International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 2 Issue 3, March 2014

Hybrid Active Power Filters for Reactive Power Compensation with Adaptive DC-Link Voltage Control

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Abstract: ***This paper presents adaptive dc-link voltage controlled LC coupling hybrid active filters for reduced switching losses and switching noise under the reactive power compensation. The adaptive DC link voltage controller for three phase four wire system LC-Hybrid Active power factor filters (LC- HAPF) is proposed. In this proposed system the reactive power compensation range as well as dc-link voltage can be adaptively changed according to different inductive loading situations. The simulation results of three phase four wire LC-Hybrid Active power filters are presented to verify the validate and the effectiveness of the adaptive dc-link voltage-controlled LC-HAPF for reactive power compensation.***

Keywords: Active power filters (APFs), dc-link voltage control, hybrid active power filters (HAPFs), passive power filters (PPFs), reactive power control

1. Introduction

The passive power filters was used to suppress the harmonic current and to compensate the reactive power due to their low cost, high efficiency simplicity and high. But passive power filters can be easily affected due to small variations in the system parameters which lead to the invention of the Active power filters. the disadvantages of the passive power filters Can be reduced by active power filters but their initial cost and operational cost are relatively high. In the Active power filters the dc-link voltage must be higher than the system voltage.

Different hybrid active power filter (HAPF) topologies composed of passive and active components in parallel and/or series have been proposed, aiming to reduce the voltage and/or current ratings (costs) of the APFs and improve the compensation characteristics of PPFs, HAPF topologies consist of many passive components, such as capacitors, transformers, resistors, reactors and thus the size and the cost of the whole system increasing. In our proposed system a transformer LC coupling Hybrid active power filters for reduced switching losses.

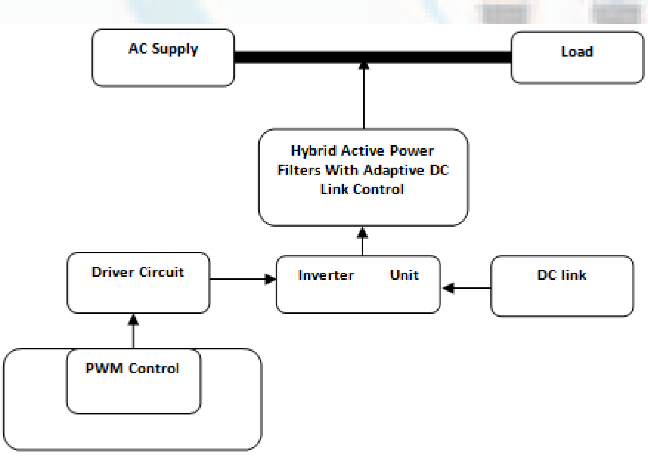

Figure 1: Block Diagram of Proposed System

Since the first installation of passive power filters (PPFs) in the mid-1940s, PPFs have been widely used to compensate reactive power and suppress current harmonics in distribution power systems due to their low cost, simplicity, and high-efficiency characteristics. Unfortunately, PPFs have many disadvantages such as resonance problems, filtering characteristics and low dynamic performance that are easily affected by small variations of the system parameters. Since the concept of an "active ac power filter" was first developed by L. Gyugyi in 1976, research studies on active power filters (APFs) are getting more and more attention for current quality compensation. APFs can overcome the disadvantages.

1.1 DC Link

A DC link exists between an inverter and a rectifier, for example, in a phase converter or VFD . On the other end, that DC is switched to generate a new AC power waveform and on one end, the utility connection is rectified into a high voltage DC. It's a link because it connects the input and output stages. The term "DC link" is also used to describe the decoupling capacitor in the DC link.

1.2 Hybrid Active Power Filters

A new topology for parallel hybrid active filters can reduce the converter voltage down to 5% of the mains voltage magnitude.

