Closed Loop Hybrid Controller based 3ϕ Input 3ϕ Output Power Conversion Using Matrix Converter

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ABSTRACT

This paper proposes a new approach of simulation design and implementation of Hybrid controller for a 3 phase to 3 phase power conversion using matrix converter. It includes the 3 phase to 3 phase power conversion by open loop and closed loop configurations. In closed loop real time control is achieved by Hybrid controller. The duty cycles of the matrix converter bidirectional switches are calculated using modified venturini algorithm for maximum voltage transfer ratio. Hybrid controller is developed to track the desired load current simultaneously with low THD% under all loading conditions and to regulate load current under sudden line and load disturbances. The entire matrix converter circuits are developed by Mathematical model and performances of the Hybrid controllers are evaluated using MATLAB for RL Load.

***Keywords* – 3 phase to 3 phase converter, Matrix converter, AC to AC conversion, 3 Phase Power conversion, closed loop controller, Hybrid Controller**

I. INTRODUCTION

The matrix converter (MC) is a single-stage power converter, capable of feeding an m-phase load from an n-phase source without using energy storage components. It is a direct frequency conversion device that generates variable magnitude variable frequency output voltage from the ac line. It has high power quality and it is fully regenerative. Due to the increasing importance of power quality and energy efficiency issues, the Matrix converter technology has recently attracted the power electronics industry. Control and modulation techniques that enhance both the ac line and motor load side performance have been well developed. Recently, direct ac/ac converters have been studied in an attempt to realize high efficiencies, long lifetime, size reduction, and unity power factors. The benefits of using direct ac/ac converters are even greater for medium voltage converters as direct ac/ac converters do not require electrolytic capacitors, which account for most of the volume and cost of medium-voltage converters. The matrix converter (MC) is a direct frequency conversion device that generates variable magnitude variable frequency output voltage from the ac line. It has high power quality and it is fully regenerative.

To control conventional and indirect matrix converter with minimized semiconductor commutation count, an appropriate digital carrier modulation schemes has been introduced [1]. A high-performance transformer less single-stage high step-up ac–dc matrix converter based on Cockcroft–Walton (CW) voltage multiplier has been proposed for deploying a four bidirectional- switch matrix converter between the ac source and CW circuit, the converter provides high quality of line conditions, adjustable output voltage, and low output ripple [2]. To improve the output performance, a novel Z-source sparse matrix converter and a compensation method based on a fuzzy logic controller to compensate unbalanced input-voltages has been proposed [3].

For various industrial adjustable speed ac drives and applications, various analysis and mathematical model is introduced in matrix converter. By varying the Modulation Index (MI), the outputs of the matrix converter are controlled and in ac drives, speeds of the drive were controlled. To reduce the computational time and low memory requirement, a mathematical model has been developed [4]-[11]. To achieve real time control with quick speed and fast response, new designs of controllers are needed [12]-[16]. Fuzzy logic controllers are the one to sense the output continuously and correct the output at the instant if any disturbance occurred. Various Fuzzy logic controllers are designed and implemented for the 3 phase to 3 phase matrix converter in closed loop configuration and the power circuit in open loop and closed loop are implemented by the mathematical modeling along with the Fuzzy logic controllers. Implementation of Fuzzy logic controllers in mathematical modeling includes the modeling of power circuit, switching algorithm, load and the controller. Merits of Mathematical model over conventional power circuit are less computation time and low memory requirement [17-22].

In this paper, Hybrid controller is developed to track the desired load current simultaneously with low THD% under all loading conditions and to regulate load current under sudden line and load disturbances. The proposed model is very simple, flexible and can be accommodated with any type of load.

II. MATRIX CONVERTER

The Matrix converter (MC) is a single stage direct ac to ac converter, which has an array of m x n bi-directional switches that can directly connect m phase voltage source into n phase load. A 3 phase matrix converter consists of 3x3 switches arranged in matrix form. The arrangement of bi-directional switches is such that any of the input phases R,Y,B is connected to any of the output phases r,y,b at any instant. The average output voltage with desired frequency and amplitude can be controlled by the bi-directional switches. The bi-directional 3x3 switches (2^9) gives 512 combinations of the switching states. But only 27 switching combinations are allowed to produce the output line voltages and input phase currents. The desirable characteristics of a Matrix converter are as follows:

- Unity input power factor at the power supply side.
- Minimal energy storage requirements
- Controllable input power factor
- Bidirectional energy flow capability
- Compact design
- Long life due to absence of a bulky electrolytic capacitor

Limitations of Matrix converter are

- Sensitive to the power source distortion due to the direct connection between input and output sides.
- The voltage transfer ratio limitation has a maximum value of 0.866

Input filter is needed in order to eliminate the harmonic components of the input current and reduce the input voltage distortion supplied to the Matrix Converter as shown in fig.1.

