PUBLICATION OF Little Lion Scientific R&D, Islamabad PAKISTAN
Journal of Theoretical and Applied Information Technology
15th June 2011. Vol. 28 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

EVALUATION OF PERFORMANCE OF NOVEL SPACE-VECTOR PULSE WIDTH MODULATION (SVPWM) FOR DUAL FIVE-LEVEL AND DUAL SIX- LEVEL INVERTER FED SIX PHASE INDUCTION MOTOR(SPIM)

S. SIVA PRASAD[1] Dr. G. TULASI RAM DAS [2] Dr. P. S. SUBRAMANYAM[3]

[1] Research Scholar,Department of Electrical and Electronics Engineering, J.N.T.University, Hyderabad, Andhra Pradesh, India.

[2]Professor & Registrar, J. N. T. University, Hyderabad, Andhra Pradesh, India.

[3]Professor& HOD, V.B.I.T, Hyderabad, Andhra Pradesh, India.

ABSTRACT

In this paper, a new simplified method for six phase Induction motor model control by Space Vector PWM scheme is implemented to dual five and dual six level inverter fed six phase induction motor. Specifically as compared with dual five, dual four, dual three and dual two level inverters, for a given dc bus voltage, a dual Six-level inverter is able to synthesize better waveforms with reduced torque ripples. This method is based on the simplification of the space–vector diagram of six-level inverter into six space vector diagrams of a four-level inverter and the each space-vector diagram of each four-level inverter is decomposed in to six space vector diagrams of three-level inverters and each three-level inverter is decomposed in to six space vector diagrams of two-level inverters. The total harmonic distortion have been calculated for dual five and six level Inverter fed six phase induction motor and found that THD is very much reduced for dual six–level inverter fed six phase Induction motor.

Key words-- *Six-Phase Induction Motor,Space-Vector Pulse width Modulation*

1. INTRODUCTION

Six phase Induction motor drives have been proposed for specific advantages over traditional three-phase Induction motor drives, such as reducing the rotor harmonic current losses, lowering the dc-link current harmonics, and better system reliability and other potential advantages are discussed in literature [1-5]. The authors [6] have demonstrated by analog simulation of six step voltage fed dual- three phase induction drive. The performance of simulation of the d-q model of dual–three phase Induction motor is demonstrated [7]. By increasing the number of phases it is also possible to increase the power /torque per rms ampere for the same volume machine of Six Phase. The Induction Motor can be started and run with some phases open and performance in this faulted mode can be as good as with all phases energized. Space-vector modulation (SVM) technique for dual three phase drive has been developed in [8].A simplified SVPWM method for three level inverters has been developed [9]. In this paper the performance of novel Space-Vector Pulse width Modulation (SVPWM) method for dual five

and dual sixlevel inverter fed Six Phase Induction Machine have been investigated. A Six phase Induction Motor can be derived either from dual voltage three phase machine without any additional cost by rewinding a standard three phase machine. There are two types of six phase machine designs, one is two sets of three phase winding that are separately shifted by 30 electrical degrees called as asymmetrical and if two sets of three phase windings are spatially shifted by 60 electrical degrees called as symmetrical six phase machine. The asymmetrical six phase machine is implemented in this paper (Fig.1). This paper aims to analyze the six phase induction motor operation and performance comparison of a new dual 5-Level and dual 6- level SVPWM schemes by means of analytical MATLAB/ Simulink simulations. This paper deals with the performance of Six-Phase Induction Motor using Dual Three Phase

PUBLICATION OF Little Lion Scientific R&D, Islamabad PAKISTAN
Journal of Theoretical and Applied Information Technology
15th June 2011. Vol. 28 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Transformation (DTPT) i.e., the balanced Six Phase system can be considered as one consisting of two mutually coupled three phase system

2. IMPLEMENTATION OF SPACE VECTOR PULSE WIDTH MODULATION FOR DUAL FIVE-LEVEL INVERTER FED SIX PHASE INDUCTION MOTOR

A simple and fast method is implemented that divides the space vector diagram of five-level inverter divided into six space vector diagrams of three-level inverters. In turn, each one of these three-level inverter diagrams is divided into six space vector diagrams of two level inverters. Then the space vector modulation of five-level inverter becomes more easy and analogous to that of traditional two-level inverter space vector modulation. To reach this proposed simplification, two corrections have to be required as follows.

