Middle-East Journal of Scientific Research 24 (S1): 440-449, 2016
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2016.24.S1.64

Fuzzy Logic Controller Based Scl Quasi Z Source Inverter Fed Synchronous Motor Drive System

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Abstract: In this paper, using Fuzzy logic controller based on SCL quasi Z source inverter performance of permanent magnet synchronous motor drive in industrial application can be analyzed. Synchronous motor drive is fed from SCL quasi Z source inverter and its speed is controlled using fuzzy logic. The proposed paper reduces the inverter cost and harmonics. Simple algorithms are used for controlling the speed of synchronous motor drive. Comparison between proposed Fuzzy-Logic-Controller-Based SCL quasi Z source inverter fed synchronous motor drive system and conventional Fuzzy-Logic-Controller-Based Four-Switch Three-Phase Inverter-Fed IPM Synchronous Motor Drive System in terms of recital and harmonic analysis is done. The sturdiness of the proposed Fuzzy-Logic-Controller-Based SCL quasi Z source inverter fed synchronous motor drive system drive is demonstrated by theoretical and simulation results at different state of operation.

Key words: Fuzzy logic · Permanent-magnet synchronous motor · SCL quasi Z source inverter · Vector control

INTRODUCTION

Earlier days they were using, four-switch three-phase (4S3Ph) inverters for ac motors drives [1]. But its cost was high and more switching loss was produced. So in this paper we have implemented SCL quasi Z source inverter which reduces the switching losses and number of interface circuits. Due to reduced number of interface circuits, there is only less chance for the switches to get damage.

Takijawa *et al.* [2] reported the purpose of a 4S3Ph inverter for BLDC motor system, in which he considered the open loop pulse width modulation technique and not the closed loop scheme [3]. Then Larsenetal [4] implemented a 4S3Ph inverter for closed-loop vector control of induction motor. In this paper he proposed a proportional–integral (PI) algorithm, to control the speed and current. The drawback of proportional–integral(PI) algorithm is it depends on machine parameters [5]. Furthermore, the reported work did not investigate dynamic performance. So in this proposed paper we have utilized fuzzy logic algorithm to control speed and current.

The reason for using Fuzzy logic control is motor drives used in robotics, rolling mills etc. requires quick and exact response, fast recovery of speed if any interruption occurs and less sensitivity to change in parameters.

But the implementation of FLC in real time motor drive will suffer from computational trouble [6]. To overcome this reason , we have proposed SCL quasi Z source inverter which will reduce the computational trouble. The reason for using PMSM is that it has the following advantages high torque-to-current ratio, large power-to-weight ratio, high efficiency, high power factor and robustness. The dynamic performance of the permanent magnet synchronous motor can be improved by using vector control theory. To control the speed of PMSM, motor variables are changed to an orthogonal set of d-q axes, and then the FLC is incorporated to closed loop scheme.

Modelling of the Traditional Drive System: The drive system can be subdivided and studied in three different sections. These include the required inverter, motor and fuzzy logic controller, which can be explained in the forthcoming section.

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Operation of Rectifier-Inverter

