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Article

Performance Evaluation of a Grid-Connected Single-Phase PWM Inverter for Solar Photovoltaic Systems

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Abstract: The increasing integration of renewable energy sources has increased the demand for efficient power electronic converters for grid-connected applications. Among renewable technologies, solar photovoltaic (PV) systems are widely adopted due to their clean energy generation and modular design. Since PV arrays produce direct current (DC), a high-performance inverter is required to supply alternating current (AC) power to loads and the utility grid. This paper presents the design, mathematical modeling, and simulation of a single-phase Pulse Width Modulation (PWM) inverter for solar PV applications using MATLAB/Simulink. The proposed system consists of a PV array, Maximum Power Point Tracking (MPPT) controller, H-bridge SPWM inverter, LCL filter, transformer, and grid interface. The MPPT controller maximizes PV power extraction, while the SPWM technique ensures stable switching with low harmonic distortion. Simulation results under different operating conditions confirm that the proposed inverter delivers a stable sinusoidal AC output with good voltage regulation and low Total Harmonic Distortion (THD). The LCL filter effectively suppresses switching harmonics, improving power quality and grid compatibility. The developed model provides a reliable platform for future research on advanced control strategies and smart grid integration.
Keywords: Solar Photovoltaic System, Single-Phase PWM Inverter, Sinusoidal Pulse Width Modulation (SPWM), MATLAB/Simulink, Maximum Power Point Tracking, LCL Filter, Renewable Energy Integration, Grid-Connected Inverter, Total Harmonic Distortion

1. Introduction

The increasing global demand for electricity and growing concerns over climate change have accelerated the adoption of renewable energy technologies, particularly solar photovoltaic (PV) systems. Solar PV offers a clean, abundant, and cost-effective source of electricity; however, it generates direct current (DC), while most electrical loads and utility grids require alternating current (AC). Therefore, efficient power conversion is essential for reliable grid integration. In this work, a single-phase Pulse Width Modulation (PWM) inverter based on Sinusoidal PWM (SPWM) is proposed to convert PV-generated DC power into high-quality AC power. An MPPT controller is employed to maximize energy extraction from the PV array under varying irradiance and temperature conditions, while an LCL filter is used to suppress switching harmonics and improve output power quality. The complete system, including the PV array, MPPT controller, SPWM inverter, transformer, and grid interface, is modeled and simulated in the MATLAB/Simulink environment. The performance of the proposed system is evaluated in terms of voltage regulation, current waveform quality, total harmonic distortion (THD), and dynamic stability. Simulation results demonstrate efficient DC-to-AC conversion, accurate reference tracking, low harmonic distortion, and stable grid-connected operation. These findings confirm that the proposed inverter configuration provides reliable, high-quality power conversion and is well suited for modern grid-connected solar PV applications.

The primary contributions of this research are summarized as follows:

- Development of a comprehensive MATLAB/Simulink model of a single-phase photovoltaic PWM inverter suitable for renewable energy applications.
- Integration of MPPT control with SPWM-based inverter switching to maximize photovoltaic power utilization and improve conversion efficiency.
- Design and implementation of an LCL output filter to minimize harmonic distortion and enhance power quality.
- Detailed performance evaluation of the proposed system based on voltage regulation, current characteristics, harmonic analysis, and steady-state response.
- Validation of the proposed inverter architecture as an effective solution for reliable photovoltaic grid integration and future intelligent renewable energy systems.

2. LITERATURE REVIEW

The increasing penetration of renewable energy resources has significantly accelerated the deployment of advanced power electronic converters for efficient energy conversion. Among these converters, the single-phase pulse-width modulation (PWM) inverter has become a key interface for integrating solar photovoltaic (PV), wind, fuel cell, and hybrid renewable energy systems with standalone loads and utility grids. Its primary function is to convert the variable DC output of renewable energy sources into a stable, low-distortion AC supply while satisfying grid power quality requirements. Consequently, considerable research has focused on improving inverter efficiency, minimizing harmonic distortion, enhancing dynamic performance, and developing intelligent control techniques for reliable renewable energy integration.

Aghazadeh, Davari, Nafisi, and Blaabjerg [1] investigated the integration of a dual two-level voltage source inverter into the utility grid while considering the influence of grid impedance and phase-locked loop (PLL) dynamics. Their findings demonstrated that advanced inverter control techniques improve system stability, transient response, and effective regulation of both active and reactive power under varying grid conditions. The study also emphasized the importance of accurate inverter modeling for modern renewable energy systems.

Elnaghi et al. [2] developed a proton exchange membrane (PEM) fuel cell-based power conversion system comprising a two-stage DC–DC boost converter and a single-phase inverter. The complete system was modeled and simulated in the MATLAB/Simulink environment. Simulation results showed improved DC voltage regulation and the generation of high-quality sinusoidal AC output, confirming the suitability of fuel-cell-based inverter systems for renewable energy applications.