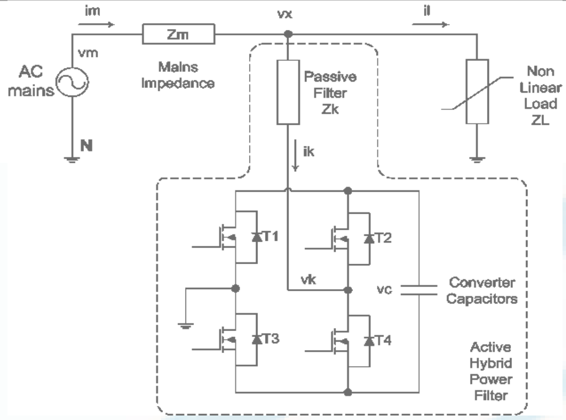

Figure 2: Hybrid Active Power Filter

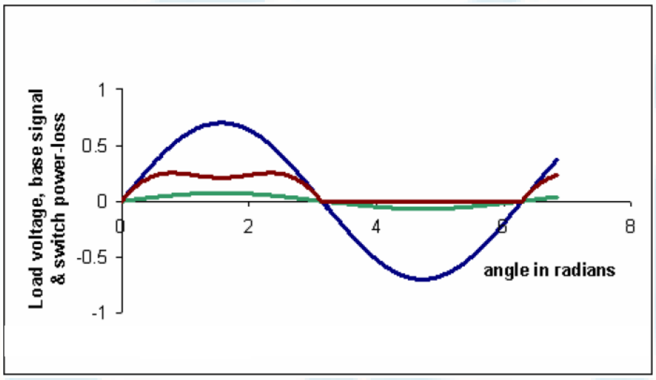

Figure 3: Switch in Amplifier mode Operation

At the fundamental harmonic - 60Hz in this example- $|\mathbf{Z}_k|$ assumes high but finite values.
The parameters $\mathbf{L}_f$ and $\mathbf{C}_f$ can be adjusted in order to set the resonant frequency (lowest $|\mathbf{Z}_k|$) at the most significant harmonic.

1.3 Half-Bridge VSI

For each capacitor maintains a constant voltage (Vi)/2 the power topology of a half-bridge VSI, consists of two large capacitors are required to provide a neutral point N The power topology of a half-bridge VSI, consists of two large capacitors are required to provide a neutral point N. A set of large capacitors (C+ and C-) is required because the current harmonics injected by the operation of the inverter are low-order harmonics.

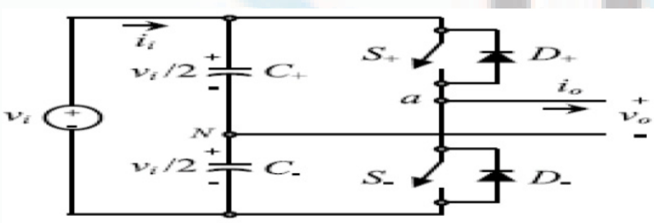

Figure 4: Single-phase half-bridge VSI

There is a circuit connection between the output (photo-diode) side and a floating dc power supply. From the floating-supply ground of the output the control (logic card) supply ground is isolated.

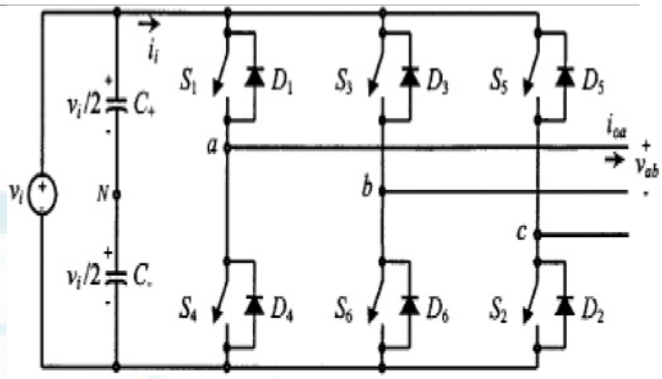

Figure 5: Full-bridge VSI

1.4 Full-Bridge VSI

This inverter is similar to the half-bridge inverter; however, a second leg provides the neutral point to the load. As expected, because a short circuit across the dc-link voltage source Vi would be produced when both switches S2+ and S2- (orS1+ and S1-) cannot be on simultaneously.

