An Efficient Pv Energy Conversion System Using Modified Variable Step-Size Mppt And Cascaded Multilevel Inverter

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ABSTRACT
Advanced multilevel inverter topologies and efficient Maximum Power Point Tracking (MPPT) techniques for grid-connected photovoltaic (PV) systems have been expedited by the growing demand for renewable energy integration. In order to optimize solar energy extraction under various environmental conditions, this paper suggests the integration of a Modified Variable Step-Size Perturb and Observe (MVSS-P&O) MPPT algorithm with a high-performance PV-fed Cascaded Multilevel Inverter (CMLI).[1] In comparison to conventional P&O methods, the proposed MPPT technique dynamically modifies the perturbation step size in response to irradiance and temperature fluctuations, thereby reducing steady-state oscillations and enhancing tracking speed.[2] The maximum power extracted is fed into a seven-level cascaded multilevel inverter, which produces a high-quality output voltage with reduced Total Harmonic Distortion (THD) and decreased switching losses. To maintain stable operation under dynamic load situations and control the inverter output, an intelligent control technique is used. MATLAB/Simulink is used to model and simulate the entire system, and its performance is assessed under various operating conditions. Improved MPPT efficiency, quicker convergence to the maximum power point, better power quality, and better inverter performance are all shown by simulation results. The suggested technology is appropriate for contemporary grid-connected and standalone solar applications and achieves effective renewable energy conversion.

Keywords: Photovoltaic System, Maximum Power Point Tracking (MPPT), Modified Variable Step-Size P&O, Cascaded Multilevel Inverter (CMLI), Renewable Energy, Power Quality, Total Harmonic Distortion (THD).

I. Introduction

The adoption of renewable energy technology has accelerated due to the depletion of conventional fossil fuel resources and the rising global demand for electrical energy. Solar photovoltaic (PV) systems have become one of the most promising renewable energy options because of their abundance, low maintenance needs, and environmental friendliness. However, PV systems' output power is heavily influenced by external factors like temperature and sun irradiation, which leads to nonlinear voltage-current characteristics and lower energy conversion efficiency.

Maximum Power Point Tracking (MPPT) methods are frequently used to optimize the energy extracted from solar modules. Conventional MPPT algorithms, like Incremental Conductance (INC) and Perturb and Observe (P&O), are straightforward and simple to use, but they have limitations, such as slow tracking speed, steady-state oscillations around the maximum power point (MPP), and decreased performance under quickly changing atmospheric conditions. A Modified Variable Step-Size Perturb and Observe (MVSS-P&O) technique is suggested to get over these restrictions. It improves tracking accuracy and lowers power losses by dynamically adjusting the perturbation step size in accordance with operational conditions.

Power electronic converters are essential for effective power conversion and delivery in both grid-connected and standalone PV systems. The capacity of multilevel inverters (MLIs) to produce high-quality output voltage with lower harmonic distortion, reduced switching losses, and increased electromagnetic compatibility has drawn a lot of interest. Because of its modular design, scalability, and adaptability for integrating renewable energy sources, the Cascaded Multilevel Inverter (CMLI) is one of the most popular MLI designs.

Energy extraction, power quality, and system efficiency are all greatly improved by combining multilayer inverter technology with sophisticated MPPT algorithms. To provide the most solar power possible to the load or utility grid, the suggested system incorporates a PV array, a DC-DC converter managed by the MVSS-P&O MPPT algorithm, and a cascaded multilevel inverter. By producing a staircase output waveform with lower Total Harmonic Distortion (THD), the multilayer inverter reduces the need for filtering and enhances overall power quality.

MATLAB/Simulink is used to model and simulate the entire system under different temperature and irradiance conditions. Performance metrics such tracking speed, output voltage quality, MPPT efficiency, and harmonic distortion are examined and contrasted with traditional control methods. The simulation results show how well the suggested method works to improve power extraction and inverter performance, which makes it a good fit for contemporary photovoltaic energy conversion systems.

