Three Level Diode Clamped Inverter for Field Oriented Control of Induction Motor

K.K.Prabhakaran,S.Shyam KumarN.Manoj Kumar

Abstract-Indirect Field Oriented Control is a control technique used in AC drive systems to obtain high performance torque control. Sine pulse width Modulation is used for control the three level diode clamped inverter. In these applications, a rotational transducer such as a shaft encoder senses the speed of rotor. PI controller is then used to alter the firing pulse of three level diode clamped inverter regulate the output voltage to achieve the reputed stator current. The work of this project is to study and evaluate the FOC with open loop and close loop control of three level diode clamped inverter applied to the induction machines through simulations. The simulations were carried out using PSIM simulation package.

Keywords–Three level diode clamped inverter, Induction Motor, Field oriented control.

I. INTRODUCTION

The field-oriented control method is widely used for induction motor drives [10]. Three level diode clamped inverter [9] is used for fixed Dc supply to Ac supply. This Ac supply is used to drive the Induction Motor [5]. The rotor flux orientation in a squirrel-cage induction machine cannot be measured easily. It can be only estimated from terminal measurements. An alternative way is to use the slip relation derived above to estimate the flux position relative to the rotor [7]. The IFOC technique is described in this application note. Indirect vector control of the rotor currents can be implemented using Instantaneous stator phase currents ia, ib, and ic and Rotor mechanical speed. To monitor the three-phase stator currents and speed, the motor must be equipped with sensors and a speed feedback device such as a tachometer respectively.PI controller is then used to alter the firing pulse of three level diode clamped inverter regulate the output voltage to achieve the reputed stator current [11].The work of this project is to study and evaluate the FOC with open loop and close loop control of three level diode clamped inverter applied to the induction machines [3] through simulations.

The rest of this paper is organized as follows. Section II describes Sinusoidal PWD. Section III describes FOC Algorithm. Section IV describes simulation and results. Section V concludes the paper and points out some future work.

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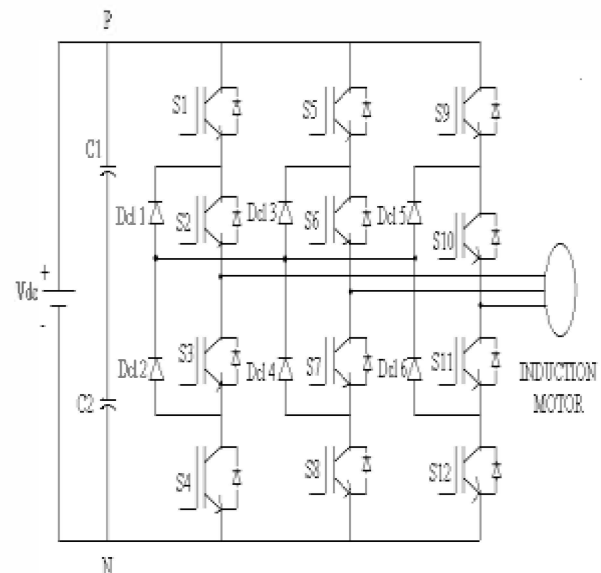N.Manoj Kumar, Assistant Professor, R.M.K. Engineering College, Tamilnadu, India.

Fig.1. Structure of 3-phase, 3-level diode clamped inverter

TABLE I
SWITCHING STATES OF 3-LEVEL DIODE CLAMPED INVERTER

VD	Sa1	Sa2	Sa3	Sa4
V3=Vdc	1	1	0	0
V2=Vdc/2	0	1	1	0
V1=0	0	0	1	1

II.SINUSOIDAL PWM

In this scheme, three sinusoidal reference waves each shifted by 120° are used. A triangular carrier wave is compared with the reference signal corresponding to a phase to generate the gating signals for that phase [2]. Magnitude and frequency of resultant wave is dependent on the magnitude and frequency of carrier wave. In the present configuration, modulation index (which is a ratio of peak value of reference wave to peak value of carrier wave) is varied in the range 0.7-0.95. Reference wave, carrier wave and resultant pulses that are generated can be viewed in Figure 2.1.
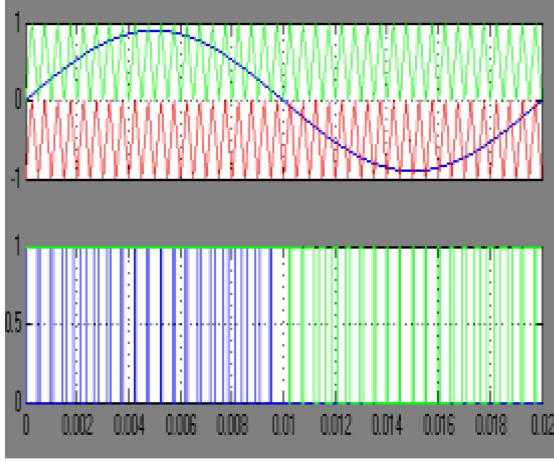
Fig 2.1.Sinusoidal PWM Technique

