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Three Level Diode Clamped Inverter Fed Induction Motor with Dtc-Svm

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ABSTRACT
This project presents a three-level diode-clamped inverter feeding an asynchronous motor drive with direct torque control (DTC). The control method is based on DTC operating principles. The stator voltage vector reference is computed from the stator flux and torque errors imposed by the flux and torque controllers. This voltage reference is then generated using a diode-clamped inverter, where each phase of the inverter can be implemented using a dc source, which would be available from fuel cells, batteries, or ultra capacitors. This inverter provides nearly sinusoidal voltages with very low distortion, even without filtering, using fewer switching devices. In addition, the multilevel inverter can generate a high and fixed switching frequency output voltage with fewer switching losses, since only the small power cells of the inverter operate at a high switching rate. Therefore, a high performance and also efficient torque and flux controllers are obtained, enabling a DTC solution for multilevel-inverter-powered motor drives.
The Pulse Width modulation technique for an inverter permits to obtain three phase system voltages, which can be applied to the controlled output. Space Vector Modulation (SVPWM) principle differs from other PWM processes in the fact that all three drive signals for the inverter will be created simultaneously. The implementation of SVPWM process in digital systems necessitates less operation time and also less program memory. This project uses SVPWM technique for generation of pulses for three-level diode clamped inverter. Simulation is carried out on MATLAB-Simulink software.
Key words-multilevel inverters, direct torque control, svpwm, induction motor

I.   INTRODUCTION

Enabled by significant technological developments in the area of power electronics, variable speed induction motor drives have evolved to a state of the art technology within the last decades. These systems, in which DC-AC inverters are used to drive induction motors as variable frequency three-phase voltage or current sources, are used in a wide spectrum of industrial applications. One of the methods for controlling the induction motor's torque and speed is Direct Torque Control (DTC), which was first introduced in 1985 by Takahashi and Noguchi and is nowadays a industrial standard for induction motor drives. The basic characteristic of DTC is that the positions of the inverter switches are directly determined rather than indirectly, thus refraining from using a modulation technique like Pulse Width (PWM) or Space Vector (SVM) modulation. In the generic scheme, the control objective is to keep the motor's torque and the amplitude of the stator flux within pre-specified bounds. The inverter is triggered by hysteresis controllers to switch whenever these bounds are violated.

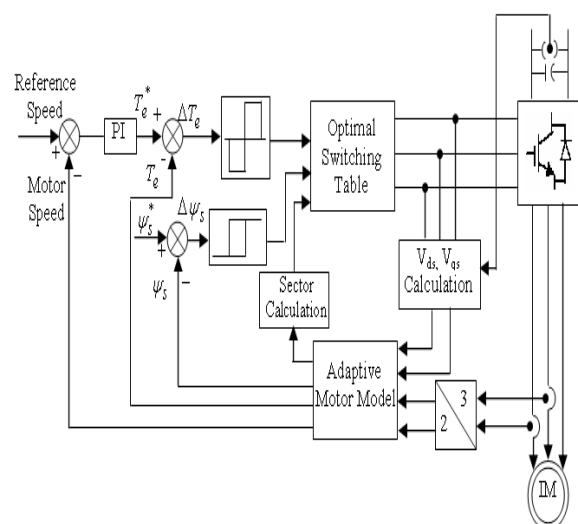## II.   Direct Torque Control for Induction Motor Drives

Fig.1. DTC using space vector modulation block diagram

Firstly, albeit their very simple controller structure, the existing DTC schemes have proven to yield a Satisfactory control performance. Secondly, the post analysis of the derived state feedback control law reveals a simple and robust pattern in the solution to the optimal control problem. These observations have motivated the control scheme presented in this paper which is based on the following fundamental

property of DTC. The control objectives only weakly relate to optimality but rather to feasibility, in the sense that the main objective is to find a control input that keeps the controlled variables within their bounds, i.e. a control input that is feasible. The second, weaker objective is to select among the set of feasible control inputs the one that minimizes the average switching frequency. The latter can be approximated by the number of switch transitions over the (short) horizon. For each input sequence, we determine the number of steps the controlled variables are kept within their bounds, i.e. remain feasible. Next we define the number of switch transitions divided by the number of predicted time-steps an input remains feasible as a cost function emulating the switching frequency. In a last step, the control input is chosen that minimizes the cost function. We refer to this concept as the *Feasibility Approach*. The simplicity of the control methodology (with the only design parameter *N*) translates into a state-feedback control law with a complexity that is of an order of magnitude lower than the one of its counterpart obtained through solving the optimal control problem.

