New Switch Ladder Topology for Five Phase Multilevel Inverter Fed Five Phase Induction Motor

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Abstract: - A five phase induction motor is modeled in the MATLAB simulink and a New Five Phase Multilevel Inverter is presented for the 5-ϕ IM to generate a maximum output voltage levels. In this topology symmetric and asymmetric source are considered and the output levels are analysed. An asymmetric source gives higher output voltage with lesser inverter switches. Percentage Total Harmonic Distortion in the output voltage of five phase multilevel inverter fed 5-ϕ IM and the corresponding dynamic performance are investigated. The results of this topology are found better when compared to that of VSI fed induction motor. The Simulation results of multilevel inverter fed 5-ϕ IM shows the effectiveness of the proposed topology.

Key-Words: - New Switch ladder five phase multilevel inverter, asymmetric source, Harmonics, Five phase Induction motor (5-ϕ IM)

1 Introduction

In general multi phase systems have many advantages and they are used in applications such as automotive industry, aeronautic and electric power generation. In case of even number phases, the poles are coinciding with each other and it will reduce the motor performance. So, odd number phases are preferred over even number phases [1]-[2]. Also output power of five phase system is greater than that of the three phase system. This has attracted the interest in the development of multi phase machines [3]-[4].

Multilevel power transfer topology has good scope for future expansion. The quality of the output voltage of multilevel inverter is improved more in the no. of output voltage steps than that of the conventional inverters. So, it is suitable for high power applications [5]-[7]. Also THD in the output voltage waveform is reduced. The main focus of the proposed work is to improve the input voltage quality of five phase induction motor by proposing a new five phase Switch Ladder Multilevel Inverter (SLMLI) generates specific no. of output voltage with maximum no. of levels and with minimum no. of switches. This results in less cost, compact design and reduction in Total Harmonic Distortion [8]-[10].

2 Modeling of Five-Phase Induction Motor

Mathematical model can be represented for an induction motor. The five phase system variables are transformed into two phase variables in d-q plane rotating with synchronous speed. The displacement between two phases is 72 degree and the number of phases must be the same before and after the transformation. The relationship between five phase and two phase variables are as follows.

$$V^s_{dq}=K_S\,V^s_{abcde} \qquad i^s_{dq}=K_S\,i^s_{abcde} \qquad \Psi^s_{dq}=K_S\,\Psi^s_{abcde}$$

$$V^r_{dq}=K_r\,V^r_{abcde} \qquad i^r_{dq}=K_r\,i^r_{abcde} \qquad \Psi^r_{dq}=K_r\,\Psi^r_{abcde} \tag{1}$$

Where,

$$K=\sqrt{\frac{2}{5}}\begin{bmatrix} 1 & \cos\left(\frac{2\pi}{5}\right) & \cos\left(\frac{4\pi}{5}\right) & \cos\left(\frac{4\pi}{5}\right) & \cos\left(\frac{2\pi}{5}\right) \\ 0 & \sin\left(\frac{2\pi}{5}\right) & \sin\left(\frac{4\pi}{5}\right) & \sin\left(\frac{4\pi}{5}\right) & \sin\left(\frac{2\pi}{5}\right) \\ 1 & \cos\left(\frac{4\pi}{5}\right) & \cos\left(\frac{8\pi}{5}\right) & \cos\left(\frac{8\pi}{5}\right) & \cos\left(\frac{4\pi}{5}\right) \\ 0 & \sin\left(\frac{4\pi}{5}\right) & \sin\left(\frac{8\pi}{5}\right) & -\sin\left(\frac{8\pi}{5}\right) & -\sin\left(\frac{4\pi}{5}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \tag{2}$$

'K' is the five-phase induction machine decoupling transformation matrix given in equation

2. The five phase machine is represented in d-q-x-y-o arbitrary plane. The d-q components are responsible for power generation, fluxes and torque production in the machine. The system losses are accounted in the remaining components (x-y) and the reason for zero components being used is to show invariance in the system. The 5-ϕ IM is modeled in the MATLAB simulink and the characteristics curves are obtained.

