International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 6 (2015) pp. 15109-15121

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Input Power Factor Compensation in Matrix Converter Fed Grid with PI Controller

[1*]D.Rajalakshmi, [2]Dr.K.Geetha and [3*]S.R.Venupriya

[1]Assistant Professor(SRG)
Department of Electrical & Electronics Engineering
Kumaraguru College of Technology, Coimbatore, India
rajalakshmi.d.eee@kct.ac.in
[2]Head of the Department
Department of Electrical & Electronics Engineering
Karpagam Institute of Technology, Coimbatore, India
geetha.arulmani@gmail.com
[3]PG Scholar
Department of Electrical & Electronics Engineering
Kumaraguru College of Technology, Coimbatore, India
venupriyaeee@gmail.com

Abstract

Power electronics equipments inject high voltage and current harmonics into the grid. Matrix converter is the newly invented topology to reduce the effect of harmonics and better input power factor compared to conventional converter. This paper mainly contributes the difference between the Matrix Converter fed grid without PI controller and with PI controller. The Matrix Converter is a single stage converter with nine bi-directional switches which converts fixed AC input into variable AC output without inter link DC capacitor. Matrix converter topology is controlled by using space vector modulation technique. Using this technique voltage transfer ratio is increased and harmonics are also reduced compared to other control techniques. In this paper the input power factor compensation is greatly achieved by the help of PI controller. Also overall load Total Harmonic Distortion is reduced by using PI controller. The proposed work is simulated using MATLAB/Simulink and the Simulation results are presented which shows the output load voltage and output load current THD of Matrix Converter fed grid without and with PI controller. Also input power factor is shown for matrix converter without and with PI controller.

Keywords— Matrix Converter; Space Vector Modulation;PI controller;Total Harmonic Distortion;Input Power Factor.

I. INTRODUCTION

Power electronic converters are used in various applications to get controlled output power. As the progress of power devices has increased rapidly, more attention is being focused on power conversion from AC to DC, from DC to AC, from DC to DC and direct conversion of fixed AC to variable AC for various applications. For this direct conversion of AC to AC many converter topologies were used and they are commonly divided into two categories such as direct conversion topology and indirect conversion topology [1]-[3]. Some of the converters which belong to conversion of AC to AC are AC voltage controllers, Cycloconverters, conventional back-to-back converters and Matrix converters. This type of AC to AC conversion is widely used in adjustable speed drives because 80% of speed drives are AC drives.

Matrix converter (MC) is a new type of converter which gives output with variable frequency and variable voltage. They are of two types called as indirect matrix converter and direct matrix converters. The indirect converter is a two stage converter which converters AC to DC and DC to AC with virtual DC link capacitor. The direct matrix converter is a single stage converter which is similar to forced commutated converter with nine bi-directional fully controllable switches connected in matrix (m*n)or array form. In MC at any time each output line is linked with each input line through bi-directional switches. The MCs have the following advantages comparing with other converter topologies such as [4]-[11]

- Four quadrant operation
- Output voltage, input current is controllable at any time
- Unity displacement factor and better power factor
- Input current is nearer to sine wave
- Power regeneration
- Longer operating life
- Suppression of power harmonics.

II. MATRIX CONVERTER

The matrix converter (MC) is a forced commutated converter that feeds an output load with sinusoidal voltages of arbitrary frequency from the three-phase mains, using fully controlled bidirectional switches. The circuit for matrix converter is shown in Fig.1. This converter does not need a dc link nor does it require large energy storage elements, making it suitable for applications that need a reduced power converter volume and a high power density. It provides controllable input power factor, power flow in both direction, sinusoidal input/output waveforms. For the above reasons matrix converters have received considerable attention and they may become a good alternative to back-to-back converters. As the dc-link capacitor is absent the matrix converter allows a compact design.

The Matrix converter having several control techniques such as[12]

- Direct transfer function approach (Venturini method)
- Scalar method
- PWM method

- Carrier based
- Space vector modulation(SVM)

A. ***Control and modulation method***

The main drawback of Venturini method is it gives voltage transfer ratio only of 0.5. The space vector modulation is a well-known and commonly used modulation method due to its high performance, relative simple operation also it is a simpler method to control input power factor. It allows independent control of input current and output voltage at the same time. Voltage transfer ratio is increased upto 0.866 without adding third harmonic by this SVM method compared with Venturini method[14]-[15].

