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# Performance Evaluation of Unipolar Sinusoidal Pulse Width Modulation based Inverter for Power Quality Improvement

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**Abstract:** The growing need for high quality AC power in current electrical and renewable energy systems has resulted in an increased requirement for efficient inverter topologies with improved harmonic performance. This study discusses the performance evaluation of a single phase inverter based on Unipolar Sinusoidal Pulse Width Modulation (SPWM) for power quality improvement. The system suggested is based on full bridge inverter topology controlled by unipolar SPWM switching to provide AC output with decreased harmonic distortion and improved waveform quality. The inverter model is designed and analyzed via simulation platform with RLC loading circumstances. The system performance is evaluated in terms of output voltage characteristics, load current behavior, RMS values and Total Harmonic Distortion (THD). The simulation results show that the inverter is capable of producing a high-quality load current waveform with considerably decreased harmonic content, even with switching harmonics in the inverter output voltage. The THD recorded for the current is restricted to 4.27% which indicates that the harmonics are well mitigated and the power quality performance is enhanced. The study demonstrates that the unipolar SPWM approach gives superior quality of waveform and improved performance of inverter for single phase power conversion applications.

**Keywords:** Unipolar SPWM; Power Quality; Total Harmonic Distortion; Pulse Width Modulation; Harmonic Analysis; Full-Bridge Inverter; FFT Analysis; Power Electronics.

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## 1. Introduction

The development of modern electrical systems, renewable energy technologies and electronic equipment has resulted in an increasing demand for efficient DC-to-AC power conversion systems with better output quality [1-3]. Inverter circuits are broadly used in many applications such as photovoltaic systems, uninterruptible power supplies, motor drives and distributed power generation. Inverter systems are widely used, however they typically add harmonic distortion into the output waveform, which can degrade system stability, efficiency, and the performance of associated loads [4, 5]. Therefore, the improvement of power quality performance of inverter systems has become an essential issue in power electronics research.

The PWM approaches are widely used for controlling the inverter switching actions and improving the output waveform performance [6-8]. SPWM is one of the various modulation methods which is generally selected because of its simple implementation, steady switching operation and capability of reducing low order harmonics [9-13]. In SPWM control, the switching pulses are generated by comparing a sinusoidal reference signal with a high frequency triangle carrier signal. Then the produced pulses are

applied to semiconductor switches in order to create an AC output waveform.

The unipolar SPWM is viewed as more efficient than the typical bipolar modulation because of its better harmonic performances and lower switching stress [13-18]. The method results in a smoother transition of the inverter output voltage between the positive, zero and negative voltage levels, leading to lower harmonic distortion. Reduction of harmonic content results in better quality of load current and less demand of filtering in practical applications. These benefits have led to a wide application of unipolar SPWM inverters in low and medium power conversion systems.

The power quality of inverter systems is normally evaluated by waveform analysis, RMS evaluation and harmonic measurements. THD is one of the most essential criteria in determining the quality of the inverter output waveforms. The Fast Fourier Transform (FFT) analysis gives a complete picture of the system's frequency spectrum and harmonic behavior. The lower the THD, the better the wave form quality and the better the inverter performance. In this study, a single phase full bridge inverter is designed and investigated on the basis of Unipolar Sinusoidal Pulse Width Modulation approach for power quality improvement. The proposed model is

implemented in RLC loading conditions in MATLAB/Simulink. The performance of the inverter is evaluated by analyzing the output voltage and current waveforms, RMS measurements and FFT based harmonic analysis. The findings obtained suggest that the proposed unipolar SPWM inverter can produce better quality load current with lower harmonic distortion, therefore it is suited for modern AC power conversion applications.

The rest of this paper is organized as follows: The working principle of PWM and unipolar SPWM technologies are explained in section 2. The proposed inverter system configuration and simulation setup are described in Section 3. Section 4 presents the simulation results and harmonic performance analysis of the designed inverter system. Finally, section 5 summarises the main outcomes of the study and comments on prospective future research topics.