Essential machine model equations for stator sides and rotor sides are in the stationary reference frame are represented as follows

$$V_{ds} = R_s i_{ds} + p\Psi_{ds}$$

$$V_{qs} = R_s i_{qs} + p\Psi_{qs} \quad (3)$$

$$\Psi_{xs} = LI_s i_{xs}$$

$$\Psi_{ys} = LI_s i_{ys}$$

$$V_{dr} = R_r i_{dr} + p\Psi_{dr}$$

$$V_{qr} = R_r i_{qr} + p\Psi_{qr} \quad (4)$$

$$\Psi_{xr} = LI_r i_{xr}$$

$$\Psi_{yr} = LI_r i_{yr}$$

Flux Linkage equations for stator and rotor sides are expressed as follows:

$$\Psi_{xs} = LI_s i_{xs} \qquad \Psi_{xr} = LI_r i_{xr} \quad (5)$$

$$\Psi_{ds} = (LI_s + L_m) i_{ds} + L_m i_{dr}$$

$$\Psi_{dr} = (LI_r + L_m) i_{dr} + L_m i_{ds} \quad (6)$$

$$\Psi_{qs} = (LI_s + L_m) i_{qs} + L_m i_{qr}$$

$$\Psi_{qr} = (LI_r + L_m) i_{qr} + L_m i_{qs} \quad (7)$$

where $L_s = LI_s + L_m$ (8)

$$\Psi_{ys} = LI_s i_{ys} \qquad \Psi_{yr} = LI_r i_{yr}$$

$$L_r = LI_r + L_m \quad (9)$$

The equation for torque can be denoted as:

$$T_e = PL_m(i_{dr} i_{qs} - i_{ds} i_{dr}) \quad (10)$$

$$\omega_r = \int \frac{P}{2J}(T_e - T_L) \quad (11)$$

3 Proposed New Switch Ladder Five Phase Multilevel Inverter

The basic structure shown in fig. 1 consist of two bidirectional switches (PW1 and TW1), six unidirectional switches (SW1, SW 2, SW 3, SW 4, SWx and SWy) and four DC sources V1,V1, V2 and V2. In this topology symmetric and asymmetric source are considered and the output levels are analysed. An asymmetric source gives higher output voltage with lesser inverter switches.

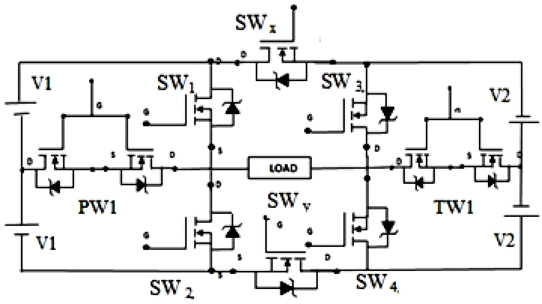


Fig.1 Basic structure of New SLMLI

Table 1 Switching conditions of proposed New SLMLI

No. of levels			Switching states						Output voltage (V)
	SW_X	SW_Y	SW_1	SW_2	SW_3	SW_4	PW_1	TW_1	
1	ON	OFF	ON	OFF	ON	OFF	OFF	OFF	0
2	OFF	ON	OFF	OFF	OFF	ON	ON	OFF	V_1
3	ON	OFF	OFF	OFF	ON	OFF	ON	OFF	$-V_1$
4	OFF	ON	OFF	ON	OFF	OFF	OFF	ON	V_2
5	ON	OFF	ON	OFF	OFF	OFF	OFF	ON	$-V_2$
6	OFF	ON	ON	OFF	OFF	ON	OFF	OFF	$2V_1$
7	ON	OFF	OFF	ON	ON	OFF	OFF	OFF	$-2V_1$
8	OFF	ON	OFF	ON	ON	OFF	OFF	OFF	$2V_2$
9	ON	OFF	ON	OFF	OFF	ON	OFF	OFF	$-2V_2$
10	OFF	ON	OFF	OFF	OFF	OFF	ON	ON	$V_1+ V_2$
11	ON	OFF	OFF	OFF	OFF	OFF	ON	ON	$-(V_1+ V_2)$
12	OFF	ON	ON	OFF	OFF	OFF	OFF	ON	$2V_1+ V_2$
13	ON	OFF	OFF	ON	OFF	OFF	OFF	ON	$-(2V_1+V_2)$
14	OFF	ON	OFF	OFF	ON	OFF	ON	OFF	$V_1+ 2V_2$
15	ON	OFF	OFF	OFF	OFF	ON	ON	OFF	$-(V_1+2 V_2)$
16	OFF	ON	ON	OFF	ON	OFF	OFF	OFF	$2V_1+2V_2$
17	ON	OFF	OFF	ON	OFF	ON	OFF	OFF	$-(2V_1+2 V_2)$

To perform bidirectional flow, the single switch (IGBT or MOSFET) with anti-parallel diode is used. In some cases, series connections of two single IGBTs are used and it can provide very good reverse blocking capability. Basically the series connection of two single IGBTs will increase the switching losses. Usually bi directional switches are used for both generation and regeneration and also higher current carrying capacity application. The switching conditions of the proposed topology are presented in table 1.