With nine bi-directional switches the matrix converter can theoretically assume 512(2^9) different switching combinations. Though 512 switching combinations are there, not all of them can be employed. The choice of the matrix converter switching combinations to be used must comply with two basic rules irrespective of the control method used. Taking into account that,

1) The converter supplied by a voltage source usually feeds an inductive load and the input phases should not be short-circuited.
2) The output phases should not be interrupted.

From a practical point of view these rules imply that one and only one bi-directional switch per output phase must be switched on at any instant. By this constrain, in a three phase to three phase matrix converter only 27 switching combinations(SCs) are permitted. These SCs are split into three groups such as[10]

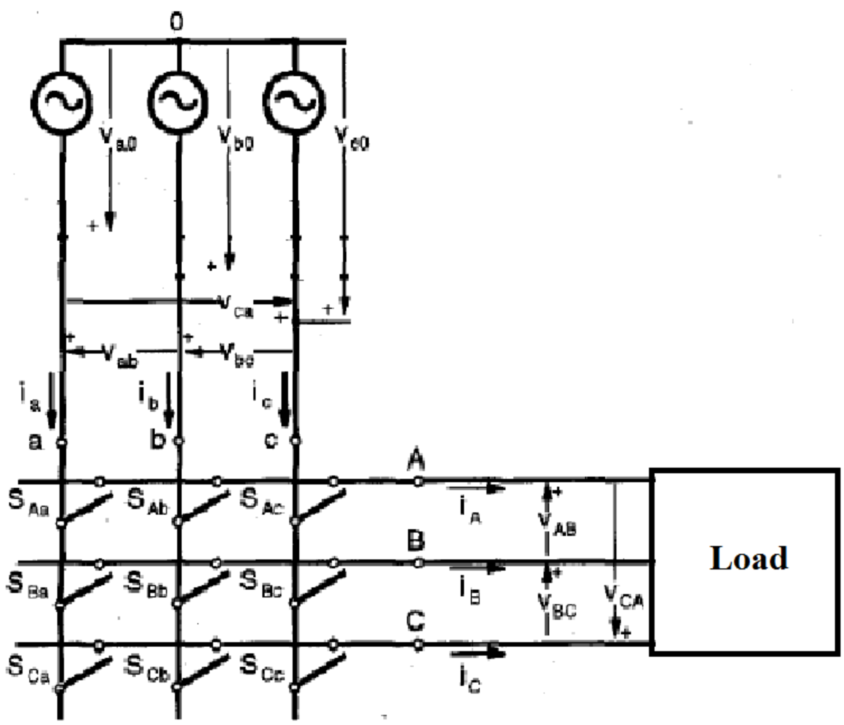

Fig.1. Matrix Converter

Group 1: Each output phase is directly connected to individual input phases in turns it having six switching combinations.

In this case output voltage and output current vector phase angles are depends on the input voltage and input current vector phase angles respectively. In space vector modulation technique, these six SCs are not used because both vector phase angles cannot be controlled independently.

Group 2: Two input phases are connected to any one output phase in turns it having 18 SCs. These 18 SCs with group 3 are used for space vector modulation technique. At variable frequency and amplitude active vectors are formed. Input line voltage decides the amplitude of output voltage.

Contrast to previous case here the output voltage and current vector phase angles does not depends on the input voltage and current vector phase angles.

Group 3: It having three SCs and all of the three output phases are connected to one input phase. These SCs are called as zero vectors which are used to complete one full cycle.

In Table.1. 27 different switching combinations of MC are shown. For space vector modulation group 2 and group 3 SCs are used. The table also shows which input and output phases are mutually connected for each allowed switching combinations, as well as the resulting output line(phase-to-phase) voltages and input phase currents.

