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Sinusoidal PWM vs SVPWM for NPC Multilevel Inverter with Proportional Control Based Neutral Point Voltage Controller for Induction Motor Drive

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This study compares sinusoidal PWM and SVPWM for v/f control of induction motor drive with three level inverter and under various modulation indices. It also suggests a proportional control-based neutral point controller for neutral point voltage balancing.When compared to the similar methodologies, the simulation results produced in the MATLAB/Simulink environment show that the proposed method is preferable.

Keywords: Sinusoidal PWM; SVPWM; NPC multilevel inverter; induction motor drive; neutral point voltage controller.

1. INTRODUCTION

Prior to the introduction of Multi-level inverters(MLI), the two-level voltage source inverter (VSI) ruled the industrial world since it has a wide range of applications in transportation and industrial conrol. For the past couple of decades, Neutral Point Clamped (NPC) or Diode

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clamped Multi-Level Inverters (MLI) have dominated the power electronics industry [1-4]. When compared to two-level inverters, these inverters have less device stresses, lower voltage harmonic distortion and lower converter losses. A. Nabae, et al., developed [5] NPC the three-level inverter in 1981 as shown in Fig. 1. Two capacitors on the DC bus link, four switching devices per phase, and two clamping diodes per phase make up an NPC three-level inverter. By utilising two capacitors, C1 and C2, the DC bus voltage is divided into three levels. Voltage stress will be confined to one capacitor level by clamping diodes, and each capacitor splits voltage as Vdc/2. The three level inverter's output voltage will be in three levels: Vdc/2, 0 and Vdc/2 whereas for two level inverter's output voltage will be in two levels: +Vdc and -Vdc. Pulse-Width Modulation (PWM) techniques are used to control drives, and they are divided into categories likely,Sinusoidal PWM, Multi-carrier PWM (MC PWM), Selective Harmonic Elimination (SHE PWM), and Space Vector PWM (SVPWM). In this context SVPWM outperforms Sinusoidal PWM approaches in terms of output voltage and harmonic reduction [6,7]. By ignoring the switching states that create high common mode voltage (CMV), it is simple to reduce CMV in SVPWM. Also because pulses in the SVPWM approach are digital, it is simple to use the DC-link in SVPWM. Although the SVPWM approach improves the performance of the NPC three-level inverter, it still has significant drawbacks, such as CMV and DC link balancing. However, because the DC-link voltage is split by capacitors in the NPC three-level inverter, current flowing out or into the neutral point might cause neutral point unbalance. Unbalanced neutral point voltage increases output voltage harmonics, can cause output voltage drift to an unacceptable level, and can damage switching devices and filter capacitors affecting the performance of the NPC three level inverter [8,9]. The neutral-point voltage is controlled in this article using a Proportional controller. A constant v/f induction motor drive with a 0.5HP output power is used to test the controller. The midpoint of two series-connected capacitors serves as the neutral point.

2. SINUSOIDAL PWM

A common PWM approach is sinusoidal PWM. The sinusoidal AC voltage reference is compared in real time with the high-frequency triangle carrier wave to determine switching times for each switches in the inverter. The amplitude of the voltage reference must remain below the peak of the triangle carrier in this PWM approach in order to achieve linear modulation [10,11]. This type of PWM technique is known as a carrier-based PWM approach because it uses a high-frequency carrier wave for voltage modulation. Because the reference is presented as the shape of a sine wave, this carrier-based technique is known as SPWM [12,13]. Because it uses the carrier of a triangular wave, it's also known as the triangle-comparison PWM approach. Fig. 2 shows the modulating waveform for sinusoidal PWM, which contains two triangular carrier waves for pulse generation since a three-level NPC inverter has four switches in a single leg, whereas a two-level inverter has just two switches in a single leg, resulting in only one carrier wave.