## 2. Pulse Width Modulation and Unipolar SPWM Technique

The PWM is one of the most frequent switching techniques in power electronic converters and inverter systems. The fundamental goal of PWM is to convert a fixed input DC to a regulated output AC by controlling the action of the switches of semiconductor devices. PWM approaches are used in inverter applications to manage the output voltage magnitude, frequency and harmonic performance. The output waveform can be adjusted to resemble sinusoidal waveform with higher power quality characteristics by modifying the switching pulse sizes.

This switching of square waves causes high harmonic distortion in the standard inverter system. This results in poor quality of waveform and higher stress on the linked electrical equipment. To mitigate such constraints, sophisticated PWM techniques like SPWM are commonly employed in current power conversion systems.

### 2.1 Principle of PWM

In PWM operation, the semiconductor switches are turned ON and OFF repeatedly at high frequency [6-8]. Average output voltage is a function of the switching pulse duration in one switching cycle. The ratio of switch ON time to total switching period is called as duty cycle.

The duty cycle can be mathematically stated as:

$$D = \frac{T_{ON}}{T} \quad (1)$$

$D = \text{duty cycle}$

$T_{ON} = \text{switch ON duration}$

$T = \text{total switching period}$

The PWM approach permits the effective control of the output voltage and decreases the harmonic content of the inverter output wave. In general, the higher switching frequency can bring a better waveform quality because it can push the harmonic components to the higher frequency zone where they can be more easily filtered.

### 2.2 Modelling of SPWM

Sinusoidal Pulse Width Modulation is a sophisticated PWM [13-18] technique in which a sinusoidal reference signal is compared with a high frequency triangle carrier waveform to generate switching pulses. The switching instances are recognized by the intersection positions of the reference and the carrier signals.

Equations (2) and (3) give the sinusoidal reference and triangular carrier signal correspondingly.

$$v_r(t) = A_m \sin(\omega_m t) \quad (2)$$

$$v_c(t) = A_c \text{triangular}(\omega_c t) \quad (3)$$

$A_m = \text{Amplitude of the sinusoidal reference signal,}$

$A_c = \text{Amplitude of the carrier waveform}$

$\omega_m = \text{Angular frequency of the reference signal}$

$\omega_c = \text{Angular frequency of the carrier signal}$

**Table 1.** Comparison Between Bipolar PWM and Unipolar SPWM Techniques

Parameter	Bipolar PWM	Unipolar SPWM
Output Voltage Levels	(+V <sub>dc</sub> ) and (-V <sub>dc</sub> )	(+V <sub>dc</sub> ), 0 and (-V <sub>dc</sub> )
Switching Method	Single reference comparison	Two reference comparisons
Harmonic Distortion	Higher	Lower

Output Waveform Quality	Moderate	Improved
Switching Frequency Effect	Lower effective frequency	Higher effective frequency
Electromagnetic Interference	Higher	Lower
Filtering Requirement	Larger filter required	Reduced filter requirement
Switching Losses	Higher	Lower
Current Ripple	Higher	Reduced
Power Quality Performance	Moderate	Better
THD Performance	Relatively high	Relatively low
Suitability	Basic inverter applications	High-performance inverter systems
Load Current Quality	More distorted	Nearly sinusoidal
Control Complexity	Simple	Moderate
Efficiency	Moderate	Improved

The switching logic is expressed as:

$$\begin{aligned}
 v_r(t) > v_c(t); & \text{the switch is turned ON} \\
 v_r(t) < v_c(t); & \text{the switch is turned OFF}
 \end{aligned}
 \tag{4}$$

The modulation index is an vital parameter in SPWM systems and is defined as:

$$m_a = \frac{A_m}{A_c} \tag{5}$$

For the developed inverter model,  $m_a$  is equal to 0.8.

The frequency modulation ratio is expressed as:

$$m_f = \frac{f_c}{f_m} \tag{6}$$

$f_c$  is the carrier frequency (1 kHz for prposed system).

$f_m$  is the modulating frequency (50 Hz for prposed system).

$m_f$  is considered 20.

The SPWM approach generates switching pulses of varying widths which more accurately correspond to the sinusoidal output waveform and reduce harmonic distortion as compared to the typical square wave inverters.

