High Voltage Transformation Ratio using Matrix converter

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Abstract— **In this paper, two similar Fuzzy Logic Controllers are developed for ac/ac matrix converters. Furthermore, total harmonic distortion (THD) is reduced significantly. Output voltage approaches the input voltage with reduced loss. A Matlab / Simulink simulation analysis of the Matrix Converter system is provided. The design and implementation of fuzzy controlled Matrix Converter is described. This AC-AC system is proposed as an effective replacement for the conventional AC-DC-AC system which employs a two-step power conversion with high voltage transformation ratio.**

Key words: fuzzy logic controllers, Matrix converter (MC), Total Harmonic Distortion (THD), High voltage transformation ratio.

I. INTRODUCTION

Total Harmonic Distortion (THD) is the most common power quality index to describe the quality of power electronic converter. In general, all the output voltage of power electronic converters is not purely sinusoidal. The THD of the output voltage can be defined as:

$$\text{THD}=\frac{\sqrt{V_2^2+V_3^2+V_4^2+------+V_n^2}}{V_1} \qquad (1)$$

Where n denotes the harmonic order and 1 is the fundamental quantity. For inverter application, THD represents how close the ac output waveform with pure sinusoidal waveform. A High quality matrix converter system should have low THD [1]. Various study has been made on harmonic losses at electrical machine, it reveals that, presence of harmonic current in winding causes an increased copper loss. The stator copper loss on a non sinusoidal supply is proportional to the square of the total rms current. The core loss in the machine is increased by the presence of harmonics in the supply voltage and current [2], [3]. By using harmonic reduction technique we can reduce transformer overheating, motor failure, fuse blowing, capacitors failures and mal functioning of power systems components. Harmonic currents are generated by the operation of nonlinear loads and equipment on power system. The third harmonic injection scheme for the three phase diode rectifier for reducing the harmonic currents has drawn some promising results. A space vector based PWM strategy that closely approximates in the switching angles of the selective harmonic elimination PWM strategy. In many AC drive applications, it is desirable to use a compact voltage source converter to provide sinusoidal output voltages with varying amplitude and frequency. While drawing sinusoidal input currents with unity power factor from the ac source, and having high power density and efficiency. In order to get pure sinusoidal wave either we have to design a filter or converter with different control techniques. Filter design for high rated machine includes weight and size of the total systems. It may affect the power processing capabilities. In order to overcome above problems, matrix converter is a good approach for power electronic engineers. In recent years, matrix converter has become increasingly attractive for these applications because they fulfill all the requirements, having the potential to replace the conventionally used rectifier - dc-link – inverter structures. Matrix converter is a single stage

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converter and they need no energy storage components except small input ac filters for elimination of switching ripples. However, a practical industrial application is still limited and the modulation method for the matrix converter is also understood to limited engineering people because of the high level of complexity and limited materials to explain its operating principle easily [4], [5]. Meanwhile, the standard voltage source inverter (VSI) and its relevant space vector modulation (SVM) are well known to many engineering people due to the opposite reasons.

Therefore, it would be a good approach to explain the operating principle of the matrix converter by adopting standard VSI topology and SVM concept. The first modulator was proposed by Venturini and he used a complicated scalar model that gave a maximum voltage transfer ratio of 0.5. An injection of a third harmonic of the input and output voltage was proposed in order to fit the reference output voltage in the input voltage system envelope, and the voltage transfer ratio reached the maximum value of 0.86 [6], [7]. In spite of several advantages of the matrix converter, industrial application of matrix converter is still very limited because of some practical issues like common mode voltage effects, high susceptibility to input power disturbances and low voltage transfer ratio.

In order to extend the horizon of matrix converter into several distributed power sources application, the objective of this research work is to propose new controller for matrix converter. The first objective of this research is to propose a PWM strategy to reduce THD, which is reported to R, RL and Motor load [12]. The THD is investigated in the matrix converter fed ASD. Matrix converter controller is modified with the addition of a fuzzy controller and thereby a new fuzzy controller is proposed together with Space Vector PWM strategy. These results are compared with various operating frequencies.

II. MATRIX CONVERTER

The ac/ac converters are commonly classified into indirect converter which utilizes a dc link between the two ac systems and direct converter that provides direct conversion. Indirect converter consists of two converter stages and energy storage element, which convert input ac to dc and then reconverting dc back to output ac with variable amplitude and frequency [9]. The operation of these converter stages is decoupled on an instantaneous basis by means of energy storage element and controlled independently, so long as the average energy flow is equal.

