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Control Techniques for MPPT of Grid Connected Photovoltaic Systems

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Abstract:
A grid-connected PV system is analyzed in this paper using MPPT techniques. A major goal of research has been finding methods that extract solar energy more efficiently, which has attracted numerous researchers towards photovoltaics (PVs). The nonlinear behavior of the device determines its output based on a variety of factors, including solar temperature and ambient irradiance. Using MPPT techniques, PV cells can achieve their maximum output. P&O and incremental conductance are two MPPT techniques that are most commonly used in this paper. As well as PWM techniques, three grid-connected inverters operating at 240 kV are compared. Solar energy systems must use Maximum Power Point Tracking (MPPT) to maximize power output under variable irradiation and climate conditions. This research deals with two MPPT algorithms for PV arrays connected to the grid: Perturb and Observe (P&O), and Fuzzy Logic Control (FLC). Analyzing and comparing the results of both algorithms is performed using MATLAB/Simulink.

Keywords: fuzzy logic controller, grid, photovoltaic, MPPT and P&O.

1. Introduction

Energy can be generated from solar power, wind power, rain power, tide power, and geothermal energy. There is no limit to how many times these resources can be replenished by nature [1]. The resources in this group can, therefore, be considered inexhaustible, contrary to conventional fossil fuels that are dwindling. Clean and Renewable Energy sources have grown and developed as a result of the global energy crunch. Across the globe, organizations are adopting Clean Development Mechanisms (CDMs) [2]. Additionally, fossil fuel reserves are rapidly declining due to pollution associated with combustion of fossil fuels. Renewable energy sources, on the other hand, are much cleaner than conventional energy sources and produce no harmful chemicals or pollution.

Scientists have been seeking and developing new renewable energy resources to answer global energy consumption and fossil fuel resource depletion. The most abundant sources of renewable energy are solar and wind power. PV energy has become a popular alternative to traditional energy sources due to its widespread availability, environmental friendliness, low operating and maintenance costs, and low balance of systems [3]. Thus, technological developments have led to lower PV module prices, enabling grid-connected PV systems, including low-voltage (LV) systems, to become more prevalent. PV systems are inefficient and their output characteristics vary with both irradiance and temperature. Solar arrays are nonlinear and their output characteristics change with both. The Maximum Power Points (MPPs) are power levels above which PV systems reach their maximum potential [4]. MPPT can be classified into two types: algorithms with low costs and low efficiency and algorithms with higher costs and higher efficiency. In the second category, we find MPPT methods that are controlled by intelligent algorithms. A complex method with high efficiency is used in these methods. It has been reported that many research studies have been conducted on MPPT techniques. A duty cycle is calculated by adjusting the load impedance only once for an MPP and not again by using the most basic of methods that do not require feedback.

By adapting the constant voltage tracking technique to weather conditions, the adaptive reference voltage (ARV)-based MPPT technique improves its performance [5]. Analog hardware can be used to implement constant voltage control. The MPPT tracking efficiency of this algorithm, however, is low in comparison with that of other algorithms. Based on the open circuit voltage, the authors designed a PV system using the SimPowerSystems platform in Matlab. A shading system was adapted to the open circuit voltage method. However, it is not always able to track the real peak, so the system operates near to the medium peak rather than at the real peak. Authors of the article presented two MPPT techniques in the article, a hybrid MPPT technique that combines Short Current Pulse (SCP) MPPT and Perturb & Observe (P&O) [6]. Due to its ease of implementation, this algorithm is the most common on standalone PV systems. Due to P&O's

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limitations, MPPT is less efficient than MPPT and requires complex control circuitry.

