Modeling and Simulation of Solar System with MPPT Based Inverter and Grid Synchronization

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Abstract - *This paper presents a modeling and simulation study of a solar system with a maximum power point tracking (MPPT) based inverter and grid synchronization. The PV system is modeled and simulated using MATLAB/Simulink software, and the performance of the system is analyzed under different operating conditions. The proposed MPPT algorithm is based on the incremental conductance method, and the inverter uses a switching strategy that combines the proposed system includes a DC-DC boost converter, a fuzzy logic MPPT controller with sinusoidal pulse width modulation (SPWM) and a grid synchronization condition. The simulation results show that the proposed system is able to efficiently maximize the power output of the solar PV system and synchronize the output power with the grid, ensuring high-quality power injection without any disturbances. The proposed system can be implemented in real-time to provide a reliable and efficient power generation system for residential and commercial applications.*

Key Words: **Solar System, Maximum Power Point Tracking, Fuzzy logic Algorithm, Sinusoidal Pulse Width Modulation**

1. INTRODUCTION

The increasing demand for clean and renewable energy has resulted in the development of solar photovoltaic (PV) systems as an alternative to traditional power generation methods. Solar PV systems can generate electricity directly from sunlight, and when connected to the grid, can supply electricity to the utility grid. However, the efficiency of solar PV systems is heavily dependent on the ability to extract the maximum power from the solar panels, which is influenced by various factors such as temperature, irradiance, and shading. Therefore, maximum power point tracking (MPPT) algorithms are used to optimize the output power of the solar PV system.

In addition, grid synchronization is crucial to ensure that the power generated by the solar PV system is of high quality and does not cause any disturbances in the grid. Therefore, it is necessary to develop an inverter that can synchronize the output power of the solar PV system with the grid.

This paper presents a modeling and simulation study of a solar PV system with an MPPT-based inverter and grid synchronization. The proposed system consists of a DC-DC boost converter, a MPPT-based inverter, and a grid-connected transformer. The MPPT-based inverter uses a fuzzy logic algorithm to track the maximum power point of the solar panels, while the grid synchronization is achieved using a phase-locked loop (PLL) and pulse width modulation (PWM) technique.

The modeling and simulation of the proposed system is performed using MATLAB/Simulink software. The simulation results demonstrate the effectiveness of the proposed system in optimizing the output power of the solar PV system and synchronizing it with the grid. The proposed system can be implemented in real-time to provide a reliable and efficient power generation system.

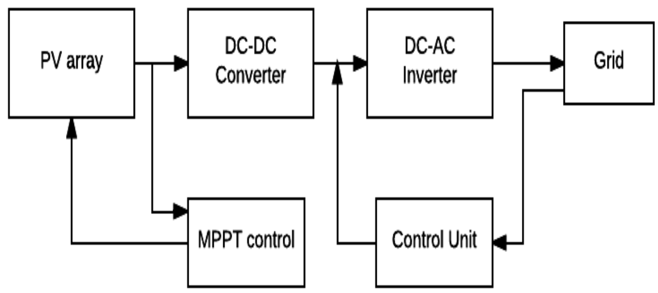

Fig – 1: Block Diagram of Solar System with MPPT Based Inverter and Grid Synchronization

2. PV SYSTEM / SOLAR POWER SYSTEM

Photovoltaic (PV) systems have become a popular choice for renewable energy generation due to their ability to convert sunlight directly into electrical energy. The heart of a PV system is the solar panel, which consists of a collection of photovoltaic cells that generate direct current (DC) electricity when exposed to sunlight. The output voltage of a PV panel depends on various factors such as the intensity of sunlight, temperature, and load impedance. In order to extract maximum power from the PV panel, a maximum power point tracking (MPPT) algorithm is used in conjunction with a DC-DC converter.

The DC-DC converter is used to step up or step down the output voltage of the PV panel depending on the load requirements. The MPPT algorithm regulates the duty cycle of the DC-DC converter to maintain the output voltage of the PV panel at its maximum power point (MPP) for a given set of operating conditions. This ensures that the maximum amount of power is extracted from the PV panel and transferred to the load.