Therefore, the instantaneous power flow does not have to equal the instantaneous power output. The difference between the instantaneous input and output power must be absorbed or delivered by an energy storage element within the converter [10]. The energy storage element can be either a capacitor or an inductor. However, the energy storage element is not needed in direct converter. In General, direct converter can be identified as three distinct topological approaches.

The first and simplest topology can be used to change the amplitude of an ac waveform. It is known as an ac controller and functions by simply chopping symmetric notches out of the input waveform. The second can be utilized if the output frequency is much lower than the input source frequency [11]. This topology is called a cycloconverter, and it approximates the desired output waveform by synthesizing it from pieces of the input waveform [8]. The last is matrix converter and it is most versatile without any limits on the output frequency and amplitude. It replaces the multiple conversion stages and the intermediate energy storage element by a single power conversion stage, and uses a matrix of semiconductor bidirectional switches, with a switch connected between each input terminal to each output terminal as shown in Figure 1.

With this general arrangement of switches, the power flow through the converter can reverse. Because of the absence of any energy storage element, the instantaneous power input must be equal to the power output, assuming idealized zero-loss switches. However, the reactive power input does not have to equal the reactive power output.

It can be said again that the phase angle between the voltages and currents at the input can be controlled and does not have to be the same as at the output. Also, the form and the frequency at the two sides are independent, in other words, the input may be three-phase ac and the output dc, or both may be dc, or both may be ac. Therefore, the matrix converter topology is promising for universal power conversion such as: ac to dc, dc to ac, dc to dc or ac to ac.

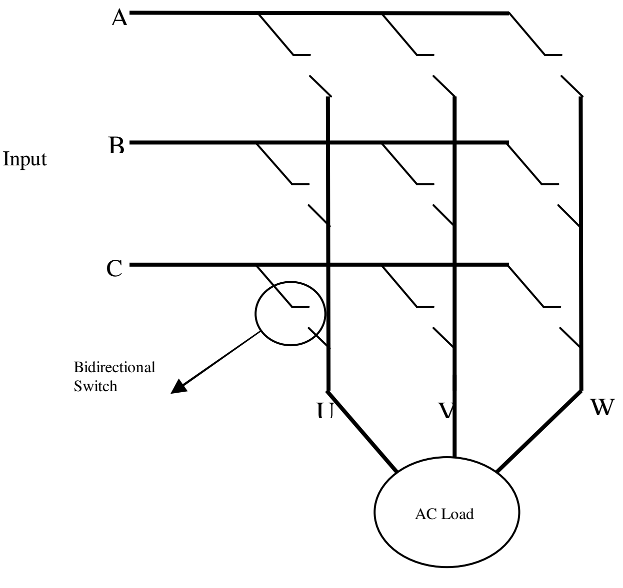

Fig.1. Matrix converter

III. CONTROL PRINCIPLE

A sinusoidal ac voltage source having an amplitude V_1 and angular frequency w_1 ($2\Pi f_1$) is connected to the input terminal of matrix converter. This is applied sinusoidal voltage is converted into an output voltage with amplitude of V_0 and angular frequency w_0 ($2\Pi f_0$), which is applied to the load. Upper limit of the range of variation of the output frequency lies at a point lower than the input frequency.

$$V_{ABC}=K_i e^{j(w_i t+\Phi_i)} \tag{2}$$

$$V_{UVW}=K_0 e^{j(w_0 t+\Phi_0)} \tag{3}$$

Control principle(S (t))

$$S(t)=\frac{K_0 e^{j(w_0 t+\phi_0)}}{K_i e^{j(w_i t+\phi_i)}} \tag{4}$$

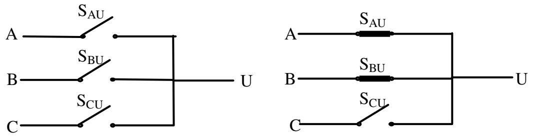

Fig. 2. Switching constrains, short circuit between input phases and open circuit between output phases

Maximum voltage transfer ratio 50% is possible in Venturini Algorithm. An improvement in the achievable voltage ratio to $\frac{\sqrt{3}}{2}$ (for 87%) is possible by adding common mode voltage to the target output. We can investigate these voltage transformation ratio based on following theoretical analysis. There are different modulation techniques available from Venturini invention (1980). Implementation of ventrini algorithm is difficult calculation. We are looking forward towards simple algorithm and improved voltage transformation ratio. Following switching equations will explain about output voltage relationship and review of switching techniques.

