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Analysis & Simulation of Total Harmonic Distortion in Hysteresis Inverter

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***Abstract*—This Paper presents the simulation of hysteresis current controlled inverters under different harmonics prevalent at the output terminal using MATLAB in which THD(Total Harmonic Distortion) has been calculated in each and every case. It has been observed that when there is no harmonics at the output implying ideal case, THD is 0%. On the contrary, in practical case, if 15^{th}, 9^{th}& 3^{rd} order harmonics are present owing to the switching impact of IGBT (Insulated Gate Bipolar Transistor), THD becomes 6.67%, 11.12% & 33.34% respectively. To visualize these precisely, FFT(First Fourier Transform) of all figures has been accomplished.**

***Keywords*—Hysteresis Inverters, IGBT, Harmonics, FFT, THD, MATLAB Simulation.**

I. INTRODUCTION

Dc-to-ac converters are known as inverters. The function of an inverter is to change a dc voltage to a symmetric ac output voltage of desired magnitude & frequency [1]. The output voltage could be fixed or variable at a fixed or variable frequency. A variable output can be obtained by varying the input dc voltage & maintaining the gain of the inverter constant. The output waveforms of an ideal inverter should be sinusoidal. However, the waveforms of practical inverters are non-sinusoidal & contain certain harmonics [2]. THD measures the shape closeness of actual & fundamental components. Some Typical applications are:

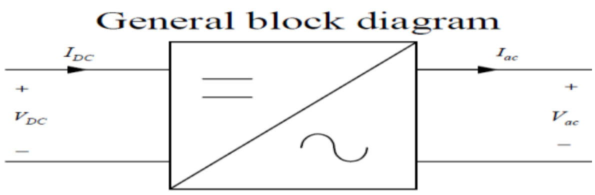

Fig 1. Block-diagram of Inverter

Hysteresis Current Controlled Inverter is a special kind of inverter in which the output current can be controlled though switching techniques. Switching devices may be BJTs, MOSFETS, GTOS,MCTS, IGBTS. But normally IGBT is used as it combines the advantages of both BJTS & MOSFETS.

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II. HYSTERESIS INVERTERS

Hysteresis inverters are used in many low and medium voltage utility applications whenthe inverter line current is required to track a sinusoidal reference within a specified error margin. Line harmonic generation from those inverters depends principally on theparticular switching pattern applied to the valves. The switching pattern of hysteresisinverters is produced through line current feedback and it is not pre-determined unlike thecase, for instance, of Sinusoidal Pulse-Width Modulation (SPWM) where the inverterswitching function is independent of the instantaneous line current and the inverterharmonics can be obtained from the switching function harmonics [8].Fig. 2 shows a single-phase neutral point inverter. For simplicity, it is assumed that the dcvoltage supplied by the DG source is divided intotwo constant and balanced dc sources, as inthe figure, each of value V_c. The RL element on the ac side represents the combined line and transformer inductance and losses. The ac source V_{sa}represents the system voltage seen at theinverter terminals. The inverter line current ia, in Fig. 2, tracks a sinusoidal referencei_a*=√2Ia*sin(wt+ø) through the action of the relay band and the error current ea(t) =ia*-ia.In Fig.2, the fundamental frequency voltage at the inverter ac terminals when the line current equals the reference current is the reference voltage,va*=√2Va*sin(wt+θ). Fig.3 compares the reference voltage to the instantaneous inverter voltage resulting from theaction of the hysteresis loop.$R.ea+L\frac{d}{dt}e(t)=va^*-va$

