International Journal of Innovative Technologies
WWW.IJITECH.ORG
ISSN 2321-8665
Volume.06, Issue.01,
January-June, 2018,
Pages:0088-0092

Space Vector Control NPC Three Level Inverter Based STATCOM With Balancing DC Capacitor Voltage

SHAIK ASLAM[1], M. RAMANJANEYULU[2]
[1]PG Scholar, VRS & YRN College of Engineering and Technology, Chirala, AP, India.
[2]Assistant Professor, VRS & YRN College of Engineering and Technology, Chirala, AP, India.

Abstract: A space vector modulation (SVM) based maneuver for a three-level neutral point clamped (NPC) inverter that is habituated as a static synchronous compensator (STATCOM) is presented. The significant attribute of the proposed SVM switching maneuver is that it enables efficient control in the voltage balancing of the DC capacitors while compensating reactive power demand by the load in power system and initiating best voltage regulation with no prior auxiliary devices or any other controlling devices. In the proposed scheme, the most appropriate length of the vector is calculated for which reactive power exchange takes place while maintaining the balance between capacitor voltages. A dynamic model of threelevel STATCOM and its performance is demonstrated in MATLAB/Simulink environment. The studies reveal the capabilities of the SVM based maneuver to maintain the capacitor voltages of the three-level NPC under various operating scenarios.

Keywords: Space Vector Modulation(SVM), Three-level Neutral Point Clamped (NPC) Inverter, Static Synchronous Compensator (STATCOM), Modulation Index, Multilevel Inverter, PCC.

I. INTRODUCTION

Reactive power compensation is the major accomplishment for control of power systems at transmission and distribution level. It improves the power factor, decreases the switching losses, improves voltage profile and overall stability of the system. The compensated power system is more superior to uncompensated one [4]. From last 20 years, traditional compensators are replaced by FACTS devices. The shunted capacitors and inductors are replaced by STATCOM. STATCOM is a voltage source converter based device. The voltage source is developed from a dc capacitor and hence, STATCOM has very little active power capability. But its active power can be increased if a suitable energy storage device is a connected across dc capacitor. The reactive power at the terminals of STATCOM depends on amplitude of voltage. If terminal voltage of STATCOM is greater than ac voltage at PCC (point of common coupling), then STATCOM generates reactive power, otherwise it absorbs reactive power. It consists of coupling transformer that serves as link between electrical power system and voltage source converter. Coupling transformer generates the voltage wave comparing it to the one of the electrical system to realize exchange of reactive power [1]-[3]. The leakage inductances of transformer can function as coupling reactors. The main function of coupling reactors is to filter out harmonic components that are generated by pulsating output voltage of power converters. Fig.1 shows the reactive power exchange between STATCOM and the load.

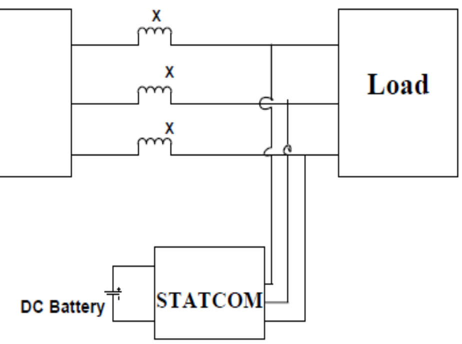

Fig1. STATCOM reactive power exchange

The rating of multilevel inverters used as STATCOM, can be augmented by increasing the number of levels in inverter output voltage without increasing the device rms ratings. As the number of levels increases, total harmonic distortion decreases. The number of achievable voltage levels is however limited by voltage imbalance problems [5]-[8]. Charge supplied by each capacitor even within the same time period considered is unequal. Hence, capacitor may discharge which results in voltage unbalance in capacitors and inverter may malfunction because the number of levels from then onwards will decrease. As a result harmonics are also produced due to capacitor voltage unbalance. To overcome the capacitor voltage unbalance problem, space vector modulation switching strategy/algorithm is used which will generate switching pulses for the multilevel inverter in a controlled way which provides an economically, rational and scientific approach to tackle the technical issues of multilevel inverter. Space vector modulation (SVM) is a special switching strategy where a reference signal is sampled [9]. The reference signal is generated from three-phase voltages using Clark's transformation [1]. The reference vector is then synthesized using an amalgamation of two adjacent active vectors and one or both zero vectors. This is because summation of three sinusoidal voltages can be represented by a rotating vector.

