IMPLEMENTATION OF MATLAB-SIMULINK APPROACH IN SHUNT ACTIVE POWER FILTERS TO MINIMIZE THE HARMONICS

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ABSTRACT
Due to the wide spread of power electronics equipment in modern electrical systems, the increase of the harmonics disturbance in the ac mains currents has become a major concern due to the adverse effects on all equipment. This paper presents the analysis and simulation using Matlab Simulink of a three-phase four wire neutral clamped active power filter (APF) compensating the harmonics and reactive power created by nonlinear balanced and unbalanced low power loads in steady state and in transients. The usefulness of the simulation approach to APF is demonstrated so APF designers have a better insight using Matlab Simulink in order to develop new APFs.

KEYWORDS: Active Power Filters, Computer Simulation, Current Harmonics, Reactive Power, Unbalance

I. INTRODUCTION
The harmonics currents causes adverse effects in power systems such as overheating, perturbation of sensitive control and communication equipment, capacitor blowing, motor vibration, excessive neutral currents, resonances with the grid and low power factor. As a result, effective harmonic reduction from the system has become important both to the utilities and to the users. The total harmonic distortion is the ratio between the RMS value of the sum of all harmonic components and the RMS value of the fundamental component, for both current and voltage. First of all we have to discuss about the definition of harmonics “A component frequency of a harmonic motion of an electromagnetic wave that is an integral multiple of the fundamental frequency is called harmonic[4].

Traditionally, the simplest method to eliminate current harmonics is the usage of passive LC filters, but they have many drawbacks such as large size, tuning problems, resonance and fixed compensation characteristics. The solution over passive filters for compensating the harmonic distortion and unbalance is the shunt active power filter (APF)[1]. In order to compensate the distorted currents the APF injects currents equal but opposite with the harmonic components.

Also, some nonlinear loads and electronics equipment tend to draw current in short pulses instead of drawing current sinusoidal thus creating harmonics. Some of the examples of nonlinear loads would be rectifiers, inverters, etc. Some of the examples of electronics equipments would be computers, scanners, printers, etc. Some of the major issues concerned with harmonics in nonlinear loads are overheating, temperature increase in generators, etc. These effects may result into permanent damage of the devices. One of the way out to resolve the issue of harmonics would be using filters in the power system. Installing a filter for nonlinear loads connected in power system would help in reducing the harmonic effect [6]. The filters are widely used for reduction of harmonics. With the increase of nonlinear loads in the power system, more and more filters are required.

There are two types of filters
- The Passive Filters
- The Active Filters

Capacitors are frequently used in the Active and Passive filters for harmonics reduction. The Passive filters are used in order to protect the power system by restricting the harmonic current to enter the power system by providing a low impedance path. Passive filters consist of resistors, inductors and capacitors. The Active filters are mostly used in distribution networks for sagging in voltage, flickering, where there are harmonics in current and voltages, etc. Using the filter would result into a better quality of power. There is also a third type of filter which is used i.e. The Hybrid Filter. Hybrid filters are composed of the passive and active filters both.

II. ACTIVE FILTERS:
Active filters are a perfect alternative to the passive filters. 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. Just like the passive filters, active filters can be connected in either series or parallel depending on the type of sources which create harmonics in the power system. The active filters minimize the effect of harmonic current by using the active power conditions to produce equal amplitudes of opposite phase there by canceling the harmonics that are caused in the nonlinear components and replace the current wave from the nonlinear load [4].

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.

Disadvantages of Active Filter over Passive Filter
- Active filters cost more than the passive filters
- Active filters cannot be used for small loads in a power system
- Due to the presence of harmonics in both current and voltage, active filter may not be able to resolve the issue in certain typical applications.