A. Torque and Flux Estimation

        The stator flux vector of an induction motor is related to the stator voltage and current vectors by

$$\Psi_s = \int (V_s - R_s I_s)dt$$

        Equation reveals that the stator flux vector is directly affected by variations on the stator voltage vector. On the Contrary, the influence of vs over the rotor flux is filtered by the rotor and stator leakage inductances and is therefore not relevant over a short-time horizon. Since the stator flux can be changed quickly while the rotor flux rotates slower, the angle between both vectors η can be controlled directly by V_s. The exact relationship between the stator and rotor fluxes shows that keeping the amplitude of ψ_s constant will produce a constant flux ψ_r. Since the electromagnetic torque developed by an induction motor can be expressed by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{\sigma L_s L_r}|\Psi_r||\Psi_s|\sin\eta$$

        It follows that a change in η due to the action of V_s allows for direct and fast change in the developed torque. DTC uses this principle to achieve the induction motor desired torque response by applying the appropriate stator voltage vector to correct the flux trajectory.

Adaptive Motor Model

        The adaptive motor model is responsible for generating Stator flux, Electromagnetic torque, Rotor speed and Stator flux linkages phasor angle (in radians).

These can be estimated by using

$$\Psi_s = \int (V_s - R_s I_s)dt$$
$$T_e = \frac{3}{2}\frac{P}{2}\left[I_{qs}\Psi_{ds} - I_{ds}\Psi_{qs}\right]$$
$$\theta = \text{Tan}^{-1}\left[\frac{\Psi_{qs}}{\Psi_{ds}}\right]$$
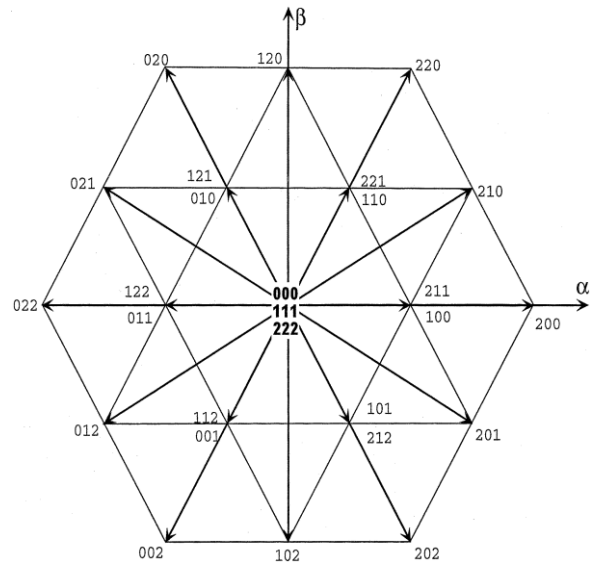
III.   VOLTAGE VECTOR SELECTION

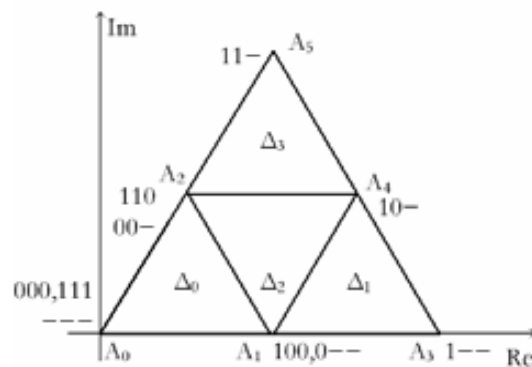Fig. 2.Switching sequence for three-level SVPWM inverter

Fig.3. Space vector diagram for sector 1

        Fig. 2 shows the space vector diagrams for three-level inverter, where each digit of the space vector identifier represents the voltage level to which the A, B, and C phase legs are respectively switched. Note that some switched states are redundant and create the same space vectors. The difficult task of selecting the optimum set of these space vectors for a given reference phasor was recently solved by Celanovic *et al.* using a linear coordinate transformation, and identified that the harmonic profile of the overall switched waveform is minimized when the nearest three space vectors are used. However, this solution does not identify how to sequence or place these three nearest space vectors in the (half carrier equivalent) switching period so as to

minimize the total number of switching transitions and fully optimize the harmonic profile of the output voltage. Depending on where in the αβ space the reference phasor is located, there are two alternatives for this sequence, viz:

i)   Select two vectors of even redundancy and one vector of odd redundancy (e.g., 211/100, 221/110 and 210); or

ii)   Select one vector of even redundancy and two vectors of odd redundancy (e.g., 211/100, 200 and 210).

