Study of Active power filters, analysis of harmonic disturbance, and their application in mitigating harmonics & power quality improvement.

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***Abstract* —Fast growing technology and rigorous use of non linear loads, has given rise to a very serious problem of power quality distortion. The reason behind, are the harmonics arising due to the operation of these non linear loads. In short, the advantages obtained from devices exhibiting non linear characteristics, face a disadvantage of generating harmonics. This paper shows various problems arising in household as well as industrial supply due to harmonic distortion. After this the paper gives an overview and scope of Active power filters or APFs for mitigation of harmonics and improvement in power quality. The problem of harmonics can be eliminated by methods implementing the use of filters. Filters are further classified into Passive filters and Active filters. Another strategy has been used widely which implements the use of shunt and series active filters and is known as Unified Power quality filter or UPQC. Various household appliances suffer exceedingly due to fluctuation in power network caused by harmonics which, in turn arise due operation of non linear load. Heavy machinery like rolling mills, where the rollers are run by DC motors and control circuitry involves use of large thyristor panels that exhibit non linear characteristics giving rise to harmonics in the power network.**

Index Terms – Harmonics, Active power filters, Digital control , THD.

I. INTRODUCTION

The use of electronic appliances has been increasing rapidly over past years in modern world, with the use of such appliances comes one of the major concerns of maintaining power quality of the supply. As the interface unit of electronic equipment, generally has a semiconductor arrangement followed by filter unit which in turns draws current, only near the peak value of voltage applied. Thus current is drawn non sinusoidal despite the voltage being sinusoidal and hence due to the non ideal voltage, the harmonic currents create voltage distortion.

A. To reduce the harmonics conventionally passive L–C filters were used and also capacitors were employed to improve the power factor of the ac loads. But the passive filters have several drawbacks like fixed compensation, large size and resonance problem.

B. The active power filter (APF) is a popular approach for cancelling the harmonics in power system.
Active power filter system consists of three major parts, Harmonic current detection circuit, Compensation current control circuit and drive circuit. The main component in the APF is the control unit. The control unit is mainly divided into two parts as follows

i. Harmonic Extraction
ii. Digital Controller

C. Many applications require a compensation of a combination of voltage- and current-based problems, a few of them being interrelated. A hybrid of active series with active shunt filters is an ideal choice for such mixed compensation.

II. POWER QUALITY ANALYSIS

A. Use of power converters to feed various electrical systems in medical and enterprises has increased the vulnerability of power systems towards non linear loading and various problems including power factor fluctuation. Extensive use of power converters induce harmonics in the power system resulting in the distortion of voltage as well as current waveforms.
Under given figure shows us the introduction of 2nd 3rd and 4th harmonics in power supply due to non linear loads.

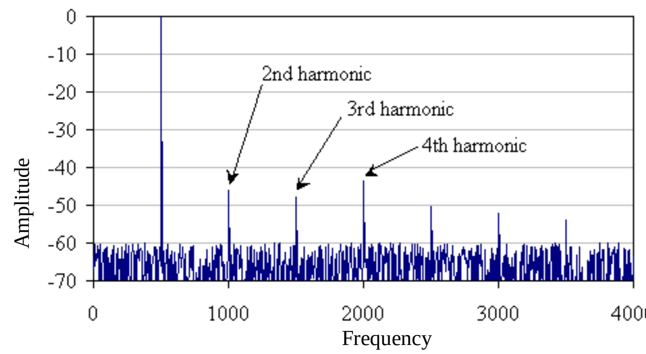

Fig.1 Analysis of harmonic in sinusoidal waveform.

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B. Harmonic introduction

Harmonics are generally introduced and cause major contribution in power quality distortion.
The normal sinusoidal waveform is distorted due to harmonic contents. The following figure is a representation of distorted waveform due to harmonic content.

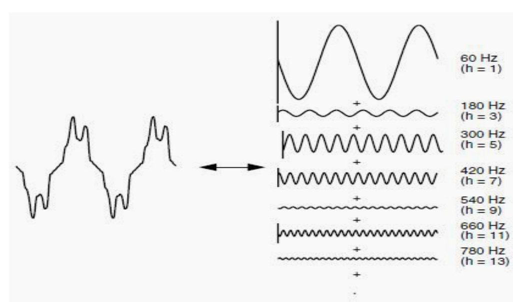

Fig 2 – Analysis of various harmonic elements.