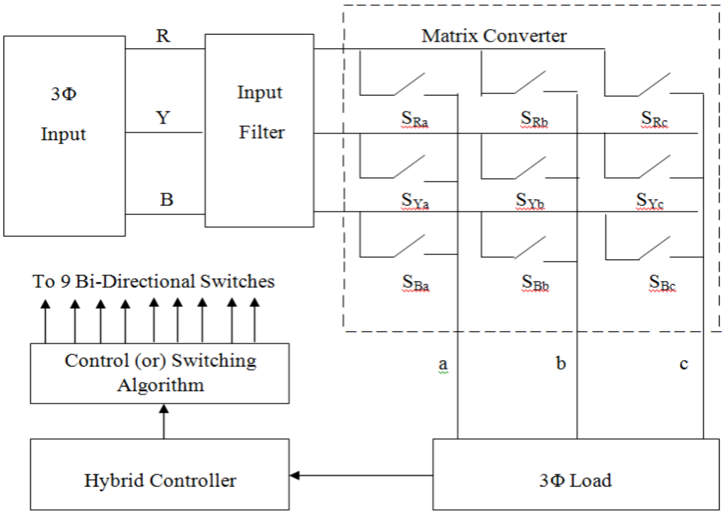

Figure-1. Scheme of 3 phase to 3 phase matrix converter

III. CONTROL ALGORITHM

When 3 phase to 3 phase converter operated with9 bi-directional switches, the following two basic rules have to be satisfied [4].

- Two or three input lines should not be connected to the same output line – to avoid short circuit
- At least one of the switches in each phase should be connected to the output – to avoid open circuit.

The switching function of single switch as

$$S_{Kj} = \begin{cases} 1, \text{switch SKj closed} \\ 0, \text{switch SKj opened} \end{cases} \quad (1)$$

Where, K = {r, y, b), j = {R, Y, B}

The above constraints can be expressed by

$$Srj + Syj + Sbj = 1, \quad j = \{R, Y, B\} \quad (2)$$

With these restrictions, the 3 x 3 matrix converter has 27 possible switching states.

The input and output voltage vector of the 3 phase to 3 phase Matrix converter is

$$V_i = \begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = \begin{bmatrix} V_{im}\cos(\omega_i t) \\ V_{im}\cos(\omega_i t + \frac{2\pi}{3}) \\ V_{im}\cos(\omega_i t + \frac{4\pi}{3}) \end{bmatrix} \quad (3)$$

$$V_o = \begin{bmatrix} V_r \\ V_y \\ V_b \end{bmatrix} = \begin{bmatrix} V_{om}\cos(\omega_o t) \\ V_{om}\cos(\omega_o t + \frac{2\pi}{3}) \\ V_{om}\cos(\omega_o t + \frac{4\pi}{3}) \end{bmatrix} \quad (4)$$

The input and output current vector of the 3 phase to 3 phase Matrix converter is

$$I_i = \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \begin{bmatrix} I_{im}\cos(\omega_i t) \\ I_{im}\cos(\omega_i t + \frac{2\pi}{3}) \\ I_{im}\cos(\omega_i t + \frac{4\pi}{3}) \end{bmatrix} \quad (5)$$

$$I_o = \begin{bmatrix} I_r \\ I_y \\ I_b \end{bmatrix} = \begin{bmatrix} I_{om}\cos(\omega_o t) \\ I_{om}\cos(\omega_o t + \frac{2\pi}{3}) \\ I_{om}\cos(\omega_o t + \frac{4\pi}{3}) \end{bmatrix} \quad (6)$$

Where, ω_i - frequency of input voltage and

ω_o - frequency of output voltage

The relationship between output and input voltage is given as

$$V_o(t) = M(t).\, V_i(t) \quad (7)$$

Where M_t is the transfer Matrix and is given by

$$M(t) = \begin{bmatrix} M_{Rr} & M_{Yr} & M_{Br} \\ M_{Ry} & M_{Yy} & M_{By} \\ M_{Rb} & M_{Yb} & M_{Bb} \end{bmatrix} \quad (8)$$

where, $M_{Rr} = t_{Rr} / T_s$, duty cycle switch S_{Rr}, Ts is the sampling period.

The input current is given by $I_{in} = M^T I_o$ (9)

Duty cycle must satisfy the following condition in order to avoid short circuit on the input side.

$$\begin{aligned} M_{Rr} + M_{Yr} + M_{Br} &= 1 \\ M_{Ry} + M_{Yy} + M_{By} &= 1 \\ M_{Rb} + M_{Yb} + M_{Bb} &= 1 \end{aligned} \quad (10)$$

The above condition is fulfilled by calculation of duty cycle using modified venturini algorithm.

