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One Cycle Control Based Active Power Filter for Power Quality Improvement Using Fuzzy Logic Control

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Abstract:
A Distribution line consists of different loads which are linear as well as non linear. The non linear loads generate a harmonic and reactive current, which leads to poor power factor, low energy efficiency, and harmful disturbance to other appliances. Active Power Filters (APFs) which are custom power devices are used to reduce the harmonics improves the power factor and can achieve better voltage regulation. A shunt APF is connected in parallel with the nonlinear loads and functions as current sources to cancel the harmonic/reactive components in the line current by injecting a reverse current with equal magnitude and reverse in phase so that the current flow into and from the grid is sinusoidal and in phase with the grid voltage. A one cycle control technique is used to control the APF which is operated in the dual boost converter mode. A fuzzy logic controller is used to regulate the converter. The experiment is done using matlab simulation tool.

Index Terms— ***Fuzzy Logic, Intelligent controllers, Conventional PI controller,***

INTRODUCTION

Nonlinearity is due to the introduction of power electronic equipment which are the main cause of harmonics. These harmonics result in problems such as Low efficiency, Low power factor, Low efficiency Power system voltage fluctuations, aging, Communication interference. To reduce the current harmonics we have to types of filters. Passive Filters consist of a bank of tuned LC elements. They are easy to design, simple structure and low cost but have many disadvantages, such as Resonance, fixed compensation character, possible overload, Large size. To overcome the disadvantages due to Passive Filters, Active Power Filters (APFs) have been used as a current-harmonic compensator. The Active Power Filter is connected in parallel or using a injection transformer with a nonlinear load. The design is based on the principle of injecting harmonic current into the distribution system, of the same amplitude and phase reverse to that of the load current harmonics. This will thus result in sinusoidal source currents and unity power factor in the input system. Generally circuit breaks are connected in the line which will isolate the faulty sections of protector tubes are connected in parallel. These devices will isolate the system there will be more loss in the load. In order to avoid this we go for a three-phase shunt APF which is typically consists of a three-phase converter and control strategy. Most of the previous control approaches such as PWM need to sense the load current as well as source currents to give a reference signal to the converter. Those control methods require fast and real-time calculation; therefore, a high-speed digital microcontrollers and high-performance analog to digital converters are necessary, which leads to high cost, complexity, and low stability. So here introduced a promising solution based on fuzzy One-Cycle control

A. Active power filter

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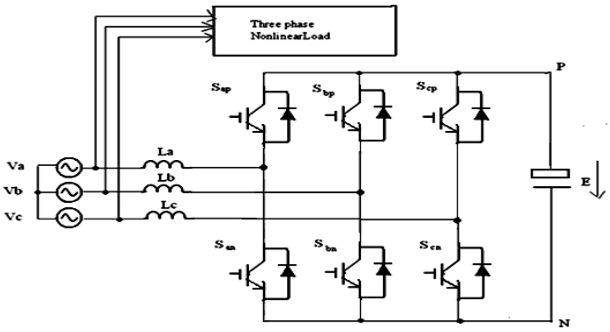

Fig.1 three-phase APF

The one-cycle control method eliminates the need of calculating the current reference as well as the use of multipliers in the control loop. The control circuitry is simple and reliable. In pulse width-modulation (PWM) active power filter, all switches are triggered with switching frequency; therefore, the switching losses are relatively higher than that of the vector operated active power filters. In this project, a three-phase APF with six-switch bridge voltage-source converter with vector operation is presented.

PARALLEL CONNECTED DUAL BOOST CONVERTER

A. Principle of operation

The three-phase voltage waveforms Va, Vb and Vc of the grid is shown in Fig..2 During each 60 region in Fig.2, the voltage-source converter in Fig.1 can be decoupled into a parallel-connected dual-boost converter.