The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms.

Introduction of harmonics in the power system, effects' it in various manners, some of them are listed below:

B.1. Harmonics can cause current and voltage distortion Can cause failure of electronic equipments and disturbance in the supply.

B.2. Harmonics can increase the heat in motors and transformers with the introduction of higher harmonic components.

B.3. Transformer inductance is frequency dependent, thus by introduction of 5th harmonics, can cause about 5 times much heat in the transformer.

B.4. Breakdown of solid state devices and insulation failure due to excess heat may be major problems caused by the harmonic pollution, but there are more.

C. Active power filters

Passive filters have been used as a solution to solve harmonic current problems, but they present several disadvantages, namely: they only filter the frequencies they were previously tuned for; their operation cannot be limited to a certain load; resonances can occur because of the interaction between the passive filters and other loads, with unpredictable results.

In order to overcome the problems of passive filters, active filters were developed and used to solve the problem of harmonics. Development and improvement in the power semiconductor devices improved the active filters a lot. Active filters solve the problem of harmonic in industrial area as well as utility power distribution.

Active filters are special equipments that use power electronic converters to compensate for current and/or voltage harmonics originated by non-linear loads, or to avoid that harmonic voltages might be applied to sensitive loads.

There are basically two types of active filters: the shunt type and the series type. It is possible to have active filters combined with passive filters as well as active filters of both types acting together.

Active power filter system consists of three major parts, Harmonic current detection circuit, Compensation current control circuit and drive circuit.

C.1. Harmonic Extraction – The core role of harmonic current detection circuit is to detect compensation objects—harmonic currents and reactive current components. It is mainly the process of generation of reference current with the use of distorted waveform. The distortion caused by harmonics in the waveform manipulates the shape of ongoing waveform. The standard waveform is quite different than distorted one, thus fluctuation in the wave is utilized for generation of a reference current that can be fed to the main supply with appropriate arrangement.

C.2. Digital Controller

Designing a suitable controller for an APF is very important. A number control strategies such as instantaneous reactive power theory, synchronous framed–q theory, synchronous detection method , notch filter and fuzzy logic controller method are used in the development of three-phase AFs and the gate pulses are generated by current control technique like sinusoidal pulse width modulation (SPWM),triangular PWM, hysteresis current control technique.

Two major parts of digital controller are Compensation current control circuit and drive circuit.

Advancement in Microelectronics has motivated new directions for APF design starting from the use of analog and digital components to microprocessors, microcontrollers, digital signal processors (DSP's) and FPGA implementation. Further, these developments have made it possible to use different control algorithm such as proportional integral (P-I), fuzzy logic etc. for improving the steady state and dynamic performance of APFs.

D. Harmonic analysis

The Fourier theorem states that all non-sinusoidal periodic functions can be represented as the sum of terms (i.e. a series) made up of:

- A sinusoidal term at the fundamental frequency,
- Sinusoidal terms (harmonics) whose frequencies are whole multiples of the fundamental frequency,
- A DC component, where applicable

The equation for the harmonic expansion of a periodic function X (t) is presented below

$$y(t) = Y_0 + \sum_{n=1}^{\infty} \mathrm{Yn}\sqrt{2}\,\sin(\mathrm{hw} - \emptyset)$$

Total harmonic distortion

$$\mathrm{THD} = \sqrt{\sum_{h=2}^{H} \left(\frac{Yh}{Y1}\right)^2} \qquad (1)$$

$$\mathrm{THD} = \frac{Y_2^2 + Y_3^2 + \quad .... \quad ... + Y_h^2}{Y_1}$$

THD is expressed in %.