In venturini switching algorithm, the maximum voltage transfer ratio is restricted to 0.5.This limit can be overcome by using modified venturini algorithm [16]. The maximum possible output voltage can be achieved by injecting third harmonics of the input and output frequencies into the output waveform [11]. This will increase the available output voltage range to 0.75 of the input when third harmonics has a peak value of $V_i/4$. Further increasing of the transfer ratio can be achieved by subtracting a third harmonic at the output frequency from all target output voltages. Hence the maximum transfer ratio of 0.75/0.866 = 0.866 of V_i when this third harmonic has a peak value of $V_o/6$.

Therefore the output voltage

$$V_{o\gamma}=qV_{im}cos(\omega_o t+\psi_\gamma)-\frac{q}{6}\,V_{im}cos(3\omega_o t)+\frac{1}{4q_m}V_{im}(3\omega_i t) \qquad (11)$$

Where,

ψ_γ= 0, 2π/3, 4π/3 corresponding to the output phase r, y, b

IV. MATRIX CONVERTER MODELING

The actual MATLAB/SIMULINK model of 3 phase to 3 phase Matrix converter is shown in fig.2. It comprises normally 4 sections.

A. Control Algorithm Modeling

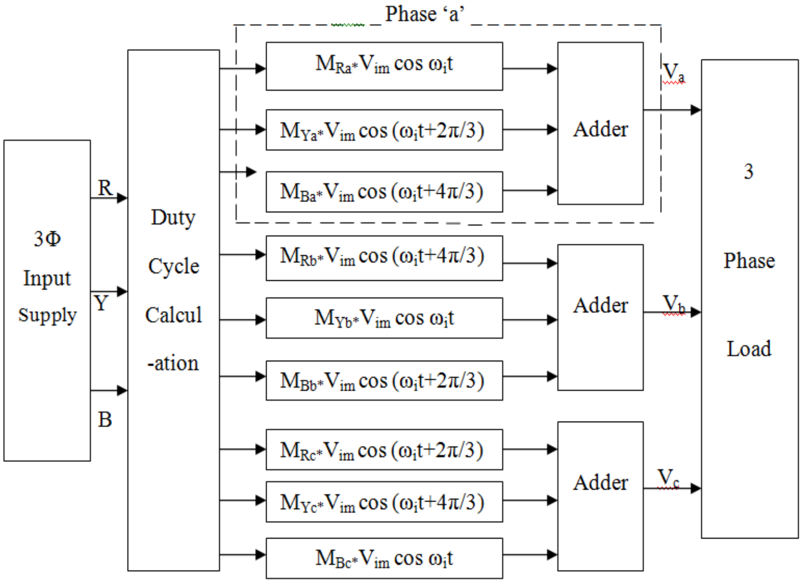

Figure-2. Mathematical Modeling of 3 phase to 3 phase Matrix converter.

The required voltage transfer ratio (q), output frequency (f_o) and switching frequency (f_s) are the inputs required for calculation of duty cycle matrix M. the duty cycle calculations for voltage transfer ratio of 0.5 and 0.866 are realized in the form of m-file in Matlab.

Duty cycles for 0.5 & 0.866 voltage transfer ratio are;

$$M_{Rr}=\frac{1}{3}\,(1+2q\,cos(\omega_m t+\theta))$$

$$M_{Yr}=\frac{1}{3}\,(1+2q\,cos(\omega_m t+\theta-\frac{2\pi}{3}))$$

$$M_{Br}=\frac{1}{3}\,(1+2q\,cos(\omega_m t+\theta-\frac{4\pi}{3}))$$

$$M_{Ry}=\frac{1}{3}\,(1+2q\,cos(\omega_m t+\theta-\frac{4\pi}{3}))$$

$$M_{Yy}=\frac{1}{3}\,(1+2q\,cos(\omega_m t+\theta)) \qquad (12)$$

$$M_{By}=\frac{1}{3}\,(1+2q\,cos(\omega_m t+\theta-\frac{2\pi}{3}))$$

$$M_{Rb}=\frac{1}{3}\,(1+2q\,cos(\omega_m t+\theta-\frac{2\pi}{3}))$$

$$M_{Yb}=\frac{1}{3}\,(1+2q\,cos(\omega_m t+\theta-\frac{4\pi}{3}))$$

$$M_{Bb}=\frac{1}{3}\,(1+2q\,cos(\omega_m t+\theta))$$

Where, $\omega_m=\omega_o-\omega_i$ = modulation frequency & θ = relative phase of output, q =voltage transfer ratio

Switching time for voltage transfer ratio of 0.866 are;

$$T_{\beta\gamma}=\frac{T_s}{3}\left[1+\frac{2V_{o\gamma}V_{i\beta}}{{V_{im}}^2}+\frac{2q}{3q_m}\sin\left(\omega_i t+\psi_\beta\right)\sin(3\omega_i t)\right] \qquad (13)$$

where,

ψ_β= 0, 2π/3, 4π/3 corresponding to the input phases R,Y,B,
q_m = maximum voltage transfer ratio,
q = required voltage ratio
, V_{im} =input voltage vector magnitude and
T_s = sampling period.

