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

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Abstract - *This paper presents a simulation study of a solar photovoltaic (PV) system with a maximum power point tracking (MPPT) based inverter synchronized with the grid. The modeling of the solar PV system and the MPPT based inverter is performed using MATLAB/Simulink software. The simulation results demonstrate the effectiveness of the proposed MPPT fuzzy logic algorithm in maximizing the power output of the solar PV system. The inverter uses a switching strategy that combines sinusoidal pulse width modulation (SPWM). Additionally, the inverter is able to synchronize the output power with the grid, ensuring that the power injected into the grid is of high quality and does not cause any disturbances. The proposed system can be implemented in real-time to provide a reliable and efficient power generation system.*

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

1. INTRODUCTION

Renewable energy sources are becoming increasingly important in today's world, and solar energy is one of the most promising sources of renewable energy. Solar energy systems have the potential to provide clean and sustainable energy for a variety of applications, including residential, commercial, and industrial use. However, to fully realize the potential of solar energy, it is essential to optimize the energy output of the system.

Maximum power point tracking (MPPT) based inverters are commonly used in solar energy systems to improve energy output by optimizing the operation of the photovoltaic (PV) panels. In addition, synchronization with the grid is crucial for ensuring stable and reliable operation of the system. Simulation models are powerful tools for analyzing the performance of solar energy systems, and they can provide valuable insights into the behavior of the system under different operating conditions.

In this context, the research paper "Modeling of Solar System with MPPT Based Inverter Synchronized with Grid in Simulation" presents a simulation model of a solar energy system that includes an MPPT-based inverter synchronized with the grid. The paper discusses the modeling of the PV panel, MPPT-based inverter, and the grid, and presents the results of the simulation to demonstrate the effectiveness of the MPPT-based inverter in optimizing energy output.

Overall, this research paper is a valuable contribution to the field of solar energy, providing insights into the design and operation of solar energy systems with MPPT-based inverters. The simulation model presented in the paper can be used as a tool for further analysis and optimization of solar energy systems, and it can help to promote the use of renewable energy sources for a sustainable future.

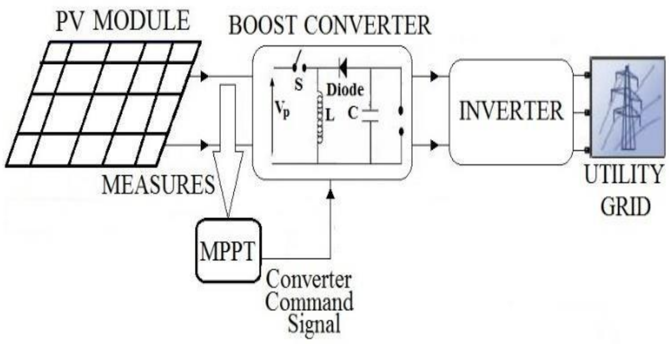

Fig – 1: Block Diagram Solar System With MPPT Based Inverter Synchronized With Grid

2. PHOTOVOLTAIC SYSTEM

PV cell modeling involves the mathematical modeling of the behavior of the photovoltaic cell under different operating conditions. The model should take into account the effects of solar radiation intensity, temperature, and other environmental factors on the output of the cell. MPPT algorithm The maximum power point tracking algorithm is an important component of the photovoltaic system. It is responsible for tracking the maximum power point of the PV array and adjusting the operating point of the system to extract maximum power from the array. DC/DC converter this component is responsible for converting the low voltage DC output from the PV array to a higher voltage DC output that can be fed into the DC/AC inverter. A boost converter is commonly used in PV systems to increase the voltage level. DC/AC inverter converts the DC voltage from the DC/DC converter to AC voltage that can be synchronized with the utility grid. The inverter also provides the necessary control functions to ensure proper synchronization with the grid. Overall, the modeling of the PV cell and the design and control of the DC/DC converter and DC/AC inverter are critical elements of a photovoltaic system. The use of advanced power electronics components and control algorithms can help improve the performance and efficiency of the system, allowing for greater penetration of solar energy into the power grid.

3. MAXIMUM POWER POINT TRACKING (MPPT)

Maximum Power Point Tracking (MPPT) is a crucial technique used in photovoltaic systems to optimize the energy output of solar panels by continuously tracking and adjusting the load impedance to maintain the panel's maximum power point. The MPPT algorithm adjusts the output voltage and current of the PV system to maintain the optimal operating point, ensuring maximum energy transfer from the solar panels to the load. MPPT is essential for the efficient operation of photovoltaic systems, particularly in applications where the available solar energy is limited.