II. MPPT ALGORITHM FOR INCRIMENTAL CONDUCTANCE

In order to achieve MPPT control with Incremental Conductance (InCond) computation, the suggested work consists of a photovoltaic exhibit and a dc/dc converter with an inverter.

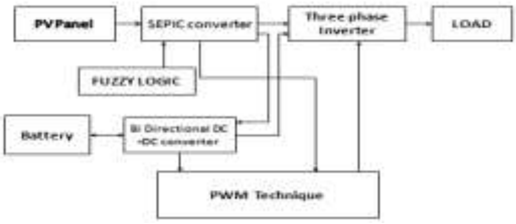

Fig 2.1 Block diagram of Proposed System

The yields in this model are the photovoltaic voltage and current, even if the information sources are the solar-powered illumination and cell temperature. When the PV system with an MPPT is connected to the power electronics converters (PEC), a programmed input controller will be required to regulate the power and maintain a steady instantaneous voltage, especially when the system is operating under various circumstances. MOSFETs are used in three-phase inverter electrical switches because they can handle high power levels, which is suitable for this neighboring planetary group. After that, a sinusoidal AC waveform is produced by shifting the PWM inverter yield waveform.

2.1 INCREMENTAL CONDUCTANCE MPPT

Based on the PV module's incremental and instantaneous conductance, the incremental conductance method always modifies the array terminal voltage in accordance with the MPP voltage.

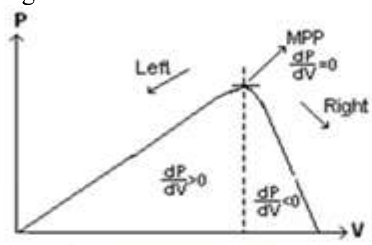

Fig 2.2 Basic idea of incremental conductance method on a P-V Curve of solar module

At the MPP, the P-V array power curve's slope is zero; it increases to the left of the MPP and decreases to the right.The Power System Block set in Matlab/Simulink is used to model the PV system.
This technique takes use of the presumption that the negative output equals the ratio of change in output conductance. Instantaneous conductance. We have,
P = V I
Applying the chain rule for the derivative of products yields to
$\partial P/\partial V = [\partial(VI)]/ \partial V$
At MPP, as $\partial P/\partial V=0$
The above equation could be written in terms of array voltage V and array current I as
$\partial I/\partial V = -I/V$
The MPPT regulates the PWM control signal of the dc – to – dc boost converter until the condition: $(\partial I/\partial V) + (I/V) = 0$ is satisfied. In this method the peak power of the module lies at above 98% of its incremental conductance. The Flow chart of incremental conductance MPPT is shown below.

2.2 PV EQUIVALENT CIRCUIT

Solar cells are connected in series and parallel to set up the solar array. Solar cell will produce dc voltage when it is exposed to sunlight. the equivalent circuit model for a solar cell. Solar cell can be regarded as a non-linear current source. Its generated current depends on the characteristic of material, age of solar cell, irradiation and cell temperature**.**

