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# Hysteresis Current Controlled High Power Factor Three Phase PWM Converter

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**ABSTRACT:**The paper is based on Hysteresis current control technique in three phases PWM rectifier. The rectifiers having semiconducting devices which act as a non-linear load on electrical power system which causes low input power factor and also having harmonics in current which affect the system. A load with a low power factor draws more current than a load with high power factor for the same amount of useful power transferred to eliminate the input current harmonics and as well as low input power factor there are many technique are developed. A hysteresis current control technique is used to maintain an input power factor unity and also reduced current harmonic. Hysteresis current controller High power factor three phase pwm converter is controlled by outer control loop by DC link voltage of a system and current is controlled by inner control loop in HCC is used to control the current error. Through this error switching frequency is generated to operate bi-directional switches by which system high power factor and it reduced harmonics.

**KEYWORDS:**Hysteresis current controller (HCC), three phase pulse width modulation Voltage source rectifier, PI Controller Park's transformation and three IGBT based switch

## I. INTRODUCTION

In an electrical system the development of power electronic technology and semi-conducting devices, more and more converters devices are adopted in the power system. An ac to dc power conversion is an essential part of many power electronic system such as an uninterruptable power supplies (UPS), battery charger, and dc motor drives. The battery charger needs to ac to dc conversion; While UPS and Motor drive typically have ac to dc to ac conversion [1].

The control devices which are used to attain unity power factor and also reduce the system harmonics so three control technique are: (i) linear proportional – integral controller. (ii) Predictive controller. (iii) Hysteresis current controller [15]. The PI controllers can limit the switching frequency of converter and produce well define harmonic content .predictive controller is the most complex method and requires the knowledge of load parameter and the extensive hardware implementation. Hysteresis current controllers have non-complex implementation, outstanding stability absence of tracking error very fast transient response and intrinsic robustness to load parameter [13].

In power electronic system especially diode and thyristor based rectifiers are used in the front end of dc-link power converter or rectifier as an interface with the ac line power. The rectifiers act as a nonlinear load on the power system which distort the current having lots of harmonics in it.Which are rich in harmonics and low input power factor and large amount of harmonics in supply current causes various undesirable effects such as harmonic distortion of line voltage, equipment overheating, malfunction and may system got damaged.[2] Power pollution remaining to the use of power converters such as harmonic distortion of the line voltage result in serious power quality problems occurs in transmission and distribution system. The figure shows a three phase diode based bridge rectifier in these three bi-directional switches is connected which is operated by getting switching signal from hysteresis band by this technique. A system improves their power factor to unity and current harmonics is reduced and reached to 2.67% approx. [12]

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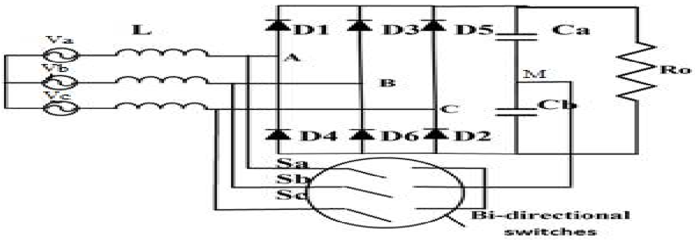


**Figure 1** The converter with Bi-directional switches

Mehl and Barbi[1] proposed a method to improve the power factor of a three phase diode based bridge rectifier with the three IGBT based Bi-directional switches[4]These switches operated at low frequency and each bi-directional switch is turn on when corresponding phase voltage crosses Zero volt and conduct for 1/12th of line voltage cycle. The circuit features are low cost, simplicity, and high power applications. The converter requires a connection to the neutral wire of the ac system and due to that connection a pulsed current is present on the neutral. It was also noticed is the circuit the energy stored by the inductor is responsible for increment high voltage stress across the switches during commutation of switches [5] [12]

