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Analysis And Modeling Of New Modified Multilevel Inverter With PMSM Apllications

R.Yazhini, M.Jagabar Sathik,Dr. K.Ramani

Abstract-This paper presents a new modified multilevel inverter with PMSM based on PI control technique. The proposed multilevel inverter using minimum number of switches and DC source. Where conventional multilevel inverters required more number of components, it seem to more complex control circuitry and bulky. For this complexities we achieve to reduce the number of switches in this proposed multilevel inverter will also reduce switching losses and conduction losses. The Total Harmonics Distortion and electromagnetic interference will be reduced in the proposed multilevel Inverter. The Proposed multilevel inverter output voltage level increased by using minimum number of switches driven by the multicarrier modulation techniques..

Index Terms- *Cascaded H- bridge,Multilevel Inverter, multicarrier modulation, PMSM, PI controller.*

NOMENCLATURES

$V_{dc1}, V_{dc2} \ldots V_{dcn}$	-	*Input DC Voltages*
$V_{1,out}/V_{2,out} \ldots V_{n,out}$	-	*Output Voltage of H Bridge*
V_o	-	*Output Voltage of CascadedH-Bridge*
S_s	-	*Subsidiary Switches*
H_{S1}, H_{S2}, H_{S3}& H_{S4}	-	*H Bridge Switches*
D_1,D_2,D_3& D_4	-	*H Bridge Freewheeling Diode*
M	-	*Number of Output Voltage Level*
Ns	-	*Number of DC Sources*
$N_{Switches}$	-	*Number of IGBTs*
S_n	-	n^{th} *Subsidiary switch*
Kp, Ki	-	*Gain values*
Ld, Lq	-	*inductances of d and q axis*
V_{ds}, V_{qs}	-	*stator voltage of d and q axis*
i_{an},i_{bn},i_{cn}	-	*Three phase currents*
S(t)	-	*Switching function*
Rs	-	*Stator resistance of PMSM*
ω_r	-	*Speed of rotor*
i_{ds}, i_{qs}	-	*Stator current in d and q axis*
Ψ_f	-	*flux linkage*

- *Yazhini. R. is currently pursuing masters degree program in power electronics and drive in J.J.college of engineering and technology,Trichy, Mobile-+91 9788953138. E-mail: yazhiniravi91@gmail.com*
- *Jagabar Sathik. M. is currently working as an Assistant Professor in the department of EEE at J.J College of Engineering and Technology, Trichy, Mobile- +91 9500525422. E-mail: jagabarsathik@gmail.com*

1 INTRODUCTION

Multilevel inverter has a very significant role in the area of high-power medium-voltage control. The desired multi-staircase output voltage is acquired by combining several dc voltage sources. Currently, there occur three commercial topologies of multilevel voltage-source inverters are as follows:

i. Neutral point clamped(NPC)
ii. Flying capacitor(FC)
iii. Cascaded H-bridge(CHB)

For these topologies the voltage level is increased by increasing the number of switches. Hence there will be switching losses and voltage stresses in these topologies and the circuit will become more complex. By using the proposed topology number of switches will reduce significantly and hence the efficiency will improve. [1,2].

The most attractive features of multilevel inverters are as follows:

i. They have very low harmonic distortion.
ii. They can operate with a lower switching frequency.
iii. Reduced Voltage Stress.
iv. Reduced switching loss, conduction loss and electromagnetic interference.

Permanent Magnet Synchronous Motor (PMSM) is widely used for exact speed and torque control, better efficiency, and higher torque to inertia ratio and high power density [6,9]. The implementation of PMSM with the voltage source inverter means for the conversion of electric energyfrom DC to AC. The main performance of the inverter is influenced by the PWM technique, the switching losses and conduction losses [4].PMSM has various advantages over other machines that are conventionally used for ac servo drives. PMSM drives are widely used for high-

performance servo applications like robotics and aerospace actuators. There is no need of supplying magnetizing current through the stator for constant air gap flux due to the presence of permanent magnet in the rotor of the PMSM.
Because of the absence of magnetizing current, the PMSM will work at a higher power factor for the same output and will be more efficient than the IM. To make PMSM highly efficient there is no need of slip rings for external excitation given to rotor and there will be low maintenance and losses in the rotor. [3,7,12].

2. PROPOSED MULTILEVEL INVERTER

The new topology produces a significant reduction in the number of power devices and capacitors required to implement a multilevel output. The new topology is used in the design of a seven-level inverter; only seven controlled switches and three capacitors are required to implement the seven-level inverter using the proposed topology. In this topology, three voltage split capacitors are used so, each phase needs just one dc voltage source. The two parts in the proposed topology are, the conventional H-bridge operates at high switching frequency and the subsidiary switches which operates in low switching frequency. This topology achieves a reduction of 42% of switches than the conventional converter.