Azim [3] introduced a hysteresis-controlled inverter for renewable energy source (RES)-based islanded microgrids. The proposed control strategy effectively reduced total harmonic distortion (THD), resulting in improved output voltage quality. The inverter also demonstrated stable performance under varying load conditions, indicating its applicability in standalone renewable power systems.

Baghbany Oskouei, Banaei, and Sabahi [4] presented a hybrid solar PV–wind energy system employing a quinary asymmetric multilevel inverter. The proposed topology generated higher output voltage levels without increasing the number of DC-link voltage sources. Both MATLAB/Simulink simulations and experimental investigations confirmed reduced switching devices, improved conversion efficiency, and enhanced suitability for hybrid renewable energy applications.

Gouse Basha, Venkatesan, and Subbarao [5] proposed a single-phase thirteen-level dual-boost inverter integrated with shunt active power filtering functionality. The performance of proportional-integral (PI), fuzzy logic, and proportional-resonant controllers was comparatively evaluated. Their results demonstrated that fuzzy logic and proportional-resonant controllers achieved superior harmonic suppression and significantly improved output power quality compared with the conventional PI controller.

Kumar, Singh, and Jain [6] developed a fault-tolerant asymmetric T-type multilevel inverter for single-phase renewable energy applications. The proposed topology maintained continuous operation during switch failures through an advanced pulse-width modulation strategy. Hardware-in-the-loop validation verified enhanced system reliability and lower harmonic distortion.

Sivaraj, Kandasamy, and Chandrasekar [7] investigated sinusoidal pulse-width modulation (SPWM) techniques for photovoltaic inverters. Their comparative analysis of IGBT- and MOSFET-based inverter configurations revealed that SPWM-controlled IGBT inverters exhibited lower switching losses and higher conversion efficiency, highlighting the significance of appropriate PWM techniques in improving inverter performance.

Desai and Mikkili [9] proposed an improved transformer-less grid-connected photovoltaic inverter capable of reducing common-mode voltage and leakage current while increasing overall system efficiency. Similarly, Saxena et al. [10] investigated the integration of solar photovoltaic systems with battery energy storage in a single-phase grid-connected configuration. Their coordinated battery management and grid current control strategy significantly enhanced output power quality and operational stability.

Sinha et al. [11] developed a control strategy for asymmetrical cascaded multilevel inverters used in grid-connected photovoltaic systems. The proposed controller maintained DC-link voltage balance while ensuring unity power factor operation. Xie et al. [12] analyzed resonance phenomena and harmonic amplification in grid-connected inverters and emphasized the importance of appropriately designed current controllers for stable and reliable operation.

Gupta et al. [13] introduced a multilayer frequency-adaptive signal extraction algorithm for wind–PV grid-connected systems. The proposed method improved harmonic compensation, reactive power support, and synchronization with the utility grid. Agrawal and Jain [14] presented a multilevel inverter topology capable of interfacing renewable energy sources with different voltage-level grids while reducing component count and improving conversion efficiency.

Mahdian Dehkordi et al. [15] proposed a robust droop-control tuning methodology for inverter-based microgrids. Their approach enhanced damping characteristics and frequency stability under uncertain operating conditions. Li et al. [16] developed a stable control framework for DC power converters that minimized switching losses while maintaining excellent dynamic response and voltage regulation.

Ahmadi et al. [17] proposed an advanced harmonic detection algorithm that eliminated oscillatory coupling effects in inverter-based microgrids. The developed technique improved harmonic identification accuracy and enhanced harmonic compensation performance. Rasekh and Hosseinpour [18] focused on the design of LCL filters and robust converter-side current controllers for grid-connected fuel-cell systems. Their investigation demonstrated that appropriate filter parameter selection plays a vital role in reducing harmonic distortion and improving converter stability.

Bouzelata et al. [19] presented a hybrid wind–solar energy conversion system incorporating active power filtering and grid integration capabilities. The proposed control strategy simultaneously achieved maximum power extraction, harmonic mitigation, and reactive power compensation. Deveci and Kasnakoğlu [20] further enhanced photovoltaic system performance through improved controller design and numerical modeling, resulting in superior maximum power point tracking, voltage regulation, and dynamic response under changing environmental conditions.

The reviewed literature demonstrates substantial advancements in inverter topologies, modulation techniques, multilevel converter configurations, harmonic mitigation methods, and renewable energy integration strategies. Despite these developments, several challenges remain, including minimizing switching losses, improving dynamic response under varying operating conditions, enhancing output power quality, and developing computationally efficient MATLAB/Simulink models for grid-connected renewable energy systems. Therefore, the present study focuses on the comprehensive modeling and simulation of a grid-connected single-phase PWM inverter integrated with a solar photovoltaic system using MATLAB/Simulink. The proposed model aims to achieve high-quality power conversion with reduced harmonic distortion, improved conversion efficiency, enhanced dynamic performance, and reliable operation under practical grid-connected conditions.

