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Non-Linear Current Control Scheme of Shunt Active Power Filter

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Abstract- **In power system harmonic should be mitigate, so for that filter is the most common solution. Filters also offer a simpler inexpensive alternative and benefits are also good. The three different types of filters are classified into passive filter, active filter and hybrid filter. Nature of the problem and the economic cost, the choice of filter is dependent on it. The performance of shunt active power filter depends upon the control strategy applied and current control technique used to synthesize reference compensating current through PWM inverter. This paper presents a method for obtaining the desired reference current for Voltage Source Converter (VSC) of the Shunt Active Power Filter (SAPF) using Synchronous Reference Frame Theory. The method relies on the performance of the Proportional-Integral (PI) controller for obtaining the best control performance of the SAPF. To improve the performance of the PI controller, the feedback path to the integral term is introduced to compensate the winding up phenomenon due to integrator. In power system harmonic should be mitigate, so for that filter is the most common solution [1-3].**

Index Terms- **Shunt Active Power Filter; Space phasor-based hysteresis Current Control; Power Quality improvement; Harmonics.**

I. INTRODUCTION

A harmonic is a component of a periodic wave having a frequency that is an integral multiple of the fundamental power line frequency. Harmonics are the multiple of the fundamental frequency, and whereas total harmonic distortion is the contribution of all the harmonic frequency currents to the fundamental. Harmonics are the by-products of modern electronics. They mainly happen because of computers (single phase loads), uninterruptible power supplies (UPSs), variable frequency drives (AC and DC) etc. harmonics are creating by non- linear loads where current is not proportional to the voltage. The distortion of current waveform leads to distortion of the voltage waveform. So, that's why the voltage waveform is no longer proportional to the current. In linear load the voltage and current waveform are sinusoidal. The current at any time is directly proportional to the voltage. They don't create harmonic distortion operate with a smooth sinusoidal wave.

Active Filters

Introduction to Active Filters:

The quality of electrical power is one of the major issue for consumers. The main reason for this issue is by the loads. There are two types of load exist one is linear load and other is non-linear load. The uses of non-linear loads have increases and the power electronics converter, uninterruptable power supplies, arc furnaces are also increases due to that power quality issues has occur. The uses of arc furnaces, thyristor power converters, rectifiers and some other non-linear load has increases due to that serious problems in electric power system has been occur.

The advantage of active filters is that it able to compensate for harmonic without fundamental frequency reactive power concerns. So, the power rating of active can be less than the passive filter power for the same non-linear load.[4-6]

Types of Active Filters:

Based on connection active filters are classified: -

- Shunt active filter
- Series active filter and
- Hybrid active filter.

Shunt Active Filter

The concept of active filter uses power electronic equipment to produce harmonic current components to cancel the harmonic current of the non-linear loads. By this configuration, from the load, the filter is connected in parallel. Therefore, the configuration is referred as an active filter or a shunt filter.

A shunt Active Power Filter (APF) for power quality improvements in terms of harmonics and reactive power compensation in the distribution network [3].

The compensation process is based only on source current extraction that reduces the number of sensors as well as its complexity [10-12]. This filter is considered as an effective tool to mitigate the harmonic current shows in Fig.1. It is classified into two types single phase and three phase shunt active filter. The method provides compensation for reactive, unbalanced, and harmonic load current components.

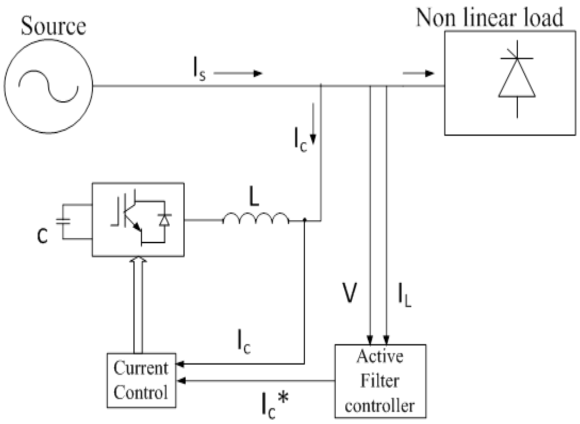

Fig. 1. Block diagram of SAPF

Shunt active power generally consist of two main blocks: -

1. The PWM converter (power processing)
2. The active filter controller (signal processing)

Proposed current error space phasor-based hysteresis control technique

➢ Principle

The space-phasor based hysteresis control technique has current (i), voltage (V) & the PCC voltage (E) are given below: -

