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Design and Real-Time Simulation of Grid-Connected Solar PV System with Enhanced MPPT and Inverter Control in MATLAB/Simulink

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Abstract: *The global shift toward renewable energy sources has made photovoltaic (PV) systems increasingly important due to their clean, modular, and sustainable characteristics. This research paper presents the design and control of a grid-connected solar PV system implemented in MATLAB/Simulink. The proposed system includes four critical components: a Maximum Power Point Tracking (MPPT) controller to maximize energy harvesting from the solar panels, a closed-loop boost converter to elevate the panel voltage efficiently, a three-phase voltage source inverter (VSI) using six IGBT switches for DC to AC conversion, and an LCL filter to minimize harmonics and ensure quality power injection into the grid. The MPPT controller, based on the Perturb and Observe (P&O) method, continuously adjusts the duty cycle of the boost converter to extract the maximum power under varying irradiance and temperature conditions. A Proportional-Integral (PI) controller is employed for the closed-loop voltage control of the boost converter, ensuring a stable output voltage suitable for grid interfacing. The inverter is operated using Sinusoidal Pulse Width Modulation (SPWM) technique to generate a balanced three-phase output. The LCL filter is designed to attenuate high-frequency switching harmonics, maintaining the Total Harmonic Distortion (THD) within IEEE-519 standards. Simulation results validate the effectiveness of the proposed system under different solar irradiance conditions. The system not only ensures optimal energy harvesting but also delivers power to the grid with high efficiency and low distortion. This paper contributes toward enhancing the reliability and performance of solar PV systems in modern power grids.*

Keywords: Solar PV, MPPT, Boost Converter, PI Controller, Grid-Connected Inverter, LCL Filter, MATLAB Simulink, SPWM, Renewable Energy, Power Quality

I. INTRODUCTION

In recent years, the need for sustainable and clean energy sources has grown rapidly due to increasing global energy demands and environmental concerns. Solar photovoltaic (PV) systems have emerged as one of the most promising alternatives to conventional fossil fuel-based power generation. They offer the benefits of being environmentally friendly, modular, and capable of being installed in both small and large-scale setups. However, the integration of solar PV systems into the electrical grid introduces several challenges, including variability in output due to environmental changes, power quality issues, and efficient energy conversion.

The fundamental challenge in PV systems lies in maximizing the power output despite fluctuations in solar irradiance and temperature. This is addressed by implementing a Maximum Power Point Tracking (MPPT) algorithm, which dynamically adjusts system parameters to ensure the PV modules operate at their optimal power point. Another challenge is to convert the low and variable DC output from the PV panel into a high-quality AC signal that can be fed into the power grid. This involves the use of a DC-DC boost converter followed by a DC-AC inverter.

The DC-DC boost converter plays a crucial role by stepping up the DC voltage from the PV array to a level suitable for grid interfacing. A PI-based closed-loop control system is employed to maintain the output voltage of the boost converter, ensuring system stability and responsiveness to changing conditions. The DC output from the converter is then fed into a three-phase voltage source inverter. The inverter is responsible for converting DC to a three-phase AC voltage

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synchronized with the utility grid. This conversion is achieved using a Sinusoidal Pulse Width Modulation (SPWM) technique. To minimize the harmonic distortion introduced by the switching of the inverter, an LCL filter is employed at the inverter output. The LCL filter design is critical to maintaining power quality and ensuring compliance with IEEE standards for grid-connected systems.

This research focuses on the simulation and analysis of a complete grid-connected solar PV system using MATLAB/Simulink. The design and integration of MPPT, a closed-loop boost converter with PI control, a three-phase inverter, and an LCL filter are explored in detail. The results demonstrate that the proposed system operates efficiently and reliably under varying environmental conditions, making it a viable solution for modern energy system

II. BLOCK DIAGRAM EXPLANATION

The Fig .1 shows the specifications of system. The block diagram of proposed system is given in Fig.2. It consists of the PV array , Boost converter , DC/AC three phase inverter, LCL filter circuit, MPPT (Maximum power point tracking), three PWM generator, local load and AC grid . The PV Array generates 360V-363V DC supply is fed to Boost converter, this block is used to boost voltage level upto 600V DC . The dc 600volt then the dc source is converted into ac source with the help of 3 Phase Inverter .Then the pulse of output of inverter is send to the LCL filter thus it is designed to remove the unwanted harmonic in converter output and produces continues output. The output of filter is given to the local grid.

