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Comparison of SPWM and SVM Based Neutral Point Clamped Inverter fed Induction Motor

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Abstract

Neutral point clamped multi-level inverter (NPCMLI) has a wide application prospect in high-voltage and adjustable speed drive systems due to its low stress on switching devices, low harmonic output, and simple structure. However, the problem of performance of induction motor needs to be solved when the Sinusoidal pulse width modulation (SPWM) is implemented on neutral point clamped inverter. In this paper, a space vector modulation (SVM) system is proposed for a three-level neutral-point-clamped (NPC) inverter with an induction motor as load. Consequently, the neutral-point potential unbalance, the d*v*/d*t* of output voltage and the switching loss are restrained effectively, and desirable dynamic and steady-state performances of induction machines can be obtained by SVM based NPC compare to the SPWM based inverter.

Keywords: Neutral Point Clamped Inverter, Total Harmonic Distortion, Sinusoidal Pulse Width Modulation, Space Vector Modulation.

1. Introduction

Motor drives are popularly applied in air-conditioning, fans, pumps, compressors, chillers, escalators, elevators and industrial drives. One of the common and most popular drives with real applications is the induction motor drive (Syed Abdul Rahaman Kashif *et.al* 2009). Three phase induction machine is most widely used in industry because of its simple construction, reliable operation, lightness and cheapness (Muhammed Safian Adeel *et.al* 2009). The AC induction motor drive is the fastest growing segment of the motor control. The most economical IM speed control methods are realized by using frequency converters. Many different topologies of frequency converters are proposed and investigated (Mohan M. Renge &Hiralal M.Suryawanshi 2008). However, a inverter consisting of a diode rectifier, a dc link and a Pulse Width Modulated (PWM) voltage source inverter is the most applied used in industry. But the major disadvantage is the less performance due to the two level inverter. To improve the performance of induction motor a multilevel neutral point clamped inverter with space vector modulation is proposed (Rajesh Kumar *et.al* 2008). One of the multi level structures that has gained much attention and widely used is Neutral Point Clamped Inverter. With the traditional method, the standard voltage source inverter (VSI) is composed of only one switching cell per-phase. But in the field of high power drive systems, the level of DC bus voltage constitutes an important limitation on the handled power. On the other hand, the very high dv/dt generated by the two-level VSI with high DC-link voltage is responsible for the electromagnetic interference (EMI) and motor winding isolation stress. So the multi-level VSI is widely studied in high power/voltage AC drive. For the three-level VSI, the voltage stress of switch is the half of the two-level inverter for the same DC voltage, and generates lower harmonics at the same switching frequency (Wei Feng Zhang & Yue Hui Yu 2007). SVM has the advantage of lower harmonics in addition to the features of complete digital implementation by a single chip microprocessor. Thus, SVM is advantageous over phase control and PWM. The performance of Space Vector Modulation technique and Sinusoidal Pulse Width Modulation is compared for harmonics, THD, output voltage and motor performance (Jin-Woo-Jung 2005). The performance of the three-level inverter mainly depends on the PWM algorithm. A typical SVM uses the nearest three output vectors (the nodes of the triangle containing the reference vector) to approximate the desired vector. When the reference vector changes from one region to another, it will induce an abrupt change in the output vector. The switching sequence and switching-time of each state are determined by acquiring the volt-seconds produced by switching vectors equal to the reference vector. However, the computational complexity is greatly increased with the increasing number of the voltage vector, and it is a main limitation of the application of SVM. In this paper, the comparison of sinusoidal PWM and space vector modulation PWM of neutral point clamped for induction motor is done. This comparison mainly based on the performance of induction motor.

2. **Neutral Point Clamped Inverter**

The conventional three-level NPC inverter is shown in the Figure 1 with this inverter topology, it is possible to produce three voltage levels at the output of inverter leg, namely, $V_{dc}/2$, 0 and $2V_{dc}/2$.