A. Venturini modulation method (Venturini first method)

$$m_{kj}=\frac{t_{kj}}{T_{sep}}=\frac{1}{3}[1+\frac{2v_k v_j}{v^2_{im}}], \tag{5}$$

for k=A, B, C and j=a, b, c

Voltage transformation ratio is 50%.From equation (5) second term q=1/2.

Venturini Optimum method (Venturini Second method)

Employs common mode addition and maximum transformation ratio is 87%. This is also known as displacement factor control. Displacement factor control can be introduced by inserting a phase shift between the measure input voltages and inserted voltage (v_k).

$$m_{kj}=\frac{t_{kj}}{T_{sep}}=\frac{1}{3}[1+\frac{2v_k v_j}{v^2_{im}}+\frac{4q}{3\sqrt{3}}\sin(\omega_i t+\beta_k)\sin(3\omega_i t)], \tag{6}$$

For k=A, B, C and j=a, b, c

$\beta_k=0, 2\Pi/3$ for k=A, B, C

B. Scalar Modulation method:

Actuation signals are calculated directly from measurement of input voltages. Voltage transformation ratio is 87%.

$$m_{kj}=\frac{t_{kj}}{T_{sep}}=\frac{1}{3}[1+\frac{2v_k v_j}{v^2_{im}}+\frac{2}{3}\sin(\omega_i t+\beta_k)\sin(3\omega_i t)] \tag{7}$$

This method yields virtually identical switch timings to the optimum Venturini method. The maximum output voltage (q=$\frac{\sqrt{3}}{2}$) are identical.

Only the difference between the methods is that the right most term addition is taken pro rata with q in the Venturini method.

C. SPVM

Space vector pulse width modulation is applied to output voltage and input current control. This method is advantage because of increased flexibility in choice of switching vector for both input current and output voltage control can yield useful advantage under unbalanced conditions.

D. Indirect Modulation method

$$v_o = (Av_i)B = \frac{3K_A K_B V_{im}}{2}\begin{bmatrix}\cos(\omega_i t)\\ \cos(\omega_i t + 2\pi/3)\ ]\\ \cos(\omega_i t + 45\pi/3)\end{bmatrix} \qquad (8)$$

This method aims to increase the maximum voltage ratio above 86.6%limit of other methods.

Voltage ratio q=3K_A K_B /2.Clearly A and B modulation steps are not continuous in time as shown above.

K_A = 2sqrt (3) V_{im}/Π (9)
K_B = 2/Π (10)
Then, q = 6sqrt (3)/$Π^2$=105.3% (11)

The voltage output is greater than the previous method. For the values q>0.866, the mean output voltage no longer equals the target output voltage in each switching interval. This inevitably leads to low frequency distortion in the output voltage and /or the input current compared to other methods with q<0.866.For q<0.866, the indirect method yields very similar results to the direct methods.

IV. CROSS COUPLED FUZZY CONTROLLER

Most widely used method of testing a fuzzy controller design is by simulation. In this research work Fuzzy Logic Toolbox in MATLAB Simulink is used to solve the problem. This toolbox can simulate in various states such as transient state response and steady state error, corresponding to each control goal. Different combination of input can easily be tested to observe the corresponding output. Figure 4 shows the flow of the typical design procedure used to develop a fuzzy structure.

The simulation and testing are conducted several times until a satisfactory result is accomplished. The results are refined by parameter tunings that are based on intuitive experiences and the qualitative results obtained from time to time. Each universe of discourse for two inputs and an output is divided into seven fuzzy subsets that consists of negative logic(nl),negative medium(nm),negative small(ns), zero(z),positive small(ps),positive medium(pm)and positive large(pl). The membership function chosen are the classical triangular shape of 50% overlap. The portion of fuzzy subsets and shapes of Membership functions are shown in figure 5, figure 6, figure 7 figure 8.

Rule base is derived based on the characteristics of the RMS value of the output signal that is similar to the response for a second order system by applying step input. If RMS value of the load voltage is less than the RMS value of the reference voltage at point, then error signal is positive consequently, the control action has to be increased, thus giving positive 'ce' to enable the load voltage to reach the set point. The combinations of inputs and control action are summarized in table1.The inference method of Mamdani is max-min composition is chosen in the work to simplify the programming algorithm.

