

## SVPWM for 3-phase 3-level Neutral Point Clamped Inverter fed Induction Motor Control

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### ABSTRACT

This paper gives Space Vector Pulse Width Modulation (SVPWM) for 3-phase 3-level Neutral Point Clamped (NPC) inverter fed induction motor control. A conventional two level inverter with 3-phase system has been developed for induction motor control. When it is applied for high voltage and power applications, which increases the voltage stress across the switch and harmonic content in the output. So multilevel inverter is much suitable for induction motor control, which provides nearly sinusoidal output voltage and diminished harmonic content in the output. Also the stator current of induction motor is minimised, speed and torque of induction motor controlled with appropriate switching NPC inverter using SVPWM method. The proposed system simulation are verified using matlab simulink.

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## 1. INTRODUCTION

In recent days the multilevel inverters used for high and medium power applications, remote sensing and industrial applications. The term multilevel began with the three-level inverter [1]. Consequently, many topologies of multilevel inverter are initiated. However, the elementary concept of a multilevel inverter to accomplish higher power is to make use power switches connected in series with many low voltage dc sources to execute the power conversion by amalgamate a staircase output voltage waveform [2]. Multiple dc sources like as fuel cells, batteries, renewable energy sources, capacitors and other devices [3].

This increased appreciation of multilevel inverter is due to the limitations of the conventional 2-level output inverters in handling high power conversions. The multilevel inverters reduce the total harmonic level and also when the number of level increases, the harmonic content starts to decrease [4]. To generate stepped waveform the multilevel inverter includes an array power semiconductor switch, capacitors, voltage sources and clamping diodes [5]. The recompenses of multilevel inverter are the dv/dt stresses on the each switching devices are abridged due to the diminutive increment in output voltage steps and minimised electromagnetic compatibility [6]. When operated at high voltage smaller rating of output voltage in term of less distortion, lower harmonics contents and lower switching losses [7]. Additionally, the complex phase shifting transformers that are necessary in the multi pulse inverters at higher level are not necessarily required, thus helps in reducing the cost [8].

One of the multilevel structures that has added much notice and broadly used is the NPC-MLI or also known as DC-MLI. This arrangement was first anticipated by Nabae. The multilevel inverter not only accomplishes high power ratings, but also enables the use of renewable energy sources [9], [10]. The renewable energy sources such as PV array, wind energy, battery cells and fuel cells are effortlessly interfaced with multilevel inverter for high power application. The NPC inverter Applications includes the typical applications are STATCOM, UPFC, power quality, power conditioners, reactive power compensators & grid connected systems [11].

Pulse width modulation (PWM) is generally used switching strategy to maintain voltage amplitude and frequency and fast dynamic response. Due to these conventional PWM methods, the circulating current in the converter system starts increase [12],[13]. Common mode voltage (CMV) of the converter also increases; it leads to failure of motor bearings and increase in electromagnetic interference problems [14]. Single/ three phase IM widely used in home and industrial applications especially at low power ranges (below 2.5 kW). These type of motors used in variable speed applications, so it requires variable voltage which can be obtained through NPC inverter. For this type of applications, inverter used with symmetric voltage magnitude and frequency and needs of large dc link capacitors and rectifier circuit [15].

The proposed system explains the SVPWM for 3-phase 3-level Neutral Point Clamped inverter fed induction motor control, which leads to minimise the stator current and to reduce THD. Multilevel inverters are much more suitable for induction motor control, which provides nearly sinusoidal output voltage. The proposed system simulation are verified using matlab simulink.

**2. 3-LEVEL NEUTRAL POINT CLAMPED (NPC) INVERTER**

NPC multilevel inverters synthesize the small step of staircase output voltage from several levels of DC capacitor voltages [16]. A k-level NPC-MLI inverter consists of (k-1) capacitors on the DC bus link, 2(k-1) power switching devices per phase and 2(k-2) clamping diodes per phase. In [17] the DC bus voltage is split into 3 levels by using 2 DC capacitors, C1 and C2. Each capacitor divides voltage as  $V_{dc}/2$  volts and voltage stress will be limited to one capacitor level through clamping diodes [18]. The Figure 1 shows the 3 level 3 phase NPC- inverter. In this proposed system, which consists of 3 phases (3 legs) and each phase contains 4 switches. From the Figure, each leg can be operated in 3 switching states like  $+V_{dc}/2$ , 0,  $-V_{dc}/2$ .