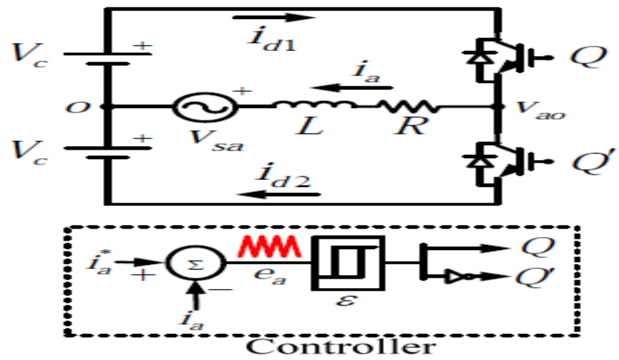

Fig 2. Single phase half bridge Hysteresis Inverter

Referring to Fig.2, when valve Q is turned on, the inverter voltage is va=Vc>va*;this forces the line current iato slope upward until the lower limit of the relay band is reached ea(t)=-ϵ . At that moment, the relay switches on Q′and the inverter voltage becomesva=-Vc<va*;this forces the line current iato slope downward until the lower limit of the relay band is reachedea(t)=ϵ .

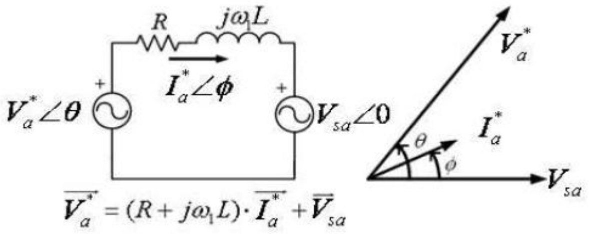

Fig 3. Reference Voltage Calculation & instantaneous outputs.

Error Current Approximation:[08]

$$e_a(t) \approx \underbrace{\left[(8-k) + k\cos(2\omega_1 t + 2\theta)\right]}_{e_1(t)}$$

$$\cdot \underbrace{\left[\frac{\varepsilon}{\pi^2} \cdot \sin\left(\omega_c t + \beta \sin(2\omega_1 t + 2\theta) - \varphi\right)\right]}_{e_2(t)}$$

.....…………………….(1)

Where, Amplitude Modulation Index, M=√2va/Vc

Average Carrier switching Frequency,fc=$\frac{Vc}{4\epsilon L}[1-\frac{M^2}{2}]$

Frequency Modulation Index,ø=βsin(2θ), K=(4-π)M^2

Care must be taken so that two switches do not on together otherwise, dc source may be shorted out. For this reason, there is a dead time between the switches [3].

Inverter Voltage, $V_a = \sum_{odd\_number}^{\alpha} \frac{2V_C}{n\pi} Sin(n\omega t)$…(2)

Inverter Current, $I_a = \sum_{odd\_number}^{\alpha} \frac{2V_C}{n\pi\sqrt{(R^2 + (n\omega L)^2)}}$

$\theta = Sin(n\omega t - \tan^{-1}(\frac{n\omega L}{R}))$ …………..………(3)

III. SWITCHING DEVICE IGBT

The Insulated Gate Bipolar Transistor (IGBT) is a minority-carrier device withhigh input impedance and large bipolar current-carrying capability. Many designers viewIGBT as a device with MOS input characteristics and bipolar output characteristic that isa voltage-controlled bipolar device. To make use of the advantages of both PowerMOSFET and BJT, the IGBT has been introduced. It's a functional integration of PowerMOSFET and BJT devices in monolithic form. It combines the best attributes of both toachieve optimal device characteristics [6].

The IGBT is suitable for many applications in power electronics, especially in PulseWidth Modulated (PWM) servo and three-phase drives requiring high dynamic range control and low noise. It also can be used in Uninterruptible Power Supplies(UPS),Switched-Mode Power Supplies (SMPS), and other power circuits requiring high switchrepetition rates. IGBT improves dynamic performance and efficiency and reduced thelevel of audible noise. It is equally suitable in resonant-mode converter circuits.

Optimized IGBT is available for both low conduction loss and low switching loss.A circuit symbol for the IGBT is shown in Figure 4. It has three terminalscalled Collector (C), Gate (G) and Emitter .