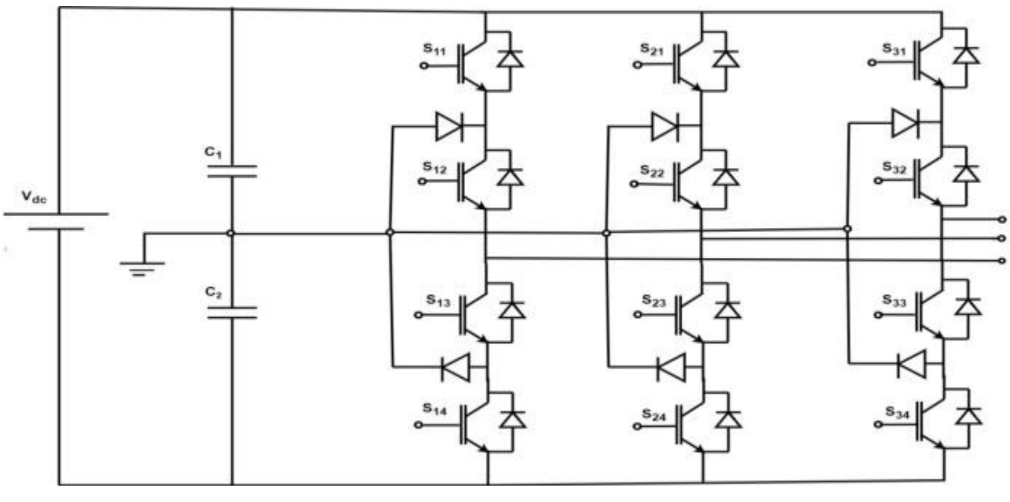

Fig. 1. Schematic diagram of Neutral point clamping based three level inverter

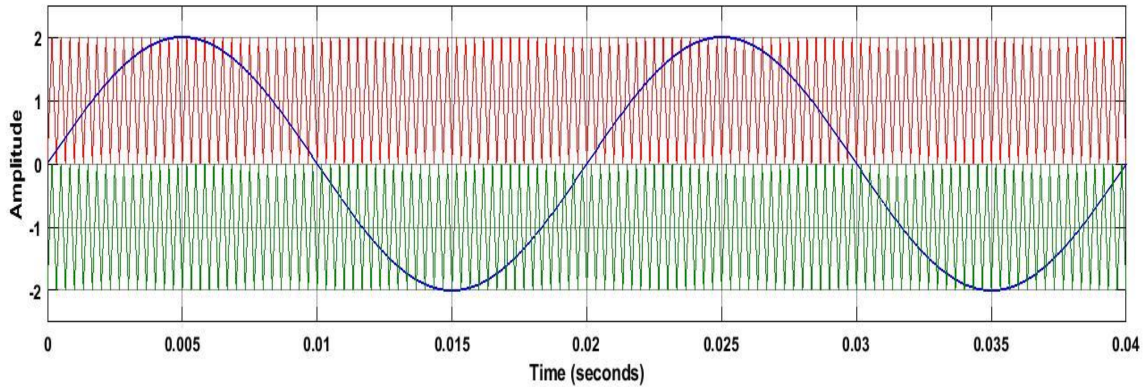

Fig. 2. Modulating waveform for sinusoidal PWM

3. SPACE VECTOR PWM

The Space vector PWM method is a digital modulation approach that generates PWM using a vector representation. These digital signals can be transmitted to switches that are controlled using a vector representation [14-20]. The magnitudes and phases of each vector are represented by placing the vectors in a hexagonal pattern. With 3 zero vectors, 12 small vectors, 6 medium vectors, and 6 large vectors, the three-level inverter has 27 switching states. Eight of the 27 switching states are redundancy states, whereas the remaining 19 voltage vector are shown in the space vector diagram in Fig. 3. The SVPWM is divided into six sectors, each of which is further divided into four sub-sectors. The Schematic of Three level VSI is shown in Fig. 1. From the schematic each leg consists of four switches and two diodes. Diodes are connected to the midpoint of DC bus which ensure that voltage across any switch never exceeds one half of DC voltage. The capacitors C_1 and C_2 are connected to maintain constant voltage at neutral point. The middle point of two capacitors is referred as neutral point. The chosen Neutral Point Clamped three level inverter has a total of 27 vectors, similar to the SVPWM of two level inverter the hexagon comprises of six sectors respectively. The voltage at the output of inverter terminal will have three levels (E/2,0, -E/2). Based on vector synthesis principle the adjacent vectors are synthesized in a certain sector. Out of 27 vectors the switching sequence is arranged in a fashion so that the ripple content in output current will be minimized [21-25]. The notation (+0-), + indicates phase R is connected to positive of DC bus,0 indicates phase Y is connected to neutral point and - indicates phase B is connected to negative of DC bus. The simulation results of three level NPC are presented and discussed.