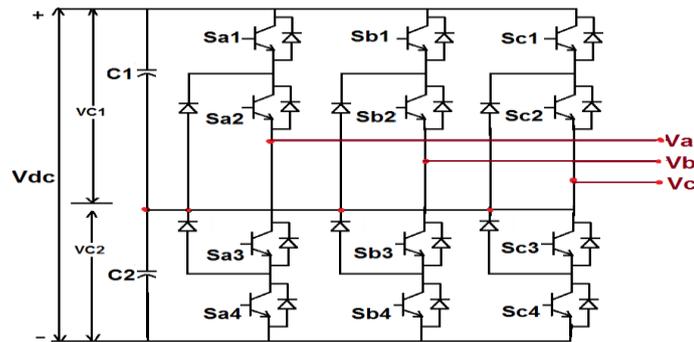


Figure 1. Circuit diagram of 3-level NPC inverter

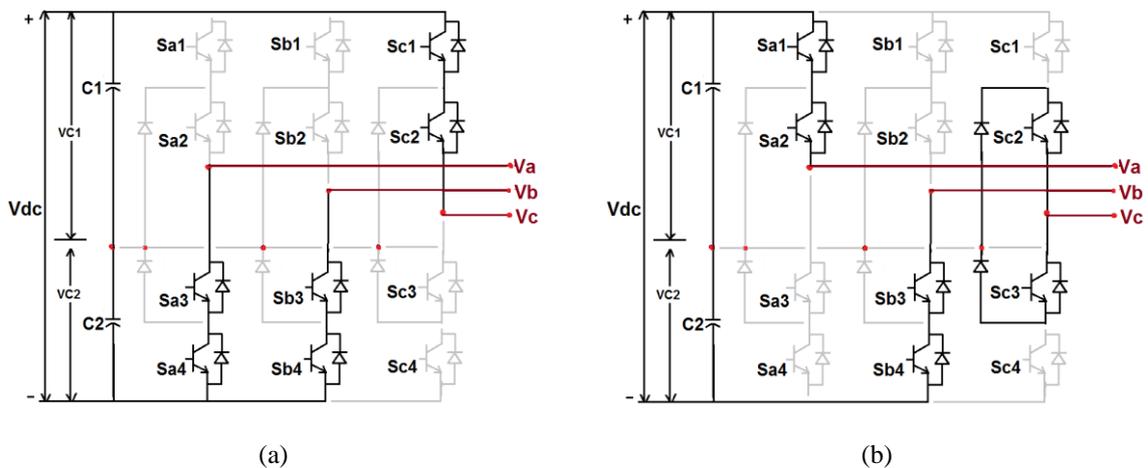


Figure 2. Modes of operation (a) -1-11 (b) 1-10

The modes of operations of 3-phase 3-level neutral point clamped (NPC) inverter with output voltage levels are shown in Figure 2.

a) The Figure 2a (-1-11) shows the switches  $S_3$  &  $S_4$  are ON in leg-1, so the output voltage is  $-V_{dc}/2$  V. The switches  $S_3$  &  $S_4$  are ON in leg-1, so the output voltage is  $-V_{dc}/2$  V. and in leg-3 the switches  $S_1$  &  $S_2$  are ON, which leads to  $+V_{dc}/2$  V.

b) Figure 2b (1-10) shows the switches  $S_1$  &  $S_2$  are ON in leg-1, so the output voltage is  $+V_{dc}/2$  V. The switches  $S_3$  and  $S_4$  are ON in leg-2, the output voltage is  $-V_{dc}/2$  and in leg-3 the switches  $S_2$  &  $S_3$  are ON, which leads to 0V.