B. Power Circuit Modeling

The modeling of power circuit is derived from basic output voltage equations

$$V_r(t) = M_{Rr}\, V_R(t) + M_{Yr}\, V_Y(t) + M_{Br}\, V_B(t)$$
$$V_y(t) = M_{Ry}\, V_R(t) + M_{Yy}\, V_Y(t) + M_{By}\, V_B(t) \qquad (14)$$
$$V_b(t) = M_{Rb}\, V_R(t) + M_{Yb}\, V_Y(t) + M_{Bb}\, V_B(t)$$

Fig.3 shows the realization of modeling block of power circuit of ‘r’ phase in 3 phase to 3 phase Matrix converter. The switching pulses for the bi-directional switches are realized by comparing the duty cycles with a saw tooth waveform having very high switching frequency

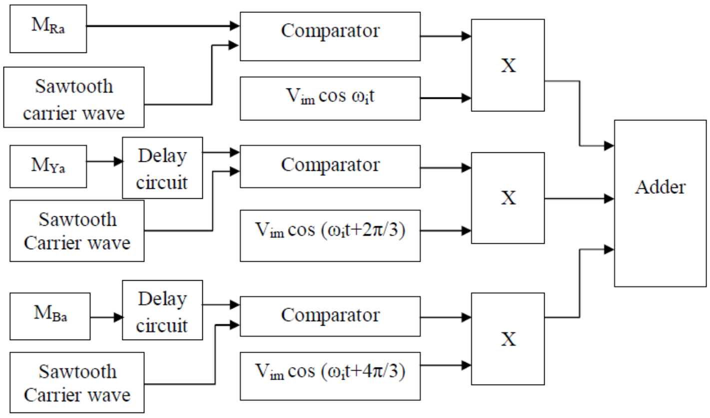

Figure-3. Modeling block of power circuit of ‘r’ phase in 3 phase to 3 phase Matrix converter.

C. Load Modeling

The transfer function of mathematical modeling of RL load is

$$\frac{I(S)}{V(S)}=\frac{1}{Ls+R} \qquad (15)$$

D. Hybrid Controller Modeling

Hybrid controller is the combination of PI controller and Fuzzy logic controller

(i) PI Controller

The proportional plus integral controller produces an output signal, u(t) consisting of two terms-one proportional to input signal, e(t) and the other proportional to the integral of input signal, e(t). The PI controller reduces the Steady state error. The PI controller model was developed using Simulink Blockset.

In PI controller, $u(t)\ \alpha\ [e(t) + \int e(t)\, dt]$ (16)
$u(t) = Kp\, e(t) + Ki \int e(t)\, dt$ (17)
where, Kp is the proportional gain =-ω1 sinθ /A1 and Ki is the integral constant or gain = cosθ/ A1
Transfer function of PI Controller is
$Gc(s) = U(s)/E(s) = Kp + Ki/s$ (18)

(ii) FL Controller

A fuzzy control system is based on fuzzy logic—a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0. Fuzzy logic control system has the following merits,

- It can be easily modified
- It can use multiple input and output sources
- Simple than linear algebraic equations
- Quick and easy to implement

The Fuzzy logic controller model was developed using Simulink Blockset.Figure.4. shows the basic block diagram of a Fuzzy logic controller and fiqure.5&6 shows the membership function of the input variables ‘e’ & ‘ce’. Figure.7. shows the membership function of the output variable ‘o’.