By choosing the nearest three vectors, to create reference vector, it is possible to maintain the voltage balance between the capacitors and minimize the harmonic content [9]. There are two essential requirements for SVM: firstly, minimum changes or rather zero are enviable when reference vector is travelling from one sector to another. Secondly, only two switches in the same leg of the inverter take part when passing from one switching state to another in order to diminish device switching frequency. In this paper, we are presenting, an efficient STATCOM implementation in power system for voltage balancing using Space Vector Modulation in a MATLAB/Simulink environment. A theoretical basis for the proposed SVM based balancing method is depicted without any need of auxiliary devices. This paper also depicts a comprehensive model for a three-level STATCOM.

II. THREE-LEVEL NPC INVERTER

Three-level NPC inverter consists of four IGBT switches with two anti-parallel diodes in each cell. Moving on to the DC side of the inverter, it uses capacitors in series to divide up the DC bus voltage into a set of voltage level, providing a neutral point ‘O’ [2]-[4]. To produce a ‘k-level’ phase voltage, NPC inverter needs ‘k-1’ capacitors. A three-level NPC inverter must be controlled such that out of four switches in the same cell, one pair of switch is complementary to the other pair of switch. Schematic diagram of three-level NPC inverter acting as STATCOM is depicted in Fig.2. When switches S2 and S3 are turned on, the inverter output phase ‘a’ is associated to the neutral point through one of the clamping diodes D1 and D2. Hence voltage of phase ‘a’ with respect to neutral point is 0 volts.

TABLE 1

SWITCHING STATES FOR NPC INVERTER

Switching status (Phase a)	State	Phase voltage Vao
S_1 = ON , S_2 = ON, S_3 = OFF , S_4 = OFF	P	$+V_{DC}/2$
S_1 = OFF , S_2 = ON, S_3 = ON , S_4 = OFF	O	0
S_1 = OFF , S_2 = OFF, S_3 = ON , S_4 = ON	N	$-V_{DC}/2$

The operating positions of the switches in the NPC inverter can be represented by the switching states as depicted in table 1. Switching state ‘P’ symbolizes that the upper two switches in cell ‘a’ are turned on and both the diodes are turned off. In this condition, voltage of phase ‘a’ with respect to neutral point is VDC/2. Switching state ‘O’ symbolizes that the interior two switches S2 and S3 in cell ‘a’ are turned on and voltage of phase ‘a’ with respect to neutral point is 0. Depending upon the direction of load current Ia, one of the two clamping diodes gets on. For example, a positive load current causes D1 to turn on and the phase ‘a’ is connected to the neutral point ‘O’ through the conduction of S2 and D1. Switching state ‘N’ symbolizes that the lower two switches in cell ‘a’ are turned on and both the diodes are turned off. Now, the corresponding voltage of phase ‘a’ with respect to neutral point is –VDC/2 [1]-[2]. Hence there are three switching states for each phase in three- level NPC inverter i.e. P, O and N that results in altogether 27 combination of switching states [1]-[2]. It must be noted that charge supplied by each capacitor must be same.

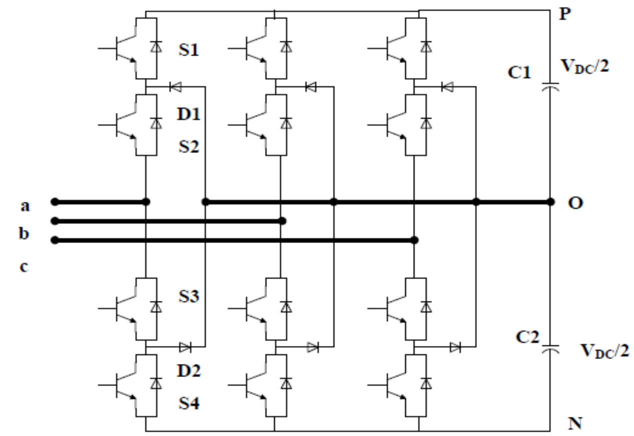

Fig2. Schematic diagram of three-level NPC Inverter.

