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Indirect Current Control of LCL Based Shunt Active Power Filter

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Abstract

In a three phase system, harmonic currents produced due to the non linear loads can be compensated by the design, control and implementation of an LCL filter based shunt active power filter(SAPF). The proposed SAPF with LCL filter offers superior switching harmonic suppression. The designed inductance value will be smaller which reduces the harmonic voltage drop across the passive output filter. This in turn minimizes the possibility of over modulation and mainly for cases where high modulation index is required. The above advantages can be obtained only by proper consideration of critical design and control issues, like the selection of LCL parameters, harmonic compensation. The performances of the proposed shunt active power filter with passive(LCL) filter and the controller were examined by using MATLAB/SIMULINK software.

Keywords: Shunt Active Power Filter (SAPF), Harmonic Compensation, Indirect Current Control.

Introduction

In modern electric power supply distribution systems, there is a sharp rise in the usage of single phase and three phase non linear loads such as computer power supplies, commercial lightning, domestic equipments like TVs, ovens, adjustable speed drives. These non linear loads generally have power semiconductor devices which draw non sinusoidal unbalanced currents from ac mains and also resulting in harmonic injection, reactive power burden, excessive neutral currents and unbalanced loading of ac mains. In addition to the above demerits, it also causes poor power factor, low efficiency and interference with nearby communication networks.

The higher order LCL filter has commonly been used in place of the conventional L-filter to give a better smoothing of output currents from a voltage source converter[1], [2]. Its applications to grid-connected inverters and pulse width modulated active rectifiers have recently attracted a lot of research attentions [1]–[8], mainly due to its ability to minimize the amount of current distortion injected into the utility grid. Power quality of the grid is hence enhanced, which is particularly important for small-scale distributed generation systems, where the ac bus is not strong [6].The application of passive filters creates system resonances which are dependent on specific system conditions [3], [4].

The overall system might therefore be unstable, but fortunately can be resolved by applying existing damping techniques, like adding a real resistor in series with the filter capacitor [5], actively feeding back some measured or estimated electrical variables for control purposes [7]-[10].

It is often difficult to design the filters to avoid leading power factor operation for some load conditions. The active power filter connected in parallel to the non linear load is a more interesting solution because it compensates the reactive power of any load. Active filters have the advantage of being able to compensate the load current harmonics. In addition to this, the active filter does not introduce system resonances that can eliminate the harmonic problem from one frequency to another.

The active filter concept uses power electronics to produce harmonic current components that cancel the harmonic current components from the non linear loads. The active filter uses power electronic switching to generate harmonic currents that cancel the harmonic currents from the non linear load. The APF is a standard voltage source inverter having an energy storage capacitor on the dc side. Hysteresis carrier less PWM current control is used to generate gating pulses to the switches of the APF.

Shunt Active Power Filter

The active filter configuration is based on the pulse-width modulated (PWM) voltage source inverter that interfaces to the system through the passive filter as shown in Figure 1. 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. Figure 1 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 non linear load.

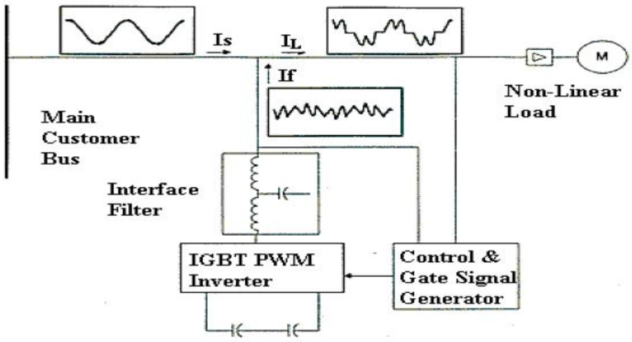

Figure 1: Shunt Active Power Filter.

The active filter does not need to provide any real power to cancel harmonic currents from the load. 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 cancelling 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 in the inverter. Control of the current wave shape 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. Therefore, there is a trade-off involved in sizing the interface inductor. A larger 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.

In a three phase symmetry circuit, one phase model is considered for analysis which is shown in Figure 2 where U_i is output voltage of VSC, U_g is the grid voltage, i_2 is compensation current. L_1, L_2 & C are the filter inductors and capacitor.