$$i_c = \frac{2}{3}(i_{ca} + a i_{cb} + a^2 i_{cc}) \quad (10)$$

$$V_k = \frac{2}{3}(V_a + aV_b + a^2 V_c) \quad (11)$$

$$E = \frac{2}{3}\left(E_a + aE_b + a^2 E_c\right) \quad (12)$$

Where

$$a = e^{j\left(\frac{2\pi}{3}\right)} \quad (13)$$

The voltage vector of the APF and the voltage at the PCC be the vectorially addition of two voltage vectors are separated [2-6]. Basically, it is analogous to the motor voltage and inverter

$$V_k = L\frac{di_c}{dt} + E \quad (14)$$

Rate of change of compensating current is

$$\frac{di_c}{dt} = \frac{1}{L}\left(V_k - E\right) \quad (15)$$

Where L = APF Inductor

Now, the current error space phasor is

$$\Delta i = i_c - i_c * \quad (16)$$

Where i_c* is the reference current space phasor. Thus, the rate of change of the current error is

$$L\frac{d\Delta i}{dt} = (V_k - E) - L\frac{di_c*}{dt} \quad (17)$$

The desired output voltage vector V_0* after eliminating the current error Δi is

$$V_0* = E + L\frac{di_c*}{dt} \quad (18)$$

The direction at which the current error space phasor moves is given by

$$\frac{d\Delta i}{dt} = \frac{V_k - V_0*}{L} \quad (19)$$

To keep the current error within the boundary by choosing the desired SAPF voltage vector. The derivative $\frac{d\Delta i}{dt}$ plays a vital role in diminishing the number of switching. Choosing a voltage vector V_k, which show the minimum value of result $\frac{d\Delta i}{dt}$ by accomplish this task. For the conventional HCC technique, coordination of the switching does not exist. However, reduced switching is caused by using space phasor-based technique. On the other hand, the utilization of non-zero vectors instead of zero voltage vectors give a steep slope for the current error because of large voltage difference $V_k - V_0*$. In conventional HCC based APF this causes limit cycle oscillations. And depending on desired space voltage vector V_0* the set of voltage space vectors are chosen, two are active voltage vectors and one is zero voltage vector [4].

By applying hysteresis controller one of the three voltage vectors of the APF which are adjacent to the voltage vector $V_0{*}$ so, the current error space phasor is kept within the boundary. In the proposed scheme current error space phasor movement is monitored along the three orthogonal axes j_A, j_B and j_C which are perpendicular to phase-A, phase-B and phase-C axes, respectively. The current error space phasor direction depends on the reference voltage vector $V_0{*}$ in two different sectors (even and odd) and according to it SAPF voltage vectors are selected.

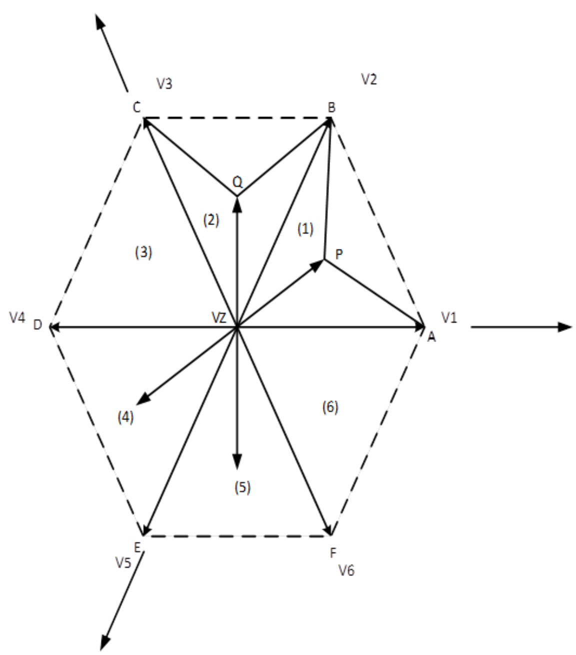

Fig. 2. Voltage space phasor structure and direction of current error space phasor for two-level