2.1 FirstCorrection of the reference Voltage Vector for five level inverter

By the location of a given reference voltage vector, one hexagon is selected in the middle of the six small hexagons that incorporate the three level space vector diagram. There exist some regions that are overlapped by two contiguous small hexagons. These regions will be splitted in equality between the two hexagons. The number ‘S’ is selected as per the Table-1. If the value of ‘S’ is determined, the origin of the reference voltage vector is changed to the center voltage vector of the selected hexagon. This translation is done by subtracting the center vector of the nominated hexagon from the original reference vector. Fig.3 shows the corrected reference voltage vector V^{5*} and the reference voltage vector after second correction V^{3*}. Table-2 gives the components *d* and *q* of the reference voltage $\mathbf{V}^{3*}$after translation for all the six hexagons.

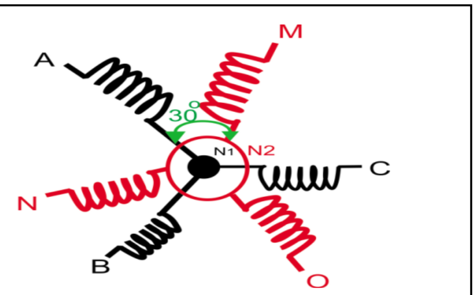


Fig.1 winding disposition of Six Phase Induction motor

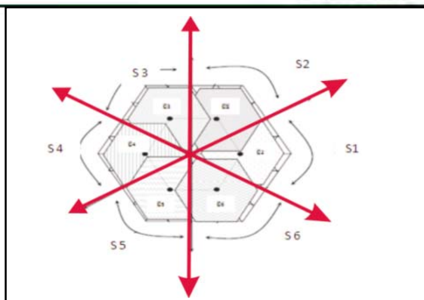


Fig.2 Selection of Hexagon’s number and overlapped regions

Table-1 Selection of Hexagons
(A): Hexagon Number‘s’
(B): Location of the reference voltagevector phase angle (ɵ)

(A)	(B)
1	$-\frac{\pi}{6} < \theta < \frac{\pi}{6}$
2	$\frac{\pi}{6} < \theta < \frac{\pi}{2}$
3	$\frac{\pi}{2} < \theta < \frac{5\pi}{6}$
4	$\frac{5\pi}{6} < \theta < \frac{7\pi}{6}$
5	$\frac{7\pi}{6} < \theta < \frac{3\pi}{2}$
6	$\frac{3\pi}{6} < \theta < \frac{11\pi}{6}$

2.2 Second Correction of the reference Voltage Vectorfor five level inverter

As made in the first correction from the location of this vector, one hexagon has chosen among those that incorporate the three level space vector diagrams. If the hexagon is resolute, the origin of the reference voltage vector is altered to the center voltage vector of the elected hexagon. Fig.4 shows the corrected reference voltage vector V^{3*} and the reference voltage vector after second correction V^{2*}. Table-3 gives the components *d* and *q* of the reference voltage $\mathbf{V}^{2*}$after translation for all the six hexagons.