**3. SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)**

SVPWM is a control technique for the MLI switches which identifies the switching sequences by placement of a switching vector in d-q space. It is better at harmonic level reduction and increasing the output voltage magnitude as compared to SPWM (Sinusoidal Pulse Width Modulation), which is commonly used. It reduces the common mode voltage which is the difference between vector sum of the potential at inverter output and ground. Reducing it improves inverter efficiency. The voltages across the two dc link capacitors should ideally be equally divided, but due to capacitor leakage current there is a voltage unbalance which produces stress on the switches.

For determining the switching state, the space vector diagram is divided into six sectors, each having four triangles. Each junction point refers to a switching state. For an n level inverter,  $n^3$  switching states are possible. Twenty seven switching states for a three level inverter are shown in Figure 3.

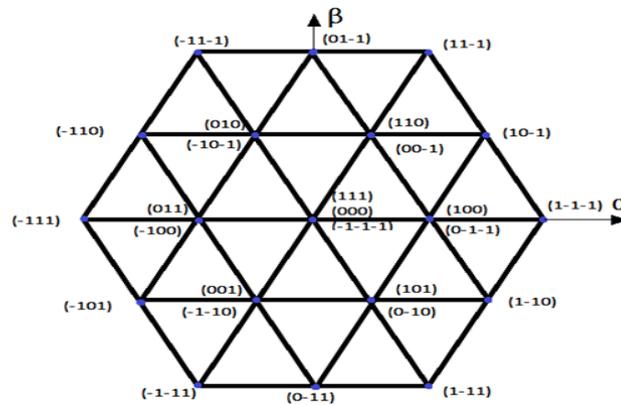


Figure 3. Switching states & vectors Space vector PWM

Based on the reference voltage level, the space vector magnitude and placement in one of the triangles of one of the six sectors is determined using abc-dq conversion. The switching state depends on the space vector position obtained. After calculation of the small triangle we need to calculate its switching time. The switching time would be the same from  $V_{dx}, V_{qx}$  reference since the vector pointing at  $V_d, V_q$  remains the same, only its axis is shifted. Let  $T_{M1}, T_{M3}, T_{M4}$  be the switching times for the three vertices of the small triangle, which is shown in Figure 4.

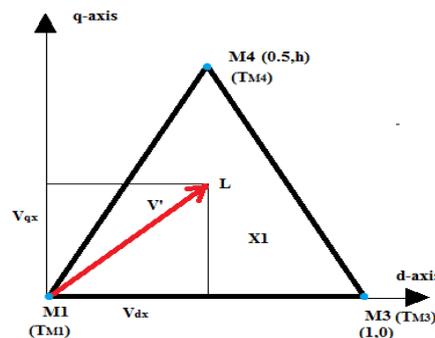


Figure 4. Switching time calculation

$$T = T_{M1} + T_{M3} + T_{M4} \quad (1)$$

where T is the total switching time.

The volt-time balance equation is,

$$V'T = V_{M3}T_{M3} + V_{M4}T_{M4} \quad (2)$$

The position of M3 and M4 w.r.t M1 is (1,0) and (0.5,h) respectively. Substituting these values of magnitude in the above equation we get

$$V_{dx}T = T_{M3} + 0.5T_{M4} \quad (3)$$

$$V_{qx}T = T_{M4}h \quad (4)$$

$$T_{M4} = V_{qx}T / h \quad (5)$$

$$\text{and } T_{M3} = T(V_{dx} - 0.5V_{qx}/h) \quad (6)$$

$$\text{and } T_{M1} = T - (T_{M4} + T_{M3}) \quad (7)$$

The switching time for the other triangles can be calculated using the same above equations.

#### 4. SIMULATION RESULTS AND DISCUSSION

To validate the performance of SVPWM for 3-phase 3-level Neutral Point Clamped (NPC) inverter fed induction motor control using matlab simulink tool 2017a. The proposed system verified with the following simulation parameters: 12 IGBT power switches, dc link capacitance of 100 micro farad, coupled inductor of 4mH, 3-phase 4KW induction motor. The switching pulses generation using SVPWM is shown in Figure 5.