### 2.3 Unipolar SPWM Technique

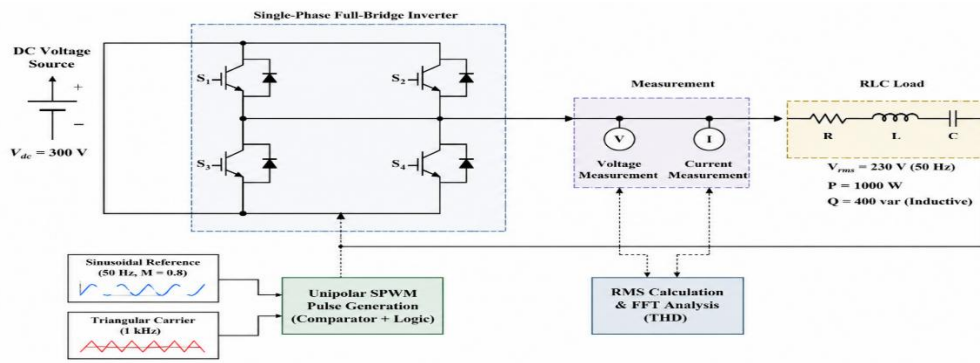
In this work, the Unipolar SPWM approach is used to improve the power quality performance of the single-phase inverter system [14-18]. In unipolar switching, two sinusoidal reference signals, 180o out of phase with each other, are compared with a common triangular carrier waveform to produce the gating signals for the inverter switches. Unlike bipolar switching where the output voltage switches directly between positive and negative levels of the DC voltage, unipolar SPWM generates voltage transitions between positive, zero and negative levels. The output voltage of the inverter can thus be expressed by the following equation.

$$V_o \in \{+V_{dc}, 0, -V_{dc}\} \tag{7}$$

The unipolar SPWM approach has various amerits including:

- decreased harmonic distortion,
- switching losses are reduced
- improved quality of output voltage,
- reduction of electromagnetic interference (EMI),
- and better load current characteristics.

The unipolar switching allows to reduce harmonics and therefore the load current is almost sinusoidal even with the presence of high frequency switching pulses in the inverter output voltage. This enhances the quality of power performance of the inverter system. Table 1 compares standard bipolar PWM with proposed unipolar SPWM for inverter applications [14, 16, 17]. The unipolar SPWM approach has better power quality features and increased harmonic performance compared with bipolar switching operation.



**Fig. 1.** Single-line diagram of the proposed unipolar SPWM inverter system

### 3. Modeling of Proposed System

The suggested method is for evaluation of power quality performance of single phase full bridge inverter operated using Unipolar SPWM technique. The overall configuration of the developed system is illustrated in Figure 1, which consists of a DC voltage source, SPWM pulse generation unit, full-bridge inverter, measurement system, FFT analysis block, and an RLC load network.

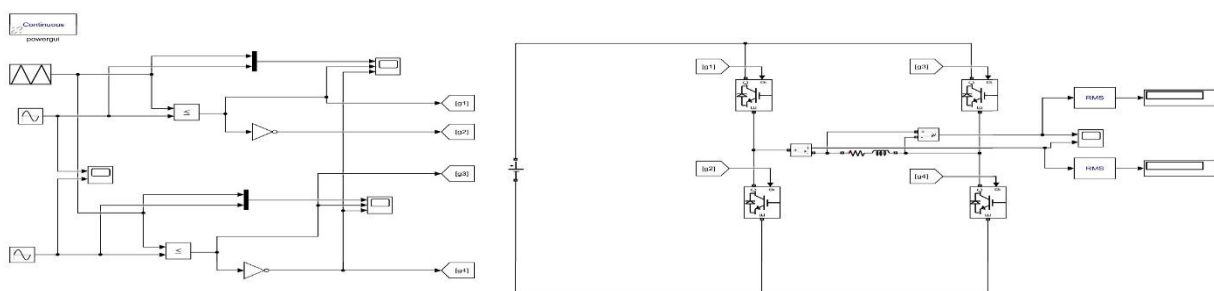
The inverter is fed with 300 V DC at its input stage. The power conversion unit is constructed utilizing a single-phase full-bridge inverter topology, which consists of four IGBT switches with anti-parallel diodes. The inverter changes the dc input voltage to a controlled ac output voltage, which is adequate for feeding the load.