3.1 Algorithm for Determining Voltage Sources

The DC voltage sources value can be determined by using the following equation.

First SLMLI:

$$V_{11} = V_{12} = V_{dc} \tag{12}$$

The max. Output voltage of 1st SLMLI is;

$$V_{01,max} = (n+1)\,(V_{11}+V_{12}) \tag{13}$$

where 'n' is the number of bidirectional switches

Second SLMLI:

$$V_{21} = V_{22} = 2(V_{01,max}) + V_{dc} \tag{14}$$

$$V_{11} = V_{22} = (4n+5)\,V_{dc} \tag{15}$$

The max. Output voltage of 2nd SLMLI is;

$$V_{02,max} = (n+1)\,(V_{21}+V_{22}) \tag{16}$$

For the mth SLMLI:

$$V_{m1} = V_{m2} = (4n+5)^{m-1} V_{dc} \tag{17}$$

No. of levels produced by the this algorithm can be calculated as;

$$N_{level,FA} = (4n+5)^{m} \tag{18}$$

Where 'm' – No. of switches

Output voltage levels can be determined by using the general equation 18.

4 Proposed New SLMLI for Induction Motor

The new Switch Ladder Multilevel Inverter (SLMLI) for 5-ϕ IM circuit diagram is shown in the appendix. The circuit consists of five legs and each one consist of six unidirectional power switches (SW1, SW2, SW3, SW4, SWx and SWy) , two bidirectional switches(PW1 and TW1) and four dc voltage sources (V1, V1, V2 and V2). The voltage source can be symmetric or asymmetric dc sources. Asymmetric sources are considered because it can able to generate higher output voltage levels.

5 PWM Modulation Strategies

In this PWM, sinusoidal function is used as ref. signal and a triangular signal is used as carrier signal. If the magnitude of sinusoidal signal is greater than that of triangular signal pulses are produced. Magnitude and frequency modulations index for multilevel inverter can be expressed as follows.

$$ma = \frac{Vr}{(m-1)Vc} \tag{19}$$

Where, Vr – Magnitude of reference (sinusoidal) signal

Vc – Magnitude of carrier (triangular) signal

In general 'ma' varies between 0 and 1.

$$mf = \frac{Fc}{Fr} \tag{20}$$

Where,

Fc- Freq. of carrier (triangular signal)

Fr- Freq. of reference (sinusoidal signal)

6 Simulation and Result

Simulations of new SLMLI and VSI fed induction motor are carried out in MATLAB simulink and the SPWM is used for generating the pulses. Five phase voltage source inverter is simulated and output voltage is shown in fig. 2. Output voltage is not pure sinusoidal and the THD value is measured as 43.02%. FFT analysis is shown in fig. 3.

Fig. 2 Individual Phase voltages of five phase voltage source inverter

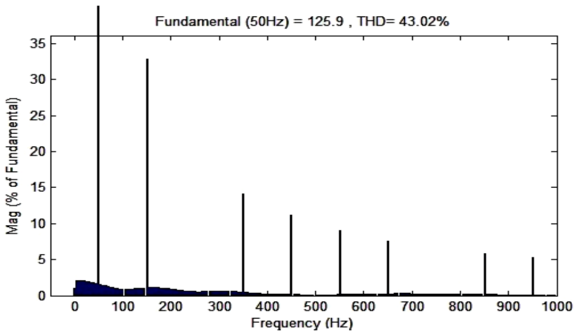


Fig. 3 THD value in Phase voltage of 5-ϕ voltage source inverter

The proposed new switch ladder multilevel inverter is simulated. In this technique the sine wave of suitable magnitude is compared with carrier signal. Sine wave magnitude of 8V is used. The carrier frequency of 1000 Hz is used. To generate a seventeen level inverter eight carrier signals are needed. The five phase SLMLI output voltages are shown in fig. 4 and 5 and the corresponding THD value is measured as 6.47% which is lesser than that of the five phase VSI. The FFT waveform of THD value is shown in fig. 6.