2.1 Principle of Operation

The conventional three level NPC inverter has 27 switching state. These 27 switching states are classified into three groups A, B and C. When switching states in group A are used in a three-level NPC inverter, the load is connected between the terminal P and N or to either one. In this case, the current through the capacitors will be equal and there will not be any voltage unbalance problems, in the capacitors C_1 and C_2. When the switching states in group B and C are used for inverter control, the neutral point is connected along with the terminals P and N to the output load. In this case, the currents flowing through the capacitors will be different and this will cause a voltage unbalance. In the proposed topology, only one active voltage source of $V_{dc}/2$ is used. The rated DC link voltage can be obtained by switching the voltage source between the top capacitor (C_1) and the bottom capacitor (C_2) with a duty ratio of 0.5. The capacitors will charge to $V_{dc}/2$ with a constant frequency irrespective of the load currents. Therefore the load current flowing through the capacitors will not create any neutral-point fluctuations. Here, the diode bridge rectifier and filter capacitor C_3 is used as input voltage source. To switch the voltage source between the capacitors C_1 and C_2, two extra switches and two extra diodes are required, as shown.

3. Space Vector Modulation

The Space Vector is defined as the vector 'V_s' having a magnitude of "$3/2V_m$" and rotates in space at a frequency of "ω" radians per second. Space Vector Modulation (SVPWM) refers to a special switching sequence of the upper three transistors of a three phase power inverter. It has been shown to generate less harmonic distortion in the output voltage which is supplied to the grid. For the operation of 3-level inverter, there are 3 switching states for each inverter leg; [P], [O] and [N]. [P] denotes that the upper two switches in leg A are ON and the inverter terminal voltage, $V_{an\ is}$ $V_{dc}/2$, while [N] means that the lower two switches are ON with a terminal voltage of $-V_{dc}/2$. Switching state [O] signifies that the inner two switches are on with the terminal voltage equals to zero. There are a total of 27 combination of switching states for NPC inverter (Jose Rodriguez 2002, Zeng Peng, F 2001, Celanovic. N & Boroyevich.D 2000).

3.1 Steps to Implement Space Vector Modulation

- Five steps can be identified to implement the space vector modulation for inverters
- Definition of the possible switching vectors in the output voltage space.
- Identification of the separation planes between the sectors.
- Identification of the boundary planes in the output voltage space.
- Obtaining of the decomposition matrices.
- Definition of the switching sequence.

3.2 Analysis of SVM Technique

The Space Vector Modulation method considers this interaction of the phase and optimizes the harmonic content of the three phase isolated neutral load. The three phase sinusoidal voltages are given in (1), (2), (3) and the balanced voltage is given in (4) as shown below,

$$\bar{v}_{an} = V_m cos(2\pi f.t) \tag{1}$$

$$\bar{v}_{bn} = V_m cos(2\pi f.t - \frac{2\pi}{3}) \tag{2}$$

$$\bar{v}_{cn} = V_m cos(2\pi f.t - \frac{4\pi}{3}) \tag{3}$$

$$\bar{V} = \frac{2}{3}[v_{an} + a v_{bn} + a^2 v_{an}] \tag{4}$$

Thus in SVM the voltages across each switch is represented as a vector and they are projected in space to form a hexagon with six sectors which are equally divided as shown in Figure 2. The six voltage vectors are represented as V_1, V_2, V_3, V_4, V_5, and V_6. These six vectors are called as the active vectors and there are another two vectors V_0, V_7 merely called as zero vectors. Thus the presence of zero vectors makes SVM to be unique control algorithm compared other pulse width modulation methods (Cataliotti A *et.al* 2002). Figure 2 shows the space vector of voltages across the switches. A space vector can be generally expressed in terms of the two-phase voltages in the α–β plane

$$V(t) = V_\alpha(t) + jV_\beta(t)$$

$$\bar{V}_{(t)} = \frac{2}{3}[\frac{2V_{DC}}{3} - a\frac{V_{DC}}{3} - a^2\frac{2V_{DC}}{3}] = \frac{2}{3}V_{DC}.e^{j\frac{\pi}{3}} \tag{5}$$

The corresponding space vector, denoted as _ *V*1, can be obtained by,

$$\bar{V}_1 = \frac{2}{3}V_{DC}.e^{j0} \tag{6}$$

Following the same procedure, all six active vectors can be derived

$$\bar{V}_k = \frac{2}{3}V_{DC}.e^{j(k-1)\frac{\pi}{3}} \tag{7}$$

$$v_{no} = \frac{1}{2} median(v_{an}, v_{bn}, v_{cn}) \tag{8}$$

$$v_{ao} = v_{an} + v_{no} \tag{9}$$

$$v_{bo} = v_{bn} + v_{no} \tag{10}$$

$$v_{co} = v_{cn} + v_{no} \tag{11}$$

Double edge modulation of reference voltage v_{ao}, v_{bo} and v_{co} are equal and they are expressed as (9), (10) and (11).