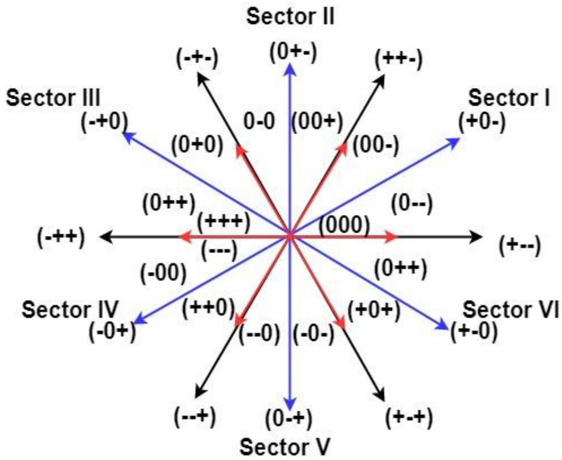

Fig. 3. Voltage vectors of three level inverter for space vector PWM

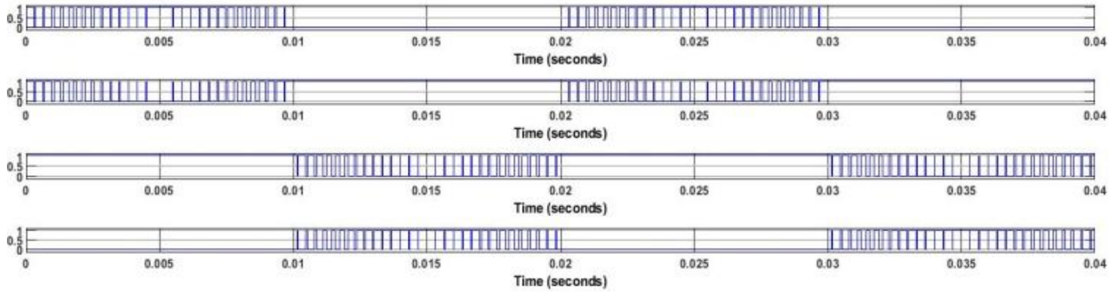

Fig. 4. SVPWM based pulse generation

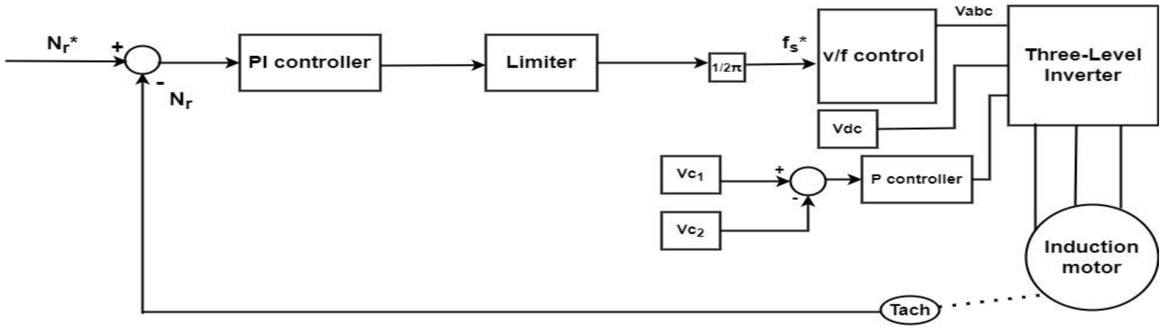

Fig. 5. Block representation of three level inverter based closed loop v/f control of induction motor drive with neutral point controller

Controlling the speed of induction motors is critical in industrial and technical applications. Efficient control measures are also employed to cut down on operating costs. Induction motor speed control approaches can be divided into two categories: scalar control and vector control. Controlling the magnitude of the induction motor's voltage or frequency is known as scalar control. The block diagram of three-phase induction motor closed-loop V/f control is shown in Fig. 5. A PI controller is used to analyse the speed error. The bandwidth of the closed loop transfer function of the neutral point controller is proportional to the gain (Kp) of the P controller and the output power of the converter [26,27]. The maximum bandwidth of the closed loop transfer function of the neutral point controller corresponds to the full load power. In all cases, the closed loop transfer function's bandwidth should be less than the switching frequency. As a result, the controller gain (Kp) should be optimised for the highest possible output power. When the drive is running on no load, the bandwidth of the closed loop transfer function of the neutral point controller will be smaller than the switching frequency. The control variable is equivalent to the output of the P controller and is denoted by the letter 'k.' Because the duty cycle of the switches in the converter is determined by the factor 'k,' the output of the P controller should be limited.