There are many types of modulations:

1.5 Pulse-Amplitude Modulation

In PAM the analog signal s (t) having some successive sample values which are used to affect the amplitudes of a corresponding sequence of pulses of constant duration occurring at the sampling rate. There is no quantization of the samples normally occurs.

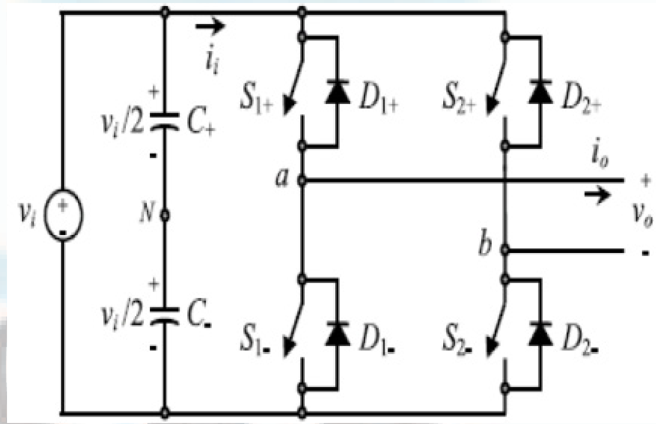

Figure 6: Pulse Amplitude Modulation

1.6 Sinusoidal Pulse Width Modulation

The switches in the voltage source inverter can be turned off and on as required. In simple way, the top switch is turned on if turned off and on only once in each cycle, a square wave waveform results.

