Performance & Analysis of Single-Phase Inverter Fed Three-phase Induction Motor Drives

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Abstract

In the proposed approach, instead of a conventional 3- Phase inverter a component minimized single phase inverter is utilized which reduces the cost of the inverter, the switching losses, and the complexity of interface circuits to generate logic signals. A performance comparison of the proposed inverter fed drive with a conventional 3Phase inverter fed drive is also mode in terms of speed response and total harmonic distortion (THD) of the stator current. The proposed inverter fed IM drive is found acceptable considering its cost reduction and other advantageous features.
A general pulse width modulation (PWM) method for control of 1-phase inverters is presented. The vector PWM offers a simple method to select three or four vectors that effectively synthesize the desired output voltage, even in presence of voltage oscillations across the two dc-link capacitors. The influence of different switching patterns on output voltage symmetry, current waveform, switching frequency and common mode voltage can be examined. The paper also discusses how the use of the wye and delta connections of the motor windings affects the implementation of the pulse width modulator.

Keywords: phase inverter, total harmonic distortion; vector PWM, induction motor, different switching pattern

INTRODUCTION

Over the years induction motor (IM) has been utilized as a workhorse in the industry due to its easy build, high robustness, and generally satisfactory efficiency [I]. With the invention of high speed power semiconductor devices three-phase inverters play the key role for variable speed ac motor drives. Traditionally, 6-switch, 3-phase (6S3P) inverters hive been widely utilized for variable speed Induction motor drives. This involves the losses of the six switches as well as the complexity of the control algorithms and interface circuits to generate six PWM logic signals In the past, researchers mainly concentrated on the development of the efficient control algorithms for high performance variable speed IM drives [3] However, the cost, simplicity and flexibility of the overall drive system which become some of the most important factors did not get that much attention to the researchers. That's why, despite tremendous research in this area most of the developed control system failed to attract the industry. Thus, the main issue of this paper is to develop a cost effective, simple and efficient high performance IM drive. This paper presents a general method to generate pulse width modulated (PWM) signals for control of four-switch, three phase voltage source inverters, even when there are voltage oscillations across the two dc-link capacitors. The method is based on the so called space vector modulation, and includes the scalar version. The proposed method provides a simple way to select either three, or four vectors to synthesize the desired output voltage during the switching period. In the proposed approach, the selection between three or four vectors is parameterized by a single variable. This permits to implement all alternatives, thus allowing for a fair comparison of the different modulation techniques. The paper also discusses how the use of the wye and delta connections of the motor windings affects the implementation of the pulse width modulator. The utilization of an induction motor, with its windings connected in delta is studied here as an alternative to reduce the dc link voltage used, in respect to the Wye connections. For the Wye connections it is investigated, how the common-mode voltage can be reduced. The reduction of the common mode voltage permits to mitigate effects of common mode currents, which commonly are responsible for damage of motor bearings and bearing lubrication Simulation and experimental results illustrate the use of the FSTPI to supply a three-phase induction motor. Most of the reported works on 4S3P inverter for machine drives did not consider the closed loop vector control scheme, which is essential for high performance drives [4]. Usually, high performance motor drives used in robotics, rolling mills

,machine tools, etc. require fast and accurate response, quick recovery of speed from any disturbances and insensitivity to parameter variations. The dynamic behavior of an ac motor can be significantly improved using vector control theory where motor variables are transformed into an orthogonal set of d-q axes such that speed and torque can be controlled separately**.** This gives the IM machine the highly desirable dynamic performance capabilities of a separately excited dc machine, while retaining the general advantages of the ac over dc motors

