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An Active Harmonic Filter Based On One Cycle Control

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Abstract:

The widespread usage of load compensators for carrying out harmonic and reactive power compensation is constrained by cost and poor efficiency due to switching losses. Hence it is customary to employ active harmonic filters for harmonic compensation only while traditional methods comprising of thyristor switched capacitors are used to carry out reactive power compensation. Load compensators based on one cycle control (OCC) have gained considerable significance as they do not require the service of a phase locked loop to synchronize with the utility grid. However, existing OCC based load compensators do not have the capability to differentiate between fundamental reactive component and harmonic components of the load currents. Hence, they cannot be employed for harmonic compensation alone, as they end up compensating for reactive current as well leading to an increase in the converter rating. In order to overcome the aforementioned limitation, an OCC based shunt harmonic filter which is capable of compensating only harmonic components of the load current is proposed in this paper. The viability of the proposed scheme is confirmed by performing detailed simulation studies and experimental validation.

Keywords:

Inverter, Active filter, One cycle control.

Introduction:

Since the rapid development of the semiconductor industry, power electronics devices have gained popularity in our daily used electrical house-hold appliances. Although these power electronics devices have benefited the electrical and electronics industry, these devices are also the main source of power harmonics in the power system [1,15]. These power harmonics are called electrical pollution which will degrade the quality of the power supply. As a result, filtering process for these harmonics is needed in order to improve the quality of the power supply. Thus, active power filter seems to be a viable alternative for power conditioning to control the harmonics level in the power system nowadays. Power system normally operates at 50 or 60 Hz. However, saturated devices such as transformers, arching loads such as florescent lamp and power electronic devices will produce current and voltage components with higher frequencies into the power line. These higher frequencies of current and voltage components are known as the power harmonics [2].

The harmonics disturbances in the power supply are caused by the nonlinearity characteristic of the loads. Due to the advantages in efficiency and controllability of power electronic devices, their applications can be found in almost all power levels. The ac power system harmonic problems are mainly due to the substantial increase of non-linear loads due to technological advances, such as the use of power electronics circuits and devices, in ac/dc transmission links, or loads in the control of power systems using power electronic or microprocessor controllers. Such equipment creates load-generated harmonics throughout the system. In general, sources of harmonics are divided into:(a) Domestic loads (b) Industrial loads (c) Control devices [3,16].

ACTIVE POWER FILTERS:

Active power filter has been proposed since 1970s. The advantages of the active filtering process over the

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passive one caused much research to be performed on active power filters for power conditioning and their practical applications.By implementing the active power filters for power conditioning; it provides functions such as reactive power compensations, harmonic compensations, harmonic isolation, harmonic damping, harmonic termination, negative-sequence current or voltage compensation and voltage regulation [4]. The main purpose of the active power filter installation by individual consumers is to compensate current harmonics or current imbalance of their own harmonic-producing loads. Besides that, the purpose of the active power filter installation by the utilities is to compensate for voltage harmonics, voltage imbalance or provide harmonic damping factor to the power distribution systems [8].

Normally, active power filters can be classified into shunt and series one and both are designed to compensate for reactive power or harmonics. Active power filter consists of an inverter with switching control circuit. The inverter of the active power filter will generate the desired compensating harmonics based on the switching gates provided by the controller [9,17]. The active power filter injects an equal-but-opposite distortion harmonics back into the power line and cancel with the original distorted harmonics on the line. Figure 2.1 shows the basic idea for the compensation principle of a shunt active power filter [5,18].

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, I_f to the line based on the changes of the load in the power supply system [19]. The supply line current, Is is described by the following equation,

$$I_S = I_f + I_L$$

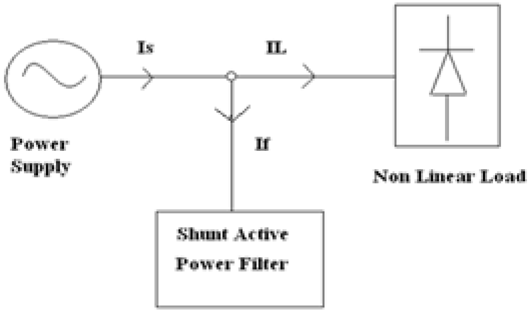
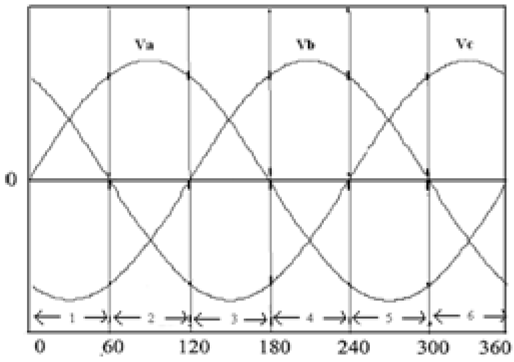


Fig.1 Basic principle of harmonic currents compensations

The line current, I_S is shaped to be sinusoidal by adding the compensating current, I_f into the distorted load current, I_L.