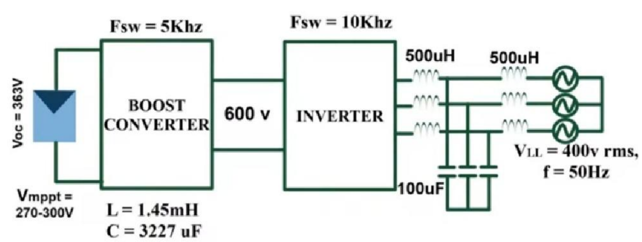

Fig .1 Specifications of the system

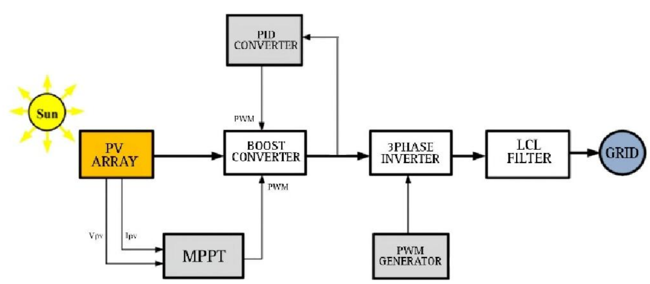

Fig . 2 Block diagram of proposed system

PV Array

A PV (photovoltaic) array is a group of interconnected solar panels that convert sunlight into electrical energy. It consists of multiple solar cells connected in series and parallel to achieve the desired voltage and current levels. PV arrays are commonly used in solar power systems for homes, industries, and grid integration. Fig .3 (a) shows the PV array model parameters value

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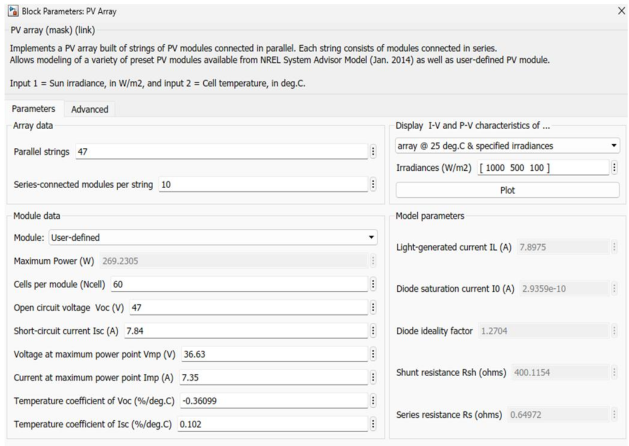

Fig .3 (a) PV array model parameters value.

Fig 3.(b) & (c) shows the V-I plot of Array with Maximum Power Point at different radiation.

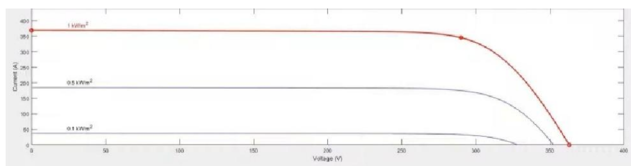

Fig . 3 (b) V-I plot of Array

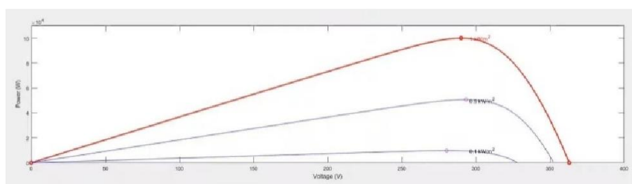

Fig .3 (c) V-I plot of Array

Boost Converter

A boost converter steps up the low DC voltage from the PV panel to a higher level suitable for the inverter. It uses components like an inductor, switch (IGBT), diode, and capacitor, and operates under control of the MPPT and PI controller.

Three-Phase Inverter

The three-phase inverter, built using six IGBTs, converts DC into synchronized three-phase AC using Sinusoidal PWM. It generates a quasi-sinusoidal output, which is filtered for grid connection using an LCL filter.

LCL FILTER

An LCL filter is used at the output of a grid-connected inverter to reduce high-frequency switching harmonics. It consists of two inductors and a capacitor arranged in an L-C-L configuration. This filter improves power quality by smoothing the inverter's AC output, ensuring compliance with grid standards like IEEE 519.

MPPT Controller

The MPPT controller ensures maximum power extraction from the solar panel by adjusting the operating voltage using the Perturb and Observe (P&O) method. It modifies the duty cycle based on power variations to track the maximum power point.