## IISYNCHRONOUS REFERENCE FRAME BASED HYSTERESIS CURRENT CONTROLLER

The front end rectifier's based topology which is used in the rectifier inverter scheme. The front end scheme is shown in figure 1 It is made up of a combination of full bridge three phase diode based rectifier with two identical series connected capacitor used for filterring the rectifier output voltage and three bi directional switches $S_a, S_b$, and $S_c$. These are made up of the combination of two anti parallel connected IGBT These three bi-directional switches $S_a, S_b$, and $S_c$ are controlled to conform supply current shape, output dc-link voltage regulation and two capacitor are used for voltage votage balancing. Now moving on the topology which is shown in figure1.The mathmatical which is formulated are:[12]

$$L\frac{di_a}{dt} = V_a - (V_{am} + V_{mo}) \quad (1)$$

$$L\frac{di_b}{dt} = V_b - (V_{bm} + V_{mo}) \quad (2)$$

$$L\frac{di_c}{dt} = V_c - (V_{cm} + V_{mo}) \quad (3)$$

Where $V_{mo}$ is voltage of node M and it is referring to the neutral point "O". Voltages $V_{am}, V_{bm}$ and $V_{cm}$ are voltages of nodes A, B, and C referring to the node M.
The expression for the node voltages are:

$$V_{am} = \text{sign}(I_a)(1 - S_a)\frac{V_{dc}}{2} \quad (4)$$

$$V_{bm} = \text{sign}(I_b)(1 - S_b)\frac{V_{dc}}{2} \quad (5)$$

$$V_{cm} = \text{sign}(I_c)(1 - S_c)\frac{V_{dc}}{2} \quad (6)$$

Now sign $(I_a)$, sign $(I_b)$ and sign $(I_c)$ are depend on the polarity of inductor currentSuch that;

$$\text{Sign } (I_a) = \begin{cases} 1, \text{if } i_a \geq 0 \\ -1 \text{ if } i_a, < 0 \end{cases} \quad (7)$$

Switches $S_a, S_b$, and $S_c$ denotes the switching state of all three bi-directional switches $S_a, S_b$, and $S_c$ recspectively. For example if sign $(I_a)$ is 1 it means that if $(I_a)$ current error vector is greater or equal then zero. If it shows -1 then the current error vector is less then zero.Now, for a balanced three phase supply system the voltage from switches to node M $(V_{mo})$ written as

$$V_{mo} = \frac{V_{am} + V_{bm} + V_{cm}}{3} \quad (8)$$

The injected current$(I_m)$,is the sum of the currents which is by three phase bi-directional switches is;

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$$i_m = i_a s_a + i_b s_b + i_c s_c \tag{9}$$

## III PROPOSED CONTROLLER

These three current are input source current of three phase abc current. The angular position of the supply voltage is define by phase lock loop circuit. Which is shown in figure 3. The phase lock loop (PLL) is used here to provide angular position to dqo to abc frame by this DC voltage is converted to refenece value. The converter's reference current is in three phase co-ordinate ane obtained by the dqo to abc park's transformation.[7]

$$\begin{bmatrix} I_a^* \\ I_b^* \\ I_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\omega t & -\sin\omega t \\ \cos(\omega t - \frac{2\pi}{3}) & -\sin(\omega t - \frac{2\pi}{3}) \\ \cos(\omega t + \frac{2\pi}{3}) & -\sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} \tag{10}$$

The current converter $I_d$ and $I_q$ are the active and reactive component of the converter park's transformation current. The perpose of using parks transformation to convert dqo rotating frame to three phase abc by the help of (wt) angular postion which is given by PLL and PLL take input as a three phase voltage.[10]. The phase locked loop circuit is provide (wt) which is increasing function of time whode derivative is constant under any AC supply voltage condition by this transformation angle is insensitive to voltage harmonics and unbalanced voltage source.[8]The dc voltage is also controlled at a constant value by coverter and this is achieved by action for parks transfomration active current ($i_d$). the parks rective current ($i_q$) must keep null or zero value in order to obtained almost unity power factor. It will happen by the absence of conection between AC supply neutral point and the zero sequence of parks transformation is always zero. In this hysteresis current controller model, neglible losses are anticipated in the AC input source inductance in the recrifier based circuit. In a three phase high power factor hysteresis current controller pwm converter. The controller is used here is hysteresis current controller through which a switching signal is generated. Switching signal is given to three phase bi-directional switches by which to attain unity power factor and to reduce harmonics distortion and THD through this controller