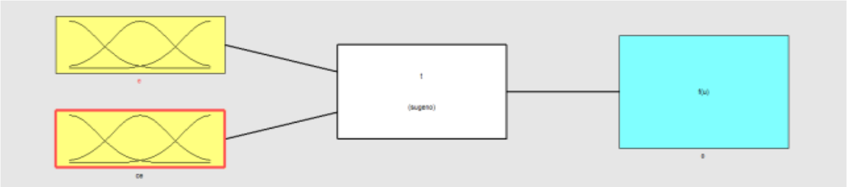

Figure-4. Block Diagram of Fuzzy logic controller

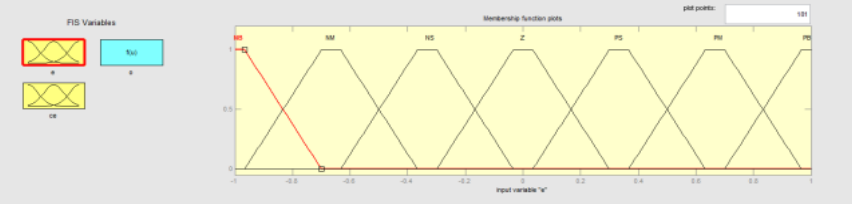

Figure-5. Block Diagram of Input Variable ‘e’ Membership Function

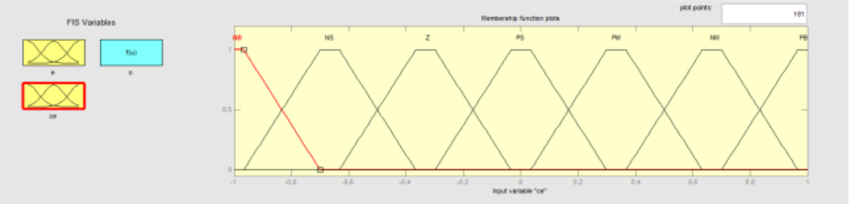

Figure-6. Block Diagram of Input Variable ‘ce’ Membership Function

Figure-7. Block Diagram of Output Variable ‘o’ Membership Function

V. SIMULATION RESULTS

Simulations results are performed for a reference current of 5 Amps and Amplitude =325.26V and time limit is 0.1 m.Sec. The output is realized with 3 phase passive RL load for R= 10 Ω and L= 20 mH. The reference current is set to 5 Amps. The output is again feedback to the input of the matrix converter through Fuzzy logic controller to achieve the real time control. Fig.8. shows the Input waveform for ‘I_{ref}’=5 amps and Amplitude =325.26V in ‘r’ Phase. The Output Voltage waveforms in ‘r’ ‘y’ &’ b’ Phases for ‘I_{ref}’=5 amps as shown in Fig.9. The Output current waveforms in ‘r’ ‘y’ &’ b’ Phases for ‘I_{ref}’=5 amps as shown in Fig.10. Fig.11 shows the Simulation waveform for ‘THD’ in ‘r’ ‘y’ &’ b’ Phases. Fig.12 shows the Average Output Voltage & Output Current waveforms for 3 phase to 3 phase Matrix converter (for ‘r’, ‘y’, ‘b’ Phases).The average output voltage is =325.26V and the average output current is 5 Amps.Fig.13 shows the simulated 3Φ load voltage & load current under set point change in reference current. Fig.14 Shows the simulated 3Φ load current under increased load variation from R=10 Ω to 15 Ω and L=20mH to 25mH. Fig.15 Shows the simulated 3Φ load current under decreased load variation from R=10 Ω to 5 Ω and L=20mH to 17mH. Fig.16 Shows the simulated FLC based equivalent load current of 3Φ MC under sudden line disturbance (+5V) at t=0.6 seconds and sudden load disturbance (+10mH) at t=1second

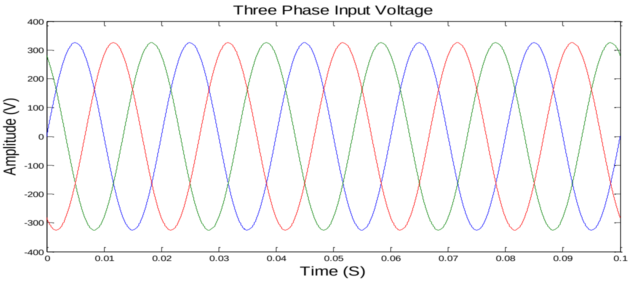

Figure-8. Input waveform for ‘‘I$_{ref}$’=5 amps and Amplitude =325.26V in ‘r’ Phase

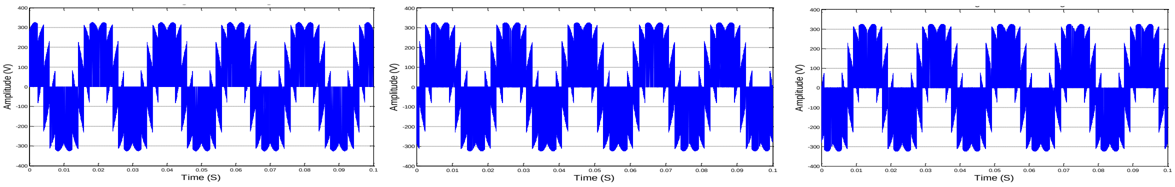

Figure-9. Output Voltage waveforms for I$_{ref}$’=5 amps in ‘r’ ‘y’ &’ b’ Phases.

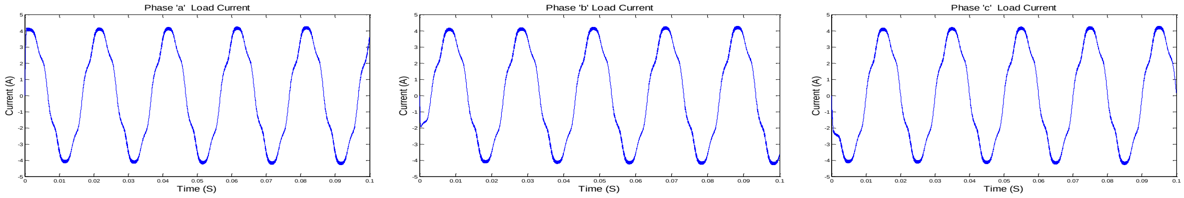

Figure-10. Output Current waveforms for ‘I$_{ref}$’=5 amps in ‘r’ ‘y’ &’ b’ Phases.