3.3 Equation Governing Space Vector Modulation

To implement the space vector PWM, the voltage equations in the abc reference frame can be transformed into the stationary dq reference frame that consists of the horizontal (d) and vertical (q) axes depicted as shown. Figure: 3 Representation of two reference frames. From the Figure 3, the relation between these two reference frames is shown in (12)

$f_{dqo} = K_s f_{abc}$

Where,

$$K_s = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \quad (12)$$

Therefore, space vector PWM can be implemented by the following three steps as follows,

Step 1: Determine V_d, V_q, V_{ref}, and angle (α):

From the Figure 4,

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (13)$$

$$|\overline{V_{ref}}| = \sqrt{{V_d}^2 + {V_q}^2} \quad (14)$$

$$\therefore \alpha = \tan^{-1}\left[\frac{V_q}{V_d}\right] = \omega t = 2\pi f t$$

Where f= fundamental frequency.

Step 2. Determine time duration T_a, T_b, T_0:

From the Figure 5 the switching times are given in (15), (16), and (17) as,

$$Ta = \frac{\sqrt{3} \cdot T_s \cdot |\overline{V_{ref}}|}{V_{dc}} \sin\left(\frac{\pi}{3} - \theta\right) \quad (15)$$

$$Tb = \frac{\sqrt{3} \cdot T_s \cdot |\overline{V_{ref}}|}{V_{dc}} \sin\theta \quad (16)$$

$$T_0 = T_s - T_a - T_b \quad (17)$$

Where,

$$T_s \cdot \overline{V_{ref}} = (T_a \cdot \overline{V_1} + T_b \cdot \overline{V_2} + T_0 \cdot \overline{V_0})$$

Step 3. Determine the Space Vectors, Switching States, and On-State Switches which is shown in table1

Thus based on the above three steps the algorithm of Space Vector Modulation is implemented and the distortion less three phase voltages are obtained.

4. Simulation Results

The simulations tests are carried on with the parameters of 7HP induction motor and the results are displayed in graphical format and the parameters used are also displayed. The sinusoidal PWM based neutral point clamped inverter fed induction motor has been simulated and the simulation circuit is shown in the Figure 6. Similarly figure 7 shows space vector modulation based neutral point clamped inverter fed induction motor. In this simulation totally twelve number of switches are used for entire three phase system. Figure 8 shows the simulation diagram for space vector modulation of neutral point clamped inverter. In this each sin wave generator displaced by 120 electrical degrees to generate three phase waveform. The output waveform obtained from the SPWM based NPC inverter with three phase induction motor is shown in the Figure 9. From this figure it clearly shows that the output has magnitude of phase voltage 230V and three level. Similarly Figure 10 shows output voltage wave of SVM based inverter fed induction motor. The Figure 11 and Figure 12 shows the speed, torque and stator current waveform of induction motor for both SPWM based NPC and SVM based NPC. It depicts that the in SPWM based inverter the speed takes 0.4msec to attain its steady state, torque takes 0.45msec to settled down its steady state and the stator current reaches its steady state 0.42msec. But by using the space vector modulation PWM for neutral point clamped inverter speed, torque and stator current reaches its steady state at 0.3mecs. From the FFT analysis the total harmonic distortion produced by the SVM is better than the SPWM based neutral point clamped inverter, which is shown in figure 13 and 14.

5. Conclusion

Space vector modulation is an important method to generate pulse widths for neutral point clamped inverter for an induction motor drive system. The main advantage is its high performance and simplicity. When the sinusoidal pulse width modulation is implemented in the three-level neutral-point clamped inverter. The induction motor performance is reduced compared to the SVM based neutral point clamped inverter. This approach provides very quickly settled performance for speed, torque, accurate and stator current of an induction motor. And also total harmonics distortion produced by the SVM based neutral point clamped inverter is low compare to THD produced by the SPWM based inverter. However the performance of induction motor and THD can be further improved by increasing the level of inverter with same topology or using cascaded H-bridge inverter.

Appendix

Motor Details

Rotor Type: Wound

Power, Voltage and Frequency: 3730 W, 400 V and 50 Hz

Stator Resistance and Inductance: 1.115Ω and 0.005974Ω

Rotor Resistance and Inductance: 1.083Ω and 0.005947Ω

References

Syed Abdul Rahaman Kashif, Muhammad Asghar Saqib, Saba Zia & Ayesha Kaleem, (2009), "Implementation of neural network based pulse width modulation inverter-induction motor drive system", *Proc. I EEE*, 978, 4244-4361.