4. SIMULATION RESULTS

MATLAB/SIMULINK is used to analyze and compare neutral point clamped three level inverter fed IM using Sinusoidal PWM and Space vector PWM. Fig. 8 & Fig. 9 shows the voltage THD% where as Fig. 6 & Fig. 7 shows the current THD% for sinusoidal PWM and Space vector PWM and it also infers that there is THD% reduction with Space vector PWM for NPC three level inverter. Fig. 11 shows the three level line to line output voltage. The gain of the P controller can be changed to influence the response of the neutral-point voltage controller. When the P is tuned online as a function of the power, In the future, it may be possible to reach ideal controller performance. however,this would necessitate more resources,during a change over time, compute. Fig. 10 shows the DC link voltage with and without application of P controller it also infers that there is reduction in DC link voltage due to P controller.

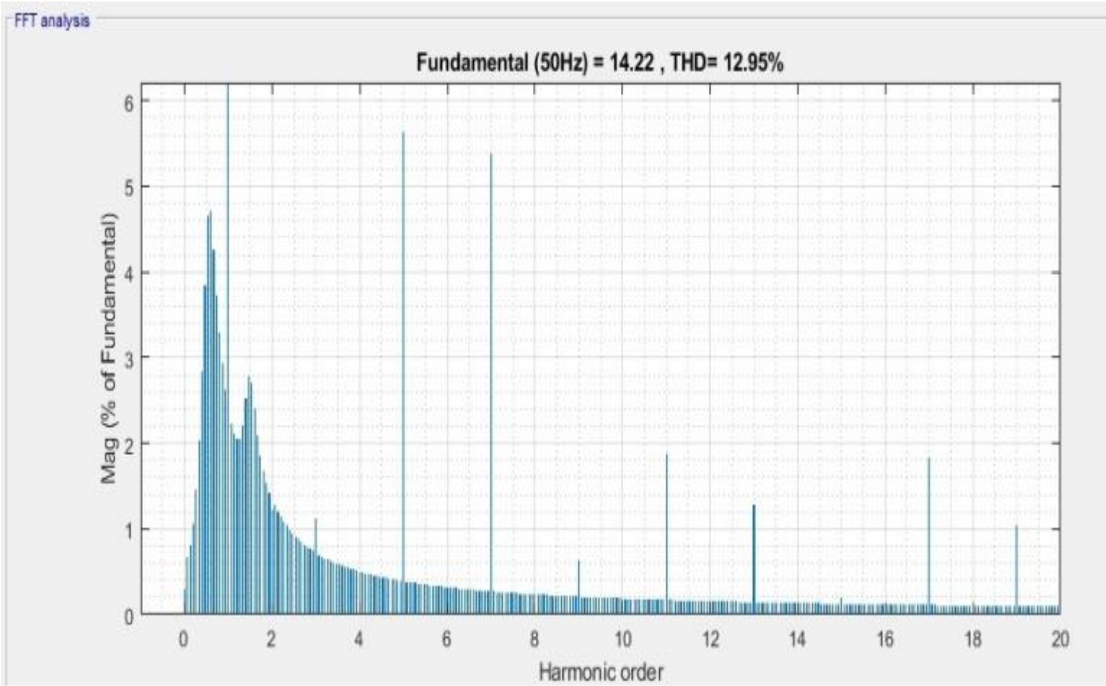

Fig. 6. Current THD% for sinusoidal PWM based three level inverter

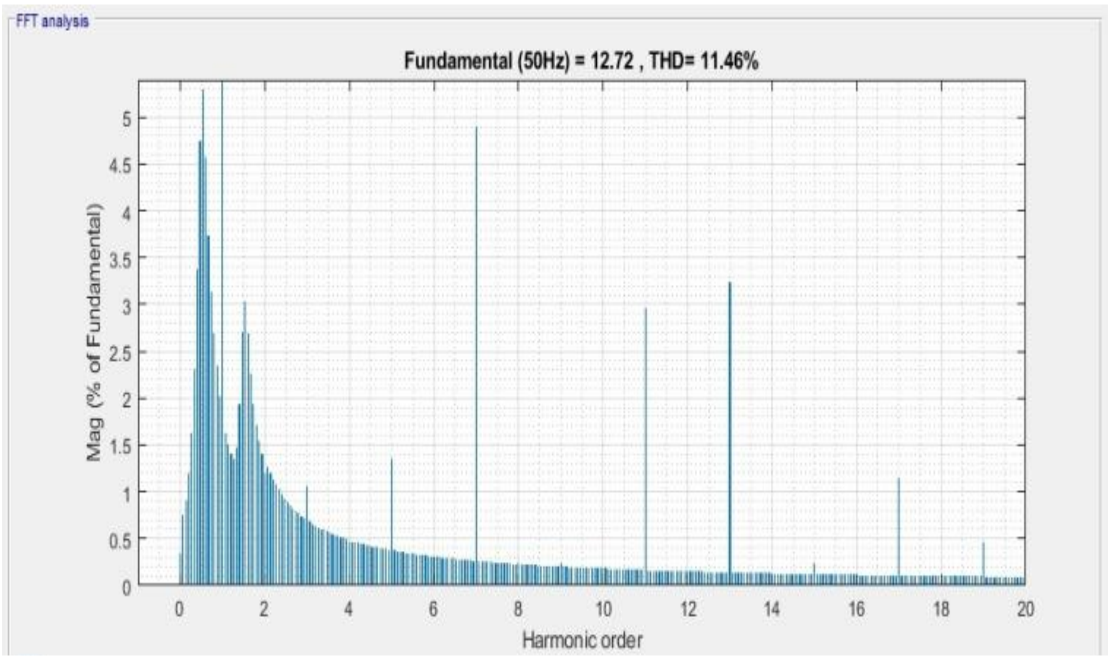

