Comparitive Study of Various Multi Level Inverter Topologies for Vector Controlled Induction Motor Drive

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Abstract— Multilevel inverter has drawn tremendous interest in high voltage/high power application due to its high voltage handing and good harmonic rejection capabilities. This paper presents comparative study between various 3-level inverter topologies with an inverter control strategy like space vector pulse width modulation (SVPWM) algorithm for a vector controlled induction motor drive. The neutral point fluctuation is a commonly encountered problem in diode clamped multilevel configuration, as the capacitors connected to the DC-bus carry load. Three level inversion may also be achieved with two 2-level inverters, driving an open-end winding induction motor from either end. In this topology the problems of neutral point fluctuations and complexity of implementation can be reduced. A new method for reducing the harmonics and vary the output voltage of inverter, Space vector Pulse Width Modulation approaches with imaginary switching times are presented. To validate the proposed method, the PWM inverter is simulated using MATLAB/SIMULINK and the results are presented.

Keywords-- open end winding induction motor, vector control, diode clamped inverter,SVPWM,imaginary switching times.

I. INTRODUCTION

Multilevel inverter has drawn tremendous interest in high voltage/high power application due to its high voltage handing without switching devices connected in series and good harmonic rejection capabilities, less switching stress on each device with a reduced harmonic content at low switching frequency. Multilevel inverters produce a stepped output phase voltage with a reduced harmonic profile when compared to a two-level inverter-fed drive system. Therefore, the multilevel inverters have been selected as a preferred power converter topology for high voltage and high power applications. Among various multilevel topologies diode clamped multilevel inverter is simple. The circuit diagram of three level diode clamped multi level inverter is shown in Fig.1
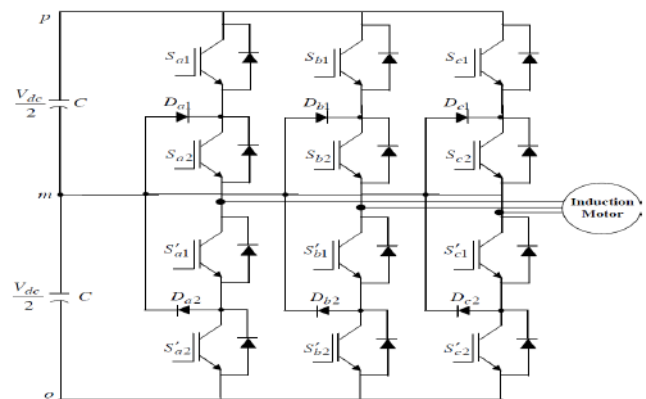

Fig.1 Three level diode clamped inverter

Though simple and elegant, the neutral-clamped circuit topology suggested above has a few disadvantages. The neutral point fluctuation is a commonly encountered problem in this configuration, as the capacitors connected to the DC bus carry load currents. Also, there is an ambiguity regarding the voltage rating of the semi-conductor devices, which are connected to the neutral point. This calls for a conservative selection of these devices for reliable operation, enhancing the cost. However, these configurations are also complex for higher number of levels. Open-end winding induction motors, obtained by removing the neutral point of the stator windings of ordinary motors, offer another approach to multilevel inversion. It has been shown that two two-level inverters, connected at either end of an open-end winding induction motor, are capable of achieving three-level inversion. The circuit configuration of open end winding induction motor is shown in Fig.2

Open-end winding motors require either harmonic filters or isolation transformers to prevent currents of the triple n harmonic order flowing in the motor phases and the semiconductor devices.
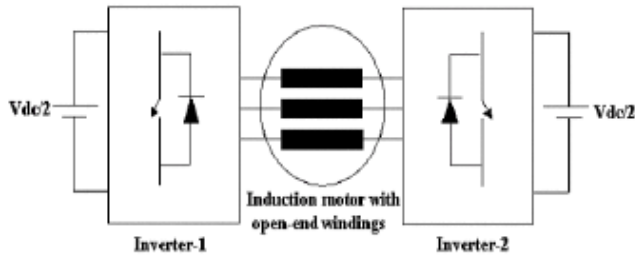
Fig.2 open end winding Induction Motor