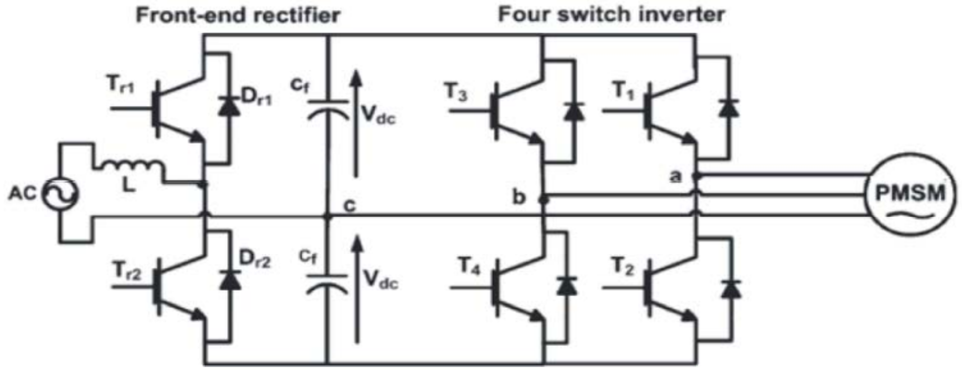


Fig. 1: PMSM fed from 4S3Ph voltage-source inverter

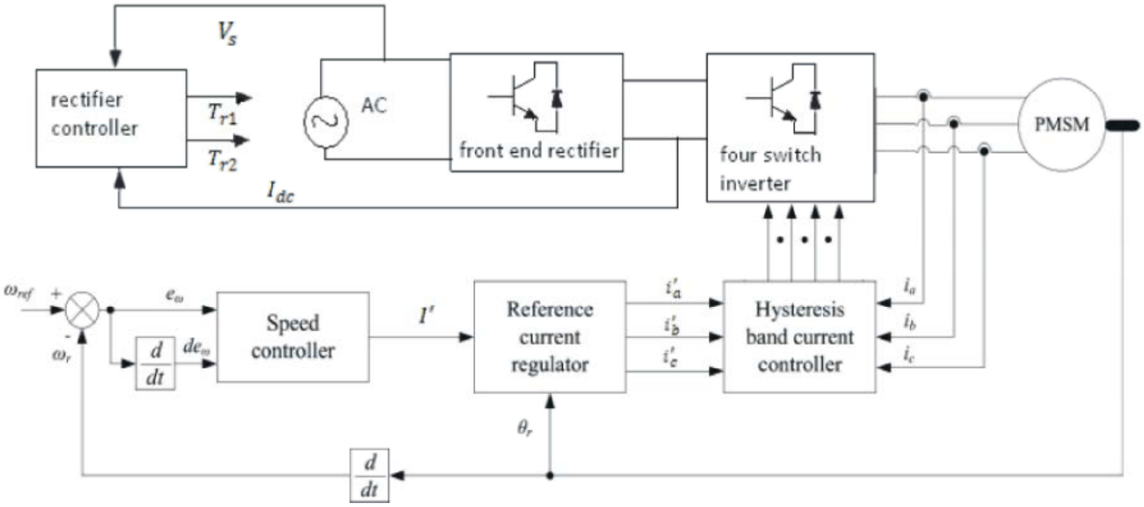


Fig. 2: PMSM fed from Fuzzy control 4S3Ph voltage-source inverter

The power circuit used is PMSM fed from 4S3Ph voltage-source inverter is shown in Figure 2. The circuit has a front end rectifier and four switched inverter. Single phase ac of fixed frequency is given to the rectifier whose output is given to the inverter used which requires sinusoidal input current. A splitcapacitor is used to provide steady output of v_{dc}. The output voltage equations are given as:

$$v_a = \frac{v_{dc}}{3}(4s_a - 2s_b - 1)$$

$$v_b = \frac{v_{dc}}{3}(-2s_a + 4s_b - 1)$$

$$v_c = \frac{v_{dc}}{3}(-2s_a - 2s_b + 2)$$

The above equations can be represented in matrix form as:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \frac{v_d}{3}\begin{bmatrix} 4 & -2 \\ -2 & 4 \\ -2 & -2 \end{bmatrix}\begin{bmatrix} s_a \\ s_b \end{bmatrix} + \frac{v_d}{3}\begin{bmatrix} -1 \\ -1 \\ 2 \end{bmatrix}$$

Table 1: Represents the different modes of operation and the corresponding output voltage vector of the inverter.

Switching functions				Output voltage vector		
S_a	S_b	Switch on		v_a	v_b	v_c
0	0	T_2	T_4	$-v_{dc}/3$	$-v_{dc}/3$	$2v_{dc}/3$
0	1	T_2	T_3	$-v_{dc}$	v_{dc}	0
1	0	T_1	T_4	v_{dc}	$-v_{dc}$	0
1	1	T_1	T_3	$v_{dc}/3$	$v_{dc}/3$	$-2v_{dc}/3$

Permanent Magnet Synchronous Motor Model

Controller Model: The input to the fuzzy controller is speed error e () and change of speed error d*e*(??) and its output is I'. The membership functions, rules and detailed development of the FLC can be found in [7].

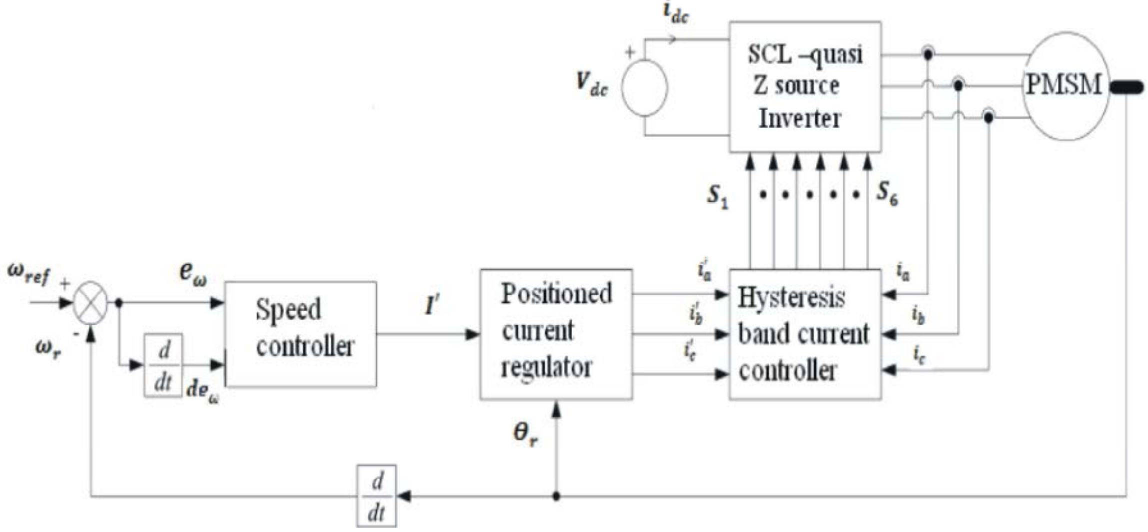


Fig. 3: PMSM fed from Fuzzy control SCL-qZSI inverter

Various scaling factors for the FLC were tuned by trial and error to get an optimum drive performance. But the disadvantage in this method is that the control current rise and fall time is more. So the actual speed of the motor does not track the set speed. These drawbacks are rectified in the proposed paper.