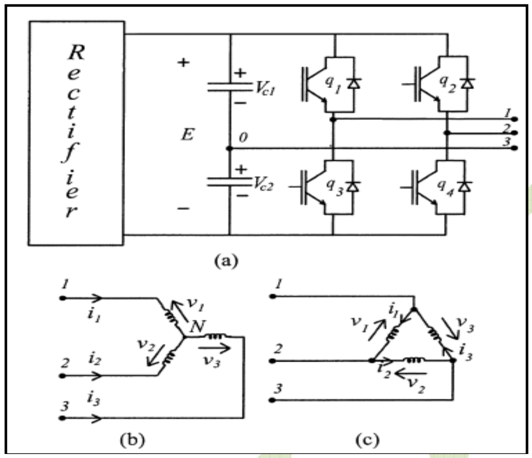


Fig. 1. AC drive system configurations

The 4 switches makes the inverter less cost, less switching losses, less chances of destroying the switches due to lesser interaction among switches, less complexity of control algorithms and interface circuits as compared to the conventional 6S3P inverter. The performance of the proposed drive is investigated both theoretical and experimentally at different operating conditions. Performance comparison of the proposed 4-switch 3-phase inverter fed drive with a conventional 6-switch, 3-phase inverter fed drive is also made in terms of total harmonic distortion (THD) of the stator current and speed response. The proposed inverter fed IM drive is found acceptable considering its cost reduction and other advantageous features mentioned earlier.

MODELING OF THE DRIVE SYSTEM AND CONTROL APPROACH

The complete drive system modeling involves the modeling of the IM, inverter and the controller, which are discussed in the following subsections:

Inverter model:

Fig. 1 presents the circuit diagrams of the four-switch three-phase dc/ac converter when fed by a single-phase or a three-phase diode rectifier. Two different single-phase input topologies are shown in Fig. 1(a) and (b) while a three-phase solution is shown in Fig. 1(c). The B4 inverter employs four switches and four diodes to generate two line-to-line voltages Vab & Vac whereas Vbc is generated according to Kirchhoff's voltage law from a split capacitor bank. Due to the circuit configuration, the maximum obtainable peak value of the line-to-line voltage equals Vdc/2.In order to get a higher dc-link voltage, an input transformer can be considered as shown in Fig. 1(c) or in the single-phase version one wire is connected to the dc bus as shown in Fig. 1(b).

The power circuit of the IM fed from 4S3P voltage-source inverter is shown in Fig. 3 (a). The circuit consists of two parts; first part is afront-end rectifier powered from single-phase supply. The output dc voltage is smoothed through a two series connected capacitors. The second part of the power circuit is the three-phase four-switch inverter.The maximum obtainable peak value of the line voltages equals Vdc, in the analysis, the inverter switches are considered as ideal switches.The output voltages are defined by the gating signals of the two leg switches and by the two dc link voltages, Vdc.The phase voltage equations of the motor can be written as a function of the switching logic of the switches and the dc-link voltage Vdc [5] by the following equations

Where,

Va, Vb, Vc inverter output voltages;
Vdc voltage across the dc link capacitors
Sa, Sb switching function for each phase leg

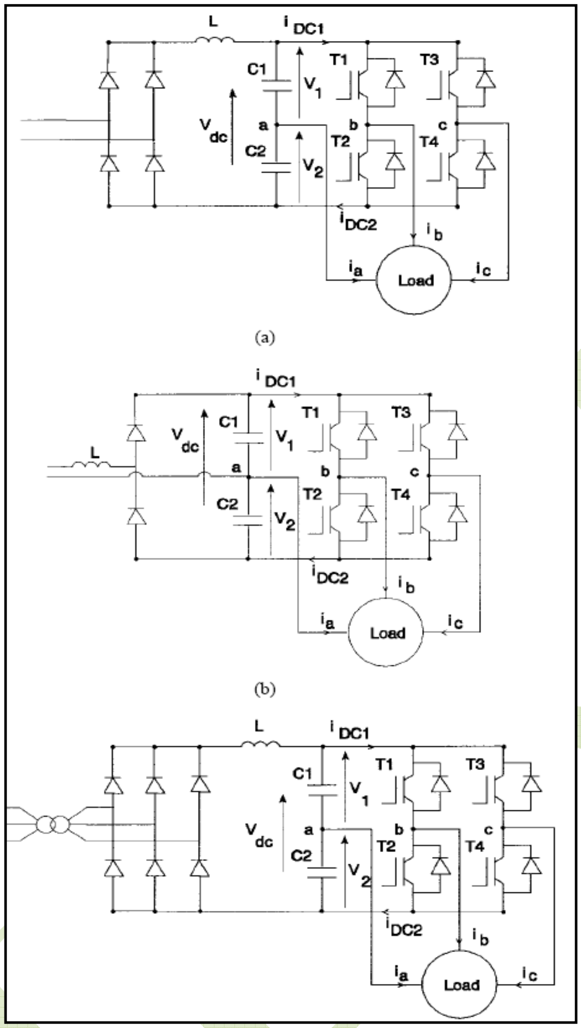


Fig. 2.Converter circuit diagram for a B4 inverter. (a) Single-phase diode rectifier and low dc-link voltage. (b) Single-phase diode rectifier and high dc-link voltage. (C) Three-phase rectifier.