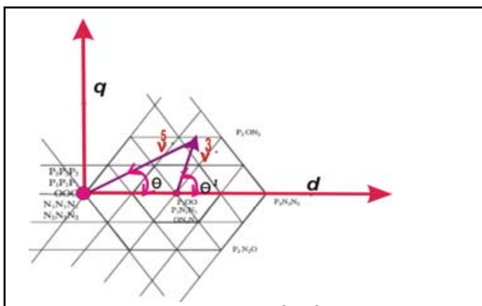


Fig3. First translation of reference voltage vector for 5-level inverter

PUBLICATION OF Little Lion Scientific R&D, Islamabad PAKISTAN
Journal of Theoretical and Applied Information Technology
15th June 2011. Vol. 28 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table-2: First correction of reference voltage vector for five level inverter

S	V_d^{3*}	V_q^{3*}
1	V_d^{5*} - 1/4 cos (0)	V_q^{5*} - 1/4 sin (0)
2	V_d^{5*} - 1/4 cos (π/4)	V_q^{5*} - 1/4 sin (π/4)
3	V_d^{5*} - 1/4 cos (2π/4)	V_q^{5*} - 1/4 sin (2π/4)
4	V_d^{5*} - 1/4 cos (π)	V_q^{5*} - 1/4 sin (π)
5	V_d^{5*} - 1/4 cos (4π/4)	V_q^{5*} - 1/4 sin (4π/4)
6	V_d^{5*} - 1/4 cos (5π/4)	V_q^{5*} - 1/4 sin (5π/4)

Table-3: Second correction of reference voltage vector for five level inverter

S	V_d^{2*}	V_q^{2*}
1	V_d^{3*} - 1/6 cos (0)	V_q^{3*} - 1/6 sin (0)
2	V_d^{3*} - 1/6 cos (π/3)	V_q^{3*} - 1/6 sin (π/3)
3	V_d^{3*} - 1/6 cos (3π/3)	V_q^{3*} - 1/6 sin (3π/3)
4	V_d^{3*} - 1/6 cos (π)	V_q^{3*} - 1/6 sin (π)
5	V_d^{3*} - 1/6 cos (4π/3)	V_q^{3*} - 1/6 sin (4π/3)
6	V_d^{3*} - 1/6 cos (5π/3)	V_q^{3*} - 1/6 sin (5π/3)

3. IMPLEMENTATION OF SPACE VECTOR PULSE WIDTH MODULATION FOR DUAL SIX-LEVEL INVERTER FED SIX PHASE INDUCTION MOTOR

A straightforward and fast technique is implemented that the space–vector diagram of six-level inverter into six space vector diagrams of a four-level inverter and the each space-vector diagram of each four-level inverter is decomposed in to six space vector diagrams of three-level inverters and each three-level inverter is decomposed in to six space vector diagrams of two-level inverters. Fig.5 shows the dual three phase six Level inverter fed six phase induction motor

3.1 First Correction of the reference Voltage Vector six level inverter

By the location of a given reference voltage vector, one hexagon is selected in the middle of the six small hexagons that incorporate the four level space vector diagram. There exist some regions that are overlapped by two contiguous small hexagons. These regions will be splitted in equality between the two hexagons. The number 'S' is selected as per the table-1. If the value of 'S' is determined, the origin of the reference voltage vector is changed to the center voltage vector of the selected hexagon. This translation is done by subtracting the center vector of the nominated hexagon from the original reference vector. Fig.6 shows the corrected reference voltage vector V^{6*} and the reference voltage vector after second correction V^{4*}. Table-4 gives the components *d* and *q* of the reference voltage $\mathbf{V}^{4*}$after translation for all the six hexagons.

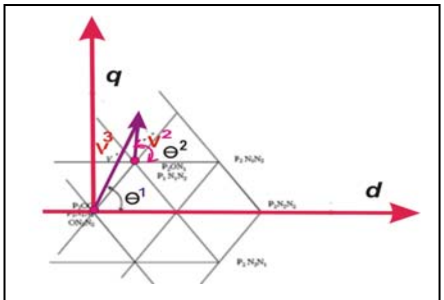


Fig.4 Second translation of reference voltage vector for 5-level inverter.

3.2 Second Correction of the reference Voltage Vector six level inverter

Similarly as made in the first correction, from the location of this vector, one hexagon has chosen among those that incorporate the four level space vector diagrams. If the hexagon is resolute, the origin of the reference voltage vector is altered to the center voltage vector of the elected hexagon. Fig.7shows the corrected reference voltage vector V^{4*} and the reference voltage vector after second correction V^{3*}. Table-5 gives the components *d* and *q* of the reference voltage $\mathbf{V}^{3*}$after translation for all the six hexagons.