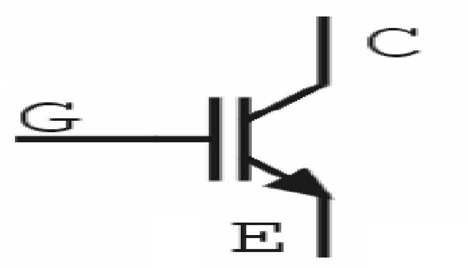

Fig 4. IGBT Circuit Symbol

IV. HARMONICS ANALYSIS

A harmonic is a signal or wave whose frequency is an integral (whole-number) multiple of the frequency of some reference signal or wave. The term can also refer to the ratio of the frequency of such a signal or wave to the frequency of the reference signal or wave. Let f represent the main, or fundamental, frequency of an alternating current (AC) signal, electromagnetic field , or sound wave. This frequency, usually expressed in hertz , is the frequency at which most of the energy is contained, or at which the signal is defined to occur. If the signal is displayed on an oscilloscope, the waveform will appear to repeat at a rate corresponding to f Hz.

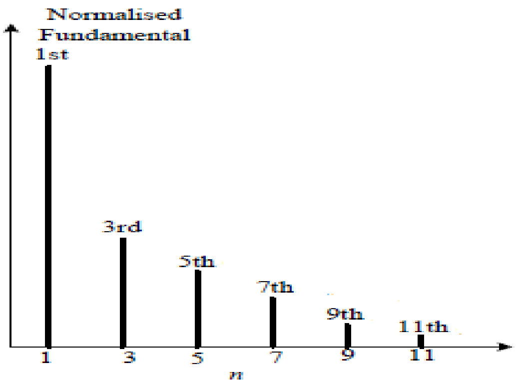

Fig.5 Harmonics Spectra of an Inverter

As is observed, Harmonic decreases as nincreases. It decreases with a factor of (1/n). Even harmonics are absent–Nearest harmonics is the 3rd. If fundamental is 50Hz, then nearest harmonic is 150Hz. Due to the small separation between the fundamental an harmonics, output low-pass filter design can be quite difficult [4].

V. FFT ANALYSIS

It is a linear algorithm that can take a time domain signal into the frequency domain and back. Fourier analysis allows a more intuitive look at an unknown signal in frequency domain[5].As is seen in Fig5, the fundamental component & the harmonic components can be perceived without cumbersome.

VI. TOTAL HARMONIC DISTORTION

THD is a measure of closeness in shape between a waveform and its fundamental components [2].

In Case of Inverter, It can be defined as the ratio of the RMS value of all odd thenonfundamentalfrequency terms to the RMS value of thefundamental[7].

Which indicates:

$$THD = \sqrt{\frac{\sum_{n\neq 1,\text{Even}} V_{n,RMS}^{2}}{V_{1,RMS}}} = \sqrt{\frac{V_{RMS}^{2} - V_{1,RMS}^{2}}{V_{1,RMS}^{2}}} \quad \text{.......................(4)}$$

VII. MATLABSIMULATION RESULTS

Since, appearance harmonics can be controlled by switching, To begin with, it is assumed that the output of the hysteresis inverter is free of harmonics. Parameters are selected randomly and plotting [Eq. 1,2 & 3] by using [9] Harmonics absent voltage. Current & error current are represented in [Fig 6,7&8].