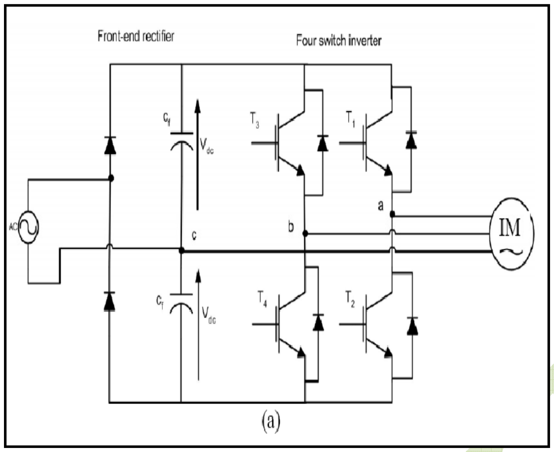
$$V_a = \frac{V_{dc}}{3}\left[4S_a - 2S_b - 1\right] \qquad (1)$$

$$V_b = \frac{V_{dc}}{3}\left[4S_b - 2S_a - 1\right] \qquad (2)$$

$$V_c = \frac{V_{dc}}{3}\left[-2S_a - 2S_b + 1\right] \qquad (3)$$

If Sa = 1 then T_1 is on and T_2 is off;
If Sa = 0 then T_1 is off and T_2 is on.
If S_b = 1 then T_3 is on and T_4 is off;
If Sb = 0 then T_3 is off and T_2 is on.
In matrix form above equation can be written as

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{V_{dc}}{3}\begin{bmatrix} 4 & -2 \\ -2 & 4 \\ -2 & -2 \end{bmatrix}\begin{bmatrix} S_a \\ S_b \end{bmatrix} + \frac{V_{dc}}{3}\begin{bmatrix} -1 \\ -1 \\ 2 \end{bmatrix} \qquad (4)$$



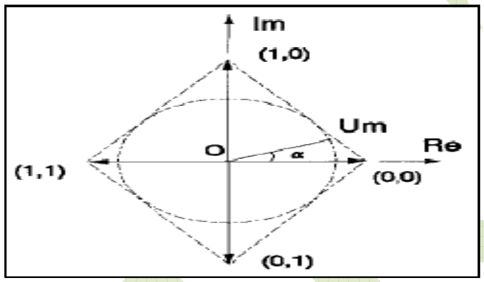


Fig. 3. (a) IM fed from 3P4S inverter;
(b) Switching vectors for 4-switch inverter.

For a balanced capacitor voltages, the four switching combinations lead to four voltage vectors as shown in Fig. 3(b) [5]. Table I shows the different mode of operation and the corresponding output voltage vector of the inverter by which we can come to know the exact amplitude of the line voltage of the inverter

Inverter Modes of Operation

Switching functions		Switch on		Output voltage		
sa	sb			Va	Vb	vc
0	0	T2	T4	-Vdc/3	-Vdc/3	2vdc/3
0	1	T2	T3	Vdc	vdc	-2vdc
1	0	T1	T4	Vdc/3	Vdc/3	-3vdc/3
1	1	T1	T3	Vdc/3	Vdc/3	-2vdc/3

Table I: it gives the Value of line voltage of the inverter at different switching cycles

IM Model

The mathematical model of a three-phase, Y-connected induction motor and the load is given by the following equations in the de-qe synchronously rotating reference frameas [1].
Where

VedsVeqs q, d-axis stator voltages,
Ieds,ieqs, q,d-axis stator currents,
iedrieqr q,d-axis rotor currents,
Rs,Rr stator and rotor resistances per phase
Lm mutual inductance,
ω r The rotor speed,
P number of poles,
p differential operator,

Te electromagnetic developed torque, TL loadtorque,*Jm*is the rotor inertia, *Bm* rotor damping Coefficient
θ rotor position.