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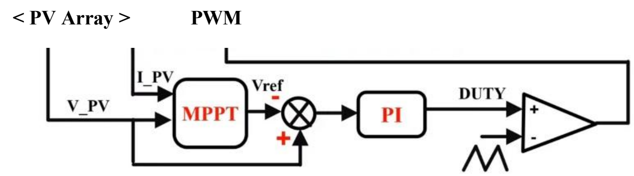

Fig . 4 . MPPT (Maximum Power Point Tracking) System

PI Controller

The PI controller regulates the boost converter’s output voltage by minimizing the error between measured and reference values. It combines proportional and integral actions to ensure voltage stability and fast dynamic response.

PWM Generator

The PWM generator produces variable-width pulses by comparing a sinusoidal reference with a triangular carrier signal. This controls the switching of power devices to efficiently regulate output voltage and minimize harmonics

IV. MODELLING AND SIMULATION OF THE PROPOSED SYSTEM

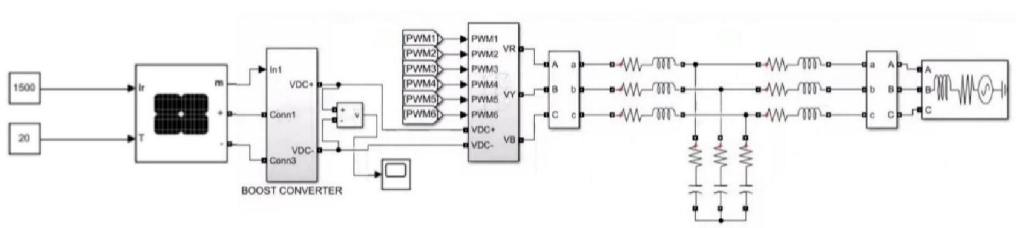

Fig . 5 Complete modelled grid connected solar PV system

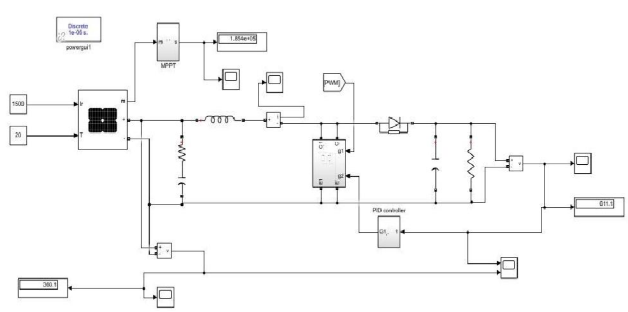

Fig . 6 Simulation diagram of Boost Converter

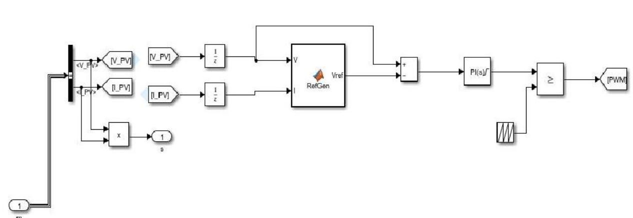

Fig . 7 Simulation diagram of MPPT

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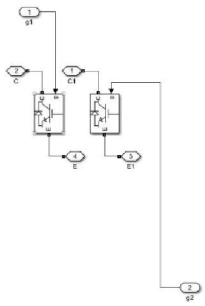