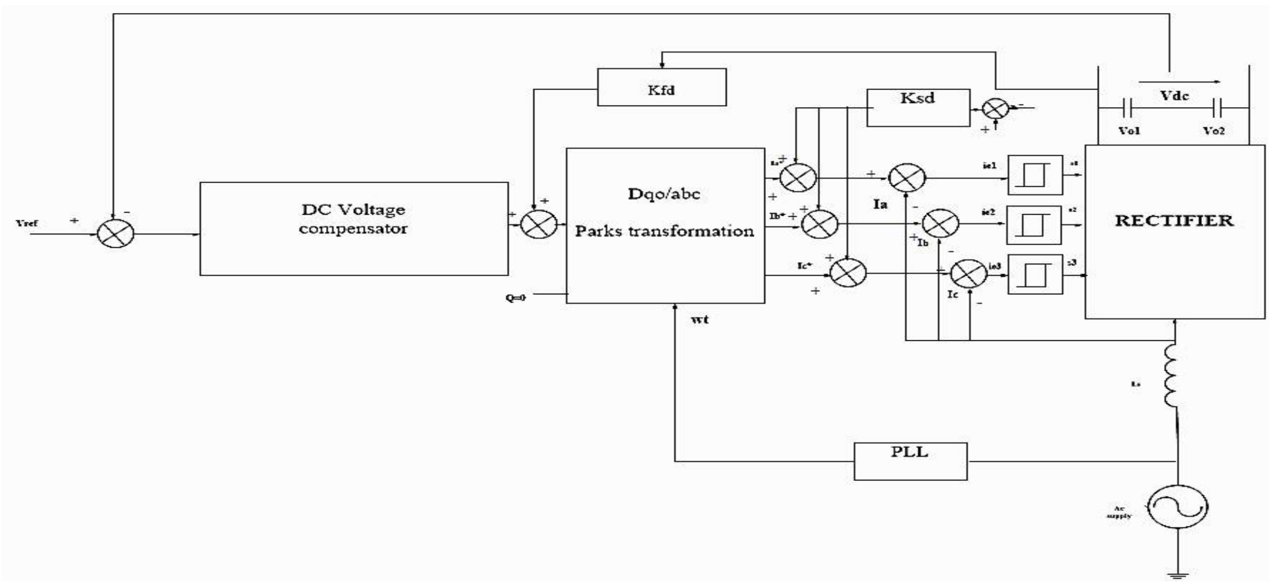


**Figure 2** Converter Model Circuit

Figure 2 is a block diagram representation of proposed front end converter control circuit .It shows the conversion and control scheme or strategy for the front end converter. The dc link rectifier output voltage is constant, and that is also tracks the reference input voltage. It has two feedback loops one is outer dc voltage loop and ensure that the DC link voltage is constant and it tracks the reference.Second inner control loop is feed forward current loop. The supply current is regulate and accomplish through the use of conventional hysteresis current controller by using park's transformation dq0 to abc and it is applied to the reference current parameter wt derived from the phase locked loop

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circuit to obtain the three phase sinusoidal reference currents. The potential of the dc-link middle point M which is also controlled to ensure the voltage balance by two series connected capacitor c1 and c2.