III. DC-AC INVERTER
DC to AC inverters is those devices which are used to produce inversion by converting a direct current into an alternating current. If the output of a circuit is AC then depending on the input i.e. either AC or DC, the devices are called as AC-AC cycloconverters or DC-AC inverters. DC to AC inverters is such devices
whose AC output has magnitude and frequency which is either fixed or variable. In case of DC to AC inverters the output AC voltage can be either single phase or three phases. Also, the magnitude of the AC voltage is from the range of 110-380 V AC while the frequencies are 50 Hz, 60Hz or 400Hz.

IV. PULSE WIDTH MODULATION TECHNIQUE

Figure shows a single phase inverter block diagram with a high frequency filter that is used in order to remove the harmonics from the output waveform. Here, \( V_o \) is the ac output while \( V_{in} \) is the input dc voltage.

![Figure 1: Single Phase Inverter with Filter](image1)

In a single phase inverter, the width of the output pulse is varied to control the output voltage. Thus, this process of controlling the output voltage of inverter in order to reduce the harmonics is known as Pulse Width Modulation.

The Pulse Width Modulation is classified into two techniques [8].

- Non sinusoidal Pulse Width Modulation
- Sinusoidal Pulse Width Modulation

Non Sinusoidal Pulse Width Modulation

In case of Non sinusoidal pulse width modulation, all the pulses that have same pulse width are modulated together. The pulse widths of pulses are adjusted together in same proportion in order to remove the harmonics from the system.

![Figure 3: Representation of Non Sinusoidal Pulse Width Modulation](image3)

Sinusoidal Pulse Width Modulation

Sinusoidal Pulse Width Modulation is a bit different compared to the non-Sinusoidal Pulse Width Modulation. In case of sinusoidal pulse width modulation, all the pulses are modulated individually. Each and every pulse is compared to a reference sinusoidal pulse and then they are modulated accordingly to produce a waveform which is equal to the reference sinusoidal waveform. Thus, sinusoidal pulse width modulation modulates the pulse width sinusoidally [4].

![Figure 4: Representation of Sinusoidal Pulse Width Modulation](image4)

For figures 3 and 4

- \( t_s \) = Time of the triangular waveform
- \( f_s \) = frequency of the triangular waveform
- \( V_{ref} \) = Reference voltage of the square or sinusoidal waveform
- \( V_{p,ref} \) = Peak value of the reference voltage
- \( t_o \) = Time of the output waveform of the Inverter which is desired
- \( f_o \) = Frequency of the output waveform of the Inverter which is desired
- \( \text{ma} \) = Amplitude modulation index of Inverter
- \( \text{mf} \) = Frequency modulation index of Inverter
- \( k \) = Number of pulses per half cycle

Shunt Active Power Filters

Figure 5 shows the basic compensation principle of the shunt active power filter [1], [2], [3]. It is controlled to draw or supply a compensating current \( i_c \) from or to the utility, so that it cancels current harmonics on the ac side.

![Fig 5](image5)
From figure 5, the instantaneous currents can be written as: 

\[ i_c(t) = i_L(t) - i_s(t) \]

The source voltage is given by: 

\[ v_s(t) = V_m \sin \omega t \]

if a nonlinear load is applied, then the load current will have a fundamental component, and the harmonic components can be represented as

\[ i_c(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n) \]

\[ i_L(t) = I_1 \sin(\omega t + \phi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \]

Instantaneous load power can be given as:

\[ p_L(t) = v_s(t) \times i_L(t) \]

\[ p_s(t) = V_m I_1 \sin^2 \omega t \cos \phi_1 + V_m I_1 \sin \omega t \cos \phi_1 \sin \omega t + V_m \sin \omega t \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \]

\[ p_c(t) = p_f(t) + p_L(t) + p_s(t) \]

From equation (4), real (Fundamental) power is drawn by the load

\[ p_f(t) = V_m I_1 \sin^2 \omega t \cos \phi_1 = v_s(t) \times i_1(t) \]

From equation (6), the source current supplied by the source, after compensation

\[ i_s(t) = \frac{p_f(t)}{v_s(t)} = I_1 \cos \phi_1 \sin \omega t = I_{sm} \sin \omega t \]

Also there are some switching losses in the PWM converter. Hence, the utility must supply a small overhead for the capacitor leaking and converter switching losses in addition to the real power of the load.

