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Implementation of Hysteresis controlled Space Vector Pulse Width Modulation Based Inverter

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Abstract : *In the field of power electronics Pulse Width Modulation (PWM) inverters play a major role for DC to AC conversion. Space Vector Modulated PWM (SVPWM) is the popular PWM method and possibly the best among all the PWM techniques as it generates higher voltages with low THD and works very well with field oriented (vector control) schemes for motor control. Good quality output spectra can be obtained by eliminating several low order harmonics by adopting a suitable harmonic elimination. In this paper, the modeling, implementation and simulation of Hysteresis controlled SVPWM are defined. There is also a sort of technique defined for getting better response of space vector via a hysteresis filter, and to control of generating specific error free vectors from switching. Simulation results give the hope to further development of space vector technique in many control systems especially in this case an inverter.*
Keywords *– SVPWM (Space vector pulse width modulation), THD (Total harmonic distortion), Hysteresis curve, 3 phase inverter, Vector control.*

I. INTRODUCTION

SVPWM method is an advanced, Computation intensive PWM method is possibly the best among all the PWM techniques for voltage source inverter, its advantage like good dc utilization and less harmonics distortion in the output waveform, it has been finding widespread application in recent years [1,2]. SVPWM contain two sides, the source side consist of (dc- link) rectifier and the other side define as a load side consist of voltage source inverter feeding induction motor as show in Figure (1).The two sides generate a wide spectrum of harmonic components (effective; Harmonics, Interharmonics and Sub- harmonics) which deteriorate the quality of the delivered energy and increase the energy losses as well as decrease the reliability. The other mainly disadvantage in the form of short picks and spikes, can cause malfunctioning or even braking down of power electronic equipment. So harmonics are one of the major power and system quality concern. The behavior and performance study of SVPWM drive induction motor related to harmonic effect is based on effective harmonics only which is measured in the supply and load side voltage. While the inter - harmonics and sub- harmonics are neglected in previous searchs.In this paper total harmonics distortion factor (THD) including Interharmonics.

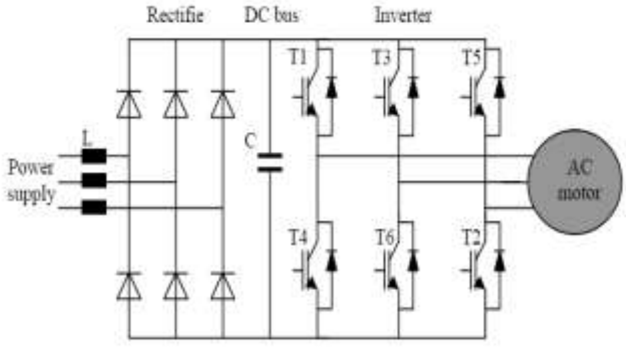


Fig -1 three phase Voltage Source Inverter

II. THD FACTOR

It is the ratio of the root mean square of the harmonic content to the root mean square value of the fundamental quantity, expressed as a percentage of the fundamental [2] . When the value of current have a harmonic

$$THD=\sqrt{\sum_{k}^{\infty}(I_{krms}^{2})} \; / \; I_{Rms} *100 \quad ....(1)$$

Where:
I_{krms} = value of the total effective harmonics component. (for Current)
I_{1rms} = rms value of the fundamental component. (for current)
K = running number of the total effective harmonic component (for current).

III. PRINCIPLE OF SPACE VECTOR PULSE WIDTH MODULATION

Eight possible combinations of on and off patterns may be achieved. The on and off states of the lower switches are the inverted states of the upper ones The phase voltages corresponding to the eight combinations of switching patterns can be calculated and then converted into the stator two phase (αβ) reference frame. This transformation results in six non-zero voltage vectors and two zero vectors. The non-zero vectors form the axes of a hexagon containing six sectors ($V_1 - V_6$) as shown in Fig. 1 the angle between any adjacent two non-zero vectors is 60 electrical degrees. The zero vectors are at the origin and apply a zero voltage vector to the motor. The envelope of the hexagon formed by the non-zero vectors is the locus of the maximum output voltage.