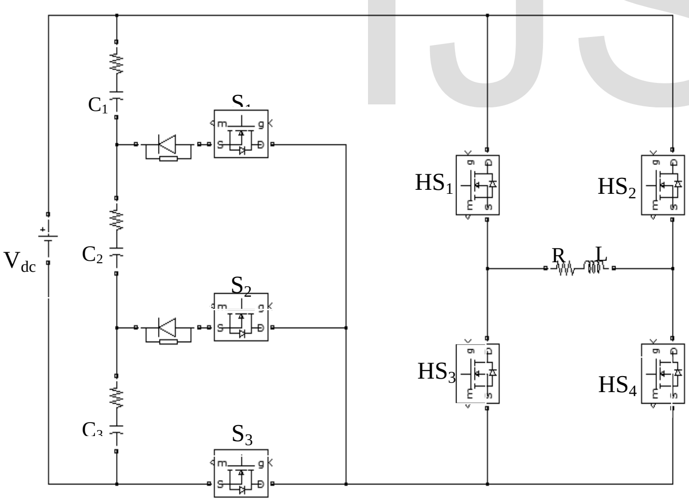

Fig. 1. Proposed seven level inverter

3. OPERATION

For positive cycle the switches HS1 and HS4 in the conventional H-bridge and the subsidiary switch S_1 , S_2 and S_3 turned ON to obtain the desired voltage levels V_{dc}, $2V_{dc}$ and $3V_{dc}$ correspondingly. For negative cycle the switches HS_2 and HS_3 in the conventional H-bridge and the subsidiary switch S_1, S_2 and S_3 turned ON to obtain the desired voltage levels $-V_{dc}$, $-2V_{dc}$ and $-3V_{dc}$ correspondingly.

Table. 1. Various switching sequence for seven level output

Switches / Levels	H_{S1}	H_{S2}	H_{S3}	H_{S4}	S_1	S_2	S_3	Voltage Level
Positive Cycle Stepped Levels	1	0	0	1	1	0	0	$+V_{dc1}$
	1	0	0	1	0	1	0	$+V_{dc2}$
	1	0	0	1	0	0	1	$+V_{dc3}$
Zero State	0	0	0	0	0	0	0	0
	1	0	1	0	0	0	0	
Negative Cycle Stepped Levels	0	1	1	0	1	0	0	$-V_{dc1}$
	0	1	1	0	0	1	0	$-V_{dc2}$
	0	1	1	0	0	0	1	$-V_{dc3}$

4. MODELING OF THE PROPOSED SYSTEM

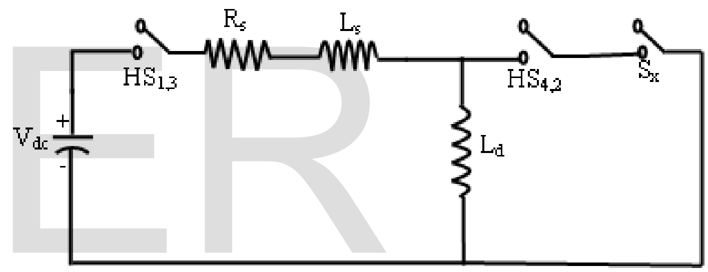

Fig. 2. Equivalent circuit of the proposed system

The State space equations illustrate the dependency of the switches, input and output equations. S(t) is Switching function w.r.t time. The state Space representation of the above circuits is,

$$i_1R_1 + L_1\frac{di_1}{dt} = V_{dc} * S(t) - (1)$$

$$i_2R_2 + L_2\frac{di_2}{dt} = V_{dc2} * S(t) - (2)$$

$$i_2R_2 + L_3\frac{di_3}{dt} = V_{dc3} * S(t) - (3)$$

$$\dot{X} = AX + BU - (4)$$

From the above equations the switching state of positive and negative cycle expressions can be written as,
(i). **Positive Cycle:** The state space equation can be written as

$$S_n(t) = \sum_{n-1}^{\frac{no.oflevels-1}{2}} -\frac{R^3}{L^2} * i_n * \frac{1}{nV_{dc}} - (5)$$

(ii).**Negative Cycle**: The state space equation can be written as

$$S_n(t) = \sum_{n-1}^{\frac{no.oflevels-1}{2}} \frac{R^3}{L^2} * i_n * \frac{1}{nV_{dc}} -(6)$$