THREE PHASE ACTIVE POWER FILTER TOPOLOGY:

A typical power stage of a three-phase APF is composed of a voltage-source converter that is connected in parallel with a nonlinear load is shown in Fig.4.1. Here Va,Vb and Vc are Three-phase grid voltages. S_{an}, S_{ap}, S_{bn} , S_{bp} , S_{cn} , S_{cp} are APF switches consist of IGBT (Insulated Gate Bipolar Transistor) and a anti parallel diode. E is the output capacitor voltage which is acts as a voltage source. L_a, L_b, L_c are input inductances of filter, which are useful to boost up the voltage across the capacitor [6]. Three phase nonlinear load is shown in Fig.4.1 which is in parallel to the Active Power Filter (APF).



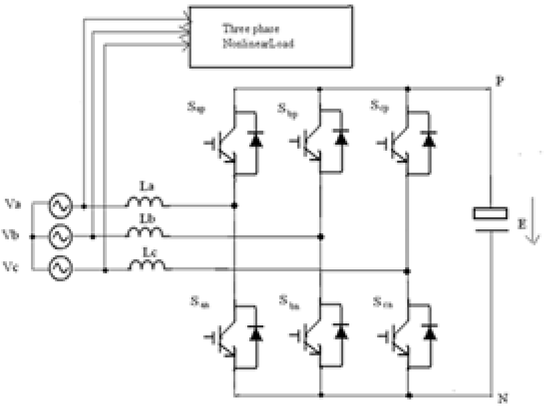


Fig.4.2 three-phase grid voltage waveforms

The three-phase voltage waveforms Va, Vb and Vc of the grid is shown in Fig.4.2. During each 60 region in Fig.4.2, the voltage-source converter in Fig.4.1 can be decoupled into a parallel-connected dual-boost converter. Here the total 360° region is divided into six regions as shown in Fig.4.2 [10,13]. In each region two voltages are either positive or negative, one voltage is either negative or positive, depending on this condition the total 360° region is divided into six regions. In each region the voltage-source converter is operated as a dual-boost converter as explained in the next section [7,14].

PROPOSED ONE-CYCLE CONTROLLER FOR THREE-PHASE APF

For the unity-power-factor three-phase APF, the control goal is to force the grid line current in each phase to follow the correspondent sinusoidal phase voltage, i.e.,

$$\left.\begin{aligned} V_a &= Re \cdot i_a \\ V_b &= Re \cdot i_b \\ V_c &= Re \cdot i_c \end{aligned}\right\} \text{-----------------(4.5)}$$

where Re is the emulated resistance that reflects the real power of the load. This control goal can be realized by controlling the equivalent currents i_p and i_n to follow the voltages V_p^* and V_n^* The control goal of three-phase APF can be rewritten as

$$\left.\begin{aligned} V_p^* &= Re \cdot i_p \\ V_n^* &= Re \cdot i_n \end{aligned}\right\} \text{---------------(4.6)}$$

Substituting (6) into (4) and considering the switch is ON for the entire 60 region, it is obtained that

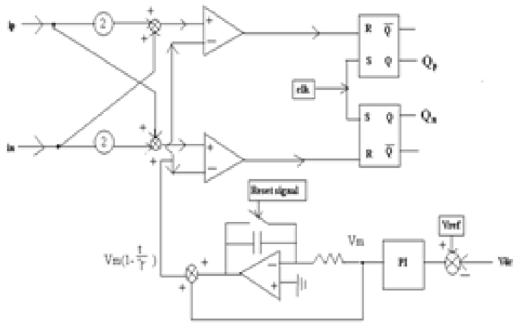
$$\left.\begin{bmatrix} (1-d_p) \\ (1-d_n) \end{bmatrix} = \frac{Re}{E\,Rs} \cdot Rs \cdot \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \cdot \begin{bmatrix} i_p \\ i_n \end{bmatrix} \right\}_{d_t=1} \text{---------------(4.7)}$$