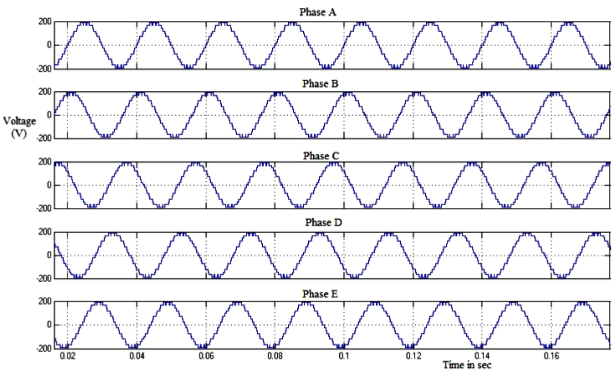


Fig. 4 Individual Phase voltage waveform of five phase SMLI

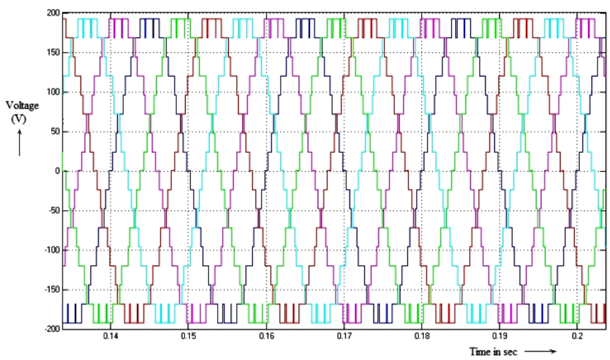


Fig. 5 five phase SLMI output phase voltage waveform

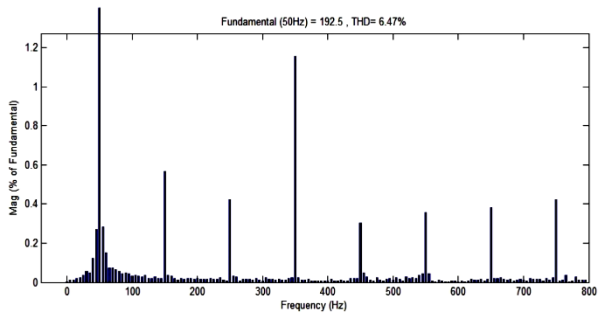


Fig. 6 THD in output voltage of five phase SLMI

The proposed novel Switch Ladder Multi Level inverter is connected to the 5-ϕ IM. The output response of induction machine is captured. Fig. 7 and 8 shows the stator currents and rotor currents of 5-ϕ IM and its values changing according to the changes in the load at 0.6 sec, 1.1 sec and 1.6 sec.

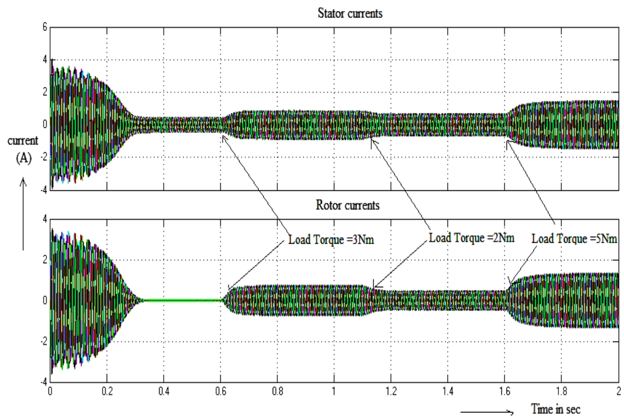


Fig. 7 Stator current and rotor current of 5-ϕ IM

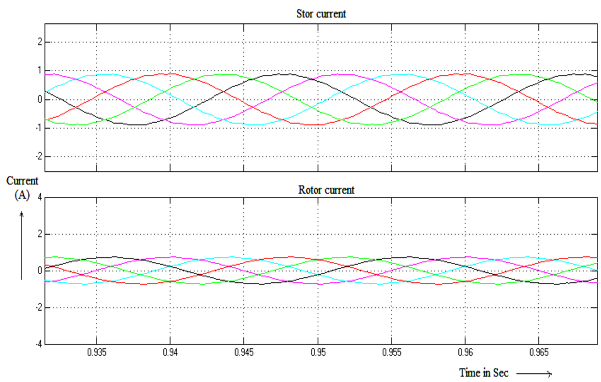


Fig. 8 Stator current and rotor current of 5-ϕ IM

Fig. 9 indicates the torque and speed response of induction motor which clearly indicates the effectiveness of the proposed new SLMLI for the induction motor. The torque and speed response of the machine changes according to the load changes of 3 Nm, 2 Nm and 5 Nm at 0.6 sec, 1.1 sec and 1.6 sec. respectively. The comparison of Output voltage and THD of VSI and new SLMLI are shown in table 2. These results shows that asymmetric configuration of proposed new SLMLI for five phase induction motor is found to be best topology.