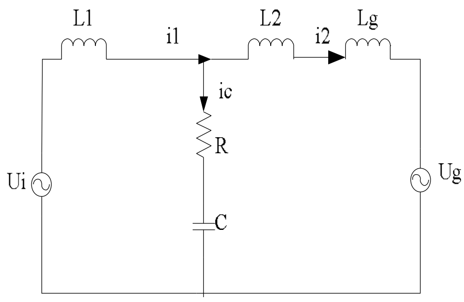

Figure 2: LCL Filter Equivalent Circuit.

The LCL-filter can be described as following equations.

$L_1\,(di1/dt)=R_1 i_1+u_i-u_c-R_d i_c$ (1)

$C\,(du_c/dt)=i_1-i_2$ (2)

$(L_2+L_g)\,(di_2/dt)=r_2 i_2+uc+R_d i_c-u_g$ (3)

Modelling of LCL Filter

Between the SAPF and utility grid is an LCL filter added for current smoothing, whose model is formulated by first making a few assumptions for simplifying the analysis. Assume that the three-phase voltages at the point of common coupling are sinusoidal and balanced.

The impedance of the filter branch is calculated by:

$Z=(E_b)$ ^2) /P (4)

Where, E_b is the line voltage

$Z=R+j(\omega L-1/\omega C)$, (5)

Where *L*, *C* and w are inductance, capacitance and angular frequency of the power system ($\omega=2\pi\omega f$) respectively.

The series resonance condition is excited when ($\omega L=1/\omega C$), which means that the inductive and capacitive reactance's tend to cancel each other at the resonant (tuning) frequency:

Carrier frequency,$(F_C)=1/(2\pi(LC)$^(1/2)) (6)

The inductive and capacitive reactance at a can be expressed as:

$X_L=\omega L;\ X_{C=}1/\omega C$, (7)

Control Scheme of the APF

The block diagram of the proposed control scheme is shown in Figure 3.

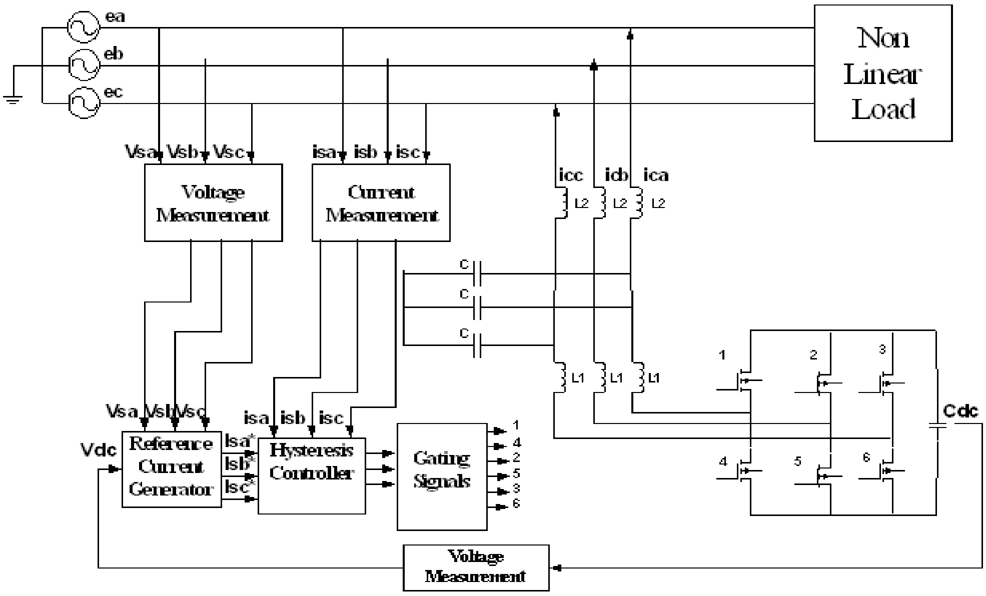

Figure 3: SAPF Block Diagram with Indirect Current Control Technique.

The system consists of the following modules:
1. Compensating currents generator.

Compensating currents generator can generate currents which have the same amplitude and opposite phase with the harmonic currents to offset the harmonic components in the power supply current.
2. Reference currents generator.

The DC voltage is controlled by a PI regulator whose output is applied as the input of power supply reference current Isp*.