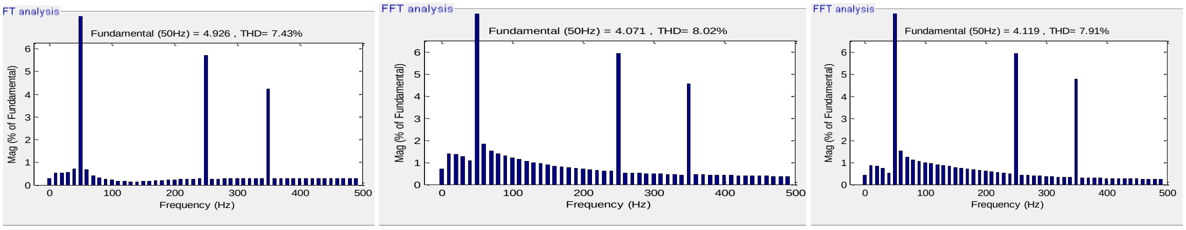

Figure-11.THD% of load current of phase ‘r’ ‘y’ &’ b’ Phases

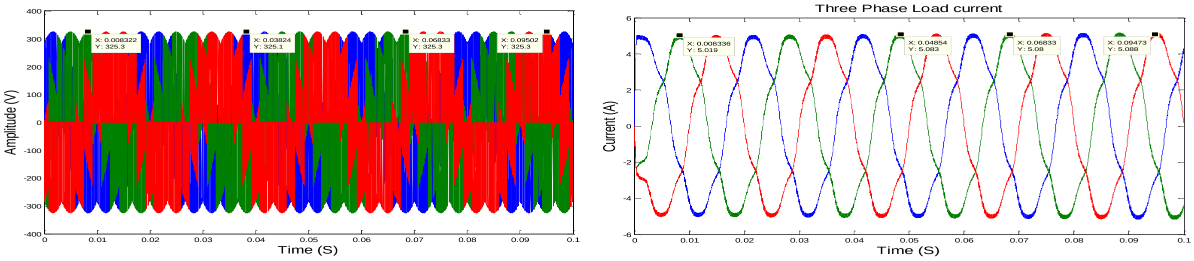

Figure-12. Output Voltage & Current waveforms for 3φ to 3φ Matrix converter (‘r’, ‘y’, ‘b’ Phases)

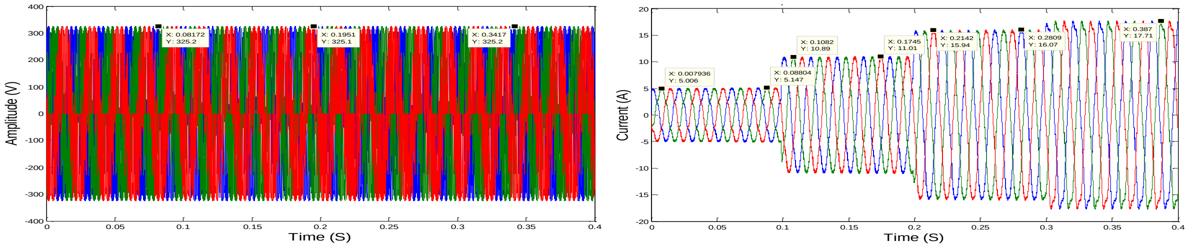

Figure-13 Simulated 3Φ load voltage &load current under set point change in ‘I$_{ref}$’=5 amps

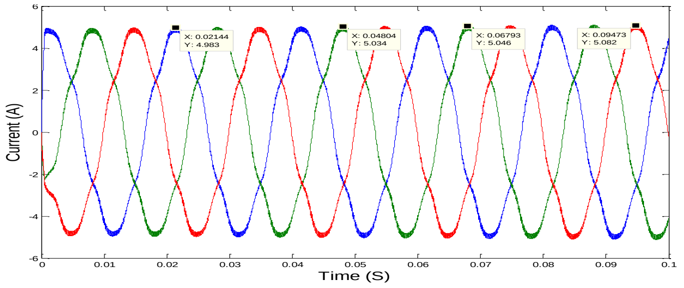

Figure-14 Simulated 3Φ load current under increased load variation from R=10 Ω to 15 Ω and L=20mH to 25mH

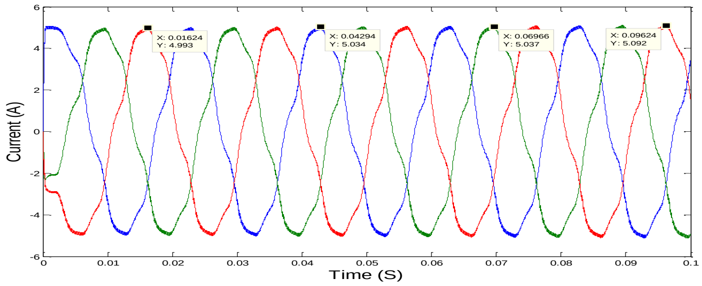

Figure-15 Simulated 3Φ load current under decreased load variation from R=10 Ω to 5 Ω and L=20mH to 17mH