- Formation of current error space phasor boundary

When $V_0{*}$ is any sector for suppose in the sector-1 three adjacent SAPF voltage vectors V_1, V_2 and V_Z are switched shows in Fig. 2. When V_1 is switched, the direction of current error will move on PA side, when V_2 is switched, the direction of current error will move on PB side and if V_Z is switched, the direction of current error will move on OP side. The reference voltage vector of SAPF is on OP and its direction, movement and amplitude depend on the reference voltage vector of SAPF [3]. But the direction of current error will be confined with in two directions. If V_1 is switched and the reference voltage vector is along OA, so the current error will be also along OA. Similarly, if reference voltage vector is along OB for the same vector V_1 current error will move in the direction of OF. So, for vector V_1 current error space phasor confined within these two direction OA and OF for the sector-1.

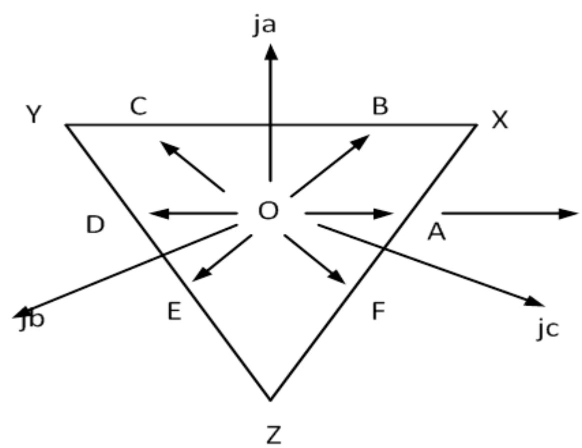

Fig. 3. Boundary of for sector 1

When the reference voltage vector of SAPF is in sector-2, three adjacent inverter voltage vector can be switched are V_2 , V_3 and V_Z shows in Fig. 3. When V_2 is switched the current error move with in OA and OB direction.

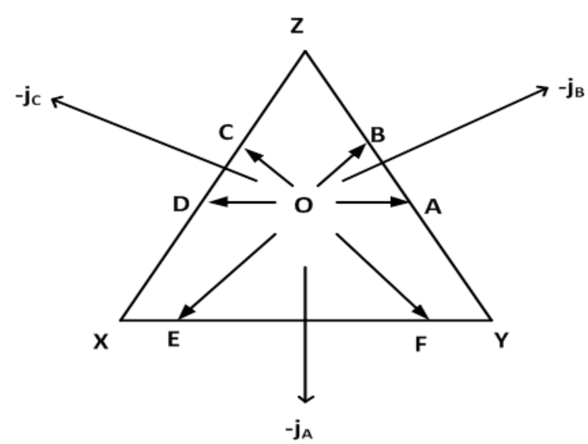

Fig. 4. Boundary of for sector 2

Boundary YZ used to control the current error between OA and OB, Similarly XZ for controlling current error OC and OD shows in Fig. 4. And same manner boundary XY for current error OE and OF.