Fig. 7. Current THD% for SVPWM based three level inverter

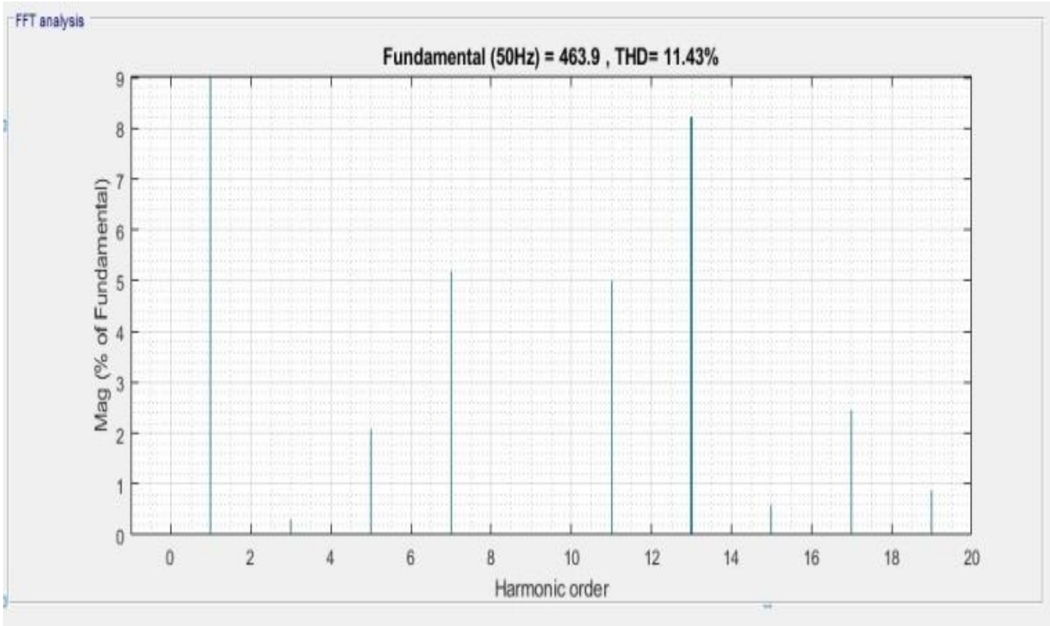

Fig. 8. Voltage THD% for SVPWM based three level inverter

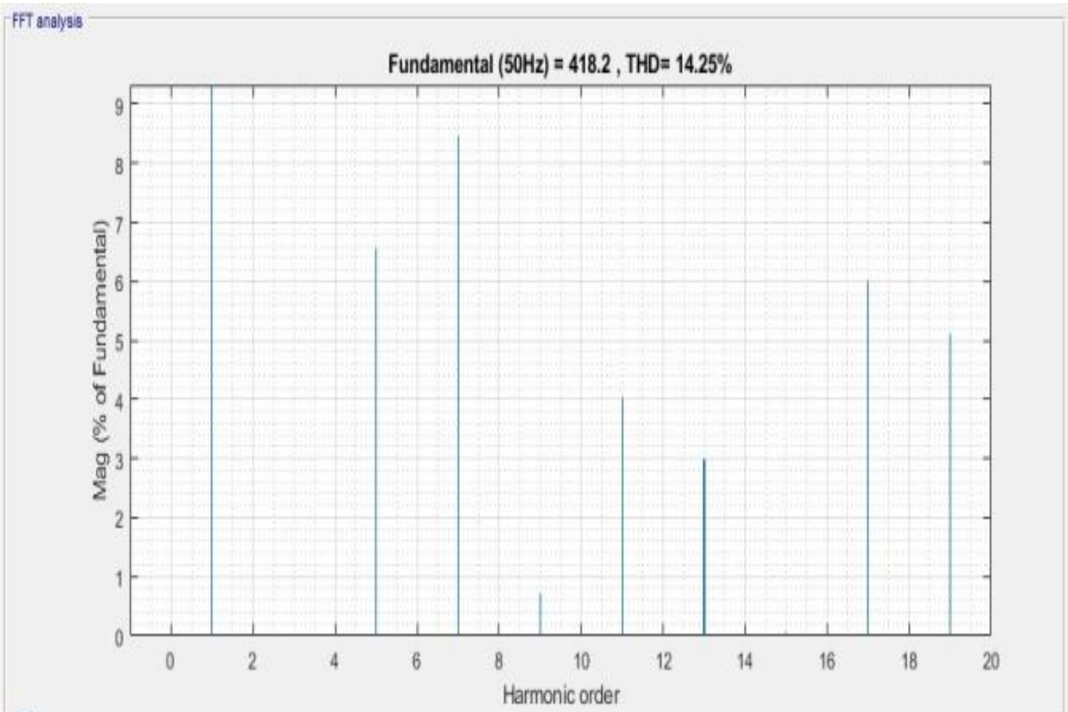

Fig. 9. Voltage THD% for Sinusoidal PWM based three level inverter

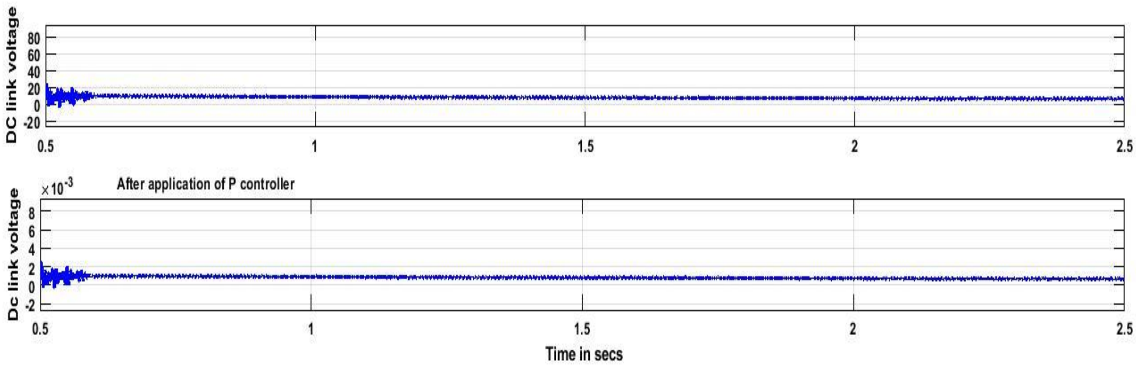

Fig. 10. DC Link voltage

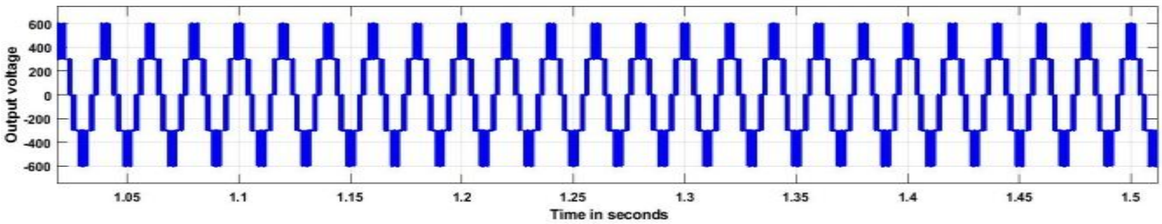

Fig. 11. Three level output voltage

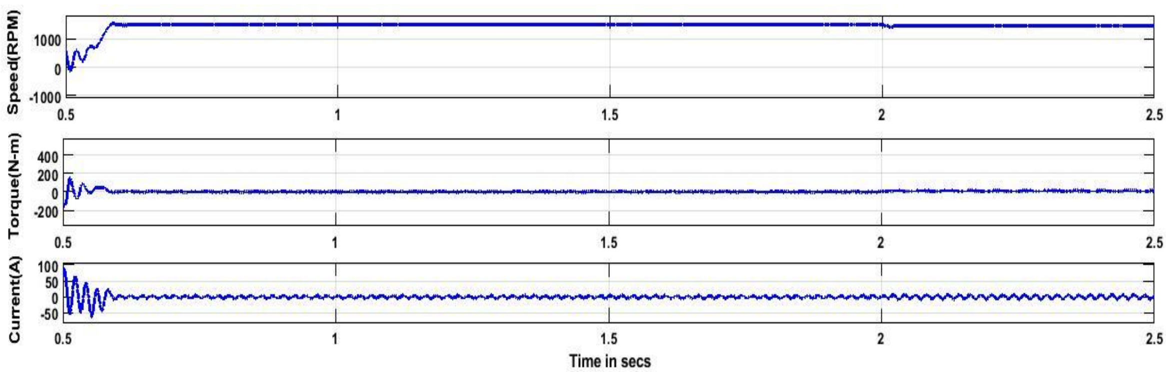

Fig. 12. Speed-Torque responses for SVPWM based three level inverter fed induction drive.