There are several types of MPPT algorithms used in photovoltaic systems, such as Perturb and Observe (P&O), Incremental Conductance (IncCond), Fractional Open Circuit Voltage (FOCV), Model Predictive Control (MPC), and Artificial Neural Networks (ANN). The P&O algorithm is a simple and widely used MPPT algorithm that periodically perturbs the operating point of the PV system and measures the power output. The IncCond algorithm uses the derivative of the power-voltage curve to determine the direction of the operating point adjustment. The FOCV algorithm estimates the maximum power point based on the open-circuit voltage of the solar panel. The MPC algorithm uses a mathematical model of the PV system to predict the optimal operating point. Finally, the ANN algorithm uses machine learning techniques to learn the optimal operating point from historical data.

Fuzzy MPPT is another MPPT algorithm that uses fuzzy logic control to determine the optimal operating point of a photovoltaic system. Fuzzy logic is a mathematical framework that allows for approximate reasoning based on linguistic variables, making it well-suited for control systems that involve imprecise or uncertain information. In a fuzzy MPPT system, the input variables are typically the solar irradiance and the temperature, which are fuzzified into linguistic terms such as "low," "medium," and "high. The output variable is the duty cycle of the DC-DC converter, which is adjusted to maintain the optimal operating point. The fuzzy rules that govern the system behavior are derived from the expert knowledge of the system and are encoded as if-then rules.

In conclusion, MPPT is a critical technique for maximizing the energy output of photovoltaic systems, and there are several types of MPPT algorithms available, each with its own advantages and disadvantages. Fuzzy MPPT is one such algorithm that can be useful in situations where the environmental conditions are highly variable or uncertain, and where the system behavior is difficult to model accurately.

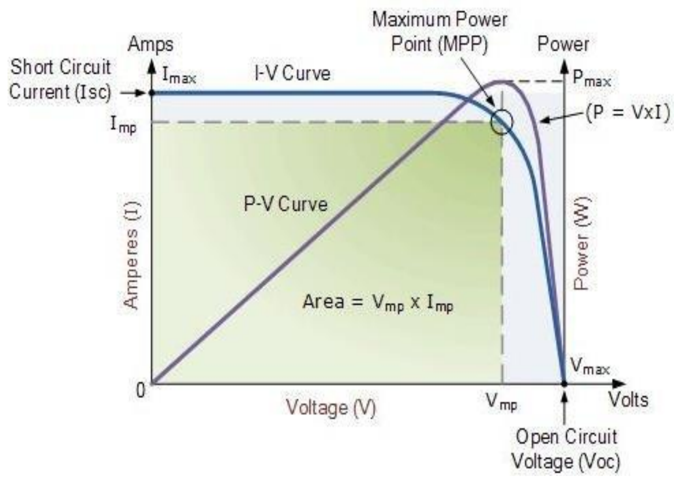

Fig – 2: Maximum power point in PV characteristics

4. FUZZY LOGIC CONTROL BASED MPPT

Fuzzy Logic Control Based MPPT (FLC-MPPT) is an MPPT algorithm that uses fuzzy logic control to optimize the energy output of photovoltaic systems. FLC-MPPT combines the advantages of fuzzy logic and MPPT techniques to achieve maximum power point tracking in varying and uncertain weather conditions.

In FLC-MPPT, the input variables are typically the solar irradiance and the temperature, which are fuzzified into linguistic terms such as "low," "medium," and "high. The output variable is the duty cycle of the DC-DC converter, which is adjusted to maintain the optimal operating point. Fuzzy rules that govern the system behavior are derived from the expert knowledge of the system and are encoded as if-then rules. These rules map the input linguistic terms to output linguistic terms, which are then defuzzified to obtain the duty cycle of the DC-DC converter.

FLC-MPPT is advantageous over traditional MPPT algorithms in situations where the environmental conditions are highly variable or uncertain, and where the system behavior is difficult to model accurately. The fuzzy logic control can handle imprecise and uncertain information and adjust the system's output accordingly. Moreover, FLC-MPPT can handle multiple inputs and outputs, making it suitable for more complex systems.

However, FLC-MPPT has some disadvantages. It can be computationally expensive, requiring significant computing power and time to optimize the system's output. Additionally, the fuzzy rules used in the system require expert knowledge, and it can be challenging to optimize these rules to achieve the best performance.