The perfect power supply would be one that is always available, always within voltage and frequency tolerances and has a pure noise-free sinusoidal wave shape. In this paper there are various types of power supplies are introducing for analysing the power quality.[1]

E. Design of active power filter

Power quality problems are common in most of commercial, industrial and utility networks. Natural phenomena, such as lightning are the most frequent cause of power quality problems. Switching phenomena resulting in oscillatory transients in the electrical supply, for example when capacitors are switched, also contribute substantially to power quality disturbances. Also, the connection of high power non-linear loads contributes to the generation of current and voltage harmonic components. Between the different voltage disturbances.

AF's can be classified based on converter type, topology, and the number of phases. The converter type can be either CSI or VSI bridge structure. The topology can be shunt, series, or a combination of both. The third classification is based on the number of phases, such as two-wire (single phase) and three- or four-wire three-phase systems.

The harmonic current compensations by the active power filter are controlled in a closed loop manner. The active power filter will draw and inject the compensating current to the line based on the changes of the load in the power supply system.

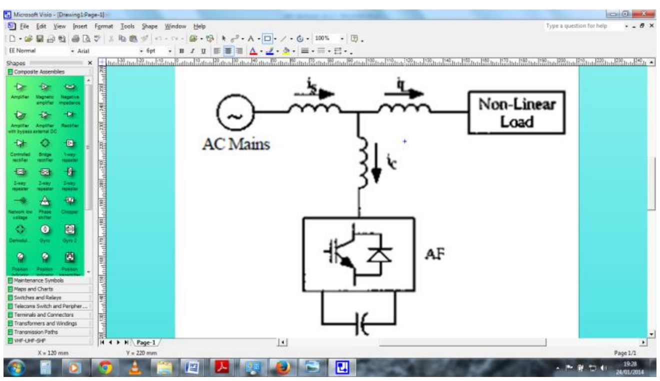

Fig 3. Shunt active power filter.

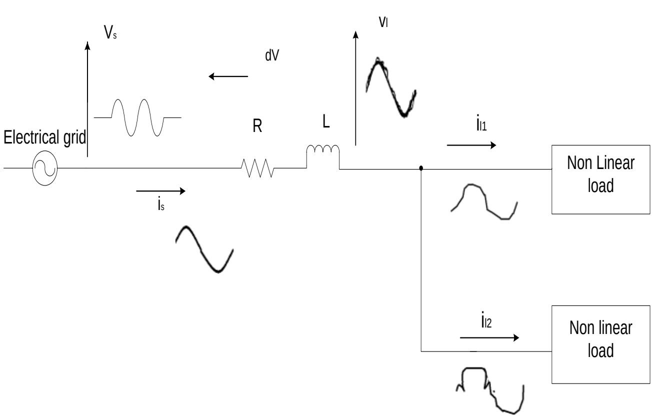

Fig 4 Series active power filter.

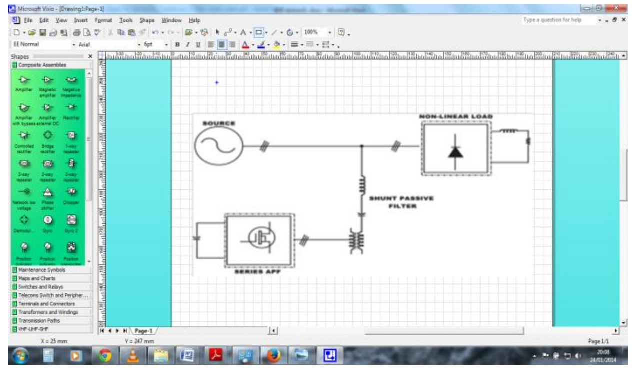

Fig 5 Unified power filter

E.1. Configuration of Active Power Filters**:-**
APFs can be classified based on converter type, topology, and the number of phases. The converter type is mainly two types:

i. Voltage source inverter (VSI)
ii. Current source inverter (CSI)

The topology of active power filter is classified in to three types:

i. Series active power filters
ii. Shunt active power filters
iii. Hybrid active power filters.

Finally based on the phases the APF mainly two types.

i. Two-wire (single phase) system.
ii. Three or four-wire three-phase system.