The increasing penetration of renewable energy resources has significantly accelerated the deployment of advanced power electronic converters for efficient energy conversion. Among these converters, the single-phase pulse-width modulation (PWM) inverter has become a key interface for integrating solar photovoltaic (PV), wind, fuel cell, and hybrid renewable energy systems with standalone loads and utility grids. Its primary function is to convert the variable DC output of renewable energy sources into a stable, low-distortion AC supply while satisfying grid power quality requirements. Consequently, considerable research has focused on improving inverter efficiency, minimizing harmonic distortion, enhancing dynamic performance, and developing intelligent control techniques for reliable renewable energy integration.

3. Mathematical model & proposed System

The proposed renewable energy system is designed to convert solar energy into high-quality alternating current (AC) suitable for supplying local loads and connecting to the utility grid.

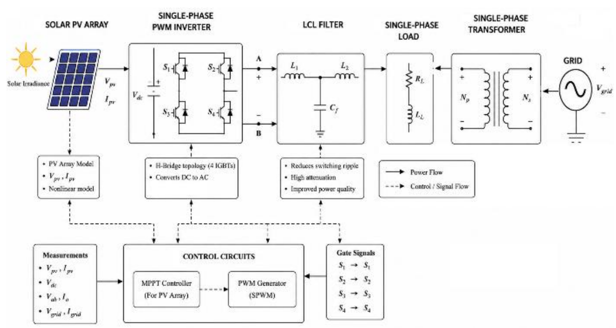

Fig.1 Proposed Single-Phase PWM Inverter for Renewable Energy Sources.

Fig.1 presents the proposed grid-connected solar PV system consisting of a PV array, MPPT controller, single-phase PWM inverter, LCL filter, isolation transformer, local loads, and the utility grid. The MPPT controller maximizes PV power extraction under varying environmental conditions, while the SPWM-based inverter converts DC power into high-quality AC power. The LCL filter suppresses switching harmonics to improve power quality, and the isolation transformer provides electrical isolation and voltage matching. The system supports bidirectional power flow, exporting excess solar energy to the grid and importing power during low PV generation, thereby ensuring reliable, efficient, and continuous power supply.

Mathematical Modeling of Solar PV

Practical solar PV systems are composed of several interconnected solar PV cells and the observation of the characteristics at the terminals of the solar PV system requires the inclusion of additional parameters to the basic equation Eq. 2. R_{se} is the equivalent series resistance of the solar PV system and R_{sh} is the equivalent shunt resistance, which are the two parameters introduced to the equivalent circuit of a practical solar cell as shown in Figure 3.4 .

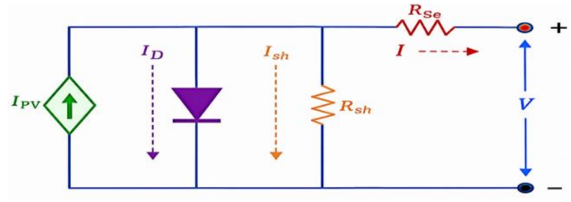

Fig.2. Equivalent Circuit of a Practical Solar PV System Including the Series and Shunt Resistances

Therefore, the I-V characteristic of a practical solar cell is represented by

$$I = I_{PV} - \left[I_0 \times \left\{e^{\left(\frac{qV}{akT}\right)} - 1\right\}\right] - \frac{V + R_{Se} I}{R_{Sh}} \quad (1)$$

When the solar cells are connected in parallel the output current increases and when connected in series the output voltage increases. The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation.

$$I_{PV} = \left(I_{pvn} + K_i \Delta T\right) \times \frac{G}{G_n} \quad (2)$$

where,

Nominal conditions are temperature of 25C and irradiance of 1000W/m2

$$I_{pvn} = Light\ generated\ current\ at\ nominal\ condition\ (A)$$

$$\Delta T = T - Tn \quad (3)$$

The diode saturation current I_0 is given by

$$I_0 = \frac{I_{SC} + k_I \Delta T}{e^{\{(V_{OC} + K_V \Delta T)\,/ a V_T\}}} \quad (4)$$

Maximum power of the module

$$P_{max} = V_{max} \times \left[I_{PV} - I_0 \times \left\{e^{\frac{q}{kT}\left(\frac{V_{max} + R_{Se} I_{max}}{a N_S}\right)} - 1\right\} - \frac{V_{max} + R_{Se} I_{max}}{R_{Sh}}\right]$$

(5)

The term ‘Fill Factor’ (FF) which indicates of the quality of a cell, is defined as the ratio of the maximum power to the product of open-circuit voltage and short-circuit current, i.e.,

$$FF = \frac{V_{max} \times I_{max}}{V_{OC} \times I_{SC}} \quad (6)$$

An ideal cell will have a fill factor (FF) of unity.