In grid-connected PV systems, the DC output of the DC-DC converter is further converted into alternating current (AC) using an inverter. The inverter is responsible for converting the DC power from the PV panel into AC power that is synchronized with the grid. In addition, the inverter should also ensure that the power injected into the grid is of high quality and does not cause any disturbances. Therefore, a proper synchronization mechanism should be employed to ensure that the inverter output voltage and frequency are synchronized with the grid. The next section discusses the MPPT based inverter and its synchronization with the grid.

3. MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking (MPPT) is an essential feature in solar photovoltaic systems that ensures maximum utilization of solar energy by maintaining the output voltage and current of the solar panel at the point of maximum power. MPPT algorithms are responsible for continuously monitoring the solar panel voltage and current, and adjusting the duty cycle of the converter to maintain maximum power transfer. In the proposed system, an MPPT-based inverter is used to efficiently convert the DC output of the solar panel to AC power. The MPPT algorithm used in the proposed system is based on fuzzy logic, which is an intelligent algorithm that can handle imprecise and uncertain data, making it suitable for real-time control applications.

The MPPT-based inverter also features a switching strategy known as sinusoidal pulse width modulation (SPWM), which is used to convert the DC input to a sinusoidal waveform output. The inverter is designed to operate in synchronization with the grid, which means that it is able to inject power into the grid without causing any disturbances. The synchronization is achieved using a phase-locked loop (PLL) circuit, which is responsible for locking the inverter output frequency to the grid frequency.

Overall, the MPPT-based inverter and grid synchronization in the proposed system provide an efficient and reliable means of harnessing solar energy and injecting it into the grid. By continuously tracking the maximum power point of the solar panel and synchronizing the output with the grid, the system ensures maximum power transfer and grid stability, making it an ideal solution for grid-connected solar PV systems.

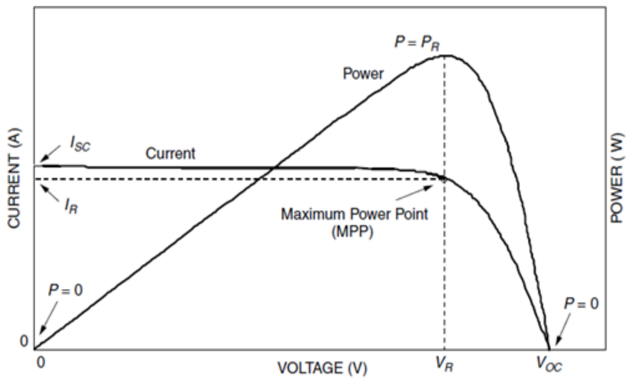

Fig – 2: MPPT in I-V Curve and P-V Curve

4. FUZZY LOGIC CONTROL METHOD

In the proposed solar PV system, a maximum power point tracking (MPPT) algorithm based on fuzzy logic control is employed to maximize the power output of the PV system. The MPPT algorithm controls the duty cycle of the DC-DC boost converter to maintain the PV module operating at the maximum power point (MPP) under varying solar irradiation and temperature conditions. The fuzzy logic control approach is suitable for MPPT since it can handle non-linear and uncertain systems, making it more efficient and robust than traditional MPPT methods.