Modeling of the Proposed Drive System: The drive system consists of Fuzzy controller, a positioned current regulator, a hysteresis band current controller, position encoder and SCL- Z inverter and is shown in Figure 3.

SCL Quasi Z-Source Inverter: Fig. 3 shows the circuit of the proposed SCL-qZSI .The proposed inverter consists of three diodes (Din, D1 and D2), three capacitors (C1, C2 and C3), an input inductor L1 and an SCL with three windings (N1, N2 andN3). Windings N1 and N2 have the same number of turns (N1- N2) and the turn ratio of windings N3 to N1 (or N2) is n, (n=N3/N1=N3/N2). Due to trifilar windings the leakage inductance of the SCL is very small .Similar to the derivation of the boost factor for trans-ZSIs [8-12].

The advantages of the proposed SCL-qZSI are as follows:

- It reduces the starting inrush current.
- Since the SCL is in series with switched-capacitor C3, the inrush of C3is reduced.
- The energy stored in the leakage inductance is absorbed by capacitorC2.Hencethere is no voltage spikes due to switching.
- It has a boost factor of3/(1-4D).
- It provides lower component-voltage stresses and better output power quality.
- Core size of the input inductor L1 in the proposed SCL-qZSI is small.

Operating Principleof the SCL-QZSI: The proposed inverter has two state, shoot-through state and Non- Shoot-through state. Shoot-through state is obtained by simultaneously closing both the switches of phase leg. During this state, diode Din is reverse biased while diodes D1and D2 are forward biased. Windings N1 and N2 are energized with C1 in parallel. Now C3 gets energized by C1 through winding N3, which increases the boost factor. Leakage inductance of the SCL is used to limit the charging current of C3.

Non-Shoot-Through State: This state consists of six active states and three zero states .During this state, diode Din is forward biased while D1and D2arereverse biased. So Capacitors C1and C2 will be charged. Since the windings (N1, N2 and N3) and capacitor C3 are in series, they get de-energized and transfer energy to the main circuit. The energy stored in the leakage inductance of the SCL is then absorbed by C2.Hencevoltage spikes due to switching is absent.

Owing to magnetic coupling $V_{N3}= nV_{N2}=nV_{N1}$,

$V_{C3} = (n+1)\ V_{C1}$.

If D is the shoot-through duty, then DT is the shoot-through time interval and (1-D) T is the non- shoot-through time interval. Applying the voltage-second balance condition on inductor L_1, gives.

$$V_{PN} = \frac{1}{1-D}\ (V_{in} + V_{C2})(1)$$

Applying the voltage-second balance condition on winding N_1 or N_2, gives.

$$V_{C2} = \frac{n+1+D}{n+2} V_{PN} \tag{2}$$

From (1) and (2), the dc-link voltage across the inverter-bridge can be expressed as,

$$V_{PN} = \frac{n+1}{(1-(3+n)D)} V_{in} \tag{3}$$

Mathematical Model of PMSM: In the block diagram the following assumptions are made ω_r is real speed, θ_r is rotor position , i'_a, i'_b, $i'_c$and i_a, i_b , i_c are reference and actual phase current with 120° phase difference between them , e_ω is the error speed and de_ω is the error speed derivative with respect to time. These variables are given as input to fuzzy controller. Now the fuzzy controller produces position current I'.

PMSM stator voltage equation is represented in matrix form as given below;

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_{ss}-M & 0 & 0 \\ 0 & L_{ss}-M & 0 \\ 0 & 0 & L_{ss}-M \end{bmatrix} \times \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

where V_a, V_b, V_c are phase voltages , i_a, i_b , i_c are phase currents, e_a, e_b, e_c are electromotive forces of phase windings, R_s is the stator resistance of PMSM.

L_{ss}-M is the motor's synchronous inductance $L_{s\ \mathrm{and}}$ it is represented as given below:

$$L_s = L_{ss} - M = L_l + L_{ms} - \left(-\frac{1}{2} L_{ms} \right) = L_l + \frac{3}{2} L_{ms} \tag{2}$$

where L_{ss} is the total phase inductance, $L_l$is the leakage inductance and L_{ms} is the mutual inductance.
State –space representation of equation 1 is given below;

$$\frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{1}{L_s} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} - \begin{bmatrix} \frac{R_s}{L_s} & 0 & 0 \\ 0 & \frac{R_s}{L_s} & 0 \\ 0 & 0 & \frac{R_s}{L_s} \end{bmatrix} - \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \frac{1}{L_s} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{3}$$