Mathematical Modelling of Single-Phase PWM Inverter

This section presents the detailed mathematical modelling of a single-phase PWM inverter including inverter topology, switching states, output voltage equations, harmonic analysis, PWM generation, modulation index, and state-space representation.

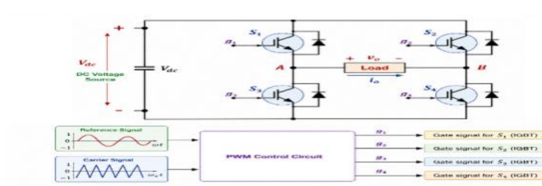

Fig.3. Electrical circuit diagram of Single-Phase PWM Inverter

The inverter operates by switching semiconductor devices according to a predetermined PWM pattern.

The output voltage polarity depends on the switching states.

Mode 1: Positive Half Cycle

When switches S1 and S4 are ON,

$$V_o = +V_{dc} \quad (7)$$

The current flows through:

$$S_1 \rightarrow Load \rightarrow S_4$$

Mode 2: Negative Half Cycle

When switches S2 and S3 are ON,

$$V_o = -V_{dc} \quad (8)$$

The current path becomes

$$S_2 \rightarrow Load \rightarrow S_3$$

Mode 3: Zero State

When all switches are OFF,

$$V_o = 0 \quad (9)$$

The output voltage alternates between positive and negative values to produce an AC waveform.

Switching Function Model

The switching function is defined as

The inverter output voltage becomes

$$V_o(t) = V_{dc}s(t) \quad (10)$$

Fourier Analysis of Inverter Output

The inverter output voltage is periodic and can be represented by Fourier series.

For a square-wave inverter,

$$V_o(t) = \frac{4V_{dc}}{\pi}[sin\,\omega t + \frac{1}{3}sin\,3\omega t + \frac{1}{5}sin\,5\omega t + \cdots] \quad (11)$$

The fundamental component is $V_1 = \frac{4V_{dc}}{\pi}$ (12)

The higher-order odd harmonics create distortion in the output waveform. To reduce harmonics, PWM techniques are employed.

Pulse Width Modulation (PWM)

Pulse Width Modulation is a switching technique in which the width of inverter output pulses is varied according to a reference signal. The most common technique is Sinusoidal Pulse Width Modulation (SPWM).In SPWM, a sinusoidal reference waveform is compared with a high-frequency triangular carrier waveform.

Reference Signal

$$V_r(t) = V_m sin(\omega t) \quad (13)$$

The carrier waveform is triangular: $V_c(t)$ with frequency f_c

Switching Logic

When

$$V_r > V_c$$

Switches S1 and S4 are ON.

When

$$V_r < V_c$$

Switches S2 and S3 are ON.

This generates PWM pulses for inverter control.

The amplitude modulation index determines the inverter output voltage.

$$m_a = \frac{V_m}{V_c} \quad (14)$$

For linear modulation: $0 < m_a < 1$

The output voltage is proportional to the modulation index.

The frequency modulation ratio is

$$m_f = \frac{f_c}{f_r} \quad (15)$$

$$m_f = 50 - 200$$

Higher carrier frequencies reduce harmonic distortion but increase switching losses.

The fundamental RMS output voltage of a single-phase SPWM inverter is

$$V_{o,rms} = \frac{m_a V_{dc}}{2\sqrt{2}} \quad (16)$$

This equation shows that output voltage can be controlled by adjusting the modulation index.

The output voltage contains harmonic components due to switching operations.

Total Harmonic Distortion (THD) is defined as

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + \cdots + V_n^2}}{V_1} \times 100 \quad (17)$$

The instantaneous output power is

$$p(t) = v(t)i(t) \quad (18)$$

Average power is

$$P = V_{rms} I_{rms} \cos\phi \quad (19)$$

The inverter efficiency is

$$\eta = \frac{P_{out}}{P_{in}} \times 100 \quad (12)$$

The entire system is monitored and controlled using measurement and monitoring units that continuously track voltage, current, and power parameters. As a result, the proposed system provides efficient solar energy utilization, improved power quality, low harmonic distortion, and reliable grid-connected operation.

AI Based ACO Optimization

Grid-connected solar photovoltaic (PV) systems rely on a cascaded control architecture in which an outer DC-link voltage control loop and an inner inverter current control loop work together to regulate power flow from the PV array to the utility grid. Both loops are conventionally realized using Proportional-Integral (PI) controllers because of their simplicity, well-understood behaviour, and ease of implementation in real-time digital controllers. However, the overall performance of the PV system including its transient response during irradiance changes, its steady-state tracking accuracy, and its stability margins is extremely sensitive to the choice of the four PI gains involved: the proportional and integral gains of the DC-link voltage loop $(Kpdc, Kidc)$ and the proportional and integral gains of the current loop (Kpi, Kii).