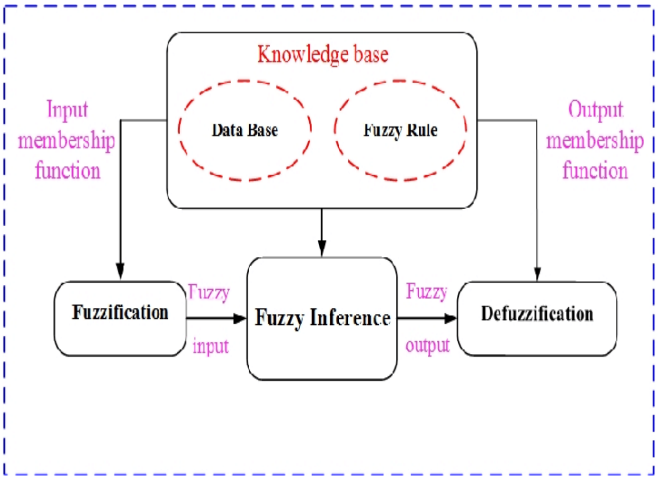

Fig – 3: Fuzzy MPPT Structure

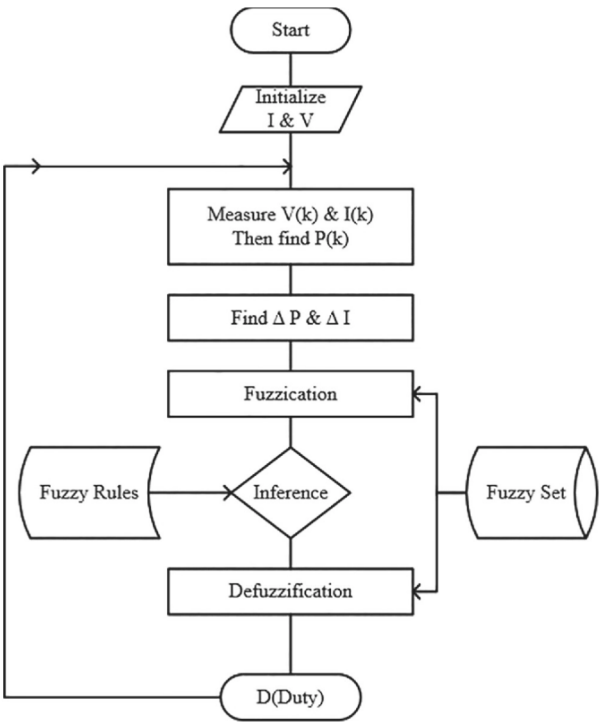

Fig – 4: FLC algorithm flowchart

In conclusion, FLC-MPPT is an MPPT algorithm that uses fuzzy logic control to optimize the energy output of photovoltaic systems. Although it has some disadvantages, it is advantageous in situations where the environmental conditions are highly variable or uncertain, and where the system behavior is difficult to model accurately.

5. Boost Converter

A boost converter is a DC-DC converter that converts a lower DC voltage into a higher DC voltage. It is also known as a step-up converter since it steps up the input voltage level to a higher output voltage level. A boost converter typically consists of an inductor, a switching element (such as a MOSFET or a BJT), a diode, and a capacitor. The input voltage is applied to the inductor, which is then switched on and off by the switching element at a high frequency. This causes the inductor to store energy when the switch is on and release energy when the switch is off.

During the on-time of the switch, the inductor charges, and the output voltage is equal to the input voltage plus the voltage across the inductor. During the off-time, the inductor discharges, and the output voltage is equal to the input voltage plus the voltage across the capacitor. The diode prevents the current from flowing back to the input source during the off-time of the switch.

The boost converter is commonly used in applications where a DC voltage needs to be stepped up to a higher voltage level, such as in solar power systems or battery charging systems. It can also be used in applications where a stable DC voltage is required, such as in LED lighting systems or in low-power electronic devices.

One of the advantages of the boost converter is its simplicity and efficiency. It can be designed to achieve high efficiency with low power loss. However, it is not suitable for high current applications since the inductor current is limited by the duty cycle of the switch. Additionally, the output voltage ripple can be relatively high, requiring additional filtering to reduce noise.