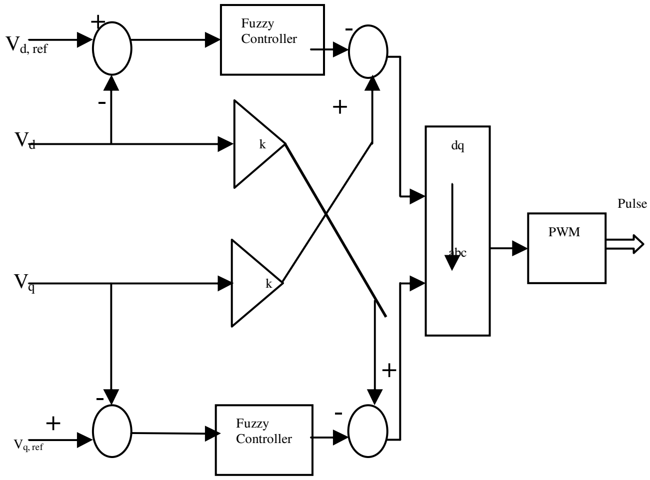

Fig.3. Cross Coupled Fuzzy Structure

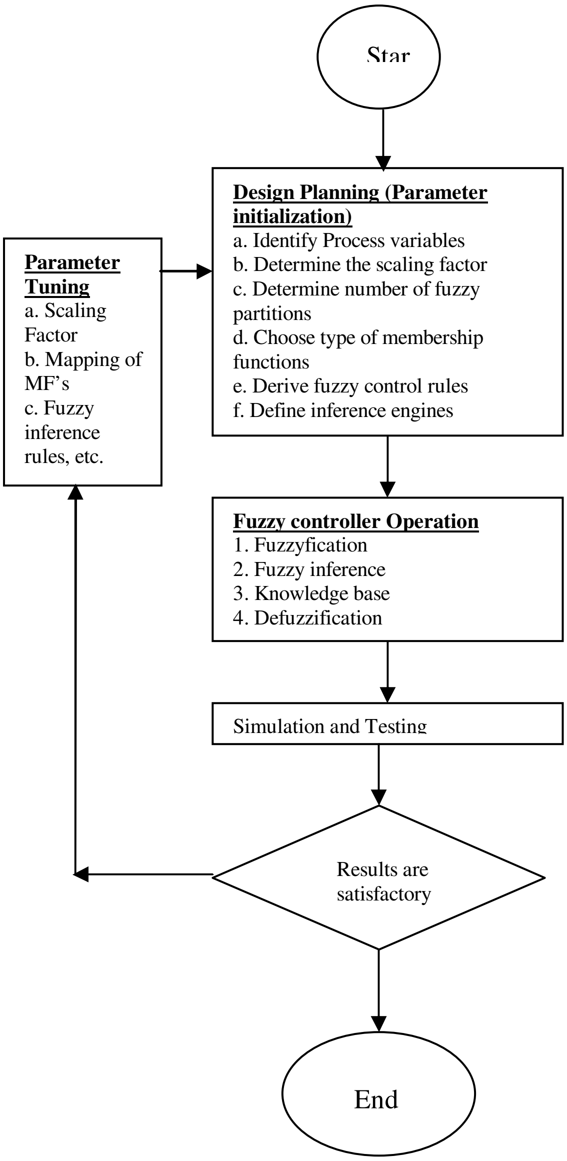

Fig.4. Fuzzy Controller design Algorithm

Fuzzy logic controller algorithm is developed based on following flowchart which is shown in figure 4. Above flowchart is common to all fuzzy controller algorithms. After several trials has been made to select membership function. And finally it is decided to select triangular membership function.