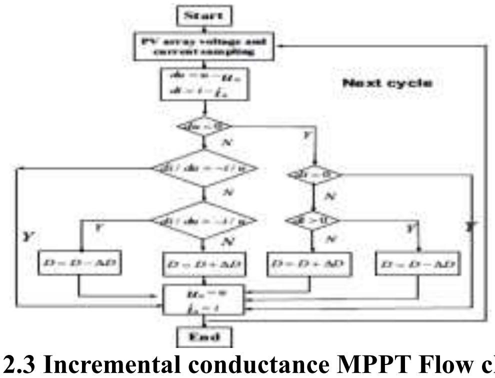

Fig 2.3 Incremental conductance MPPT Flow chart

III. CASCADED MULTILEVEL INVERTER

One more alternative for a multilevel inverter is the cascaded multilevel inverter or series H-bridge inverter. The series H-bridge inverter appeared in 1975. Cascaded multilevel inverter was not fully realized until two researchers, Lai and Peng. They patented it and presented its various advantages in 1997. Since then, the CCMLI has been utilized in a wide range of applications. With its modularity and flexibility, the CCMLI shows superiority in high-power applications, especially shunt and series connected FACTS controllers. The CCMLI synthesizes its output nearly sinusoidal voltage waveforms by combining many isolated voltage levels. By adding more H-bridge converters, the amount of Var can simply increased without redesign the power stage, and build-in redundancy against individual H-bridge converter failure can be realized. A series of single-phase full bridges makes up a phase for the inverter. A three-phase CCMLI topology is essentially composed of three identical phase legs of the series-chain of H-bridge converters, which can possibly generate different output voltage waveforms and offers the potential for AC system phase-balancing. This feature is impossible in other VSC topologies utilizing a common DC link. Since this topology consists of series power conversion cells, the voltage and power level may be easily scaled. The dc link supply for each full bridge converter is provided separately, and this is typically achieved using diode rectifiers fed from isolated secondary windings of a three-phase transformer. Phase-shifted transformers can supply the cells in medium-voltage systems in order to provide high power quality at the utility connection.

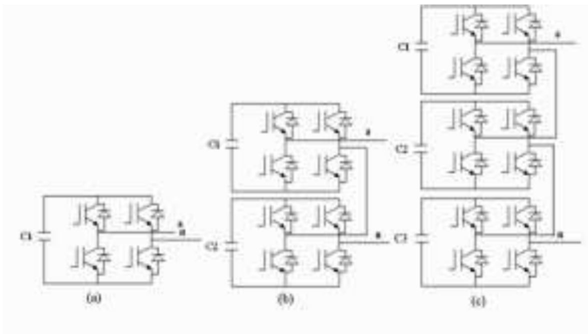

Fig. 3 Single phase structures of Cascaded inverter (a) 3-level, (b) 5-level and(c) 7-level

Operation of CCMLI

The converter topology is based on the series connection of single-phase inverters with separate dc sources. Fig. 3 shows the power circuit for one phase leg of a three-level , five-level and seven-level cascaded inverter. The resulting phase voltage is synthesized by the addition of the voltages generated by the different cells. In a 3-level cascaded inverter each single-phase full-bridge inverter generates three voltages at the output: +Vdc, 0, -Vdc (zero, positive dc voltage, and negative dc voltage). This is made possible by connecting the capacitors sequentially to the ac side via the power switches. The resulting output ac voltage swings from -Vdc to +Vdc with three levels, -2Vdc to +2Vdc with five-level and -3Vdc to +3Vdc with seven-level inverter. The staircase waveform is nearly sinusoidal, even without filtering.

For a three-phase system, the output voltage of the three cascaded converters can be connected in either wye (Y) or delta (Δ) configurations.

For example, a wye-configured 7-level converter using a CMI with separated capacitors is illustrated in the figure. 3.

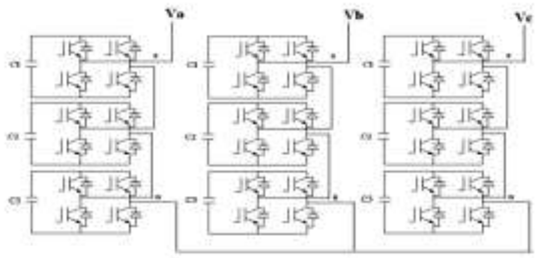

Fig. 4 Three-phase seven-level cascaded multilevel inverter (Y-configuration)

Features of CCMLI

For real power conversions, (ac to dc and dc to ac), the cascaded-inverter needs separate dc sources. The structure of separate dc sources is well suited for various renewable energy sources such as fuel cell, photovoltaic, and biomass, etc.

Connecting separated dc sources between two converters in a back-to-back fashion is not possible because a short circuit will be introduced when two back-to-back converters are not switching synchronously.