III THE FOC ALGORITHM

An abbreviated version of the FOC (or vector-control) algorithm is summarized below:

1. Measure the stator phase currents i_a, i_b and i_c. If only the values of i_a and i_b are measured i_c can be calculated as for balanced current $i_a + i_b + i_c = 0$.

2. Transform the set of these three-phase currents onto a two-axis system. This conversion provides the variables i_α and i_β from the measured i_a, i_b and ic values where i_α and i_β are time-varying quadrature current values, as viewed from the stator's perspective. This conversion is popularly known as Clarke Transformation.

3. Calculate the rotor flux and its orientation.

4. Rotate the two-axis coordinate system such that it is in alignment with the rotor flux, using the transformation angle calculated at the last iteration of the control loop. This conversion provides the i_d and i_q variables from i_α and i_β. This step is more commonly known as the Park Transformation.

5. Flux error signal is formed using flux reference and estimated flux value. A PI controller is then used to calculate i^*_d using this error signal. i^*_q is generated using the reference torque value and the estimated flux value.

6. i^*_d and i^*_q are converted to a set of three phase currents to produce i^*_a, i^*_b, i^*_c.

7. i^*_a, i^*_b, i^*_c and Reference signal (triangular signal) comparator to generate inverter gate signals.

A.   Mathematical Expression

The rotor pole is directed on the q^e axis and $\omega_e = \omega_r + \omega_{sl}$, we can write[8] ,

$$\theta_e = \int \omega e\, dt = \int (\omega r + \omega sl)dt = \theta r + \theta_{sl} \qquad (3.1)$$

The rotor circuit equation can be written as

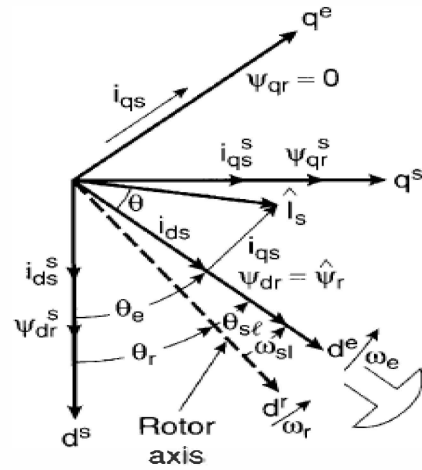$$\frac{d\psi_{dr}}{dt} + R_r i_{dr} - (\omega_e - \omega_r)\psi_{qr} = 0 \qquad (3.2)$$

Fig3.1. Phasor diagram explaining indirect vector control

$$\frac{d\psi_{dr}}{dt} + R_r i_{qr} + (\omega_e - \omega_r)\psi_{dr} = 0 \qquad (3.3)$$

The rotor flux linkage expressions can be given as

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \qquad (3.4)$$
$$\psi_{qr} = L_r i_{qr} + L_m i_{qs} \qquad (3.5)$$

From the above equation, we can write

$$i_{dr} = \frac{1}{L_r}\psi_{dr} - \frac{L_m}{L_r} R_r i_{ds} \qquad (3.6)$$
$$i_{qr} = \frac{1}{L_r}\psi_{qr} - \frac{L_m}{L_r} R_r i_{qs} \qquad (3.7)$$

The rotor currents in the equation (3.1) and (3.2), which are inaccessible, can be eliminated with the help of Equation (3.3) and (3.4) as

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r}R_r i_{ds} - \omega_{sl}\psi_{qr} = 0 \qquad (3.8)$$
$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r}R_r i_{qs} + \omega_{sl}\psi_{dr} = 0 \qquad (3.9)$$

Where $\omega_{sl} = \omega_e - \omega_r$ has been substituted.