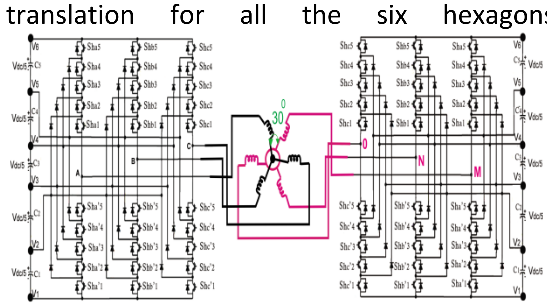


Fig.5 Dual three phase six Level inverter fed six phase induction motor

3.3 Third Correction of Reference Voltage Vector for six level inverter

After chosen three-level inverter space vector diagram, one hexagon is chosen from the position of a given reference voltage vector surrounded by the six small hexagons that restrain the Three level

PUBLICATION OF Little Lion Scientific R&D, Islamabad PAKISTAN
Journal of Theoretical and Applied Information Technology
15th June 2011. Vol. 28 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

space vector diagram. Subsequent choice of one hexagon, it is required the third translation (Fig.8) of the reference vector V^{3*} in the direction of the centre of this hexagon. This translation is completed by subtracting the centre vector of the selected hexagon from the original reference vector. For all six hexagons the components d and q of the reference voltage V^{2*} are furnished in Table-6.

Table-4 First Correction of Reference Voltage Vector for six level Inverter

S	V_d^{4*}	V_q^{4*}
1	V_d^{6*} - 1/4 cos (0)	V_q^{6*} - 1/4 sin (0)
2	V_d^{6*} - 1/4 cos(π/3)	V_q^{6*} - 1/4 sin (π/3)
3	V_d^{6*} - 1/4 cos(2π/3)	V_q^{6*} - 1/4 sin (2π/3)
4	V_d^{6*} - 1/4 cos (π)	V_q^{6*} - 1/4 sin (π)
5	V_d^{6*} - 1/4 cos (4π/3)	V_q^{6*} - 1/4 sin (4π/3)
6	V_d^{6*} - 1/4 cos (5π/3)	V_q^{6*} - 1/4 sin (5π/3)

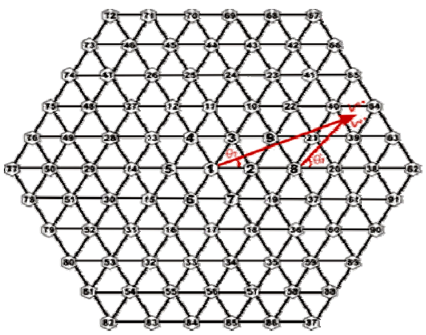


Fig.6 First Translation of Reference Voltage Vector for six level inverter

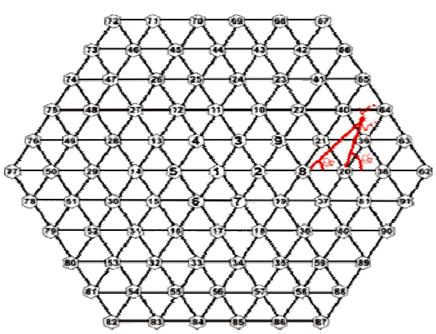


Fig.7 Second Translation of Reference Voltage Vector for six level Inverter

Table-5 Second Correction of reference voltage vector for six level inverter

S	V_d^{3*}	V_q^{3*}
1	V_d^{4*} - 1/6 cos (0)	V_q^{4*} - 1/6 sin (0)
2	V_d^{4*} - 1/6 cos (π/3)	V_q^{4*} - 1/6 sin (π/3)
3	V_d^{4*} - 1/6 cos (2π/3)	V_q^{4*} - 1/6 sin (2π/3)
4	V_d^{4*} - 1/6 cos(3π/3)	V_q^{4*} - 1/6 sin (3π/3)
5	V_d^{4*} - 1/6 cos (4π/3)	V_q^{4*} - 1/6 sin (4π/3)
6	V_d^{4*} - 1/6 cos (5π/3)	V_q^{4*} - 1/6 sin (5π/3)