➢ SAPF voltage vector selection for each sector

The SAPF voltage vector is continued till the current error space phasor touches another side of boundary. Once the current error space phasor hits another side of boundary, the SAPF voltage vector is changed so that current error space phasor is brought back within the boundary, and moves towards

the opposite side of the triangular boundary. . For odd sectors triangular boundary are R_1 , R_2 & R_3 while for even sectors is divided into $\overline{R_1}$, $\overline{R_2}$ & $\overline{R_3}$. For sector 1 if current error hit region R_1, the zero-voltage vector V_Z is selected. Similarly, when region R_2 and R_3 are hit by current error pace phasor voltage vector V_1 and V_2 are selected. For sector 3 vector V_Z, V_4, V_3 are selected when the current error hit anywhere in region R_1, R_2 and R_3 respectively shows in Fig. 5. Similarly for sector 5 vector V_5, V_6 and V_Z are selected when the current error hit anywhere in region R_1, R_2 and R_3 respectively.

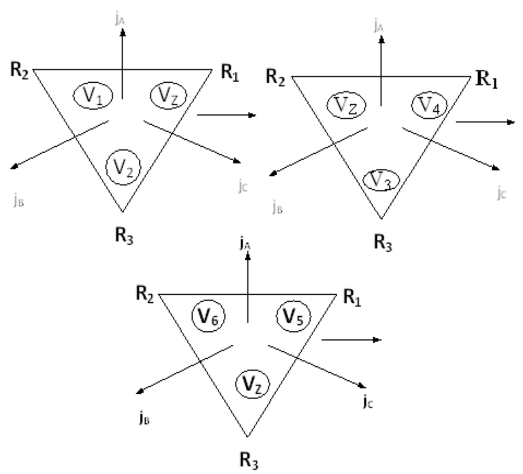

Fig. 5. Regions and corresponding SAPF voltage vectors for all odd sectors

Similarly, $\overline{R_1}$, $\overline{R_2}$ & $\overline{R_3}$ are the associate voltage vector for all even sector. For sector 2 when current error hit in region $\overline{R_1}$ vector V_2 is selected so that the current error space phasor moves towards the opposite side. In the same manner when current error hit in region $\overline{R_2}$ and $\overline{R_3}$ vector V_3 and V_Z are selected. In the same manner for sector 4 when current error hit in region $\overline{R_1}$ vector V_Z is selected so that the current error space phasor moves towards the opposite side [5]. In the same manner when current error hit in region $\overline{R_2}$ and $\overline{R_3}$ vector V_4 and V_5 are selected. Similarly for sector 6 vector V_1, V_Z and V_6 are selected when the current error hit anywhere in region, $\overline{R_1}$, $\overline{R_2}$ and $\overline{R_3}$ respectively Shows in Fig. 6.

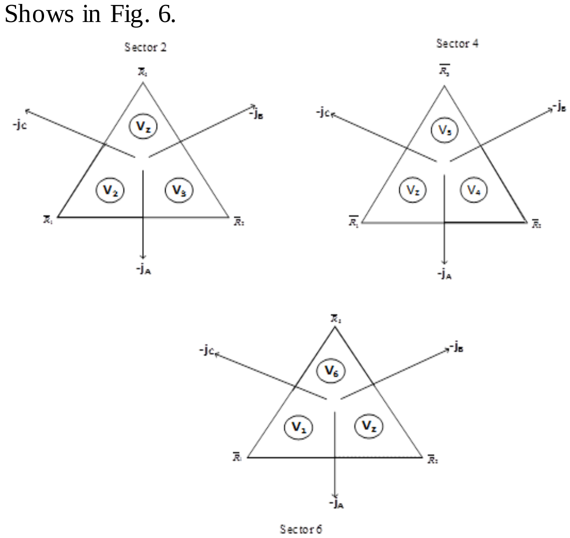

Fig. 6 Regions and corresponding SAPF voltage vectors for all even sectors

The three boundaries are along $-j_A$, $-j_B$ and $-j_C$ for all the even sector (2, 4, 6) and the j_A , j_B and j_C for all the odd sector (1, 3, 5), current error space phasor bounded by this triangular boundary.