TABLE I. **MATRIX CONVERTER SWITCHING COMBINATIONS**

Group	#	Name	A	B	C	v_{AB}	v_{BC}	v_{CA}	i_a	i_b	i_c	V_o	α_o	I_i	β_i
	1	-	a	b	c	v_{ab}	v_{bc}	v_{ca}	i_A	i_B	i_C	v_i	α_i	i_o	β_o
	2	-	a	c	b	$-v_{ca}$	$-v_{bc}$	$-v_{ab}$	i_A	i_C	i_B	$-v_i$	$-\alpha_i+4\pi/3$	i_o	$-\beta_o$
I	3	-	b	a	c	$-v_{ab}$	$-v_{ca}$	$-v_{bc}$	i_B	i_A	i_C	$-v_i$	$-\alpha_i$	i_o	$-\beta_o+2\pi/3$
	4	-	b	c	a	v_{bc}	v_{ca}	v_{ab}	i_C	i_A	i_B	v_i	$\alpha_i+4\pi/3$	i_o	$\beta_o+2\pi/3$
	5	-	c	a	b	v_{ca}	v_{ab}	v_{bc}	i_B	i_C	i_A	v_i	$\alpha_i+2\pi/3$	i_o	$\beta_o+4\pi/3$
	6	-	c	b	a	$-v_{bc}$	$-v_{ab}$	$-v_{ca}$	i_C	i_B	i_A	$-v_i$	$-\alpha_i+2\pi/3$	i_o	$-\beta_o+4\pi/3$
	7	+1	a	b	b	v_{ab}	0	$-v_{ab}$	i_A	$-i_A$	0	$2/\sqrt{3}\ v_{ab}$	$\pi/6$	$2/\sqrt{3}\ i_A$	$-\pi/6$
	8	−1	b	a	a	$-v_{ab}$	0	v_{ab}	$-i_A$	i_A	0	$-2/\sqrt{3}\ v_{ab}$	$\pi/6$	$-2/\sqrt{3}\ i_A$	$-\pi/6$
IIa	9	+2	b	c	c	v_{bc}	0	$-v_{bc}$	0	i_A	$-i_A$	$2/\sqrt{3}\ v_{bc}$	$\pi/6$	$2/\sqrt{3}\ i_A$	$\pi/2$
	10	−2	c	b	b	$-v_{bc}$	0	v_{bc}	0	$-i_A$	i_A	$-2/\sqrt{3}\ v_{bc}$	$\pi/6$	$-2/\sqrt{3}\ i_A$	$\pi/2$
	11	+3	c	a	a	v_{ca}	0	$-v_{ca}$	$-i_A$	0	i_A	$2/\sqrt{3}\ v_{ca}$	$\pi/6$	$2/\sqrt{3}\ i_A$	$7\pi/6$
	12	−3	a	c	c	$-v_{ca}$	0	v_{ca}	i_A	0	$-i_A$	$-2/\sqrt{3}\ v_{ca}$	$\pi/6$	$-2/\sqrt{3}\ i_A$	$7\pi/6$
	13	+4	b	a	b	$-v_{ab}$	v_{ab}	0	i_B	$-i_B$	0	$2/\sqrt{3}\ v_{ab}$	$5\pi/6$	$2/\sqrt{3}\ i_B$	$-\pi/6$
	14	−4	a	b	a	v_{ab}	$-v_{ab}$	0	$-i_B$	i_B	0	$-2/\sqrt{3}\ v_{ab}$	$5\pi/6$	$-2/\sqrt{3}\ i_B$	$-\pi/6$
IIb	15	+5	c	b	c	$-v_{bc}$	v_{bc}	0	0	i_B	$-i_B$	$2/\sqrt{3}\ v_{bc}$	$5\pi/6$	$2/\sqrt{3}\ i_B$	$\pi/2$
	16	−5	b	c	b	v_{bc}	$-v_{bc}$	0	0	$-i_B$	i_B	$-2/\sqrt{3}\ v_{bc}$	$5\pi/6$	$-2/\sqrt{3}\ i_B$	$\pi/2$
	17	+6	a	c	a	$-v_{ca}$	v_{ca}	0	$-i_B$	0	i_B	$2/\sqrt{3}\ v_{ca}$	$5\pi/6$	$2/\sqrt{3}\ i_B$	$7\pi/6$
	18	−6	c	a	c	v_{ca}	$-v_{ca}$	0	i_B	0	$-i_B$	$-2/\sqrt{3}\ v_{ca}$	$5\pi/6$	$-2/\sqrt{3}\ i_B$	$7\pi/6$
	19	+7	b	b	a	0	$-v_{ab}$	v_{ab}	i_C	$-i_C$	0	$2/\sqrt{3}\ v_{ab}$	$3\pi/2$	$2/\sqrt{3}\ i_C$	$-\pi/6$
	20	−7	a	a	b	0	v_{ab}	$-v_{ab}$	$-i_C$	i_C	0	$-2/\sqrt{3}\ v_{ab}$	$3\pi/2$	$-2/\sqrt{3}\ i_C$	$-\pi/6$
IIc	21	+8	c	c	b	0	$-v_{bc}$	v_{bc}	0	i_C	$-i_C$	$2/\sqrt{3}\ v_{bc}$	$3\pi/2$	$2/\sqrt{3}\ i_C$	$\pi/2$
	22	−8	b	b	c	0	v_{bc}	$-v_{bc}$	0	$-i_C$	i_C	$-2/\sqrt{3}\ v_{bc}$	$3\pi/2$	$-2/\sqrt{3}\ i_C$	$\pi/2$
	23	+9	a	a	c	0	$-v_{ca}$	v_{ca}	$-i_C$	0	i_C	$2/\sqrt{3}\ v_{ca}$	$3\pi/2$	$2/\sqrt{3}\ i_C$	$7\pi/6$
	24	−9	c	c	a	0	v_{ca}	$-v_{ca}$	i_C	0	$-i_C$	$-2/\sqrt{3}\ v_{ca}$	$3\pi/2$	$-2/\sqrt{3}\ i_C$	$7\pi/6$
	25	0	a	a	a	0	0	0	0	0	0	0	-	0	-
III	26	0	b	b	b	0	0	0	0	0	0	0	-	0	-
	27	0	c	c	c	0	0	0	0	0	0	0	-	0	-