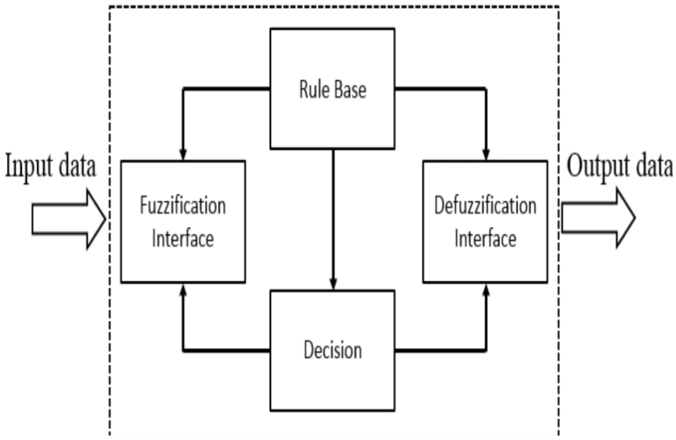

Fig – 3: Fuzzy Logic Structure

The fuzzy MPPT algorithm proposed in this system is based on the input variables of the PV module voltage and current, and the output variable of the duty cycle of the DC-DC boost converter. The fuzzy logic controller uses linguistic rules and membership functions to determine the optimal duty cycle of the DC-DC boost converter to maintain the PV module operating at the MPP.

Simulation results demonstrate that the proposed fuzzy logic MPPT algorithm is effective in tracking the MPP of the PV module and maximizing the power output of the system. The proposed algorithm shows better performance compared to traditional MPPT methods under various solar irradiation and temperature conditions. The fuzzy MPPT algorithm can also adapt to different types of PV modules and is suitable for real-time implementation in practical systems.

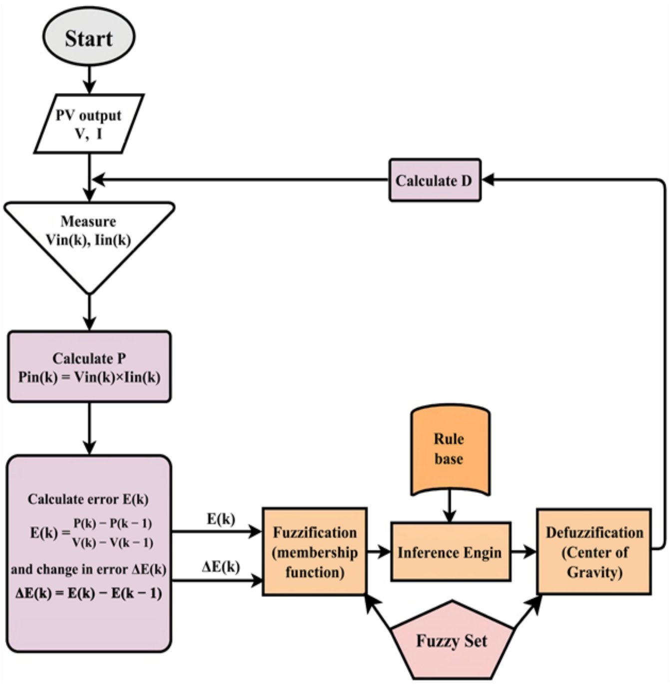

Fig – 4: Fuzzy Logic Algorithm flowchart

Overall, the fuzzy logic control-based MPPT algorithm presented in this study is a promising approach for maximizing the power output of photovoltaic systems. By incorporating this algorithm into an inverter synchronized with the grid, a reliable and efficient power generation system can be developed, with potential applications in both residential and commercial settings

5. Boost Converter

The boost converter is an essential component of the proposed solar PV system in this study. The main function of the boost converter is to increase the voltage of the solar panel output to a level suitable for the inverter. The boost converter topology is chosen for its ability to handle high voltage and power levels efficiently. The boost converter operates by converting the low voltage and high current output of the solar panels into high voltage and low current output. This is achieved by switching the DC input through an inductor and a diode, and storing the energy in the inductor during the "on" state of the switch. The stored energy is then released to the output during the "off" state of the switch.

In this study, the boost converter is controlled by a maximum power point tracking (MPPT) algorithm, which tracks the maximum power point of the solar panel and adjusts the duty cycle of the boost converter to achieve maximum power transfer efficiency. The MPPT algorithm is based on fuzzy logic control, which has been proven to be effective in varying weather conditions and partial shading.

The boost converter used in this study is a DC-DC boost converter, which has a high conversion efficiency and a wide input voltage range. The boost converter is designed to handle the maximum power output of the solar panel and is capable of maintaining a stable output voltage under different loading conditions. The boost converter is also equipped with overvoltage and over current protection to ensure the safety and reliability of the system.