The EMFs generated due to flux linking the permanent magnet can be calculated as follows

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = -\lambda_f \omega_r \geq \begin{bmatrix} sin\theta_r \\ \sin(\theta_r - 2\pi/3) \\ \sin(\theta_r + 2\pi/3) \end{bmatrix} \tag{4}$$

$$T_e = -\lambda_f \frac{p}{2}(i_a \sin\theta_r + i_b \sin(\theta_r - \frac{2\Pi}{3}) + i_c sin(\theta_r + \frac{2\Pi}{3})\} \quad (5)$$

$$\frac{d}{dt}\omega_r = \frac{P}{2}(T_e - T_l - B(\frac{2}{P})\omega_r)/J \quad (6)$$

$$\frac{d}{dt}\theta_r = \omega_r \quad (7)$$

The equation 5, 6 and 7 represents equation of torque generated, rotor speed and rotor position.

Hysteresis Band Current Controller: It is used to control the SCL quasi Z source inverter. Hysteresis band current controller makes the SCL quasi Z source inverter to produce an output current which follows the reference current. To obtain this a closed loop control is implemented as shown in Figure 1.

Fuzzy Logic Controller: For designing a fuzzy controller, first we have to decide the number of inputs and outputs. Then each attributes is divided into appropriate number of fuzzy sets. For each fuzzy set a membership function is defined. Next we have to decide the suitable method and create a decision table according to human knowledge, practice and perception. The reason for using fuzzy control is to reduce the complication of mathematical formulation .The advantages of FLC are;

- It can operate with less specific inputs;
- It does not require fast processors;
- It requires less data storage in the form of membership functions and rules than conventional look up table for non-linear controllers; and
- It is stronger than other non-linear controllers.

Fuzzification: Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable (real number or crisp variable) into a linguistic variable (fuzzy number) is called fuzzification. Error is normalized by dividing the actual error in speed with the reference speed. This normalization is useful for using the fuzzy controller for any speed reference.

Defuzzification: The reverse of fuzzification is called defuzzification. The use of FLC inference engine produces required output in a linguistic form. According to real world requirements, the linguistic variables have to be transformed to crisp output. Weighted average method is the best well-known defuzzification method.

Rule Table: The input variables are calculated for each sampling time as;

$e_\omega(t) = \omega_{rs} - \omega_r(t)$

$de_\omega(t) = (e_\omega(t) - e_\omega(t-1))/T$

where T is the sampling period, t and t-1 is real and earlier time value, ω_{rs} is set speed and ω_r is actual speed. The actual motor speed is fed back and is compared with set speed. After comparison, error signal and the change in error are calculated and are given as input to fuzzy controller. In this work, the error is normalized to per unit value with respect to the set speed. This helps in using the fuzzy controller for any set speed. The fuzzy controller will attempt to reduce the error to zero by changing duty cycle of switching signal.

The rules are formed in the format, ‘If error is Ai and change in error is Bi then output is Ci’. Here the if ‘part’ of a rule is called the rule-antecedent and is a description of a process state in terms of a logical combination of atomic fuzzy propositions. The ‘then’ part of the rule is called the rule consequent and is a description of the control output in terms of logical combinations of fuzzy propositions. *For fuzzy variable* e_ω added, five fuzzy sets are considered and they are negative big (NB), negative (NE), zero (Z), positive big (PB) and positive (PO). For change in controller output currentÄi’ seven fuzzy set are considered and they are negative big (NB), negative small (NS), negativemedium (NM), zero (Z), positive big (PB), positivemedium (PM) and positive small (PS).Triangular shaped membership function is selected for the fuzzy controller. The universe of discourse for the input and output variable is in the range of [-1, +1] and is represented in Fig 4.

The rule table is given below and it consists of two input variables added and one output variable Δi’. The following rule is followed in the Table 2.

R_{12}: if e_ω is NB and de_ω is NE then $\Delta i'$ is NM
R_{23}: if e_ω is NE and de_ω is Z then $\Delta i'$ is NS
R_{34}: If e_ω is Z and de_ω is PO then $\Delta i'$ is PS
R_{45}: If e_ω is PO and de_ω is PB then $\Delta i'$ is PM
R_{51}: If e_ω is PB and de_ω is NB then $\Delta i'$ is Z and so on

In the defuzzification process Äi’ is calculated by the following equation.

$$\Delta i' = = \frac{\sum_{i=1}^{n} \mu(\mu_i)\mu_i}{\sum_{i=1}^{n} \mu(\mu_i)}$$