Fig . 8 Simulation diagram of IGBT switches

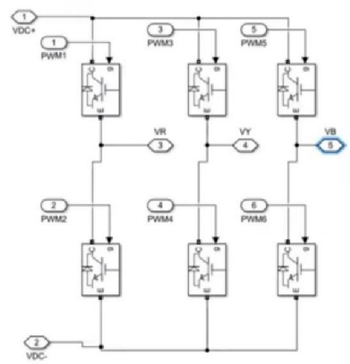

Fig . 9 Simulation diagram of three phase inverter

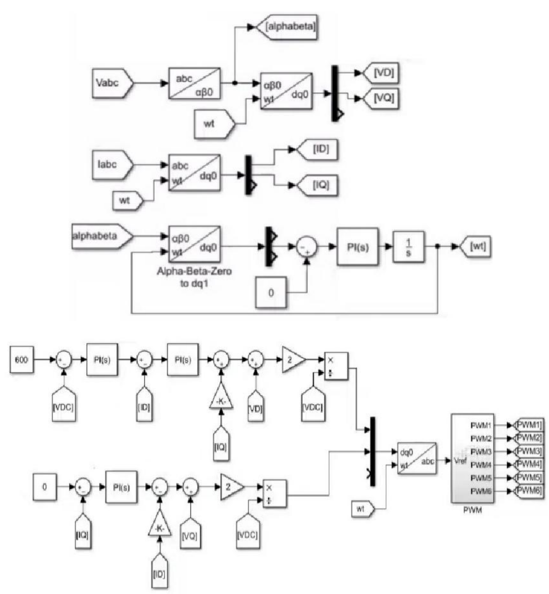

Fig . 10 Simulation diagram of PWM Generator

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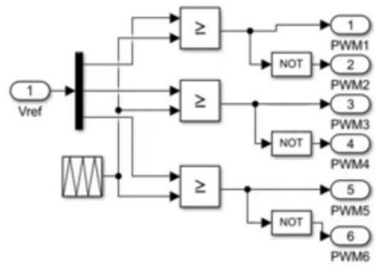

Fig. 11 Simulation diagram of PWM

IV. SIMULATION RESULT

The output of the boost converter is shown in Fig.12 . The Fig.13 and Fig.14 shows the grid voltage and current respectively .

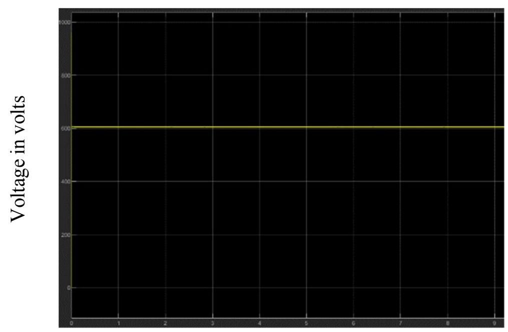

Fig .12 Dc voltage at boost converter output

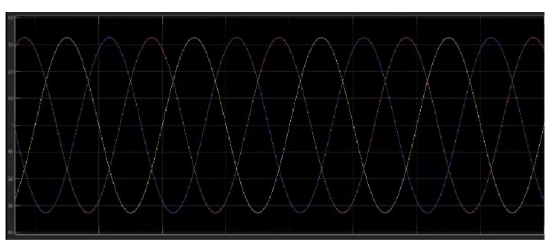

Fig .13 Waveform of the grid voltage

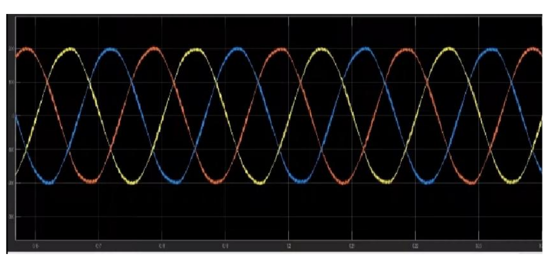

Fig .14 Grid current

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V. ADVANTAGES

1. Simulink enables accurate modeling and simulation of complex solar PV systems.
2. MPPT algorithm ensures efficient energy extraction from solar panels.
3. Boost converter increases voltage for better grid compatibility.
4. PI controller provides stable voltage regulation.
5. SPWM-based inverter delivers clean and synchronized AC output.
6. LCL filter minimizes harmonics and improves power quality.
7. System supports clean, renewable, and eco-friendly energy generation.
8. Modular and scalable design for various power levels.
9. Simulation helps validate system behavior under varying conditions.
10. Enhances understanding of real-time control in grid-connected systems.

VI. DISADVANTAGES

1. Real-world implementation may differ from simulated results.
2. System complexity increases due to multiple control loops.
3. Requires technical expertise in MATLAB/Simulink and power electronics.

VII. FUTURE SCOPE

Future of grid-connected solar PV systems lies in enhancing system intelligence, efficiency, and scalability. One major area of development is the integration of Artificial Intelligence (AI) and Machine Learning (ML) techniques for predictive MPPT and adaptive control. Instead of conventional P&O, algorithms such as fuzzy logic or neural networks can predict solar irradiance trends and adjust control parameters in real-time, improving response under fast-changing conditions.

