A Novel DTC-SVPWM control for 3-level inverter Fed- induction motor sensor less drive with an Additional leg in inverter circuit

A.Siva Prasad, A.A.Bhole
Department of Electrical Engineering,
Government College of Engineering, Aurangabad
shiva.avg9@gmail.com

Abstract— The stability and reliability enhancement of three phase induction motor (IM) drive while any leg/switch failure in three level diode clamped inverter is Presented in this paper. The proposed model consists of an additional leg in inverter circuit along with three leg in conventional model. The quick Torque response and highly effective control strategy of an Induction motor, which is DTC-SVPWM has been used to select the optimum vectors. The disturbance which occurs at the time of leg/switch failures can be eliminated and stability of the system can be obtained by using proposed model. The proposed scheme is able to reduce the toque and flux ripple's significantly compared to two level inverter and any scalar control methods. Time based control of speed has been achieved in this model . The proposed model executed in the MATLAB/SIMULIK and the results are presented in the paper with comparison of standard three level inverter fed by induction motor and scalar control of Induction motor.

Index Terms— Induction motor (IM), Direct Torque control (DTC), SVPWM (Space Vector Pulse width Modulation), Diode Clamped Inverter, Torque ripple.
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1 Introduction

In recent years, Induction motor (IM) drives have been extensively used in industrial Variable speed, Hybrid and Electrical Vehicle applications by adopting the Direct Torque Control(DTC) Strategies. Direct Torque Control was introduced in the middle of 1980s, the first Direct Torque control strategy (DTC) Involves a simple control Scheme [1],[2],[3],[4] and robustness against motor parameter variation. The main disadvantage of conventional DTC is high Torque ripple in transient and Steady State [5],[6]. There are Several techniques to reduce the torque ripples. One of them is based on Space Vector Modulation [SVM] technique [7],[8]. The combination of DTC-SVM is used to compensate the flux and Torque errors by taking reference voltage Space Vector in every sampling time period. The simple structure in the Conventional DTC will be missed by using combination of DTC and SVM control strategy.

Multi level Inverters are extensively used to reduce the THD, Torque ripples caused by the voltage jumps from one level to another level and these are helped to reduce the stress across the Switching Devices Compared to two level Inverter. It is also useful to reduce the switching frequency and switching losses of the controlled switching devices. The possibility of switching device failure modes are

- Short Circuit
- Open Circuit
- Parameter drift

Parameter drift occurs as a part degrades and the electrical characteristics such as Voltage or Current drift from the acceptable operating range due to the accumulation of damage with in a device or module.

The three phase, 3- level diode clamped voltage source inverter (VSI) fed by Induction motor (IM) consists of 3-legs and twelve switching devices with a pair of complementary power switches per phase. The proposed model consist of 4-legs and 14 Switches. Additional one leg consist only 2-switching devices one at upper and another at lower leg shown in Fig.3. Several Articles has covered three phase, three level SVM-DTC [9], And the many Articles has covered faults in standard three phase, two level inverter switch/leg with adoption of Four switch [10],[11],[12],[13],[14],[15],[16],[17] three phase Inverter. The main disadvantage of this model is unbalance system voltage and huge torque ripples. The block diagram of DTC system shown in Fig.1, and Standard three level inverter and Proposed model are shown in Fig.2 and .3 respectively.