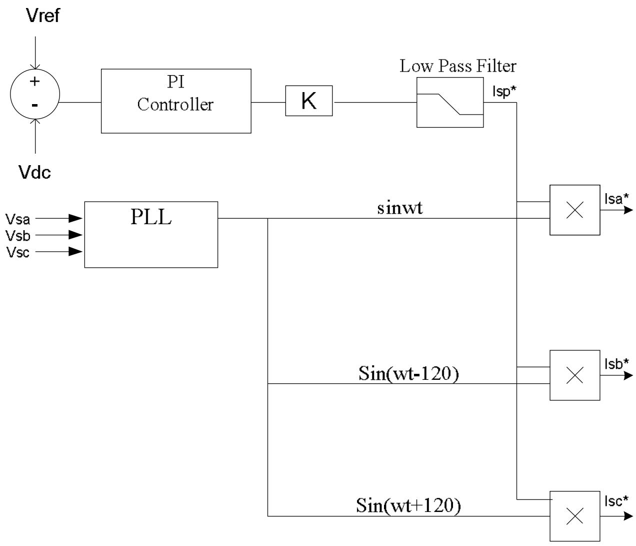

Figure 4: Reference Current Generator.

The power supply reference currents should have the same phase with the power supply voltage, so the unit sinusoidal signals (sin(ωt),sin(ωt+120), sin(ωt-120)) can formed with Phase Locked Loop(PLL). The supply reference currents (I_{sa}*, I_{sb}*,I_{sc} *) can be obtained by multiplying I_{sp}^* and the unit sinusoidal signals.

3. Hysteresis Current Controller.

Hysteresis rule based carrier less PWM current controller is used to generate gating signal for the devices of the APF. The component of reference converter current (I_{ca}*, I_{cb} *, I_{cc}*) is computed by using generated and reference source currents. Three phase instantaneous reference currents of an APF (Ica*, Icb*, Icc*)are computed by subtracting load currents (I_{la}, I_{lb}, I_{lc}) from reference supply currents.

Estimation of Reference Source Currents

The 3 phase source voltages may be expressed as,

$V_{sa}=V_{sm}\sin\omega t$ (8)

$V_{sb}=V_{sm}\sin(\omega t-2\pi/3)$ (9)

$V_{sc}=V_{sm}(\sin\omega t-4\pi/3)$ (10)

The 3 phase source currents may be estimated using unit current templates in phase with source voltages and their peak values

$U_{sa}=V_{sa}/V_{sm}$ (11)

$U_{sb}=V_{sb}/V_{sm}$ (12)

$U_{sc}=V_{sc}/V_{sm}$ (13)

Where, Vsm is the peak value of the source voltage and ω is the source frequency. The instantaneous reference source currents may be computed as

$i_{sa}^*=I_{sp}*U_{sa}$ (14)

$i_{sb}^*=I_{sp}*U_{sb}$ (15)

$i_{sc}^*=I_{sp}*U_{sc}$ (16)

Computation of Reference APF Currents

The 3 phase APF reference currents may be computed using reference source currents and sensed load currents as

$i_{ca}^*=i_{sa}^*-i_{La}$ (17)

$i_{cb}^*=i_{sb}^*-i_{Lb}$ (18)

$i_{cc}^*=i_{sc}^*-i_{Lc}$ (19)

Where, i_{sa}^*,i_{sb}^*, i_{sc}^* are the reference source currents & i_{La} ,i_{Lb}, i_{Lc} are the load currents

Non Linear Load

Switched Mode Power Supply is considered as the non linear load which is shown in Figure 5. In today's environment, all computer systems use SMPS that convert utility AC voltage to regulated low voltage DC for internal electronics. These non-linear power supplies draw current in high amplitude short pulses. These current pulses create significant distortion in the electrical current and voltage wave shape. This is referred to as a harmonic distortion and is measured in Total Harmonic Distortion (THD).

The distortion travels back into the power source and can affect other equipment connected to the same source. Any SMPS equipment will create continuous distortion of the power source that stresses the facility's electrical distribution system and power equipment.

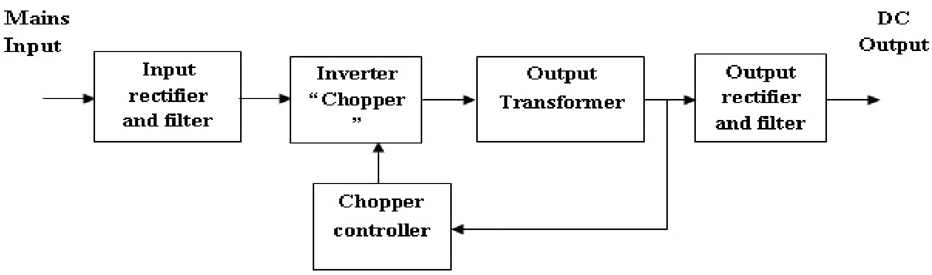

Figure 5: Block Diagram of SMPS.