Apfs are generally implemented in power equipments and power systems for active mitigation of power quality problems. Classification of AF's is based on the supply and/or the load system having single-phase (two wire) and three-phase (three wire or four wire) systems. There are many nonlinear loads, such as domestic appliances, connected to single-phase supply systems. Some three-phase nonlinear loads are without neutral, such as ASD's, fed from three-wire supply systems. There are many nonlinear single-phase loads distributed on four-wire three-phase supply systems, such as computers, commercial lighting, etc.
Two-wire (single phase) system is available in three mode of configuration (active series, active shunt and combination of both). Whereas in general, in four wire power systems, it is usual to use APLCs with three phase configurations. I n this case, a split capacitor will be necessary in the DC side.

F. Unified power quality conditioner
The UPQC is a combination of series and shunt active filters connected in cascade via a common DC link capacitor. The main purpose of a UPQC is to compensate for supply voltage power quality issues such as, sags, swells, unbalance, flicker, harmonics, and for load current power quality problems such as, harmonics, unbalance, reactive current and neutral current. UPQCs consist of combined series and shunt APFs for simultaneous compensation of voltage and current. The series APF inserts a voltage, which is added at the point of common coupling (PCC) such that

the load end voltage remains unaffected by any voltage disturbance, whereas, the shunt APF is most suitable to compensate for load reactive power demand and unbalance, to eliminate the harmonics from supply current, and to regulate the common DC link voltage.

The UPQC has two distinct parts:

i. Power circuit formed by series and shunt PWM converters.
ii. UPQC controller.

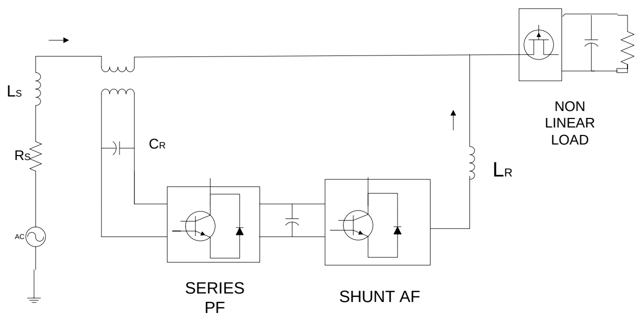

Fig. 6 Unified power quality conditioner.

Classification of AF's is based on the supply and/or the load system having single-phase (two wire) and three-phase (three wire or four wire) systems. There are many nonlinear loads, such as domestic appliances, connected to single-phase supply systems. Some three-phase nonlinear loads are without neutral, such as ASD's, fed from three-wire supply systems. There are many nonlinear single-phase loads distributed on four-wire three-phase supply systems, such as computers, commercial lighting, etc.

F.1 Two-Wire (Single Phase) System

Two-wire (single phase) system is available in three mode of configuration (active series, active shunt and combination of both). Also available according to converter configuration i.e. current source PWM with inductive energy storage elements and voltage source PWM with capacitive dc-bus energy storage elements.

F.2 Three or Four-Wire Three-Phase System

There are several nonlinear loads with three phase configuration. In three phase four wire systems with unbalanced loads, it is possible to use three single phase inverters as an APLC power circuit. The main objective is to compensate the phase by phase. In general, in four wire power systems, it is usual to use APLCs with three phase configurations. I n this case, a split capacitor will be necessary in the DC side

III. Digital control

Digital control of APF utilizes several digital components like micro computers and micro controllers. Some of the steps towards digital control can be enlisted below:

A. Signal Conditioning –

For the purpose of implementation of the control algorithm, several instantaneous voltage and current signals are required. These signals are also useful to monitor, measure, and record various performance indexes, such as total harmonic distortion (THD), power factor, active and reactive power, crest factor, etc. The typical voltage signals are ac terminal voltages, debus voltage of the AF, and voltages across series elements. The current signals to be sensed are load currents, supply currents, compensating currents, and dc-link current of the AF. Several rigorous developments in microcomputer and micro processors has lead to considerable development in the design of control circuits or digital controllers for the control of active power filters. The compensation current signal is generated with the use of digital circuitry.

B. Compensating Signal analysis-

The control strategies to generate compensation commands are based on frequency-domain or time-domain correction techniques. Control methods of the AF's in the time domain are based on instantaneous derivation of compensating commands in the form of either voltage or current signals from distorted and harmonic-polluted voltage or current signals.