Muhammed Safian Adeel, Tahir Izhar & Muhammed Asghar Saqib, (2009), "An efficient implementation of the space vector modulation based three phase induction motor drive", *Proc. I EEE*, 978-1-4244-4361-1.

Mohan M. Renge &Hiralal M.Suryawanshi, (2008) "Five-level diode clamped inverter to eliminate common mode voltage and reduce dv/dt in medium voltage rating induction motor drives" , *IEEE Trans. on Power Elec*t., Vol. 23, No. 4.

Rajesh Kumar, Gupta. R.A & Rajesh. S. Surjuse (2008), “A vector controlled motor drive with neural network based space vector pulse width modulator”, *Journal of Theoretical and Applied Information Technology*, pp 577-584.

Wei Feng Zhang and Yue Hui Yu (2007), “Comparison of three SVPWM strategies”, *Journal of Electronics Science and Technology of China*, Vol.5, No.3.pp 283-287.

Jin-Woo-Jung, (2005), “Space vector PWM inverter”, *Mechatronics Systems Laboratory DECE*, The Ohio State University.

Jose Rodriguez, Jih-Sheng Lai & Fang Zheng Peng (2002), “Multilevel inverters: A survey of topologies, controls and applications”, *IEEE Trans. Ind. Electronics.* Vol-49, No.4, pp 724-738.

Zeng Peng, F (2001), “A generalized multilevel inverter topology with self voltage balancing”, *IEEE Trans. on Ind. App.*, Vol. 37, No. 2, pp 611-618.

Celanovic, N & Boroyevich, D (2000), “A comprehensive study of neutral-point voltage balancing problem in three-level neutral-point-clamped voltage source PWM inverters”, *IEEE Trans. Power Electron*. Vol. 15, No. 2, pp. 242–249.

Cataliotti A, Genduso F & Ricco Galluzzo G (2002) , “A New SVM Algorithm for VSI based electrical drive fed by Photovoltaic arrays” *EERR (Electrical Engineering Research Report)* Naples, April