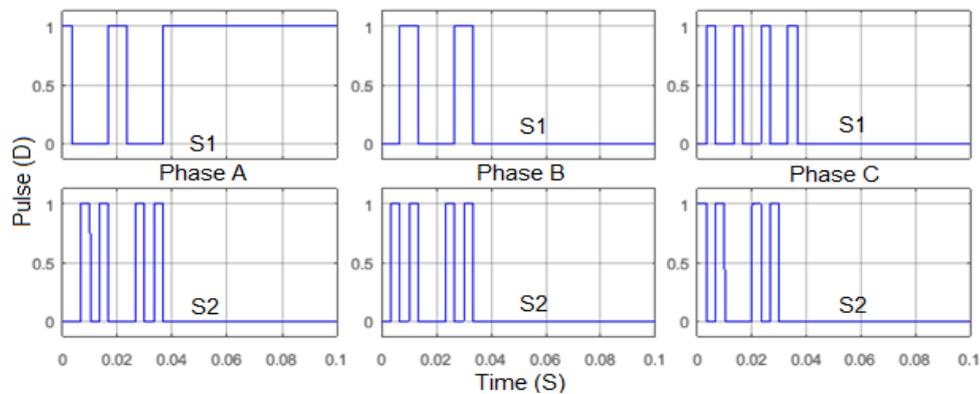


Figure 5. Switching pulse generation using SVPWM

The Figure 6 shows stepped output voltage of 3-phase 3-level NPC inverter with 388V. And the inverter output voltage with coupled inductor, which is nearly sinusoidal voltage is shown in Figure 7. The Figure 8 shows the stator current of 3-phase induction motor. And the Figure 9 shows the speed curve of 3-phase induction motor.