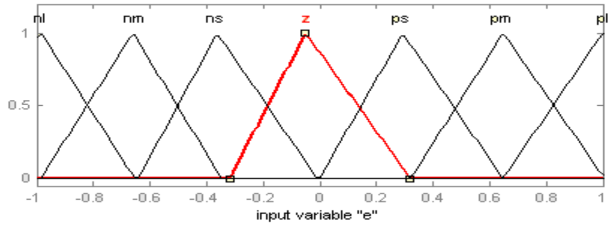

Fig.5.Input membership function

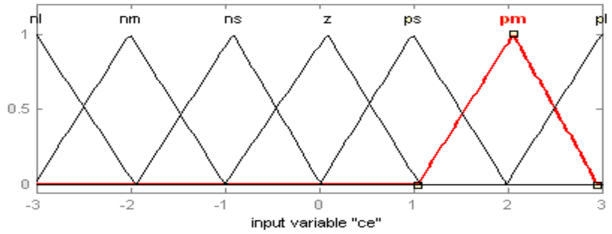

Fig.6.Input ce membership function

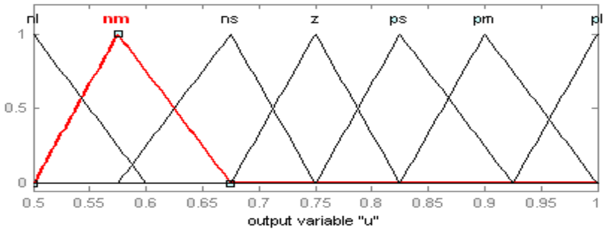

Fig.7. Output variable membership function

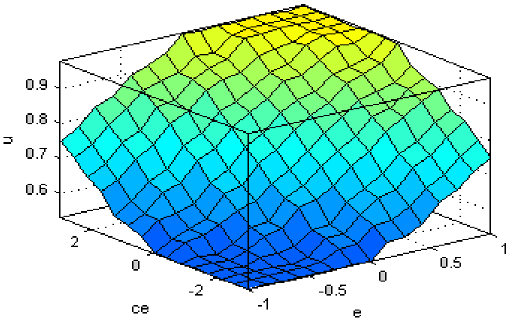

Fig.8. Correlation between membership functions

TABLE 1
RULE BASE FOR FUZZY CONTROLLER

		Change in error(ce)						
		NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
E R R O R (e)	**NB**	NB	NB	NM	NM	NS	NS	ZE
	NM	NB	NM	NM	NS	NS	ZE	PS
	NS	NM	NM	NS	NS	ZE	PS	PS
	ZE	NM	NS	NS	ZE	PS	PS	PM
	PS	NS	NS	ZE	PS	PS	PM	PM
	PM	NS	ZE	PS	PS	PM	PM	PB
	PB	ZE	PS	PS	PM	PM	PB	PB

Current control in the voltage source inverter plays an important role in high performance inverter. It plays an important role in high performance applications such as AC motor drives, AC active filters and UPS. Many types are found in the literature. Two kind of current controller are extensively used due to its simplicity: hysteresis controller and ramp comparison controller.

The hysteresis controller keeps the error within a specified band, presents good accuracy and robustness. Its major drawback is the resultant variable switching frequency of the converter. In the ramp comparison controller the instantaneous current error is fed to a Proportional integral regulator, which generates the voltage command. The voltage command is then compared to a triangular carrier at the desirable switching frequency. In this work voltage command is tracked by fuzzy controller and compared with current controller as shown in figure 9.

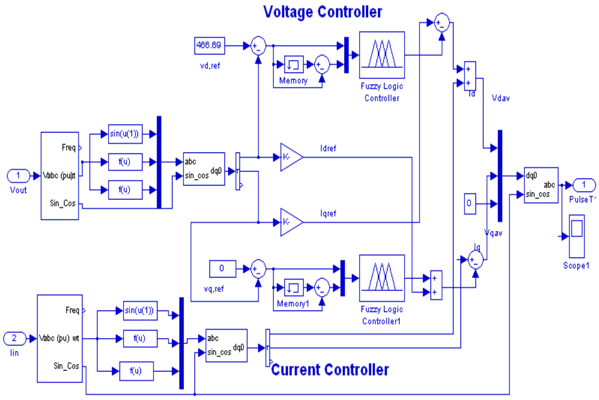

Fig.9. Cross coupled fuzzy structure for matrix converter

Computations of d and q axis parameters are shown in equation 12 to equation 14.