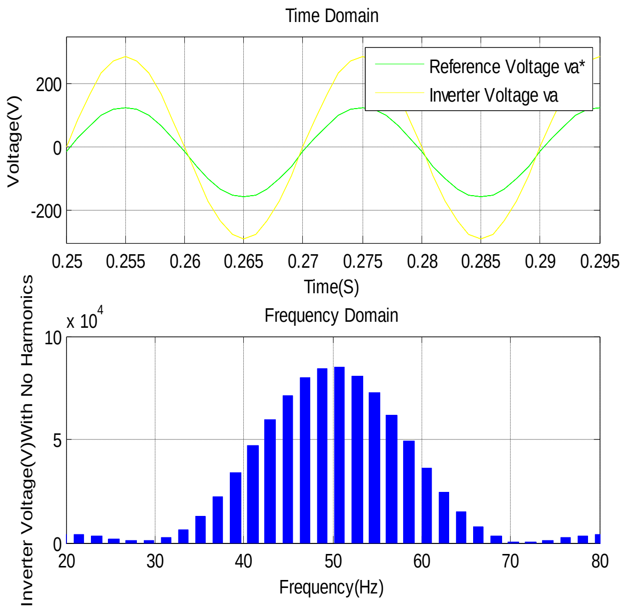

Fig. 6 Voltage Wave-shapes With No Harmonics

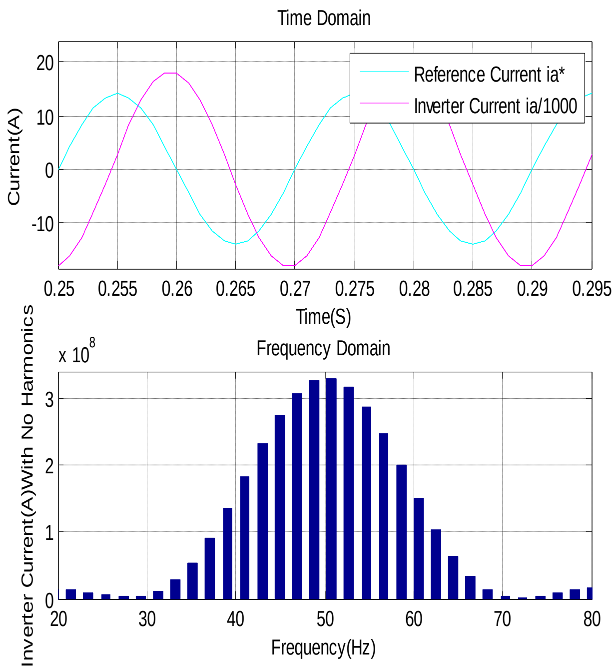

Fig. 7 Current Wave-shapes With No Harmonics

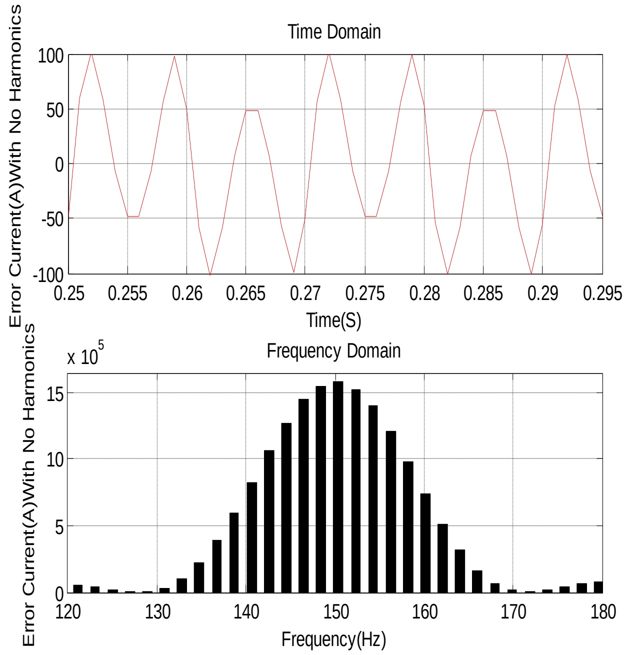

Fig. 8 Error Current Wave-shapes With No Harmonics

V_{01}=202.5V

From [Eq. 4]

THD=0%

Hence it is an output of an ideal Inverter.

Now, switching is done in a way that 15th harmonics occur at the inverter output. Inverter output voltage, current & error current containing 15th harmonics has been displayed in [Fig 9,10&11].

