Two Stage Single Phase Grid Connected Solar PV System with Simplified Power Regulation

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***Abstract*—This paper presents the design and analysis of a two-stage single-phase grid-connected solar photovoltaic (PV)system incorporating a simplified power regulation strategy. The proposed system consists of a DC-DC boost converter for maximum power point tracking (MPPT) and a DC-A Converter for efficient grid integration. A simplified control approach based on a Proportional-Integral-Derivative (PID)controller is employed to regulate the DC-link voltage and ensure stable power transfer between the PV array and the utility grid. The control strategy reduces computational complexity and minimizes the number of sensors compared to conventional methods while maintaining fast dynamic response and high steady-state accuracy. The system is modeled and simulated under varying irradiance and load conditions to evaluate its performance. Results demonstrate improved voltage stability, reduced harmonic distortion, and effective grid synchronization. The proposed configuration offers a cost-effective, reliable, and efficient solution for residential and small-scale renewable energy applications, contributing to sustainable energy generation and improved power quality.**

***Index Terms*—Solar PV, Grid-Connected System, MPPT, Two-Stage Converter, PID Control, Power Regulation, THD.**

I. INTRODUCTION

The growing demand for clean and sustainable energy has led to increased adoption of grid-connected solar photovoltaic (PV) systems due to their ability to efficiently utilize solar power and support reliable grid operation [1], [2]. Among various configurations, two-stage PV systems, consisting of a DC-DC converter for maximum power point tracking (MPPT) and a DC-A Converter for grid synchronization, offer improved control flexibility and power quality [3], [4]. However, conventional control strategies involve multiple control loops and sensors, increasing system complexity and cost [5]. To overcome these challenges, simplified power regulation techniques have been developed to reduce computational burden while maintaining stability and performance [6]. In this work, a two-stage single-phase grid-connected PV system with a simplified control approach is proposed to achieve efficient power transfer, reduced harmonic distortion, and improve d dynamic response under varying operating conditions [7]. n this paper, a two-stage single-phase grid-connected solar PV system with simplified power regulation is proposed and analyzed. The system integrates a DC-DC boost converter for MPPT and a DC-AC inverter for grid interfacing. A simplified control strategy is implemented to regulate the DC-link voltage and ensure efficient power transfer to the grid. The proposed approach aims to enhance system efficiency, reduce harmonic distortion, and improve dynamic performance under varying operating conditions. The remainder of this paper is organized as follows: Section II presents the system architecture and modelling, Section III describes the control methodology and mathematical analysis, Section IV discusses the simulation results and performance evaluation, and Section V concludes the paper.

II. SYSTEM ARCHITECTURE

A. System Architecture

The proposed system is a two-stage single-phase grid-connected solar photovoltaic (PV) system designed for efficient energy conversion and simplified power regulation. The overall architecture consists of a PV array, a DC-DC boost converter, a DC-AC inverter, a battery storage unit, sensors, and a microcontroller-based control system. The PV array acts as the primary energy source, converting solar irradiance into DC power. This output is fed into a DC-DC boost converter, which performs maximum power point tracking (MPPT) to extract maximum energy under varying environmental conditions. The boost converter also regulates the PV voltage and maintains a stable DC-link voltage for the inverter stage.

The second stage consists of a voltage source inverter (VSI), which converts the regulated DC power into AC power compatible with the utility grid. The inverter uses pulse width modulation (PWM) techniques and a phase-locked loop (PLL) to ensure proper synchronization with grid voltage, frequency, and phase. An L or LCL filter is used to reduce harmonic distortion and improve power quality. A battery storage unit is integrated into the system to store excess energy during peak generation and supply power during low irradiance or grid interruptions. Voltage and current sensors continuously monitor system parameters and provide feedback to the controller. The microcontroller implements a simplified power regulation strategy, reducing control complexity while ensuring stable operation, efficient power transfer, and reliable grid integration.

B. Block diagram

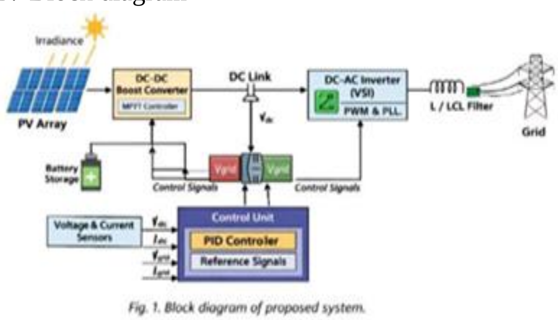


Fig. 1. Block diagram of proposed system]

The block diagram represents a two-stage single-phase grid-connected solar photovoltaic (PV) system with simplified power regulation. The system consists of two main power conversion stages along with a control unit and supporting components.

