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Design of Multi-Level NPC Inverter using SVPWM Control for Power Quality Integration of Energy Resources in Grids

Satyam Rajput[1], Saurabh Vishwakarma[2], Dr. Deepak Agrawal[3], Dr. Shiv Kumar Sonkar[4]

Department Of Electrical & Electronics Engineering
Prestige Institute of Management & Research, Bhopal (M.P.)
satyamrajputjio@gmail.com,saurabh_vishwakarma@pimrbhopal.ac.in, hod_ex@pimrbhopal.ac.in, shiv.sonkar19@gmail.com

ABSTRACT- :

This study presents a comprehensive analysis and simulation of a fifteen-level neutral point clamped (NPC) inverter using space vector pulse width modulation (SVPWM) technique. The proposed system is designed to operate at a frequency of 50 Hz with a modulation index of 0.9 and a switching frequency of 10 kHz. The input DC voltage is set at 400 V, and a sample size of 10,000 is used for the simulation. The reference three-phase voltages are generated, and the corresponding two-phase voltages (Vd and Vq) are calculated. The reference voltage vector (Vref) and its angle (alpha) are determined, and the sector of the reference vector is identified. The time durations of the active and null vectors (T1, T2, and T0) are computed based on the sector and the modulation index. The duty cycles of the high-side switches (S1, S3, and S5) are calculated for each sector. A reference sawtooth waveform is generated, and the PWM signals for all the switches are obtained by comparing the duty cycle waveforms with the sawtooth waveform. The three-phase inverter is implemented, and the output phase voltages (Van, Vbn, and Vcn) and line voltages (Vab, Vbc, and Vca) are plotted. Fast Fourier Transform (FFT) analysis is performed on the Van waveform to calculate the total harmonic distortion (THD). The simulation results demonstrate the effectiveness of the proposed fifteen-level NPC inverter with SVPWM technique in generating high-quality output voltages with reduced harmonic content.

Keywords: - Power Quality Improvement, SVPWM, Multilevel inverter, mitigate current, dc to ac converter.

Introduction.

In recent years, multilevel inverters have attracted considerable interest due to their capability to produce high-quality output waveforms with minimized harmonic distortion and reduced switching losses. Among the various multilevel inverter configurations, the Neutral Point Clamped (NPC) inverter has become a favoured option for medium to high-power applications. This research is cantered on the design and execution of a fifteen-level NPC inverter utilizing Space Vector Pulse Width Modulation (SVPWM) control. SVPWM is a sophisticated modulation technique that provides numerous benefits over conventional sinusoidal PWM methods, such as enhanced DC bus utilization, decreased harmonic distortion, and increased overall system efficiency. The proposed fifteen-level NPC inverter seeks to amplify these advantages by raising the number of voltage levels, which leads to a more sinusoidal output waveform and diminished electromagnetic interference.

The application is used for the power distribution networks. There are two types of distribution systems: primary and secondary. Depending on the needs of the large consumers, the primary distribution voltage can be 11, 6.6, or 3.3 KV. The secondary usable voltage is 415/240V. Power generation and transmission is a complicated process that necessitates the cooperation of numerous power system components in order to optimize output. The system's reactive power is one of the primary elements that contribute significantly. For the active electricity to be sent through the wires, the voltage must be maintained. Reactive power is necessary for the operation of loads such as motor loads and other loads. The work contributed to implement a three-level NPC inverter using Space Vector Modulation (SVPWM). Reference three-phase voltages are generated and converted to a two-phase system (Vd, Vq). Duty cycles for high-side switches (S1, S3, S5) are calculated based on sectors. PWM signals are generated by comparing duty cycles with a reference sawtooth waveform. The three-phase inverter is implemented using switching logic based on PWM signals. Output phase voltages (Van, Vbn, Vcn) and line voltages (Vab, Vbc, Vca) are plotted. Fast Fourier Transform (FFT) analysis is performed to calculate Total Harmonic Distortion (THD). the THD performance of the three level and fifteen level (15) MLI are compared as contribution of the work.