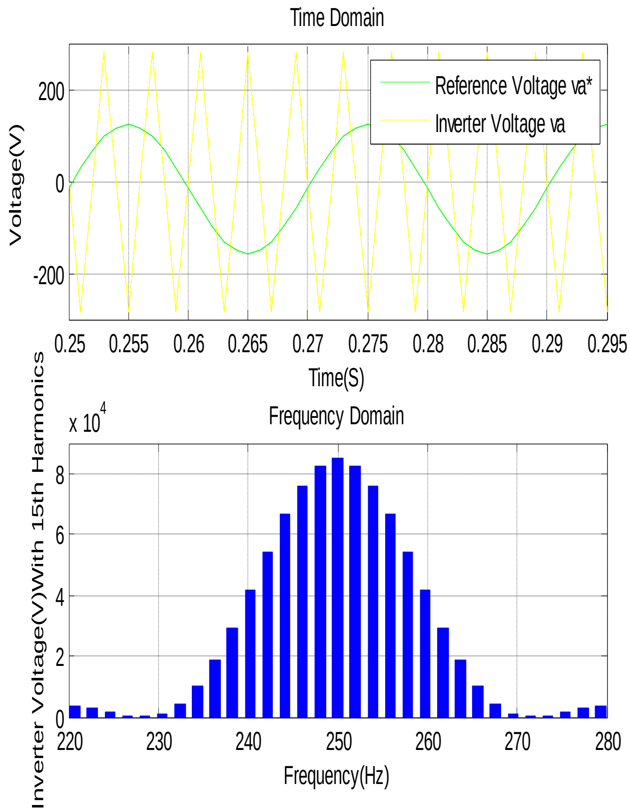

Fig. 9 Voltage Wave-shapes With 15th Harmonics

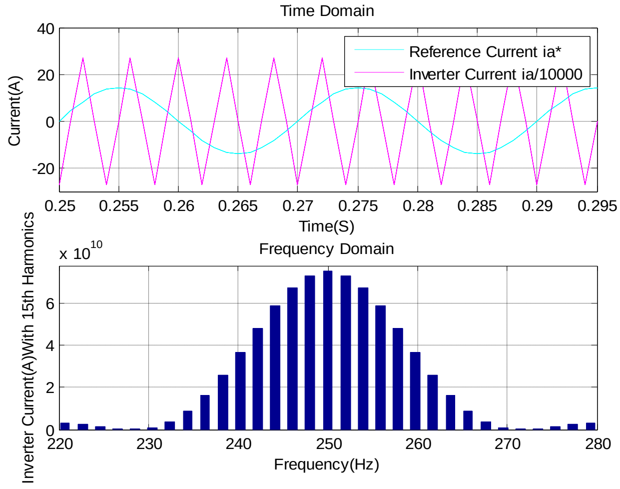

Fig. 10 Current Wave-shapes With 15th Harmonics

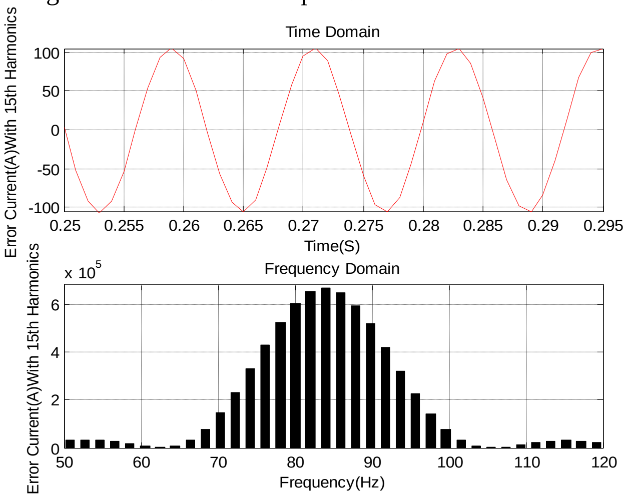

Fig. 11 Error Current Wave-shapes With 15th Harmonics

$$V_{15}= V_{01}/15=13.5V$$

From [Eq. 4]

$$THD=6.67\%$$

So, THD has increased due to the presence of harmonics. For more convince, it is thought that 9th harmonics are present at the output. This has been demonstrated in[Fig 12,13&14].