The maximum output phase voltage and line-to-line voltage that can be achieved by applying SVPWM

$V_{ph\ MAX} = V_{dc} /\sqrt{3}$ $\qquad V_{11\ MAX} = V_{dc}$

And the r.m.s. voltage (output phase and line to line voltage)

$V_{ph\ rms} = V_{dc} / \sqrt{6}$ $\qquad V_{11\ rms} = V_{dc} /\sqrt{2}$

Therefore the dc voltage V_{dc} for a given motor r.m.s. voltage
$V_{ph\ rms}$ is

$V_{dc} = \sqrt{6} * V_{ph\ rms}$

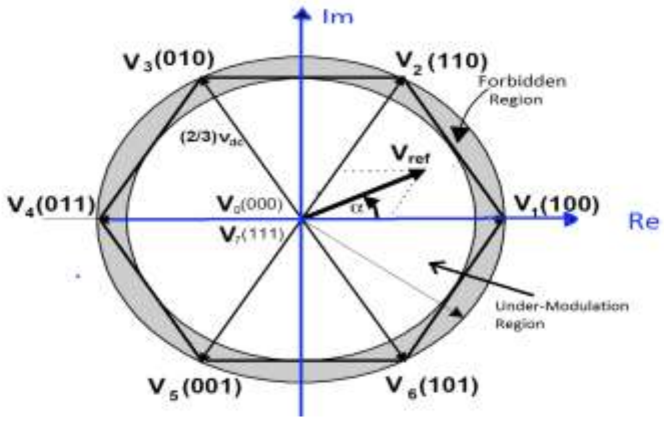


Fig -2: - Non-zero vectors forming a hexagon and zero Vectors in space vector pwm

Practically, only two adjacent non-zero voltage vectors V_x and V_{x+60} and the zero vectors should be used. Depending on the reference voltages V_α and V_β, the corresponding sector is firstly determined. The sector identification is carried out using the switching patterns in the six sectors are illustrated in Fig. 2. This is the best choice of three general patterns that will be introduced later in this paper. The procedure of calculating the time intervals Tz and Tz+1 is discussed as follows:

$$\vec{V}_k = \begin{cases} \frac{2}{3} V_{dc} e^{j(k-1)\frac{\pi}{3}} & \text{if } k = 1,2,3,4,5,6 \\ 0 & \text{if } k = 0,7. \end{cases} \qquad \text{………………………………………………… (A)}$$

The non-zero vectors can be represented

$V_X^*(k) = \frac{2}{3} V_d e^{j(k-1)\frac{\pi}{3}}$………………………….. (1)

Where（k=1， 2， 3， 4， 5， 6）
Therefore

V_X^* (k) = $\frac{2}{3}$ $V_d\,[\cos(k-1)\frac{\pi}{3} + j\sin(k-1)\frac{\pi}{3}]$… (2)

V_X^* (k+1) = $\frac{2}{3}$ $V_d\,[\cos(k)\frac{\pi}{3} + j\sin(k)\frac{\pi}{3}]$……….. (3)

also

V_X^* (k+1) = $\frac{2}{3}$ $V_d\, e^{\frac{jk\pi}{3}}$

Due to symmetry in the patterns in the six sectors, the following integration can be carried out for only half of the pulse width modulation period (Ts/2).

$$\int_0^{\frac{T_S}{2}} V_X^*\, dt = \int_0^{\frac{T_0}{4}} V_0\, dt + \int_{\frac{T_0}{2}}^{\frac{T_0}{4}+T_k} V_X^*\, dt + \int_{\frac{T_0}{4}+T_k}^{\frac{T_0}{4}+T_k+T_{k+1}} V_X^*\, dt + \int_{\frac{T_0}{4}+T_k+T_{k+1}}^{\frac{T_S}{2}} V_7\, dt \text{ …………………………. (4)}$$

Assuming that the reference voltage, the voltage vectors Vk and Vk+1 are constants during each pulse width modulation period (Ts) and splitting the reference voltage V_{ref} into its two components Vα and Vβ gives the following result:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \frac{T_S}{2} = \frac{2}{3}\, V_d \left[T_S \begin{bmatrix} \cos\frac{(k-1)\pi}{3} \\ \sin\frac{(k-1)\pi}{3} \end{bmatrix} + T_{k+1} \begin{bmatrix} \cos\frac{k\pi}{3} \\ \sin\frac{k\pi}{3} \end{bmatrix} \right] \text{….. (5)}$$

$$= \frac{2}{3} V_d \begin{bmatrix} \cos\frac{(k-1)\pi}{3} & \cos\frac{k\pi}{3} \\ \sin\frac{(k-1)\pi}{3} & \sin\frac{k\pi}{3} \end{bmatrix} \begin{bmatrix} T_k \\ T_{k+1} \end{bmatrix}$$