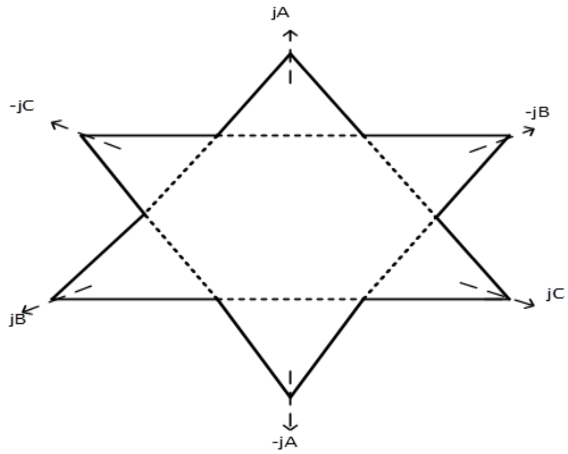

Fig. 7. Boundary of (starfish boundary)

Above Fig. 7 by adding both even and odd boundary shows the current error space phasor will move within this structure. the boundary within which the current error space phasor will move when the SAPF reference voltage vector moves through all the sectors of voltage space phasor structure.

For both odd as well as even sectors, if the boundaries are placed along these axes, it would result in a hexagonal boundary shown in fig. 8

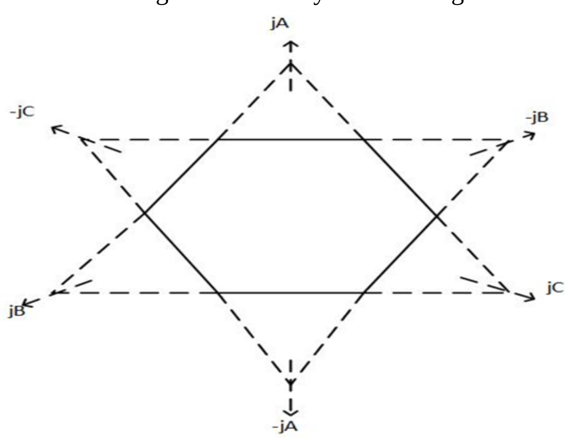

Fig. 8. Hexagonal boundary of

The hysteresis controller is implemented with this hexagonal boundary, where along all the six directions (j_A, j_B, j_C, $-j_A$, $-j_B$ and $-j_C$), the current error is held always within the hexagonal boundary limits.

The following Table I shows the vector selection according to the sector and the region of the hexagonal boundary.

TABLE I

SECTOR	REGIONS					
	R_1	R_2	R_3	R_4	R_5	R_6
1	V_Z	V_1	V_2	-	-	-
2	-	-	-	V_2	V_3	V_Z
3	V_4	V_Z	V_3	-	-	-
4	-	-	-	V_Z	V_4	V_5
5	V_5	V_6	V_Z	-	-	-
6	-	-	-	V_1	V_Z	V_6

change logic without using outer hysteresis band by zero crossing detection of PCC voltage. For selecting the sector, the voltage at the PCC is taken as reference and depending on the movement of this voltage space phasor sector change is detected.

Controller logic calculates time interval required for each sector. Once positive zero crossing of voltage at PCC is detected, by using the time interval required for each sector the sector in which V_0^* lies is detected.

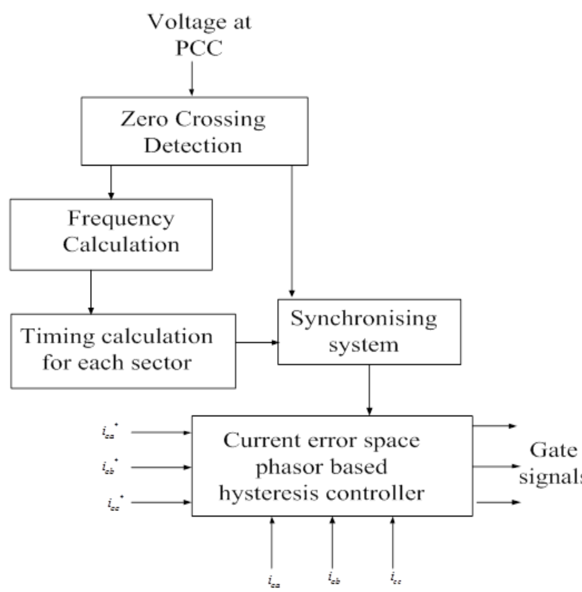

Fig. 9. Block diagram of sector change detection

The above block diagram Fig. 9 of sector change logic has defined. The overall result shows the better compensation and improved harmonic elimination.