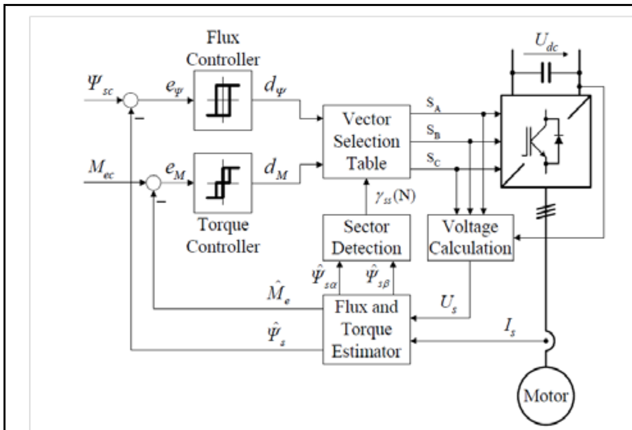

Fig. 1.Block diagram of DTC control strategy

ISSN 2229-5518

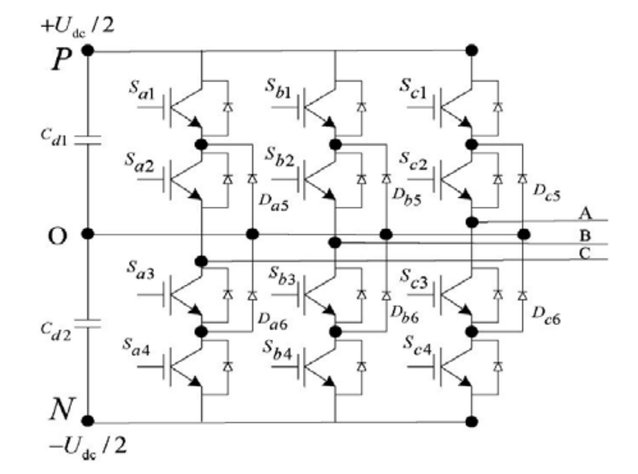

Fig.2. Stranded 3-level Diode Clamped Inverter.

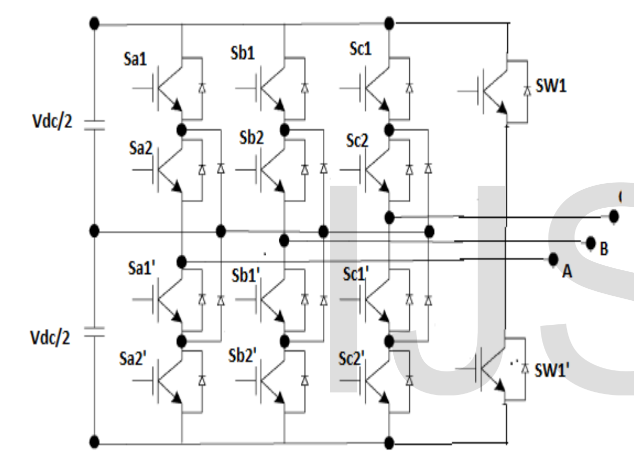

Fig.3. Proposed Structure of Inverter Fed by an IM

2 Mathematical Model of IM

Using the space vector method the induction motor equations can be written as.

$$V_s = I_s R_s + \frac{d\Psi_s}{dt}$$
$$V_r = I_r R_r + \frac{d\Psi_r}{dt}$$
$$\Psi_S = L_s I_s + \mathrm{M}e^{j\gamma_m} I_r$$
$$\Psi_r = L_r I_r + \mathrm{M}e^{-j\gamma_m} I_s$$

To obtain a complete set of electric motor equations it is necessary to, firstly transform the equation in to a common rotating co. ordinate system and secondly bring the rotor value in to the stator side and thirdly these equations are written in the Coordinate system 'K' rotating with angular speed of ω_k.

$$V_{sk} = I_{sk} R_s + \frac{d\Psi_{sk}}{dt} + \mathrm{j}\omega_k \Psi_{sk}$$

$$V_{rk} = I_{rk} R_r + \frac{d\Psi_{rk}}{dt} + \mathrm{j}(\omega_k - \Psi_{sk} P_s \omega_m)\Psi_{rk}$$
$$\Psi_{Sk} = L_s I_{sk} + L_M I_{rk}$$
$$\Psi_{rk} = L_s I_{rk} + L_M I_{sk}$$

The equation of the dynamic rotor rotation can be expressed as:

$$\frac{d\omega_m}{dt} = \frac{1}{J}[T_e - T_L - B\omega_m]$$

Where B Is Viscous Constant. In further Consideration the friction factor will be neglected (B=0).