Solving equations we get,

$$\begin{bmatrix} T_k \\ T_{k+1} \end{bmatrix} = \frac{\sqrt{3}}{2V_d} T_S \begin{bmatrix} \cos\frac{k\pi}{3} & -\cos\frac{k\pi}{3} \\ \sin\frac{(k-1)\pi}{3} & \cos\frac{(k-1)\pi}{3} \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \text{……… (6)}$$

Since the sum of 2Tk and 2Tk+1 should be less than or equal to Ts, the inverter has to stay in zero state for the rest of the period. The period of zero voltage is

$T_0 = T_S - 2(T_k + T_{k+1})$ ……………………………. (7)

Having determined the time intervals Tk, Tk+1, and T0, every PWM period, three general patterns can be applied.

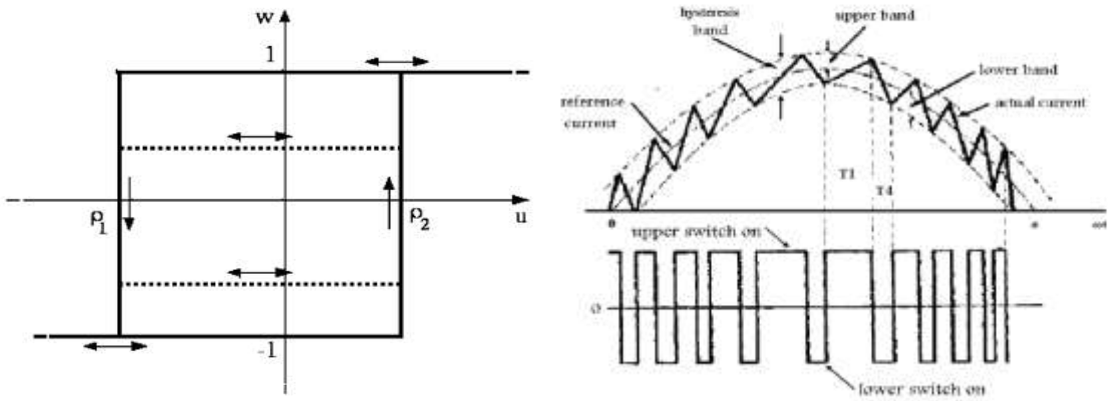
IV. Hysteresis Band

The hysteresis curve (band) is nothing but a threshold detector (RELAY) in MATLAB simulation. The use of this function is to give a desired output level if the space vector PWM doesn't have the proper voltage. The formula for RELAY and hysteresis curve are as follows:

$$w(t) = \begin{cases} |w| \leqslant 1 \\ (w-1)(u-\rho_2) \geqslant 0 & \text{a.e. in }]0, T[, \\ (w+1)(u-\rho_1) \geqslant 0 \end{cases}$$

The output of the system follows from eq. A as:

Output Vo = V_k * w (t) ………………………………………………………………………………(B)



(a) (b)

Fig – 3: (a) Relay or hysteresis curve (2 level curve), (b) hysteresis curve controlling current