Table 2: Fuzzy Rules

	Change in error de_ω				
Controller output $\Delta i'$	NB	NE	Z	PO	PB
NB e_ω	NB	NM	NS	NS	Z
NE	NM	NS	NS	Z	PS
Z	NS	NS	Z	PS	PS
PO	NS	Z	PS	PS	PM
PB	Z	PS	PS	PM	PB

where in number of fuzzy set and is equal to 7 and μ (μ_i) is the membership value corresponding to output membership function corresponding to i th fuzzy rule. Final output of the controller is;

$$I'(t) = I'(t-1) + K_u \Delta i'(t)$$

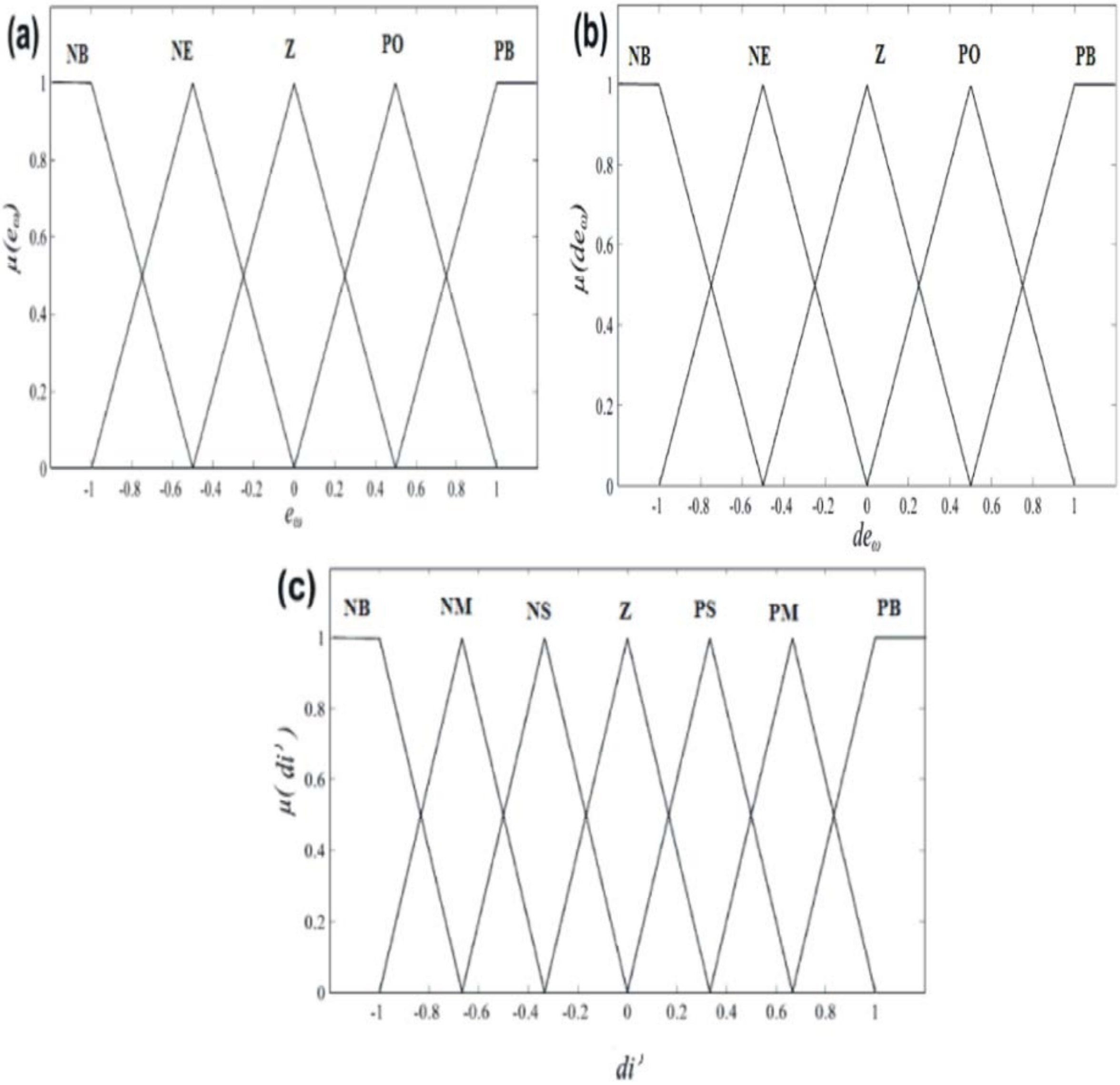


Fig. 4: Fuzzy set on the universe of discourse for (a) Speed erroreω(t) (b) change in Speed error de_ω(t) and(c) control current di'.

Simulation Result: The current generated at the starting is more in proposed paper and it is 4.6 Also more starting torque is generated and drops to 2A during the steady state. In the proposed paper the rise and drop time related to the control current is less. Therefore the actual speed of the controller will track the reference speed closely with minimum lagging. But in the traditional drive system the stating current is less and the time duration is more, so there will be a greater difference in speed. The simulation result of the control current of traditional and proposed fuzzy controller basedSCL quasi Z source inverter fed PMSM is shown in Figure 5.

From the simulation result it is clear that proposed inverter produces fewer harmonic.

Similarly the waveform of phase current of (a) fuzzy controller based SCL quasi Z source inverter fed PMSM and (b) traditional Fuzzy Logic Controller Based 4S3Ph Inverter-Fed IPM Synchronous Motor Drive System in represented in Figure 6(a) and 6(b).