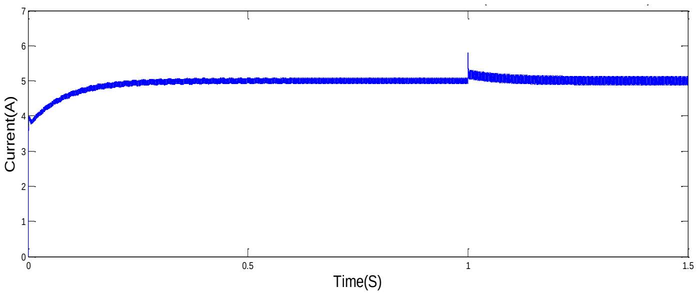

Figure-16 Simulated hybrid controller based equivalent load current of 3Φ MC under sudden line disturbance (+5V) at t=0.6 seconds and sudden load disturbance (+10mH) at t=1second

Table 1 shows the performance evaluation of closed loop MC under load variations. Table 2 shows the performance evaluation of closed loop MC under set point changes in reference current. Table 3 shows the comparison of THD% output load current under load variation

Table 1 Performance evaluation of MC under load variations

Load		Set point I_{ref} in (A)	Output voltage in (V)	Output current in(A)	Set point tracking time (S)	Steady state error in (%)
R in Ω	L in mH					
10	20	5	325.26V	4.94	0.003	0.06
5	17	5	325.26V	4.94	0.004	0.06
15	25	5	325.26V	4.86	0.004	0.14
10	17	5	325.26V	4.94	0.003	0.06
10	25	5	325.26V	4.94	0.005	0.06
5	20	5	325.26V	4.92	0.005	0.08
15	20	5	325.26V	4.85	0.003	0.15

Table 2 Performance evaluation of MC under set point change in reference current

Load		**Set point I_{ref} in (A)**	**Output current in (A)**	**Set point tracking Time (S)**	**Steady state error in (%)**
R in Ω	**L in mH**				
10	20	4	4.02	0.002	0.02
		5	5.02	0.002	0.02
		6	6.32	0.01	0.32
		10	10.89	0.11	0.89
		15	16.07	0.21	1.07
		20	17.71	0.31	2.29

Table 3 Comparison of load current THD% for load variations

Load		**THD% of output load current**		
R in Ω	**L in mH**	**Phase 'a'**	**Phase 'b'**	**Phase 'c'**
10	20	7.43	8.02	7.91
5	17	7.30	7.95	8.58
15	25	6.33	6.86	6.47
10	17	9.62	10.11	9.98
10	25	5.43	6.24	6.17
5	20	6.02	6.73	7.54
15	20	8.93	9.32	8.98

VI. CONCLUSION

Design and implementation of hybrid controller for 3 phase to 3 phase Matrix converter has been presented in this paper. A mathematical model is developed for open loop matrix converter using MATLAB/Simulink which is also utilized for closed loop hybrid controller configuration. Hybrid controller is developed provides robust tracking control of current reference (5Amps) for the 3Φ to 3Φ matrix converter with load variations. Results also indicate good regulation of load current under sudden line and load disturbances. In addition, controller developed provides lesser THD% in load current under load variations compared to open loop. Satisfactory tracking of load current with fixed load is also achieved with developed controller. It is also observed that hybrid controller developed provides faster tracking of load current compared to PI Controller and fuzzy logic controller based MC under fixed as well as variable loads. The future extension of this paper is possible for three phase to 'n' phase Matrix converter with various passive loads and different voltage transfer ratio.

REFERENCES

[1] Poh Chiang Loh, Runjie Rong, Frede Blaabjerg and Peng Wang, "Digital carrier modulation and sampling issue of matrix converter", IEEE Transactions on Power Electronics, Vol.24, No.7, July 2009.

[2] Sungmin Kim, Young-Doo Yoon and Seung-Ki Sul, "Pulsewidth modulation method of matrix converter for reducing output current ripple", IEEE Trans. on Power Electronics, Vol.25, No.10, October 2010.

[3] Kiwoo Park, Kyo-Beum Lee and Frede Blaabjerg, "Improving output performance of a Z-source sparse matrix converter under unbalanced input-voltage conditions", IEEE Transactions on Power Electronics, Vol.27, No.4, April 2012

[4] Imayavaramban, K.Lath and G.Uma, Analysis of different schemes of matrix converter with maximum voltage conversion ratio", IEEE MELECON'04 MAY12 -15, 2004, pp1137 1140.

[5] A.Alesina and M.G.B.Venturini, "Analysis and design of optimum amplitude nine-switch direct AC-AC converters", IEEE Trans. Power Electronics, vol.4, pp.101-112, Jan. 1989.