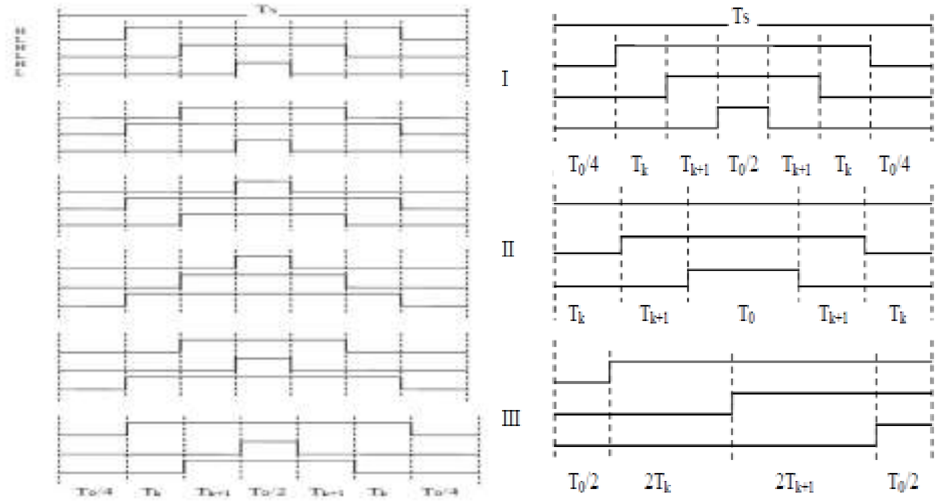
V. Inverter Model

The inverter is modeled using three functions that calculate the output phase voltages of the inverter depending on the following relations between the dc voltage (Vdc) and the switching states of the upper switches Sa, Sb, and Sc.

Va = (2 Sa – Sb – Sc) * Vdc / 3 (8)

Vb = (2 Sb – Sa – Sc) * Vdc / 3 (9)

Vc = (2 Sc – Sa – Sb) * Vdc / 3 (10)



(a) (b)

Fig-4 (a) switching level pattern of six sectors, (b) generalized pwm pattern

VI. Switching Intervals Generator

The current controllers produce the voltage references in the d-q rotor reference frame. The voltage references Vd and Vq are transformed to the stator two phase (αβ) reference frame to give the reference voltages Vα and Vβ. These voltage references are the inputs to the switching intervals generator that is shown in Fig. 4. This block works according to equation 6 to produce finally the switching intervals Tk and Tk+1. The outputs of this block are supplied to the control signals generator which is described in the following section.

VII. Control Signal Generator

The block of the signals generator and its details are illustrated in Fig. 4. The input of the model is the switching intervals Tk and Tk+1. The off period T0 is calculated as given in equation 7.

VIII. Simulation model of Hysteresis controlled SVPWM

The simulation model as below fig-5 in which the yellow colored block contain hysteresis and SVPWM, the red colored block have a DC supply of 400 volts and light green block have the simple 3 leg IGBT base 3 phase inverter block. A series RLC load is connected in light blue section; the lower blocks are for measuring currents and THD in all three phases.

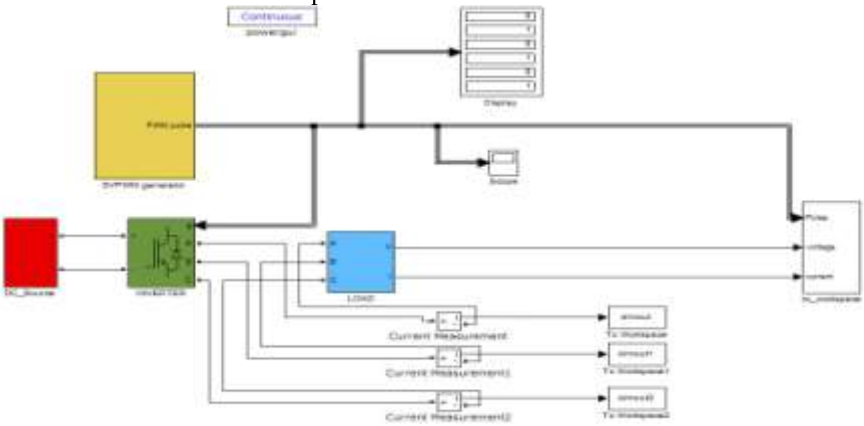


Fig-5 Model of Hysteresis controlled SVPWM

The switching which gives the equation (A) and equation (B) as shown in figure 6. After generation of vector control the vectors multiply (sampled) via hysteresis function, the function itself gives some harmonics which is detected in incremented THD form.