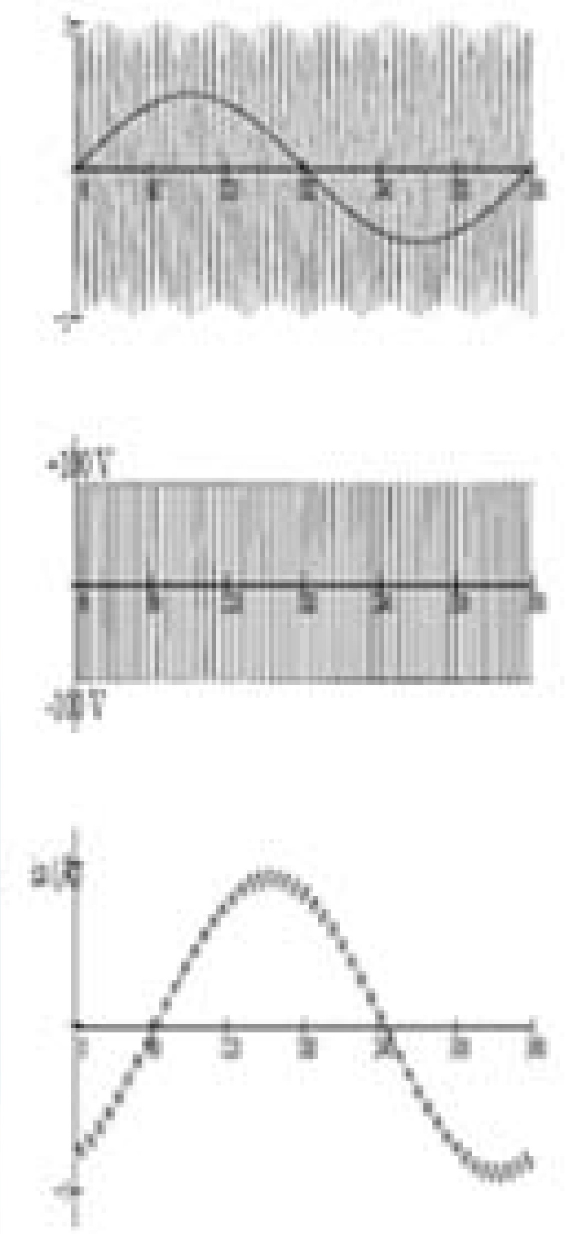

Figure 7: Switching Pattern Using POD

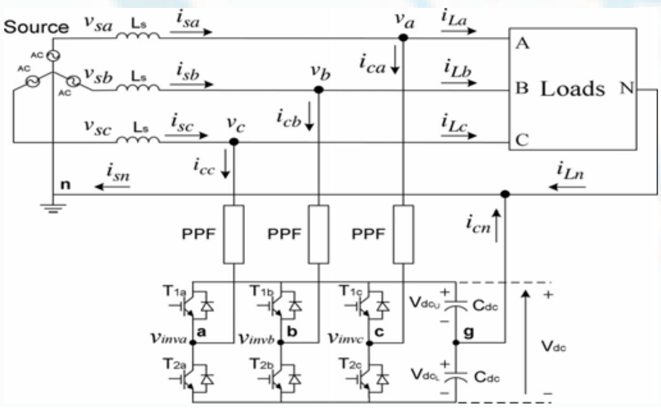

Figure 8: Complete Circuit Diagram

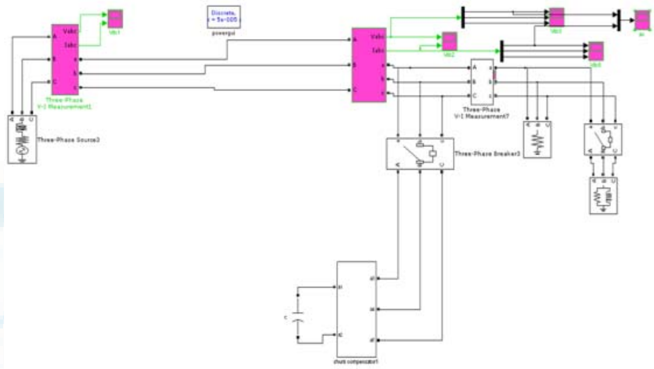

Figure 9: Simulation Diagram

2. Simulation Result

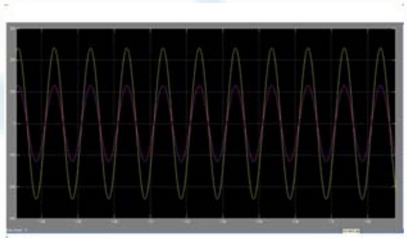

Figure 10: R-L Load

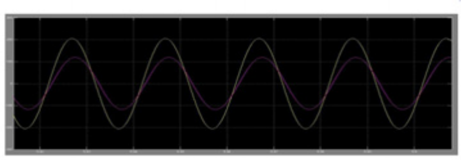

Figure 11: During The R and L Load

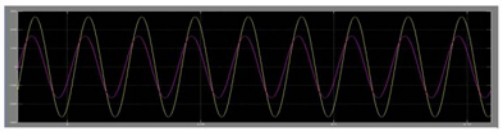

Figure 12: Presence of Active Filter

Capacitor: A capacitor (formerly known as condenser) is a device for storing electric charge. The forms of practical capacitors vary widely, but all contain at least two conductors separated by a non-conductor.

A typical electrolytic capacitor

Figure 13: A typical Electrolyte Capacitor

3. Theory of Operation

A capacitor consists of two conductors separated by a non-conductive region called the dielectric medium though it may be a vacuum or a semiconductor depletion region chemically identical to the conductors. An ideal capacitor is wholly characterized by a constant capacitance C, defined as the ratio of charge ±Q on each conductor to the voltage V between them.

$$C = \frac{Q}{V}$$

3.1 Energy Storage

$$W = \int_{q=0}^{Q} V\,\mathrm{d}q = \int_{q=0}^{Q} \frac{q}{C}\mathrm{d}q = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2 = \frac{1}{2}VQ.$$

Resistor: A linear resistor is a two-terminal, linear, passive electronic component that implements electrical resistance as a circuit element.

This relation is represented with a well-known Ohm's law.

$$I = \frac{V}{R}$$

3.2 Introduction of LC Filter

In electronics an LC circuit, also called a resonant circuit, tank circuit, or tuned circuit, consists of two electronic components connected together; an inductor, represented by the letter L, and a capacitor, represented by the letter C.

An LC circuit is an idealized model since it assumes there is no dissipation of energy due to resistance.