A Flexible Alternating Current Transmission System (FACTS), which is made up of static equipment intended for the AC transmission of electrical energy, is implemented using the MLI-based NPC inverter technology that has been supplied. Through sophisticated power electronics, FACTS systems improve electrical networks' controllability and power transmission capacity. Reactive power compensation, or effective reactive power management, is crucial for maximizing the performance of AC power systems. Voltage support and load correction are the two primary facets of this. Enhancing power factor, balancing actual power extracted from the supply, and guaranteeing improved voltage control for big variable loads are the main goals of load compensation. The goal of voltage support is to reduce voltage variations at certain transmission line terminals. Paper have presented the space vector PWM based controlled NPC inverter design. SVPWM is a sophisticated modulation technique that provides numerous benefits over conventional sinusoidal PWM methods, such as enhanced DC bus utilization, decreased harmonic distortion, and increased overall system efficiency. The proposed fifteen-level NPC inverter seeks to amplify these advantages by raising the number of voltage levels, which leads to a more sinusoidal output waveform and diminished electromagnetic interference.

The rest of paper is organized to demonstrate the proposed methodology and the research results and discussion section typically follows a structured approach to effectively convey the findings. It begins with a presentation of specific findings derived from experiments or simulations, providing a clear overview of the outcomes. This is followed by a detailed data analysis and interpretation, where the significance of the results is explored. The discussion then compares the current findings with previous studies or theoretical predictions, highlighting similarities and differences. Additionally, the implications of the results are examined to understand their relevance and potential impact on the field. Finally, the section addresses the limitations of the study, acknowledging any constraints that may affect the interpretation of the results. This systematic approach ensures a comprehensive understanding of the research outcomes and their context within existing literature.

LITERATURE REVIEW

This section has presented the literature summary Table 1 based on the references provided, highlighting the methodology, compensation method used, inverter type, and limitations of the inverters and compensation methods Table summarizes the key aspects of each reference.

Table 1 Summary of the Literature and review limitations

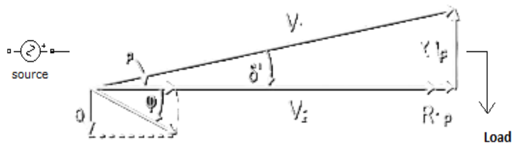
Reference	Methodology	Compensation Method Used	Inverter Type	Limitations
Yiqiao Liang and C. O. Nwankpa [1]	Cascading voltage source inverters	STATCOM	Voltage Source Inverter	Complexity in control strategy
P. Giroux et al. [2]	Modeling and simulation using Simulink	STATCOM	Not specified	Simulation accuracy dependent on model fidelity
N. Hingorani and L. Gyugi [3]	Conceptual understanding of FACTS	General FACTS principles	Not specified	Limited practical implementation details
C. A. C. Cavaliere et al. [4]	Multi-pulse operation under unbalanced voltages	STATCOM	Multi-pulse Inverter	Performance under severe voltage imbalances
R. M. Mathur and R. K. Varma [5]	Thyristor-based control	FACTS Controller	Thyristor Inverter	Slower response time due to thyristor switching
H. K. Tyll [6]	Technology overview for reactive compensation	Reactive Power Compensation	Not specified	Generality may overlook specific applications
M. S. El-Moursi and A. M. Sharaf [7]	Novel controller design	Voltage regulation and reactive compensation	48-pulse VSC	Complexity in controller design
A. H. Norouzi and A. M. Sharaf [8]	Development of control schemes	Dynamic performance enhancement	Not specified	May require extensive tuning
M. S. ElMoursi and A. M. Sharaf [9]	Novel FACTS STATCOM scheme	Voltage stabilization and reactive compensation	STATCOM	Implementation challenges in real-world scenarios
A. K. Sahoo et al. [10]	Modeling and simulation using Simulink	STATCOM	48-pulse VSC	Dependence on simulation tools for validation
M. P. Donsion et al. [11]	Benefits analysis of FACTS devices	Power Quality Improvement	Not specified	Variability in effectiveness across different systems
A. V. Gonzalez and J. M. Ramirez [12]	DSP-based control implementation	Voltage control	Multi-pulse STATCOM	Need for robust DSP hardware
Tiefu Zhao et al. [13]	Operation of converters with NPC converter	Series and shunt compensation	Three-level NPC Converter	Complexity in control and operation
A. Valderrabano and J. M. Ramirez [14]	Implementation details for conventional control	Conventional STATCOM control	Not specified	Limited adaptability to modern requirements

REACTIVE POWER COMPENSATION

The proposed method uses the shunt compensation method for reactive power control and RC filter is applied for the improvement in THD.