SIMULATION RESULTS

The proposed technique space phasor-based hysteresis current control, shunt APF is modelled and by using the MATLAB and its Simulink toolbox it is simulated. Various types of simulation results are obtained by different parameters.

The essential parameters show in Table II selected for simulation studies are

TABLE II Simulation Parameter

Supply voltage	400 V
DC link voltage	650V
DC link capacitor	3000 μF
Load Inductor (L)	35mH
Load Resistor (R)	35 Ω
APF coupling capacitor	20 μF
APF coupling inductor	15mH
Hysteresis band (HB)	1.6 to 1.2

The three-phase source voltage is measured with respect to time shows in Fig. 10.

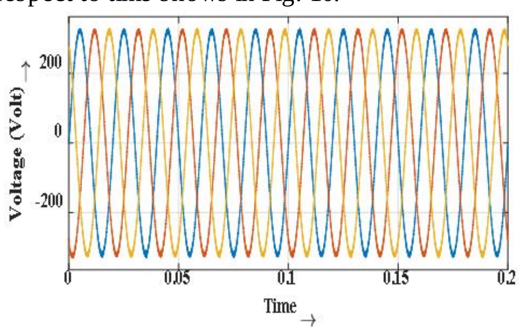

Fig. 10. Three phase source voltage

All the three-phase current is shown below Fig. 11 on the simulation result.

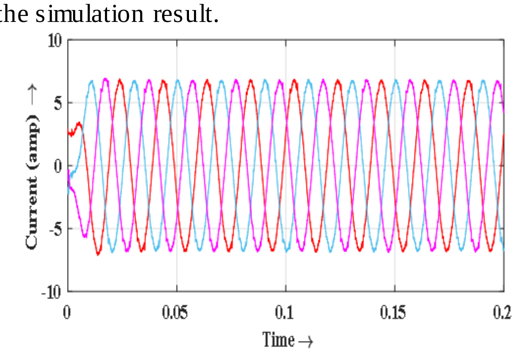

Fig. 11. Three phase source current

In hexagonal boundary current error moves in any random direction and it can also, be controlled. In a same controller state repeated switching in any three axes may occur, without going through the opposite state Fig. 12. To make it easier two hysteresis controller with a small hysteresis band is placed. At both end of axis level comparator is required. The vector selection is done by the current error, if current error hit anywhere in the region R1 in sector 1 then the opposite voltage vector will be selected and V_Z so according to that in every region of every sector the same theory will be applied.

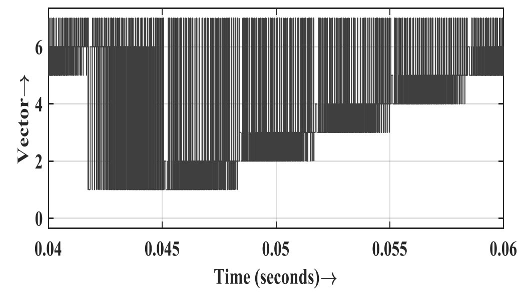

Fig. 12. Vector Selection

The regions can be identified by using the comparator block, three phase compensating current j_A, j_B & j_C can be determine by making the difference of the actual current and the feedback current through the comparator shows in Fig. 13.