Simulation Results

Simulation was conducted with Matlab/Simulink software. The aim was to examine the performance of the proposed SAPF system which is shown in Figure 6.

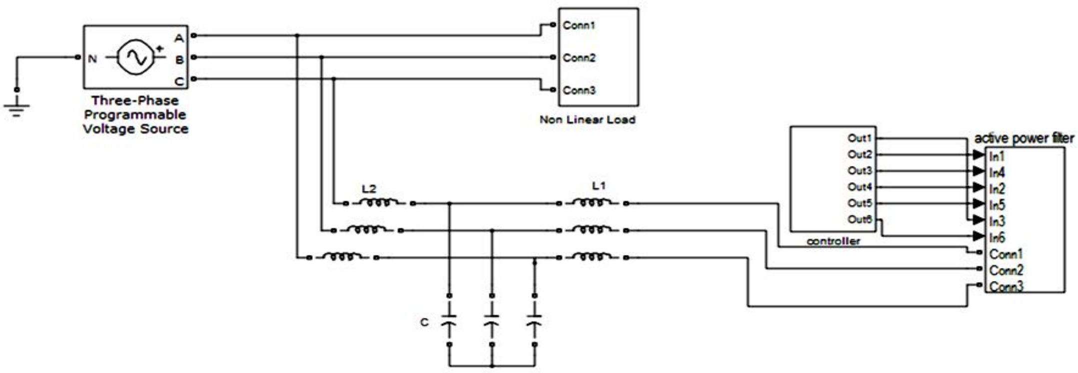

Figure 6: Overall Implementation.

The Figure 7 & 8 indicates the input source voltage and current waveform in which X axis denotes the time and Y axis indicates the input source voltage and current.

Initially, there is a peak rise in the current magnitude which is mainly due to the charging of the energy storage element (dc side capacitor) in the active power filter. By controlling the active power filter using hysteresis current control technique, the input source current is made pure sinusoidal. The sinusoidal input source current magnitude is 20A.

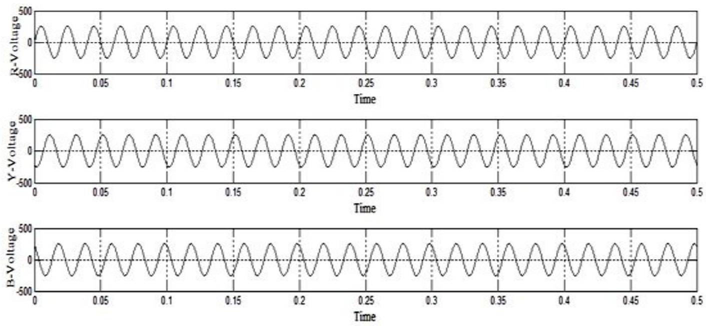

Figure 7: Input Source Voltage Waveform.

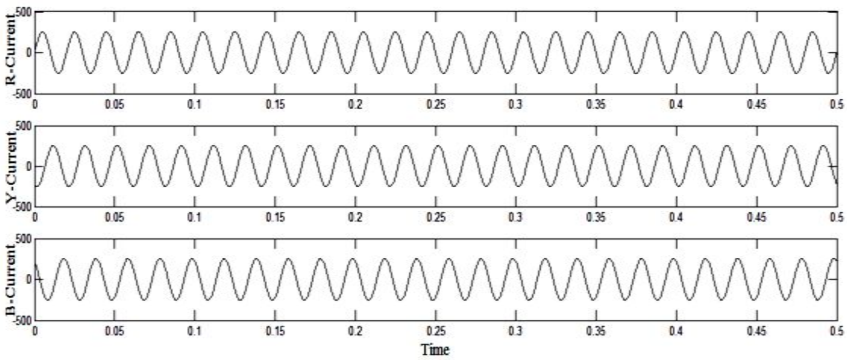

Figure 8: Input Source Current Waveform.