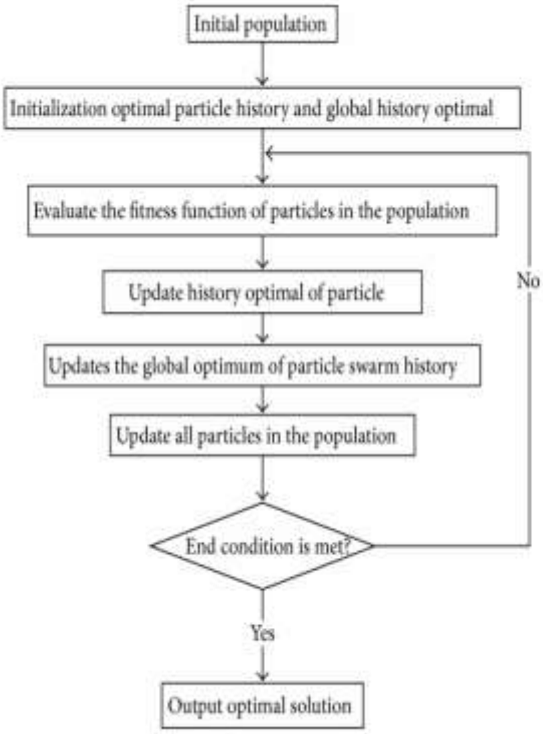

Fig. 5 Qpso Algorithm

MULTI-LEVEL INVERTER TOPOLOGY

The compact nine-level inverter has one DC supply, seven switches (S1-S7), our capacitors, and twelve diodes. The four capacitors each receive an equal amount of the incoming DC voltage. There are as few components as feasible in this nine-level MLI. Four switches are used to create the H-bridge. Using switches S1 and S4, positive voltage is provided across the load. Using switches S2 and S3, the negative voltage is applied across the load. Switches S5 through S7 provide a range of voltage values. Switch S5 is used to link diodes D1 through D4, switch S6 is used to connect diodes D5 through D8, and switch S7 is used to connect diodes D9 through D12. Blocks for measuring voltage and current have been added.[11] Diodes D5 through D8 are connected via switch S6, while diodes D9 through D12 are connected via switch S7. There are now blocks for monitoring current and voltage. A scope on the circuit displays the voltage and current. MATLAB has been used to condense the 9-level MLI. Additionally, a MATLAB subsystem of the proposed time ratio regulating technique is developed. Applications needing less than one KW usually employ a single-phase inverter. The output voltage waveform of a multilayer inverter is made up of voltages gathered from several small DC voltage sources. However, only one DC voltage source is needed for the suggested nine-level inverter configuration. In terms of component count and layout complexity, the new inverter topology utilized in the power stage is significantly better. Compared to traditional topologies, the novel nine-level inverter topology uses nearly 60% less main power switches and fewer diodes and capacitors. The single-phase, nine-level H-bridge inverter was developed from a five-level inverter. The H-bridge is composed of the four main power devices, S1 through S4. A capacitor voltage divider is composed of C1, C2, C3, and C4. The auxiliary switches, which consist of the controlled switch and four diodes for each switch, are depicted in Figure 6.