The electromagnetic torque T_e can be expressed by the following formulas:

$$T_e = \frac{3}{2} N_s \frac{L_m}{\text{ꝑ} L_S L_r} \Psi_r \otimes \Psi_s$$
$$T_e = \frac{3}{2} N_s \frac{L_m}{\text{ꝑ} L_S L_r} \|\Psi_r\| \, \|\Psi_s\| \, \sin(\delta_{sr})$$
$$\text{ꝑ} = 1 - \frac{L_m^2}{L_s L_r}$$

Where δ_{sr} in the spatial angle between the stator and rotor fluxes, N_s is the number of motor pole pair, and the T_e is the electromagnetic Torque. In DTC strategy the magnitude of the stator flux is to be kept constant and a fast torque response is obtained by changing the spatial angle (δ_{sr}) between the stator and rotor fluxes.

The voltage vectors on the alpha and beta axis can then be described as:

$$V_\alpha = \frac{2}{3}\left(V_a - \frac{1}{2}V_b - \frac{1}{2}V_c\right)$$
$$V_\beta = \frac{2}{3}\left(\frac{\sqrt{3}}{2}V_b - \frac{\sqrt{3}}{2}V_c\right)$$

When the three phase voltages are applied to an AC machine a rotating flux is developed. This flux is represented as one rotating voltage vector. The magnitude and angle of this vector can be with Clark's Transformation:

$$V_{ref} = V_\alpha + \mathrm{j}V_\beta$$

The magnitude and angle of the reference Vector is

$$|V_{ref}| = \sqrt{V_\alpha{}^2 + V_\beta{}^2}$$
$$\theta = tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right)$$

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3 DTC-SVPWM Scheme for IM Drive

The DTC scheme utilizes vectors of three-level diode clamped inverter directly and inserts appropriate intermediate vectors to smoothed vector switching.

According to the demand of the flux and Toque, vector is going to be selected, Switching pattern and neutral point balance will be considered later on. Figure.4. shows the space vector diagram for a three level DTC control strategy and its Sector to Sector division. There are 12- Sectors and the shadowed area is the first sector, Which is same as that of the conventional two level DTC. Each sector consists of 30 electrical degree span. The basic principles of the vector selection are shown in Table-I and these are useful to meet the demands of the flux and Torque. 'i' represents the stator flux located in i^{th} Sector. In addition to that "↑" means increases, "↓" means decreases and "=" means no change is needed. To meet the demands of torque and flux more than two vectors are taken as reference.

However, In many cases the selected vector usually cannot meet the requirements of the Vector switching and neutral point balance, Which means that the selected vector cannot be applied to the three level inverter directly. For example, suppose the stator flux is located in the first sector, and the working voltage vector at the moment is V_1. To increase the stator flux and torque, according to Table-I , V_3 would be selected. But there is a high jump, which should be avoided. In this case V_2 will be inserted as an intermediate vector to smooth the high-voltage jump. There are three aspects with respect to the voltage jumps: 1) Phase voltage jump 2) Line voltage jump and 3) three phase jump at the same time. High voltage jump increase the harmonic content
and stress across the power semiconductor devices, which negates the advantage of three level inverter, To overcome this problem, an appropriate intermediate vector should be inserted to decrease the voltage jump level by half magnitude.

The principles for selection of final vector are summarized as follows.

a) To meet the demands for flux and torque, the voltage vector should be selected based on the rules listed in Table-I

b) If the selected vector cannot meet the requirement of voltage jump an appropriate intermediate vector will be inserted.

1) Large vectors or middle vectors should be selected preferably to increase the utilization ration of the DC bus.

2) Middle vectors can switch to adjacent small vectors and large vectors freely.

3) Large vectors can switch to the small vectors on the same spatial orientation.

4) Small vectors can switch to zero vectors freely.