For each of the SCs given in the Table.1[12] the input line and output line voltages can be written in the terms of space vector as,

$$\bar{v}_i = 2/3(v_{ab}+v_{bc}e^{j2\Pi/3}+v_{ca}e^{j4\,\Pi/3}) = V_i e^{j\propto_i} \quad (1)$$

$$\bar{v}_o=2/3(v_{AB}+v_{BC}e^{j2\Pi/3}+v_{CA}e^{j4\,\Pi/3})= V_o e^{j\alpha_o} \quad (2)$$

In the same manner, the input line and output line currents cam be written as,

$$\bar{i}_i = 2/3(i_a+i_b e^{j2\Pi/3}+i_c e^{j4\,\Pi/3}) = I_i e^{j\propto_i} \quad (3)$$

$$\bar{I}_o = 2/3(i_A+i_B e^{j2\Pi/3}+i_C e^{j4\,\Pi/3}) = I_o\, e^{j\beta_o} \quad (4)$$

B. ***Space vector control strategy***

The SVM strategy, based on space vector representation becomes very popular due to its simplicity. In contrast to sinusoidal PWM, SVM treats the three phase quantities as a single equation(1) known as space vector. where Va, Vb and Vc are the phase voltages. If Va, Vb and Vc are balanced three phase sinusoidal voltage, then the locus of space vector is circular with a radius equals the amplitude of the phase voltage. The concept of space vector is derived from the rotating field of ac machine which is used for modulating the converter output voltage. Three phase quantities can be transformed to their equivalent two phase quantity either in synchronously rotating frame (or) stationary d-q frame in this modulation method. The reference vector magnitude can be found from the above two phase component and used for modulating the converter output. SVM treats the sinusoidal voltage as a constant amplitude vector rotating at constant frequency. This technique approximates the reference voltage Vref by a combination of the eight switching patterns (V_0 to V_7). The representation of rotating vector with six active vectors and with two zero vectors are shown in complex plane in Fig.3.

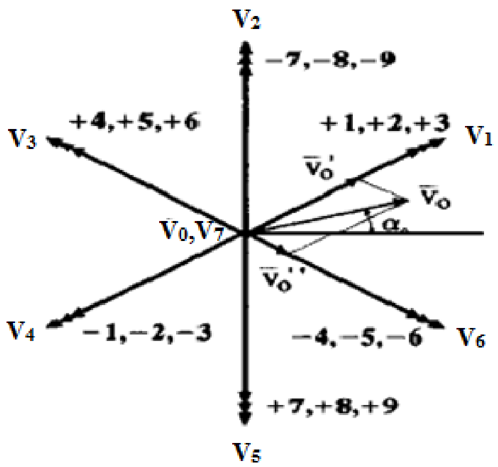

Fig.2. Output voltage space vector

The control strategy is to generate the desired output voltage vector with the constraint of unity input power factor. For this purpose, let v_o, be the desired output line voltage space vector and v_i, the input line voltage space vector at a given time instant(Figs.3). For example, if the reference voltage is located in sector 1, voltage vectors V_1, V_2, V_0 and V_7 would be selected and applied within a sampling period.

III. CONVERTER WITHOUT AND WITH CONTROLLER

The matrix converter without PI controller has less input power factor and high amount of THD. PI controller is introduced in this proposed work to improve the input power factor and to reduce THD in output load voltage and output load current.

A. Matrix converter without PI controller

In normal the input power factor of the matrix converter is low and also it has high amount of THD in output voltage and output current. The general circuit of the matrix converter contains three phase input supply with phase voltage of 100V.