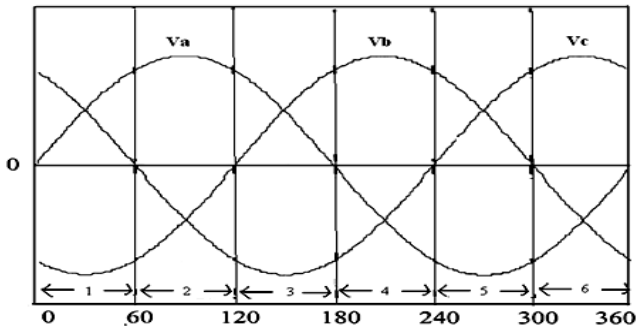

Fig.2 three-phase grid voltage waveforms

From fig 2 the total 360o is divided into six regions in which each region consists of two voltages either positive or negative.the voltage source converter in each region is operated as dual boost converter explained in the next section. From (0o -60o) the phase voltage Vb is low, the switches Sbn is on and Sbp is kept off while the other switches in same region (San,Sap and Scn,Scp) are controlled complementally at the switching frequency. For example,during each cycle if Sap is kept on and San is off then we say switching frequency(50hz) is higher than line frequency(60hz).

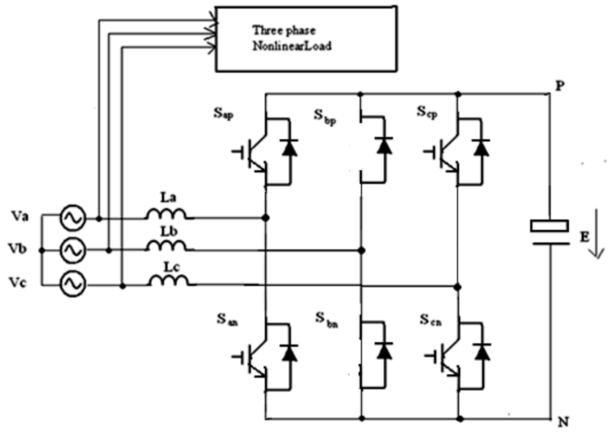

Fig.3 three-phase APF during 0 _ 60o regions.

For a three-phase APF with a constant switching frequency, only two switching sequences are possible, i.e., I, II, IV (the condition dp >dn , dp , dn are the duty ratios of switches , Tp, Tn respectively) or I, III, IV (condition dp <dn) during each switching cycle, if trailing-edge modulation is performed. From assumption made that switching frequency is much higher than the line frequency, the inductor voltage-second balance is approximately valid, that is

$$\left.\begin{aligned} V_p^* d_n + \left(V_p^* + \tfrac{1}{3}E\right)\cdot\left(d_p - d_n\right) \quad \left(V_p^* - \tfrac{1}{3}E\right)\cdot\left(1 - d_p\right) &= 0 \\ V_n^* d_n + \left(V_n^* - \tfrac{2}{3}E\right)\cdot\left(d_p - d_n\right) + \left(V_n^* - \tfrac{1}{3}E\right)\cdot\left(1 - d_p\right) &= 0 \\ V_t^* d_n + \left(V_t^* - \tfrac{1}{3}E\right)\cdot\left(d_p - d_n\right) + \left(V_t^* - \tfrac{2}{3}E\right)\cdot\left(1 - d_p\right) &= 0 \end{aligned}\right\} \text{------------} (2)$$

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The following equation is true for a symmetrical three-phase system:

$V_p^* + V_n^* - V_t^* = 0$ -------------------- (3)

From (2) and (3) with further simplification we will get

$$\begin{bmatrix} (1-d_p) \\ (1-d_n) \end{bmatrix} = \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \cdot \begin{bmatrix} \frac{V_p^*}{E} \\ \frac{V_n^*}{E} \end{bmatrix} \text{ ------------- } (4)$$

It has been verified that this equation is valid for the other switching sequence I, III, and IV (dp<dn) as well.

State	T_p	T_n	$\overline{T_p}$	$\overline{T_n}$	V_{Lp}	V_{Ln}	V_{Lt}
I	ON	ON	OFF	OFF	V_p^*	V_n^*	V_t^*
II	ON	OFF	OFF	ON	$V_p^*+\frac{1}{3}E$	$V_n^*-\frac{2}{3}E$	$V_t^*-\frac{1}{3}E$
III	OFF	ON	ON	OFF	$V_p^*-\frac{2}{3}E$	$V_n^*+\frac{1}{3}E$	$V_t^*-\frac{1}{3}E$
IV	OFF	OFF	ON	ON	$V_p^*-\frac{1}{3}E$	$V_n^*-\frac{1}{3}E$	$V_t^*-\frac{2}{3}E$

Equation (4) gives a relationship between the duty cycle and the input, output voltage for the dual-boost converter.