As In light of the increase in renewable energy sources, the need to maximize the efficiency of those sources is becoming more pressing. Indian power plants currently have an installed capacity of 353.90 GW as of 2019. Three quarters of the total capacity is accounted for by renewable power plants. Among the world's top producers and consumers of electricity, India is the third largest. There is a 6.7% solar power generation, a 9.8% wind power generation, a 15.04% hydro power generation, and a 2.5% biomass power generation [7]. Therefore, solar power is gaining more attention due to its abundance, freeness, eco-friendliness, and distribution of energy worldwide. The problem with it is that PV cells have a maximum efficiency of 18-21 % and their electrical power yield varies according to the weather conditions. Currently, the most common type of PV system is a grid-connected one [8]. It is also possible for the module to generate energy in addition to supplying it to the utility grid. In addition to balancing load, utility grids also take in power generated at the grid.

It maintains a phase relationship between its output current and the grid voltage by controlling its output current. Voltage or frequency outside normal ranges cause the inverter to disconnect. It reconnects after about five minutes when the voltage or frequency returns to normal. There should be no more than 5% THD in the AC voltage injected into the grid [9]. The power system becomes distorted by harmonic effects when voltages and currents are distorted, and equipment that maintains a steady and reliable flow of power is affected. The result is improper equipment behavior and nonsinusoidal currents and voltages due to high THD components. Furthermore, this equipment has a number of serious issues, including overheating, vibration, low power factor, overloading, and interference with communication. The most serious threat to the power system is harmonic pollution, since it pollutes the entire system. It is necessary to develop and implement solutions at the end of the supply chain in order to ensure high levels of power quality and continuity. Through appropriate inverter control, voltage and current harmonics are reduced, thus improving power quality.

2. Literature Review

30-40% of the incident energy can be converted into electrical energy by the solar panels. Maximum Power Point Tracking is a technique for increasing the efficiency of solar panels.

As well as experimenting with Perturb and Observe (hill climbing method), Incremental Conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Controls, and Neural Network Controls, there are several other MPPT methods available [10]. P&O and incremental conductance are the most popular methods for tracking MPPs, because they are simple, reduce time requirements, and have several other economic benefits. When MPP changes continuously due to abrupt changes in weather conditions (irradiance level), P&O defines this as a disturbance rather than an irradiance change, and therefore calculates MPP incorrectly [11]. By calculating MPP from two voltage and current samples, the incremental conductance method avoids this problem. Compared to the previous algorithm, this one is much more complex, which increases the implementation costs instead of lowering them. The trade-off between complexity and efficiency must be made to mitigate the problem.

There is no doubt that the converter has a significant influence on the system's efficiency. In buck-boost topology there are the most nodes, in boost topology there are the least nodes, in buck-boost topology there are the most nodes [12]. Other analog techniques, such as TEODI, which equalizes output operation points with displacements of input operation points, are also very effective when several solar modules are connected in parallel. Simple to implement, highly efficient, and usable in stationary and time-varying atmospheric conditions, it is one of the best atmospheric models available.

There are many natural resources that produce energy. Solar energy, wind power, rain power, tide power, and geothermal power are among them. Natural replenishment of these resources is possible [13]. In contrast to conventional fossil fuels, which are disappearing at an alarming rate, these resources are inexhaustible. A resurgence of growth and development is taking place in Clean and Renewable Energy due to the global energy crunch. Across the globe, organizations are adopting Clean Development Mechanisms (CDMs). Pollution associated with the combustion of fossil fuels is another major concern, in addition to the rapid decline in fossil fuel reserves [14]. In contrast, renewable energy sources produce clean energy without polluting the environment like conventional energy sources.

In recent years, photovoltaic power systems have gained popularity among renewable energy sources due to the high demand for energy and the need to reduce environmental pollution.

There are a number of ways in which grid-connected systems can be designed. PV systems connected to the grid can be classified in four types: one with a centralized inverter, one with a string inverter, one with a multistring inverter, or one with a module integrated inverter [15]. The advantages of PV systems linked to the grid include: low environmental impact, installation close to the consumer, reduction of transmission losses, low maintenance costs due to the lack of moving parts, modularity allows the system to expand its installed capacity, and no carbon dioxide is emitted. Aside from centralized inverter systems, all the types of inverters mentioned above can be applied to residential power distribution systems. Obtaining high voltage gains is the main challenge of photovoltaic distributed generator systems. A photovoltaic model has an open circuit voltage of about 20 volts, a maximum power point voltage of 16 volts, and a utility grid voltage of 220 volts [16].