III. SPACE VECTOR MODULATION (SVM)

Space Vector Modulation technique was originally developed as a vector approach to pulse width modulation (PWM) for three-phase inverters [10]. It deals with the space vectors to be applied in a particular sector where the output voltage vector is located. For a n-level, m-phase inverter, total number of combination of switching states will be nm. Here we are having 3 levels and three-phase, so total number of switching combinations will be 33=27. Each switching state will correspond to a vector and based on the magnitude, the voltage vectors are distinguished into four groups: zero vector having length of zero volts, small vector having length of VDC/3, medium vector having length of VDC/√3 and large vector having length of 2VDC/3 [2]. Zero vector has three redundant switching states (PPP, OOO and NNN). Hence, they will be counted as one vector only. Each small vector has two redundant switching states; for example, switching state POO and ONN has same magnitude and direction (VDC/3∟00). Hence, they will be counted as one vector only and altogether there are six small vectors. Each medium vector has only one redundant switching state only and altogether there are six medium vectors. Each large vector has only one redundant switching state and hence, there are six large vectors [1]-[4].

To implement Space Vector Modulation (SVM), a reference signal Vref is sampled. The reference signal is generated from three separate vectors (zero, small, medium or large vector) by Clarke’s transformation [1]. The reference vector is synthesized using a combination of two adjacent active vectors and one or both zero vectors. This is because of three sinusoidal voltages whose resultant can be represented by a rotating vector. Fig3 depicts SVM diagram of total 27 switching states corresponding to 19 voltage vectors altogether for a three-level NPC inverter.

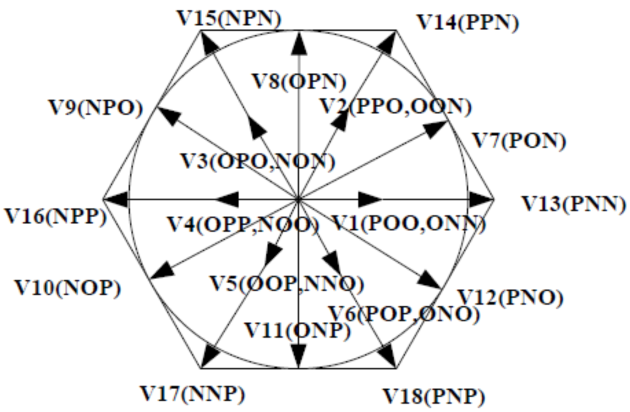

Fig3. SVM diagram for three-level inverter

IV. PROBLEM FORMULATION

Fig4 shows the combined schematic diagram of three-level NPC based STATCOM. It can be seen that, the SVM strategy needs the magnitude of the reference vector and angle of the reference vector that should be synchronized with the PCC voltage phase ‘a’ angle. Through SVM algorithm, gate pulses are provided to the three-level NPC based STATCOM. Because of this algorithm, the switching states of three-level NPC based STATCOM are controlled. The STATCOM is connected to PCC via a three-phase transformer, so that it can fulfill the reactive power demand of the load Ideally, the source should give active power to load and STATCOM should not compensate the active power demand of the load to keep both the capacitor voltages balanced.