$$Vm = \frac{E\,Rs}{Re} \text{ --------------(4.8)}$$

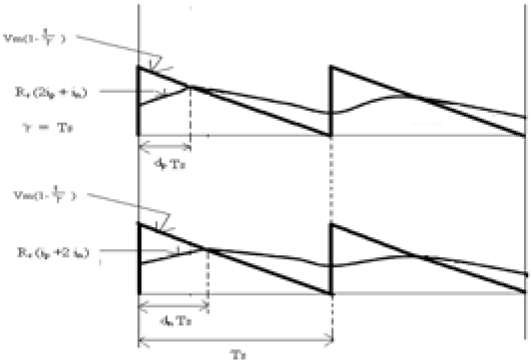
where the signal V_m can be generated from the output voltage feedback compensator, which is used to regulate the output capacitor voltage E of the voltage source converter according to the load level; Rs is equivalent current sensing resistance and it is fixed constant [11]. Combining of the two equations 7,8 and the control key equation is derived as

$$\left. Vm \cdot \begin{bmatrix} (1-d_p) \\ (1-d_n) \end{bmatrix} = Rs \cdot \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \cdot \begin{bmatrix} i_p \\ i_n \end{bmatrix} \right\}_{d_t=1} \text{---------------(4.9)}$$

The above equation indicates that three-phase power factor can be achieved by controlling the duty ratios of switches so that first-order polynomial equation (9) is satisfied. This can be realized by the one-cycle control core as shown in Figure [12]. The operation waveforms are shown in Figure



One- cycle control logic



Operation waveforms of one-cycle controlled APF controller

V. DESIGN CONSIDERATION FOR ONE-CYCLE CONTROLLED APF CONTROLLER

5.2.1. DC-Link Capacitor Design

The output dc-link capacitor of voltage source converter is determined by the output voltage ripple. The equation is given by

$$c \geq \frac{P_o}{2 * f_{line} * (V^2_{omax} - V^2_{omin})} \text{------ (5.13)}$$

where V_{omax} , V_{omin} is the peak to peak of the output dc-link voltage ripple.

For example, suppose the power is 7000 W; APF and outputvoltage is 400 V with 2% ripple. The line frequency is 60 Hz. The capacitance is calculated by

$$C \geq \frac{P_o}{2 \cdot f_{line} \cdot (V^2_{omax} - V^2_{omin})}$$

$$\geq \frac{7000}{2 \cdot 60 \cdot 400^2 \cdot [(1+0.02)^2 - (1-0.02)^2]}$$

$$\geq 0.0048 \text{ F}$$

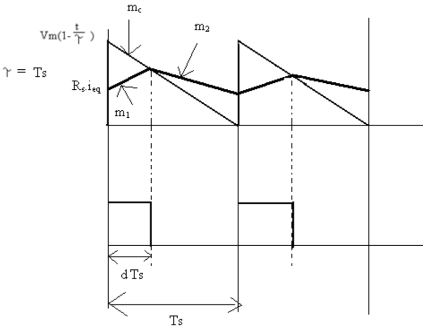
5.2.2 Selection of APF Inductance

The concept of the proposed control is using one-cycle control to implement the control key equation as follows:

$$R_s.i_{eq} = V_m.(1-d) \text{ ----------------(5.14)}$$

Where

i_{eq} = $(2i_p + i_n)$ (OR) $(i_p + 2\ i_n)$



Operation waveforms for the control block.

The operation waveforms are shown in Fig.5.1. Similar to the peak current model control, there is the convergency condition. The stability condition is given by

$$m_c \geq \frac{(m_2 - m_1)}{2} \text{ --------- (5.15)}$$

where m_1 is the ON slope of the input current and m_2 is the OFF slope of the input current; m_c is the equivalent slope of the carrier signal, which is implemented by integrator with reset. Considering that the load current is low frequency and the influence of load current can be neglected, we only concern the inductor current in the stability analysis, we have

$$m_1 = Rs \bullet \frac{V_g}{L}$$

$$m_2 = Rs \bullet \frac{V_o - V_g}{L} \qquad \text{-------------------- (5.16)}$$

$$m_c = \frac{V_m}{\Upsilon} = \frac{V_m}{Ts}$$

Where $\Upsilon = Ts$

Substitution of (5.16) into (5.15) yields the convergence condition

$$V_m \geq \frac{Rs \bullet Ts}{2\,L} \bullet \left(V_o - 2 \left| V_g \right| \right) \qquad \text{-------------------- (5.17)}$$

$$\geq \frac{Rs \bullet Ts}{2\,L} \bullet \left(V_o - 2 \bullet V_{grms} \left| \sin(wt) \right| \right)$$