Low total harmonic distortion (THD) and grid synchronization can only be achieved by using high voltage amplification. A grid-connected PV system's power electronics inverter converts power, interconnects, and optimizes its control [17]. To achieve grid synchronization, it is imperative to analyze and control the steady state. An inverter's output should be sinusoidal to ensure proper grid synchronization. PV systems require high power factor inverters with low THD, fast dynamic response, and low THD when it comes to control strategies. With the perturb and observe (P&O) algorithm, the controller must be able to track the maximum power point tracking mechanism (MPPT) and maintain power levels with the main voltage. MPPT, inverters, and power factor correction are three stages required to implement PV systems [18].

A renewable energy source is a renewable energy source that utilizes the sun, wind, rain, tides, and geothermal heat. It is possible to replenish these resources naturally and they are renewable. The resources from these sources are therefore unlimited, unlike conventional fossil fuels, which are depleting. Clean and renewable energy sources have been given an additional push by the global energy crisis. Worldwide, organizations of all sizes are adopting Clean Development Mechanisms (CDMs) [19]. Further deterrents to the use of fossil fuels include a rapidly diminishing supply of fossil fuels, as well as pollution caused by their combustion.

In contrast, renewable energy sources produce energy without the negative effects of pollution associated with traditional energy sources.

A growing number of renewable energy resources need to be exploited to their maximum potential. Presently, India has 354.50 GW of installed power generation capacity. Three-quarters of the total capacity comes from renewable power plants. With India ranking third in terms of electricity production and consumption, the country has an important role to play in balancing energy supply and demand [20]. About 5.7% of the total generation comes from solar power, 9.9% from wind power, 14.4% from hydro power, and 2.6% from biomass. Due to its abundance, free nature, eco-friendliness, and worldwide distribution, solar power is attracting more attention. PV cells have a maximum efficiency of 17-20%, but their electric power yield varies depending on weather conditions.

PV systems that are grid-connected are most commonly installed today. Energy can be generated and delivered to the utility grid through the module. Utility grids balance generation and load to provide power [21]. Using an inverter, the power grid voltage and output current are maintained in phase. The inverter disconnects and reconnects itself within five minutes when the voltage or frequency falls outside of normal ranges. A maximum THD of 5% is recommended for AC voltage injected into the grid. When harmonic distortions occur in voltage and current waveforms, power system equipment that is responsible for maintaining a steady power flow will behave improperly, causing nonsinusoidal currents and voltages to occur. There are many problems with this equipment, including overheating, vibration, low power factor, overloading, decreased efficiency, and communications interference. Power grid pollution is primarily caused by harmonics, which can be considered the main pollutant. The development and implementation of power delivery solutions is essential for ensuring power quality and continuity of supply [22]. Harmonic voltages and currents are reduced by using appropriate inverter control techniques to improve power quality.

Currently, the world is experiencing an acute energy crisis, which makes renewable energy sources more essential. By 2022, India will produce 20 gigawatts of solar power, while we had developed just half of our potential as a nation in March 2010. The use of solar energy is vital for a tropical country like ours due to its untapped potential [23].

High capital costs and low efficiency are the main obstacles to solar PV's penetration. By utilizing a PV module to the maximum extent possible, our study explores a schematic for using solar power for DC applications. The Maximum Power Point Tracking (MPPT) technique can significantly increase the efficiency of solar photovoltaic systems.