Hence, total peak current supplied by the source

\[ I_{sp} = I_{sm} + I_{sl} \]

If the active filter provides the total reactive and harmonic power then \( i_{c1}(t) \) will be in phase with the utility voltage and pure sinusoidal. At this time, the active filter must provide the following compensation current:

\[ i_{c1}(t) = i_L(t) - i_s(t) \]

Hence for the accurate and instantaneous compensation of reactive and harmonic power, it is necessary to calculate \( i_{c1}(t) \), the fundamental component of load current, as the reference current.

**V. ESTIMATION OF REFERENCE SOURCE CURRENT**

The peak value of the reference current \( I_{sp} \) can be estimated by controlling the dc side capacitor voltage. The ideal compensation requires the main current to be sinusoidal and in phase with the source voltage irrespective of the load’s current nature. The desired source currents after compensation can be given as

\[ i_{sa}^* = I_{sp} \sin \omega t, \]

\[ i_{sb}^* = I_{sp} \sin(\omega t - 120^\circ), \]

\[ i_{sc}^* = I_{sp} \sin(\omega t + 120^\circ), \]

Where \( I_{sp} = I_1 \cos \phi_1 + I_{sl} \) is the amplitude of the desired source current, while the phase angles can be obtained from the source voltages. Hence, the waveform and phases of the source currents are known only the magnitude of the source currents needs to be determined.

The peak value of the reference current has been estimated by regulating the dc side capacitor voltage of the PWM converter. This capacitor voltage is compared by a reference value and the error is processed in a PI controller. The output of the PI controller has been considered as \( t_e \), amplitude of the desired source current, and the reference currents are estimated by multiplying this peak value with the unit sine vectors in phase with the source voltage.

**VI. ROLE OF DC SIDE CAPACITOR**

The dc side capacitor serves two main purposes, it maintains a dc voltage with a small ripple in steady state, and it serves as an energy storage element to supply the real power difference between load and source during the transient period. In the steady state, the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate for the losses in the active filter. Thus, dc capacitor voltage can be maintained at a reference value. However, when the load condition changes, the real power balance between the source and the load will be disturbed. This real power difference is to be compensated for by the dc capacitor. This changes the dc capacitor voltage away from the reference voltage. In order to keep the satisfactory operation of the active filter, the peak value of the reference current must be adjusted to change proportionally the real power drawn from the source. This real power charged or discharged by the capacitor compensates for the real power consumed by the load. If the dc capacitor voltage is recovered and attains the reference voltage, the real power supplied by the source is supposed to equal that consumed by the load again.

Thus, in this fashion the peak value of the reference source current can be obtained by regulating the average voltage of the dc capacitor. A smaller dc capacitor voltage than the reference voltage means that the real power supplied by the source is not enough to supply load demand. Therefore, the source current (i.e. the real power drawn from the source) needs to be increased; while a larger dc capacitor voltage than the reference voltage tries to decrease the reference source current. The real reactive power injection may result in the ripple voltage of the dc capacitor. A low pass filter is generally used to filter these ripples which introduce a finite delay. To avoid the use of this low pass filter, the capacitor voltage is sampled at the zero crossing of the source voltage. A continuously changing reference current makes the compensation non instantaneous during transient. Hence this voltage is sampled at the zero crossing of one of the phase voltage. This makes the compensation instantaneous. Sampling only twice in a cycle as compared to six times in a cycle gives a little higher dc capacitor voltage rise or drip during transients, but the settling time is less.