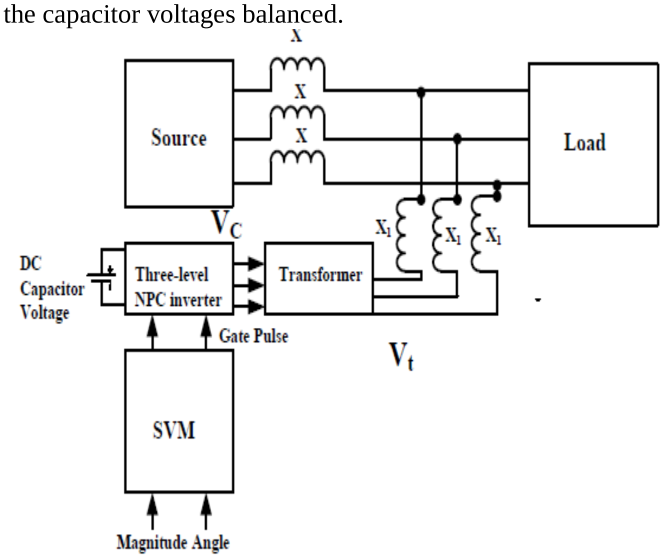

Fig4. Three- level NPC based STATCOM.

A. Mathematical Model of three-level STATCOM

To proceed for the mathematical modeling let us assume, the following system parameters as shown below in table 2. The above system parameters have validity, only when PCC voltage is maintained at 11KV (no voltage drop is taking place) and STATCOM is compensating only reactive power demand of the load which is 10.35MVAR. Since no voltage drop is taking place at PCC, therefore current supplied by the transformer on secondary side (I) directly reaches the load after bypassing the PCC branch. The simplified equivalent circuit of fig4 can be shown below in fig5 for the calculation of the magnitude of vector.

TABLE 2

SYSTEM PARAMETERS

Parameters	Values
AC system line voltage	11 kV
Load active Power P at rated voltage 11 kV	18.27 MW
Load reactive power Q at rated voltage 11 kV	10.35MVAR
Transmission line inductance X	1.5mH
Filter inductance X1	50mH
Line frequency	50 Hz
Net DC voltage V_{DC}	18 kV
DC capacitor C	0.646F
Sampling frequency	4 kHz
Transformer Rating	24.25MVA
Transformer Turn Ratio	1:3.06
Transformer secondary current	543.23A

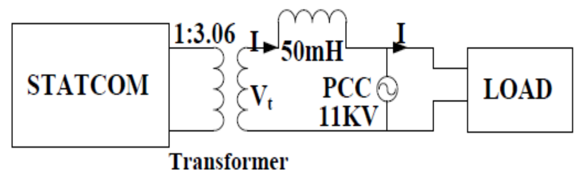

Fig5. Simplified equivalent circuit.

The reactive power demand of the load is 10.35MVAR which should be compensated by the STATCOM alone. Hence by per phase calculations, reactive power per phase will be 3.45MVAR. Now, since PCC voltage has to be maintained at 11KV i.e. 6350.85KV per phase, therefore there should be no voltage drop in the PCC branch as shown in fig5 of simplified equivalent. That means no current should enter PCC branch and because of this transformer secondary side current should reach the load directly. Now, we have calculated PCC per phase voltage, reactive power per phase and phase angle is 90°, therefore current (I) comes out to be 543.23Amperes. If we apply KVL at the transformer secondary side, we will get thevalue of transformer secondary voltage (Vt), which comes out to be 14883.88V. Since we know the turn ratio of transformer, we will get the value of primary voltage as 4864V. Finally, the magnitude of the reference vector comes out to be √2 times 4864, which comes out to be 6878.73Volts.

B. Mathematical Model of SVM

Calculation of vectorial length: Any three-phase rotating system can be transformed into two-phase rotating system by the help of Clarke’s Transformation [10].