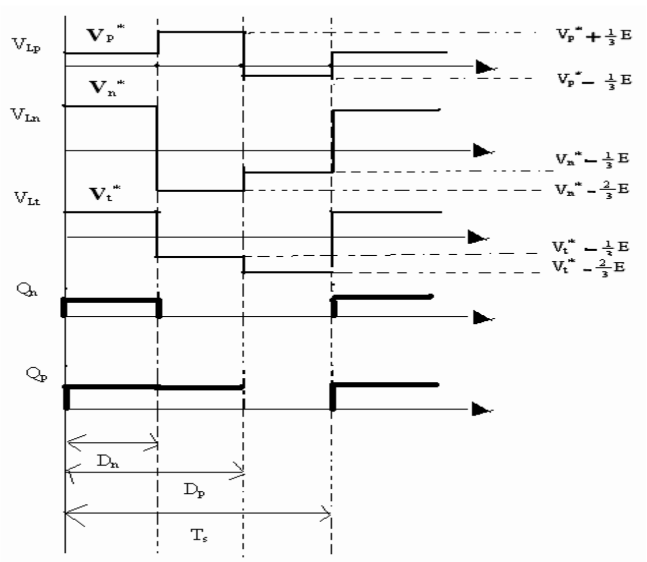

Fig.4 voltage waveforms across the inductor for the converter under the condition dp > dn

ONE-CYCLE CONTROLLER FOR THREE-PHASE APF

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

$$\left.\begin{aligned} V_a &= Re \cdot i_a \\ V_b &= Re \cdot i_b \\ V_c &= Re \cdot i_c \end{aligned}\right\} \text{ ---------------- } (5)$$

where Re is the resistance that reflects the real power of the load. This control aim can be realized by controlling the equivalent currents ip and in to follow the voltages Vp* and Vn* The control aim of three-phase APF can be rewritten as

$$\left.\begin{aligned} V_p^* &= Re \cdot i_p \\ V_n^* &= Re \cdot i_n \end{aligned}\right\} \text{ ---------------- } (6)$$

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

$$\left.\begin{bmatrix} (1-d_p) \\ (1-d_n) \end{bmatrix} = \frac{Re}{E\,Rs} \cdot Rs \cdot \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \cdot \begin{bmatrix} i_p \\ i_n \end{bmatrix}\right\}_{d_t=1} \text{ ---------------- } (7)$$

Define

$$Vm = \frac{E\,Rs}{Re} \text{ ------------- } (8)$$

Where the signal Vm can be generated from the output voltage compensator, which is used to regulate the output capacitor voltage E of the VSC according to the load level; Rs is equivalent resistance and it is fixed constant. Combining of the two equations 7,8 and the control equation is derived as

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$$V_m \cdot \begin{bmatrix} (1-d_p) \\ (1-d_n) \end{bmatrix} = R_s \cdot \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \cdot \begin{bmatrix} i_p \\ i_n \end{bmatrix} \Bigg\}_{d_t=1} \text{------------- (9)}$$

The above equation says that three-phase power factor can be achieved by controlling the duty ratios of switches so that first-order equation (9) is satisfied. This can be realized by the one-cycle control core as shown in Fig.5.