For decoupling control, it is desirable that

$$\psi_{dr} = 0 \qquad (3.10)$$

That is

$$\frac{d\psi_{dr}}{dt} = 0 \qquad (3.11)$$

So that the rotor flux $\overline{\psi_r}$ is directed on the d^e axis. Substituting the above conditions in Equations (3.8) and (3.9), we get

$$\frac{L_r}{R_r}\frac{d\overline{\psi_r}}{dt} + \overline{\psi_r} = L_m i_{ds} \qquad (3.12)$$
$$\omega_{sl} = \frac{L_m R_r}{L_r \overline{\psi_r}} i_{qs} \qquad (3.13)$$

Where $\overline{\psi_r} = \psi_{dr}$ has been substituted.

If rotor flux $\overline{\psi_r}$ = constant, which is usually the case, then from Equation (3.12),

$$\overline{\psi_r} = L_m i_{ds} \qquad (3.14)$$

IV.SIMULATION RESULTSAND DISCUSSION

The three level diode clamped inverter produces the staircase output which reduces ripple in speed in the Induction Motor. Open loop operation and closed loop

operation of the Induction Motor has been simulated. The measured parameter of open loop operation is three phase stator voltage, current and speed.   In closed loop operation the stator current measurements are transformed to a transformation of the stator currents. The I_d current and reference flux added with PI controller and it's given to d axis. The reference speed and constant speed is added with PI controller and it's given to q axis. The output from the PI controllers is given to dq-abc transformation. The resulting output from this transformation is fed to inverter as a carrier signal. This carrier signal is being compared with triangular signal to produce the gate pulse for three level diode clamped inverter. The measured parameters of close loop operation are voltage, current, speed. In the closed loop operation by varying load the speed can be maintained constant.
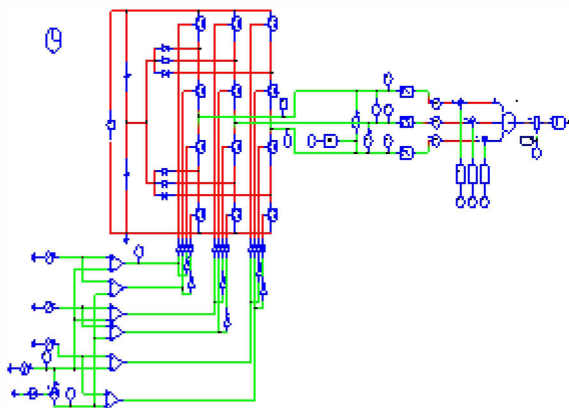
A.Simulation Circuits For Open Loop Operation

Fig.4.1.Open Loop Operation of Three level Diode Clamped Inverter

B. Simulation Results For Open Loop Operation

Figures 4.2 present the phase to phase voltage during the transient and steady state periods respectively. The complete five voltage levels are formed when the machine reaches the steady state.
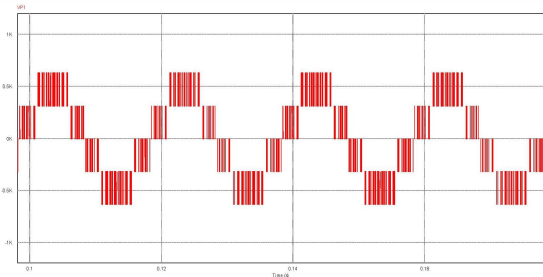

Fig. 4.2.Phase - Phase Voltage in volts

Figures 4.3 present the machine achieves the rated speed at 0.15s and it tries to reach the steady state.
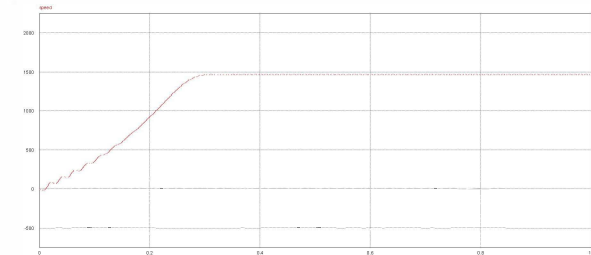

Fig. 4.3.Speed in RPM

Figures 4.4 present the Line current during the transient and steady state periods respectively. The complete five voltage levels are formed when the machine reaches the steady state.
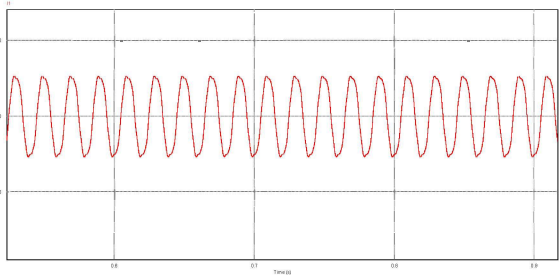