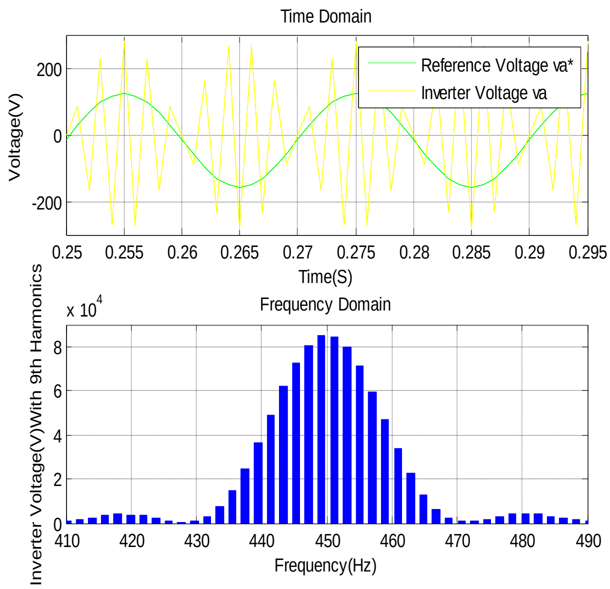

Fig.12 Voltage Wave-shapes With 9th Harmonics

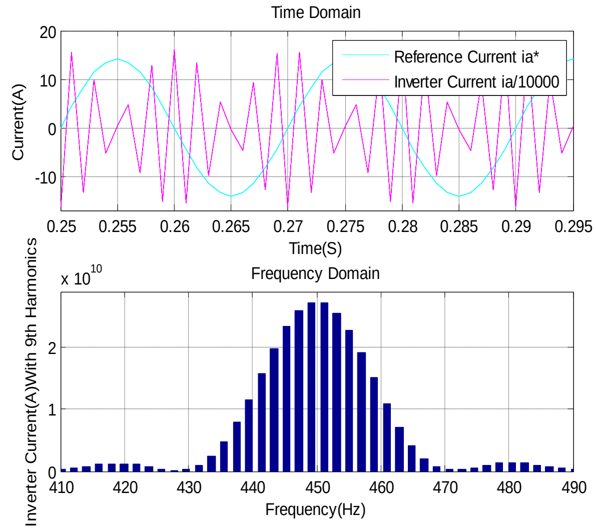

Fig. 13 Current Wave-shapes With 9th Harmonics

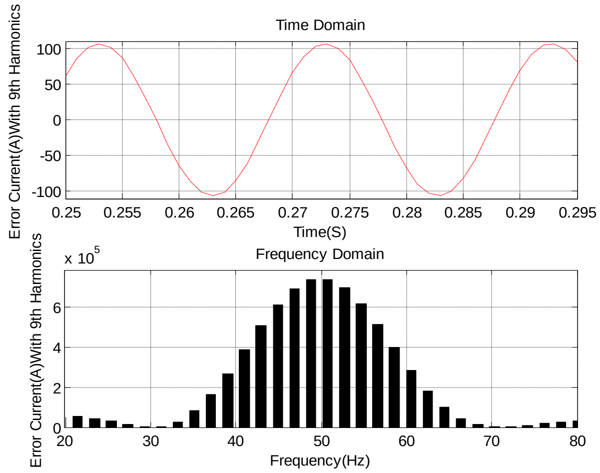

Fig. 14 Error Current Wave-shapes With 9th Harmonics.

$$V_{09}= V_{01}/9=22.5V$$

From [Eq. 4]

$$THD=11.12\%$$

Therefore, once again, an increment in the total harmonic distortion has been noticed.

Since, 3rd harmonics frequency is the nearest frequency of the fundamental one, let us plot it both in time domain & frequency domain which has been revealed in [Fig 15,16&17].