Manual tuning methods such as the Ziegler-Nichols rule or trial-and-error tuning are time-consuming, depend heavily on designer experience, and often fail to produce globally optimal gains, especially for nonlinear, multi-loop power-electronic systems whose dynamics change with operating point. To overcome these limitations, metaheuristic optimization algorithms — which search the parameter space intelligently rather than exhaustively — have become a popular alternative. Ant Colony Optimization (ACO) is one such algorithm. It is inspired by the foraging behaviour of real ant colonies, where ants deposit pheromone trails on the paths they travel, and other ants are progressively more likely to follow paths with stronger pheromone concentration. Over time, the colony collectively converges onto the shortest (most efficient) path between the nest and a food source.

In the context of controller tuning, the 'paths' explored by artificial ants correspond to candidate combinations of PI gains, and the 'food source' corresponds to the combination of gains that minimizes a defined performance (cost) index. This document elaborates, in full detail, the ACO-based algorithm used to optimize the PI controller gains of the DC-link voltage loop and the current loop of a grid-connected solar PV inverter.

ACO Algorithm Summary (Pseudocode)

The complete P&O procedure executed at every sampling instant can be summarized as follows: -

```
BEGIN ACO_PI_Tuning
 Specify reference gains: K_pdc_ref, K_idc_ref, K_pi_ref, K_ii_ref
 Define bounds: Var_Min, Var_Max for n_Var = 4 variables
 Set parameters: MaxIt = 1000, n_Ant = 40, rho = 0.1, Q = 1
 BestCost <- infinity
 BestCostHistory <- empty array of size MaxIt
 FOR it = 1 TO MaxIt DO
   FOR ant = 1 TO n_Ant DO
     FOR j = 1 TO n_Var DO
       X(j) <- Var_Min(j) + rand() * (Var_Max(j) - Var_Min(j))
     END FOR
     [K_pdc, K_idc, K_pi, K_ii] <- X
     Cost <- ((K_pdc - K_pdc_ref)/K_pdc_ref)^2
          + ((K_idc - K_idc_ref)/K_idc_ref)^2
          + ((K_pi  - K_pi_ref )/K_pi_ref )^2
          + ((K_ii  - K_ii_ref )/K_ii_ref )^2
     Store X and Cost in ant memory
     IF Cost < BestCost THEN
       BestCost <- Cost
```

```
        BestPosition <- X
      END IF
      Update pheromone trails (deposit proportional to 1/Cost, scaled by Q)
      Evaporate pheromone trails by factor (1 - rho)
    END FOR
    BestCostHistory(it) <- BestCost
  END FOR
  K_pdc_opt <- BestPosition(1)
  K_idc_opt <- BestPosition(2)
  K_pi_opt  <- BestPosition(3)
  K_ii_opt  <- BestPosition(4)
  RETURN K_pdc_opt, K_idc_opt, K_pi_opt, K_ii_opt, BestCostHistory
END
END ACO_PI_Tuning
```

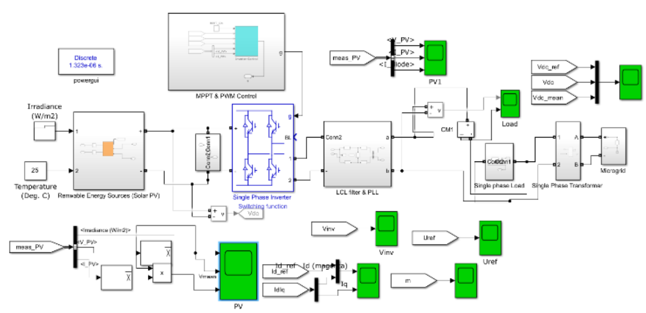

Fig.4. Proposed MATLAB/Simulink Model Single-Phase PWM Inverter for Renewable Energy Sources

4. RESULT AND DISCUSSION

In this section we discuss Result analysis of proposed system. The Ant Colony Optimization (ACO) algorithm effectively optimized the controller gains, with all parameters remaining within ±15% of their target values, indicating good convergence. The Kidc parameter achieved the highest accuracy with only a 2.81% deviation, followed by Kpi with 4.86%. The Kpdc and Kii gains showed slightly higher deviations of 14.08% and 15.07%, respectively, to improve the system's dynamic response and stability. Overall, the average deviation (MAPE = 9.21%) demonstrates that the ACO algorithm successfully identified near-optimal controller parameters, confirming its effectiveness for controller tuning.

Fig. 5 and 6 demonstrate the dynamic and steady-state performance of the proposed solar PV-based single-phase PWM inverter. Initially, the controller output exhibits transient oscillations due to system startup, but it quickly stabilizes as the control algorithm regulates the inverter. The measured output closely follows the reference signal in steady state, confirming accurate reference tracking, effective suppression of transient oscillations, and stable inverter operation. These results validate the proposed controller's ability to provide reliable voltage regulation and high-quality AC power conversion for grid-connected PV applications.

