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A Novel Scheme for Reduction of Torque Ripple in Direct Torque Control of Three Phase Squirrel Cage Induction Motor Using Seven Level Neutral Point Clamped Inverter

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Abstract: Direct torque control of a 3 phase squirrel cage Induction motor though offers a good dynamic response and is free from dynamic coordinate transformation has a major disadvantage of producing rippled torque which degrades the performance of entire drive system. A scheme is proposed in this study which employs seven levels Neutral point clamped inverter which helps in alleviating the torque disturbances. The control scheme for the proposed method is described in this study and the simulation results are reported to demonstrate its effectiveness.

Keywords: DTC, induction motor, NPC inverter, torque control

INTRODUCTION

In recent years, industry has begun to demand higher power equipment, which now reaches the megawatt level. Controlled ac drives in the megawatt range are usually connected to the medium-voltage network. But it is hard to connect a single power semiconductor switch directly to medium-voltage grids. For these reasons, a new family of multilevel inverters have emerged as the solution for working with higher voltage levels (Lai and Peng, 1996; Peng and Lai, 1996). Multilevel inverters include an array of power semiconductors and capacitor voltage sources, the output of which generates voltages with stepped waveforms (Pravin and Starbell, 2011). The commutation of the switches permits the addition of the capacitor voltages, which reach high voltage at the output, while the power semiconductors must with stand only reduced voltages. An Induction Motor (IM) being rugged, reliable and relatively inexpensive makes it more preferable in most of the industrial drives. Recently, power electronics and control systems have matured to allow these components to be used for motor control which not only control the motor's speed, but can also improve the motor's dynamic and steady state characteristics. Adjustable speed ac machine system is equipped with an adjustable frequency drive that is a power electronic device for the control of this machine. To improve the performance of the drive, the converter has to be switched at high frequency which will introduce the additional switching losses. Another possibility is to put a motor input filter between the converter and motor, which causes additional weight. The Diode Clamped Multilevel Inverter can be applied to higher level converters. As the number of level increases, the synthesized output waveform adds more steps, producing a staircase waveform (Lai *et al*., 2002; Pandian and Reddy, 2009). A zero harmonic distortion of the output wave can be obtained by large number of levels (Rashid, 2004).

With the enormous advances in converters technology and the development of complex and robust control algorithms, considerable research effort is devoted for developing optimal techniques of speed control for Induction Machines. Also, induction motor control has traditionally been achieved using Field Oriented Control (FOC). This method involves the transformation of the stator currents into a synchronously rotating d-q reference frame that is aligned with one of the stator fluxes, typically the rotor flux. The implementation of FOC system is however complicated and furthermore in FOC, particularly the indirect type of control, which is widely used, is well known to be highly sensitive to parameters variations due to the feed-forward structure of its control system. In recent years, many studies have been carried out to develop different solution for the induction motor control having the features of precise and quick torque response and reduction of complexity of the field-oriented algorithms (Benalla *et al*., 2007; Kodad *et al*., 2011). The DTC technique has been recognized as viable solution to achieve these requirements (Davood and Ehsan, 2008).

Neutral-point clamped inverter: The Neutral Point Clamped or the Diode Clamped Multilevel Inverter is well-suited for a common three phase supply with a common dc bus. In the Adjustable Speed Drive (ASD)

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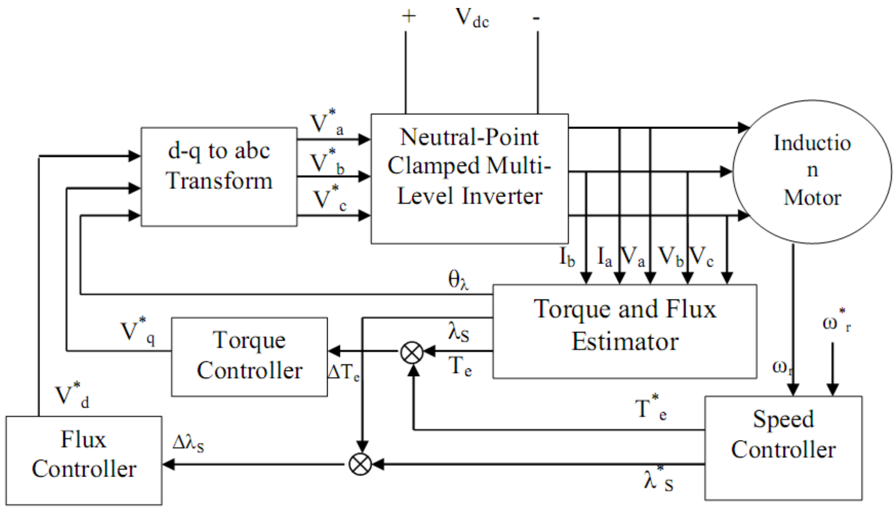