A. Current Control

The hysteresis modulation is a feedback current control method where the motor current tracks the reference current in a hysteresis band.the conduction period which is generated by hysteresis current controller is to provide switches. The hysteresis controlof supply current with independent controllers the switching signal $S_x$(x=123) of the bi directional switches are.

$$Sx = \begin{cases} 1,\ (i_x > 0 \ and \ i_x < i_x^* - h \\ \text{or } (i_x < 0 \ and \ i_x > i_x^* + h) \\ 0,\ \text{if } (i_x > 0 \ and \ i_x > i_x^* + h) \\ \text{or } (i_x < 0 \text{ and} i_x < \ (i_x^* - h) \end{cases} \tag{11}$$

The switching pattern is illustrated by figure 2. The voltage is determined by the switching states and current signs of all phases. Due to this interaction the instentaneous current error can be [13]

B. DC Voltage control

The rectifier input power at any instant is the sum of the output power and the rate of change of the energy elements. Analysis of the system characteristics by the mathematical modeling. Taking some condition before approaching mathematical analysis is: Negligible losses are anticipated in AC input inductance and in rectifier.The rectifier input power at any instant is the sum of the output power and the rate of change of the energy storage. A power balance equation for a synchronous frame based controller of the rectifier.[12]

$$\frac{d}{dt}\left(\frac{1}{2}c_{eq}v_{dc}{}^{2}\right)+V_{dc}I_{dc}=\sqrt{3}V_pI_d\cos\alpha \ - \frac{d}{dt}\left(\frac{1}{2}L_sI_d{}^{2}\right) \tag{12}$$

Where $c_{eq} = \frac{c}{2}$ (half of the capacitor $c_a$ or $c_b$ which are connected in series)

$V_p$ = Vrms of the supply voltage

Now, solving equation (6) the above equation can be linearized around the steady state operating point ($I_{dc}V_{dc}$) is:

$$C_{eq}V_{dc}s\,\overline{V}_{dc}(s) - I_{dc}\overline{V}_{dc}(s) = (\sqrt{3}\cos\alpha\, V_pI_d(s) - L_sI_dsi_d(s) - V_{dc}I_{dc}(s) \tag{13}$$

$$(C_{eq}V_{dc}s - I_{dc})\overline{V}_{dc}(s) = (\sqrt{3}\cos\alpha\, V_p - L_sI_ds)I_d(s) - V_{dc}I_{dc}(s) \tag{14}$$

Now putting Cosα = 1 so equation can be written as:

$$(C_{eq}V_{dc}s - I_{dc})\overline{V}_{dc}(s) = (\sqrt{3}V_p - L_sI_ds)I_d(s) - V_{dc}I_{dc}(s) \tag{15}$$

Now the steady state operating current $I_{dc}$ can be obtained by solving equation (3.6.4)

$$\sqrt{3}V_pI_d = V_{dc}I_{dc} \tag{16}$$

The response time of inner current control loop is much faster than outer voltage loop, two voltage loops are delinked.[12] Inner current control block can be ignored by assuming that the output current controller is completely followed by its input current command is shown in control block outer voltage control loop

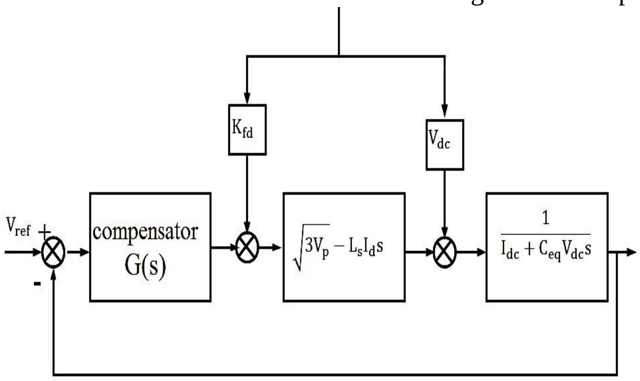


Figure 3 Simple Voltage Control Scheme

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The current feed-forward control loop is also used here to improve the dc link output voltage response the load disturbance. By equation (9). it can be see that the one right half plane zeros is in the control system which causes system unbalance. The open loop transfer function of voltage control loop can be written as [5]