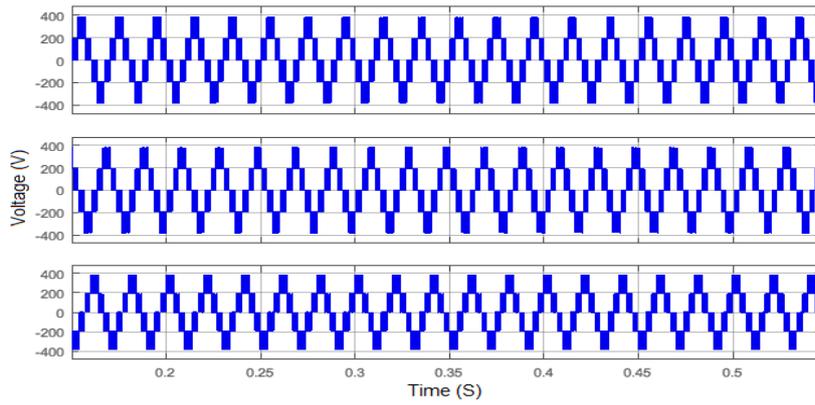


Figure 6. Stepped output voltage of 3-level NPC inverter

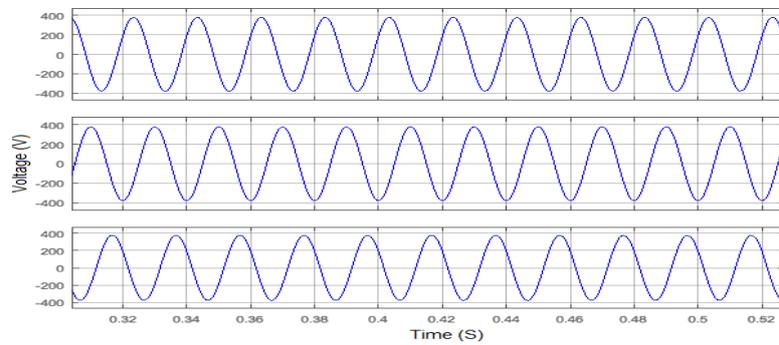


Figure 7. Inverter output voltage with filter (coupled inductor) circuit

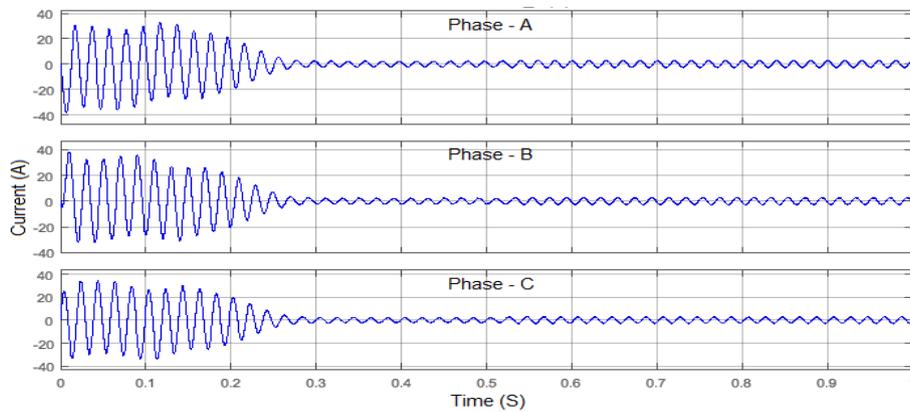


Figure 8. Stator current of 3-phase induction motor

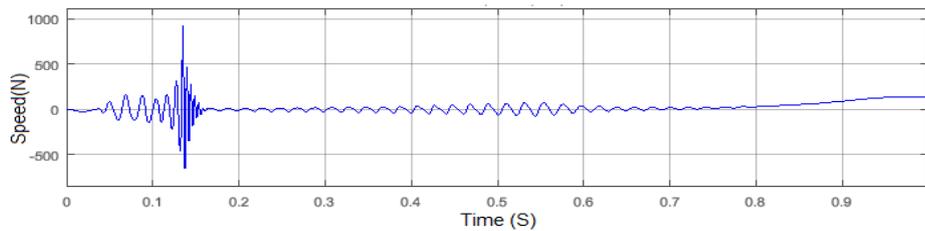


Figure 9. Speed curve of 3-phase induction motor

The Figure 10 shows the torque of 3-phase induction motor and the rotor current of proposed system fed 3-phase induction motor is shown in Figure 11. The inverter 3-phase output current with filter circuit is shown in Figure 12 and comparison of reference current and actual current is shown in Figure 13. The THD analysis of output voltage of 0.22% and for output current of 1.79%, which is shown in Figure 14.