5. CONCLUSION

A comprehensive and comparative study with detailed analysis is carried out for sinusoidal PWM and SVPWM for three level NPC inverters. The chosen performance parameters like stator current and voltage THD% are presented and analysed for both the techniques. Mathematical depiction vis-a-vis simulation in Matlab/Simulink gives a comprehensive understanding of comparative study.Based on the simulation results,it isobserved that SVPWM performs better in three level NPC inverter compared to sinusoidal PWM by providing lesser THD and better DC bus utilisation.As the paper illustrates mathematical analysis apart from simulation study ,it provides avenues to easily incorporate and analyse several other switching techniques for the chosen converter. This work also presents an NPC three-level inverter with P controller-based neutral point control and closed loop v/f control of an induction motor drive using space vector PWM. The suggested approach decreases total harmonic distortion in the output stator current while also controlling the drive's speed and torque. Furthermore, the P controller, which is placed between two capacitor DC links, controls the neutral point current, saving switching devices and making the system more efficient for electric vehicle applications.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Rashid MH. Power electronics: circuits, devices, and applications. India: Pearson Education; 2009.
2. McGrath BP, Holmes DG. Multicarrier PWM strategies for multilevel inverters. IEEE Trans Ind Electron. 2002; 49(4):858-67.
3. Nguyen TH, Chan PKW, Shrivastava Y, Hui SYR. A three dimensional space vector modulation scheme for three-level three-wired neutral point clamped converters 36th Power Electronics Specialists Conference. Vol. 2005. IEEE Publications. 2005;230-2314.
4. Lavanya K, Rangavalli V. A novel technique for simulation & analysis of SVPWM two & three-level inverters. IJERA J. 2013;3(5):455-60.
5. Nabae A, Takahashi I, Akagi H. A new neutral-point-clamped PWM inverter. IEEE Trans Ind Appl. 1981;5:518-23.
6. Rodriguez J, Lai J-S, Peng FZ. Multilevel inverters: a survey of topologies, controls, and applications. IEEE Trans Ind Electron. 2002;49(4):724-38.
7. Bhalodi KH, Agrawal P. Space vector modulation with DC-link voltage balancing control for three-level inverters International Conference on Power Electronic, Drives and Energy Systems. IEEE Publications; 2006.
8. Tan Z, Li Y, Li M. A direct torque control of induction motor based on three-level NPC inverter 32nd Annual Power Electronics Specialists Conference. Vol. 3. IEEE Publications. IEEE Publications; 2001 (IEEE. Cat. No. 01CH37230).
9. Krishnan R. Electric motor drives modeling, analysis and control Pearson education. Virginia Tech; 2001.
10. Baader U, Depenbrock M, Gierse G. Direct self control (DSC) of inverter-fed induction machine: A basis for speed control without speed measurement. IEEE Trans Ind Appl. 1992;28(3):581-8.