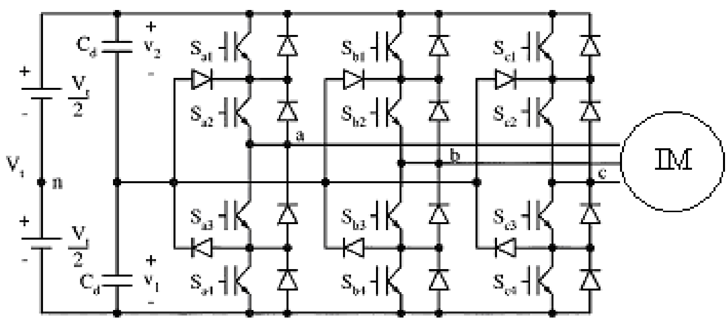

Figure 1. Proposed Circuit of Neutral Point Clamped Inverter

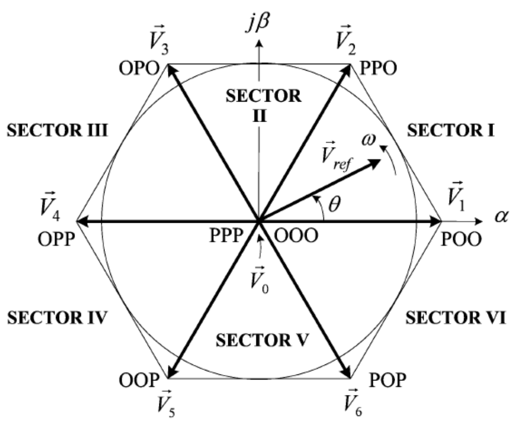

Figure 2. Projection of Voltage Vector

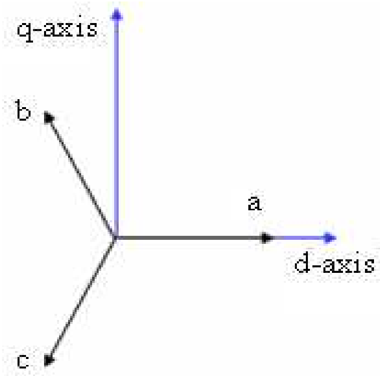

Figure 3. Representation of two reference frames

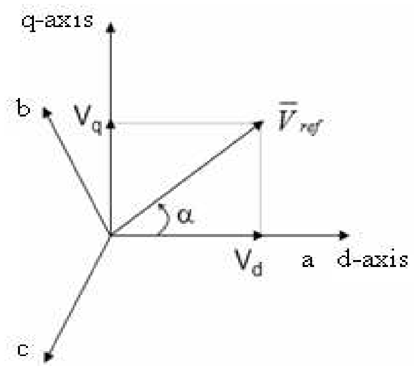

Figure 4. Representation of reference voltage in two reference frame

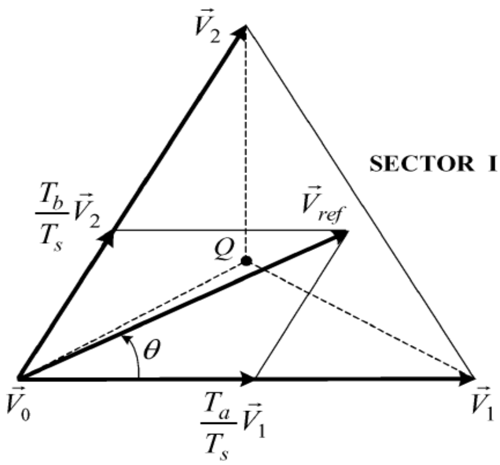

