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Building A Single-Phase Grid-Tied Inverter With Maximum Power Point Tracking (MPPT)

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ABSTRACT

Renewable energy has been used in many electrical appliances to make our world pollution-free, environmentally friendly, and reliable. In this paper, solar power as renewable energy is used in different types of inverters to convert all DC power to AC power which will fed into the electric utility in case any power outages happen. The grid-tied inverter (GTI) uses a local oscillator to synchronize the frequency (range: 50 or 60 Hz) with the grid. In GTI operation there are two different types of charge controllers used such as Pulse Width Modulation (PWM) and MPPT. MPPT is an electronic converter that converts a solar panel's high-voltage DC output to lower DC voltage to charge the battery bank or the utility grid. In this paper main objective is to review the GT inverters with MPPT techniques with different scenarios. The aim of this paper is to discuss and research different types of GT inverters with different charge controllers.

Keywords: *Renewable energy, Single-phase grid-tied inverter, Maximum Power Point Tracking (MPPT), Pulse Width Modulation (PWM)*

INTRODUCTION

Renewable energy sources are used in many different electric applications. The most commonly used renewable energy is solar power. Here the electricity is generated through solar thermal systems and solar Photovoltaic (PV) panels. These renewable inverters are also used in terms of inverter to give and store power in case of any power emergency. PV systems contain one or more solar panels. These solar panels are combined with electrical and mechanical hardware and an inverter to generate electricity from the energy of the Sun. The sun's light has energy called photons which fall on the solar panel to create electric current through the 'PV effect' (Vinod & Singh, 2018). The electricity is produced from solar panels or solar arrays in the form of DC. Then the inverter helps to convert the DC to AC and send the power to the electric grid for use. Basically, inverters are the source of power like emergency power backup. There are different types of inverters used in many applications.

Types of PV Inverters

Solar pump inverters are designed for solar water pump systems without battery storage. These inverters are used for livestock watering, irrigation systems, agricultural irrigation systems, etc. applications in remote areas.

1. **Standalone Inverter or Off-grid Inverter:** These inverters are designed for off-grid power systems with battery backup. These are suitable for village electrification, solar home systems, and rural electrification in remote areas (utility grid unavailable).
2. **Grid Connected Inverter or Grid Tie Inverter:** These are solely intended for applications linked to the grid. These applications that are connected to the grid don't need a battery backup solution. These inverters assist in converting the DC power from the PV array to AC power and supplying electricity to electrical appliances.
3. **Grid Interactive Inverter:** These Inverters are for industry, residential, and commercial applications. They can be applicable for both stand-alone off-grid and grid-tied operations. When the utility power is available, the inverter operates as a grid tie inverter. When the utility power is not available, the inverter operates as the backup power source to supply power.

4. **Hybrid Inverter:** These inverters are designed for hybrid power systems, which combines renewable energy sources like hydro generator, turbine generator, etc., and solar array with diesel generator. These inverters operate as either a GTI or a standalone inverter.

GTIs are used in residential areas to distribute the stored power to all houses as AC power. GTI with MPPT helps to charge the solar battery and maximize the power from solar panels, which is a renewable energy source. In residential settings, these GTIs are utilized to make sure that the grid electricity is delivered to each distribution panel of the home. The input side of GTI is DC and the output side is AC. The MPPT optimizes the power output on the DC side of GTI and the inverter confirms the sinusoidal output is synchronized to 60Hz grid frequency on the AC side. In order to extract the greatest power from solar panels, the MPPT technology is employed in grid-tie inverters and solar battery chargers. The GTI's solar panel capability can be divided into On-Grid and Off-Grid systems PV inverters. The On-Grid systems are used for power utilization in residential areas and Off-Grid systems are used for power utilization from solar panels and wind (Kumar, Gupta, Ranjan, & Shrivastava, 2017).