11. Beig AR, Narayanan G, Ranganathan VT. Modified SVPWM algorithm for three level VSI with synchronized and symmetrical waveforms. IEEE Trans Ind Electron. 2007;54(1):486-94.
12. Hu H, Yao W, Lu Z. Design and implementation of three-level space vector PWM IP core for FPGAs. IEEE Trans Power Electron. 2007;22(6):2234-44.
13. Maheshwari RK, Munk-Nielsen S, Busquets-Monge S. Neutral-point current modeling and control for neutral-point clamped three-level converter drive with small DC-link capacitors IEEE Energy Conversion Congress and Exposition. IEEE Publications; 2011.
14. Jayakumar V, Chokkalingam B, Munda JL. A comprehensive review on space vector modulation techniques for neutral point clamped multi-level inverters. IEEE Access. 2021.
15. Mondal SK, et al. Space vector pulse width modulation of three-level inverter extending operation into overmodulation region. IEEE Trans Power Electron. 2003;18(2):604-11.
16. Gupta AK, Khambadkone AM. A simple space vector PWM scheme to operate a three-level NPC inverter at high modulation index including overmodulation region, with neutral point balancing. IEEE Trans Ind Appl. 2007;43(3):751-60.
17. Ben-Brahim L. A discontinuous PWM method for balancing the neutral point voltage in three-level inverter-fed variable frequency drives. IEEE Trans Energy Convers. 2008;23(4):1057-63.
18. Gopinath A, Aneesh Mohamed AS, Baiju MR. Fractal based space vector PWM for multilevel inverters—A novel approach. IEEE Trans Ind Electron. 2008;56(4):1230-7.
19. Jiang W-D, et al. Hybrid PWM strategy of SVPWM and VSVPWM for NPC three-level voltage-source inverter. IEEE Trans Power Electron. 2010;25(10): 2607-19.
20. Chaturvedi PK, Jain S, Agarwal P. Reduced switching loss pulse width modulation technique for three-level diode clamped inverter. IET Power Electron. 2011;4(4):393-9.
21. Lewicki A, Krzeminski Z, Abu-Rub H. Space-vector pulsewidth modulation for three-level NPC converter with the neutral point voltage control. IEEE Trans Ind Electron. 2011;58(11):5076-86.
22. Chen J, et al. A comprehensive study on equivalent modulation waveforms of the SVM sequence for three-level inverters. IEEE Trans Power Electron. 2015;30(12):7149-58.

23. Xia C, et al. Adjustable proportional hybrid SVPWM strategy for neutral-point-clamped three-level inverters. IEEE Trans Ind Electron. 2012;60(10):4234-42.
24. Das S, Narayanan G, Pandey M. Space-vector-based hybrid pulsewidth modulation techniques for a three-level inverter. IEEE Trans Power Electron. 2013;29(9): 4580-91.
25. Bhattacharya S, Mascarella D, Joos G. Space-vector-based generalized discontinuous pulsewidth modulation for three-level inverters operating at lower. IEEE J Emerg Sel Top Power Electron. 2017;5(2):912-24.
26. Nandhini E, Sivaprakasam A. A review of various control strategies based on space vector pulse width modulation for the voltage source inverter. IETE J Res. 2020.
27. Sivaprakasam A, Nandhini E. 30° discontinuous PWM-based closed loop volts/Hz control of induction motor drive with slip regulation. IETE J Res; 2021.

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