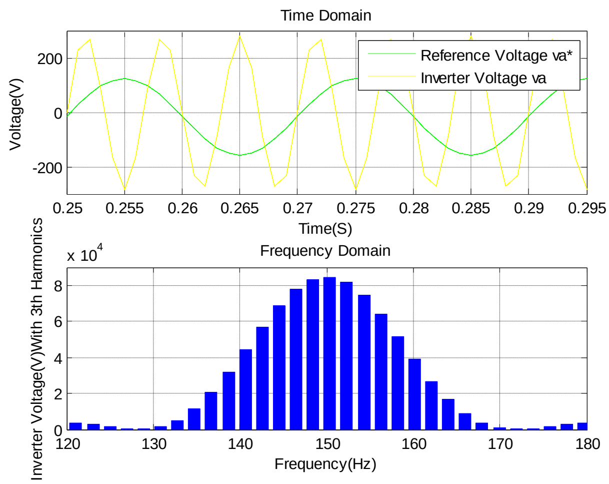

Fig. 15 Voltage Wave-shapes With 3rd Harmonics

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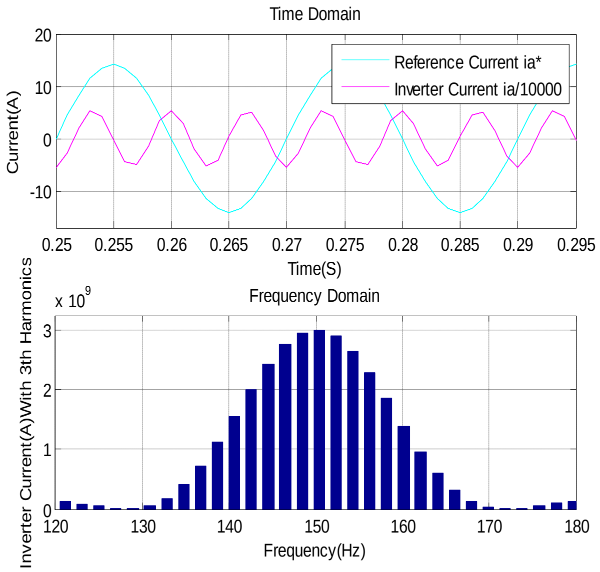

Fig. 16 Current Wave-shapes With 3rd Harmonics

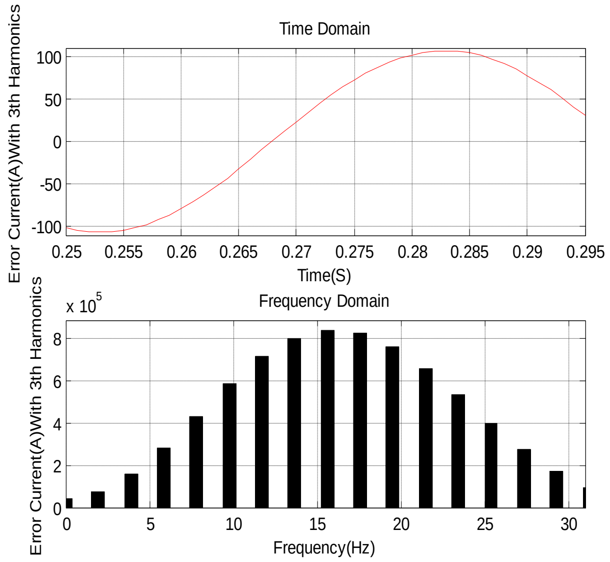

Fig. 17 Error Current Wave-shapes With 3rd Harmonics

$$V_{03}= V_{01}/3=67.5V$$

From [Eq. 4], THD=33.34%

Thence, THD is much more than all other harmonics. Finally, all found THD's are summarized in Table-I

VIII. Results & Discussions

The total harmonic distortion derived in various harmonic state found in the output of hysteresis inverter has been summarized in Table-I

Table-I
(Total Harmonic Distortion analysis)

Output Harmonics	THD
0	0%
15th	6.67%
9th	11.12%
3rd	33.34%

IX. Conclusion

The analysis of Total Harmonic Distortion under various harmonics occurrence is the purpose of this paper. Without a hint of doubt, it is understood that in hysteresis current control practical inverters, the harmonics phenomenon is quite common. If several harmonic components is present at the inverter output terminal undeniably THD will be much more which is not desirable. So it is needed to control the harmonics. For this LC filter will a pioneering role because that could trigger parallel resonance & amplify the harmonic voltage & current in the ac network. Furthermore, the reference current has been considered pure sinusoidal, Now if it contains harmonic or non sinusoidal then it is needless to say that there will be a deviation in the error current as it the difference between the reference current & the inverter output current.

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