The MC consist of nine bi-directional switches in which each switch is comprises of two IGBTs connected in anti-parallel. It allows forward voltage and blocks the reverse voltage. The voltage and current rating of IGBT is 250V and 100A respectively. The output of MC is connected to grid i.e at point of common coupling.

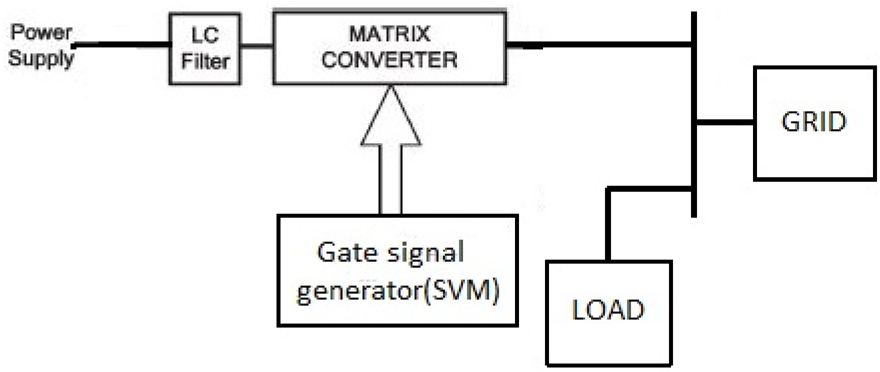

Fig 3. Matrix converter without PI controller

The grid is composed of programmable voltage source of 100V phase-phase voltage with source inductance. Output of the matrix converter is also supplied to the R-L load. The input filter is used to get reduce amount of THD in the input current.

B. Matrix convert with PIcontroller

Fig 4. shows the matrix converter with PI controller. To improve the input side power factor, PI controller is used. Ψi is the displacement angle between the input voltage and input current which is compared with the Ψref to produce the error signal. That error signal is used as the input to the PI controller, the better input power factor is obtained by using suitable values of K_p and K_i values[13]-[15].

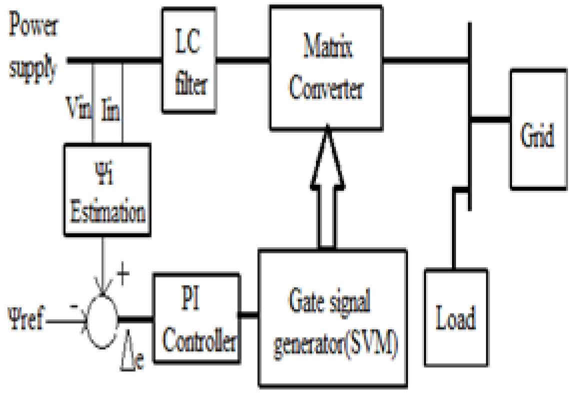

Fig 4. Matrix converter with PI controller

PI controller is noted by

$$\delta comp = (K_p + \frac{K_i}{S})\Delta e$$

Where
Δe is the error signal
K_p= proportional gain
K_i = integral gain

The value of compensated angle $\delta comp$ is maintained between the values 0 and δmax. The calculated compensated angle is inserted as a displacement angle between input current and voltage. The values of K_p and K_i values are selected in a correct manner in order to avoid overshoot and to get stable performance[15]-[16].

IV. SIMULATION RESULTS

Simulation has been performed and comparison of input power factor and THD for matrix converter without and with PI controller is given in Fig.5-Fig.9. The load parameters are taken as 5Ω and 5mH. The switches are controlled by using space vector control algorithm. The input is three- phase supply which has line voltage and frequency of 100V and 60Hz respectively.

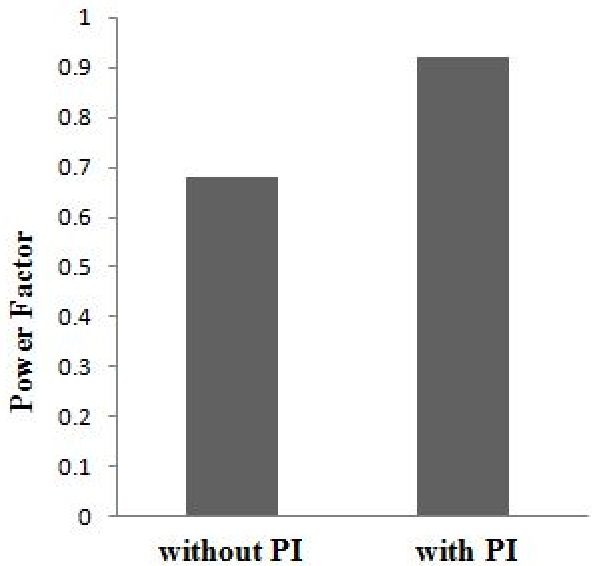

Fig.5 Power factor comparison

A. Results without PI controller

Fig.6-Fig.7 are gives the overall THD values of the output current and output voltage of matrix converter without PI controller.