Fig. 4.4.Line current in Amps

Figures 4.5 present the FFT Analysis of Line current during the transient and steady state periods respectively. The complete five voltage levels are formed when the machine reaches the steady state. The third and fifth harmonics are reduced in the of Three level Diode Clamped Inverter fed Induction motor.
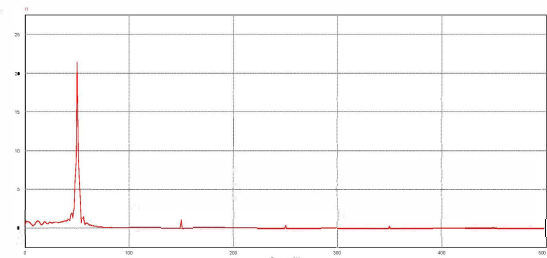

Fig. 4.5.FFT Analysis of Line current

TABLE II

OPEN LOOP PERFOMANCE OF THREE LEVEL DIODE CLAMPED INVERTER FED INDUCTION

l (Nm)	a	b	c	d	e	f	eed
5	0	0	0	9	9	9	484
10	0	0	0	8	8	8	465
15	0	0	0	4	4	4	445
20	0	0	0	9	9	9	420

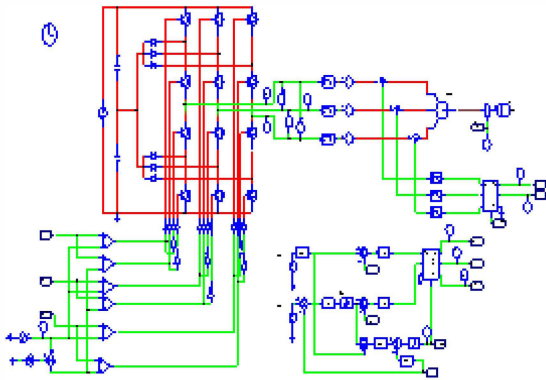*C.Simulation Circuits For Close Loop Operation*

Fig.4.6. Close Loop Operation *of* Three level Diode Clamped Inverter with FOC

D. Simulation Results For Close Loop Operation

Figures 4.7 present the line voltage during the transient and steady state periods respectively. The complete three voltage levels are formed when the machine reaches the steady state.
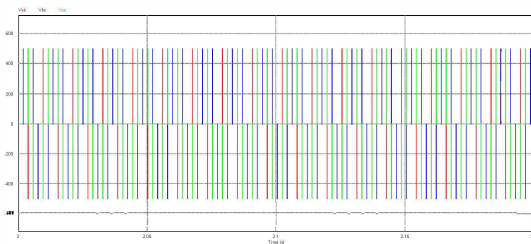

Fig.4.7. Three Phase Voltage in volts

Figures 4.8 present the direct axis current during the transient and steady state periods respectively.
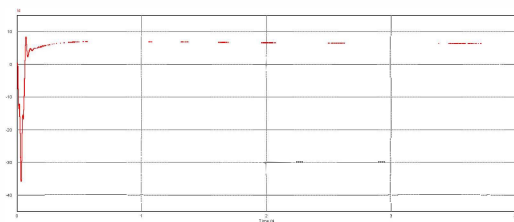

Fig: 4.8Direct axis current in Amps

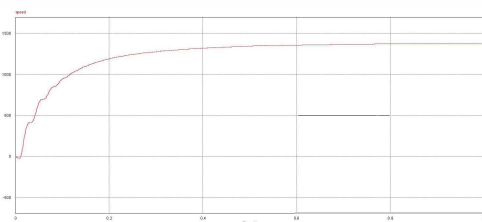Figures 4.9 present the machine achieves the rated speed at .1s and it tries to reach the steady state.

Fig: 4.9. Speed in RPM

V CONCLUSION

The three level diode clamped inverter produces the staircase output which reduces ripple in speed in the Induction Motor. Open loop operation and closed loop operation of the Induction Motor has been simulated.The features of the proposed field oriented control method include 1) providing constant inverter switching frequency, 2) dramatically increasing the inverter switching frequency without requiring any high frequency dither signal, 3) significantly reducing the torque and speed ripple. The proposed FOC approach isverified using a three-level inverter system. Our future work is toapply FOC to a five-level invertersystem and multi-level inverter system.

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