Figure 5. Representation of V_{ref}

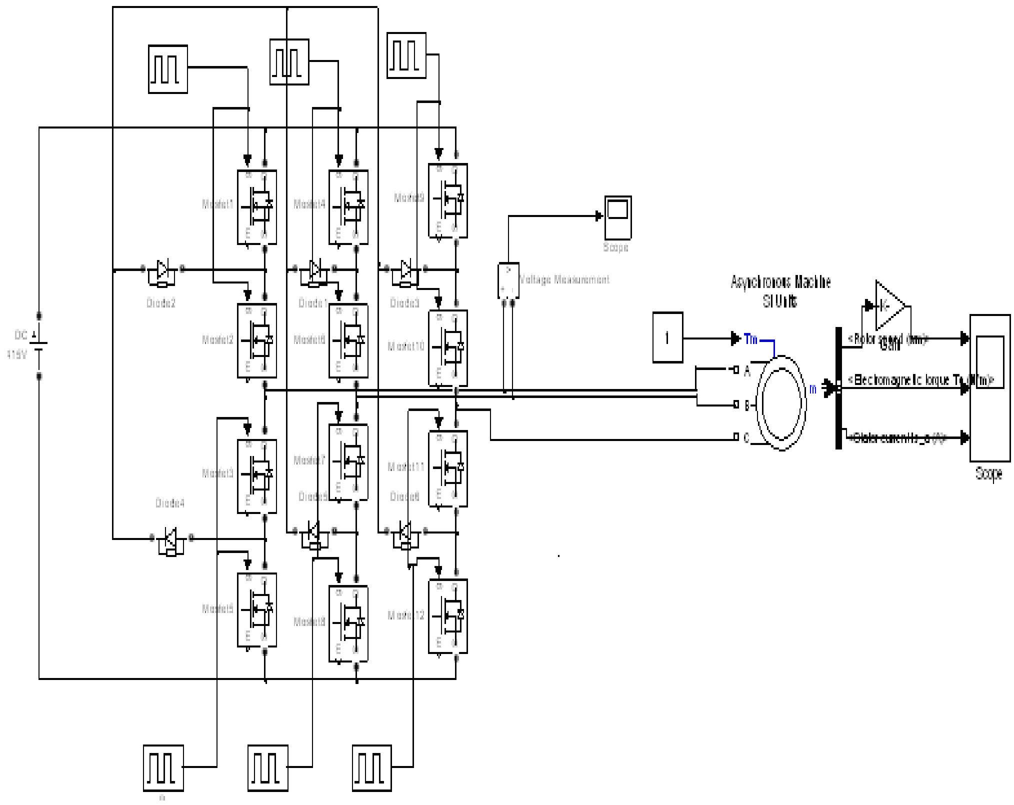

Figure 6. Simulation diagram SPWM based NPC inverter fed Induction motor

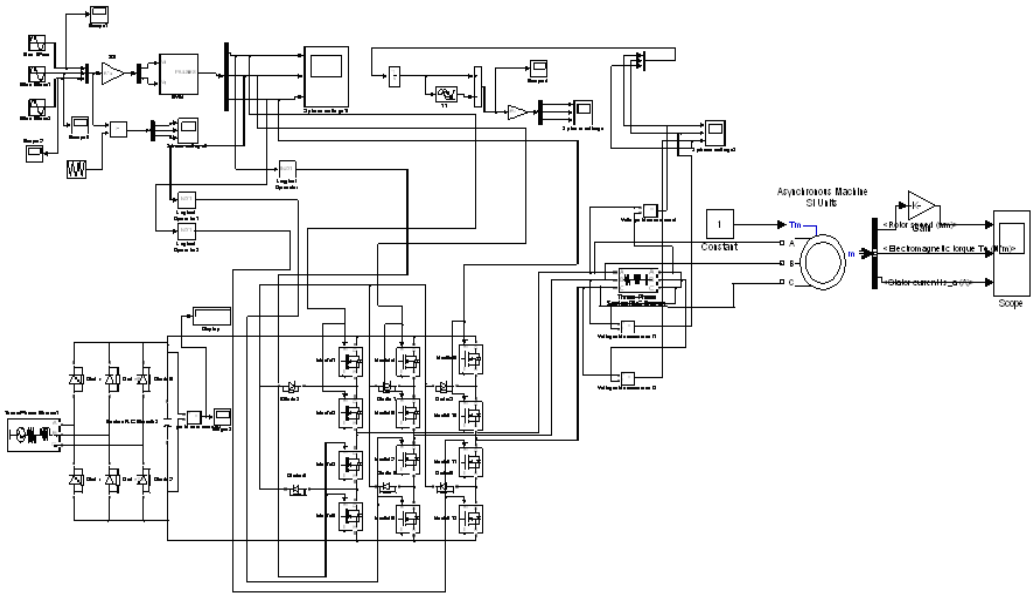

Figure 7. Simulation diagram SVPWM based NPC inverter fed Induction motor

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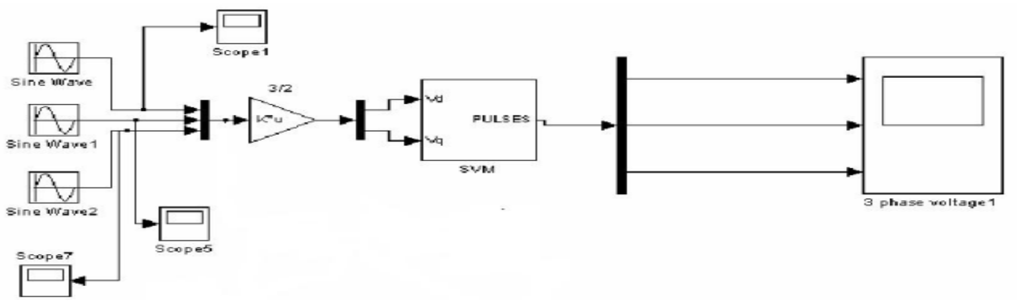
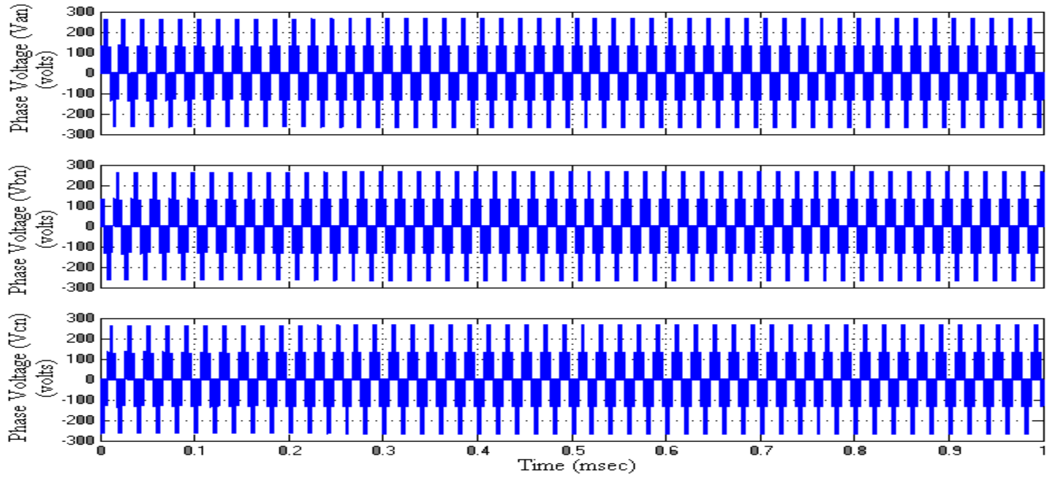


