus for Active Power Filters

This apparatus is invented by James Lazar, assigned by Taiyo Yuden Co., Ltd. Its patent no. is US 6,940,341 B2 and it was patented on Sep. 6, 2005 with 25 claims. This invention is about an active filtering method and apparatus for controlling a current generator that sources/ sinks an APF current for compensating polluting harmonics on a power line connecting a power source and a load [1, 2, 3, 4, 11].

An active filtering method and apparatus for controlling a current generator that sources/sinks an APF current for compensating polluting harmonics on a power line connecting a power source and a load. A feedback loop regulates the APF current by sensing the current output of the current generator and the current flowing through the load. The feedback loop controls the current generator to force the APF current to track a current command signal to effectively limit the APF current to a safe value within the limitations of a particular design.
This can be understood more effectively with the help of diagram given below:

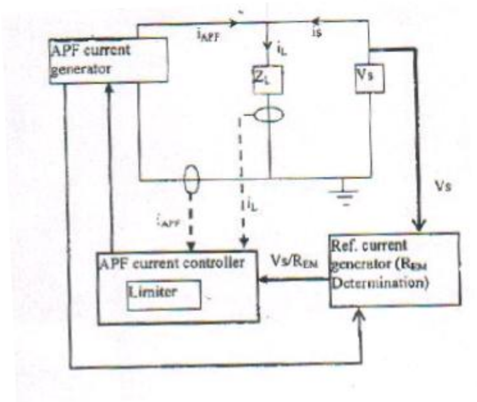

Fig 1 Block Diagram of Apparatus for Active Power Filters

In this apparatus the inventor has taken two conventional APF design references and then compares them with his invention and tells the improvement over them [1,2].

In one conventional APF design, an open loop scheme is used to control the APF current [1].

In these systems the APF is controlled such that the output voltage of the APF is proportional to the input source current. This causes the impedance seen by the power source to appear resistive, hence maintain the input current approximately proportional to the input voltage.

In another conventional APF design, a closed input current loop with a reference multiplier is used [2].

A current loop is used to force the input source current to track the input source voltage, thereby achieving near-unity power factor.

However in the above approaches, only the input source current is measured. This makes it difficult to control the current flow from the APF and the load. Hence, if there is an overlaid condition at the load, the APF control will attempt to deliver the current demanded, even if the demand is beyond the design limits of the APF. There is, therefore, a need for an APF control method and apparatus that limit the APF current, and allow transition from a normal condition to an overload condition and back again in stable manner, while maintains the lowest input current distortion within the design limits of the APF [4].

This patent addresses the above needs. In one embodiment the present invention provides an active filtering method and apparatus for controlling a current generator that generated an APF current for compensating polluting harmonics on a power line that connects a power source and a load. A feedback loop regulates the APF current by sensing the current output of the current generator and the current flowing through the load. The feedback loop controls the current generator to force the APF current to track a current command signal to provide near unity power factor (i.e., proportional current), while effectively limiting the APF current to a safe value within the limitations of a particular design.

A limiter is configured in this apparatus to control the current generator such that even if the APF current necessary to compensate for the polluting harmonics on the power line exceeds said selected threshold value, the APF current generated by the current generator is limited to at most the selected threshold value. This apparatus provides protection of the APF, low input current distortion, and stable operation of the APF into and out of overload conditions while maintaining minimum input current distortion within the bounds of the APF design limits.

2. Active Power Filter for Isolating Electrically Noise Load from Low Noise Power Supply

This apparatus is invented by Sam Ochl, assigned by IXYS Corporation. Its patent no. is US 6,771,119, B2 and it was patented on AUG. 3, 2004 with 10 claims. This invention relates to field of supplying direct current (DC) power, and specially, to filtering noise between the power supply and the load driven by the power supply.
An active power filter includes a feedback resistor and a shunt capacitor, an operational amplifier equivalent subcircuit, and a voltage drop source. The shunt capacitor connects the positive terminals of the low noise power supply and the noisy load to the positive terminal of the operational amplifier subcircuit. The feedback resistor connects the negative terminal of the noisy load and the output of the operational amplifier equivalent subcircuit to the negative terminal of the shunt capacitor. The voltage drop source connects the negative terminal of the low noise power supply to the negative terminal of the operational amplifier equivalent subcircuit. The operational equivalent subcircuit includes an operational amplifier, three resistors, three capacitors, and a transistor. The first resistor connects the positive terminal of the voltage source to the negative input terminal of the operational amplifier. The second resistor connects the output of the operational amplifier to the gate the gate of the transistor. The drain of the transistor is coupled to the negative terminal