The convergence condition is dependent on the angular angle of input voltage wt and the V_m, which is related to the output power and input voltage. When the convergency condition is satisfied partially, the system will still be stable.

According to (5.17), convergence condition for region 0^o~360^o is given by

$$V_m \geq \frac{Rs \bullet Ts}{2\,L} \bullet V_o \qquad \text{--------------------(5.18)}$$

But

$$Vm = \frac{V_o\,Rs}{Re} \qquad \text{--------------------(5.19)}$$

V_m is related to input voltage and output power through (5.19) . It can be rewritten as

$$V_m = \frac{P_o \bullet Rs \bullet V_o}{\eta \bullet V_{grms}^2} \qquad \text{------------------------- (5.20)}$$

where η is the estimated efficiency.

Combination of the above equations yields

$$L \geq \frac{1}{2} \bullet \eta \bullet Ts \bullet \frac{V_{grms}^2}{P_o} \qquad \text{--------------------------- (5.21)}$$

The above equation was used to determine the size of inductor.

At full load and maximum input voltage condition, the system should be fully stable, then the inductor can be selected by

$$L \geq \frac{1}{2} \bullet \eta \bullet Ts \bullet \frac{\max\left(V_{grms}^2 \right)}{\max\left(P_o \right)} \qquad \text{------------------------(5.22)}$$

For η=90% , Ts=20µs, $\max(V_{grms})$=170 v, $\max(P_o)$=7000W then the minimum inductance is calculated as L = 250µH.

5.2.3 Design of the Control stage:

The large-signal model for a single-phase APF in line cycle can be derived based on energy balance. Suppose the efficiency is 100%. The input power equal to the output power, that is

$$P_{in} = \frac{V_{grms}^2}{Re} = P_o = P_{load} + V_o \bullet i_c \qquad \text{------------------------- (5.23)}$$

where R_e is emulated resistance and P_{load} is the load power and i_c is the current flowing into the dc-link capacitor.

By definition, we have

$$Vm = \frac{V_o\,Rs}{Re} \qquad \text{------------------------- (5.24)}$$

Combination of the above equation yields

$$\frac{V_{grms}^2}{V_o\,Rs} \bullet Vm = P_{load} + V_o \bullet i_c \qquad \text{------------------------- (5.25)}$$

Considering the small ac signal disturbation, that is

$$\left.\begin{aligned} V_{grms} &= \overline{V}_{grms} + \hat{v}_{grms} \\ V_0 &= \overline{V}_0 + \hat{v}_0 \\ Vm &= \overline{Vm} + \hat{v}_m \\ i_c &= \overline{I}_c + \hat{i}_c \end{aligned}\right\} \qquad \text{------------------------------}(5.26)$$

Neglecting the influence of load power, substitution of the (5.26) equation into (5.27) and linearize by considering the following conditions

During each line cycle, the average current flowing in the dc capacitor is zero,

$$\overline{I}_c = 0$$

,

In addition, we can neglect the influence of input voltage disturbance by setting $\hat{v}_{grms} = 0$, then we can get simplified solution as

$$\frac{\hat{i}_c}{\hat{v}_m} = \frac{V_{grms}^2}{Rs \cdot V_0^2} \qquad \text{------------------------------}(5.27)$$

The transfer function from capacitor current to output voltage is given by

$$\frac{\hat{v}_0}{\hat{i}_c} = \frac{1}{S\,c} \qquad \text{------------------------------}(5.28)$$