Computation of dq axis

$$V_d = \frac{2}{3}\left[V_A \sin wt + V_B \sin(wt - \frac{2\pi}{3}) + V_C \sin(wt + \frac{2\pi}{3})\right]$$

(12)

$$V_q = \frac{2}{3}\left[V_A \cos wt + V_B \cos(wt - \frac{2\pi}{3}) + V_C \cos(wt + \frac{2\pi}{3})\right]$$

(13)

$$V_0 = \frac{1}{3}\left[V_A + V_B + V_C\right] \quad (14)$$

Where w=rotation speed in rad/s

Computation of dq to abc

$$V_A = \lfloor V_d \sin wt + V_q \cos(wt) + V_0)\rfloor \quad (15)$$

$$V_B = \left[V_d \sin(wt - \frac{2\pi}{3}) + V_q \cos(wt - \frac{2\pi}{3}) + V_0\right] \quad (16)$$

$$V_C = \left[V_d \sin(wt + \frac{2\pi}{3}) + V_q \cos(wt + \frac{2\pi}{3}) + V_0\right] (17)$$

Where w=rotation speed in rad/s

Input contains vectorized signal of V_d, Vq and V_o components.

V. RESULTS

In order to analyze the performance of the proposed cross coupled dq axis controller using fuzzy logic controller, a simulation mode of the Matrix converter was implemented in Sim power systems from Simulink using ideal switches. A three phase start connected RL load with R=10Ω and L=200μH were used in the simulation. The switching frequency of Matrix converter is 16 KHz and input voltage is 440V, 60 Hz. The modulation index is dynamically corrected by the fuzzy controller and the output current is almost sinusoidal and balanced.

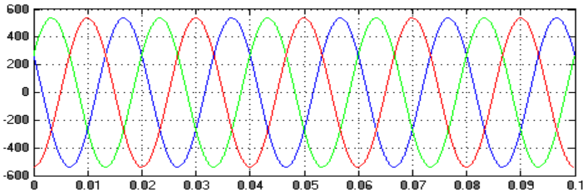

Fig.10. Input voltage (F=50Hz)

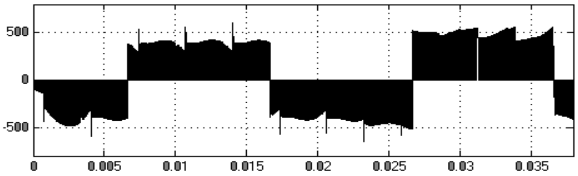

Fig.11. Output Voltage (F=50Hz)

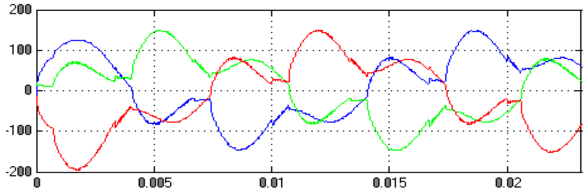

Fig.12. Input current (F=50Hz)

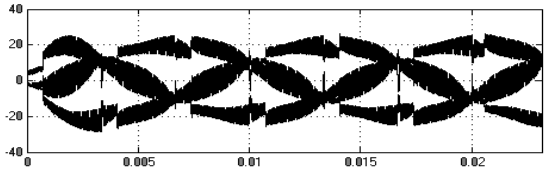

Fig.13. Output current (F=50Hz)

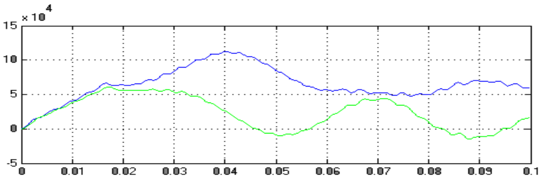

Fig.14. PQ Setting (Input side:F=50Hz)

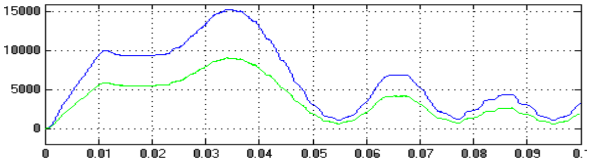

Fig.15. PQ Setting (Output side: F=50Hz)

From the figure 10 to figure 15 shows the difference between input parameters and output parameters for 50Hz fixed frequency. While comparing input voltage with output voltage from figure 10 and figure 11 maximum voltage transformation has been made. This can be possible by this proposed method. Here output parameters are measured without output filters. These parameter waves can be still shaped by using output filters. PQ settings are linearly varies each other. For same RL load different values of frequency settings are made and results were obtained for 30Hz and 60Hz. Along with this Voltage transformation ratio is measured. We proved that this measured value is high quality output.