From the simulation of Fig. 6(a) and Fig. 6(b) it is clear that the proposed SCL quasi Z source inverter provides boosted supply to PMSM compared to traditional 4S3Ph Inverter.

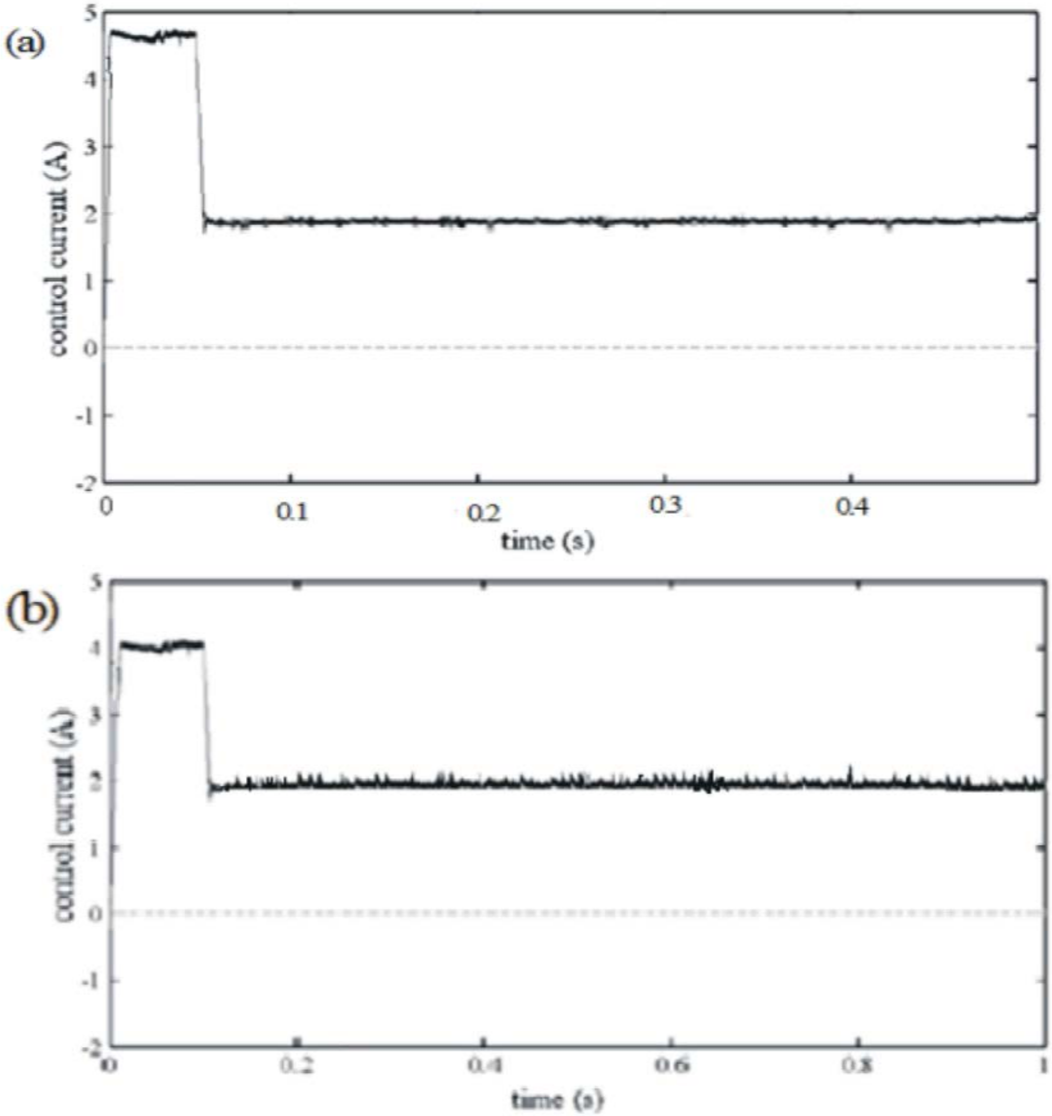
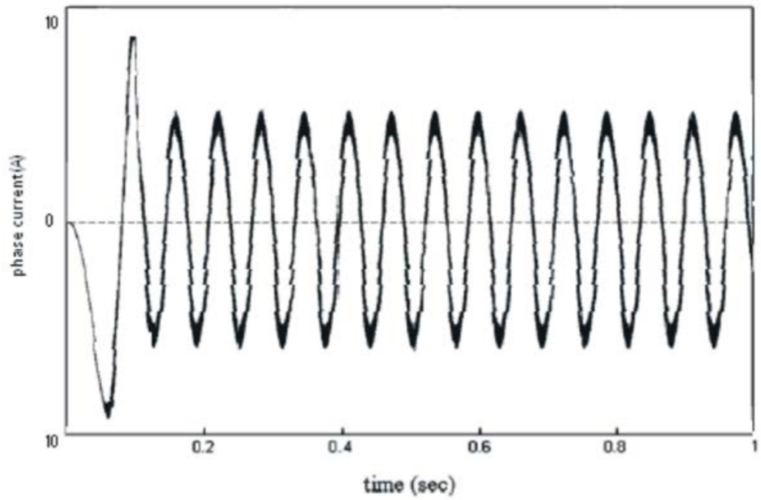