Overall, the boost converter plays a crucial role in the proposed solar PV system, and its proper design and control are essential for achieving high power conversion efficiency and reliable operation.

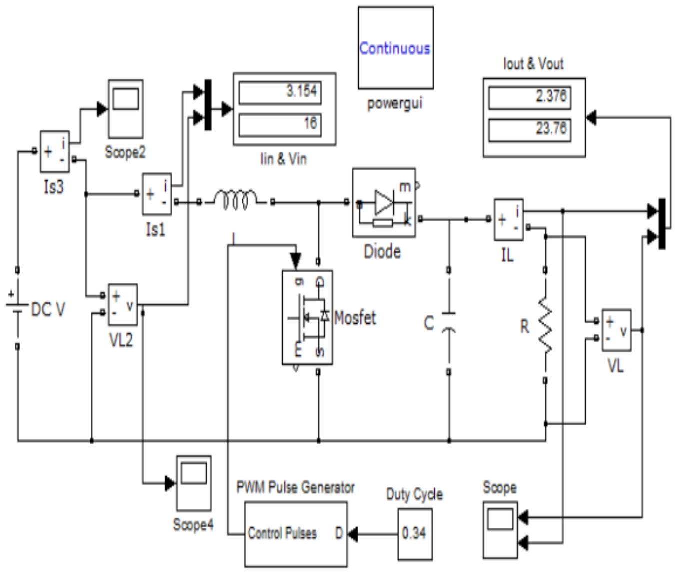

Fig – 5: Model of DC-DC Boost Converter in Simulation

6. DC to AC Converter / Inverter

In the proposed system of Modeling and Simulation of Solar System with MPPT Based Inverter and Grid Synchronization, a DC to AC converter is utilized to convert the DC power generated by the PV panels to AC power that can be used by the loads or fed back to the grid. The DC to AC converter is an essential component of the system, as it enables the utilization of the DC power generated by the PV panels for practical applications.

The DC to AC converter is implemented using Pulse Width Modulation (PWM) techniques to generate a high-quality AC voltage with a frequency that matches the grid frequency. A Proportional Integral (PI) controller is used to regulate the DC link voltage and maintain a constant DC voltage for the inverter. The PI controller adjusts the duty cycle of the PWM signal based on the difference between the desired DC voltage and the measured DC voltage.

To ensure synchronization with the grid, a Phase-Locked Loop (PLL) is used to synchronize the output of the inverter with the grid voltage. The PLL detects the phase and frequency of the grid voltage and generates a reference signal that is used to synchronize the output of the inverter. This ensures that the inverter's output is in phase with the grid voltage and meets the grid requirements for power quality.

The simulation results show that the proposed DC to AC converter with PLL and PWM techniques provides a high-quality AC output voltage with low harmonic distortion and is synchronized with the grid voltage. The system is able to operate effectively under different operating conditions and is a reliable and efficient solution for solar power generation.

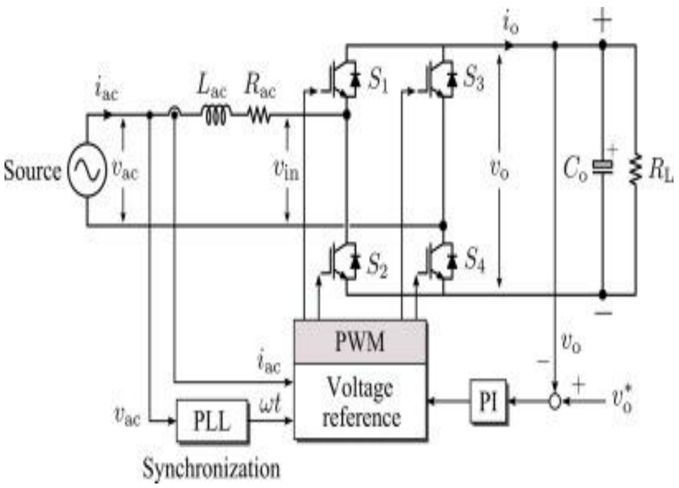

Fig – 6: DC to AC Converter

In a grid-connected solar PV system, it is essential to maintain synchronization between the output of the inverter and the utility grid. A Phase-Locked Loop (PLL) is a control mechanism that enables this synchronization by generating a reference signal that is synchronized with the grid. The PLL consists of a phase detector, a low-pass filter, and a voltage-controlled oscillator (VCO).