Where n= 0, 1, 3, 5…. M
The three phase current are expressed as,

$$i_{an} = \left(L^2 * V_{dc} * \sin(\omega t)\right) / \left(n * R^3\right) -(7)$$

$$i_{bn} = \left(L^2 * V_{dc} * \sin(\omega t - (2\Pi/3))\right) / \left(n * R^3\right) -(8)$$

$$i_{cn} = \left(L^2 * V_{dc} * \sin(\omega t + (2\Pi/3))\right) / \left(n * R^3\right) -(9)$$

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ \frac{1}{\sqrt{3}} & \frac{2}{\sqrt{3}} & 0 \end{bmatrix} \begin{bmatrix} i_{an} \\ i_{bn} \\ i_{cn} \end{bmatrix} -(10)$$

$$i_d = -\left(L^2 * V_{dc} * \sin(\gamma - \varpi t)\right) / \left(n * R^3\right) -(11)$$

$$i_q = -\left(L^2 * V_{dc} * \cos(\gamma - \varpi t)\right) / \left(n * R^3\right) -(12)$$

Modeling of PMSM:

The modeling of PMSM is vital for proper simulation of the system. The d-q model on the rotor reference frame is developed. Make the rotor d-axis as zero in the reference frame and the rotor angle θ_r is combined with the q-axis current to form the reference current I_{rabc}. Stator mmf rotates at the same speed as that of the rotor.
The mathematic model of PMSM is based on the following assumptions [5,8,11]

1. Neglecting the saturation of armature;
2. Neglecting the wastages of eddy and magnetic hysterics;
3. There is no rotor damp resistance.

Voltage equations of PMSM are,

$$\begin{bmatrix} v_{ds} \\ v_{qs} \end{bmatrix} = \begin{bmatrix} R_s + pL_d & -\omega_r L_q \\ \omega_r L_d & R_s + pL_q \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} -(13)$$

$$V_{ds} = \left(R_s + pL_d\right) i_{ds} - \left(\omega_r L_q\right) i_{qs} -(14)$$

$$V_{qs} = \left(\omega_r L_d\right) i_{ds} + \left(R_s + pL_q\right) i_{qs} -(15)$$

$$where\ p = \frac{d}{dt},$$

$$V_{ds} = R_s i_{ds} + \frac{dL_d}{dt} i_{ds} - \omega_r L_q i_{qs} -(16)$$

$$V_{ds} = \omega_r L_d i_{ds} + R_s i_{qs} + \frac{dL_q}{dt} i_{qs} -(17)$$

$$\frac{dL_d}{dt} i_{ds} = R_s i_{ds} - V_{ds} - \omega_r L_q i_{qs} -(18)$$

$$\frac{dL_q}{dt} i_{qs} = R_s i_{qs} - V_{qs} - \omega_r L_d i_{ds} -(19)$$

$$\dot{i}_{ds} = \frac{R_s}{L_d} i_{ds} - \frac{v_{ds}}{L_d} - \omega_r \frac{L_q}{L_d} i_{qs} -(20)$$

$$\dot{i}_{qs} = \omega_r \frac{L_d}{L_q} i_{ds} - \frac{v_{qs}}{L_q} - \frac{R_s}{L_q} i_{qs} -(21)$$

Combined equation of multilevel inverter and PMSM

$$\begin{bmatrix} \dot{i}_{ds} \\ \dot{i}_{qs} \end{bmatrix} = \begin{bmatrix} \frac{R_s}{L_d} & -\omega_r \frac{L_q}{L_d} \\ \omega_r \frac{L_d}{L_q} & \frac{R_s}{L_q} \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} + \begin{bmatrix} -\frac{1}{n} \sin(\gamma - \omega) \\ -\frac{1}{n} \cos(\gamma - \omega) \end{bmatrix} \begin{bmatrix} -\frac{1}{L_d} \\ -\frac{1}{L_q} \end{bmatrix} \begin{bmatrix} v_{ds} \\ v_{qs} \end{bmatrix} -(22)$$

5. PI CONTROLLER

PI regulators are also employed for motor control whereas a PI controller is used in a closed control loop which controls position, speed, torque, current or voltage of the system. Hence PI controller reacts to an error signal and tries to regulate the controlled quantity to attain the desired system response. Generally PMSM is a nonlinear system with multiple coupled states and parameter variations [5,12]. Hence it is difficult to obtain a adequate high performance using linear control algorithms. PI control was widely used for speed control where the difference between the reference speed and the actual speed are calculated and an error is produced, which is fed to the PI controller [10]. The output produced by the proportional gain will be proportional to the input error and an integration will be taken to obtain the steady state error as zero.