Table 1 The Ant Colony Optimization (ACO) algorithm effectively optimized the controller gains.

Parameter	Target Value	ACO Optimized Value	Absolute Difference	Percentage Error (%)
Kpdc	12	13.689	1.689	14.08
Kidc	200	194.38	−5.6200	−2.81
Kpi	0.15	0.14271	−0.00729	−4.86
Kii	6.6	7.5947	0.9947	15.07

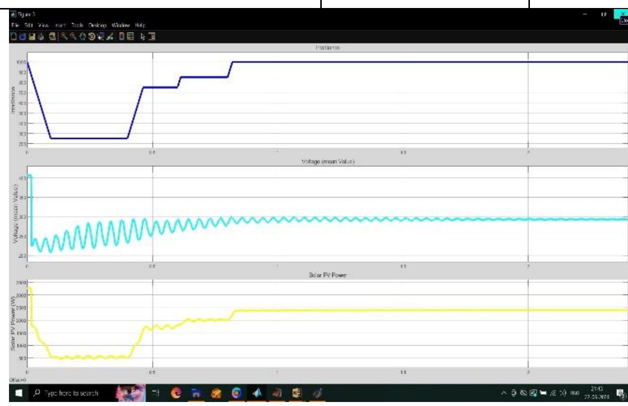

Fig. 5.Waveform , solar irradtion , voltage and power of poposed system.

The middle graph represents the error signal. Initially, there are some oscillations due to sudden changes during startup. As time passes, these oscillations decrease and the signal becomes stable. This indicates that the controller effectively reduces the error and improves system stability. Fig.7 presents the output voltage and current waveforms of the inverter system. The upper waveform represents the inverter output voltage, while the lower waveform represents the output current supplied to the load. The voltage waveform shows a smooth alternating AC signal with constant frequency and amplitude, indicating proper inverter operation. The current waveform follows the voltage waveform and remains balanced throughout the simulation. Small ripples are visible due to PWM switching, but they are minimized by the filtering system. These results confirm that the inverter successfully converts solar-generated DC power into stable AC power suitable for load and grid applications.

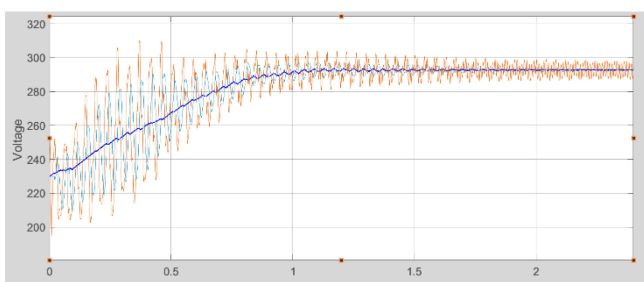

Fig.6. Waveform DC voltage of poposed system.

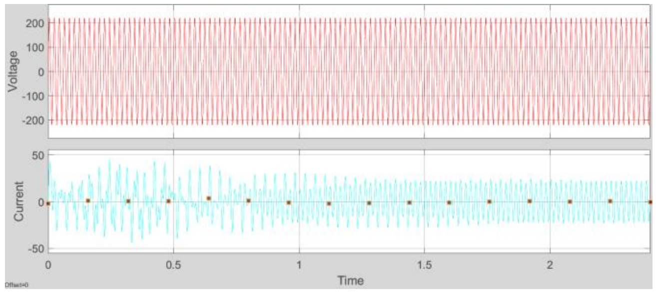

Fig.7.Output load volatage and cureent Waveform \ of poposed system.

Fig.8 shows the FFT (Fast Fourier Transform) analysis of the output voltage waveform. The upper section displays the filtered voltage waveform, which is nearly sinusoidal and stable. The lower section shows the harmonic spectrum. The fundamental frequency is 50 Hz with a voltage magnitude of approximately 220.1 V. The calculated Total Harmonic Distortion (THD) is only 0.05%, indicating excellent voltage quality and very low harmonic content. This demonstrates the effectiveness of the LCL filter in removing switching harmonics and improving power quality.

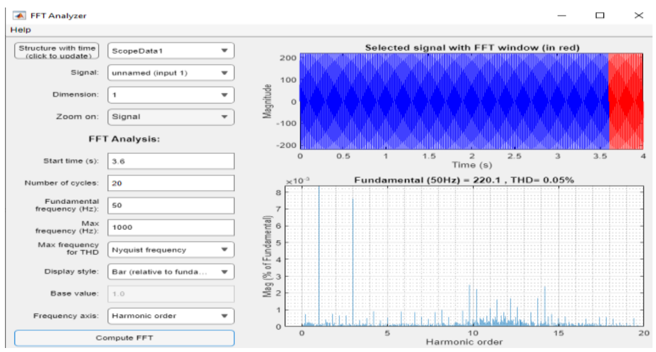

Fig. 8. FFT (Fast Fourier Transform) analysis of the output voltage waveform.