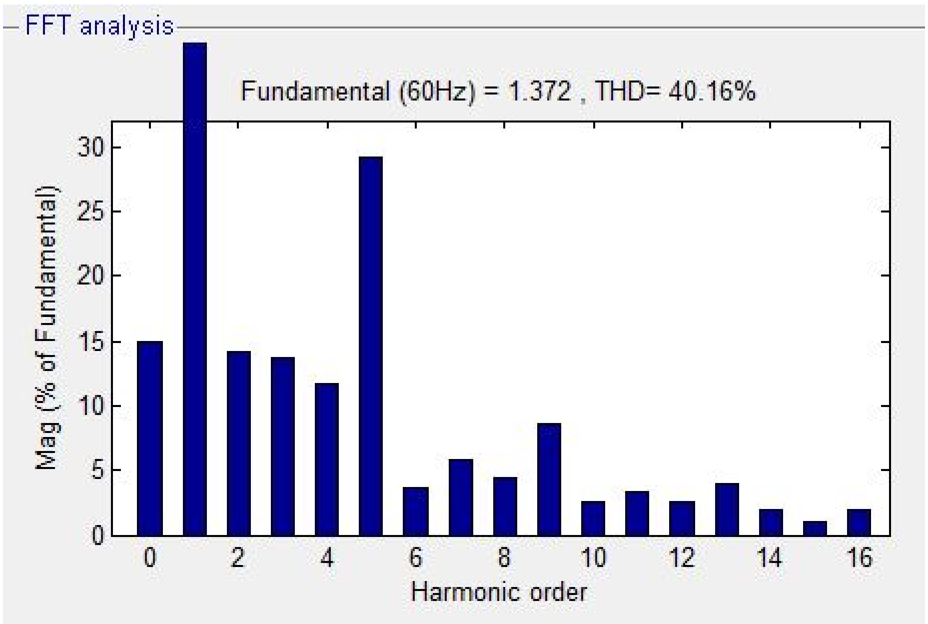

Fig.6 THD for output current without PI controller

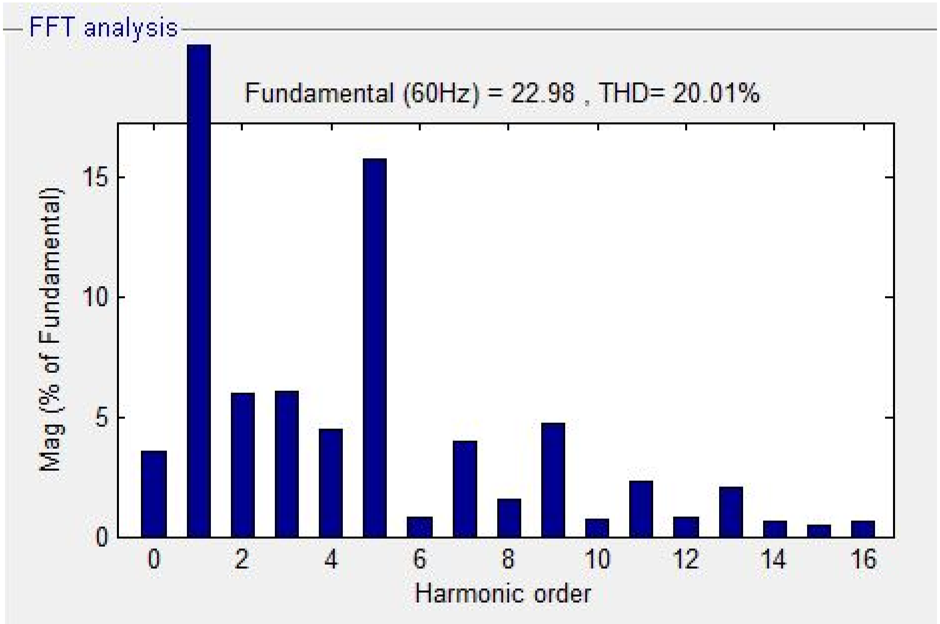

Fig.7 THD for output voltage without PI controller

B. Results with PI controller

Fig.8-Fig.9 gives the THD values of output current and output voltage with PI controller.