Unipolar SPWM technique is used to create switching pulses for the inverter. In the pulse generation stage a low frequency sinusoidal reference signal is continually compared with a high frequency triangular carrier waveform; The reference signal is running at 50 Hz with a modulation index of 0.8 and the triangular carrier signal is picked at the switching frequency of 1 kHz. The comparison process produces complimentary gating pulses which are applied to the inverter switches to achieve unipolar switching function.

The switching states of the inverter devices are controlled by the generated SPWM pulses, which result in output voltage transitions between positive, zero and negative voltage levels. This switching technique enhances the harmonic profile of the inverter and lowers the distortion of load current waveform.

The inverter output terminals are linked to series RLC load rated 230 V with active power requirement of 1000 W and inductive reactive power of 400 var. The inverter output is connected with the voltage and current measuring blocks to monitor the wave form characteristics and RMS values during the operation of the system.

The harmonic performance of the proposed inverter is studied utilizing FFT analysis by powergui analysis tool. The FFT block calculates the harmonic spectrum and THD of the waveforms of output voltage and load current. The acquired findings are utilized to evaluate the effectiveness of the suggested unipolar SPWM approach for power quality improvement. The detailed implementation of the suggested unipolar SPWM inverter system in MATLAB/Simulink is shown in Figure 2. The SPWM pulse generation circuit, full-bridge inverter topology, measurement blocks and RLC load configuration are shown in the figure.



**Fig. 2.** MATLAB/Simulink model of the proposed unipolar SPWM inverter system

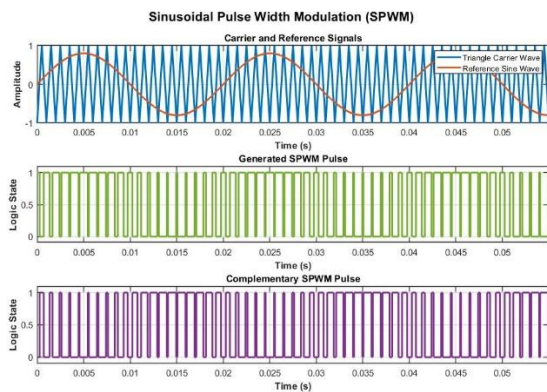
**Table 2** Electrical and Inverter Parameters of Proposed System

Parameter	Value
DC Input Voltage	300 V
Fundamental Frequency	50 Hz
Carrier Frequency	1 kHz
Modulation Index	0.8
Inverter Type	Single-Phase Full-Bridge
Switching Device	IGBT/Diode
PWM Technique	Unipolar SPWM

**Table 3** Load and Simulation Parameters

Parameter	Value
Load Type	Series RLC Load
Rated Load Voltage	230 V
Active Power	1000 W
Reactive Power	400 var
Simulation Environment	MATLAB/Simulink
Simulation Mode	Continuous

The complete system model is implemented in MATLAB/Simulink under continuous simulation mode. The single line diagram of the suggested unipolar SPWM inverter system is shown in Figure 1 and the complete MATLAB/Simulink implementation



**Fig. 3.** Generation of unipolar SPWM pulses using reference and carrier signals

The produced pulses are applied to the inverter switches in a complimentary mode for unipolar switching. The pulse generation mechanism allows for a controlled switching action and an improved harmonic performance with respect to a standard square-wave operation.

is shown in Figure 2. The acquired results are explained in details in the following section.

#### 4. Results and Discussion

The performance of suggested unipolar SPWM inverter is studied under RLC loading condition by MATLAB/ Simulink simulation. The acquired results are SPWM pulse production characteristics, inverter output voltage waveform, load current responsiveness, RMS performance and harmonic analysis with FFT tool. The effectiveness of the suggested inverter to enhance the power quality performance is evaluated using simulation data.