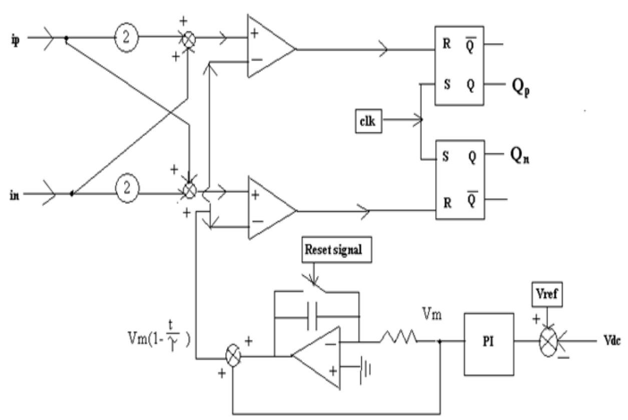

Fig.5 One- cycle control logic

At the starting of each switching cycle, the clock pulse sets or resets the two flip-flops. The currents ip and in from the current selection logic is combined to form an input to each of the two comparators. At other input of the two comparators is the value of Vm minus the integrated value of Vm. Signal Vm(1-t/Ts) is compared with Rs(2 ip+ in) in the upper comparator and is compared with Rs(ip+2 in) in the lower comparator as shown in Fig.5. When the two inputs of a comparator meet as the comparator changes its state, which sets or resets the correspondent flip-flop. As a result, the correspondent switch is turned off or on. Therefore, the duty ratios dp and dn are obtained for the correspondent switch in each switching cycle.

THE PRESENTED ONE-CYCLE CONTROL APPROACH HAS THE FOLLOWING FEATURES

3-ϕ unity power factor and Low THD are achieved by using one integrator with reset, several logic and linear components. Only AC mains current and voltage zero crossing points are sensed. This method is reliable, simple and no multipliers are required because no sensors are used for load current and APF inductor and the complication in the calculation of reference for APF inductor current is eliminated. In a 3-ϕ bridge converter to reduce switching losses only two switches are operated at high frequency. Hence constant switching frequency obtained is desirable for industrial applications.

DESIGN CONSIDERATION

Design of Dc-Link Capacitor

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

$$c \geq \frac{P_o}{2^* f_{line} {}^*(V^2_{omax} - V^2_{omin})} \text{ ----------(10)}$$

Inductance Selection for APF

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

$$R_s.i_{eq} = V_m.(1\text{-}d) \text{ ----------------(11)}$$

Where

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

for the system to be stable The stability condition is given by

$$m_c \geq \frac{(m_2 - m_1)}{2} \text{ ------------ } \mathbf{(12)}$$

where m1 is the ON slope and m2 is the OFF slope of the input current; mc is the equivalent slope of the carrier signal, which is implemented by integrator using reset.Using 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

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

$$m_2 = Rs \cdot \frac{V_o - V_g}{L} \qquad \text{------------} \ \mathbf{(13)}$$

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

Where

$$\Upsilon = Ts$$

Substitution of (13) into (12) yields the optimal condition

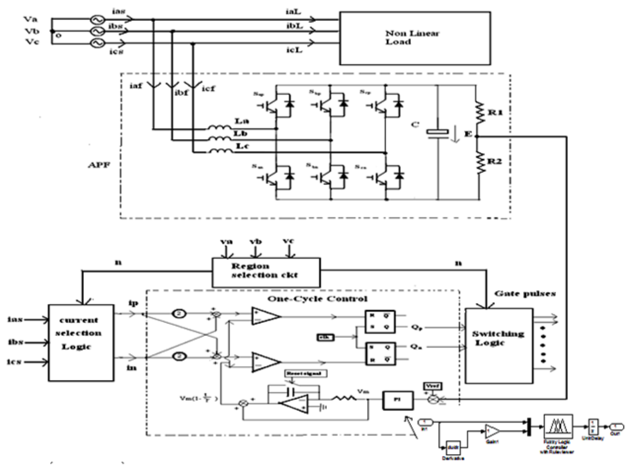

Fig.7 Block diagram of One-Cycle controlled APF with PI and Fuzzy controllers

$$V_m \geq \frac{Rs \cdot Ts}{2\,L} \cdot \left(V_o - 2\,|V_g| \right) \qquad \text{----------} \ \mathbf{(14)}$$

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

the optimal condition is dependent on the angle of input voltage wt and the Vm, which is related to the output power and input voltage. When the optimal condition is satisfied partially, the system is said to be stable.

According to (14), optimal condition for region 0o~360o is given by

$$V_m \geq \frac{Rs \cdot Ts}{2\,L} \cdot V_o \qquad \text{-----------} \ \mathbf{(15)}$$

But

$$Vm = \frac{V_o\,Rs}{Re} \qquad \text{------------}\mathbf{(16)}$$

Vm is related to input voltage and power output through (16) . It can be rewritten as

$$V_m = \frac{P_o \cdot Rs \cdot V_o}{\eta \cdot V_{grms}^{2}} \qquad \text{-------------}\mathbf{(17)}$$

Where η is the estimated efficiency.