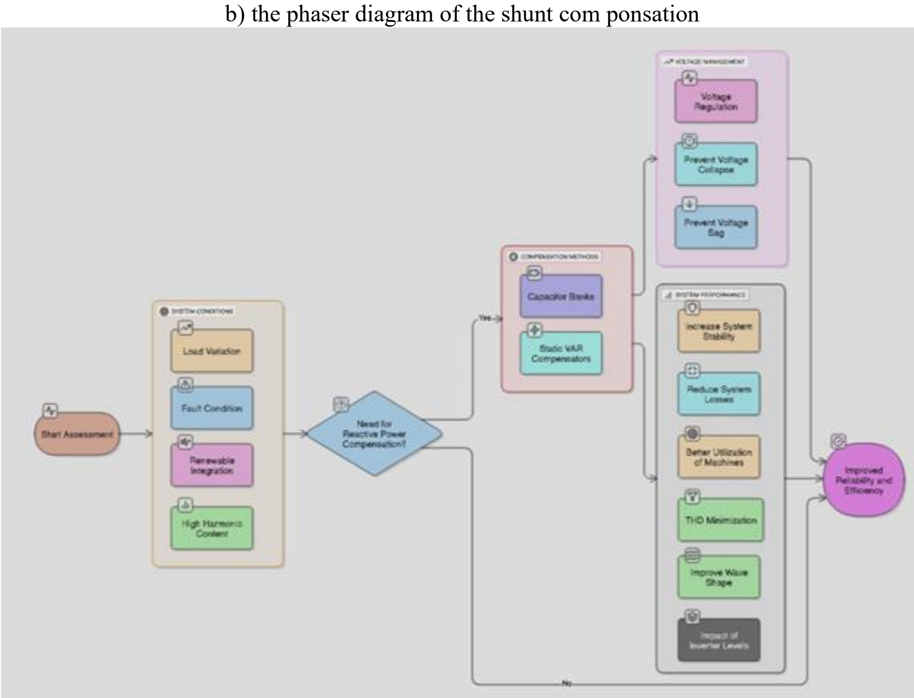
2.1 SHUNT COMENSATION METHOD

The principles of both shunt reactive power compensation techniques is illustrated in the Figure 1 a) to c). the figure



a) shunt componsation

b) the phaser diagram of the shunt com ponsation



c) Flow chart of the Proposed system design

Figure. 1. Proposed control and compensation methodology for Shunt Compensation and SVPWM

The flowchart procedure for reactive power correction in a system is shown in Figure 1c). Following an assessment, system factors such as load fluctuation, fault situations, integration of renewable energy sources, and high harmonic content are taken into account. The flowchart recommends the use of static VAR compensators or capacitor banks if reactive power correction is required. This results in voltage management techniques including voltage regulation, voltage sag prevention, and voltage collapse prevention. The ultimate objective is to enhance system performance, which includes boosting stability, decreasing losses, optimizing machine use, minimizing THD, enhancing wave shape, and controlling the influence of inverter levels, all of which lead to increased efficiency and dependability.

A current source device is used for lagging and leading shunt compensation, improving voltage regulation and reducing reactive current components. In shunt compensation, power systems are connected parallel to FACTS, acting as controllable current sources. There are two types of shunt compensation.

A. Shunt capacitive compensation

The power factor is raised by using this technique. Power factor lags whenever an inductive load is coupled to a transmission line due to lagging load current. A shunt capacitor is connected to draw current from the source voltage in order to compensate. The end effect is an increase in power factor.

RESULTS AND DISCUSSIONS

The provided text does not appear to be a specific results and discussion section of a research paper. Instead, it presents a general overview of scenarios where reactive power compensation is applied in power systems.

The text provided is more of an informational list of applications for reactive power compensation. It covers various scenarios such as load variations, sawtooth wave timing, space vector PWM control, duty cycle variation. transmission line compensation, fault conditions, renewable energy integration, system stability and THD performance enhancement, harmonics mitigation energy efficiency improvement.

The input three phase waveform are plotted in the Figure 2. the voltages are represented respectively as Va, Vb,Vc. for three phases 120 degree apart.