Fig. 1: The proposed closed loop DTC using NPC multilevel inverter

application (Davood and Ehsan, 2008), the multilevel inverters can be used for a utility compatible with the input from the utility constant frequency ac source and the output to the variable frequency ac load (Ishak, *et al.*, 2009). A seven level NPC is considered for the proposed scheme.

Direct torque control method: DTC is one of the most recent and popular torque control methods for induction motors drive systems. DTC is used to reduce the distortion in flux and it offers better dynamic performance. It's essentially based on a localization table which allows selecting the space vectors to apply to the inverter according to the position of the stator flux vector and of the direct control of the stator flux and the electromagnetic torque. DTC control scheme gives the possibility of separating the flux and torque controls. Based on both torque and flux instantaneous errors it provides a good torque response in both steady state and transient operation conditions. However in this scheme the torque disturbance is larger. This torque disturbance can be reduced by employing a multilevel inverter (Davood and Ehsan, 2008). Hence DTC of IM which is fed from seven levels NPC inverter is presented in this study.

NPC multilevel inverter with conventional DTC technique: The operation of the proposed closed loop system is can be explained by the following general block diagram as shown in the Fig. 1. The Neutral-Point clamped multilevel controller generates the required Voltage vectors, Va, Vb, Vc, for the Induction Motor in each of its legs. The corresponding individual voltage vectors, along with the corresponding Line currents Ia and Ib are measured by the Torque and Flux Estimator. The third current vector, Ic is internally generated by the vector difference of these 2 current vectors. Meanwhile, the speed controller generates the reference torque, T*e and reference flux, λ*S, vectors by comparing the electrical rotor speed, ωr, with the set reference speed, ω*r, input given to the controller. As already discussed, the rotor flux linkages reference λ*r is derived from the rotor speed via an absolute-value function generator. λ*r is kept at 1 p.u. for from the 0-to 1- p.u. rotor speed; beyond 1-p.u speed. The reference torque value, T*e, is generated by a suitable PI Controller.

The Torque and flux estimator includes the 'abc' to'd-q' transformation and then generates the corresponding actual torque, Te, actual flux, λs by the following equations:

$$\lambda_{ds} = \int (V_d - R_s i_{ds})dt$$
$$\lambda_{ds} = \int (V_d - R_s i_{ds})dt$$
$$\lambda_s = \sqrt{\left[(\lambda_{qs})^2 + (\lambda_{ds})^2\right]}$$
$$\theta_f = \tan^{-1}\left(\frac{\lambda_{qs}}{\lambda_{ds}}\right)$$
$$T_e = \frac{3}{2}\frac{p}{2}(i_{qs}\lambda_{ds} - i_{ds}\lambda_{qs})$$

Computation steps and dependence on many motor parameters could be very much reduced by using the stator flux linkages and calculating the electro-magnetic torque, using only the stator flux linkages and stator currents. Then only stator resistance is employed in the computation of the stator flux-linkages, thereby removing the dependencies of mutual and rotor inductances of the machine for this calculation. This approximation is suitable only in case of high or medium voltage drives as considered here.

The Torque and Flux errors, ΔTe and $\Delta\lambda s$ respectively, thus computed by comparing the reference values and the actual measured values are given to the Torque and Flux controllers respectively. These incorporate suitable PI Controllers to generate the corresponding reference voltage vectors in'd-q' plane, V*d and V*q respectively. In order, to obtain the actual three phase voltage reference vectors they are transformed from 'd-q' stationary plane to 'abc' synchronous plane. Then these reference voltage vectors, V*a, V*b and V*c are compared with the suitable carrier signal to generate appropriate PWM pulses for the switching of the Neutral-Point Clamped Multilevel Inverter switches in each leg at corresponding phase differences respectively. Thus the Inverter outputs the required voltage vectors and current vectors of suitable magnitudes and phases in order to meet the required load values at reduced harmonics due to higher level inverter and reduced torque ripple content with the implementation of the closed loop DTC Technique.