II.   CONTROL STRTEGY

As shown in Fig.2 by feeding an open-end winding from either side with two two-level inverters, one may obtain three level inversion. In the scheme the inverters are controlled by SVPWM, which has better DC utilization and low harmonic distortion when compared to Sinusoidal pulse width modulation (SPWM). The conventional SVPWM technique maintains the balance between reference voltage and the applied volt-seconds over an every sub cycle (T_s). The reference vector Vref is synthesized using two active vectors and two zero vectors as shown in Fig.3
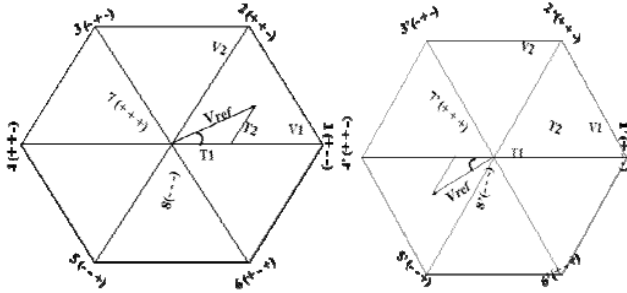

Fig.3 space vector location for inverter-I and inverter-II

From the Fig.3 V_{ref} vector is constructed using the active voltage vectors V_1 and V_2 which are applied for duration of T_1 and T_2. The zero voltage vectors V_0 and V_7 are applied for the duration of Tz. The time durations T_1, T_2 and Tz are given by the equation (1).

$$\left.\begin{aligned} T_1 &= \frac{V_{ref}\sin(\pi/3-\alpha)}{\sin(\pi/3)}T_s \\ T_2 &= \frac{V_{ref}\sin(\alpha)}{\sin(\pi/3)}T_s \\ T_z &= T_s - T_1 - T_2 \end{aligned}\right\} \quad (1)$$

In the conventional SVPWM approach from (1) at every instant of time angle and sector information is to be calculated and this disadvantage is overcome by concept of imaginary switching timesThe actual switching times derived directly from the reference phase voltages defined as in equation (3)

$$T_{an} = \frac{T_s}{V_{dc}}V_{an} \quad T_{bn} = \frac{T_s}{V_{dc}}V_{bn} \quad T_{cn} = \frac{T_s}{V_{dc}}V_{cn} \quad (2)$$

Here T_s is sampling time V_{dc} is the dc link voltage V_{an}, V_{bn}, V_{cn} are phase voltages if reference voltages are positive then switching times T_{an}, T_{bn}, T_{cn} are also positive. Hence times are called imaginary switching times.In every sampling time maximum, minimum and medium values of imaginary switching times are calculated as

$$\begin{aligned} T_{max} &= max(T_{an}, T_{bn}, T_{cn}) \\ T_{min} &= min(T_{an}, T_{bn}, T_{cn}) \\ T_{mid} &= mid(T_{an}, T_{bn}, T_{cn}) \end{aligned} \quad (3)$$

The active states T_1, T_2 can be calculated as
$T_1=T_{max} - T_{mid}$
$T_2=T_{mid} - T_{min}$

As each inverter is capable of assuming 8 states independently of the other, a total of 64 space vector combinations are possible with the dual inverter drive shown in Fig.3. These space vector combinations are distributed over 19 space vector locations compared to 27 with the conventional NPC three-level inverter. Thus, this scheme renders advantages such as redundancy of the space vector combinations for the same number of space vector locations and the absence of neutral point fluctuations

III.   INDUCTION MOTOR MODELLING

The mathematical modeling of three phase squirrel cage induction motor is described by equations in stationary reference frame is given by, the stator and rotor flux linkages and voltage equations in stationary reference frame is given by,

$$\left.\begin{aligned} \lambda_{qs} &= L_s i_{qs} + L_m i_{qr} \\ \lambda_{ds} &= L_s i_{ds} + L_m i_{dr} \\ \lambda_{qr} &= L_r i_{qr} + L_m i_{qs} \\ \lambda_{dr} &= L_r i_{dr} + L_m i_{ds} \end{aligned}\right\} \quad (4)$$

$$\left.\begin{aligned} v_{ds} &= R_s i_{ds} + \frac{d\lambda_{ds}}{dt} \\ v_{qs} &= R_s i_{qs} + \frac{d\lambda_{qs}}{dt} \\ 0 &= R_r i_{dr} + \omega_r \lambda_{qr} + \frac{d\lambda_{dr}}{dt} \\ 0 &= R_r i_{qr} - \omega_r \lambda_{dr} + \frac{d\lambda_{qr}}{dt} \end{aligned}\right\} \quad (5)$$

where $\omega r = \dfrac{d\theta}{dt}$

The electromagnetic torque of the induction motor in stator reference frame is given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\lambda_{ds}i_{qs} - \lambda_{qs}i_{ds}\right) \quad (6)$$