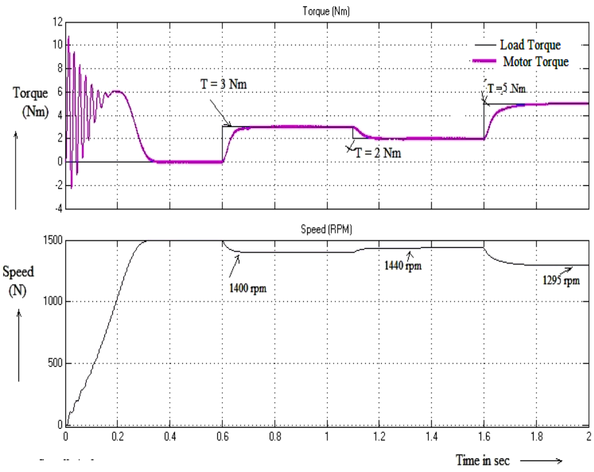


Fig. 9 Torque and speed response of five phase induction motor

Table 2 Comparison of THD values for VSI and SLMLI

Inverter Topology	Output Voltage THD (%)
VSI	43.02
SLMLI (Symmetric)	18.81
SLMLI (Asymmetric)	6.47

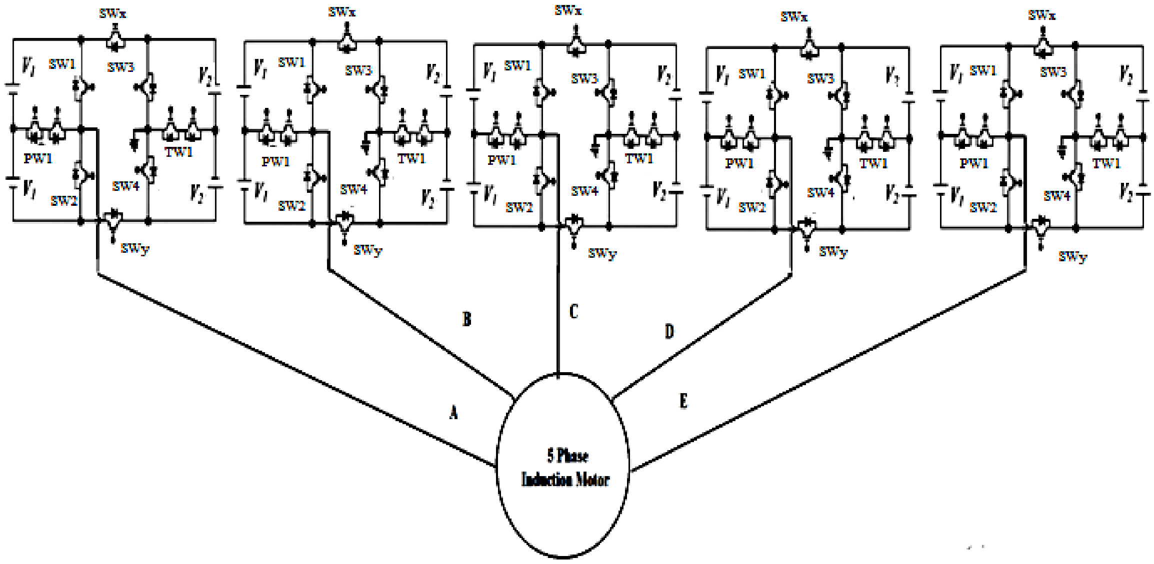
7 Conclusions

This paper mainly focused on improving the input voltage quality of five phase induction motor by proposing a new SLMLI. This inverter topology generates specific no. of output voltage with maximum no. of levels and with less no. of switching devices. The quality of output voltage of multilevel inverter is found to be superior when compared to the output voltage of VSI. The SPWM technique is used to generate the pulses for SLMLI fed 5-ϕ IM. The achievements of this SPWM technique are the reduction of THD for asymmetric configuration (6.47%) and its output voltage is close to the sine wave without any use of filters in the output of multilevel inverter. This helps to drive the five phase induction motor with distortion free environments.

Appendix 1

Five phase induction motor Parameters

Parameters		**Values**
Power (P)		1 hp
Voltage (V)		220
Phase		5
Freq. (f)		50
Number of Poles (p)		4
Stator	Resistance	10.1 Ω
	Inductance	9.854 Ω
Rotor	Resistance	0.833 Henry
	Inductance	0.833 Henry
Mutual	Inductance	0.782 Henry
Inertia		0.0088



Appendix 2 New Switch Ladder Multilevel Inverter fed 5-ϕ IM

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