$$\begin{bmatrix} v_{qs}^e \\ v_{ds}^e \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + pL_s & \omega_e L_s & pL_m & \omega_e L_m \\ -\omega_e L_s & R_s + pL_s & -\omega_e L_m & pL_m \\ pL_m & (\omega_e - \omega_r)L_m & R_r + pL_r & (\omega_e - \omega_r)L_r \\ -(\omega_e - \omega_r)L_m & pL_m & (\omega_e - \omega_r)L_r & R_r + pL_r \end{bmatrix} \begin{bmatrix} i_{qs}^e \\ i_{ds}^e \\ i_{qr}^e \\ i_{dr}^e \end{bmatrix} \tag{5}$$

$$T_e = \frac{3}{2}\frac{P}{2} L_m \left(i_{qs}^e i_{dr}^e - i_{ds}^e i_{qr}^e \right) \tag{6}$$

$$T_e = T_L + J_m \frac{d\omega_r}{dt} + B_m \omega_r \tag{7}$$

$$d\theta r \big/ dt = \omega_r \tag{8}$$

The motor parameters are given in the Appendix [2]

Controller Model

Two independent sinusoidal band hysteresis current controllers are used to force the phases 'a' and 'b' currents to follow their commands [9]. These commands are generated from the vector control and speed control loops as shown in Fig. 2. The outputs of the controllers are in the form of four logics. Those logics are used to switch on and off the inverter power switches. In the speed control loop, a conventional PI controller is used to regulate the speed to follow its command speed. The PI controller gains are obtained by trial and error (*k p* = 0.3, *ki*= 0.05) compromising between the settling time and overshoot/undershoot so that all of them can be in acceptable ranges.

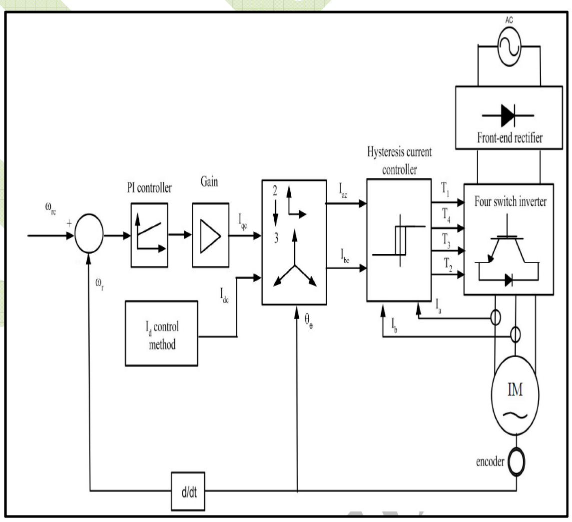


Fig.No. 4 Proposed Control Scheme

The proposed vector control scheme is shown in Fig. 2. The speed error is processed through a PI controller to generate the torque producing component of the stator current (i_q^*). The magnetizing component of the stator currents i_d^* along with i_q^* are then used to generate the reference currents i_a^*, i_b^*, and i_c^*. The reference currents are formulated as follows:

$$i_a^* = i_d^* \cos\theta - i_q^* \sin\theta \qquad (8)$$

$$i_b^* = i_d^* \cos(\theta - 120^0) - i_q^* \sin(\theta - 120^0) \qquad (9)$$

$$i_c^* = i_d^* \cos(\theta - 240^0) - i_q^* \sin(\theta - 240^0) \qquad (10)$$

Two independent hysteresis current controller with a suitable hysteresis band are used to command the motor currents i_a, and $i_b$to follow the reference currents. The hysteresis controllers also generate four switching signals which will fire the power semiconductor devices of the three phase inverter to produce the actual voltages to the motor.