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & \frac{-1}{3} & \frac{-1}{3} \\ 0 & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

Now, we know that any sinusoidal voltage can be represented by a rotating vector whose magnitude is given by:

$$V_{ref} = V_\alpha + jV_\beta \quad (2)$$

From (1) and (2), we get

$$V_{ref} = \frac{2}{3}(V_a + e^{j120^o}V_b + e^{-j120^o}V_c) \quad (3)$$

From (3), we can calculate the length of zero, small, medium and large vectors by utilizing 27 switching states of a threelevel NPC inverter. Boundary conditions for subsectors in sector-K: If we rotate a sector in fig3 such that the rotation is from 0° axis to 60° anticlockwise, then we will get the following sector (K) as shown below in fig6. It consists of all the other four subsectors within it, whose modulation indices or the boundary conditions are calculated. The term modulation index can be defined as the ratio of reference vector to the length of largest vector [9]. It is a factor which tells us whether the reference vector is lying within the sector or not.

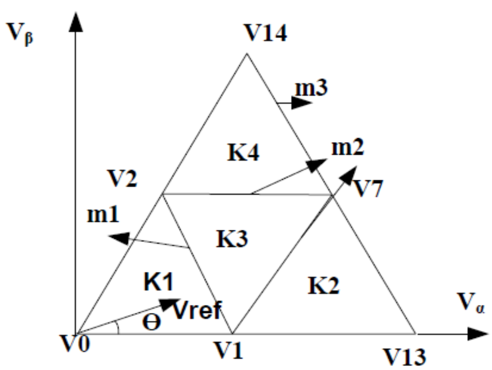

Fig6. Space vector diagram of sector-K

The boundary conditions are as follows:

$$m_1 = \frac{\sqrt{3}}{2(\sqrt{3}\cos\theta + \sin\theta)};\ 0 \le \theta \le 60^o \quad (4)$$

$$m_2 = \frac{\sqrt{3}}{2(\sqrt{3}\cos\theta - \sin\theta)};\ 0 \le \theta \le 30^o \quad (5)$$

$$m_2 = \frac{\sqrt{3}}{4\sin\theta};\ 30^o \le \theta \le 60^o \quad (6)$$

$$m_3 = \frac{\sqrt{3}}{(\sqrt{3}\cos\theta + \sin\theta)};\ 0 \le \theta \le 60^o \quad (7)$$

Timing ratios of 3 nearest vectors in sector-K: For each subsector there are 3 nearest vector of timing ratios X, Y and Z that will create reference vector. The timing ratio can be defined as the ratio of on time to the total sample time Ts.

$$T_x + T_y + T_z = T_s \quad (8)$$

Here, x T , y T , z T are the time durations of each of 3 nearest vectors within a particular subsector.

$$X = 1 - \frac{4m\sin\theta}{\sqrt{3}}$$

$$Y = 1 - 2m(\cos\theta - \frac{\sin\theta}{\sqrt{3}}) \quad ;\ m_1 < m < m_2 \quad (10)$$

$$Z = 2m(\cos\theta + \frac{\sin\theta}{\sqrt{3}}) - 1$$

$$X = 2m(\cos\theta - \frac{\sin\theta}{\sqrt{3}}) - 1$$

$$Y = \frac{4m\sin\theta}{\sqrt{3}} \quad ;\ m_2 < m < m_3 \text{ and } 30^o < \theta < 60^o \quad (11)$$

$$Z = 2 - 2m(\cos\theta + \frac{\sin\theta}{\sqrt{3}})$$

$$X = 2m(\cos\theta - \frac{\sin\theta}{\sqrt{3}})$$

$$Y = \frac{4m\sin\theta}{\sqrt{3}} - 1 \quad ;\ m_2 < m < m_3 \text{ and } 30^o < \theta < 60^o \quad (12)$$

$$Z = 2 - 2m(\cos\theta + \frac{\sin\theta}{\sqrt{3}})$$

V. SIMULATION RESULTS

The control algorithm is developed by using (1)-(12) and switching pulses are developed. These switching pulses are used to trigger the IGBT's of three-level STATCOM. The magnitude or the length of the reference vector is calculated i.e. 6878.73volts and given to the SVM block developed in a simulink environment. The angle of the reference vector is synchronized with the PCC phase 'a' angle. The algorithm is developed for under modulation case. The switching pulses are shown in fig7 for the cell 'a' of the inverter. Since switch pair S1a and S3a are complementary and switch pair S2a and S4a are complementary, hence first two waveforms are complementary to each other and last two waveforms are complementary to each other.