Combination of the above equations leads to

$$L \geq \frac{1}{2} \cdot \eta \cdot Ts \cdot \frac{V_{grms}^{2}}{P_o} \qquad \text{--------------}\mathbf{(18)}$$

INTRODUCTION TO FUZZY LOGIC:

A fuzzy logic controller is a multivalued controller. It is derivrd from the crisp logic.a fuzzy controller consists of three steps. Step one is fuzzification. In this step the input which is a value or a wavwform is converted into membeeship function. Second step is rule base which is based on the input membership function.

IF THEN rules are mostly used. The third step is defuzzification which converts rule based fuzzy into a defuzzified value. The obtained defuzzified value is the controller signal fir the flip flop In this work a fuzzy remote controllers is developed for speed control of a converter fed dc motor. The performance of the fuzzy controller is compared with conventional P-I controller.

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SIMULATION RESULTS

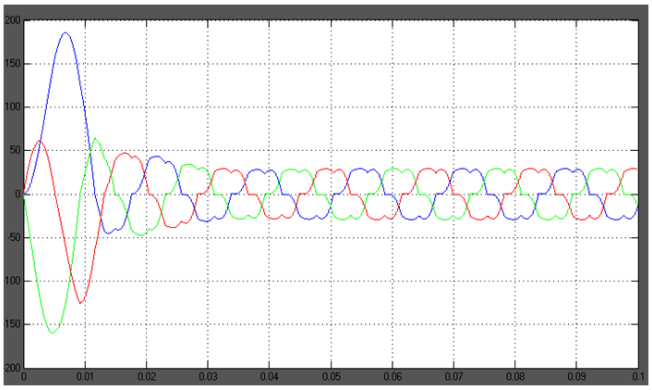

Fig.8 Source current without APF

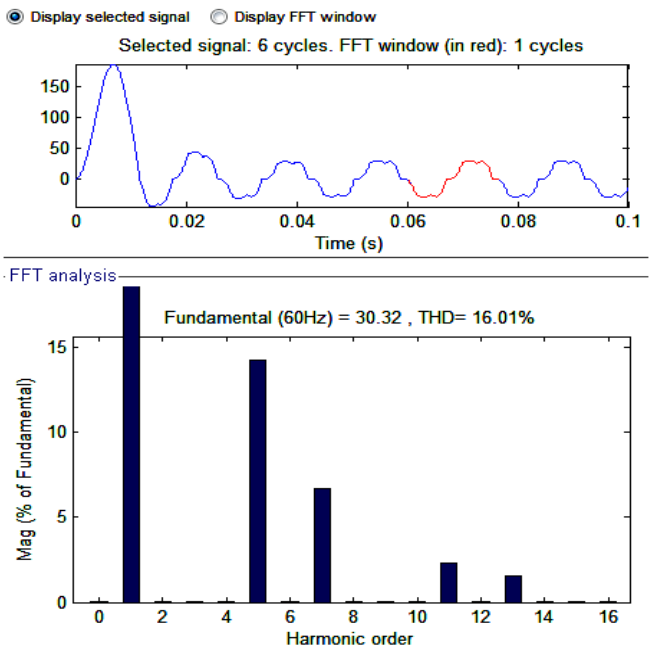

Fig.9 THD without APF

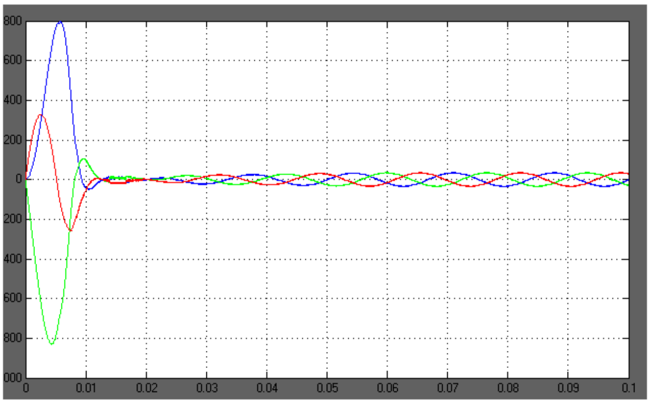