Fig. 5: Waveform of Control current for (a) fuzzy controller basedSCL quasi Z source inverter fed PMSM and (b) traditional Fuzzy Logic Controller Based 4S3Ph Inverter-Fed IPM Synchronous Motor Drive System



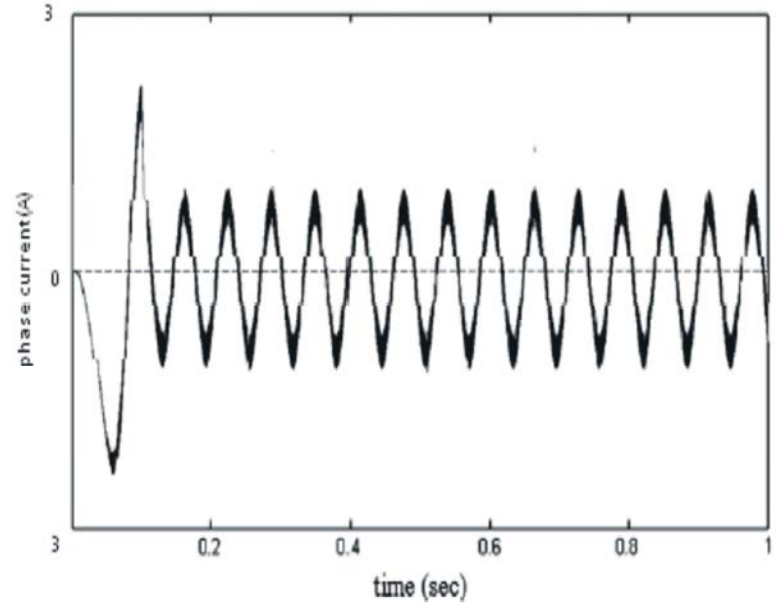


Fig. 6(a): Phase current waveform for fuzzy controller basedSCL quasi Z source inverter fed PMSM

Fig. 6(b): Phase current waveform for fuzzy controller based4S3Ph Inverterfed PMSM

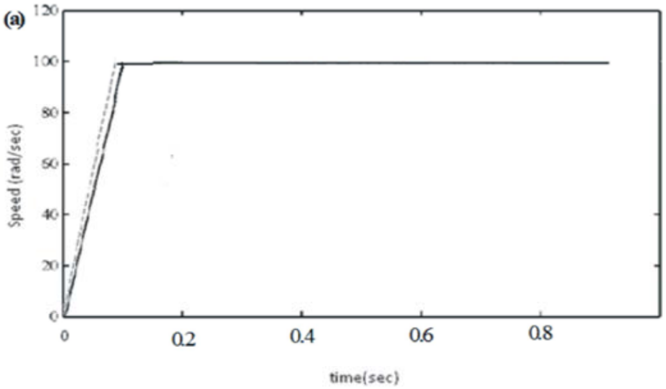


Fig. 7(a): Speed(ω) response of fuzzy controller basedSCL quasi Z source inverter fed PMSM