The electro-mechanical equation of the induction motor drive is given by

$$T_e = T_L + J\frac{d\omega_m}{dt} = T_L + \frac{2}{P}J\frac{d\omega_r}{dt}$$ -(7)

IV. VECTOR CONTROL TECNIQUE

The vector control methods are widely used for the control of induction motor drives in high performance applications. With the vector control methods, the decoupling of torque and flux control commands of the induction motor is guaranteed, and the induction motor can be controlled as a separately excited dc motor. However, the vector control algorithm uses hysteresis type current controllers for the generation of gating signals, which results in variable switching frequency operation of the inverter.

To achieve constant switching frequency operation of the inverter, the space vector PWM (SVPWM) algorithm has been used for vector controlled induction motor drive. The Space Vector Pulse Width Modulation (SVPWM) method is an advanced, computation-intensive PWM method and possibly the best among all the PWM techniques for variable frequency drive application. Because of its superior performance characteristics.
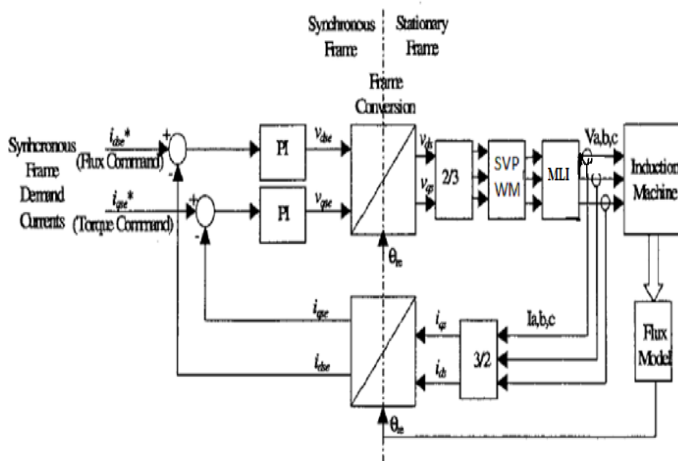

Fig.4 Proposed Block Diagram of Vector Controlled Drive

V. SIMULATION RESULTS

Rated speed	1500 RPM	Rotor resistance	0.94Ω
frequency	50Hz	Inverter input DC Voltage	540V
Stator resistance	0.94Ω	Mutual inductance	176mH
Stator inductance	183mH	Rotor inductance	183mH
Inverter switching frequency=5000 Hz			

MATLAB/Simulink based simulation studies are carried out to predict the performance of the 3-level diode clamped multi level inverter and open end winding induction motor drive which is controlled by SVPWM strategy. The simulation results of open end winding induction motor (IM) are shown in Fig.8 to Fig.10.
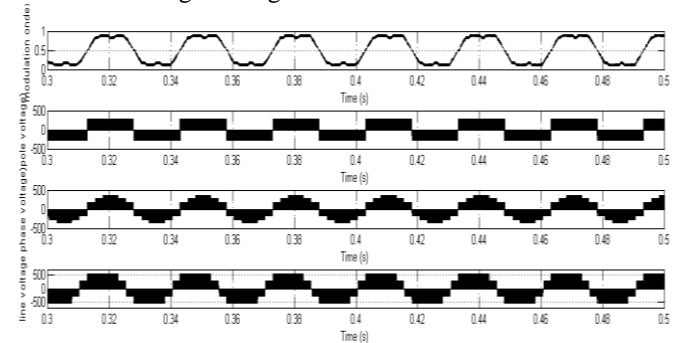

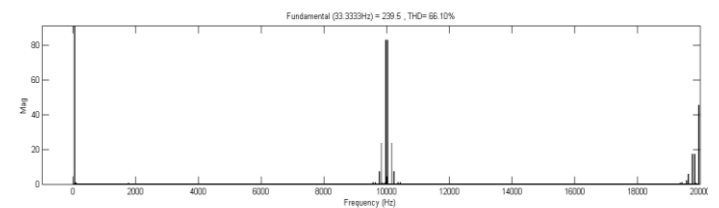Fig.5 Modulating waves, pole voltage, phase voltage, line voltage of open end induction motor.