IV.   SIMULATION RESULTS

To show the effectiveness of the DTC-SVM with three level inverter and SVPWM switching technique a simulation work has been carried out on induction motor with the specifications given in Appendix. The proposed scheme is simulated with Matlab/Simulink. This results show that the torque ripples in the three-level scheme has been reduced significantly.
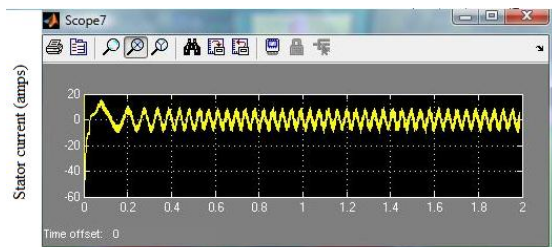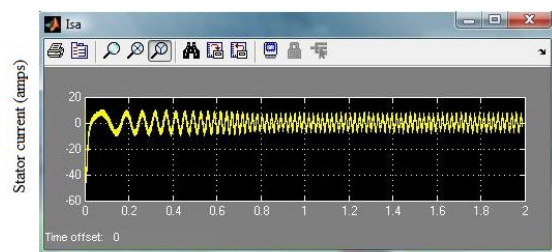
Fig. (a)

Fig. (b)

Fig. 4. Simulation results for stator current of (a) general DTC   (b) DTC-SVM with three level neutral point clamped inverter for 1440 rpm.
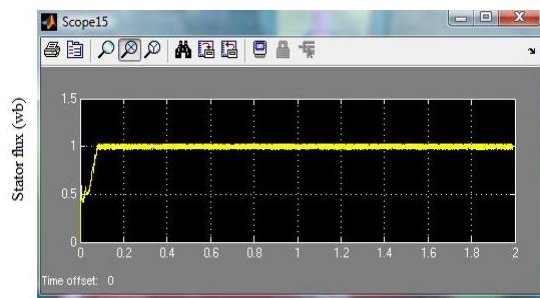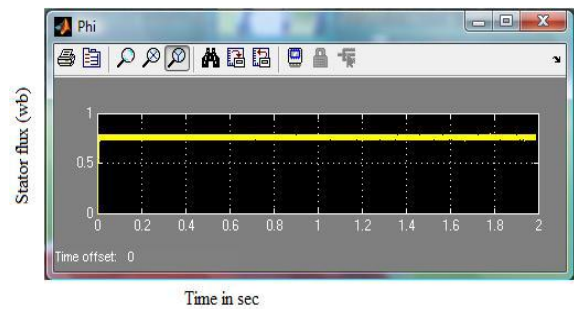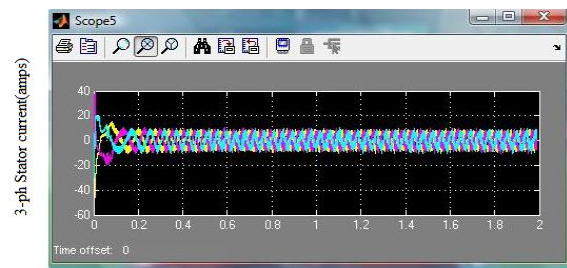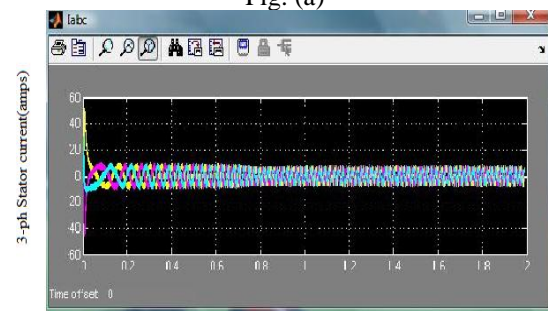

Fig. (a)

Fig. (b)

Fig. 5 Simulation results for flux response of (a) general DTC (b) DTC-SVM with three level diode clamped inverter for 1440 rpm

Fig. (a)

Fig. (b)