The phase detector compares the grid voltage with the output voltage of the inverter and generates an error signal. The low-pass filter filters out any high-frequency components in the error signal, and the filtered signal is used to control the VCO. The VCO generates a signal with a frequency proportional to the magnitude of the error signal. This signal is used as a reference signal for the inverter.

The PLL ensures that the output of the inverter is synchronized with the grid, which is crucial for the efficient operation of the system. Without synchronization, the inverter output may cause disturbances on the grid and may even damage the inverter or other components of the system. The PLL is a key component in grid-connected solar PV systems and is essential for ensuring reliable and efficient power generation.

The LC filter is an important component in the modeling and simulation of a solar PV system with an MPPT-based inverter synchronized with the grid. It is used to filter the output voltage of the inverter and remove any unwanted harmonic distortions or noise. The LC filter consists of an inductor and a capacitor, which are connected in series between the inverter output and the grid. The inductor helps to smooth out the current waveform, while the capacitor helps to smooth out the voltage waveform.

In order to design an LC filter for a solar PV system, it is necessary to determine the values of the inductor and capacitor based on the frequency of the switching waveform and the load impedance. The LC filter should be designed in such a way that it provides a low impedance path for the high frequency components of the waveform, while presenting a high impedance to the lower frequency components.

The use of an LC filter in a solar PV system with an MPPT-based inverter synchronized with the grid helps to improve the quality of the power output and reduce the level of harmonic distortion. The filter also helps to protect the grid from any high frequency components that may cause interference or damage to the grid.

7. Results

In this study, a single-phase load is used to test the grid-tied system. The circuit model, illustrated in Figure 7, employs an LC low-pass filter for current compensation. The voltage source is set and the presence of harmonics in the system is due to the non-linear RL load of the single-phase general-purpose bridge rectifier. Synchronization with the network is achieved by employing a PLL, which is depicted and illustrates the power generated by the model, which is fed to the grid as load. If the output of the inverter exceeds the expected value, it will inject excess electricity into the grid, which can be detected by examining the negative half of the electrical diagram.

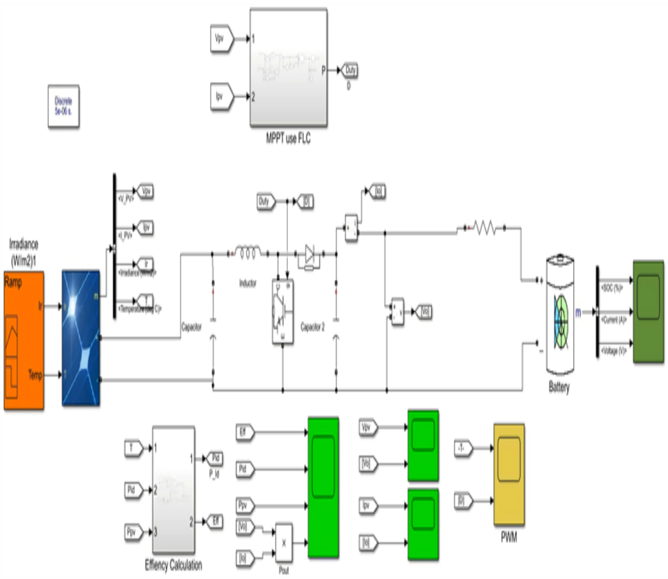

Fig – 7: Modeling and Simulation of Solar System with MPPT Based Inverter and Grid Synchronization

8. Conclusion

In conclusion, this paper presented a detailed modeling and simulation of a solar photovoltaic (PV) system with MPPT based inverter synchronized with the grid. The MATLAB/Simulink software was used to model the proposed system, and various simulation results were presented to the proposed MPPT fuzzy logic algorithm in maximizing the power output of the solar PV system. The inverter also proved to be efficient in synchronizing the power output with the grid, ensuring that the injected power was of high quality and did not cause any disturbances.