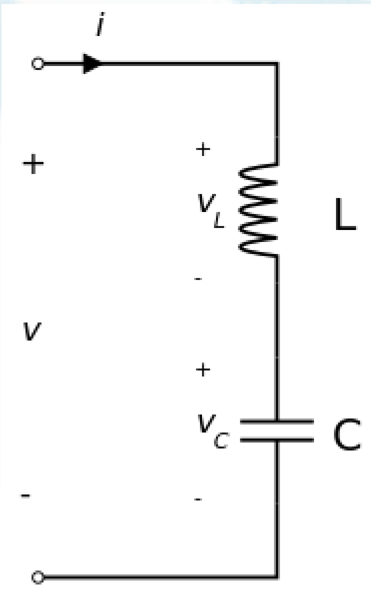

Figure 14: Series LC Filter

In the series configuration of the LC circuit, the inductor *L* and capacitor *C* are connected in series, as shown here. The total voltage *v* across the open terminals is simply the sum of the voltage across the inductor and the voltage across the capacitor. The current *i* flowing into the positive terminal of the circuit is equal to the current flowing through both the capacitor and the inductor.

V=VL + Vc
I=IL = ic

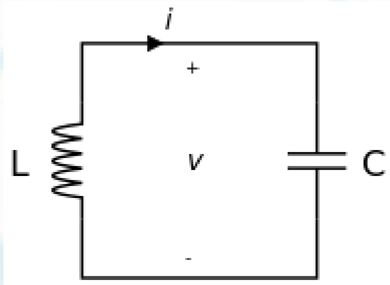

Figure 15: Parallel LC Filter

In the parallel configuration, the inductor *L* and capacitor *C* are connected in parallel, as shown here. The voltage *v* across the open terminals is equal to both the voltage across the inductor and the voltage across the capacitor. The total current *i* flowing into the positive terminal of the circuit is equal to the sum of the current flowing through the inductor and the current flowing through the capacitor.

V=VL=Vc
I=IL=ic

- A Lowpass filter allows energy from DC to a specified (cutoff) frequency to pass with little or no attenuation while energy above this frequency is rejected.
- A Bandpass filter passes energy within a certain bandwidth and rejects frequencies below and above this bandwidth.
- A Bandstop filter or band-rejection filter passes most frequencies without disrupting them but significantly attenuates frequencies over a specific region.
- A Highpass filter passes energy above a specified cutoff frequency, and rejects signals at frequencies lower than the cutoff frequency.

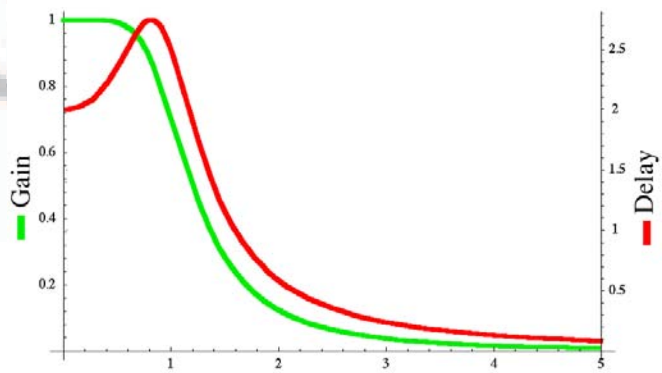

Figure 16: Gain Vs Delay

4. Introduction of MOSFET

The power MOS field effect transistor (MOSFET) evolved from the MOS integrated circuit technology. MOSFETs also have comparatively higher on state resistance per unit area of the device cross section which increases with the blocking voltage rating of the device. Consequently, the use of MOSFET has been restricted to low voltage (less than about 500 volts) applications where the ON state resistance reaches acceptable values. The electric fields produced by the gate voltage modulate the conductivity of the semiconductor material in the region between the main current carrying terminals.

4.1 Constructional Features of a Power MOSFET

As mentioned in the introduction section, Power MOSFET is a device that evolved from MOS integrated circuit technology. The first attempts to develop high voltage MOSFETs were by redesigning lateral MOSFET to increase their voltage blocking capacity. The resulting technology was called lateral double diffused MOS (DMOS). However it was soon realized that much larger breakdown voltage and current ratings could be achieved by resorting to a vertically oriented structure. Since then, vertical DMOS (VDMOS) structure has been adapted by virtually all manufacturers of Power MOSFET.