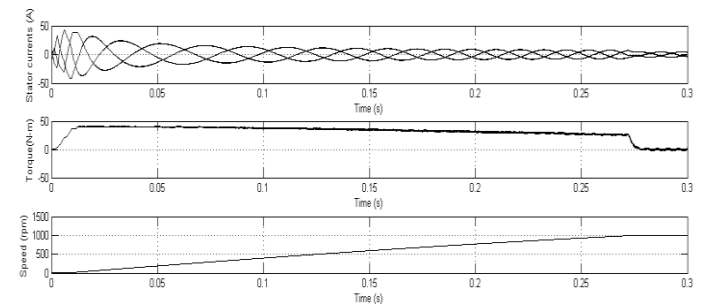Fig.6 Steady state Phase voltage THD with SVPWM algorithm

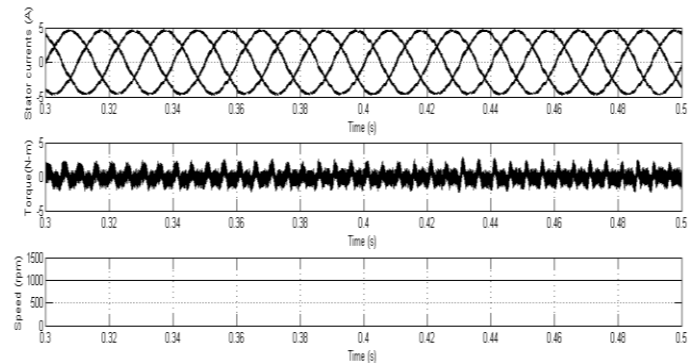Fig7. Simulation results of vector control IM drive: No-load starting transients

Fig.8 Simulation results of vector control IM drive: No-load steady state plots
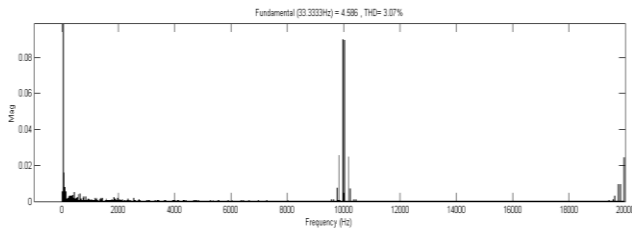
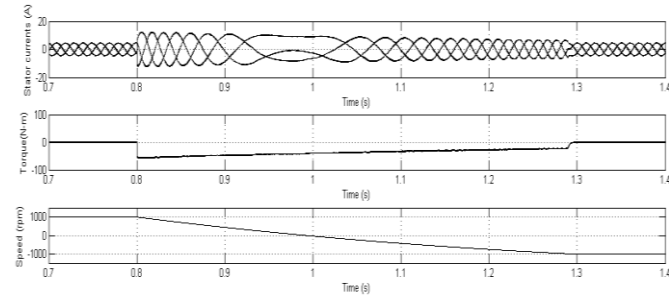**Fig.9 Steady state current THD with SVPWM algorithm**

Fig. 10 Simulation results of vector control IM drive -Transients during speed reversal

The simulation results of 3-level diode clamped inverter for vector controlled IM drive are shown in Fig to Fig
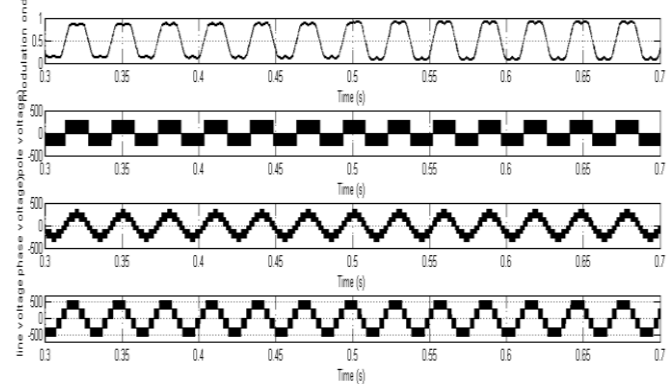

Fig.11 Modulating waves, pole voltage, phase voltage, line voltage of open end induction motor.
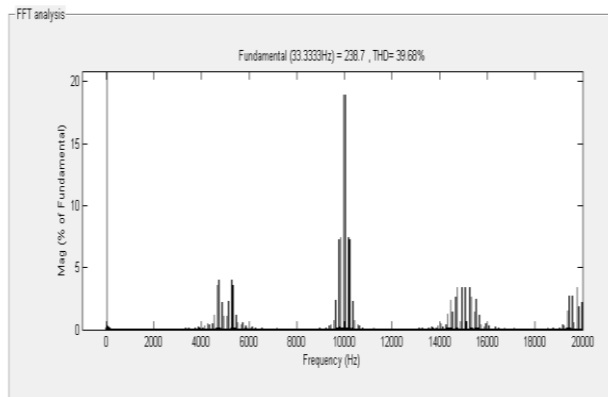