Simulated circuits were first run without the MPPT algorithm block, bypassing the MPPT algorithm block [24]. Without an MPPT algorithm, we observed 95 Watts of power at the load for 85 Watts per square meter solar irradiation. This level of solar irradiation generated approximately 250 Watts of power from the PV panel. Due to this, the conversion efficiency was extremely low. Afterward, MPPT mode was switched on for the simulation. The P & O algorithm calculated the Vref and fed it to the PI controller. Among the circuit components was the MPPT block. Around 250 Watts of power continued to be generated by the PV panel under the same irradiation conditions [25]. The photovoltaic system in this case, however, was able to generate around 215 Watts of power on the load side, increasing its conversion efficiency.

3. MPPT Techniques

Based on the position of the sun, the temperature, and the level of insulation, solar panels produce different amounts of electricity. PV systems also suffer from partial shading and cloudy days, which affect their output power. When the above conditions occur, PV panels' output power will decrease due to their low efficiency of 11 to 24.76 percent. Unlike solar panels, PV panels cannot be made more efficient, instead they can only be exploited at their maximum power, which is known as MPPT. PV array/panel locus maximum power point or MPPT is what the controller tracks in the PV array/panel.

MPPT can be classified into the following types [26]:

- Perturb & Observe
- Incremental Conductance
- Fuzzy Logic
- Fractional open circuit
- Fractional short circuit

3.1 Perturb & Observe

The MPPT method is a popular way to track maximum power points in photovoltaic systems (PVs) [27]. This system works by continuously perturbing (changing) the operating point of the PV system and observing the effect on power output. An algorithm adjusts the operating point based on whether the power increases or decreases. This algorithm tracks the maximum power point (MPP) of a PV system, which refers to the point at which the PV system can produce the most power possible under a given set of environmental circumstances (such as sunlight intensity). There are some drawbacks to the P&O algorithm, despite its simplicity and ease of implementation. For instance, it can oscillate around the MPP under certain conditions, especially when the PV system is subjected to rapidly changing irradiance levels [28]. Additionally, it may not converge quickly in some situations, leading to slower tracking of the MPP. Several more sophisticated MPPT algorithms have been developed to address some of these limitations, including the Incremental Conductance and Fractional Open Circuit Voltage algorithms. If voltage increases, MPPs operating on the left increase power and decrease power as voltage decreases, whereas if voltage decreases, MPPs operating on the right decrease power as well [29]. To achieve the desired MPP, perturbation must increase as power increases, and as power decreases, perturbation must increase.

3.2 Incremental Conductance

A negative slope is observed during MPP, a positive slope is observed on the right hand side, and a zero slope is observed at MPP. This technique assumes that MPP is symmetrical, that PV array slope is zero at MPP, that the slope is negative on the right side of MPP, and that the slope is positive on the left side [30]. When exposed to high levels of solar radiation, the system is highly efficient. Sensors perform the measurement. These tasks can easily be performed by microcontrollers and digital signal processors. The left side of the solar panel shows its instantaneous conductance. A MPP has been reached when instantaneous conductance equals solar conductance. Voltage and current are being sensed simultaneously, as you can see. In this way, the error resulting from changes in irradiance is eliminated. In spite of this, implementation costs and complexity increase. Implementing algorithms that are suitable for highly complex systems becomes more complex and expensive as you move down the list.

In order to solve this type of problem, both the Perturb and Observe algorithm as well as the Incremental Conductance algorithm have been extensively employed. Since Perturb & Observe is the simplest implementation of the two algorithms, we chose it.

3.3 Fuzzy Logic

Maximum Power Point Tracking (MPPT) techniques can be used to dynamically track photovoltaic systems [31]. In order to maximize power generation, these techniques use fuzzy inference systems to make decisions about adjusting the PV system's operating conditions. MPPT has become increasingly popular over the last decade due to microcontrollers [32]. The advantages of fuzzy logic controllers include the ability to handle nonlinear inputs, the lack of a mathematical model, and the ability to work with imprecise inputs.