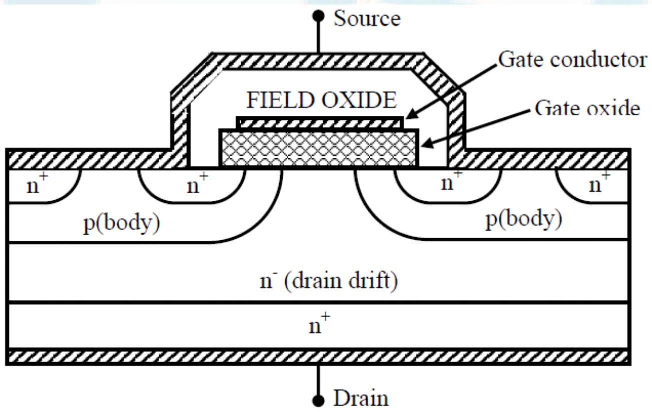

Figure 17: MOSFET

4.2 Operating Principle of a MOSFET

At first glance it would appear that there is no path for any current to flow between the source and the drain terminals since at least one of the **p n** junctions (source – body and body-Drain) will be reverse biased for either polarity of the applied voltage between the source and the drain.

4.3 Components Details

- Step down transformer -230V/12V
- Microcontroller -DSPIC33FJ64MC802
- MOSFET driver/Opto coupler -FOD3120 or IRS2110
- Inductor -47uh, 10mh, 100uh
- Capacitors -1000uf, 2200uf, 10uf, 0.01uf
- PN junction diodes -1N4007
- MOSFET - IRF 840

5. The Trouble with Harmonics in Modern Power Systems

5.1 Introduction

Harmonics are a distortion of the normal electrical current waveform, generally transmitted by nonlinear loads. Switch-mode power supplies (SMPS), variable speed motors and drives, photocopiers, personal computers, laser printers, fax machines, battery chargers and UPSs are examples of nonlinear loads. It causes Hardware damage, such as Overheating of electrical distribution equipment, cables, transformers, standby generators, etc.

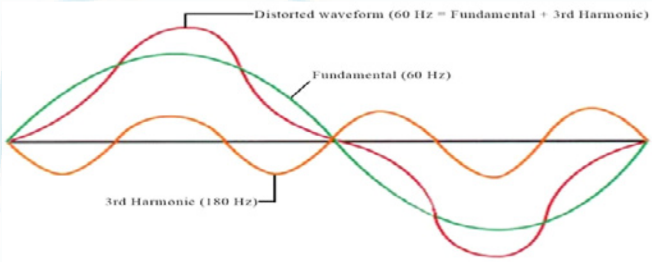

Figure 18: Harmonic Distortion of the Electrical Current Waveform

All periodic waves can be generated with sine waves of various frequencies. The Fourier theorem breaks down a periodic wave into its component frequencies.

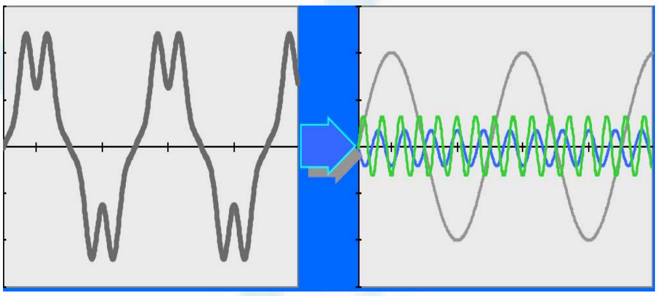

Figure 19: Distorted Current Waveform Equivalent Harmonic Components

6. Conclusion

An adaptive dc-link voltage-controlled LC-HAPF with dynamic reactive power compensation capability in the three phase four-wire system is proposed in this paper. In order to implement the adaptive dc-link voltage control algorithm, the LC-HAPF required minimum dc-link voltage for compensating different reactive power is deduced and its adaptive control block diagram is also built. Moreover, the viability and effectiveness of the proposed adaptive dc-link voltage control for the three-phase four-wire LCHAPF have been proved by both simulation and experimental results, in which it can achieve a good dynamic reactive power compensation performance.

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