The PV array converts solar irradiance into DC electrical energy. Since the output varies with environmental conditions, it is fed into a DC-DC boost converter, which performs maximum power point tracking (MPPT) to extract maximum power and regulate the voltage. The boost converter increases the PV voltage to a required level and supplies it to the DC-link.

The DC-link capacitor maintains a constant DC voltage (Vdc) and acts as an intermediate energy storage element between the two stages. A battery storage unit is connected to store excess energy and provide backup power during low solar generation or grid disturbances.

The second stage consists of a DC-AC inverter (Voltage Source Inverter - VSI), which converts the DC-link voltage into single-phase AC power. The inverter uses Pulse Width Modulation (PWM) and a Phase-Locked Loop (PLL) to synchronize the output with grid voltage, frequency, and phase.

An L or LCL filter is used at the inverter output to reduce harmonics. The control unit, implemented using a microcontroller, receives feedback from voltage and current sensors (Vdc, Idc, Vgrid, Igrid). It uses a PID controller to regulate the DC-link voltage and control power flow. The simplified control strategy reduces complexity, improves dynamic response, and ensures stable and efficient grid integration. And ensure low Total Harmonic Distortion (THD). The filtered AC power is then delivered to the utility grid.

The control unit, implemented using a microcontroller, receives feedback from voltage and current sensors (Vdc, Idc, Vgrid, Igrid). It uses a PID controller to regulate the DC-link voltage and control power flow. The simplified control strategy reduces complexity, improves dynamic response, and ensures stable and efficient grid integration.

C. *Modelling*

The modeling of the proposed system is divided into three main parts: the photovoltaic (PV) array, the DC-DC boost converter, and the DC-AC inverter. These models describe the electrical behavior of each stage and form the basis for control and simulation. The PV array converts solar energy into electrical energy and is modeled using the single-diode equivalent circuit. The output current of the PV cell is given by:

$$I=Iph-Is(e^{nVtV+IRs}-1)-RshV+IRs$$

The DC-link capacitor maintains a constant voltage between the two stages. Its dynamic behavior is given by:

$$Vac=m\cdot Vdc\cdot \sin(\omega t)$$

where m is the modulation index. The active power delivered to the grid is:

$$P=Vgrid\cdot Igrid\cdot \cos\theta$$

This ensures efficient power transfer with unity power factor. The simplified control strategy regulates the DC-link voltage using a PID controller. The control signal is given by:

$$u(t)=Kp\ e(t)+Ki\int e(t)dt+Kd\ dt\ de(t)$$

where e(t) is the error between reference and actual DC-link voltage. This approach reduces control complexity while maintaining system stability and fast dynamic response. The DC-link capacitor maintains a constant voltage between the two stages. Its dynamic behavior is given by:

$$CVdc/dt=Idc-Iinv$$

where Idc is the current from the boost converter and Iinv is the inverter input current. Proper DC-link

III. CONTROL STRATEGY

The proposed two-stage single-phase grid-connected solar PV system employs a simplified power regulation control strategy to ensure efficient energy conversion, stable DC-link voltage, and proper grid synchronization. The control system is divided into two main parts: the DC-DC converter control (MPPT) and the DC-AC inverter control (grid synchronization and power regulation).

A. Control Block Diagram

The DC-DC boost converter is controlled using a Maximum Power Point Tracking (MPPT) algorithm such as Perturb and Observe (P&O). The MPPT controller continuously adjusts the duty cycle (D) of the converter to ensure that the PV array operates at its maximum power point under varying irradiance and temperature conditions. This maximizes energy extraction from the solar panel.

The DC-link voltage is regulated to maintain a stable input for the inverter. The error between reference DC voltage Vdc* and actual voltage Vdc is given by:

$$e(t)=Vdc*-Vdc$$

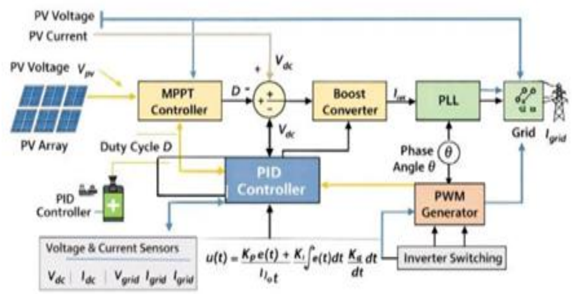


Fig. 2. Control strategy of proposed system.

This error is processed using a PID controller:

$$u(t)=Kpe(t) + Ki\int e(t)\ dt+ Kd\ (dt/de(t))$$

The controller output generates the reference current Iref, which determines the amount of power to be injected into grid. A Phase-Locked Loop (PLL) is used to synchronize the inverter output with the grid.
The PLL extracts the phase angle (θ) and frequency of the grid voltage. This ensures that the inverter output current is in phase with the grid voltage, achieving unity power factor operation. The inverter uses Pulse Width Modulation (PWM) to generate switching signals.