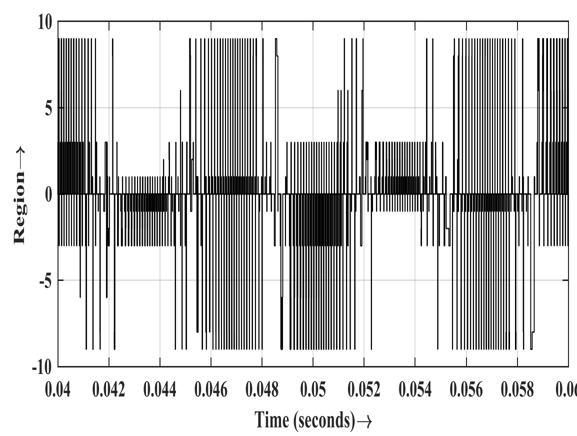

Fig. 13. Region Selection

The sector is identified by the method of comparing and sensing the instantaneous values of voltages of the three phases at PCC. According to the angles the sector is detected shows in Fig. 14

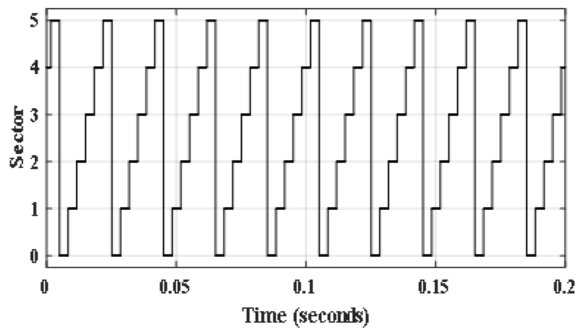

Fig. 14. Sector selection

After implementing the multi axis space phasor technique the THD of source current is shows in Fig. 15.

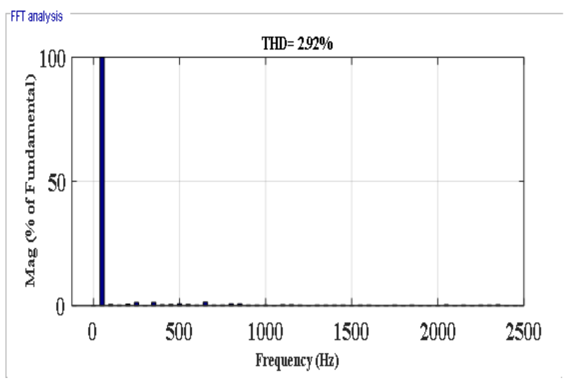

Fig. 15. FFT analysis of Source current

The current error by using space phasor-based technique is given below Fig. 16

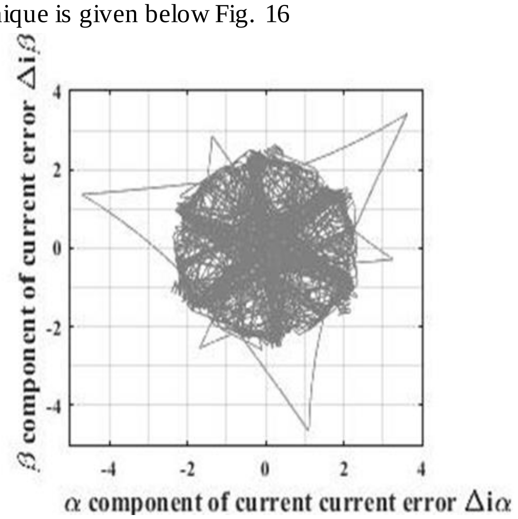

Fig. 16. Current error of Multi axis space phasor-based HCC

CONCLUSION

In this paper the space phasor-based current error hysteresis controller is presented with unique approach is applying in it. TMS320F28335 controller. DSP. TMS320F28335 has been used for generation of reference compensating current by implementing of IRP theory. By using the simple look up tables of inverting switching and the hysteresis comparators the current controller is achieved. As compared to conventional HCC the number of inverter switching is always less for its operation. All the advantages of the conventional current hysteresis controllers, as regards to simple implementation and quick response, are obtained in the proposed scheme. The current error result within the desired hexagonal boundary by applying the multi- axis current error space phasor-based hysteresis controller which is far better than the conventional hysteresis current control. Harmonics are compensated by APF with having a good THD and low harmonics.

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