Figure 8. Simulation diagram for Space Vector Modulation



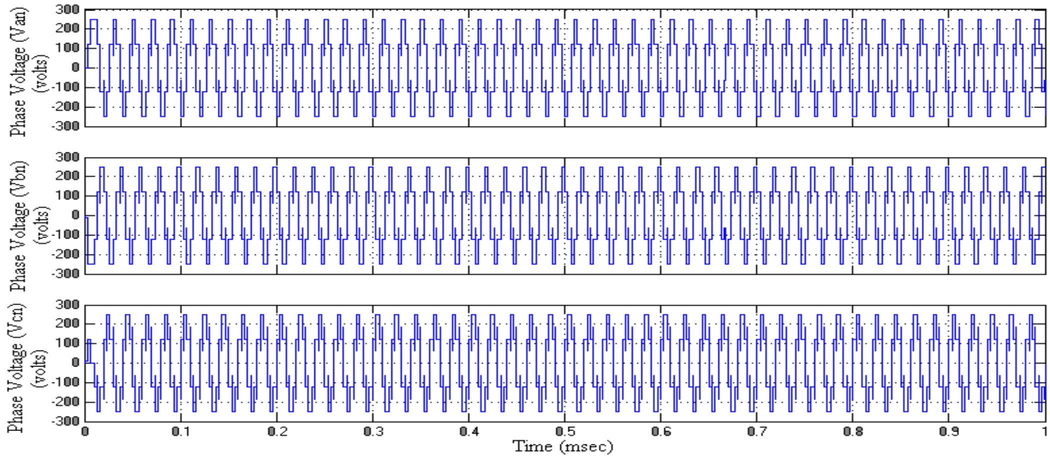


Figure 9. Simulation phase output voltage waveform of SPWM based NPC fed induction motor

Figure 10. Simulation phase output voltage waveform of SVM based NPC fed induction motor

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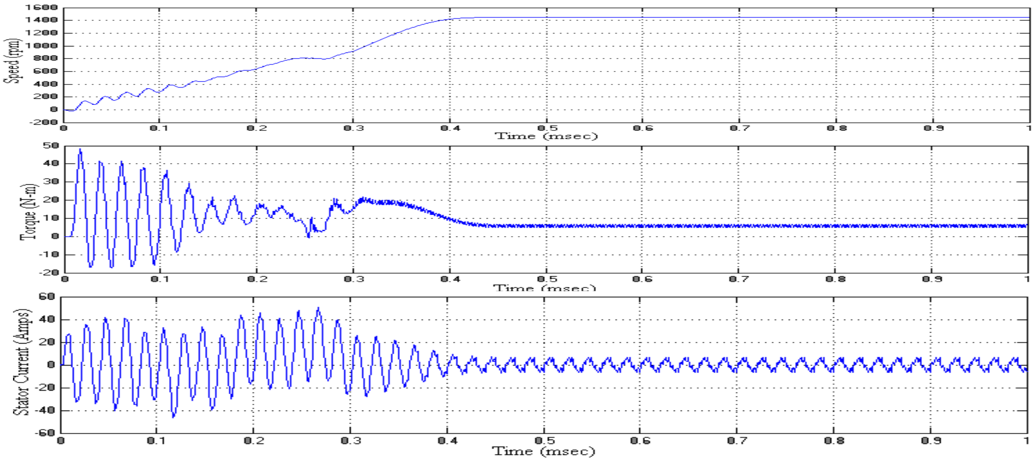

Figure 11. Simulation output of SPWM based NPC fed induction motor a) Speed b) Torque c) Stator Current