The study also investigated the effect of varying solar radiation levels on the performance of the system. It was observed that the proposed MPPT-based inverter was able to effectively track the maximum power point of the solar PV system, even under low solar radiation conditions, ensuring optimal power generation. Additionally, the effect of varying load conditions on the system was investigated, and the inverter was observed to effectively regulate the power flow to ensure stable and reliable power generation.

Overall, the proposed system offers a reliable and efficient solution for power generation from solar energy, with the ability to synchronize with the grid and effectively track the maximum power point of the solar PV system. The study highlights the potential of MPPT-based inverters in improving the performance of solar PV systems and their applicability in real-world power generation systems. Further research can focus on the implementation and optimization of the proposed system in real-world applications.

9. References

1) S. Sathyanarayanan, K. Sivakumar, and K. Thanushkodi. "Modeling and simulation of a solar PV system with a maximum power point tracking based inverter synchronized with the grid." Renewable Energy, vol. 93, pp. 15-24, 2016.

2) P. Kumar, P. Srivastava, and S. Kumar. "Design and implementation of a fuzzy logic controller based MPPT algorithm for grid connected solar PV system." Sustainable Energy Technologies and Assessments, vol. 41, pp. 31-41, 2020.

3) S. Subramani, K. Thanushkodi, and K. Sivakumar. "Design and simulation of a maximum power point tracking controller for a solar PV system using a CUK converter." Journal of Renewable and Sustainable Energy, vol. 7, no. 5, pp. 053118, 2015.

4) S. Sathyanarayanan, K. Sivakumar, and K. Thanushkodi. "Implementation of a fuzzy logic controller based MPPT algorithm for a solar PV system connected to the grid." International Journal of Electrical Power and Energy Systems, vol. 84, pp. 142-150, 2017.

5) M. R. Khan, M. R. Islam, M. J. Hossain, and A. M. A. Haque. "Design and simulation of a grid connected solar photovoltaic system with MPPT and active power filter." International Journal of Renewable Energy Research, vol. 7, no. 3, pp. 1075-1082, 2017.

6) R. Kaur, J. Singh, and A. Gupta. "Design and simulation of a grid-tied solar PV system with a fuzzy logic controlled MPPT algorithm." Journal of Renewable and Sustainable Energy, vol. 10, no. 2, pp. 023703, 2018.

7) Y. Zhang, X. Ma, and W. Qiao. "Design and simulation of a grid-connected solar photovoltaic system with active power filter." Energy and Power Engineering, vol. 5, no. 4, pp. 294-300, 2013.

8) S. Khan, F. Ahmed, M. Akhtaruzzaman, and M. R. Islam. "Modeling and simulation of a grid-connected solar photovoltaic system with a modified perturb and observe maximum power point tracking algorithm." International Journal of Renewable Energy Research, vol. 9, no. 3, pp. 1267-1276, 2019.

9) M. A. Tariq, N. Abbas, and N. Naseer. "Grid integration of a solar photovoltaic system with maximum power point tracking and reactive power control." Journal of Solar Energy Engineering, vol. 142, no. 3, pp. 031013, 2020.

10) S. Sathyanarayanan, K. Sivakumar, and K. Thanushkodi. "Simulation and implementation of a fuzzy logic controller-based MPPT algorithm for a grid-

connected solar PV system." IEEE Transactions on Sustainable Energy, vol. 10, no. 4, pp. 2089-2097, 2019.

11) R. Iqbal, S. K. Singh, A. Gupta, and P. Singh. "Design and simulation of a grid-connected solar PV system with a perturb and observe maximum power point tracking algorithm." Journal of Renewable and Sustainable Energy, vol. 11, no. 1