Fig.12 Steady state Phase voltage THD with SVPWM algorithm
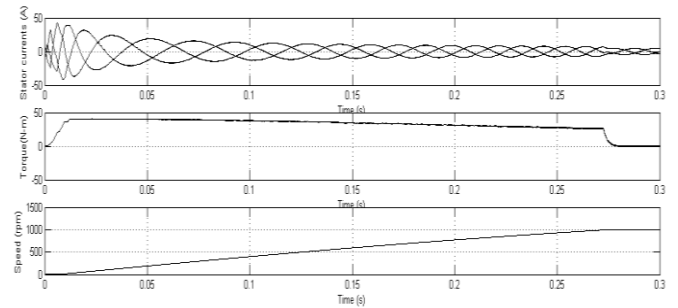

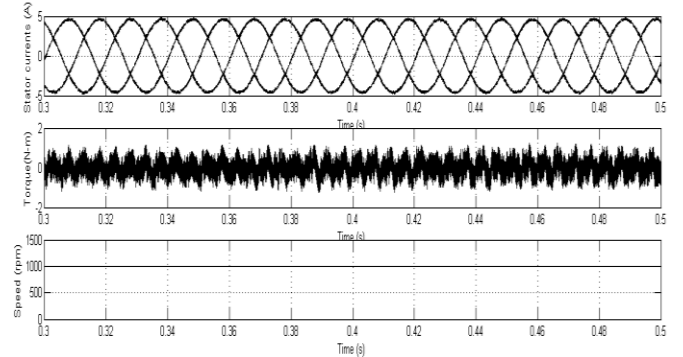**Fig.13 Simulation results of vector control IM drive: No-load starting transients**

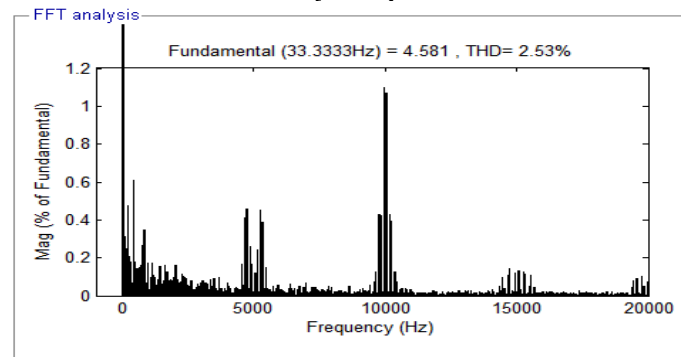**Fig.14 Simulation results of vector control IM drive: No-load steady state plots**

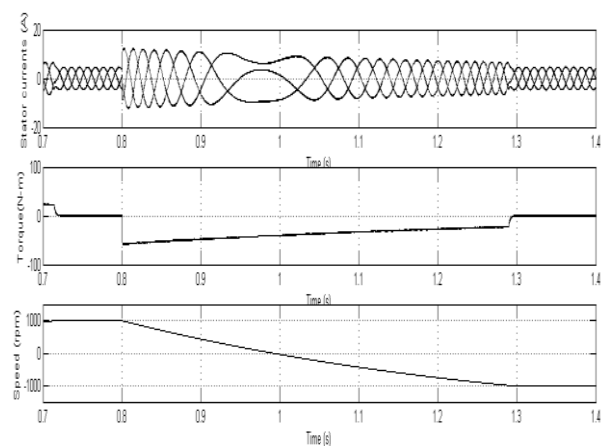**Fig.15 Steady state current THD with SVPWM algorithm**

Fig.16 Simulation results of vector control IM drive -Transients during speed reversal

VI.   CONCLUSION

Open end winding induction motor provide better voltage profile and eliminate neural point fluctuations. It also reduces the ratings of the switching devices used in the construction of inverter. Tough in open end winding IM drives complexity is reduced the THD is more than diode clamped inverter. With the vector control methods, the decoupling of torque and flux control is achieved similarly to DC motors where the transient performance is improved when compared to scalar control drives. The complexity involved in implementation of SVPWM algorithm is reduced because of imaginary switching times.

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