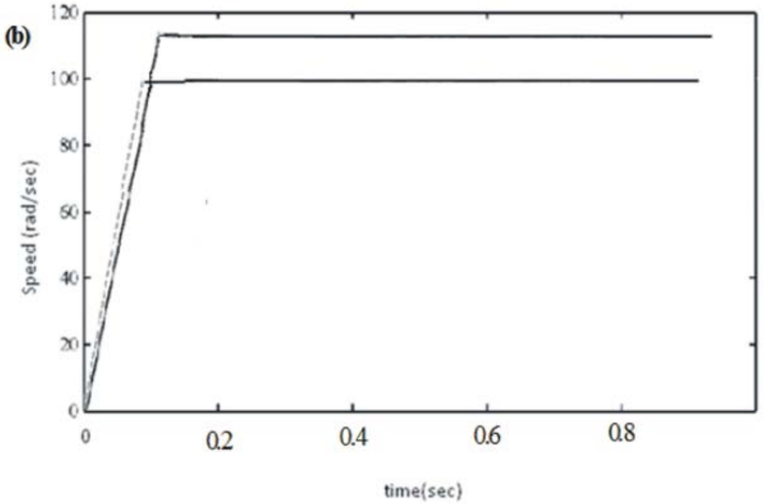


Fig. 7(b): Speed (ω) response of fuzzy controller based 4S3 Phinverter fed PMSM

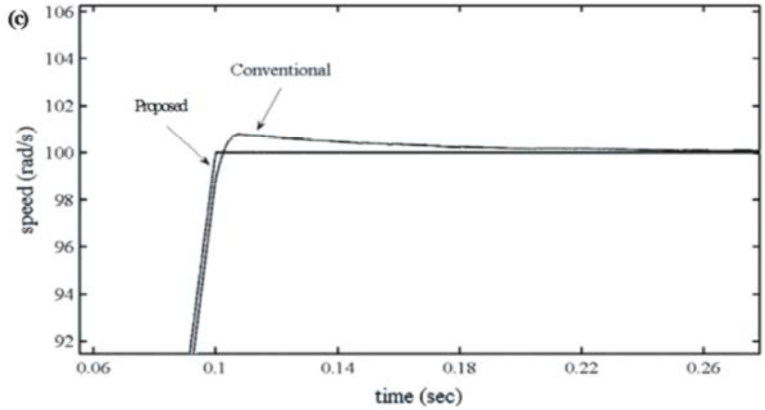


Fig. 7(c): Speed (ω) response comparison of fuzzy controller based proposed and conventional inverter.

The speed response of the fuzzy controller basedSCL quasi Z source inverter fed PMSM and fuzzy controller based4S3Ph inverter fed PMSM under 0.3 Nm load is represented in Figure7(a) and 7(b). The reference speed (dashed line) is set as ramp at 0 sec and 100 rad/sec at 0.1 sec time interval. The actual speed of the motor follows the reference speed in the case of fuzzy controller based SCL quasi Z source inverter fed PMSM. So it provides better transient performance because it has less settling and overshoot time. But in the case of conventional one the actual speed of the motor will not follow the reference speed.

CONCLUSION

A comparison between proposed Fuzzy-Logic-Controller-Based SCL quasi Z source inverter fed synchronous motor drive system and conventional Fuzzy-Logic-Controller-Based Four-Switch Three-Phase Inverter-Fed IPM Synchronous Motor Drive System is done in terms of recital and harmonic analysis. The sturdiness of the proposed Fuzzy-Logic-Controller-Based SCL quasi Z source inverter fed synchronous motor drive system drive is demonstrated by theoretical and simulation results. With the help of the proposed Fuzzy control inverter, the performance of the PMSM is improved.

REFERENCES

1. Nasir Uddin, M., Tawfik S. Radwan and M. Azizur Rahman, 2006. “Fuzzy-Logic-Controller-Based Cost-Effective Four-Switch Three-Phase Inverter-Fed IPM Synchronous Motor Drive System” IEEE Transactions on Industry Applications, 42(1).

2. Takijawa, S., M. Tabata, T. Tanigawa, S. Igarashi and K. Kuroki, 2000. "High ef?ciency drive techniques for the brushless dc motor using a four switch, three-phaseinverter, "in Proc. Int. Power Electronic Conf. (IPEC), Tokyo, Japan, pp: 1692-1697.
3. Cruise, R.J., C.F. Landy and M.D. McCulloch, 1999. "Evaluation of a re- duced topology phase-converter operating a three-phase induction motor, " in Conf. Rec. IEEE Int. Electric Machines and Drives Conf. (IEMDC), Seattle, WA, pp: 466-468.
4. Larsen, J.S., K. Jespersen, M.R. Pedersen, F. Blaabjerg and J.K. Pedersen, 1998. "Control of a complete digital based component-minimized single-phase to three-phase AC/DC/AC converter, " in Proc. IEEE In- dustrial Electronics Society (IECON) Conf., Aachen, Germany, pp: 618-625.
5. Rubaai, A., D. Rickattes and M.D. Kankam, 2002. "Development and im- plementation of an adaptive fuzzy-neural network controller for brush- less drives," IEEE Trans. Ind. Appl., 38(2): 441-447.
6. Uddin, M.N., T.S. Radwan and M.A. Rahman, 2002. "Performances of fuzzy logic based indirect vector control for induction motor drive, "IEEETrans. Ind. Appl., 38(5): 1219-1225.
7. Uddin, M.N. and M.A. Rahman, 2000. "Fuzzy logic based speed control of an IPM synchronous motor drive," J. Adv. Comput. Intell., 4(3): 212-219.
8. Qian, W., F.Z. Peng and H. Cha, 2011. "Trans-Z-source inverters," IEEE Trans. Power Electron., 26(12): 3453-3463.
9 Adamowicz, M., R. Strzelecki, F.Z. Peng, J. Guzinski and H.A. Rub, 2011. "New type LCCTZ-Z-source inverters," in Proc. Eur. Conf. Power Electron. Appl., pp: 1-10.
10. Nguyen, M.K., Y.C. Lim and S.J. Park, 2013. "Improved trans-Z-source inverter with continuous input current and boost inversion capability, " IEEE Trans. Power Electron., 28(10): 4500-4600.
11. Li, D., P.C. Loh, M. Zhu, F. Gao and F. Blaabjerg, 2013. "Cascaded multicell trans-Z-source inverters, " IEEE Trans. Power Electron., 28(2): 826-835.
12. Shin, D., H. Cha, J.P. Lee, D.W.Yoo, F.Z. Peng and H.G. Kim, 2011. "Parallel operation of trans-Z-source inverter," in Proc. IEEE 8th Int. Conf. Power Electron and ECCE Asia, pp: 744-748.