of the noisy load. The source of the transistor is coupled to the negative terminal of the voltage source and to the negative terminal of the low noise direct current power supply. The first capacitor connects the output of the operational amplifier to the negative input terminal of the operational amplifier. The second capacitor connects the output of the operational amplifier to the gate of the transistor and the negative terminal of the low noise direct current power supply [5].

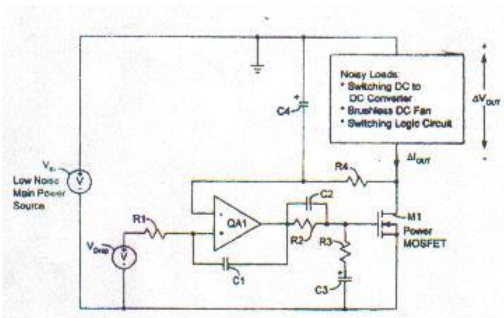

Fig 2 Active Power Filter for Isolating Electrically Noisy Load from Low Noise Power Supply

The objective of this apparatus is to create an active power filter which behaves like a filter circuit having a large inductor, but without producing, magnetic interference or physically large components as would be produced by a conventional large inductor. The power filter according to the present apparatus is suitable for use with switching DC to DC converters, brushless DC fans, switching logic circuits, and other noisy loads.

According to the present patent, an active power filter includes a feedback resistor and a shunt capacitor, an operational amplifier equivalent subcircuit, and a voltage drop source. The shunt capacitor connects the positive terminals of the low noise power supply and the noisy load to the positive terminal of the operational amplifier equivalent subcircuit. The feedback resistor connects the negative terminal of the shunt capacitor. The voltage drop source connects the negative terminal of the low noise power supply to the negative terminal of the operational amplifier equivalent subcircuit.

According to the present patent, the impedance of the active power filter at a minimum noise frequency is carefully designed so as to be large in comparison to an impedance of the noisy load, for example, the impedance of the active power filter is 1000 times the impedance of the noisy load at the minimum noise frequency. The active power filter according to the present invention is equally capable of protecting a low noise load device to a noisy direct current power supply.

According to another aspect of the present invention, the operational equivalent subcircuit includes an operational amplifier, first and second resistors, and a transistor. The first resistor connects the positive terminal of the voltage drop source to the negative input terminal of the operational amplifier. The second resistor connects the output of the operational amplifier to the gate of the transistor. The drain of the transistor is coupled to the negative terminal of the noisy load. The source of the transistor is coupled to negative terminal of the voltage source and to the negative terminal of the low noise direct current power supply. The source of the transistor is coupled to the negative terminal of the voltage drop source and to the negative terminal of the low noise direct current power supply. The positive input terminal of the operational equivalent subcircuit.

In an exemplary embodiment of the active power filter according to the present invention, the operational amplifier equivalent subcircuit further includes first and second capacitors. The first capacitor connects the output of the operational amplifiers to the negative input terminal of the operational amplifier. The second capacitor connects the output of the operational amplifier to the gate of the transistor. In addition, the operational amplifier equivalent subcircuit may contain a third capacitor and a third resistor which are connected in series between the gate of the transistor and negative terminal of the low noise direct current power supply. In an exemplary embodiment, the transistor comprises an N-channel enhancement mode MOS field effect transistor.

3. Control System for Active Power Filter

This apparatus is invented by Gary L. S., Dongsheng Z., Frederick L.H., Naihu L., Qiang Y. It's patent Pub. No. is US 2003/ 0062776 A1 and its patent application pub. date is Apr. 3, 2003 with 19 claims. This invention concerns electrical filters for eliminating transients and distortion in an alternating current (AC) utility grid and more specifically to active filters for such use.