Another promising direction is the development of advanced energy storage integration. Incorporating batteries or supercapacitors with intelligent battery management systems (BMS) will help smooth power fluctuations and allow for energy shifting, improving grid stability. Coupled with smart energy meters and IoT-enabled controllers, these systems could participate in demand-side management and ancillary grid services. Furthermore, multilevel inverters and silicon carbide (SiC) or gallium nitride (GaN)-based switching devices promise higher efficiency and compactness. These can operate at higher frequencies with reduced losses, allowing for smaller passive components and better power density. Hybrid renewable systems, combining solar with wind, hydro, or biomass, can also be modeled and optimized in platforms like MATLAB. Additionally, real-time hardware-in-the-loop (HIL) simulation will enable testing control strategies under near-actual conditions.

From a policy perspective, the advancement in grid codes and smart grid infrastructure will create more opportunities for decentralized solar systems to contribute actively to the grid.

This project lays a strong foundation for these enhancements by demonstrating a robust control strategy and modular design approach. Continued research and development will ensure grid-connected PV systems are not only technically sound but also economically and environmentally viable for a sustainable future.

VIII. CONCLUSION

This paper presents a complete MATLAB/Simulink model for the design and control of a grid-connected solar PV system. By integrating an efficient MPPT algorithm, a PI-controlled boost converter, and a synchronized three-phase inverter with LCL filtering, the system achieves high performance and power quality under varying solar conditions. The MPPT controller effectively tracks the maximum power point, ensuring optimal utilization of solar energy. The boost converter steps up the fluctuating PV voltage and stabilizes it, while the PI controller maintains precise regulation.

The inverter, configured using six IGBTs, converts the stabilized DC voltage into AC power compatible with the utility grid. The use of a well-tuned LCL filter ensures minimal harmonic distortion, complying with IEEE standards for grid interfacing. The simulation results verify the robustness and efficiency of the proposed system under dynamic irradiance and temperature changes.

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This project demonstrates that with appropriate control strategies and component integration, a solar PV system can be effectively connected to the grid while maintaining system stability and reliability. It provides a strong foundation for further research into intelligent energy systems, battery integration, and hybrid energy models. The successful implementation of this model in MATLAB/Simulink confirms the viability of simulation-based design as a powerful tool in renewable energy research and deployment.

REFERENCES

[1]. Esram, T., & Chapman, P. L. (2007). Comparison of photovoltaic array maximum power point tracking techniques. IEEE Transactions on Energy Conversion, 22(2), 439–449. https://doi.org/10.1109/TEC.2006.874230

[2]. Hassaine, L., et al. (2014). Smart PV inverter with grid fault detection and control capabilities. Renewable Energy, 69, 206–213. https://doi.org/10.1016/j.renene.2014.03.027

[3]. Batarseh, I. (2004). Power Electronic Circuits. John Wiley & Sons.

[4]. Villalva, M. G., Gazoli, J. R., & Filho, E. R. (2009). Comprehensive approach to modeling and simulation of photovoltaic arrays. IEEE Transactions on Power Electronics, 24(5), 1198–1208. https://doi.org/10.1109/TPEL.2009.2013862

[5]. Rodriguez, P., et al. (2007). Multilevel converters: Topologies, control, and applications. IEEE Transactions on Industrial Electronics, 49(4), 724–738. https://doi.org/10.1109/TIE.2007.899403

[6]. Wu, B. (2006). High-Power Converters and AC Drives. Wiley-IEEE Press.

[7]. He, J., & Li, Y. W. (2011). An enhanced microgrid load demand sharing strategy. IEEE Transactions on Power Electronics, 27(9), 3984–3995. https://doi.org/10.1109/TPEL.2012.2187288

[8]. C. Cecati, F. Ciancetta, & P. Siano. (2010). A multilevel inverter for photovoltaic systems with fuzzy logic control. IEEE Transactions on Industrial Electronics, 57(12), 4115–4125. https://doi.org/10.1109/TIE.2009.2038497

[9]. IEEE Std 519-2014. (2014). IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems. IEEE Standards Association.

[10]. MATLAB & Simulink Documentation. Simscape Electrical™ / Specialized Power Systems. https://www.mathworks.com/help/physmod/sps/

[11]. Rashid, M. H. (2013). Power Electronics: Circuits, Devices and Applications (4th ed.). Pearson Education.

[12]. Singh, B., Bist, V., & Chandra, A. (2013). Grid interfaced solar photovoltaic power generating system with power quality improvement features. IET Power Electronics, 6(4), 737–745. https://doi.org/10.1049/iet-pel.2012.0280

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