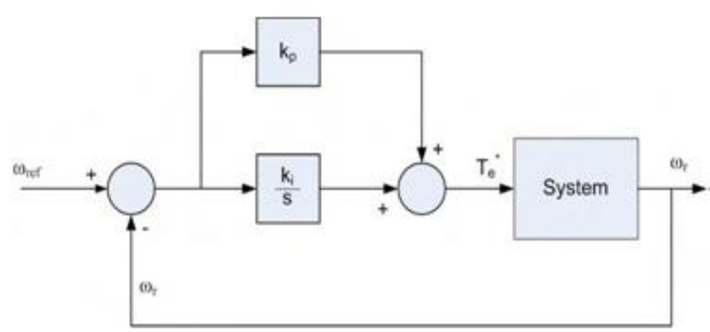

Fig. 3. PI controller

For determining the proportional and integral constants of the controller, the K_p and K_i values are given as,

$$K_p = 2\pi\left[\frac{\varphi_f}{i_{qs}} + \left(L_{sd} - L_{sq}\right)\right]$$

$$k_i = \sqrt{\left(1 - \omega_r \frac{L_d}{L_q} i_{ds} + \frac{v}{n}\cos(\gamma - \omega) + \frac{V_{qs}}{V_{ds}}\right)\frac{L_q}{R_s}}$$

6. MODULATION TECHNIQUE

A common method of multicarrier PWM technique called Phase Disposition (PD) method is applied to the multilevel inverter and can be drawn-out to any number of voltage levels. Among the various carrier based modulation technique PD has better performance than others. In PD method all the carrier waveforms must be in phase with the reference. Here number of levels will be 'm' then the carrier waveforms must be in the condition of (m-1). For example, the level is 5 then there are 4 carrier waveforms are arranged, so that all carrier waveforms are in phase. Hence for $+V_{dc}$ when the reference is greater than both carrier waveforms. If the inverter is switched to zero when the reference is greater than the lower carrier waveform but less than the upper carrier waveforms. For -Vdc the reference will be less than both carrier waveforms.

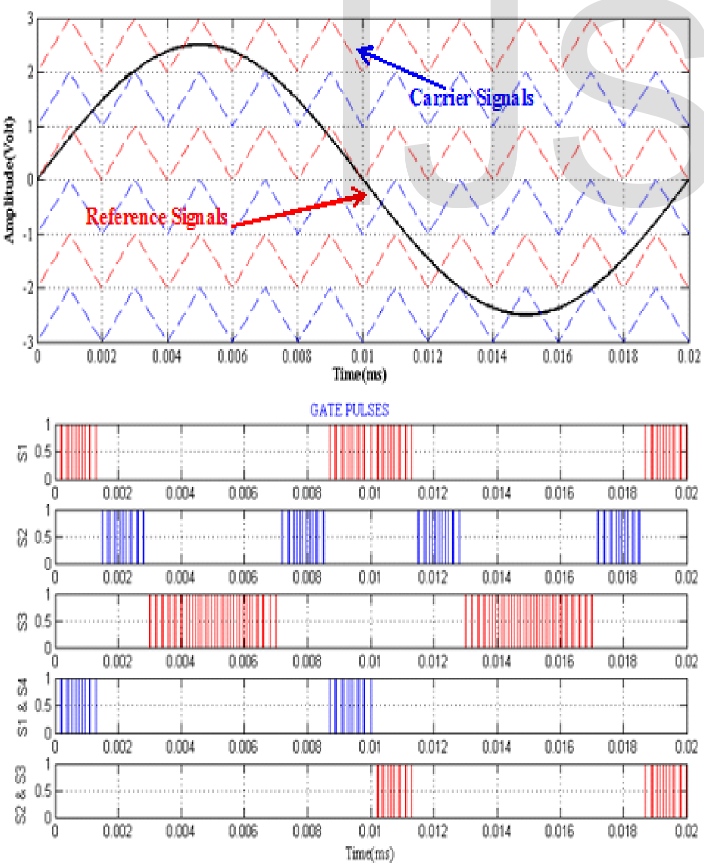

Fig. 4: Modulation Waveform of Phase Disposition PWM

7. SIMULATION RESULTS

The newly developed multilevel inverter topology has been simulated with the help of MATLAB/Simulink2009b. The simulation was carried out using speed control to study the performance of the motor drive. The closed loop speed control for PMSM drive is achieved by using PI controller. Speed is taken as reference and the desired speed obtained from the PMSM is compared with it, an error is produced which is fed to the PI controller. Output of the controller will be the current i_q and i_d is assumed to be zero. By using inverse park transformation the dq0 values are transformed to three phase reference current $I_{r\text{-}abc}$ which is compared with the feedback current I_{abc}. The reference and feedback current are compared and the output is fed to the multilevel inverter. Then the speed of the multilevel inverter is controlled using the close loop control technique