Table-6 Third Correction of reference voltage vector for six level inverter

S	V_d^{2*}	V_q^{2*}
1	V_d^{3*} - 1/6 cos (0)	V_q^{3*} - 1/6 sin (0)
2	V_d^{3*} - 1/6 cos (π/3)	V_q^{3*} - 1/6 sin (π/3)
3	V_d^{3*} - 1/6 cos (2π/3)	V_q^{3*} - 1/6 sin (2π/3)
4	V_d^{3*} - 1/6 cos (π)	V_q^{3*} - 1/6 sin (π)
5	V_d^{3*} - 1/6 cos (4π/3)	V_q^{3*} - 1/6 sin (4π/3)
6	V_d^{3*} - 1/6 cos (5π/3)	V_q^{3*} - 1/6 sin (5π/3)

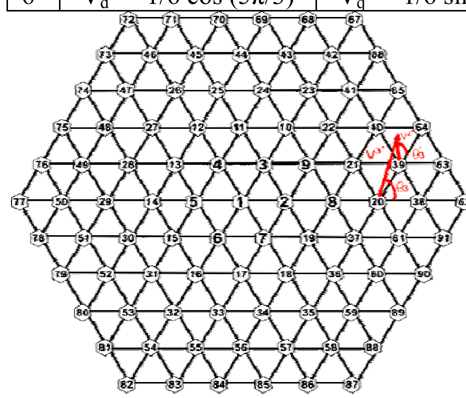


Fig. 8 Third Translation of Reference Voltage Vector for six level inverter

4. RESULTS AND DISCUSSIONS

Simulations were carried out for the dual 5-level and dual 6-level Inverter fed six phase induction motor using the new Space vector PWM technique and the results are presented and analysed in this paper. The simulated output voltage and its harmonic spectrum are shown for dual 6-level inverter respectively inFig.9. It shows that the total harmonic distortion (THD) is greatly reduced for 6-level inverter fed SPIM in this method.Fig.10 (A)&(B) shows the torque responses of dual 6-level inverter fed six phase Induction motor and corresponding speed response of dual 6-level inverter fed six phase Induction motor respectively.Fig.11(A)&(B) shows thetorque response of dual 5-level inverter fed six phase Induction motor and torque response comparison for dual 5-level and dual6-level inverter fed six phase induction motor respectively when torque of 25 N.m is applied at t = 0.52 seconds and torque is released at t = 0.81 Seconds. It is observed the speed drop and rise at the points t = 0.52 sec and t = 0.81sec respectively in Fig.10(b). From the Fig.11, it is observed that the reduced torque ripples for dual 6-level Inverter fed SPIM compared to dual 5-level Inverter fed SPIM. Fig.12 (A) & (B) shows

PUBLICATION OF Little Lion Scientific R&D, Islamabad PAKISTAN
Journal of Theoretical and Applied Information Technology
15th June 2011. Vol. 28 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

the six phase stator currents for dual 5- level and 6-level inverter fed six phase induction motor respectively. The Fig.12 (C) shows the expanded view of 6- level inverter fed six phase induction motor. From the results (Table-7) it is observed that the dual 6-level Inverter, proposed algorithm has better dynamic response and less ripples than the dual 5-level inverter fed six phase Induction motor.