SIMULATION AND RESULTS

The closed loop simulation of the seven Level Neutral Point clamped Multilevel Inverter with the Direct Torque Control of induction Motor is shown in the Fig. 2.

Machine parameters: For Simulation Purpose, A 4 kW, 500 V, 50 Hz, 2 pole Induction Motor, considered in this Simulation has the following parameters with Stator and Rotor Resistances, Rs = Rr = 1.5Ω. Similarly, the Stator and Rotor inductances, Ls = Lr = 5.8 mH. While the Mutual Inductance, Lm = 0.210 mH and Moment of Inertia, J = 0.013 Kg/m^2 with Friction Co-efficient, F = 0.003 NMS and a Load Torque, TL = 10 Nm is assumed to be connected to the Machine. The output voltage of each leg of the Seven Level NPC Inverter is shown in Fig. 3. The motor Torque is shown in the Fig. 4. Further the Speed is shown in the Fig. 5.

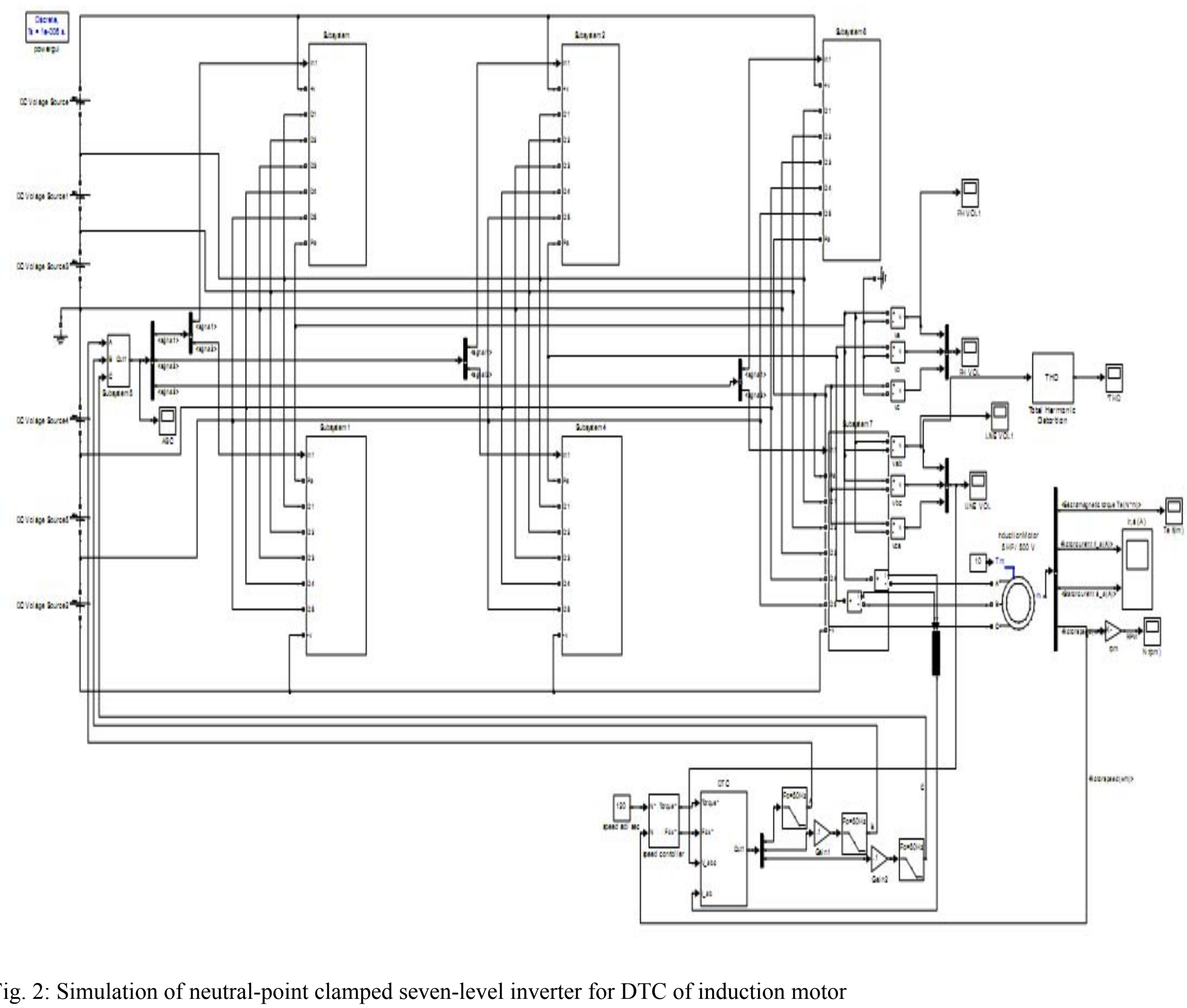

Fig. 2: Simulation of neutral-point clamped seven-level inverter for DTC of induction motor