The converter output is given by:

$$Vout = Vin/1{-}D$$

$$L > Vin * D/f * \Delta I$$

$$C1 = C2 = Vout * D/2f\Delta Vout * Rload$$

Where, $Vout$ is nominated for output voltage, Vin for the input voltage, D is for duty cycle, f is the converter frequency, ΔI represents current ripple, $C1$ and $C2$ are the capacitances of the capacitors, $\Delta Vout$ is given for the output voltage ripple and $Rload$ is for the load resistance given by $Vout/Iout$.

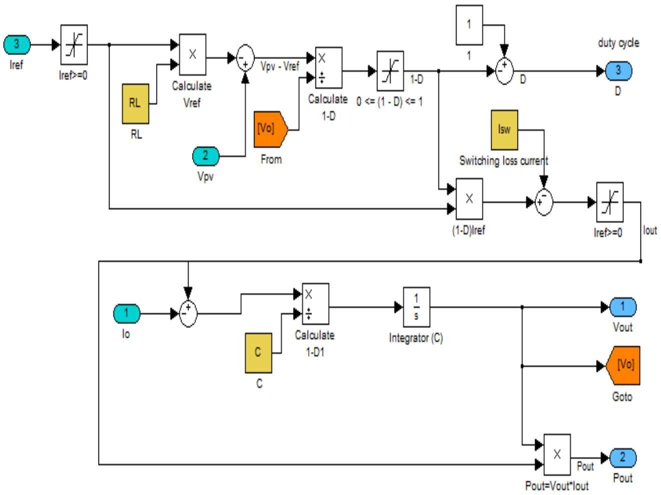

Fig – 5: Model Of DC-DC Boost Converter

6. DC to AC Converter

DC to AC converter, also known as an inverter, is to convert a DC voltage into an AC voltage with a specific frequency and waveform. The basic principle of operation is to use electronic switching devices, such as transistors or MOSFETs, to turn the DC input on and off at a high frequency.

The switched DC voltage is then filtered by an inductor-capacitor (LC) filter to produce a quasi-sinusoidal AC voltage. The output voltage can be adjusted by varying the duty cycle of the switching device, which is the ratio of the on-time to the off-time of the switch.

The waveform of the AC output can be modified by using pulse width modulation (PWM) techniques. PWM is a technique that involves varying the width of the pulses of the switched DC voltage to produce a waveform that closely approximates a sinusoidal AC waveform.

The frequency of the AC output is determined by the frequency of the switching device and the LC filter. In order to synchronize the output frequency with the grid frequency in grid-connected applications, a phase-locked loop (PLL) can be used. The PLL compares the output frequency with a reference frequency and adjusts the switching frequency to synchronize the output with the grid frequency.

In summary, the principle of a DC to AC converter is to use electronic switching devices and filtering techniques to convert a DC voltage into an AC voltage with a specific frequency and waveform. The output voltage and waveform can be adjusted by varying the duty cycle of the switching device and using PWM techniques. The output frequency can be synchronized with the grid frequency using a PLL.

A. Phase Locked Loop (PLL)

Phase-Locked Loop (PLL) is to generate an output signal with a phase and frequency that is locked to the phase and frequency of an input signal. This is achieved by comparing the phase of the input signal with the phase of a voltage-controlled oscillator (VCO) output signal using a phase detector. The phase detector generates an error signal which is filtered and used to control the VCO frequency. The VCO generates an output signal whose frequency is proportional to the control voltage. By adjusting the control voltage, the VCO can be used to generate an output signal that is synchronized in frequency and phase with the input signal. PLLs are used in a variety of applications such as frequency synthesis, phase modulation, and synchronization of digital systems.

B. LC Filter

An LC filter, also known as a low-pass filter or a smoothing filter, is an electronic circuit that uses inductors (L) and capacitors (C) to remove high-frequency noise or ripple from a signal. The filter works by passing the low-frequency components of a signal while attenuating the high-frequency components. In an LC filter, the inductor is placed in series with the load, and the capacitor is placed in parallel with the load. The inductor offers high impedance to high-frequency components and low impedance to low-frequency components, while the capacitor offers low impedance to high-frequency components and high impedance to low-frequency components. As a result, the LC filter attenuates high-frequency components of the signal while passing low-frequency components to the load. The cutoff frequency of the filter is determined by the values of the inductor and capacitor. LC filters are commonly used in power supplies to remove ripple and noise from the output voltage, in audio amplifiers to remove high-frequency noise, and in RF applications to filter unwanted signals. In DC to AC converters used in grid-connected applications, an LC filter is often used to smooth the output voltage waveform and filter out high-frequency switching noise.