An active filter controller for use with both pure and hybrid shunt filters wherein the controller maintains a minimum DC bus voltage required to generate a compensating current on coupling lines and also extrapolates to estimate an expected feedback current to be compensated so that compensation currents are more accurate and harmonic currents are appreciably reduced.

Ideally, a utility grid for providing three phase AC power to factories and offices (i.e., industrial environments) includes three AC power conductors or lines, each line providing a pure sine wave of current and voltage, the sine waves having equal and constant amplitude and frequency, and each separated from the others by 120^0. The utility lines are linked to facility coupling lines at a point of common coupling (PCC) (i.e., a utility-customer connection point) which in turn provide power to facility equipment. As well known in the power industry, all power electronic equipment can potentially act as non-linear loads creating utility line disturbances and distorting utility waveforms by injecting harmonic currents into the utility grid.

In addition to voltage waveform distortion at the PCC, other problems related to harmonic currents include additional heating and possibly over voltages in utility distribution and transmission equipment, errors in metering and malfunctioning of utility relays, interference with communication and control signals and equipment damage from voltage spikes created by high frequency resonance's.

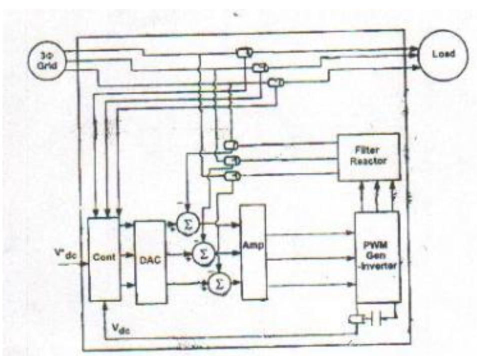

Fig 3 Control System for Active Power Filter

Unfortunately, harmonic or non-linear loads comprise an ever increasing portion of the total load for a typical industrial plant. In fact, by 1992, harmonic loads had become such a pervasive problem that the Institute of Electrical and Electronic Engineers (IEEE) recommended stringent harmonics standards, including strict utilities limitations, un a document referred top in the industry as IEEE standard 519 which has generally been accepted in North America. IEEE Standard 519 was written with the general understanding that harmonics should be within a reasonable limit at the PCC and therefore puts limits on individual load and total (i.e., distortion from all loads connected at a PCC) harmonic distortion.

An exemplary embodiment of the patent includes an active filter controller for use with both pure and hybrid shunt filters wherein the controller maintains a minimum DC bus voltage required to generate a compensating current on coupling lines and also extrapolates to estimate an expected feedback current to be compensated so that compensation currents are more accurate and harmonic currents are appreciably reduced [6].

4. Active power filter apparatus with reduced VA rating for neutral current suppression

This apparatus is invented by Se-wan Chol. It's patent Pub. No. is US 2005/ 00253564 A1 and its patent application pub. date is Nov. 17, 2005. This invention relates to an active power filter apparatus for reducing harmonic currents in a neutral line, and more particularly for an active power filter apparatus which can effectively reduce harmonic currents occurring in a neutral line of a three-phase four-line power transducer system ,and also reduce the VA rating of an Internal inverter.

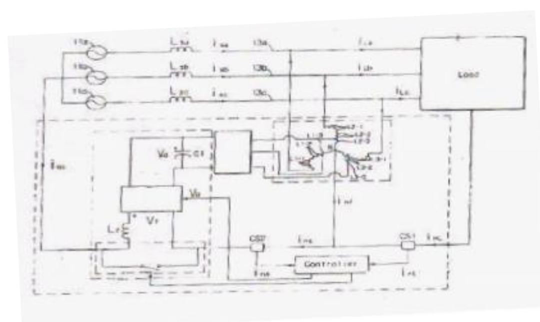

Fig 4 Active power filter apparatus with reduced VA rating for neutral current suppression

Various methods have been proposed to reduce the excessive neutral current. One proposed method is to connect a zigzag transformer to the neutral and phase lines of the conventional three-phase power supply [3]

This method aims to remove the harmonic components of neutral currents flowing into the power supply by circulating the zero phase components of triplen harmonic currents generated from loads by means of the zigzag transformer. However, this method has problems in that the efficiency of removing neutral current is affected by system impedance, and a specially-designed transformer is needed in order to reduce an impedance of the zero phase components, thereby increasing the size of the transformer.