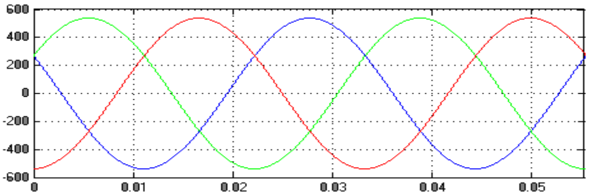

Fig.16. Input Voltage (30Hz)

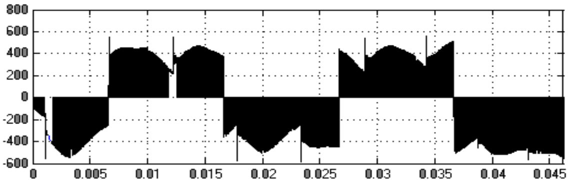

Fig.17. output voltage (30Hz)

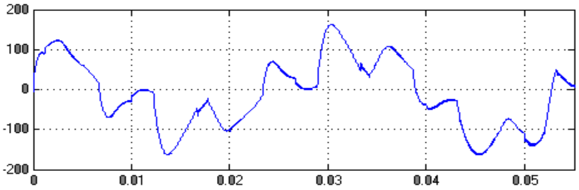

Fig.18. Input Current (30Hz, per phase)

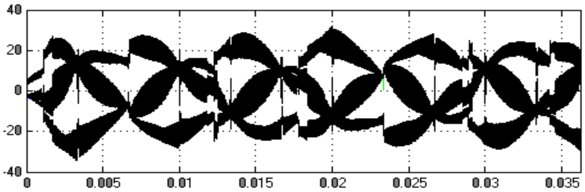

Fig.19. output current (30Hz)

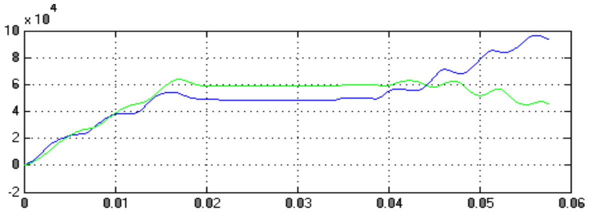

Fig.20. Input PQ setting (30Hz)

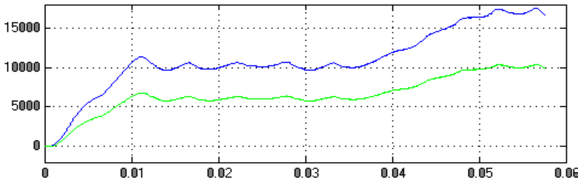

Fig.21. output PQ setting (30Hz)

Change in frequency normally makes lot of difference in output side. Here we have done simulation work for 30Hz, 25Hz and 60Hz. PQ setting for power system load was measured .Figure 16 to Figure 21 shows that input and output parameters variations for 30Hz frequency. From Figure 22 to Figure 27 shows variation of input and output voltage for 60Hz.

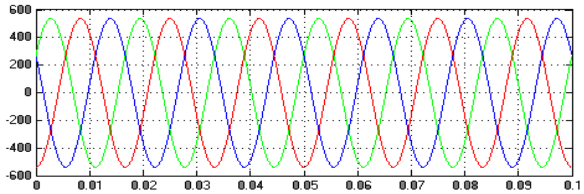

Fig.22 Input voltage (60Hz)

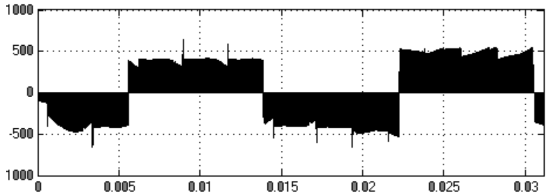

Fig.23. Output Voltage (60Hz)

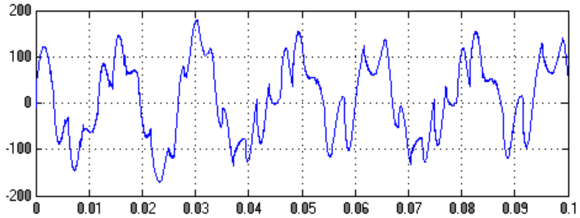

Fig.24. Input current (60Hz)

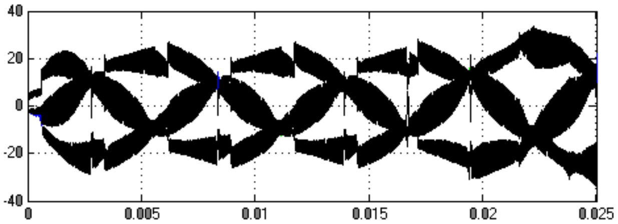

Fig.25. Output Current (60Hz)