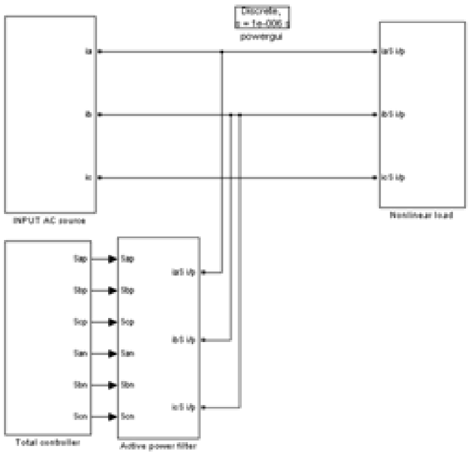
Therefore, combination of the above equations (5.27) &(5.28) yields the following transfer function:

$$\frac{\hat{v}_0}{\hat{v}_m} = \frac{V_{grms}^2}{Rs \cdot V_0^2} \cdot \frac{1}{S\,c} \qquad \text{------------------------------}(5.29)$$

Equation (5.27) can be used to determine the design of the output feedback compensator.

VI. SIMULATIONS

SIMULINK MODELS OF ONE-CYCLE CONTROLLED APF



6.1 Simulink Model of One-Cycle Controlled APF for the Three-Phase Power System

Here in Fig.6.1 total system is shown as four sub systems, those are Three phase ac source, which is supplying for Nonlinear load.

Active Power Filter (APF) ,that is connected parallel to the load and also Total control circuit which is giving pulses to the APF such that it will inject compensation currents into the power line which are opposite in phase to the harmonic currents introduced by the nonlinear loads. Ultimate goal is to improve source side power factor to unity, and protects the power grid from the harmonic currents, so improving the power quality.

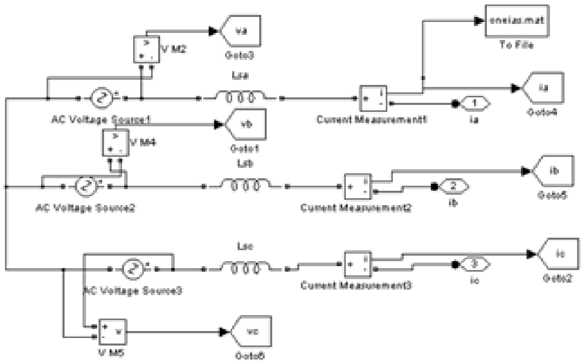


Fig 6.2 Simulink Model for the Three-phase input Source of the Power System.