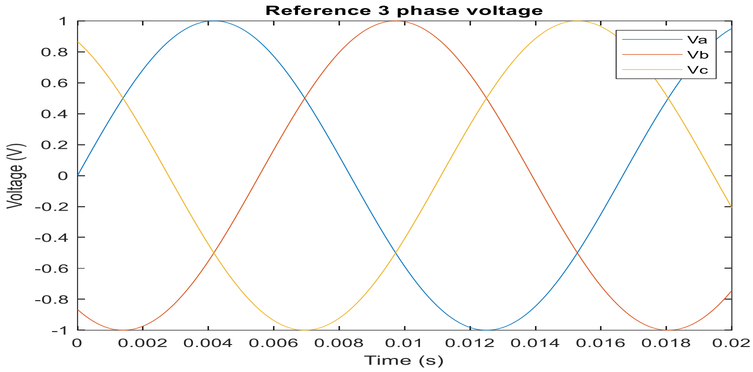


Figure 2 input three phase a,b,c waveforms

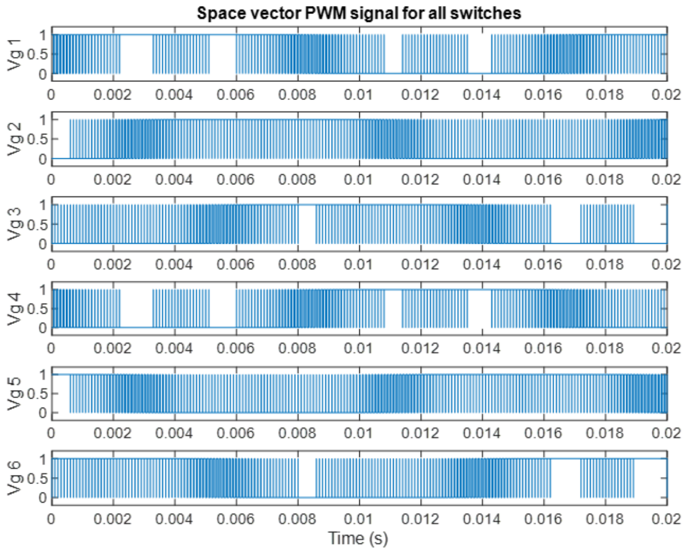


Figure. 3 Waveform of the SVPWM contorted signal response as simulated for the three level NPC inverter control

The Figure 3 have presented the results of a series of six waveforms, labeled Vg1 through Vg6, which represent the Space Vector Pulse Width Modulation (SVPWM) signals for all switches in a three-level Neutral Point Clamped (NPC) inverter control system. The x-axis of each waveform represents time in seconds, ranging from 0 to 0.02 seconds. The y-axis represents the signal amplitude, ranging from 0 to 1. The waveforms show the switching patterns of the inverter, which are used to generate a desired AC voltage from a DC source. The title indicates that these are simulated results, likely used for analysis or design verification of the inverter control system. The SVPWM technique is commonly used in power electronics to improve the efficiency and reduce the harmonic distortion of inverter outputs.