Here it is shown how harmonic elimination is done in Inverter by Pulse Width Modulation technique by solving the non linear equations. Equations are used to determine switching angles of an Inverter. Switching angles play an important role to produce the desired output by eliminating selected harmonics. In order to form the equation set, fundamental component is given desired output value and all other harmonics are equated to zero. In my simulation I find...
the switching angles for the 5th, 7th and 11th harmonics.
The equation which is derived for Total Harmonic Distortion of the output voltage and current of an inverter is used in order to reduce the harmonics that are produced in the inverter. The percentage of the Total Harmonic Distortion is given by the following formula.

\[
\%THD = \left[ \frac{1}{a_1^2} \sum_{n=5}^{\infty} (a_n^2) \right] \times 100
\]

Where \( n = 6i \pm 1 \) (i = 1, 2, 3,...)

VII. SIMULINK MODEL

The Shunt active filter [4] concept uses power electronic equipment [2] to produce harmonic current components that cancel the harmonic current components that cancel the harmonic current components from the nonlinear loads. In this configuration, the filter is connected in parallel with the load being compensated. Therefore the configuration is often referred to as an active parallel or shunt filter. Fig 5 illustrates the concept of the harmonic current cancellation so that the current being supplied from the source is sinusoidal. The voltage source inverter used in the active filter makes the harmonic control possible. This inverter uses dc capacitors as the supply and can switch at a high frequency to generate a signal that will cancel the harmonics from the nonlinear load. The active filter does not need to provide any real power to cancel harmonic currents from the load. The harmonic currents to be cancelled show up as reactive power. Reduction in the harmonic voltage distortion occurs because the harmonic currents flowing through the source impedance are reduced. Therefore, the dc capacitors and the filter components must be rated based on the reactive power associated with the harmonics to be cancelled and on the actual current waveform (rms and peak current magnitude) that must be generated to achieve the cancellation. The current waveform for canceling harmonics is achieved with the voltage source inverter in the current controlled mode and an interfacing filter. The filter provides smoothing and isolation for high frequency components. The desired current waveform is obtained by accurately controlling the switching of the insulated gate bipolar transistors (IGBT’s) in the inverter [4]. Control of the current waveform is limited by the switching frequency of the inverter and by the available driving voltage across the interfacing inductance. The driving voltage across the interfacing inductance determines the maximum di/dt that can be achieved by the filter. This is important because relatively high values of di/dt may be needed to cancel higher order harmonic components [4]. Therefore, there is trade–off involved in sizing the interface inductor. A large inductor is better for isolation from the power system and protection from transient disturbances. However, the larger inductor limits the ability of the active filter to cancel higher order harmonics. The inverter in the Shunt Active Power filter is a bilateral converter and it is controlled in the current Regulated mode i.e. the switching of the inverter is done in such a way that it delivers a current which is equal to the set value of current in the current control loop. Thus the basic principle of Shunt Active Filter is that it generates a current equal and opposite to the harmonic current drawn by the load and injects it to the point of coupling thereby forcing the source current to be pure sinusoidal.
VII. RESULTS WITH NONLINEAR LOAD AND WITHOUT SHUNT ACTIVE FILTER

Figure 8 Three phase shunt active power filter

Figure 9 Three phase supply voltage A, B, and C without shunt active filter

Figure 10 Three phase supply Current A, B, and C without shunt active filter
VIII. RESULTS WITH NONLINEAR LOAD AND WITH SHUNT ACTIVE FILTER.
Figure 13 Three phase supply current A, B, and C with shunt active filter

Figure 14 Three phase Current A, B, and C with shunt active filter

Figure 15 THD of supply voltage with active power filter
IX. CONCLUSION
The power electronic equipments lead 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 Shunt active filters. In this paper I explain harmonics of power system, inverter circuit and shunt active filter for the three-phase circuit is simulated and the THD measured verifies the reduction of harmonics based shunt active filter. I using the MATLAB Simulink software to simulate the shunt active filter based model. The Shunt AF is able to compensate balanced and unbalanced nonlinear load currents of a four-wire system with the neutral wire connected to the capacitor midpoint. The proposed shunt active power filter can compensate on demand the harmonic currents as well as the reactive currents.

REFERENCES