##### 4.1 SPWM Pulse Generation Analysis

The inverter switching pulses are generated by comparing sinusoidal reference waveforms with a high frequency triangular carrier signal. The desired output frequency is set by the sinusoidal waveform, while the switching frequency of the inverter switches is controlled by the triangle waveform.

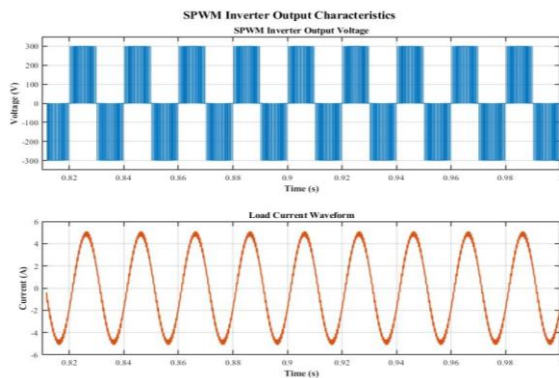
Figure 3 shows the carrier signal, the reference sine wave signal, the generated SPWM pulse and the complementary SPWM pulse. The pulse widths change continuously with the instantaneous amplitude of the reference sine wave. This produces sinusoidal modulation of the inverter output voltage.

##### 4.2 Output Voltage and Load Current Characteristics

The simulated inverter output voltage and load current waveforms of the proposed system are presented in Figure 4. The inverter output voltage waveforms have high frequency switching pulses due to the SPWM operation. The inverter devices are switched on/off as per the switching sequence and results in an alternating positive and negative voltage levels.

The waveform of load current is virtually sinusoidal but there are switching harmonics in the output voltage. This behavior is due to the inductive part of the RLC load suppressing higher order harmonic components and smoothing the current waveform considerably.

The generated load current exhibits stable sinusoidal features with low ripple content which shows the effective harmonic reduction capacity of the proposed unipolar SPWM inverter system.



**Fig. 4.** Inverter output voltage and load current waveforms

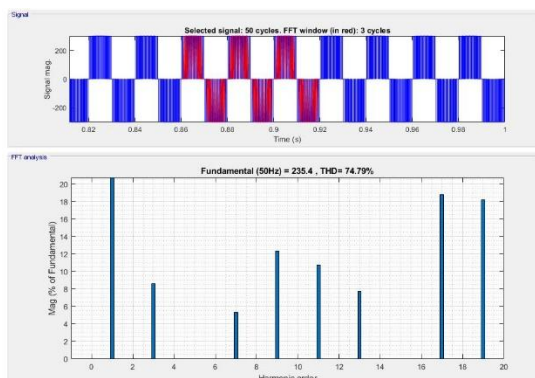
### 4.3 RMS Performance Evaluation

The steady-state performance of the inverter under the given operating circumstances are analyzed by measuring RMS values of output voltage and load current. The RMS output voltage and current are 214.2 V and 3.46 A correspondingly. The RMS output voltage obtained shows that the inverter is working properly and efficiently using the DC input source. Obtained RMS load current shows steady power delivery to the associated RLC load. The RMS results prove the fact that the suggested unipolar SPWM inverter may give satisfactory AC output performance in the case of practical loading situations.

### 4.4 FFT and Harmonic Analysis

The powergui FFT analysis tool is used for FFT analysis to determine the harmonic features of the inverter output voltage and load current waveforms. The analysis is performed at the fundamental frequency of 50 Hz.

The FFT spectrum of the inverter output voltage waveform is shown in Fig.

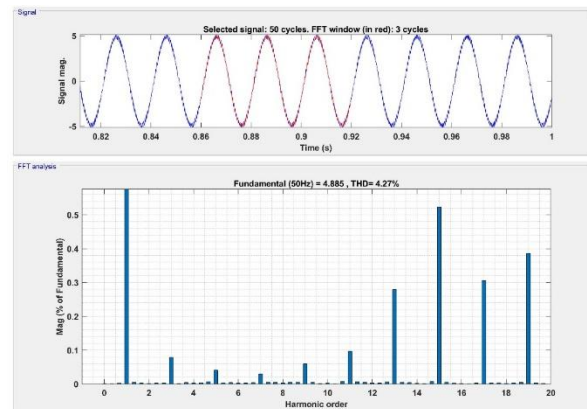


**Fig. 5.** FFT analysis of inverter output voltage waveform

The obtained voltage Total Harmonic Distortion is:

$$THD_v = 74.79\%$$

The switching action of the SPWM inverter output comprises of high frequency pulse transitions. The voltage waveform contains considerable switching harmonics. Figure 6 shows the FFT spectrum of the load current waveform.