In addition, a three-phase four-line active power filter has been proposed to compensate for each phase current's harmonics as well as the neutral current without being affected by system impedance. However, because of a complicated control operation, a higher capacity of the active power filter with respect to load capacity, and a higher manufacturing cost, this active power filter has failed to gain wide acceptance, while limited for use in some important loads.

Therefore, the present apparatus has been made in view of the above problems, and it is object of the present invention to provide an active power filter apparatus with a reduced VA rating for removing neutral currents whereby it is possible to effectively reduce harmonic currents occurring in a neutral line of a three-phase four-line power transducer system and also to reduce the voltage and current ratings of an internal inverter wit h respect to load capacities.

In accordance with the present patent, the above and other objects can be accomplished by the provision of an active power filter apparatus with a reduced VA rating for reducing harmonic currents generated in a neutral line connected between a load and a three-phase AC power source in a three-phase four-line power distribution system, the apparatus comprising: an inverter unit connected in series with the neutral line for controlling current flow of the neutral line based on a predetermined voltage control signal so that a fundamental component of a load-side neutral current flows to the three-phase AC power source and a harmonic component of the load-side neutral current is circulated to the load. A transformer is connected between the neutral line and each phase line of three-phase AC power source for forming a current path which allows the harmonic component of the load-side neutral current to flow to the load through the phase line. A rectifier unit is connected between the transformer and the inverter unit for rectifying a predetermined drive voltage, supplied to the transformer, into a DC voltage and applying the rectified DC voltage to the inverter unit and a controller for generating the voltage control signal for use in controlling a PWM operation of the inverter unit based on a first small signal of the load-side neutral current and a second small signal of the power-source-side neutral current, which are extracted from the neutral line.

According to such a configuration of the present patent, it is possible to reduce the voltage and current ratings of the internal inverter with respect to load capacity as well as effectively suppress the harmonic currents generated in the neutral line [7].

5. Three Phase Three Wire Active Power Filter

This apparatus is invented by Hung-Liang. C., Chin-Chang W., Wen-Pin H., Ya-Tsung F., Yao-Jen C. assigned by UIS Abler Electronics Co., Ltd . It's patent Pub. No. is US 2006/ 0033479 A1 and its patent application pub. date is Feb. 16, 2006. This invention relates to a three-phase three-wire active power filter. More particularly, the present invention relates to the active power filter applied to a three-phase three-wire power system for filtering harmonic current generated therein.

A three-phase three-wire active power filter includes a dc power capacitor, a power converter, a filter inductor set, a reactive power compensating capacitor set, a combined capacitor/resistor filtering set and a control circuit. The dc power capacitor provides with a regulated voltage. The power converter includes a two-arm bridge power converter, and has a pair of ac terminals and a pair of dc terminals .a phase of the three-phase three-wire active power filter, without control of the power electronic switch set, directly connects with any one of the dc terminals. Consequently, the number of power electronic switches employed in the two-arm bridge power converter of the three-phase three-wire active power filter can be reduced.

The power electronic devices with high-voltage rated, high- current rated, and high switching speed characteristics have been developed due to the improvement of semiconductor manufacturing technique, recently. Power electronic devices are applied in electric power facilities, such as switching power supply, uninterruptible power supply, motor driver, arc furnace, trolley car, battery charger, and lighting appliance etc. The electric power facilities may generate a large amount of harmonic current due to the nonlinear input characteristics of such loads. The harmonic current will pollute the power system and result in the problems such as transformer overheat, rotary machine vibration, degrading voltage quality, electric power components destruction, medical facilities malfunction etc.