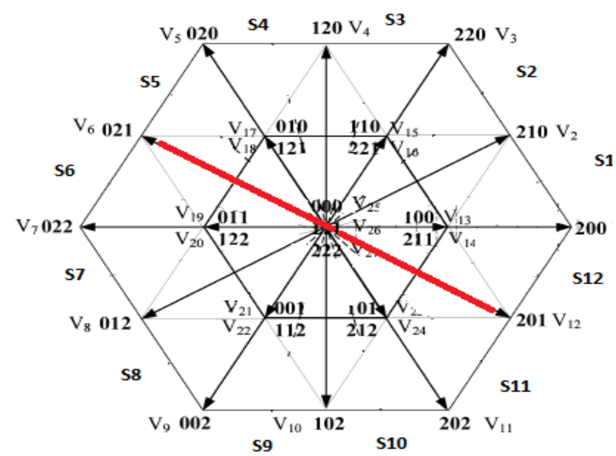

Fig.4. Space Vector diagram for 3-level DTC.

The major difference between the conventional DTC for three level and Proposed model with addition leg is the absence of two small middle vectors with failure of switch/leg in any one of the phases fed by Induction motor. The affected vectors are listed below based on leg/switch failure in corresponding phases.

Effected phase	A	B	C
Diminishing of Vectors	V_4 and V_{10}	V_2 and V_8	V_6 and V_{12}

In the respective effected sectors the voltage jumps will be high compared to the other sectors regions. In this condition also the system will provide balanced power supply to the motor. The simulation is performed by considering failure in the leg/switch corresponding to phase-C

Table-I
Vector selection table for 3-level DTC

Flux	Torque	Selected Vector
↑	↑ = ↓	K+2 0 K-2
↓	↑ = ↓	K+2 0 K-2

ISSN 2229-5518

4 SIMULATION MODEL AND RESULTS

To verify the simulation and performance of proposed and conventional model for an IM based on the DTC-SVPWM, simulation are executed in this section. The parameters of the Induction motor used in simulation research are as perTable-II

Table-II
Simulation and experimental parameters

Rated motor Power	7.5 kW
Rated Frequency	50 Hz
Rated Line voltage	400 Volts
Full load speed	1440 RPM
Stator resistance	0.7384 ohm
Stator inductance	3.0445 mH
Rotor resistance	0.7402 ohm
Rotor inductance	0.1241mH
Mutual Inductance	0.1241 mH
Pole pairs	2

The simulink models of IM Drive of proposed and conventional three level diode clamped inverter by using DTC-SVPWM scheme are shown in Fig.5 and 6 respectively. the direct controlled model are shown in Fig.7 .The reference speed for system has been taken as 800 rpm and -800 rpm within the time span shown Fig.8, the output speed of the motor and electromagnetic torque of scalar controlled induction motor Drive are shown in Fig.9.In normal condition for the DTC-SVPWM method the characteristics of speed and electromagnetic torque are shown in Fig.10. The line current of phase A is shown in Fig. 11.

The characteristics of IM speed and torque in abnormal condition are shown in Fig.12 and the current is shown in Fig.13 .In abnormal condition the torque ripples are reaching maximum at an angles of 150 to 180 electrical degrees and at 330 to 360 electrical degrees whenever the V6 and V12 Vectors are absent, even though the system is reliable with less torque ripple once it reaches steady state. To achieve the maximum torque ripples of system the three systems has been implemented at very low load and low speed.