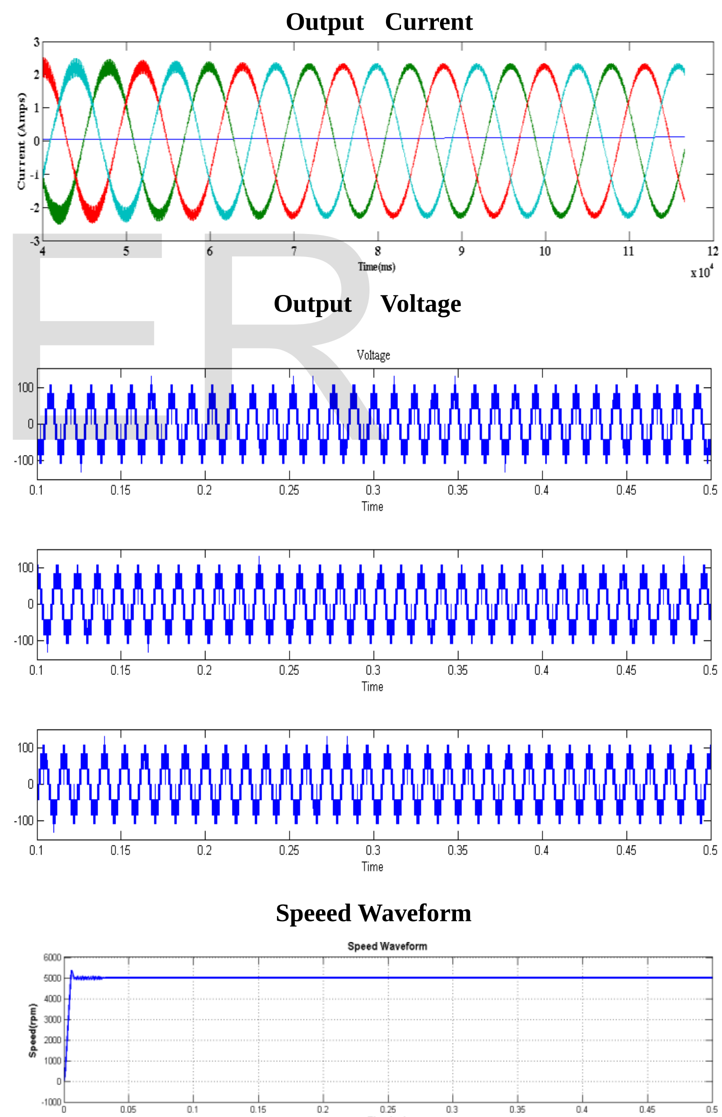

Fig. 5. Simulation Output Waveforms

8. Conclusion

The proposed new modified multilevel inverter fed PMSM using reduced number of switches was developed. The proposed topology shows that the switching devices and gate driver circuits need not required more numbers. The size of the proposed multilevel inverter is smaller than the other multilevel inverters. The Conduction losses and switching losses are reduced. The overall cost will be reduced by reducing the number of main switches and control circuits etc. The outputs are verified by simulation model developed using the Matlab/Simulink software.

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Bibliographies

R.Yazhini was born in Tamilnadu, India, on March 10, 1991. She received her B.E degree in Instrumentation and Control Engineering from A.V.C. College of Engineering, Mayiladuthurai, in 2012; currently she is doing M.E degree in Power Electronics and drives from J.J. College of Engineering and Technology, Trichy. Her current research interests include simulation of multilevel inverters, Ac Drives and Control System.

M. M.Jagabar Sathik is Post graduated in 2004 from Anna University, Chennai. He is currently working as an Assistant Professor in the department of EEE at J.J College of Engineering and Technology, Trichy from January 2011 onwards. Currently he is pursuing Ph.D from Anna University, Chennai and he has presented 4 papers in various international conferences/Journals. His current research interests include Power Converters, AC Drives, FACTS and Optimization.

K.Ramani is graduated in 2004 from Bharathiar University, Coimbatore and post graduated in 2006 at Anna University, Chennai. He received his Ph.D from Anna University Chennai. He is currently working as an Associate Professor in the department of EEE at K.S.Rangasamy College of Technology, Tiruchengode from January 2006 onwards. He received the 2013 Young Teacher Award from the AICTE.He published more than 15 international/national conferences and journals. His research interests involve power electronics converters, modeling of induction motor and optimization techniques. He is guiding UG, PG Students. He is an ISTE, IETE member