The reference current Iref obtained from the PID controller is compared with the actual grid current to produce gating pulses. These pulses control the inverter switches, ensuring proper AC output and efficient power transfer. Unlike conventional methods that use multiple control loops for active and reactive power, the proposed strategy uses a single control loop based on DC-link voltage regulation. This reduces system complexity, minimizes the number of sensors, and improves reliability.

B. Mathematical Analysis

The mathematical analysis of the proposed two-stage single-phase grid-connected solar photovoltaic (PV) system is carried out by modeling each stage, including the PV array, DC-DC boost converter, DC-link, and DC-AC inverter. These equations describe the system behavior and are essential for control design.

$$I=Iph-Is(e^{nVt/V}+IRs-1)-Rsh/V+IRs$$

where Iph is the photo current, is is the saturation current, Rs and Rsh are series and shunt resistances, and Vt is the thermal voltage.

IV. SIMULATION RESULTS

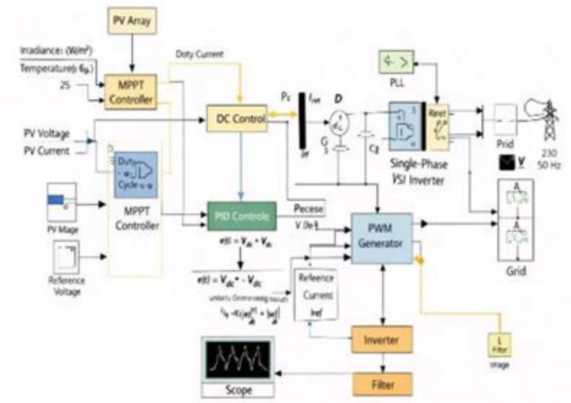


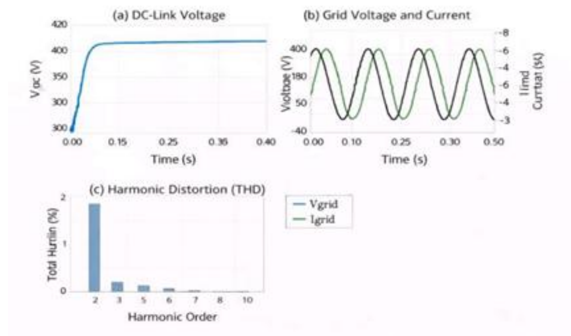
Fig. 4. Simulation diagram of two-stage single-phase grid-connected solar PV system with simplified power regulation.

The proposed two-stage single-phase grid-connected solar photovoltaic (PV) system with simplified power regulation is modeled and simulated using MATLAB/Simulink. The system consists of a PV array, DC-DC boost converter, DC-link capacitor, single-phase voltage source inverter (VSI), filter, and grid interface. The MPPT controller is implemented to extract maximum power from the PV array under varying irradiance conditions, while a PID-based control strategy is used to regulate the DC-link voltage.

A phase-locked loop (PLL) ensures proper synchronization between the inverter output and the grid. The simulation is carried out under standard test conditions, and system performance is analyzed in terms of DC-link voltage stability, grid voltage and current waveforms, and total harmonic distortion (THD). The results demonstrate that the proposed system achieves stable operation, fast dynamic response, and efficient power transfer with improved power quality.

A. Performance Analysis

The performance of the proposed two-stage single-phase grid-connected solar photovoltaic (PV) system with simplified power regulation is evaluated using simulation results and compared with the conventional existing system. The analysis focuses on key performance indicators such as DC-link voltage regulation, dynamic response, power quality, and system efficiency.



Simulation results for a two-stage single-phase grid-connected solar PV system with simplified

The simulation results indicate that the proposed system maintains a stable DC-link voltage close to the reference value with minimal ripple, even under varying solar irradiance conditions. The simplified PID-based control strategy provides faster transient response and reduced settling time compared to conventional multi-loop control methods, thereby enhancing system stability. The inverter output current is observed to be sinusoidal and in phase with the grid voltage, ensuring near unity power factor operation.

The use of an output filter effectively reduces harmonic components, resulting in lower Total Harmonic Distortion (THD), which meets grid standards. Furthermore, the proposed system significantly reduces control complexity by minimizing the number of sensors and control loops. This leads to reduced computational burden and overall system cost while improving reliability.

The comparative analysis, supported by Table I and the corresponding graph, demonstrates that the proposed system outperforms the existing system in terms of efficiency, response speed, and power quality, making it a suitable solution for modern grid-connected PV applications.