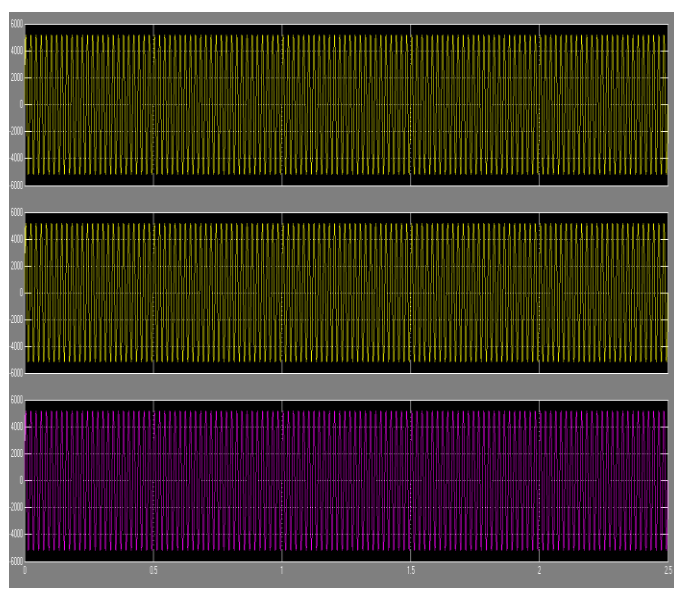

Fig7. Synchronization of source voltage and PCC voltage.

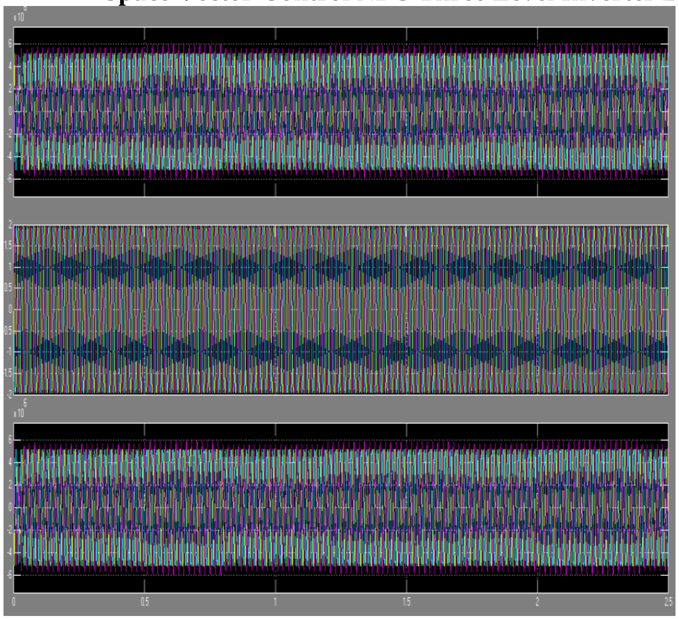

Fig8.Load current, STATCOM current and source current.