For compensation in frequency domain, Fourier transform is implemented. Using the Fourier transformation, the compensating harmonic components are separated from the harmonic-polluted signals and combined to generate compensating commands. The device switching frequency of the AF is kept generally more than twice the highest compensating harmonic frequency for effective compensation.

C. Control signal generation-

The control signal is generated based on received reference signal. A variety of approaches, such as hysteresis-based current control, PWM current or voltage control, deadbeat control, sliding mode of current control, fuzzy-based current control, etc., are implemented, either through hardware or software (in DSP-based designs) to obtain the control signals for the switching devices of the AF's.

Instantaneous active and reactive power is calculated with the help of P-Q and reference current is generated to be fed to the line for compensation of harmonic components.

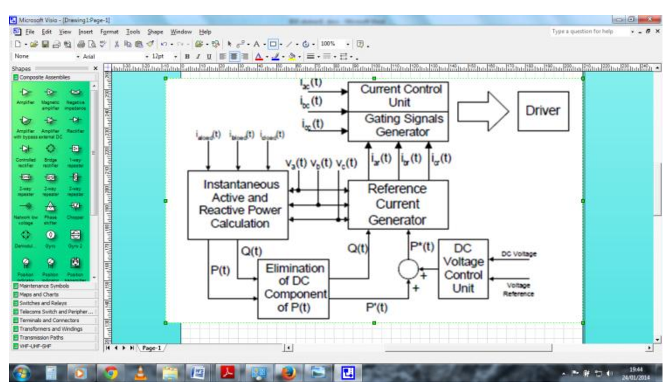

Fig. 7 Digital controller for APF

Figure 4 shows the scheme of a series active filter for a three-phase power system. It is the dual of the shunt active filter, and is able to compensate for distortion in the power line voltages, making the voltages applied to the load sinusoidal (compensating for voltage harmonics). The filter consists of a voltage-source inverter (behaving as a controlled voltage source) and requires 3 single-phase transformers to interface with the power system. The series active filter does not compensate for load current harmonics but it acts as high-impedance to the current harmonics coming from the power source side. Therefore, it guarantees that passive filters eventually placed at the load input will not drain harmonic currents from the rest of the power system.

IV. CONCLUSION

One of the major factors in advancing the AF technology is the advent of fast self-commutating solid-state devices. In the initial stages, thyristors, bipolar junction transistors (BJT's) and power MOSFET's were used for AF fabrication. Later, static induction thyristors (SIT's) and gate-turn-off thyristors (GTO's) were employed to develop AF's. With the introduction of insulated gate bipolar transistors (IGBT's), the AF technology got a real boost and, at present, they are considered as ideal solid-state devices for AF's. The improved sensor technology has also contributed to the enhanced performance of the AF. The availability of Hall-effect sensors and isolation amplifiers at reasonable cost and with adequate ratings has improved the AF performance.

This paper covers the wide aspects of power quality problems and their mitigation by the use of active compensation current generated by active power filters. with several different arrangements of active power filters, the desired result can be obtained. Further, the power systems in domestic and industrial network differ considerably, and thus it becomes mandatory to consider the two aspects of power quality control in a complete separate context.

The selection of components of the AF's is an important factor to achieve improved performance. The main component of the AF is the solid-state device. In the earlier days, BJT's followed by MOSFET's were used in small ratings. Nowadays, the IGBT is an ideal choice up to medium ratings, and GTO's are used in higher ratings. There are widely varying application requirements, such as single-phase or three-phase, three-wire and four wire systems, requiring current- or voltage-based compensation. Moreover, there is a number of AF configurations which may cater to the needs of individual users.

AF technology is well developed, and many manufacturers are fabricating AF's with large capacities. The utilities in the long run will induce the consumers with nonlinear loads to use the AF's for maintaining the power quality at acceptable levels. A large number of AF configurations are available to compensate harmonic current, reactive power, neutral current, unbalance current, and harmonics.

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[6] Diagrams have been prepared using MSVISIO©.