Literature Survey

(Raiker, et al., 2018) used a Current Referenced Boost Converter which performs both stepping up the voltage and tracking the maximum power point. Here they used PMW mode control with current feedback. This model was developed by the authors using integrated BESS and Solar PV to the grid through GTI. They used the Perturb and Observe (P&O) algorithm of MPPT to reduce the oscillation and accelerate tracking.
(Diouri, Es-Sbai, Errahimi, Gaga, & Alaoui, 2019) suggested a single-phase H-bridge inverter utilizing back-stepping control to remove the error between the target value and inverter's voltage and a DC-DC boost converter using a voltage created by the Perturb and Observation (P&O) method to extract the MPP. In order to verify the stability between the boost inverter and the H-bridge inverter, the authors used Lyapunov's stability theory. A reliable control strategy using a PV inverter system was given in this research.
(Estévez-Bén, Alvarez-Diazcomas, Macias-Bobadilla, & Rodríguez-Reséndiz, 2020) reviewed the state-of-the-art of grid-connected inverters. The authors settled that the grid-connected systems fulfil with specific standards according to each country or region. They did some analysis of common-mode voltage and the value of leakage current. The authors summarized and highlighted some advantages and disadvantages of the main strategies and topologies to reduce the leakage current in transformer-less schemes. Finally, they made the comparative analysis of each converter with different aspects such as; types of modulation strategy used, number of components, leakage current values, and types of modulation strategy.
(Shah, Dhaneria, Modi, Khambhadiya, & Kumar D, 2020) proposed a smart method for GT solar inverter using MPPT based on fuzzy logic. For the simulation part, the authors considered a single-phase dual-stage GT solar inverter using MATLAB Simulink. They made a comparative analysis between the fuzzy logic MPPT algorithm and the conventional MPPT algorithm (incremental conductance and integral regulator) to get better results.
(Sorte, Panda, Peesapati, & Panda, 2020) represented a “Single-phase Single-stage GT Photovoltaic Power Conditioning System (SSGPS) integrated with the Current Reference Control MPPT technique (CRC MPPT). The CRC MPPT technique was used by the authors to enable the fast-tracking maximum global power and inject the sinusoidal current into the grid at unity power factor using the current controller”. The authors did the analysis and simulation to get the experimental results that validate the stability of SSGPS’s dynamic workability and control scheme with the help of grid voltage change and sudden irradiation change.
Several researchers did some research on PV power generation. This research implies how to decrease environmental cleaning and pollution-free power on the Earth using solar power. The main parameter of the GTI is the charge controller. Furthermore, identify the charge controller of GTI which can be used in all areas including residential and professional areas. So, the main objective of this study is to make a comparative analysis of different charge controllers of GTI that can be used in every situation with their different parameters.

METHODOLOGY

There are two types of PV systems such as standalone and grid-connected. The PV system of standalone converts the PV electricity to the consumer’s appliance-wise AC loads. These power converters make the interaction between the AC loads and solar PV modules (Morales-Caporal, Rangel-Magdaleno, Peregrina-Barreto, & Morales-Caporal, 2018). The PV system of grid-connected is used to inject the DC power of the PV’s output into the grid as an interface.

The Grid-Tied Inverter (GTI)

GTI helps to convert the DC electric power to AC, which is suitable for injecting into an electric power grid with a range of 60 Hz at 120 V RMS or 50 Hz at 240 V RMS. These GTIs are used for local electric generators such as; wind turbines, solar panels, hydroelectric, and grid. These GTIs are designed so that if the utility grid goes

down, the inverters disconnect from the grid as soon as possible, (Diouri, Es-Sbai, Errahimi, Gaga, & Alaoui, 2019).
There are three types of GTIs, (Khan, Liu, Yang, & Yuan, 2020);

Table.1 Different Types of GTIs

Types	Micro Inverter	String Inverter	Central Inverter
No. of Solar Panels to convert DC to AC current	Single Solar Panel	Series of Solar Panels	Series of String Inverters
Current	DC to AC	DC to AC	DC to AC
Maximum DC Input Power (Pdcmax)	250Wp to 300Wp	2Wp to 30kWp	50Wp to 1MWp
Advantages	Offers individual monitoring systems.	Used in most common types GTIs.	Suitable for large solar farms and resistant to environmental damage.