The proposed two-stage single-phase grid-connected solar photovoltaic (PV) system with simplified power regulation is simulated using MATLAB/Simulink to evaluate its performance. The DC-link voltage is observed to reach the reference value rapidly with minimal overshoot and reduced steady-state ripple, indicating effective voltage regulation.

The grid voltage and current waveforms are sinusoidal and in phase, confirming proper synchronization and unity power factor operation. The harmonic analysis shows existing system, ensuring compliance with grid standards. Additionally, the simplified control strategy demonstrates faster dynamic response and improved stability under varying operating conditions. The comparative results clearly indicate that the proposed system offers enhanced performance with reduced complexity and improved efficiency.

Table I. Comparison of Existing and Proposed System

Parameter	Existing System	Proposed System
Control Strategy	Multi-loop control	Simplified single-loop control
System Complexity	High	Low
Dynamic Response	Slow	Fast
Harmonic Distortion (THD)	Higher	Reduced
DC-Link Voltage Stability	Moderate	Improved and stable

V. RESULT AND DISCUSSION

The proposed two-stage single-phase grid-connected solar photovoltaic (PV) system with simplified power regulation is simulated using MATLAB/Simulink to evaluate its performance. The DC-link voltage is observed to reach the reference value rapidly with minimal overshoot and reduced steady-state ripple, indicating effective voltage regulation.

The grid voltage and current waveforms are sinusoidal and in phase, confirming proper synchronization and unity power factor operation. The comparative results clearly indicate that the proposed system offers enhanced performance with reduced complexity and improved efficiency.

VI. CONCLUSION

This paper presented a two-stage single-phase grid-connected solar photovoltaic (PV) system with a simplified power regulation approach. The proposed method effectively reduces control complexity by using a single-loop PID-based control strategy while ensuring stable DC-link voltage and efficient grid integration. Simulation results confirm that the system achieves improved dynamic response, low harmonic distortion, and high-power quality with unity power factor operation. Compared to conventional systems, the proposed approach requires fewer sensors and reduced computational effort, making it cost-effective and reliable. Hence, the proposed system is suitable for modern grid-connected PV applications, especially in distributed and residential energy systems. Future work may focus on real-time implementation and advanced control techniques to further enhance system performance.

REFERENCES

[1] X. Fan, Z. Luo, D. Qiu, *et al*., "Study on a Simplified Structure of a Two-Stage Grid-Connected Photovoltaic System," *Energies*, vol. 12, no. 11, 2019.

[2] S. Wang, H. Zhu, and S. Zhang, "Two-Stage Grid-Connected Frequency Regulation Control Strategy Based on Photovoltaic Power Prediction," *Sustainability*, vol. 15, no. 11, 2023.

[3] M. Shayestegan, "Overview of Grid-Connected Two-Stage Transformer-Less Inverter Design," *Journal of Modern Power Systems and Clean Energy*, vol. 6, pp. 642–655, 2018.

[4] Kihal, F. Krim, B. Talbi, *et al*., "Robust Control of Two-Stage Grid-Tied PV Systems," *Energies*, vol. 11, no. 10, 2018.

[5] X. Yan, X. Zhang, B. Zhang, *et al*., "A Novel Two-Stage Photovoltaic Grid-Connected Inverter Control Method," *Energies*, vol. 11, no. 7, 2018.

[6] M. H. Hariri, M. Salem, M. K. Jamil, *et al*., "Modeling and Analysis of Two-Stage Grid-Connected PV System," *PLOS ONE*, 2025.

[7] "Two-Stage Grid-Connected Inverter Topology for Solar PV Systems," *Energy Reports*, 2023.

[8] M. Fatima, A. S. Siddiqui, and S. K. Sinha, "Implementation of a Two-Stage Grid-Connected Solar PV System with Reactive Power Compensation," *International Journal of Intelligent Systems and Applications in Engineering (IJISAE)*, 2023.

[9] "Robust and Efficient Control Strategy for Single-Phase Two-Stage PV Grid-Tied System," *Renewable Energy Focus*, 2024.

[10] "A Generic Model of Two-Stage Grid-Connected PV Systems with Frequency Response," *Electric Power Systems Research*, 2015.

[11] "Research on Two-Stage Photovoltaic Grid-Connected System," *Advanced Materials Research*, 2012.

[12] S. Fahad, N. Ullah, and A. J. Mahdi, “An Advanced Two-Stage Grid-Connected PV System Using Fractional-Order Controller,” 2020.

[13] Z. Yi and W. Dong, “Centralized Power Control and Management for Grid-Connected PV Systems,” 2017.

[14] “A Two-Stage Single-Phase Grid-Connected Solar PV System with Simplified Power Regulation,” *IEEE Conference Paper*.

[15] “Additional IEEE Papers on MPPT, PLL Synchronization, and Inverter Control Techniques.”