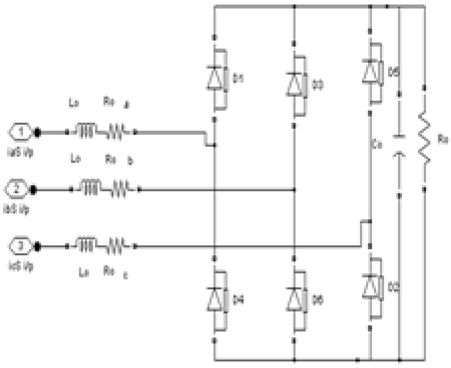


Fig 6.3 Simulink Model for the Three-phase Nonlinear load of the Power System

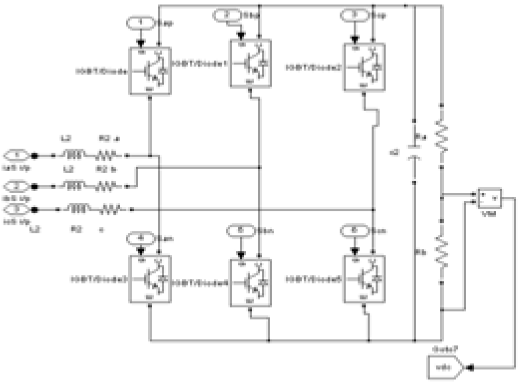


Fig 6.4 Simulink Model for the Three-phase Active Power Filter

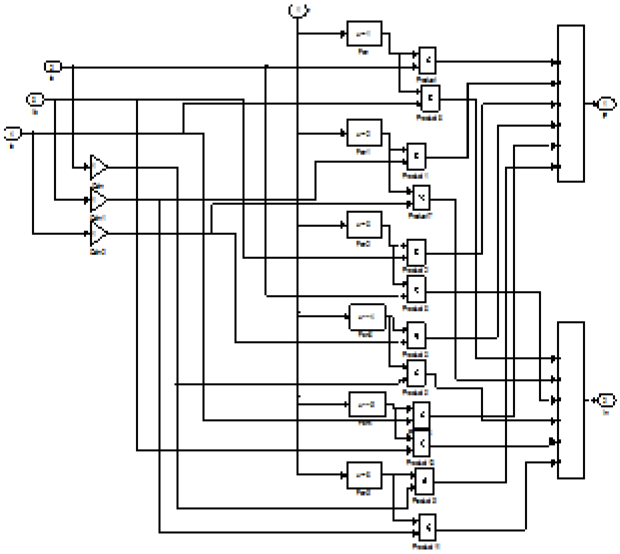


Fig 6.7 Simulink Model for finding ip , in currents in each vector region

Switching logic circuit block takes the region selection number (n) and switching pulses from the One-Cycle control block and it decides the switches of power converter for which this switching pulses has to give depending on the operating region (n).

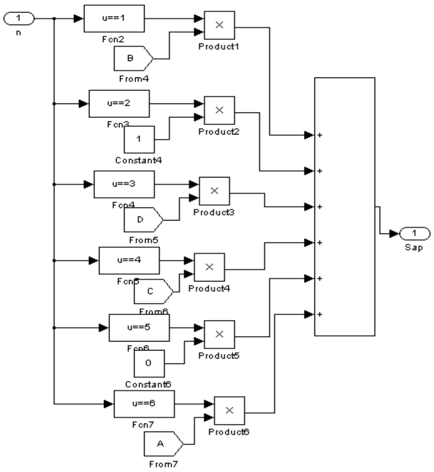


Fig 6.8 Simulink Model for Switching Logic to give Gate pulses to the APF

Fig.5.6 is Simulink Model for the APF Operating Vector Region Selection Logic , here the internal logic is shown as an expression. Fig.6.7 is a simulink model for finding ip,in currents in each vector region. For example if n=1, ip,in are ia,ic respectively from the logic circuit.Fig.6.8 shows the logical simulink model for finding the gate pulses to the power converter switch Sap only. The logic is similar to all other switches also. Here Sap is always ON for n=2, always OFF for n=5 and in the remaining regions(1,3,4,6) acts depending on the inputs (A,B,C,D) from the One-Cycle control block. Here A,B,C,D are Qp,Qp^{-},Qn,Qn^{-} respectively as shown in Fig.6.9.

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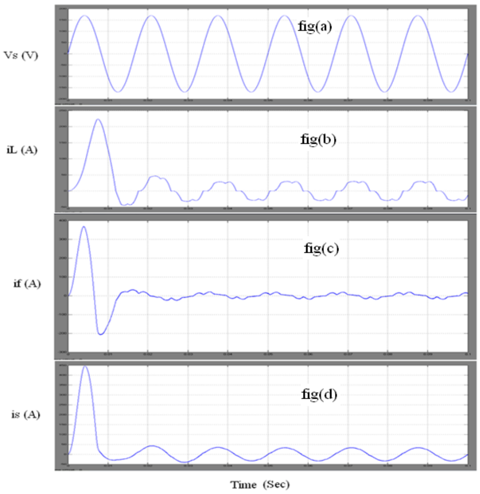
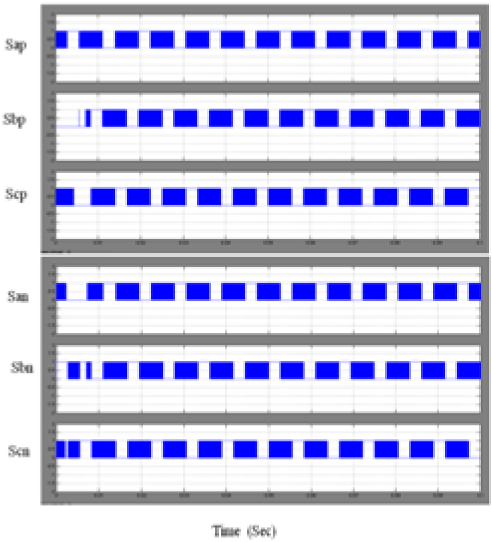


Fig.6.10 simulation results of One-Cycle controlled APF

Note : Before compensation iaS wave form is same as iaL as shown in Fig.6.10.(b) Gating pulses to the active power filter.



For example from the above waveforms it is clear that at first in (0-60^{o}) region Sbp is always OFF, Sbn is always ON, and the remaining switches are toggled depending on One-Cycle control outputs.