$$L(s) = G_c(s)\frac{L_s I_d}{c_{eq} v_{dc}}\left[\frac{\left(\frac{\sqrt{3v_p}}{L_s I_d}\right) - s}{s + \left(\frac{I_{dc}}{c_{eq} V_{dc}}\right)}\right] \qquad (17)$$

a right hand plane (RHP) zeros imposes fundamental limitations on the control system bandwidth, as it forces to reach upper limit to the achievable gain cross over frequency for stable operation[11]. It is shown in [11] that the systems with one right hand plane zero at z, shows the maximum achievable gain cross frequency $w_{gc}$ of the open loop compensated control system is limited to.

$$\omega_{gc} = \tan\left(\frac{\pi}{2} - \frac{\alpha_m}{2} + n_{gc}\frac{\pi}{4}\right) \qquad (18)$$

Where $\alpha_m$ is the phase margin of the compensated control system in radian and$n_{gc}$is the slope of Bode plot of compensated minimum phase part of control to output of the transfer function at $w_{gc}$system. The feed forward control system parameter $K_{fd}$ is determined by

$$K_{fd} = \left.\frac{V_{dc}}{\sqrt{3v_p} - L_s I_d s}\right| \qquad (19)$$

Putting S = 0 in above equation

$$K_{fd} = \frac{v_{dc}}{\sqrt{3v_p}}$$

**C.** Balancing Dc Link Capacitor Voltage

The dc link capacitor voltage causes some error the voltage which is of capacitor $c_a$and $c_b$are $V_{01}$ and $V_{02}$ voltages have some variation or error which disturb the system ideal condition. Overcome this is to balancing the DC link capacitor voltage. In synchronous reference frame based hysteresis current controller due to the existence of errors in the current hysteresis comparator, the DC capacitor voltage is $V_{01}$ and $V_{02}$ are different.

The $V_{01}$ and $V_{02}$ asymmetry will causes an increased voltage stress on the capacitor and hence increase blocking devices. The dc capacitor voltages difference $V_m$ is given as

$$V_m = \frac{1}{2}(V_{01} - V_{02}) = \frac{1}{2c}\int_{t1}^{t2} i_m \, dt \qquad (20)$$

Where $V_{01}$ and $V_{02}$are the voltages across capacitance $c_a$ and $c_b$respectively. The three independent hysteresis current controller injects current $i_m$ which is sum of current through bi-directional switches is:

$$i_m = i_a s_a + i_b s_b + i_c s_c \qquad (21)$$

From equation (21) it can be see that the $i_m$ is not null. So this asymmetry of the output voltage occurs. However, the voltage balance between the two dc capacitors $c_a$and $c_b$ can be reached by introducing a tiny DC offset which is presented below to the reference currents [7]

$$\begin{cases} i_a^{*\prime} = i_a^* + i_0 \\ i_b^{*\prime} = i_b^* + i_0 \\ i_c^{*\prime} = i_c^* + i_0 \end{cases} \qquad (22)$$

This zero current component is calculated by equation (11)

$$i_o = k_m(v_{01} - v_{02})/2 \qquad (15)$$

By this equation the dc voltage is balanced. And under steady state condition this dc component will be null [12]

## IV. SPECIFICATION OF CONTROLLER

A hysteresis current controller pulse width modulator voltage source rectifier is used in three phase diode based rectifier to convert AC to DC power. It is used for the operating DC drive system or used to AC drives and the

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AC drive system is controlled by use of an inverter to convert DC to AC with the help of inverter frame with this circuit.[12] AC drive system is controlled but in this paper the load is used is rectifier DC load topology is used. To illustrate the design feasibility of the proposed converter, a prototype with the following specification is chosen:
1) Supply line-to-line voltage: 220 V; 50Hz frequency
2) Reference output voltage: 750 V;
3) input inductance: 5 mH;
4) dc-link capacitance: Ca= Cb= 2000 uF;
5) Load resistance is 100 ohm; and
6) Bidirectional switches operating frequency: 6.6 kHz.
According to (12) and (13), a simple proportional-integral Controller (0.4 + 15 */s*) is chosen for the dc voltage compensator *G*c(*s*). A MATLAB/SIMULINK model for the proposed rectifier structure is developed to perform a digital Simulation and verify the predicted results. Under balanced supply and nominal output power condition, the supply voltage and current waveform is shown in Fig. 7. The input power factor is found to be 0.999 and supply current THD 2.67%.