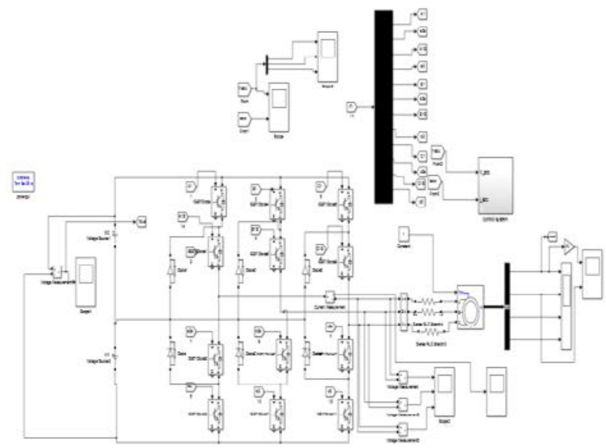

Fig.6. Conventional three level-DTCSVPWM

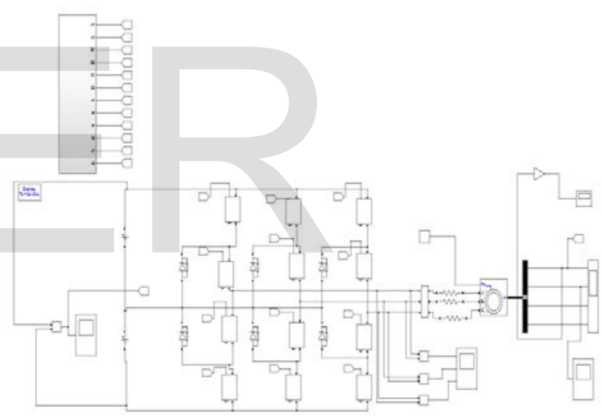

Fig.7. The direct controlled(Scalar controlled) IM drive

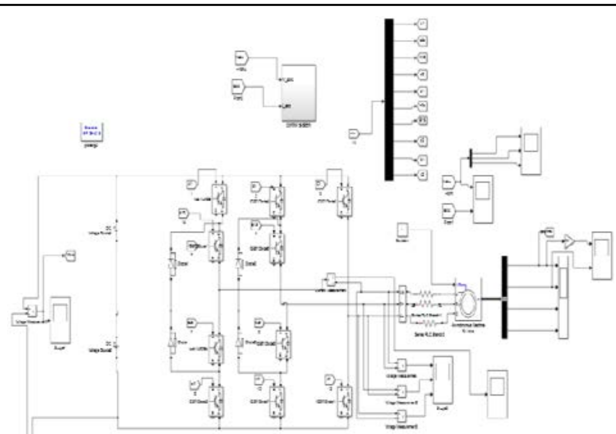

Fig.5. Proposed simulink model

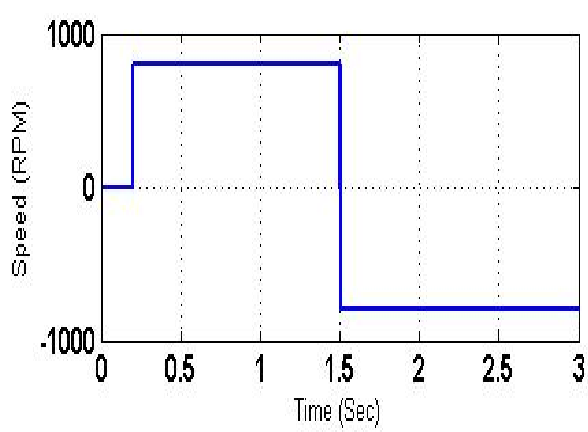

Fig.8. Reference speed for the systems

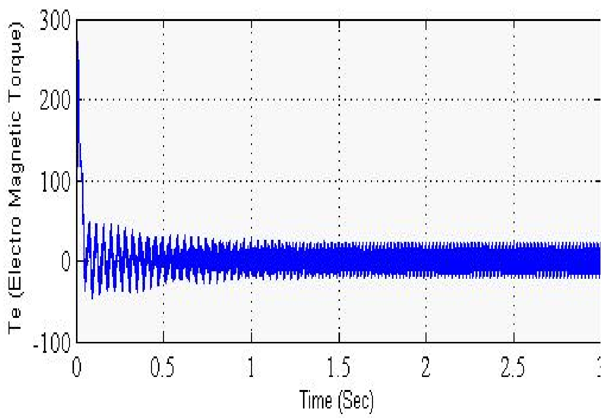

Fig.9. Electromagnetic Torque without using DTC

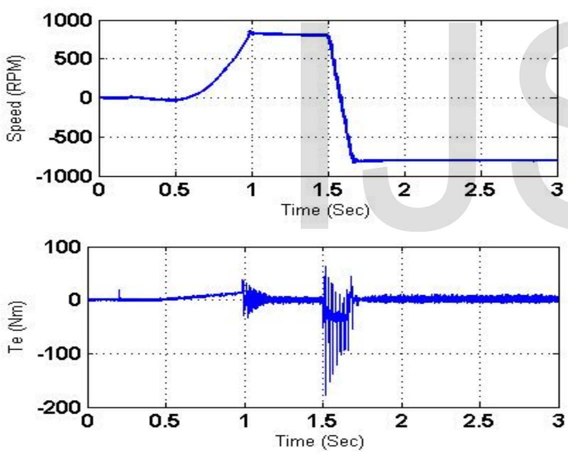

Fig.10. Speed and Torque characteristics of IM drive in normal condition.

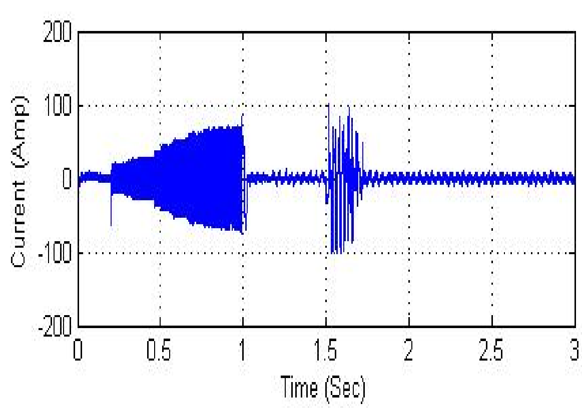

Fig.11. Line current of IM in normal condition.

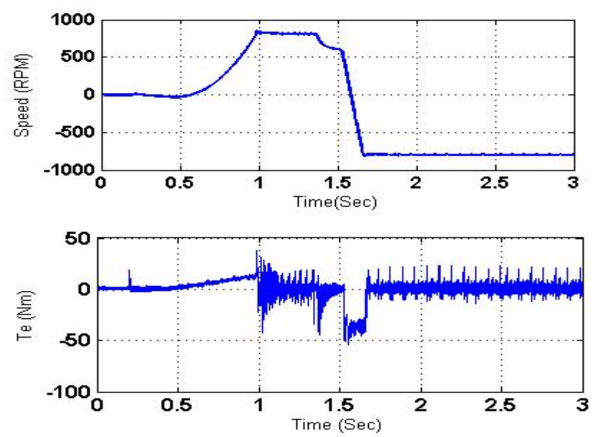

Fig.12. Speed and Torque characteristics of IM drive in abnormal condition.

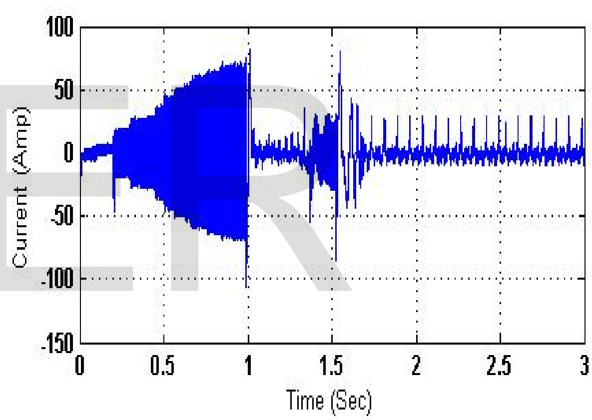

Fig.13. Line current of IM during abnormal condition.

5 Conclusion

A DTC-SVPWM scheme has been implemented for the IM drive fed by three level inverter in normal and abnormal conditions. Two systems are executed by taking the same reference input. The major difference in the normal and abnormal condition in the torque ripples are high at an instant of V6 and V12 vectors are absent. These torque ripples are in the span of $\pm 20\ Nm$ at a particular load. The torque ripples of the system in abnormal condition are very less than any scalar controlled technique and V/f technique used for IM drive. These torque ripples are almost reduced to half by using DTC-SVPWM Scheme. By additional leg in the inverter, In abnormal conditions like leg/switch failure, the system will be in stable region.