In order to improve the problems of harmonic pollutions effectively, many harmonic control standards, such as IEEE 519-1992, IEC 61000-3-5, and IEC 61000-3-4 etc., have been established by international research institute. Therefore, how to solve the harmonic problems is an important topic in today's power system worldwide.

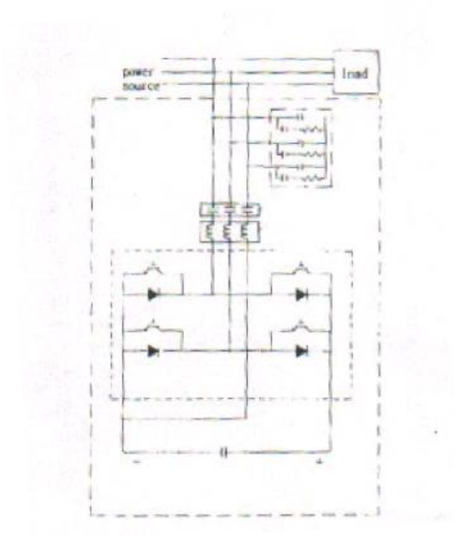

Fig 5 Three-Phase Three-Wire Active Power Filter

The present patent intends to provide a three-phase three-wire active power filter including a reactive power compensating capacitor and a power converter. The power converter only employs a power electronic switch set with a two-arm bridge structure and permits one of power lines of a three-phase three-wire power system to be connected to either a positive or negative dc terminal of the power electronic switch set without passing through a power electronic switch. Consequently, the number of the power electronic switches employed in the three-phase three-wire active power filter can be reduced.

The primary object of this apparatus is to provide a three-phase three-wire active power filter including a dc power capacitor, a power converter, a filter inductor set, a reactive power compensating capacitor set and a combined capacitor/filtering set. The dc power capacitor provides with a regulated voltage. The power converter includes a two-arm bridge power converter, and has a pair of ac terminals and a pair of dc terminals. The dc terminals of the power converter electrically connect to the positive and negative terminals of the dc power capacitor. There inductors of the filter inductor set correspondingly connect in series with three ac power capacitors of the reactive power compensating capacitor set for compensating reactive power, and wherein two serial-connected inductor ac power capacitor sets connect to two points between two power lines o a three-phase three-wire power system and the two ac terminals of the power converter. The other serial-connected inductor/capacitor set connects with a point between the other power line of the three-phase three-wire power system and one of the two dc terminals of the power converter. Consequently, the number of power electronic switches employed in the bridge power converter of the three-phase three-wire active power filter can be reduced [8, 10].

6. Power Converter for Hybrid Power Filters

This apparatus is invented by Hung-Liang. C., Chin-Chang W., Wen-Pin H.., Yao- Jen C. assigned by UIS Abler Electronics Co., Ltd with 9 claims. It's patent Pub. No. is US 2005/ 0207197 A1 and its patent application pub. date is Sep. 22, 2005. This invention relates to a power converter for a hybrid power filter. More particularly, the present invention related to the hybrid power filter adapted to filter harmonic current which is generated from a single-phase power system, a three-phase, three-wire power system or a three-phase, four wire power system. A power converter for a hybrid power filter includes a power electronic switch set and a DC capacitor. The power converter permits a power line of a power system to directly connect or connect through the passive power filter to a positive or a negative terminal of the DC capacitor of the power converter for free control of the power electronic switches. Consequently, the power converter has a lesser number of the power electronic switches that can reduce the manufacture cost.