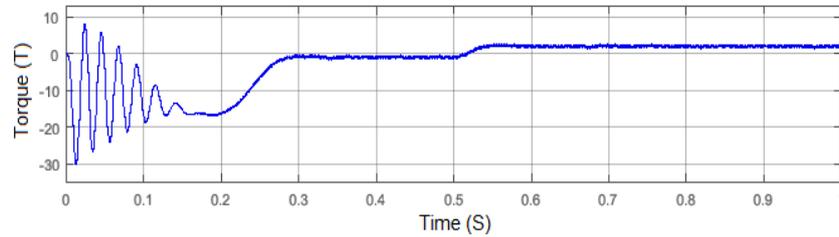


Figure 10. Torque of 3-phase induction motor

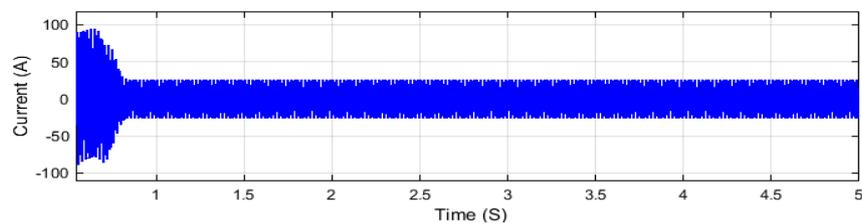


Figure 11. Rotor current of 3-phase induction motor

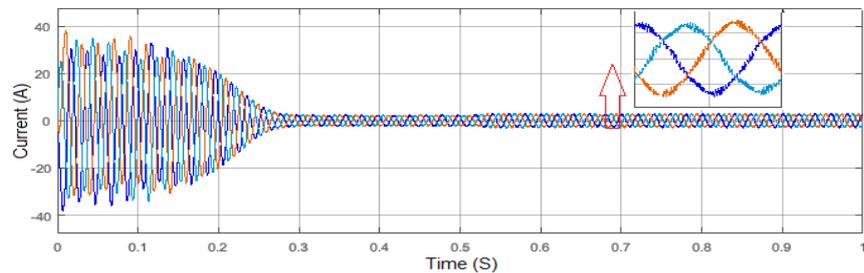


Figure 12. Inverter output current with filter (coupled inductor) circuit

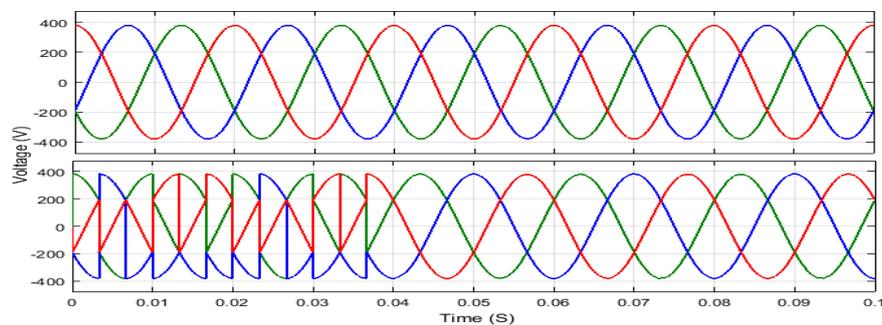


Figure 13. Comparison of reference voltage and actual voltage

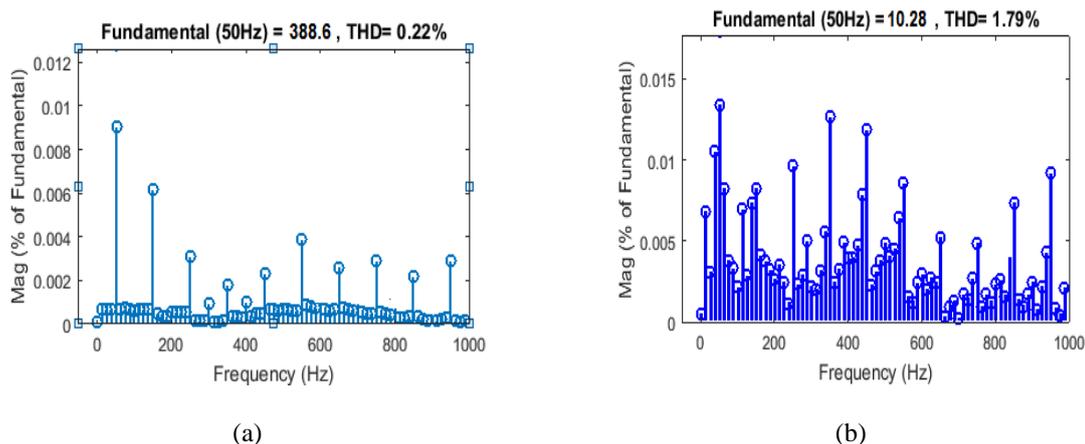


Figure 14. THD analysis (a) output voltage (b) output current

## 5. CONCLUSION

This work explains the SVPWM for 3-phase 3-level Neutral Point Clamped inverter fed induction motor control. This proposed system used to minimise the stator current of induction motor, speed and torque of induction motor also controlled. And the proposed inverter output synchronised with 3-phase induction motor through coupled inductor, which is able to maintain the bearing current of induction motor and leads to avoid bearing failure. The total harmonic distortion also minimised for output voltage and current of 0.22% and 1.79% respectively. The proposed system results are verified using matlab simulink tool.

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