Fig. 9 presents the FFT analysis of the output current waveform. The harmonic spectrum shows a dominant fundamental component at 50 Hz with a current magnitude of approximately 21.58 A.

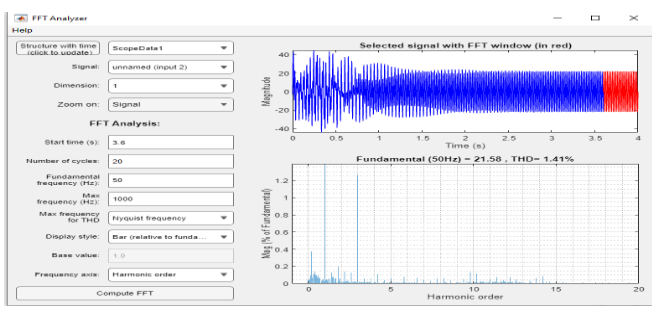

Fig.9. FFT (Fast Fourier Transform) analysis of the output current waveform

The calculated THD is 1.41%, which indicates low harmonic distortion and good current quality. The low THD value confirms that the inverter control strategy and filtering system effectively reduce harmonics and provide a clean output current. Overall, the results demonstrate stable operation, improved power quality, efficient power conversion, and reliable performance of the proposed Solar PV-based Single-Phase PWM Inverter system.The smooth settling of the signal shows good dynamic performance and damping characteristics.

Table 2 compersion Analysis of proposed system

Ref.	Method/Topology	Voltage THD (%)	Current THD (%)	Remarks

[3]	Hysteresis Controlled Inverter	4.5	3.8	Improved waveform quality in islanded microgrid
[4]	Hybrid PV/Wind Multilevel Inverter	3.7	3.2	Reduced switch count and improved efficiency
[10]	Grid-Connected PV-Battery System	2.9	2.7	Improved power quality and battery management
This work	Solar PV PWM Inverter	0.05	1.41	Excellent voltage quality and stable operation

5. CONCLUSION

This paper presents the modeling and simulation of a single-phase PWM inverter for renewable energy applications using MATLAB/Simulink. The developed system integrates a solar photovoltaic panel, MPPT controller, SPWM inverter, LCL filter, transformer, and utility grid interface. Simulation results show that the proposed inverter efficiently converts DC power into high-quality AC power, maintaining low harmonic distortion and stable operation. The MPPT controller ensures maximum power extraction from the solar photovoltaic panel, while the LCL filter significantly improves the power quality. This study confirms that the proposed system is an efficient and reliable solution for integrating renewable energy into modern power systems and provides a solid foundation for future research involving intelligent control techniques and advanced optimization methods.

REFERENCES

1. Amir Aghazadeh, MasoudDavari, Hamed Nafisi, and FredeBlaabjerg, “Grid Integration of a Dual Two-Level Voltage-Source Inverter Considering Grid Impedance and Phase-Locked Loop,” IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 9, no. 1, pp. 401–422, Feb. 2021, doi: 10.1109/JESTPE.2019.2953522.
2. Basem E. Elnaghi, Ahmed M. Ismaiel, Hany S. E. Mansour, and M. N. Abd-Alwahab, “Fuel Cell Stack Design and Modelling with a Double-Stage Boost Converter Coupled to a Single-Phase Inverter,” Clean Energy, vol. 8, no. 1, pp. 188–196, 2024, doi: 10.1093/ce/zkad083.
3. M. Imran Azim, “An Inverter Control Technique for an RES-Based Islanded Microgrid,” International Journal of Renewable Energy Research, vol. 6, no. 2, pp. 581–584, 2016.
4. Aida BaghbanyOskouei, Mohamad Reza Banaei, and Mehran Sabahi, “Hybrid PV/Wind System with Quinary Asymmetric Inverter Without Increasing DC-Link Number,” Ain Shams Engineering Journal, vol. 7, no. 2, pp. 579–592, 2016, doi: 10.1016/j.asej.2015.06.008.
5. ShaikGouseBasha, Mani Venkatesan, and MopideviSubbarao, “Single-Phase Thirteen-Level Dual-Boost Inverter Based Shunt Active Power Filter Control Using Resonant and Fuzzy Logic Controllers,” CSEE Journal of Power and Energy Systems, vol. 8, no. 3, pp. 849–863, 2022, doi: 10.17775/CSEEJPES.2020.02640.
6. V. Kumar, Sanjeev Singh, and Shailendra Kumar Jain, “Single-Phase Cross-Connected Sources Asymmetric T-Type Multilevel Inverter with Fault Tolerant Capabilities,” International Journal of Power Electronics, vol. 17, no. 3, pp. 280–298, 2023, doi: 10.1504/IJPELEC.2023.129975.
7. P. Sivaraj, KarunanithiKandasamy, and PerumalChandrasekar, “Modelling and Simulation of Sinusoidal Pulse Width Modulation Controller for Solar Photovoltaic Inverter to Minimize the Switching Losses and Improving the System Efficiency,” Archives of Electrical Engineering, vol. 71, no. 3, pp. 615–626, 2022, doi: 10.24425/aee.2022.141674.
8. Arjen Mentens, Harold R. Chamorro, Valéry Ann Jacobs, David Topolanek, Jiri Drapela, and Wilmar H. Martinez, “Impact of Advanced Inverter Functions on Low-Voltage Power Grids,” IET Energy Systems Integration, vol. 3, no. 4, pp. 426–436, 2021, doi: 10.1049/esi2.12018.
9. Aditi Atul Desai and Suresh Mikkili, “Improved Transformer-Less Grid-Connected PV Inverter with CCMV for Enhanced Efficiency,” CPSS Transactions on Power Electronics and Applications, vol. 10, no. 4, pp. 351–359, 2025, doi: 10.24295/CPSSTPEA.2025.00034.
10. NupurSaxena, B. P. Singh, and Anoop Lal Vyas, “Integration of Solar Photovoltaic with Battery to Single-Phase Grid,” IET Generation, Transmission and Distribution, vol. 11, no. 8, pp. 2003–2012, 2017, doi: 10.1049/iet-gtd.2016.1455.
11. Akanksha Sinha, Madan Kumar Das, and Jana Chandra Kartick, “Control of Asymmetrical Cascaded Multilevel Inverter for a Grid-Connected Photovoltaic System,” IET Renewable Power Generation, vol. 13, no. 9, pp. 1456–1465, 2019, doi: 10.1049/iet-rpg.2018.5230.