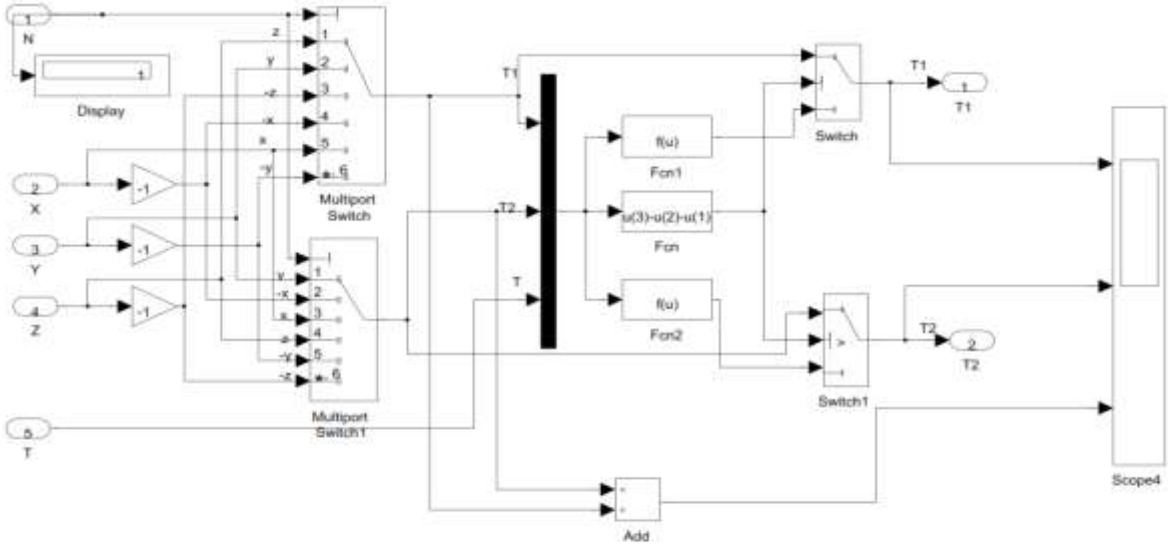
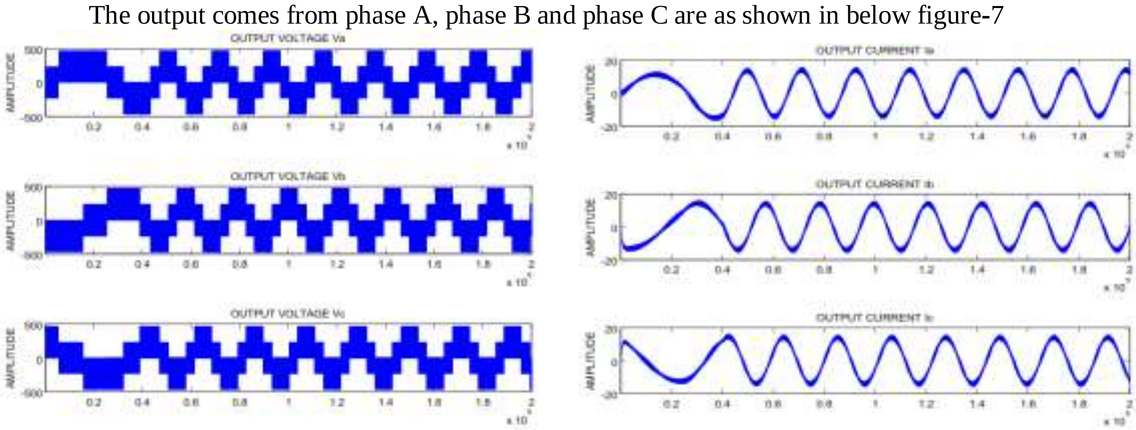


Fig –6 Switching state generator simulated circuit

IX. Simulation Results

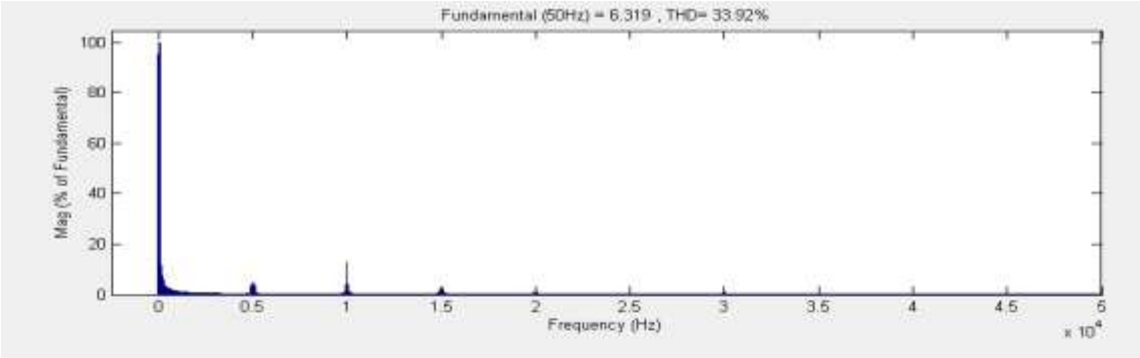
The output comes from phase A, phase B and phase C are as shown in below figure-7