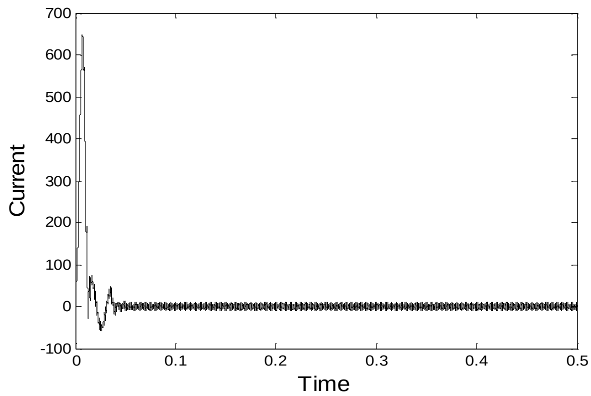

Figure 9: APF Compensating Waveform.

APF compensating current waveform is shown in Figure 9. APF compensating current versus time is shown below. The compensating current magnitude is 20A.

Load current Vs Time graph is shown in Figure 10 where X axis is time and Y axis is the load current. The distorted load current magnitude is 5A.

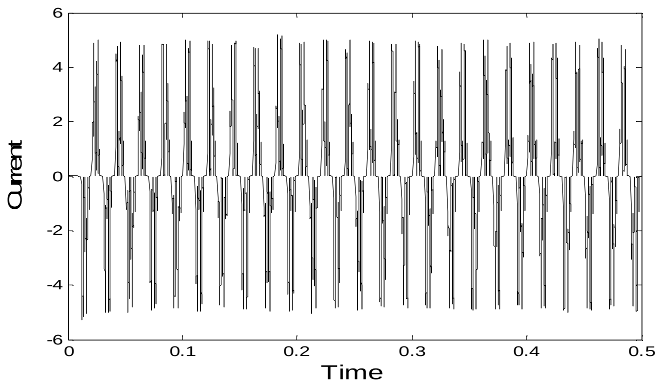

Figure 10: Load Current Waveform.

The total harmonic distortion is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. The total harmonic distortion of the load current is 80.55 which is shown in below Figure 11.

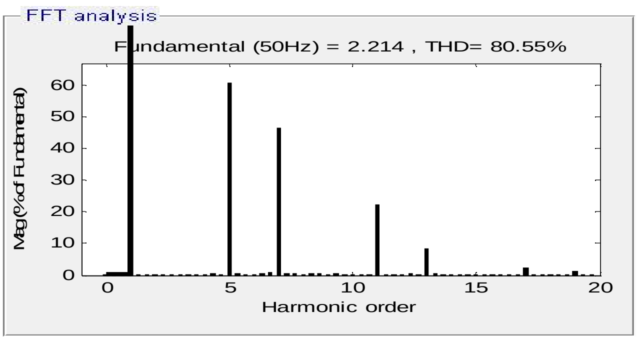

Figure 11: Load Current THD.

The proposed shunt active power filter with LCL filter will reduces the total harmonic distortion of the source current which is very low when compared to the load current total harmonic distortion The reduced total harmonic distortion of source current is 2.71 which is shown in below Figure 12.

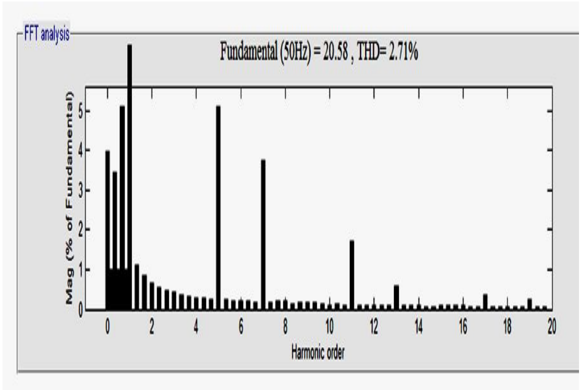

Figure 12: Source Current THD.

Conclusion

The new control scheme for the three phase active power filter is proposed and it results in sinusoidal, unity power factor and balanced supply currents. The performance of the APF is observed to be excellent as it leads to reduced harmonics, reactive power burden. The unbalancing caused by unbalanced non linear load is also compensated at the ac supply mains. The current controller gives fast response without any transients in supply current. It maintains supply current always below load current. The proposed APF is able to reduce the THD of supply current. The proposed shunt active filter enhances the system efficiency because it avoids harmonic injection, reactive power compensation and also results in harmonic free unity power-factor supply current.

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