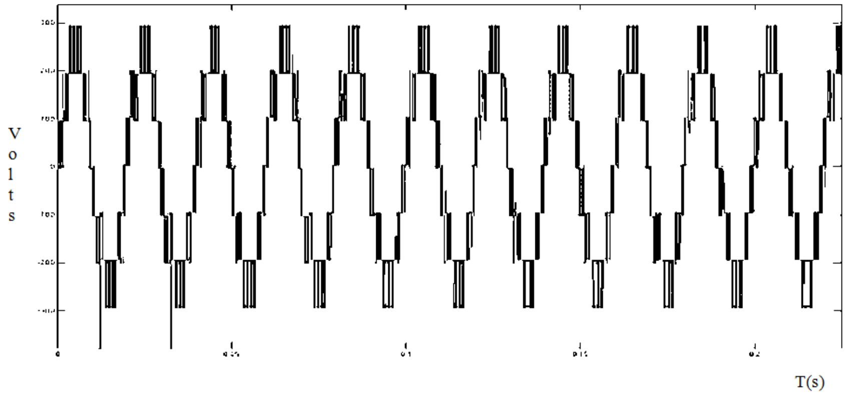

Fig. 3: The phase voltage output of the seven levels NPC inverter

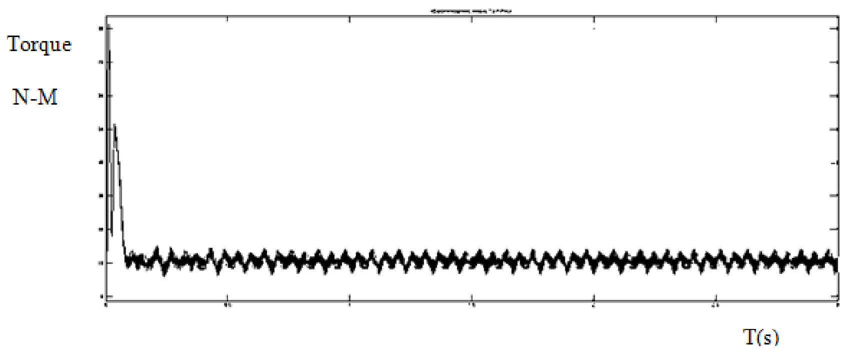

Fig. 4: The simulation result of the motor torque

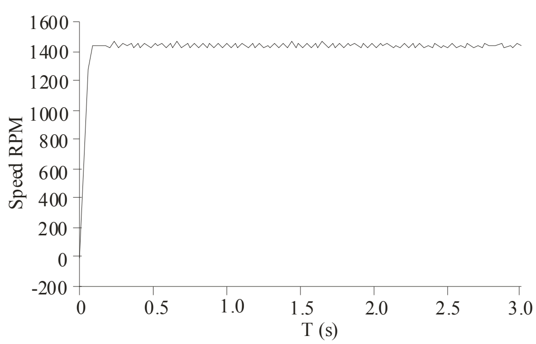

Fig. 5: The speed of induction motor fed from seven levels NPC inverter

CONCLUSION

The Design of seven Level Neutral-Point Clamped Multilevel inverter for the Direct Torque control of Induction Motor was successfully simulated by implementing the Direct Torque Control Method. From the simulated torque profile it is observed that the torque ripples are reduced in proposed scheme compared to conventional scheme.

The Future Scope of this scheme would include the inclusion of NPC Multilevel Inverter with Higher Levels like 9, 11-, 13-, 15-... Levels, which is expected to provide more near Sinusoidal Output Waveform when compared to the proposed seven Level Inverter. The implementation of DTC Strategy can enhance by using Neuro-Fuzzy implementation in order to have efficient control of the drive over a wide range of speed and torque values. So far, such implementation has been done only up to 3 level NPC Inverters. These improvements in the proposed scheme would make this drive a more convenient and useful tool in the Industrial and High/Medium Power applications.

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