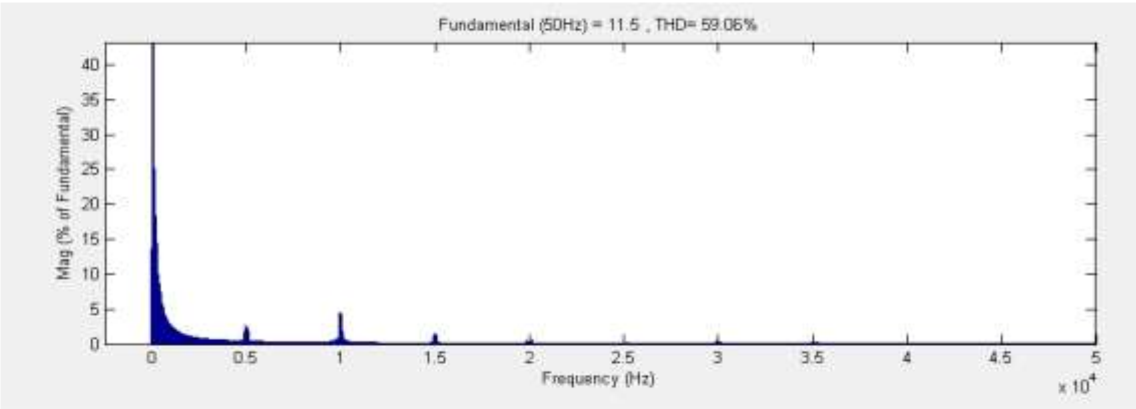
(a) (b)

Fig – 7 (a) Inverter output voltages (3 phase via HCSVPWM), (b) Inverter output currents (3 phase via HCSVPWM

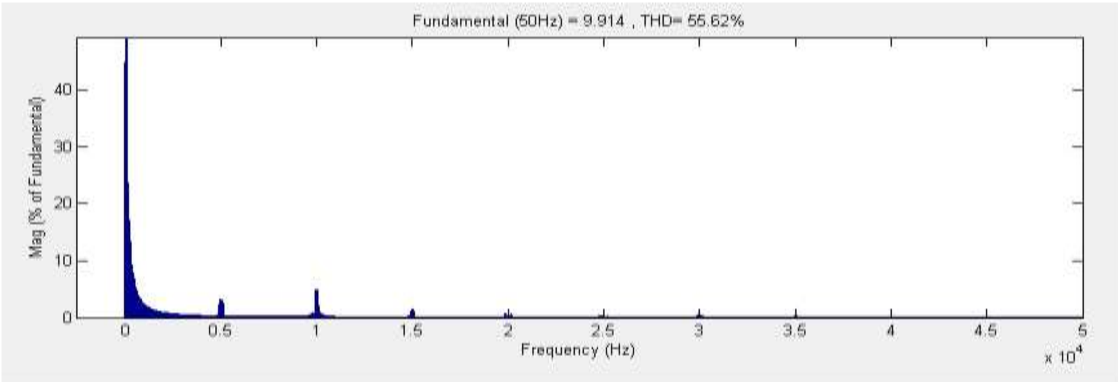
The three phase current THD are shown in figures below with percentage values, the THD have its value because of Hysteresis curve injected harmonics are presented in the system. These can be controlled via appropriate value of filters.



(a)



(b)



(c)

Fig – 8 (a) THD of phase A, (b) THD of phase B, (c) THD of phase C

X. Conclusion

For this paper the simulation of hysteresis curve based space vector pulse width modulation base Inverter is performed. The result of three phase voltage output have some initial level long generation time as well as the notches are presented if we expand the output waveform, same in the three phase current wave form also have THD within initial 2000 cycles as described in the previous figures. The main features of this paper is that the hysteresis curve's generated THD is fatherly controlled by mean of Active and Passive filters, thus the bandwidth of the sector selection is increased or in another word the more switching is performed by the presence of hysteresis curve. This process recovers the loss in voltage.

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