## V. SIMULATION RESULT

According to figure. 1threephase High power factor PWM rectifier with three parallel connected IGBT based switch. A simulation diagram is design to get simulation result and the parameter are used to design simulation diagram as mentioned above.The figure 4.Shows the balanced supply voltages are of three phase PWM rectifier based circuit having 220$V_{rms}$ and 50 Hz frequency each phase and three phases are $\frac{2\pi}{3}$radian a part each otherFigure5. is a waveform of voltage and current with using current control technique voltage $v_a$is phase A voltage waveform and $i_a$ is input phase current. This figure also represents unity power factor the phase difference between voltage and current waveform is zero it represents unity power factor. Figure 6. Represents the input power factor of three phase rectifier without using current controller and the input power factor is 0.707. The voltage $v_a$ is phase A voltage waveform and $i_a$ is input phase A current. The input current Ia is discontinuous and in each pulse it is zero for some duration by source inductor.Figure 7. Shows DC output voltage of three phase rectifier without using Hysteresis current control technique at starting to 0.01 seconds it shows transient after 0.01 seconds it shows steady state.Now figure 8. and figure 9. Represents the FFT analysis of phase A input current of three phase pwm rectifier without using current control technique. It shows total harmonics of input current is 30% and the fundamental value of current is 25.83 ampere.at 25 ohm resistanceNow figure 10. and figure 11. Represents the FFT analysis of phase A input current of three phase pwm rectifier with using Hysteresis current control technique. It represents the total harmonics of input phase A current is 2.67% at 50 Hz frequency and the fundamental value of current is 11.5 ampere.at 100 ohm resistance

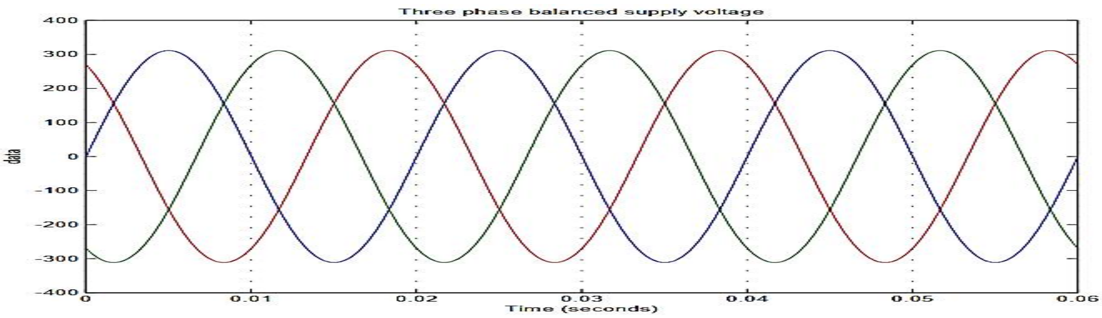

Figure 4 Three phase balanced supply voltage

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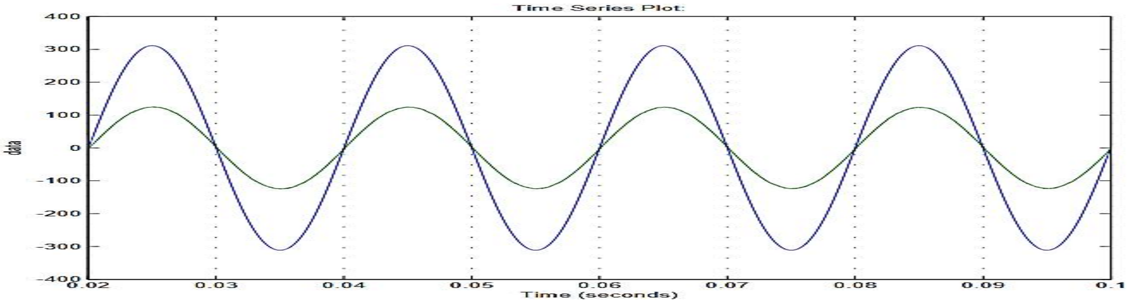