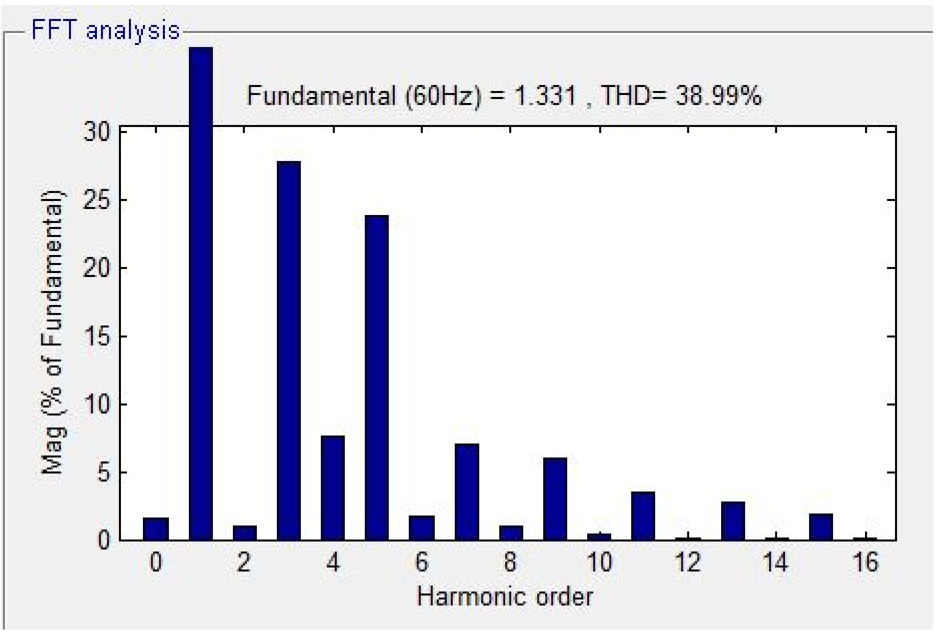

Fig.8 THD for output current with PI controller

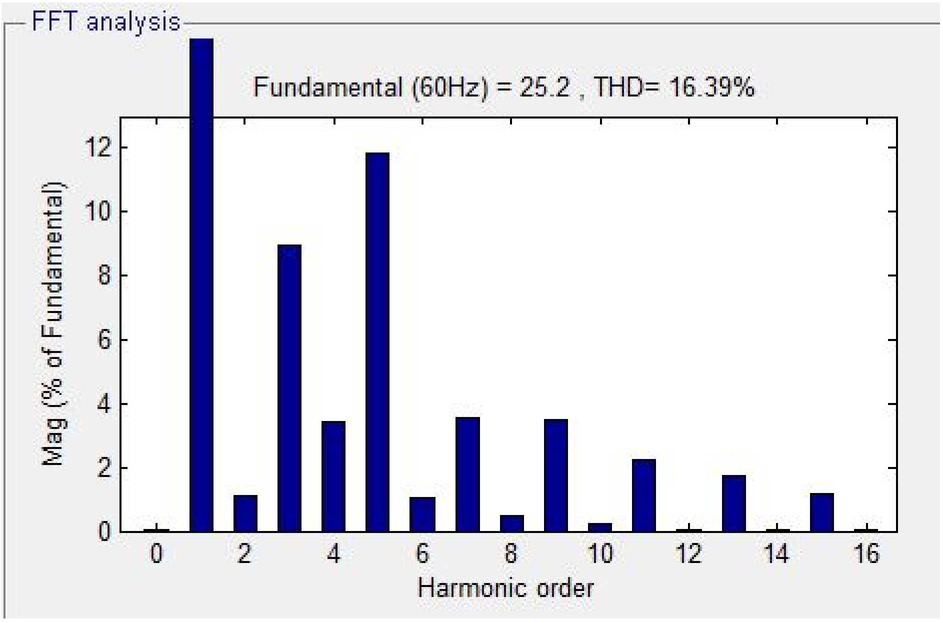

Fig.9 THD for output voltage with PI controller

Fig .10-Fig.11 shows the comparison of THD values of the output current and the output voltage without and with PI controller respectively.