**Fig. 6.** FFT analysis of load current waveform

The obtained current Total Harmonic Distortion is:

$$THD_i = 4.27\% < 5\%$$

The present THD is much lower than the voltage THD because of the filtering operation from the inductive load component. The higher order harmonics in the inverter voltage are efficiently reduced before they reach the load current waveform. The FFT analysis reveals that the suggested unipolar SPWM approach enhances the load current quality and reduces the harmonic distortion greatly under RLC load conditions.

### 4.5 Overall Performance Discussion

The simulation findings show that the proposed unipolar SPWM inverter generally performs satisfactorily for AC power conversion applications. The suggested switching method is able to successfully generate controlled SPWM pulses and to assure stable inverter functioning under RLC loading conditions. The proposed modulation technique is effective to control the switching action of the inverter and produce the desired AC output waveform from the DC input source.

The output voltage waveform of the inverter features high frequency switching harmonics, which is a frequent characteristic of PWM inverters. However, the load current waveform is almost sinusoidal with a much reduced harmonic distortion because of the

filtering action of the inductive part of the RLC load. This shows that the suggested unipolar SPWM technique is capable of improving the quality of the current provided to the load.

The obtained load current and RMS output voltage data confirm the correct operation of the inverter and load stability. Besides, FFT analysis showed that the voltage THD is considerable due to the switching pulses, but the current THD is decreased to 4.27%, which shows the effective harmonic suppression on the load side. The lower current distortion confirms the capabilities of the proposed inverter for improved power quality performance.

The simulation findings also reveal that the unipolar SPWM technique provides a smoother current response, fewer harmonic distortion and improved load characteristics compared to the standard inverter switching techniques. The unipolar switching technique also helps in suppressing the lower order harmonics and improves the overall quality of the inverter system. Thus, the proposed inverter structure can be assumed as suited for low and medium power applications where better harmonic performance and better current quality are required.

## 5. Conclusion

In this paper, a single phase full bridge inverter using Unipolar SPWM technology for power quality improvement applications is presented and examined. The suggested inverter system is simulated using MATLAB/Simulink and tested with RLC load. The SPWM switching pulses are generated by comparing the high frequency triangular carrier waveform with the sinusoidal reference signals. The new unipolar switching approach has created a regulated AC output voltage with better current waveform characteristics.

The simulation results show that the inverter output voltage has high frequency switching harmonics because of the PWM operation, yet the load current waveform is virtually sinusoidal due to the filtering impact of the inductive load component. The RMS output voltage and load current obtained were around 214.2 V and 3.46 A, respectively. FFT analysis was used to analyze the harmonic performance of the proposed inverter system. The measured voltage THD was 74.79 % and the current THD was decreased dramatically to 4.27 %. The lower current harmonic distortion indicates the success of the unipolar SPWM technique to improve the power quality performance on the load side.

As a whole, the designed inverter system was characterized with stable operation, better harmonic performance, and adequate capacity to convert AC power. Therefore, the suggested unipolar SPWM inverter can be considered as suited for low- and medium-power applications with better current quality and lower harmonic distortion. The introduction of output filters, closed-loop control approaches, and hardware validation are expected to improve further the inverter performance and reduce the output voltage harmonic distortion for future development.