This apparatus intends to provide a power converter for a hybrid power filter applied to a single-phase power system, a three-phase, three-wire power system or a three-phase, four-wire system. The power converter has less one arm than the conventional power converter that can omit a pair of power electronic switches. A power line from the power system directly connects to a DC side of the power converter or through the passive power filter to a DC side of the power converter that can reduce manufacture cost of the hybrid power filter

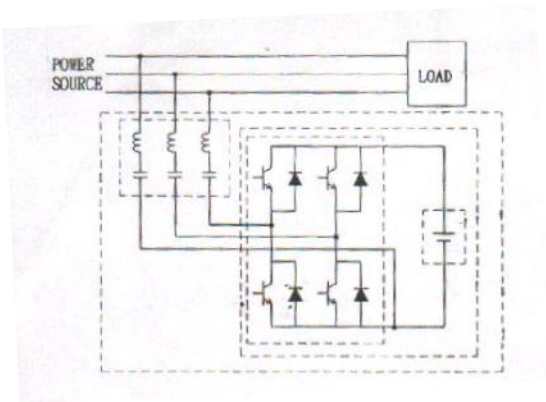

Fig 6 Power converter for Hybrid Power Filters

The primary objective of this apparatus is to provide a power converter for a hybrid power filter. The power converter permits a power line of a power system to directly connect or connect through a passive power filter to a positive or negative terminal of a DC side of the power converter for free control of power electronic switches. When the power converter is applied to a single-phase power system, only a single-arm configuration for power electronic switch set (i.e. two power electronic switches) of the power converter is provided. When the power converter is applied to a three-phase three-wire power system, only a double-arm configuration for power electronic switch set (i.e. four power electronic switches) of the power converter is provided. When the power converter is applied to a three-phase, four-wire power system, only a triple-arm configuration for power electronic switch set (i.e. six power electronic switches) of the power converter is provided. Consequently, the power converter can reduce the number of the power electronic switches [9].

CONLUSION

The paper presented a brief and critical evaluation of each of the U.S. patent apparatuses supported with their merits over the conventional approaches. This paper will help research workers, users and suppliers of electrical power to gain an overview and an inspiration for further research on the subject of active power filters.

REFERENCES

1. E Dallago and M. Passoni, "Single-Phase Active Power Filter with Only Line Current Sensing", *IEEE Electronics Letters, 20 Jan. 2000,* Vol. 36, No. 2, pp. 105-106.
2. F. P. de Souza, I. Barbi, "Single-Phase Active Power Filters for Distributed Power Factor Correction", *IEEE PESC 2000,* pp. 500-505.
3. P.P. Khera, "Application of Zigzag Transformers for Reducing Harmonics in The Neutral Conductor of Low Voltage Distribution System", *IEEE IAS conf. Rec, 1990*, pp. 1092.
4. James Lazar, "Current Control Method and Apparatus for Active Power Filters", *U.S. Pat. No. 6,940,341 B, Sep. 6, 2005*.
5. Sam Ochl, "Active Power Filter for Isolating Electrically Noise Load from Low Noise Power Supply", *U.S. Pat. No. 6,771,119, B2, AUG. 3, 2004*.
6. Gary L. S., Dongsheng Z., Frederick L.H., Naihu L., Qiang Y, "Control System for Active Power Filter", *U.S. Pat. Pub. No. 2003/ 0062776 A1, Apr. 3, 2003.*
7. Se-wan Chol, "Active Power Filter Apparatus with Reduced VA Rating for Neutral Current Suppression", U.*S. Pat. Pub. No 2005/ 00253564 A1, Nov. 17, 2005.*
8. Hung-Liang. C., Chin-Chang W., Wen-Pin H., Ya-Tsung F., Yao- Jen C., "Three Phase Three Wire Active Power Filter", *U.S. Pat. Pub. No. 2006/ 0033479 A1, Feb. 16, 2006*
9. Hung-Liang. C., Chin-Chang W., Wen-Pin H.., Yao- Jen C, "Power Converter for Hybrid Power Filters", *U.S. Pat. Pub. No 2005/ 0207197 A1, Sep. 22, 2005.*
10. C.A. Quinn, N. Mohan, "Active filtering of harmonic currents in three-phase, four-line systems with three-phase and single-phase non-linear loads", *APEC 1992,* pp. 829-835.
11. M. Smedley, L. Zhou, and C. Qiao, "Unified Constant Frequency Control of Active Power Filters-Steady State and Dynamics", *IEEE Trans. on Power Electronics, Vol. 16, No. 3, May 2001*, pp. 428-436.