The GT inverter or on-grid inverter requires voltage/frequency reference provided by the Grid/ Diesel and the off-grid inverter does not have any grid reference to start any appliances.

Maximum Power Point Tracking (MPPT)

MPPT helps with increasing the electricity amount from the solar panels and extracts most energy. PV cells are used as building blocks of solar panels. They use solar energy to generate electricity. The MPPT helps to track the maximum voltage of solar panels and adjusts the power according to the home appliance's power requirements. In the case of an on-grid solar system, the power is fed into the grid. PWM solar charge controller is a current control type controller. This helps to switch the PV array's input current in PWM modulation. PWM is a digital output of the microprocessor which controls the analog circuit.
The MPPT inverter has the built-in operation of a DC-to-DC converter. MPPT inverter produces maximum power and generates more electricity as soon as possible.

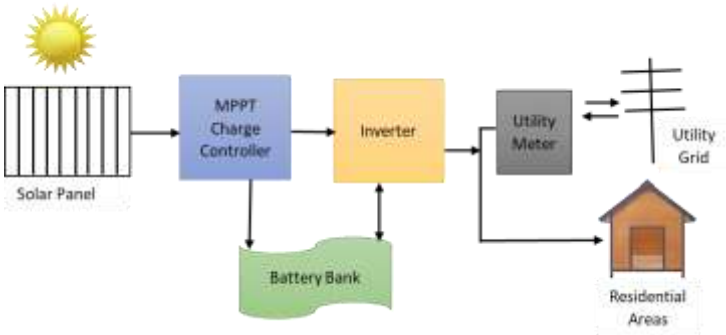

Figure.1 Grid-Tied Inverter with MPPT

The power generation at the solar station is lower than the original value. This causes waste of the system and brings inconvenience to the appliances. The MPPT charge controller helps to improve power generation. The efficiency of the MPPT solar controller's power generation is 20% higher than the PWM solar controller. This MPPT controller helps to perform intelligent calculations and tracks real-time monitoring of the solar panel's generation voltage with the highest voltage and current values (VI), (Khan, Liu, Yang, & Yuan, 2020).

$$\text{Power (P)} = \text{Solar Cell's Voltage (V)} * \text{Solar Cell's Current (I)} \quad \text{..... (1)}$$

MPPT helps to minimize power waste and maximize power generation of solar panels in both off-grid and on-grid systems.
Different MPPT Techniques that are used in inverters, (Baba, Liu, & Chen, 2020):

1. **Fixed Duty Cycle:** This technique does not need any feedback system where the maximum power is tracked only once when the load impedance is adjusted.
2. **Constant Voltage Method:** This technique shows that the voltage at MPP is high at the open circuit PV atmospheric condition.
3. **Perturb and Observe:** It operates the output terminal voltage of the photovoltaic and compares the current cycle power with precious cycle power.
4. **Incremental Conductance:** This technique implies that the PV's power slope is null at MPPT. The MPPT is found as an increment in array conductance because the positive is in the left and the negative is in the right.
5. **Ripple Correlation:** It is based on the MPPT principle where it uses oscillation's power in every pass filter. Finally, this technique captures the high-frequency ripple and optimal point in voltage and power using high-frequency filters.

6. **System Oscillation:** This technique uses oscillations to get the optimum point of operations. Here the ratio of the oscillation's amplitude and average voltage is constant at the MPPT.