SIMULATION & RESULTS

In order to verify the effectiveness of the proposed inverter configuration and its control strategy, first acomputer simulation model is model developed inMATLAB/Simulink software

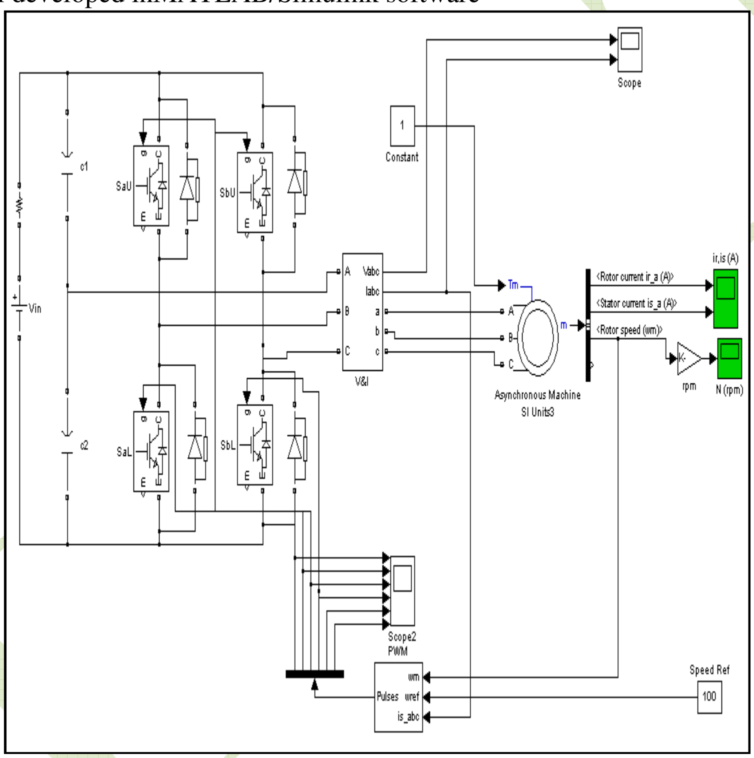


Fig. Simulation Model

Simulation Results

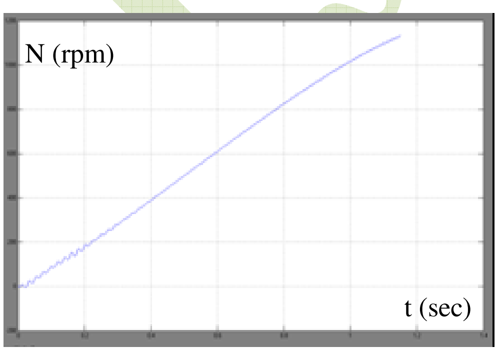


Fig.(a)

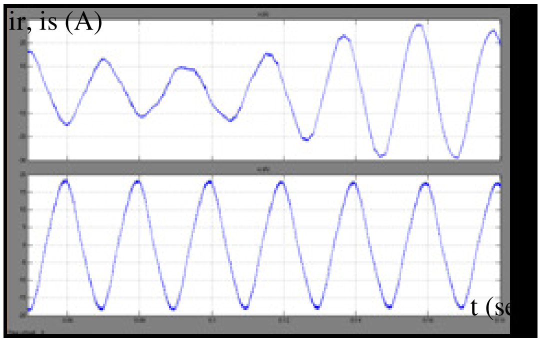


Fig. (b)

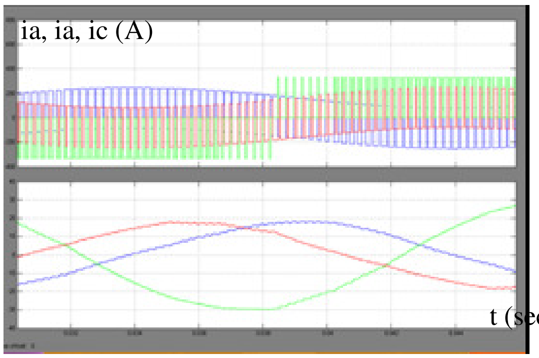


Fig.(c)

Fig.No.5 Simulation Response of Proposed Inverter
Fig.(a) Speed, Fig.(b) Current is,ir,Fig.(c) Steady state 3phase currents

CONCLUSIONS

The proposed control approach reduces the cost of the inverter, the switching losses, and the complexity of the control algorithms and interface circuits as compared to the conventional 6Switch 3Phase inverter based drive. The vector control scheme is incorporated in the integrated drive system to achieve high performance. The performance of the proposed drive is investigated both theoretically and experimentally at different operating conditions. A performance comparison of the proposed 4S3P inverter fed drive with a conventional 6S3Pinverter fed drive is also made interms of the stator current and speed response. The proposed 4S3P inverter fed IM drive isfound acceptable for high performance industrial variable speed drive applications considering its cost reduction and other advantageous features

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