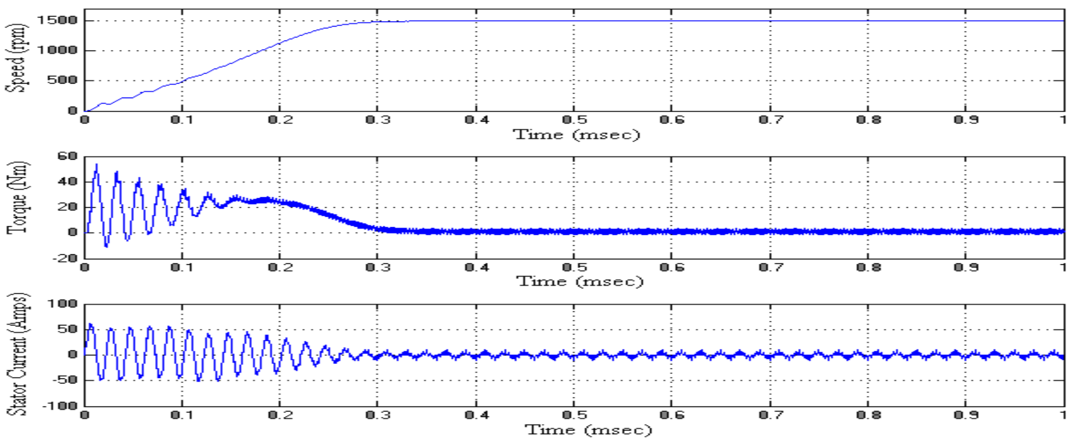

Figure12. Simulation output of SVM based NPC fed Induction motor a) Speed b) Torque c) Stator Current

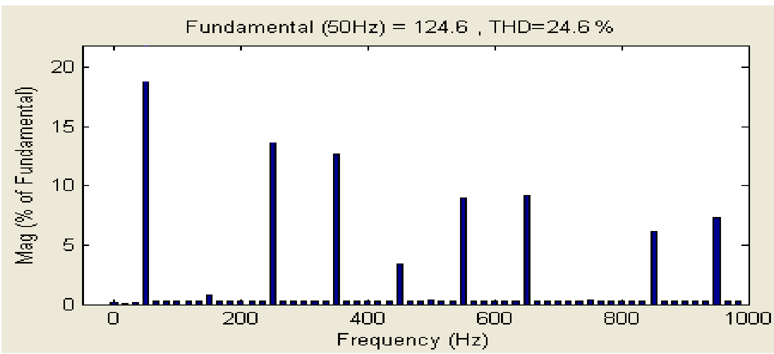

Figure 13. FFT analysis of SPWM based NPC fed Induction motor

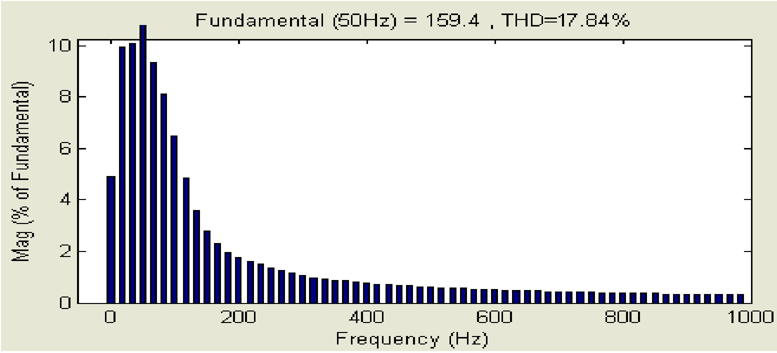

Figure 14. FFT analysis of SVM based NPC fed Induction motor

Table 1. Space Vectors, Switching States, and On-State Switches

Space Vector		Switching State (Three Phases)	On-State Switch	Vector Definition
Zero Vector	$\vec{V}_0$	[PPP] [OOO]	S_1, S_3, S_5 S_4, S_6, S_2	$\vec{V}_0 = 0$
Active Vector	$\vec{V}_1$	[POO]	S_1, S_6, S_2	$\vec{V}_1 = \frac{2}{3} V_d e^{j0}$
	$\vec{V}_2$	[PPO]	S_1, S_3, S_2	$\vec{V}_2 = \frac{2}{3} V_d e^{j\frac{\pi}{3}}$
	$\vec{V}_3$	[OPO]	S_4, S_3, S_2	$\vec{V}_3 = \frac{2}{3} V_d e^{j\frac{2\pi}{3}}$
	$\vec{V}_4$	[OPP]	S_4, S_3, S_5	$\vec{V}_4 = \frac{2}{3} V_d e^{j\frac{3\pi}{3}}$
	$\vec{V}_5$	[OOP]	S_4, S_6, S_5	$\vec{V}_5 = \frac{2}{3} V_d e^{j\frac{4\pi}{3}}$
	$\vec{V}_6$	[POP]	S_1, S_6, S_5	$\vec{V}_6 = \frac{2}{3} V_d e^{j\frac{5\pi}{3}}$

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