## References

- [1] Alsokhiry, F., & Adam, G. P. (2020). Multi-port DC-DC and DC-AC converters for large-scale integration of renewable power generation. *Sustainability*, 12(20), 8440.
- [2] LV, S. K., & GV, N. K. (2017). Power conversion in renewable energy systems: A review advances in wind and PV system. *International Journal of Energy Research*, 41(2), 182-197.
- [3] Bose, B. K., & Wang, F. (2019). Energy, environment, power electronics, renewable energy systems, and smart grid. *Power Electronics in Renewable Energy Systems and Smart Grid: Technology and Applications*, 1-83.
- [4] Du, Y., Lu, D. D. C., James, G., & Cornforth, D. J. (2013). Modeling and analysis of current harmonic distortion from grid connected PV inverters under different operating conditions. *Solar Energy*, 94, 182-194.
- [5] Hamid, Muhammad Imran, and Awang Jusoh. "Reduction of waveform distortion in grid-injection current from single-phase utility interactive PV-inverter." *Energy conversion and management* 85 (2014): 212-226.
- [6] Ravindranath, Adda, Santanu K. Mishra, and Avinash Joshi. "Analysis and PWM control of switched boost inverter." *IEEE Transactions on industrial electronics* 60.12 (2012): 5593-5602.
- [7] Chen, Henglin, and Huan Zhao. "Review on pulse-width modulation strategies for common-mode voltage reduction in three-phase voltage-source inverters." *IET Power Electronics* 9.14 (2016): 2611-2620.
- [8] Hava, Ahmet M., and Emre Ün. "Performance analysis of reduced common-

- mode voltage PWM methods and comparison with standard PWM methods for three-phase voltage-source inverters." *IEEE Transactions on Power Electronics* 24.1 (2009): 241-252.
- [9] Colak, Ilhami, and Ersan Kabalci. "Developing a novel sinusoidal pulse width modulation (SPWM) technique to eliminate side band harmonics." *International Journal of Electrical Power & Energy Systems* 44.1 (2013): 861-871.
- [10] Meraj, Sheikh Tanzim, Law Kah Haw, and Ammar Masaoud. "Simplified sinusoidal pulse width modulation of cross-switched multilevel inverter." *2019 IEEE 15th International Colloquium on Signal Processing & Its Applications (CSPA)*. IEEE, 2019.
- [11] Haq, S. Syed Abdul, et al. "A sinusoidal pulse width modulation (SPWM) technique for capacitor voltage balancing of nested I-type four-level inverter." *Materials Today: Proceedings* 45 (2021): 2435-2439.
- [12] Wang, Jiaxin, et al. "Common-mode voltage reduction of modular multilevel converter based on chaotic carrier phase shifted sinusoidal pulse width modulation." *2020 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI)*. IEEE, 2020.
- [13] Sharma, Chandra Prakash, et al. "Harmonic analysis and comparison between single phase three-level pulse width modulation (PWM) inverter and sinusoidal pulse width modulation (SPWM) inverter implementing analog circuits." *2019 Second International Conference on Advanced Computational and Communication Paradigms (ICACCP)*. IEEE, 2019.
- [14] Yuditya, Banu Hermawan, et al. "Performance comparison of single-phase multilevel inverter with SPWM unipolar and bipolar switching techniques." *2020 FORTEI-International Conference on Electrical Engineering (FORTEI-ICEE)*. IEEE, 2020.
- [15] Aihсан, M. Z., et al. "Performance Analysis of Unipolar SPWM Inverter: Resistive load and Inductive load." *IOP Conference Series: Materials Science and Engineering*. Vol. 932. No. 1. IOP Publishing, 2020.
- [16] Behera, Pradyumna Kumar, Subhadip Das, and Monalisa Pattnaik. "Performance comparison between bipolar and unipolar switching scheme for a single-phase inverter based stand-alone photovoltaic system." *2019 IEEE 16th India Council International Conference (INDICON)*. IEEE, 2019.
- [17] Baburajan, Silpa, et al. "Effect of unipolar and bipolar spwm on the lifetime of dc-link capacitors in single-phase voltage source inverters." *2020 22nd European Conference on Power Electronics and Applications (EPE'20 ECCE Europe)*. IEEE, 2020.
- [18] Abella, Anderson Fabian, José D. Morcillo, and Fabiola Angulo. "Bubbling phenomenon in a unipolar SPWM inverter." *2021 IEEE 5th Colombian Conference on Automatic Control (CCAC)*. IEEE, 2021.