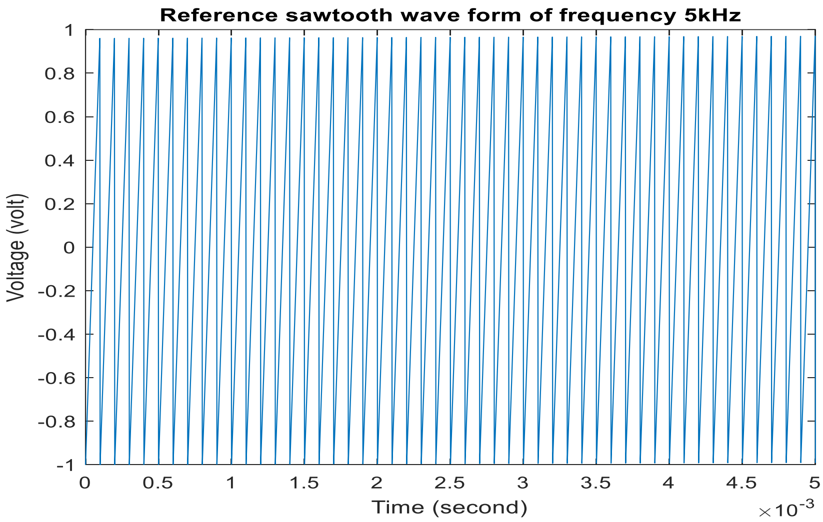


Figure.4 the example of the three-level controlled validation sawtooth wave form

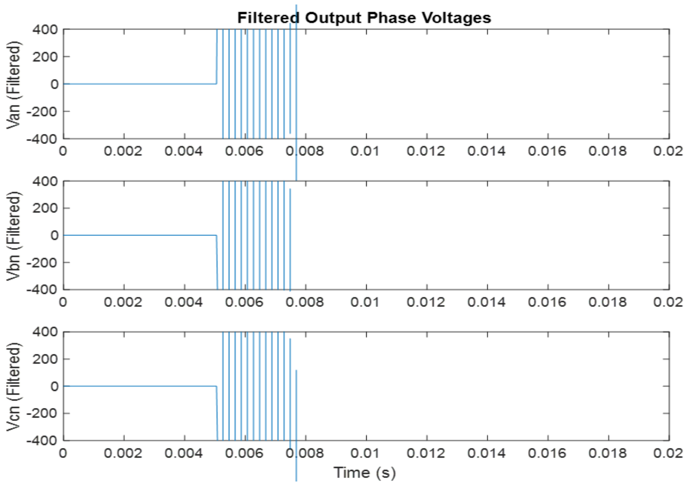


Figure 5 results of RC filtered controeld oputput ised for THD mitigationas sim,ulated

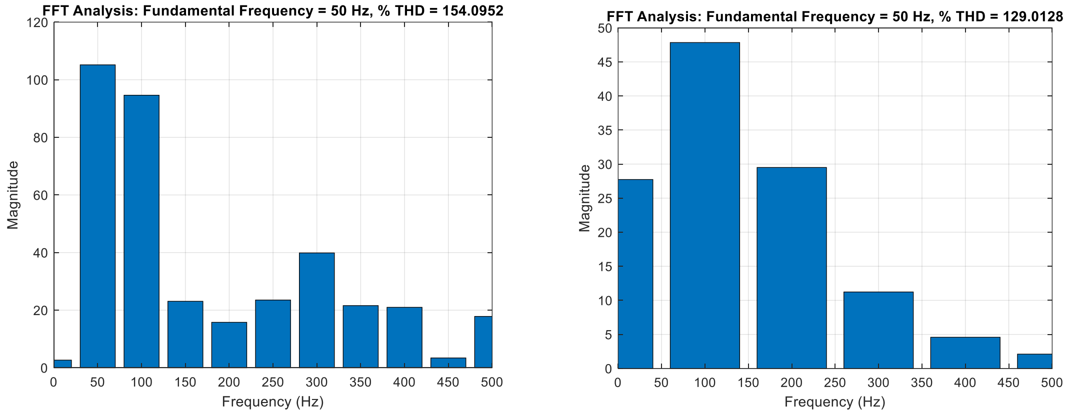


Figure. 6 Bar graph of THD comparison for the different 3 and 15 level inverters as validated.

The Figure 6 have compared the THD results from the two FFT analyses are being compared. The left graph shows a THD of 154.0952%, reported in simulation for 3 level NPC inverters. While the right graph shows a THD of 129.0128% reported with 15 level inverters. Therefore, the percentage THD result in the left figure is higher than the percentage THD result in the right figure. The performance of the designed inverter is evaluated through simulation using MATLAB. Various output parameters, including phase voltages, line voltages, and Total Harmonic Distortion (THD), are analysed to assess the effectiveness of the proposed design.

CONCLUSION

This study aims to provide a comprehensive understanding of the design process for a multi-level NPC inverter using SVPWM control and demonstrate its potential for improving power quality in various applications. In this paper MATLAB simulation is presented which implements a three-level NPC inverter using Space Vector Pulse Width Modulation (SVPWM) technique. It generates PWM signals for the inverter switches based on the reference three-phase voltages and calculates the output phase and line voltages. The simulation also performs FFT analysis to calculate the Total Harmonic Distortion (THD) of the output voltage waveform. The simulation is done for a fundamental frequency of 60 Hz, modulation index of 0.85, switching frequency of 10 kHz, and input DC voltage of 40 V. The simulation plots various waveforms, including the reference voltages, duty cycles, PWM signals, output phase voltages, output line voltages, and the FFT spectrum of the output voltage. Results representing Space Vector Pulse Width Modulation (SVPWM) signals in a three-level Neutral Point Clamped (NPC) inverter control system. The SVPWM technique is used in power electronics to improve efficiency and reduce harmonic distortion. The left graph shows a higher Total Harmonic Distortion (THD) than the right graph, with a higher THD for 3 level NPC inverters. The performance of the designed inverter is evaluated using MATLAB, analyzing output parameters like phase voltages and THD.

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