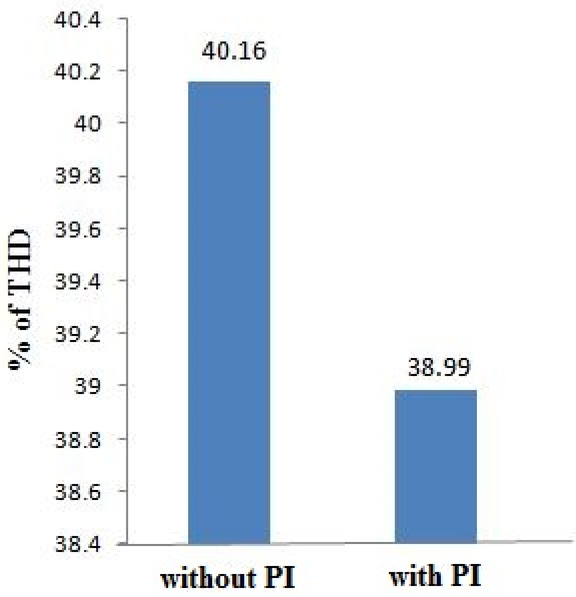

Fig.10 Overall THD comparison of output current

From the Fig.10 the matrix converter fed grid without and with PI controller gives overall THD values of output load current for converter , it is seen that the converter with PI controller having low value of THD than converter without PI controller.

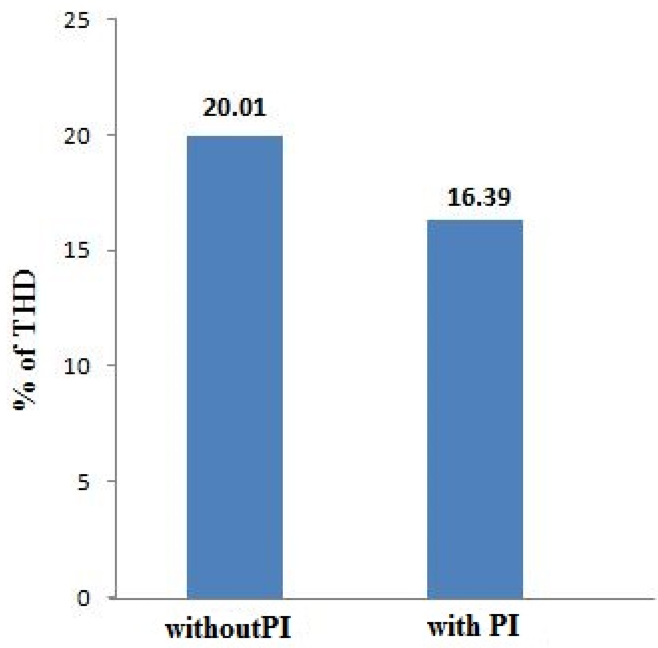

Fig.11 Overall THD comparison of output voltage

Fig.11 shows the comparison of overall output load voltage THD of converter without and with PI controller. It is seen that the converter with controller having reduced THD than converter without PI controller.

TABLE II. **COMPARISON OF POWER FACTOR WITHOUT AND WITH PI CONTROLLER**

Matrix Converter	**Input Power Factor**
Without PI controller	0.680
With PI controller	0.921

Table.II shows the comparison of input power factor of both matrix converter fed grid without and with PI controller. Finally it gives matrix converter with high input power factor by introducing displacement angle between voltage and current in with the help of PI controller.

TABLE III. **COMPARISON OF THD WITHOUT AND WITH PI CONTROLLER**

Converter	**THD (%)**	V_5	V_7	V_{11}	V_{13}	V_{17}
Without PI controller	20.01	15.75	3.98	2.31	2.05	1.10
With PI controller	16.39	11.81	3.54	2.21	1.72	0.79

Table III shows the comparison of lower order harmonics and over all THD value of the matrix converter without and with PI controller. The matrix converter fed grid with PI controller has reduced THD and less amount of selective harmonic contents compared to matrix converter fed grid without PI controller.

V. CONCLUSION

In this study, simulation and comparison of three phase MC employing space vector modulation technique fed grid without and with PI controller have been obtained using MATLAB/Simulink. From the comparison it is clearly seen that the input side power factor is improved from 0.68 to 0.921 with the help of PI controller. In addition the THD of output load voltage and output load current of the matrix converter with PI controller is reduced than matrix converter without PI controller. The Matrix Converter is capable of operating at high power factor using proposed method. Due to Four quadrant operations and absence of bulk DC link capacitors ,matrix converter is a better choice for conversion of fixed AC voltage to variable AC variable with high input power factor and low THD.

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