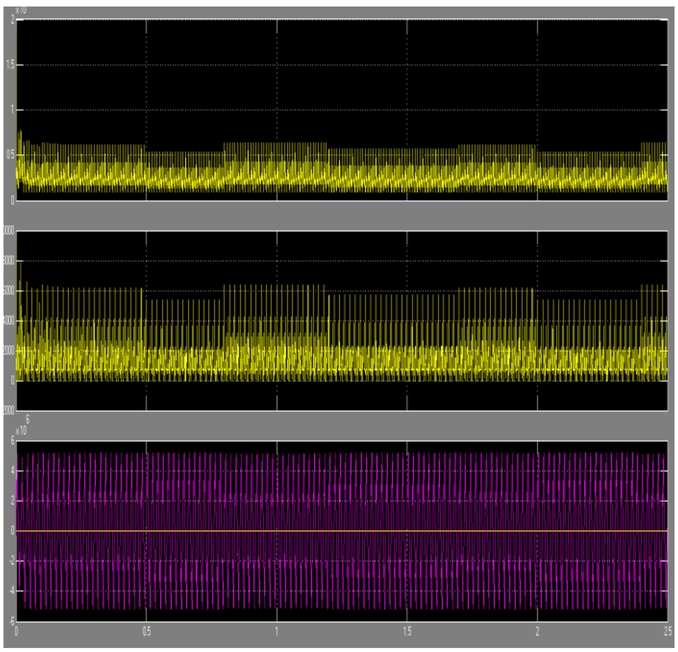

Fig9. DC-link voltage and DC capacitor voltage Uncompensated and Compensated PCC voltage and current.

VI. CONCLUSION

This paper focuses on application of SVM strategy in three level NPC inverter for DC capacitor voltage balancing. The magnitude of the reference vector is mathematically calculated and encoded to frame the SVM algorithm. Also proper utilization of redundant states and variation of modulation index is kept in mind for the minimization of neutral point voltage deviation. The compensated PCC voltage is restored to its rated value, thus maintaining the voltage stability and improving the power factor. The key to the simulation is that the angle of the reference vector should be synchronized with the angle of PCC phase ‘a’ voltage.

VII. REFERENCES

[1] H. C. Tsai, C. C. Chu and S. H. Lee, "Passivity-based nonlinear STATCOM controller design for improving transient stability of power systems," Transmission and Distribution Conference and Exhibition: Asia and Pacific, IEEE/PES, pp. 1-5, 2005.

[2] D. Dupuis and F. Okou, "Modeling and control of a five-level Diode- Clamped Converter based STATCOM," in proc. ICIT’09 proc. of the 2009 IEEE International Conference on Industrial Technology, pp. 100-105, 2009.

[3] S. F. Faisal, A. H. M. A. Rahim and J. M. Bakhashwain, "A robust STATCOM controller for a multi-machine power system using Particle Swarm Optimization and Loop-Shaping," International Journal of Electrical, Computer and Systems Engineering, vol. 1, no. 3, pp. 64-70, 2007.

[4] S. Kincic, A. Chandra and S. Babic, “Multilevel inverter and its limitation when applied as STATCOM,” 9th IEEE Mediterranean Conference on Control Automation, ISBN: 953-6037-34-3, 953-6037-35-1-CD,pp.1-5, June 27-29, 2011.

[5] S. A. Khajehoddin, A. Bakhshai, and P. K. Jain, "A Voltage balancing method and its stability boundary for five-level Diode-Clamped Multilevel Converters," Power Electronics Specialists Conference, IEEE , pp. 2204,2208, 17-21 June, 2007.

[6] G. P. Adam, S. J. Finney, A. M. Massoud and B. W. Williams, "Capacitor balance issues of the Diode-Clamped Multilevel Inverter operated in a Quasi two-state mode," Industrial Electronics, IEEE Transactions on , vol.55, no.8, pp. 3088-3099, Aug. 2008.

[7] M. Marchesoni and P. Tenca, "Diode-clamped multilevel converters: a practicable way to balance DC-link voltages," Industrial Electronics, IEEE Transactions on, vol.49, no.4, pp. 752-765, Aug. 2002.

[8] A. V. Jouanne, S. Dai and H. Zhang, "A multilevel inverter approach providing DC-link balancing, ride-through enhancement, and commonmode voltage elimination," Industrial Electronics, IEEE Transactions on, vol.49, no.4, pp. 739-745, Aug. 2002.

[9] K. Zhou and D. Wang, "Relationship between space-vector modulation and three-phase carrier-based PWM: a comprehensive analysis [threephase inverters]," Industrial Electronics, IEEE Transactions on, vol.49, no.1, pp. 186-196, Feb. 2002.

[10] D. Rathnakumar, J. L. Perumal and T. Srinivasan, "A new software implementation of space vector PWM," SoutheastCon, Proceedings. IEEE, pp. 131-136, 8-10 April 2005.