RESULTS AND DISCUSSION

From the above research, GTI has micro, string, and central inverters with different Maximum DC input power. These inverters are used in most residential areas to distribute appropriate power to every house. GTIs convert DC power to AC power. There are two types of charge controllers used MPPT and PWM. PWM is only used for off-grid PV modules with Vmp of 17 to 18 Volts for every 12V battery whereas MPPT is used for on-grid and off-grid PV modules. GTI with the MPPT technique charges the solar battery and maximizes the power.
The process of GTI with the MPPT method is;

i. It evaluates the PV cell's output.
ii. Compares the PV cell's output with the voltage of the solar panel battery.
iii. It determines the power that is produced from the PV cell to charge the solar panel battery.
iv. Finally converts the power into voltage and ensures that the solar panel battery receives maximum current.

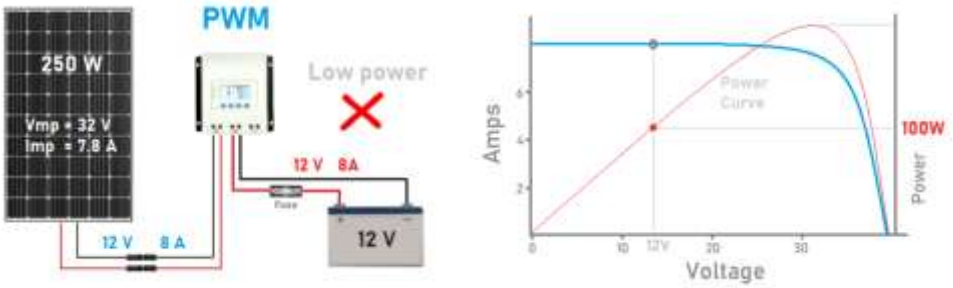

Figure.2 PWM Charge Controller and their Output, (Svarc, 2022)

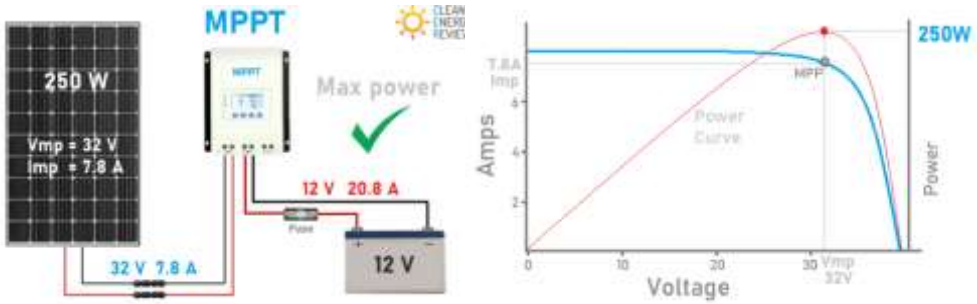

Figure.3 MPPT Charge Controller with their Output, (Svarc, 2022)

From the below table, we observe that GTI with an MPPT charge controller is better than PWM. MPPT charge controller can be used in both small appliances and professional appliances with high current, battery, and solar array power.

Comparative Analysis

Table.2 Different Charge Controllers that are Used in Solar Energy Systems

Parameters	**PWM**	**MPPT**
Efficiency	Less efficient (75% according to rule of thumb conversion)	More efficient (95%)
Battery	12 V	12 V
Solar Array	12 V	36 V
Max PV Voltages	25-50 volts	100-150 volts
Current	20-30 amps	30-40 amps
Connection	Requires wire to connect solar panels in parallel	It has high PV voltage limits to connect the wire with the solar panel series
Flexibility	Less	More
Expensive	Less	More
Use	Used in small applications	Used in professional applications

CONCLUSION

The main aim of this paper is to review a single-phase GTI with MPPT and PWM methods. The usages of GTI are in wind turbines, solar panels, hydroelectric, and grid. There are standalone inverters or off-grid inverters, grid-connected inverters or grid-tie inverters, grid-interactive inverters, and hybrid inverter types of different PV inverters used for solar panels. In this paper, we compare the PWM and MPPT charge controllers with their usage, voltage, current, flexibility, etc. in the GT inverters. The MPPT technique is used in solar battery chargers and GT inverters to get maximum power from solar panels.

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