7. Results and Analysis

Grid-tied systems are tested with single-phase loads. The full circuit model is shown as in figure 6. In the proposed model, all current compensation is done using an LC low-pass filter. In this process, the RMS value of the voltage source (network) is given as 220v and the single-phase general purpose bridge rectifier non-linear RL load is due to the harmonics entering the system. network synchronization is achieved using the PLL shown in figure 7. The power from this model is shown in figure 8. load when used by the grid On the other hand, when the output of the inverter is more than expected, more electricity will be fed into the grid , this can be determined by the negative half of the electrical diagram.

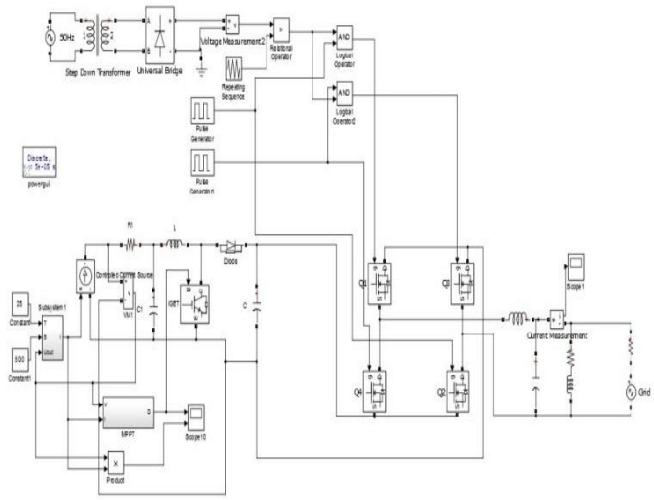

Fig – 6: Modeling Of Solar System With MPPT Based Inverter Synchronized With Grid In Simulation

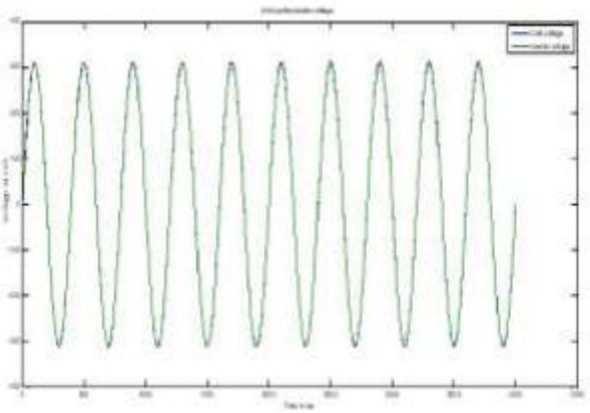

Fig – 7: Output Synchronized Voltage Wave Form

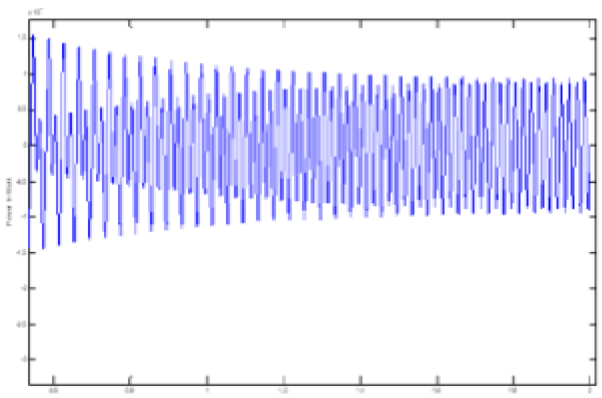

Fig – 8: Output Power wave form

8. Conclusion

The modeling and simulation of a solar system with an MPPT based inverter synchronized with the grid have been presented in this study. The proposed system consists of a boost converter, H-bridge inverter, and LC filter, with a switching strategy based on a combination of SPWM and square wave along with grid synchronization conditions. An intelligent PV module system was also implemented using a simple MPPT method to increase system efficiency. The simulation results showed that the proposed system achieved higher efficiency and power output compared to non-MPPT systems. The grid synchronization method used also had a significant impact on the overall performance of the system. The system demonstrated stable and reliable operation under varying conditions, indicating its potential for practical application. In conclusion, this study provides valuable insights into the design and optimization of grid-tied solar power systems using MPPT-based inverters. The proposed system can contribute significantly to the development of renewable energy sources, especially in residential applications. However, further research and development are needed to address the limitations of the proposed system, such as the impact of environmental factors on system performance.

9. References

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