<u>Six Phase Induction motor parameters</u>:
Rr=0.39 ohm;
Rs=0.19 ohm;
Lls=.21e-3 H;
Llr=.6e-3 H;
Lm= 4e-3 H;
p=4; J=0.025 Kg/m^2

<u>SVPWM parameters</u>:
Modulation index m = 0.8
DC Supply voltage = 430V
No. of switching intervals = 192

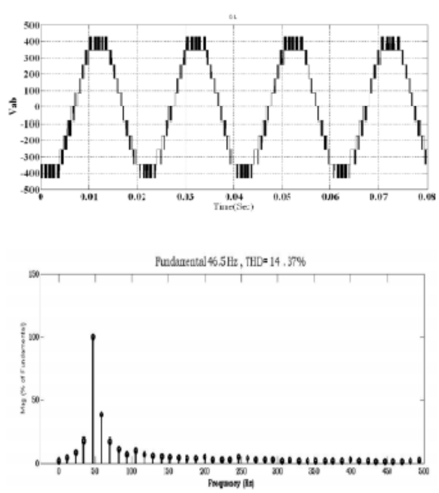


Fig.9 The output line to line voltage and its harmonic spectrum for 6-Level inverter

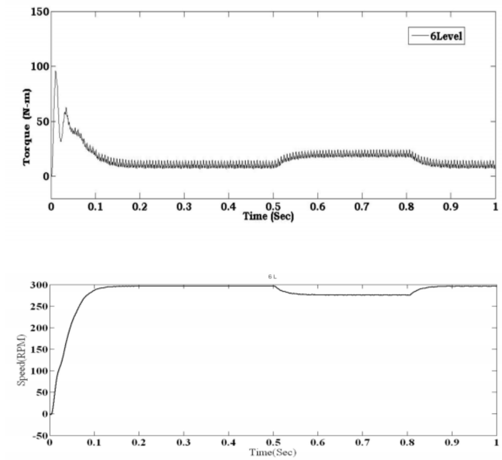
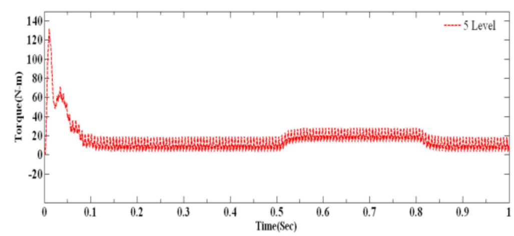
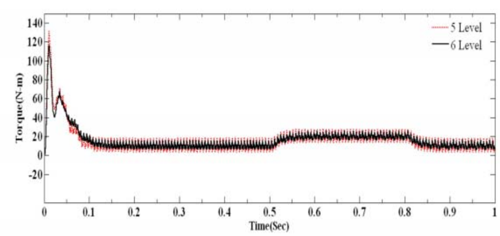


Fig.10

(A)Torque response of dual six level inverter fed SPIM
(B)Corresponding speed response of dual six level inverter fed Six Phase Induction Motor

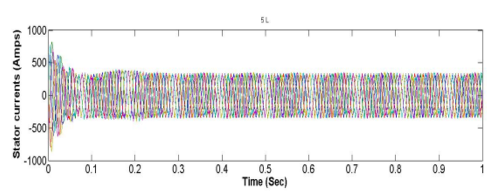


(A)



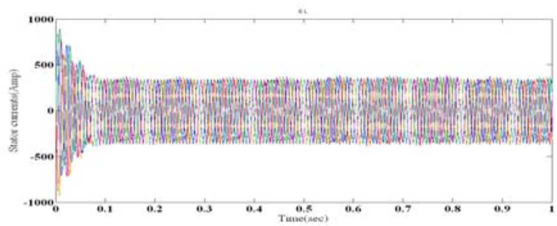
(B)

Fig11.
(A) Torque response of dual 5- level inverter fed SPIM
(B) Torque response comparison of dual five level and dual six level inverter fed SPIM

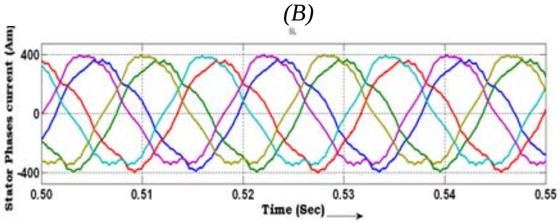


(A)