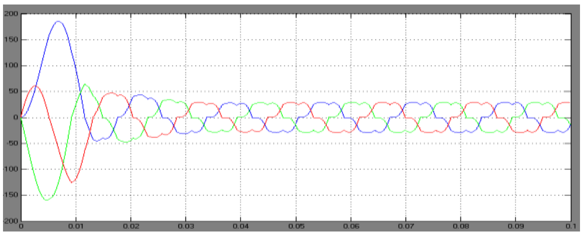


Fig.6a Source current without APF

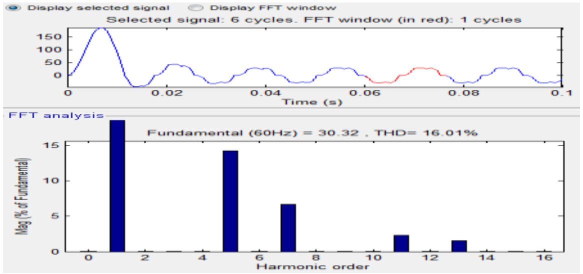


Fig.6b THD without APF

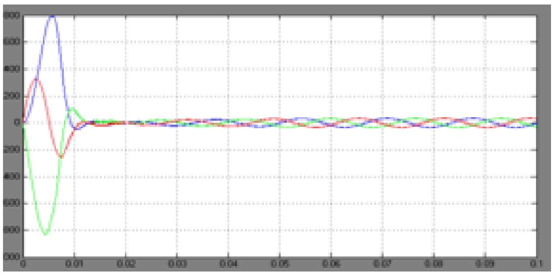


Fig.6c Source current with fuzzy one cycle control

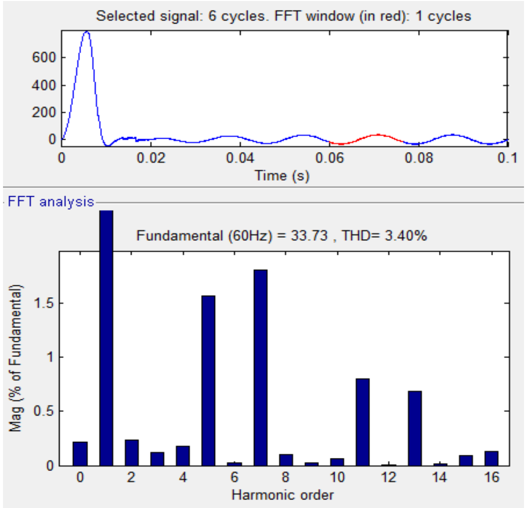


Fig.6d THD with pi one cycle controller

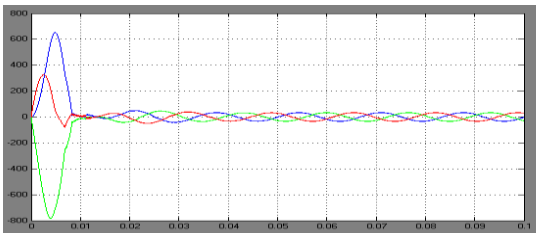


Fig.6e Source current with fuzzy one cycle control

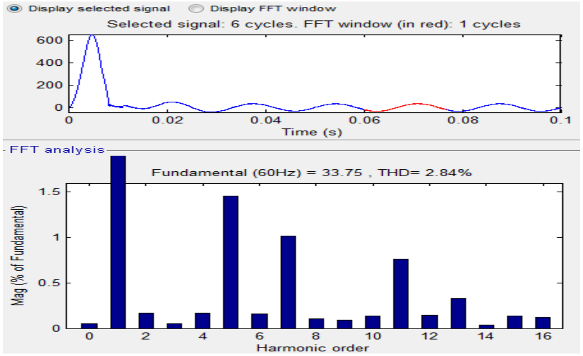


Fig.6f THD with fuzzy one cycle controller

VII. CONCLUSION

In this project, In this paper, a three-phase APF with fuzzy one-cycle control has been proposed. The proposed control approach senses only the mains current and the zero crossing of grid voltage. Furthermore, there is no need to calculate the reference for APF inductor current so that the intensive digital computation is eliminated. A non linear load is connected to a distribution system which produces harmonics in the source. In order to reduce the harmonics a fuzzy logic one cycle control APF is connected in parallel to the system. The total harmonic reduction without APF - 16.1% and with PI - 3.40% and with Fuzzy – 2.84%. hence the harmonics are reduced using fuzzy logic controller APF.

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