Fig. 6 Simulation results for stator current of (a) general DTC (b) DTC-SVM with three level diode clamped inverter for 1440 rpm
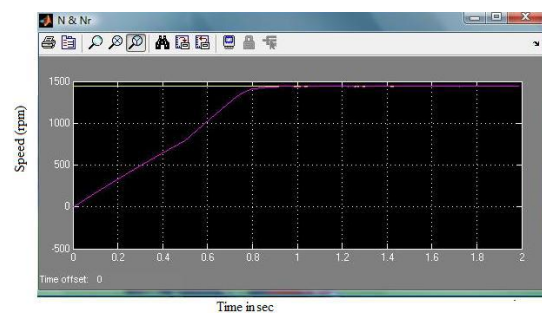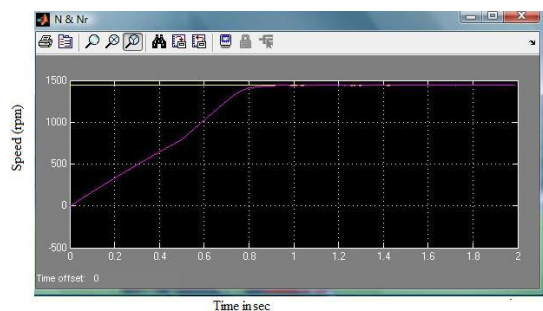

Fig. (a)

Fig. (b)
Fig. 7 Simulation results for Speed of (a) general DTC (b) DTC-SVM with three level diode clamped inverter for 1440 rpm
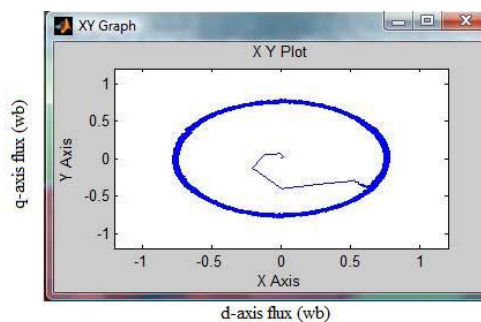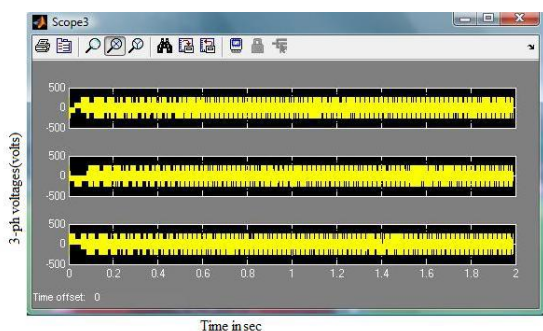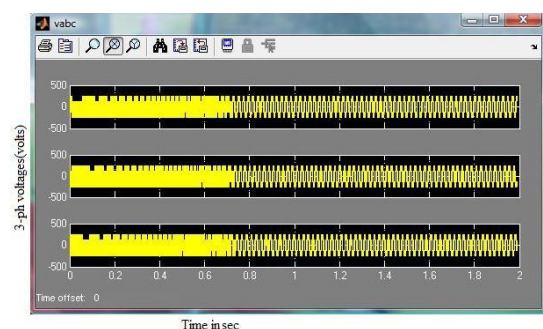

Fig. (a)

Fig. (b)
Fig. 8 Simulation results for 3-phase voltages of ((a) general DTC (b) DTC-SVM with three level diode inverter for 1440 rpm

Fig. (a)

Fig. (b)
Fig. 9 (a) and (b) show stator flux trajectory for general and DTC-SVM at 1440 rpm.
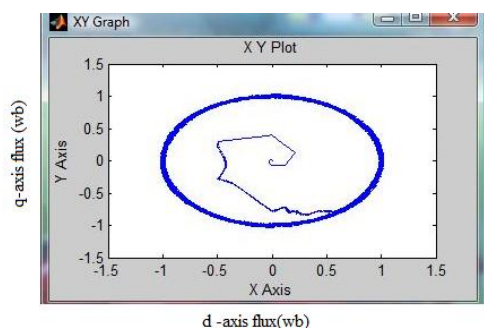
V.   CONCLUSION

In this paper the DTC principle is presented and it is shown that with a simple SVPWM approach for a three-level inverter based on a standard two-level inverter we can implement this method easily. The simulation results obtained for the DTC-SVM with three level inverter illustrate a considerable reduction in torque ripple and flux ripple compared to the existing classical DTC system and DTC-SVM utilizing two level inverter.

APPENDIX

RATED DATA OF THE SIMULATED AND
TESTED INDUCTION MOTOR

1Kw, 50 Hz, 400/230 V, 3.4/5.9 A, 1440 r/min, R_s=4.67 Ω, R_r=8 Ω, L_s=L_r=0.347 H, M=0.366 H, J= 0.06 kg*m^2, β= 0.042 N*m*s

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