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195



(B)



(C)

Fig.12
(A)Stator phases current for dual five level fed SPIM
(B)Stator phases current for dual Six-Level fed Six Phase Induction Motor
(C)Expanded view of Stator phases current for dual Six-Level fedSix-Level fed Six Phase Induction Motor

Table-7 Simulation results of six phase induction motor

Level No / Parameter	5-Level Inverter fed SPIM	6-Level Inverter fed SPIM
% THD	16.02	14.37
Peak value of Torque at starting(N-m)	75	94
Time taken for steady state Torque(sec)	0.13	0.128
Torque ripple after Steady state (N-m)	8	7.5

5. CONCLUSIONS

Two different dual inverter levels are implemented to Six phase Induction motor for operation and control. One of the level were a simple approach to the dual five level SVPWM inverter fed six-phase induction machine. Further In this paper a new space vector pulse width modulation algorithm approach has been proposed and applied to dual six level inverter fed six-phase induction machine. The total harmonic distortion (THD) with the proposed method for six level inverter is very less as compared with the other conventional methods of SVPWM techniques and generated harmonic spectrum is very much improved with reduced torque ripples when applied to six phase induction motor.From these results it is found that the dual six level inverter fed six phase induction motor with SVPWM method has better harmonic spectrum, less THD and reduced Torque ripples compared with dual five level inverter SVPWM fed six phase Induction motor. This scheme reduces the execution time and saving the memory and it can be easily applied to the multilevel inverters above the dual six-level for six phase induction motor. Further this six phase machine also easily extended to any number of phases, which are multiples of three.

REFERENCES:

[1] M. Lazzari, P.Ferraris,"Phase number and their related effects on the characteristics of inverter-fed induction motor drives", Conf.Rec.IEEE – IAS'83 Maxico city, Maxico , oct.1983, p.p.494-502.

[2] R.Bojai, M.Chiadocaponet, G.Grieco, M.Lazzari, F.Profitmo, A.Tenconi "Computation and measurements of dc link current in Six-Phase voltage source PWM inverters for ac motor drives", Conf.Rec. Pcc'02, Osaka, japan, April 2002 pp. 953-958

[3] R.O.C. Lyra, T.A. Lipo, Torque density improvement in a six-phase induction motor with third harmonic current injection, IEEE Trans. Ind. Appl. 38 (5) (2002) 1351–1360.

[4] R. Bojoi, F. Farina, A. Tenconi, F. Profumo, E. Levi, Stationary frame digital current regulation for dual-three phase induction motor drives, in: Proceedings of IEEE Power Electronics Specialists Conference PESC, Aachen, Germany, 2004, pp. 2121– 2127.

[5] Y. Zhao, T.A. Lipo, Space vector PWM control of dual three-phase induction machine using space vector decomposition, IEEE Trans. Ind. Appl. 31 (5) (1995), pp.1100–1109.

[6] R.H.Nelson and P.C.Krause,"Induction Machine analysis from arbitrary displacement between multiple winding sets,"IEEE Tran.Power App.Syst.Vol, PAS-93, pp 841-848, May/June 1974.

[7] T.A.Lipo, "A d-q model for six phase induction drives",inproc.Int.conf. Electrical machines, Vol.2, 1980, pp.860-867.

Journal of Theoretical and Applied Information Technology
15th June 2011. Vol. 28 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[8] K. Gopakumar, V.T. Ranganathan, S.R. Bhat, Split-phase induction motor operation from PWM voltage source inverter, IEEE Trans. Ind. Appl. 29(5) (1993) 927–933.

[9] Jae HyeongSeo, Chang Ho Choiand Dong Seok Hyun, “A New Simplified Space–Vector PWM Method for Three-Level Inverters,” IEEE Transactions on power electronics, Vol. 16, no. 4, July 2001, pp 545-550.