Figure 5Input power factor with current controller

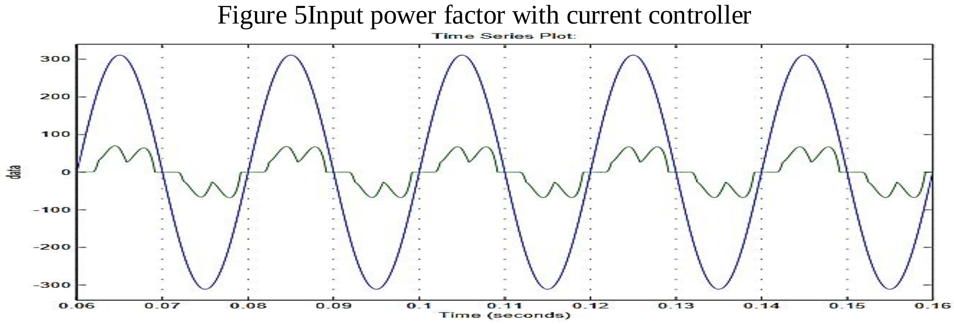


Figure 6 Input power factor without current controller

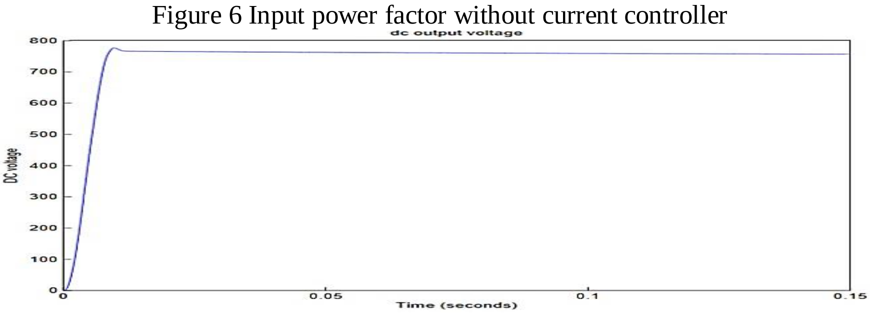


**Figure 7** DC output voltage

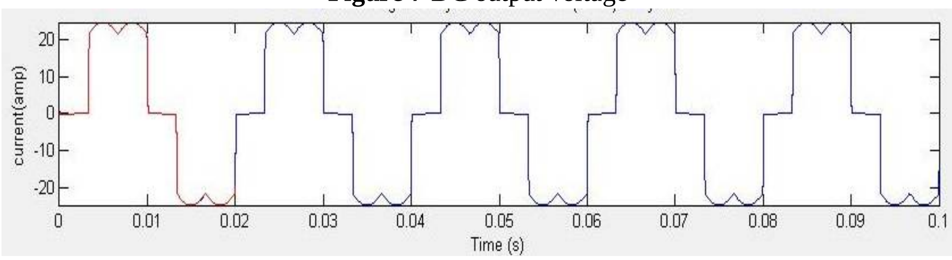


Figure 8 Input phase A current

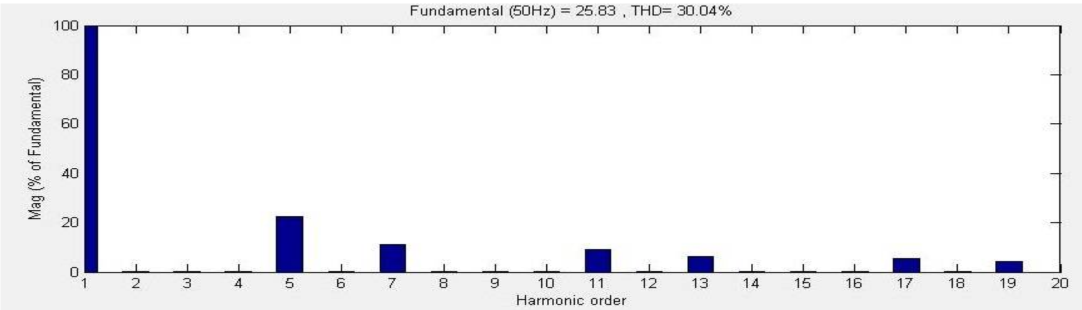


Figure 9 THD without current control

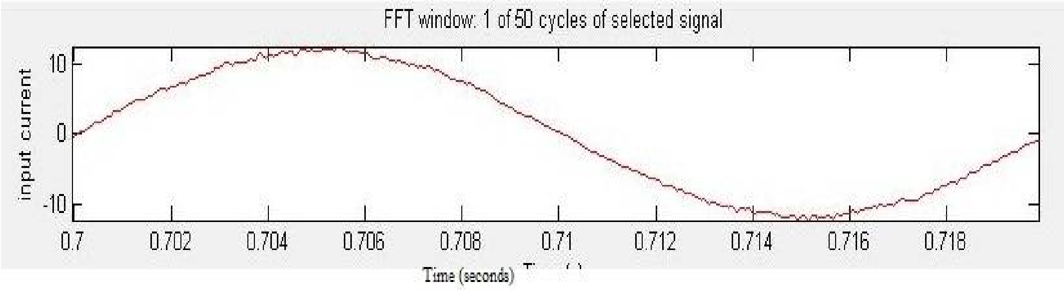


Figure 10 Input Phase A current

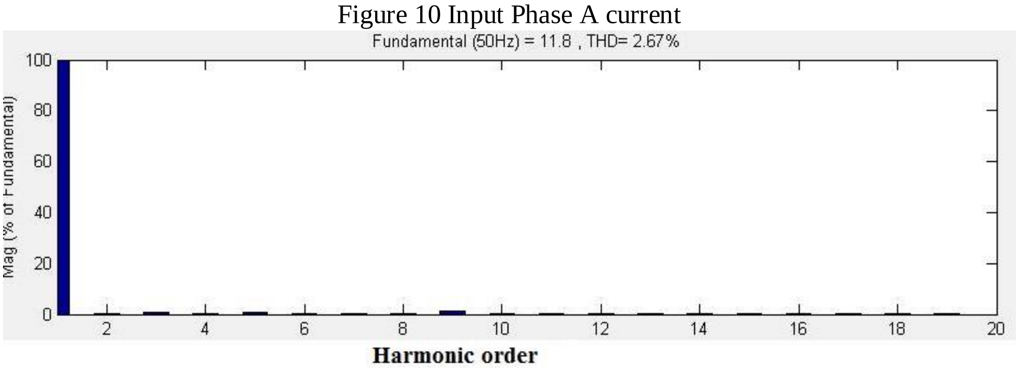


Figure 11 THD with current control

## VI.CONCLUSION

A hysteresis current controller synchronous reference frame as an inner current control loop and DC link voltage control outer loop are proposed for the front side rectifier of the unity power factor rectifier. The mathematical equation expressing the converter input /output as well as the converter currents and voltages are developed and the converter performance is evaluated. It shows that with the proposed control strategy, the converter draws unity power factor and offers good performance to supply voltage regulation and it exhibits good performance to supply voltage are developed. The front end converter has a common capacitive point that allows the three level operations and a power density with reduced production cost. The proposed bi-directional switch along the controller is expected to be a good retrofit to the front end rectifiers of the existing small to medium power ac drives.

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