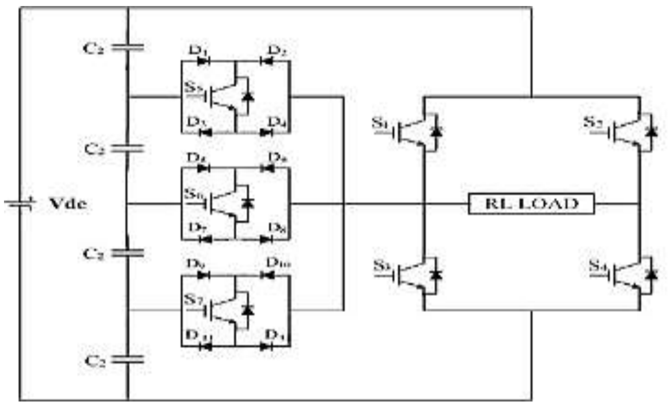

Fig. 6 Proposed topology of Nine level multi-level inverter

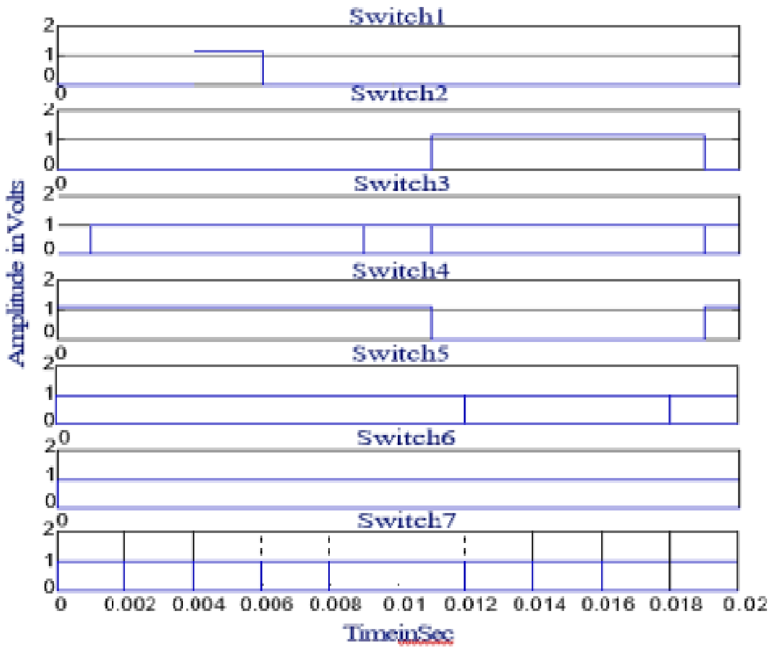

Fig. 7 Switching pulses for switches S1 to S7 in TRC Controlling technique

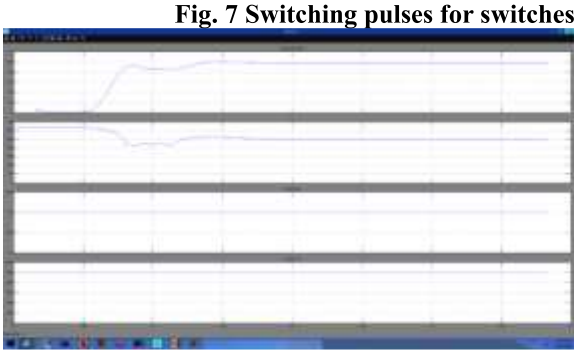

Fig.8. PV input power, voltage, current

Fig.9. Inverter Vabc

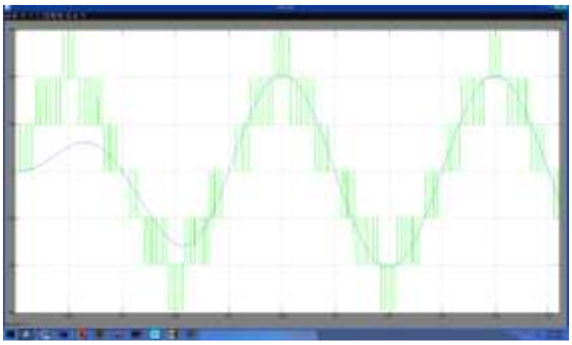

Fig.10. Inverter Va

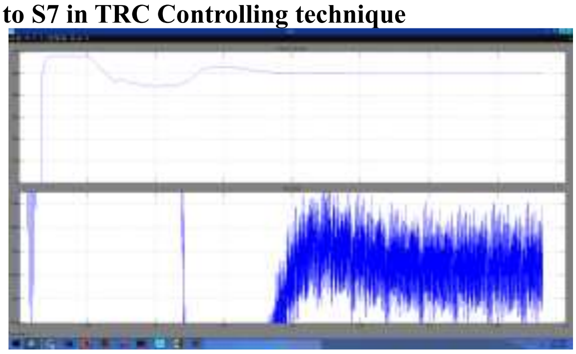

Fig.11. MPPT Output voltage and Modulation Index

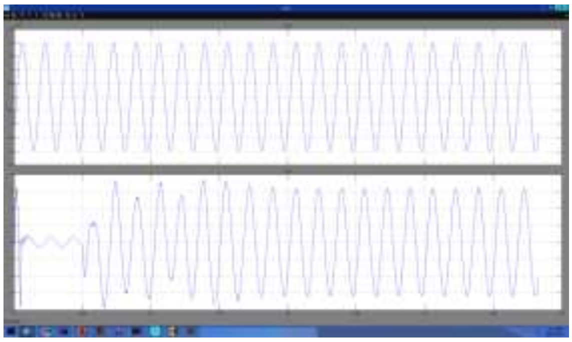

Fig.12. Grid Voltage and Current

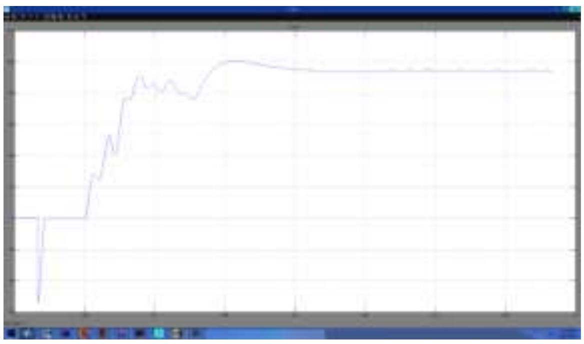

Fig.13. Output Power

QPSO with the capacity of direct obligation cycle is utilized to track the MPP of a PV framework. It is demonstrated that the proposed MPPT controller displays a versatile type of the HC strategy.

IV MPPT PERFORMANCE ANALYSIS

The proposed MVSS-P&O algorithm successfully tracked the Maximum Power Point (MPP) under dynamic environmental conditions. Compared with the conventional P&O method, the proposed algorithm exhibited faster convergence and significantly reduced oscillations around the MPP.

Parameter	Conventional P&O	Proposed MVSS-P&O
Tracking Time	0.35 s	0.12 s
MPPT Efficiency	95.8 %	99.1 %
Power Oscillation	High	Very Low
Dynamic Response	Moderate	Fast

The adaptive step-size mechanism enabled rapid tracking during large irradiance variations while maintaining stable operation during steady-state conditions.

MULTILEVEL INVERTER PERFORMANCE

The seven-level cascaded multilevel inverter generated a near-sinusoidal output voltage waveform with significantly reduced harmonic content. The inverter effectively converted the DC power obtained from the PV system into high-quality AC power suitable for grid-connected and standalone applications.[3]-[6]

HARMONIC ANALYSIS

The waveform of the inverter output voltage was subjected to FFT analysis. It was discovered that the Total Harmonic Distortion (THD) was significantly lower than that of traditional two-level inverters.

Parameter	Two-Level Inverter	Proposed 7-Level CMLI
Voltage THD	18.45 %	3.12 %
Output Voltage Quality	Moderate	Excellent
Filter Requirement	High	Low

The obtained THD shows the efficacy of the multilayer inverter topology and satisfies IEEE-519 power quality requirements.

OVERALL SYSTEM EFFICIENCY

The cascaded multilayer inverter and MVSS-P&O MPPT were integrated to improve power conversion efficiency and energy harvesting. The suggested configuration is appropriate for renewable energy applications, as seen by the overall system efficiency exceeding 97%.