Fig.10 Source current with fuzzy one cycle control

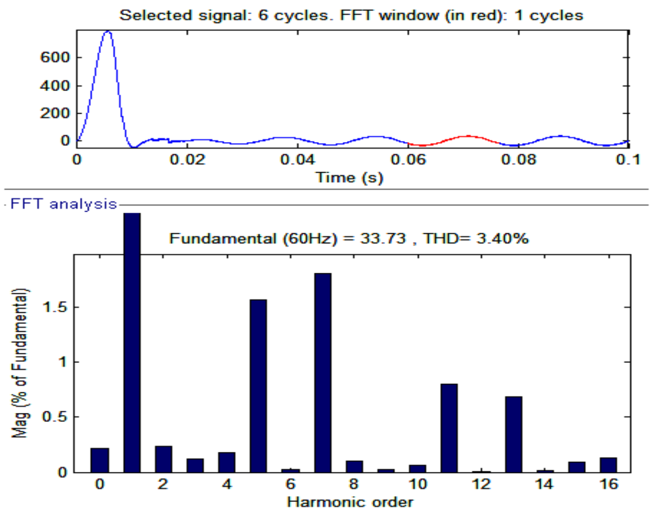

Fig.11 THD with pi one cycle controller

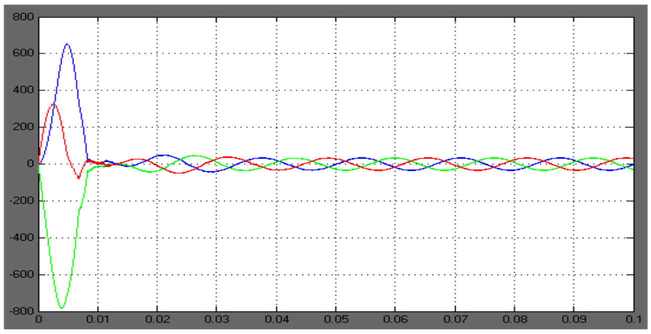

Fig.12 Source current with fuzzy one cycle control

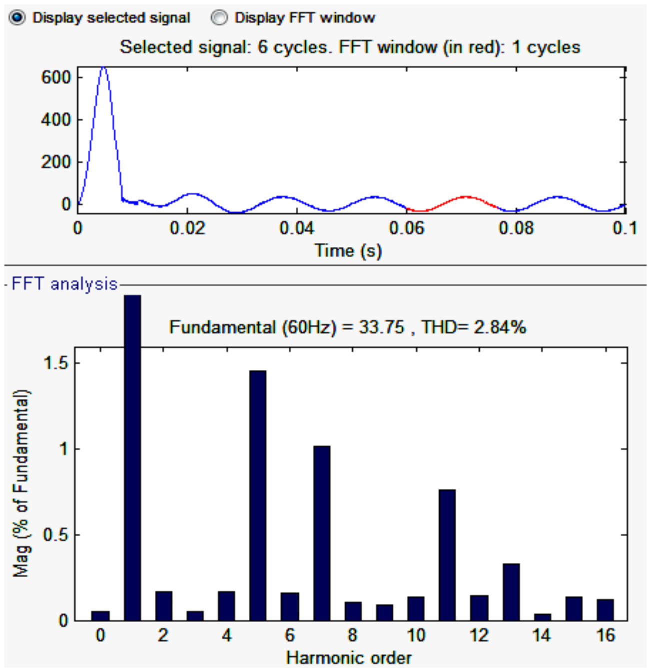

Fig.13 THD with fuzzy one cycle controller

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CONCLUSION

A 3 phase APF with fuzzy logic one cycle control has been proposed in this paper. In this type of control only main current and the zero crossing of grid voltage is sensed. Moreover by using this type of control the intensive digital computation can be eliminated as there is no need of calculating the reference for APF induction current. In order to produce harmonics in the source a non linear load is connected to the distribution system. A fuzzy logic one cycle control APF is connected in parallel to the system so that the harmonics are reduced. Total harmonic reduction without APF is 16.1% while with PI it is 3.40% where as with fuzzy it is 2.84%. Hence using fuzzy logic controller APF the harmonics can be reduced.

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