[6] P.W. Wheeler, J.Clare and A.Weinstein, "Matrix Converters:A Technology Review",IEEE Industrial Electronics Vol.49, No.2, April 2002,pp. 276-287.

[7] Zuckerberger,A., Weingstock, D,and Alexandrovitz,A., "Single-phase matrix converter", IEE proceedings Electric Power Application,Vol144(4), July 1997, pp235-240.

[8] P.W.Wheeler, Jon C. Clare and M. Bland, drive level intelligence and current sensing for matrix converter current commutation", IEEE Industrial Electronics, Vol.49, No.2, April 2002, pp. 383-389.

[9] Sedat Sunter and Tatar Y, "Pspice modeling and design of a snubber circuit for the matrix converter", Int. Jour. of Engineering Model 13, 2000, pp.41-46.

[10] Zuckerberger, A., Weinstock, D. and Alexandrovitz,A, "Simulation of three- phase loaded matrix converter", Electric Power Applications, IEE Proceedings, Vol.143, Issue:4, July1996, pp.294- 300.

[11] "Modeling and simulation of single-phase AC-AC matrix converter using SPWM", Student conference on Research and Development proceedings, Malaysia, 2002, pp. 286-289.

[12] J.M.Carrasco, J.Tomps, A.Torralba, F.P.Ridao and L.G.Franquelo, "An analog fuzzy logic controller for power converters", in IEEE conference Rec:0-7803-3026-9/95, 1995, pp. 1490-1495.

[13] F.Colodro, A.Torralba, F.P.Ridao and L.G.Franquelo, "A circuit for learning in fuzzy logic based controllers", in IEEE conference Rec:0-7803-2570-2/95, 1995, pp. 279-282.

[14] Sung-Hoe Huh and Gwi-Tea Park, "An adaptive fuzzy controller for power converters", in proceedings of IEEE international fuzzy systems conference, seoul, korea, 1999, pp. 434-439.

[15] K.Viswanathan, D.Srinivasan and R.Oruganti, " A universal fuzzy controller for a non linear power electronic converters", in IEEE conference Rec: 0-7803-7289-8/02, 2002, pp. 46-51.

[16] Imayavaramban, A.V. Krishna Chaithanya and B.G. Fernandes, "Analysis and Mathematical Modelling of Matrix Converter for Adjustable Speed AC Drives" IEEE PSCE 2006. pp 113-1120.

[17] B.Muthuvel, T.S.Anandhi, P.Sivagnanam and M.Jananiraj, "Modeling and Implementation of Closed Loop PI Controller for 3 Phase to 3 Phase Power Conversion Using Matrix Converter", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 11, Issue 1 Ver. I (Jan – Feb. 2016), PP 01-08. Paper ID: B56084.

[18] B.Muthuvel, T.S.Anandhi, P.Sivagnanam and K.Ramash kumar, "Simulation of 3 Phase to 3 Phase Power Conversion Using Matrix Converter with Maximum and Minimum Voltage Transfer Ratio", International Journal of Engineering Research and applications (IJERA) ISSN: 2248-9622, Vol. 5, Issue 11, (Part - 2) November 2015. Paper ID: 510198

[19] B.Muthuvel, T.S.Anandhi and M.Jananiraj, "Simulation of Closed Loop Fuzzy Logic Controller for a 3 Phase to 3 Phase Power Conversion Using Matrix Converters", International Journal of Scientific Engineering and Research (IJSER) ISSN (Online): 2347-3878, Volume 4 Issue 1, January 2016 (PP 5-11), Paper ID: IJSER15646

[20] B.Muthuvel, K.C.Balaji, Dr.T.S.Anandhi, M.Jananiraj, "Designing of Closed Loop Controller for 3 Phase to 3 Phase Power Conversion Using Matrix Converter", International Journal of Scientific Engineering and Technology ISSN: 2277-1581, Volume No.5 Issue No.2, pp: 110-115 01 Feb.2016

[21] Dr.B.Muthuvel, Dr.N.Arunkumar, Dr.S.Vijayakumar and Mr.Surya Prasad Samsani, " Mathematical Modelling of Matrix Converter for Power Conversion under Various Load Condition using FLC", International Journal of Scientific Research and Review ISSN 2279-543X Volume 7, Issue 10, 2018 PP 275-287, DOI:16.10089.IJSRR.2018.V7I10.287391.2761

[22] Dr.B.Muthuvel, Dr.N.Arunkumar, Mr.Surya Prasad Samsani and Dr.N.Dhasarathan "Performance Evaluation of PI Controller based 3 Phase Power Conversion using Matrix Converter", International Journal of Management, Technology and Engineering ISSN 2249-7455 Volume 8, Issue 10, 2018 PP 805-816, DOI:16.10089.IJMTE.2018.V8I10.16.2112