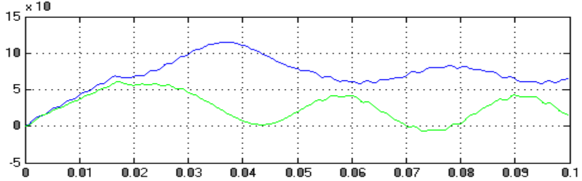

Fig.26. Input PQ Setting (60Hz)

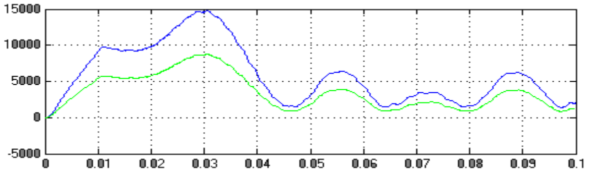

Fig.27. Output PQ Setting (60Hz)

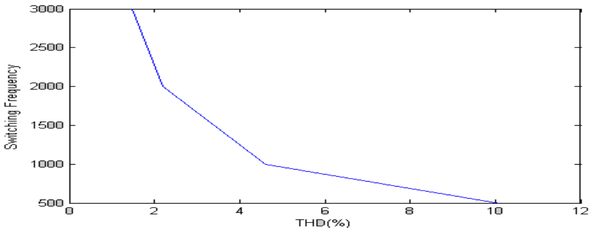

Fig.28. THD variation with respect to switching frequency,open loop simulation

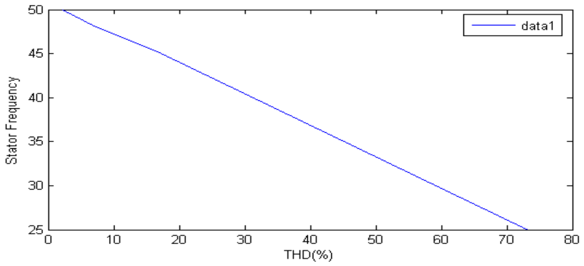

Fig.29. THD Variation with respect to stator frequency,Open loop simulation

Table 2 shows the open loop simulation of matrix converter with different load conditions. In figure 28 and 29 THD are measured for open loop Space vector control method.By changing the switching behavior of the inverter, the audible noise can also be influenced and therefore be minimized. Space Vector Modulation provides excellent output performance, optimized efficiency, and high reliability compared to similar inverters with conventional Pulse Width Modulation.

TABLE 2
THD COMPARISION R,RL AND MOTOR LOAD
(OPEN LOOP SIMULATION),WITHOUT OUTPUT FILTER

Parameter	R Load	RL Load	Motor Load
Switching Frequency	16KHz	16KHz	16KHz
Output THD	65.64%	22.05%	4.9%
Input THD	22.7%	22.59%	22.43%

From the above analysis it seems that voltage transformation ratio of the matrix convertere is almost reaches to maximum level .

VI. CONCLUSION

In this paper a new and simple cross coupled dq axis controller for MC was proposed. Voltage control was implemented using fuzzy logic controller and space vector modulation .So that the switching frequency of the MC is kept constant. The fuzzy controller forces the amplitude of the output current space vector to be constant so that the output current is free of harmonic.

APPENDIX A

Design Specifications of the proposed approach (Power system load)

Load Resistance =10Ω
Line Inductance =200μH
Device Switching Frequency =16KHz

Design Specifications of Motor Load (Open loop configuration)

V_{ll}=220V,F=60Hz,R_s =0.435Ω, L_s=2mH, R_r=0.816 Ω, L_r=2mH, L_m=69.31mH

Where,

V_{ll}=Line to Line voltage, R_s =Stator Resistance, L_s= Stator Inductance, R_r=Rotor Resistance and L_r=Rotor Inductance

APPENDIX B

Input filter Design

Input filter Capacitor: C_f

$C_f=\frac{2\times P}{3V^2{}_m\omega_i}$, Where P=Power Rating, Vm=Peak of Input voltage and ω_i=angular input Frequency.

$L_f=\frac{1}{(2\pi f_c)^2 c_f}$, Where f_c=cut off frequency lower than the switching frequency

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