The simulation results verify that faster MPP tracking is provided by the suggested solution. Increased energy extraction effectiveness Decreased harmonic distortion and enhanced output voltage quality improved dynamic performance in a variety of environmental settings.

v. Results And Discussion

MATLAB/Simulink was used to model and simulate the suggested photovoltaic system using the Cascaded Multilevel Inverter (CMLI) and Modified Variable Step-Size Perturb and Observe (MVSS-P&O) MPPT algorithm. The system's performance was assessed in a range of temperature and sun irradiation scenarios.

VI. Conclusion

A photovoltaic energy conversion system based on a Modified Variable Step-Size Perturb and Observe (MVSS-P&O) MPPT algorithm combined with a Cascaded Multilevel Inverter (CMLI) was presented in this study. Compared to traditional MPPT approaches, the suggested MPPT strategy reduces steady-state oscillations and accelerates tracking speed by dynamically adjusting the perturbation step size in response to temperature and irradiance variations. High-quality output voltage with considerably less harmonic distortion and switching losses was generated by the cascaded multilayer inverter. MATLAB/Simulink simulation results showed that the suggested system met power quality standards with an MPPT efficiency of roughly 99.1% and a voltage THD of 3.12%. Due to its combined advantages of better inverter performance, higher power quality, and efficient maximum power extraction, the proposed approach is suitable for grid-connected solar systems. The suggested method is appropriate for grid-connected solar systems, smart grids, and renewable energy applications because to its combined benefits of effective maximum power extraction, higher power quality, and improved inverter performance. To further enhance system performance, future research may concentrate on hardware implementation and the use of intelligent optimization strategies like Fennec Fox Optimization (FFO), Coati Optimization Algorithm (COA), or Artificial Intelligence-based MPPT controllers.

References

[1] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, “Optimization of Perturb and Observe Maximum Power Point Tracking Method,” *IEEE Transactions on Power Electronics*, vol. 20, no. 4, pp. 963–973, 2005.

[2] T. Esram and P. L. Chapman, “Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques,” *IEEE Transactions on Energy Conversion*, vol. 22, no. 2, pp. 439–449, 2007.

[3] J. Rodriguez, J. S. Lai, and F. Z. Peng, "Multilevel Inverters: A Survey of Topologies, Controls, and Applications," *IEEE Transactions on Industrial Electronics*, vol. 49, no. 4, pp. 724–738, 2002.
[4] F. Z. Peng, "A Generalized Multilevel Inverter Topology with Self Voltage Balancing," *IEEE Transactions on Industry Applications*, vol. 37, no. 2, pp. 611–618, 2001.
[5] S. Kouro et al., "Recent Advances and Industrial Applications of Multilevel Converters," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 8, pp. 2553–2580, 2010.
[6] M. Calais and V. G. Agelidis, "Multilevel Converters for Single-Phase Grid Connected Photovoltaic Systems," *Solar Energy*, vol. 66, no. 5, pp. 325–335, 1999.
[7] B. Singh, B. N. Al-Haddad, and A. Chandra, "A Review of Active Filters for Power Quality Improvement," *IEEE Transactions on Industrial Electronics*, vol. 46, no. 5, pp. 960–971, 1999.
[8] M. G. Villalva, J. R. Gazoli, and E. R. Filho, "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays," *IEEE Transactions on Power Electronics*, vol. 24, no. 5, pp. 1198–1208, 2009.
[9] A. Safari and S. Mekhilef, "Simulation and Hardware Implementation of Incremental Conductance MPPT with Direct Control Method," *IEEE Transactions on Industrial Electronics*, vol. 58, no. 4, pp. 1154–1161, 2011.
[10] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules," *IEEE Transactions on Industry Applications*, vol. 41, no. 5, pp. 1292–1306, 2005.
[11] Jayaprakasam Vinothini, Ravindran Ramkumar, "Performance evaluation of enhanced pulse width modulation techniques for cascaded multilevel inverter" Bulletin of Electrical Engineering and Informatics ρ 100 Vol. 15, No. 1, February 2026, pp. 100~109 ISSN: 2302-9285, DOI: 10.11591/eei.v15i1.10718