12. BaoXie, Lin Zhou, and Mingxuan Mao, “Analysis of Resonance and Harmonic Amplification for Grid-Connected Inverters,” IET Generation, Transmission and Distribution, vol. 13, no. 10, pp. 1821–1828, 2019, doi: 10.1049/iet-gtd.2018.6499.
13. TripurariNath Gupta, ShadabMurshid, and B. P. Singh, “Improving Power Quality of Single Phase Utility Grid Connected to Wind-PV System Using Multilayer-Frequency Adaptive Fundamental Signal Extractor,” IET Renewable Power Generation, vol. 14, no. 12, pp. 2126–2134, 2020, doi: 10.1049/iet-rpg.2019.0928.
14. Rekha Agrawal and Shailendra Kumar Jain, “Multilevel Inverter for Interfacing Renewable Energy Sources with Low/Medium- and High-Voltage Grids,” IET Renewable Power Generation, vol. 11, no. 14, pp. 1822–1831, 2017, doi: 10.1049/iet-rpg.2016.1034.
15. NimaMahdianDehkordi, Nasser Sadati, and Mohsen Hamzeh, “Robust Tuning of Transient Droop Gains Based on Kharitonov's Stability Theorem in Droop-Controlled Microgrids,” IET Generation, Transmission and Distribution, vol. 12, no. 14, pp. 3495–3501, 2018, doi: 10.1049/iet-gtd.2017.1767.
16. Po Li, Ying He, Xia Lin, and Mingjie Guan, “A Practical Stable Control Scheme Under End Point Equivalence Modulation for DC Power Supply Converters,” IET Power Electronics, vol. 14, no. 14, pp. 2374–2388, 2021, doi: 10.1049/pel2.12186.
17. Mojtaba Ahmadi, Mohammad Hossein Mousavi, Hassan MoradiCheshmehbeigi, and KumarsRouzbehi, “A New Approach for Harmonic Detection Based on Eliminating Oscillatory Coupling Effects in Microgrids,” IET Renewable Power Generation, vol. 17, no. 14, pp. 3536–3553, 2023, doi: 10.1049/rpg2.12867.
18. NavidRasekh and Majid Hosseinpour, “LCL Filter Design and Robust Converter Side Current Feedback Control for Grid-Connected Proton Exchange Membrane Fuel Cell System,” International Journal of Hydrogen Energy, vol. 45, no. 23, pp. 13055–13067, 2020, doi: 10.1016/j.ijhydene.2020.02.227.
19. YahiaBouzelata, Necmi N. Altın, RachidChenni, and Erol Kurt, “Exploration of Optimal Design and Performance of a Hybrid Wind-Solar Energy System,” International Journal of Hydrogen Energy, vol. 41, no. 29, pp. 12497–12511, 2016, doi: 10.1016/j.ijhydene.2015.12.165.
20. OnurDeveci and CoşkuKasnakoğlu, “Performance Improvement of a Photovoltaic System Using a Controller Redesign Based on Numerical Modeling,” International Journal of Hydrogen Energy, vol. 41, no. 29, pp. 12634–12649, 2016, doi: 10.1016/j.ijhydene.201 6.05.149