REFERENCES

[1] I. Takahashi and T. Noguchi, "A new quick-response and high-efficiency control strategy of an induction motor," IEEE Trans. Ind. Appl., vol. IA-22, no. 5, pp. 820–827, Sep. 1986.

[2] M. Depenbrock, "Direct self-control (DSC) of inverter-fed induction machine," IEEE Trans. Power Electron., vol. 3, no. 4, pp. 420–429, Oct. 1988.

[3] D. Casadei, F. Profumo, G. Serra, and A. Tani, "FOC and DTC: Two viable schemes for induction motors torque control," IEEE Trans. Power Electron., vol. 17, no. 5, pp. 779–787, Sep. 2002.

[4] G. S. Buja and M. P. Kazmierkowski, "Direct torque control of PWM inverter-fed AC motors—A survey," IEEE Trans. Ind. Electron., vol. 51, no. 4, pp. 744–757, Aug. 2004.

[5] Y. S. Lai and J. H. Chen, "A new approach to direct torque control ofinduction motor drives for constant inverter switching frequency andtorque ripple reduction," IEEE Trans. Energy Convers., vol. 16, no. 3,pp. 220–227, 2001.

[6] S. Mir, M. E. Elbuluk, and D. S. Zinger, "PI and fuzzy estimators for tuning the stator resistance in direct torque control of induction machines," IEEE Trans. Power Electron., vol. 13, no. 2, pp. 279–287, 1998.

[7] A. Arias, J. L. Romeral, and E. Aldabas, "Fuzzy logic direct torquecontrol," in Proc. IEEE ISIE, 2000, vol. 1, pp. 253–258.

[8] D. Seyoum, M. F. Rahman, and C. Grantham, "Simplified flux estimation for control application in induction machines," in IEMDC'03,2003, vol. 2, pp. 691–695.

[9] Yongchang Zhang, Jianguo Zhu, Zhengming Zhao, Wei Xu, David G. Dorrell,"An Improved Direct Torque Control for Three-Level Inverter-Fed Induction Motor Sensorless Drive"IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 27, NO. 3, MARCH 2012

[10] H. W. van der Broeck and J. D. vanWyk, "A comparative investigation of a three-phase induction machine drive with a component minimized voltage-fed inverter under different control options," IEEE Trans. Ind. Appl., vol. IA-20, no. 2, pp. 309–320, Mar./Apr. 1984.

[11] W. McMurray, "Modulation of the chopping frequency in dc choppers andPWMinverters having current-hysteresis controllers," IEEE Trans. Ind. Appl., vol. IA-20, no. 4, pp. 763–768, Jul./Aug. 1984.

[12] F. Blaabjerg, S. Freysson, H. H. Hansen, and S. Hansen, "Comparison of a space-vector modulation strategy for a three phase standard and a component minimized voltage source inverter," in Proc. EPE Conf., 1995, pp. 1806–1813.

[13] G. Kim and T. A. Lipo, "VSI-PWM rectifier/inverter system with a reduced switch count," in Proc. IEEE-IAS Annu. Meeting, 1995, pp. 2327–2332.

[14] R. L. A. Ribeiro, C. B. Jacobina, E. R. C. da Silva, and A. M. N. Lima, "AC/AC converter with four switch three phase structures," in Proc. IEEE PESC, Jun. 1996, pp. 134–139.

[15] F. Blaabjerg, S. Freysson, H. H. Hansen, and S. Hansen, "A new optimized space-vector modulation strategy for a component-minimized voltage source inverter," IEEE Trans. Power Electon., vol. 12, no. 4, pp. 704–714, Jul. 1997.

[16] D. T. W. Liang and J. Li, "Flux vector modulation strategy for a four-switch three-phase inverter for motor drive applications," in Proc. IEEE PESC, Jun. 1997, pp. 612–617.

[17] F. Blaabjerg, D. Neacsu, and J. Pedersen, "Adaptive SVM to compensate DC-link voltage ripple for four-switch three-phase voltage-source inverters," IEEE Trans. Power Electon., vol. 14, no. 4, pp. 1331–1337, Jul. 1999.