3.4 Fractional open circuit

A fractional VOC could be calculated for PV arrays at different temperature and irradiance proportionality constants by considering VMPP and VOC [33]. PV array properties are empirically determined at various levels of irradiance and temperature in order to determine VMPP and VOC before hand because k1 depends on PV array properties. The value of k1 has been reported to range from 0.72 to 0.79. The VMPP can be calculated by taking periodic measurements of VOCs while the power converter is turned off for a short period of time. Though this is beneficial, there are some drawbacks, such as a brief loss of potency.

3.5 Fractional short circuit

When the proportionality constant k2 is used, fractional ISC results because IMPP is roughly linearly related to PV array ISC under a variety of atmospheric conditions [34]. When determining k2, it is important to consider the PV array being used, just like with fractional VOC. There is usually a range of 0.77 to 0.90 for the constant k2. It is challenging to measure ISC when in operation. The ISC is typically measured with a current sensor by

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periodically shorting the PV array as part of the power converter.

3.6 PWM Technique

In this technique, the width of the output pulses of a converter is changed in order to control its amplitude and frequency [35]. Furthermore, PWM reduces EMI, switching loss, and harmonic spectrum as well as Total Harmonic Distortion (THD). There are two types of PWM techniques: sinusoidal and triangular. Distribution and transmission networks can benefit from grid-tied inverters because they can use existing utility grid infrastructure. Various DC sources can be used to power the system, including batteries, solar cells, and solar panels. DC-DC converters can be used to boost voltage because the grid voltage is higher than the DC input voltage. The MPPT Algorithm Is Implemented as Follows:

MPPT is compared with PWM with the aim of determining which technique produces the least harmonic distortion of the output waveform. Simulation of the inverter is performed using MATLAB/Simulink using perturb & observe, incremental conductance, and PWM algorithms.

Table 1 lists the PV array's variables.

	Variables	SUNPOWER SPR415E-WHT-D
1	Number of cells per module	117
2	Maximum Power	412.203 W
3	Open Circuit Voltage (Voc)	82.7
4	Short Circuit Current (Isc)	5.89
5	Voltage at Maximum Power point (Vmp)	73.19
6	Current at Maximum power point (Imp)	6.09

PV There are 86 strings of 6 series on this module. They are connected to form a 240 KW PV array (86× 117× 412.203 = 252.46 KW).

Table: 2 Control Techniques and THD range

	Techniques	**“THD (%)”**
1	Incremental Conductance	14.326%
2	Perturb & Observe	13.418%
3	PWM	18.526%
4	Fractional open circuit	12.225%
5	Fractional short circuit	11.453%

240kV grid connected inverter simulation results are compared with THD based on all three techniques in table 2. Due to harmonics in the output current waveform, the system's efficiency is reduced. A comparison is made between MPPT and PWM techniques in this paper. A grid connected 240kV inverter is studied and compared using different inverter control techniques in Table 2.

Perturb & Observe technique shows to be more effective than other techniques since THD found by Perturb & Observe is 13.418%, as opposed to 14.326% and 18.526% found by Incremental conductance and PWM techniques. According to the results, fractional open circuits and fractional short circuits are both 12.225% and 11.453%, respectively. As can be seen in table 2, the results are as follows. Due to the fact that simulations are done under ideal conditions with no variation in load. Due to this, it is necessary to verify the results when performing with other hybrid systems.

4 Results and Discussions

4.3 *PV system connected to the grid using different techniques*

A step-up transformer 240V/25KV connects the PV module to the 240 KV grid via a DCDC converter, IGBT inverter, and step up converter.

Grid systems consist of the following components:

• There are three levels in this VSC, and it operates at 1980Hz (33*60). By converting 500 V DC to 260 V AC, the Voltage Source Converter maintains unity power factor.

• VSC-related harmonics are filtered by capacitor banks of 10 kVAR.

• Transformer with 260V/25KV three-phase coupling of 100KVA

• Distribution feeder with 25KV capacity and an equivalent transmission line with 120KV capacity.

In With Simulink, MPPT models of grid-connected PV systems are presented in figures 1 and 2.

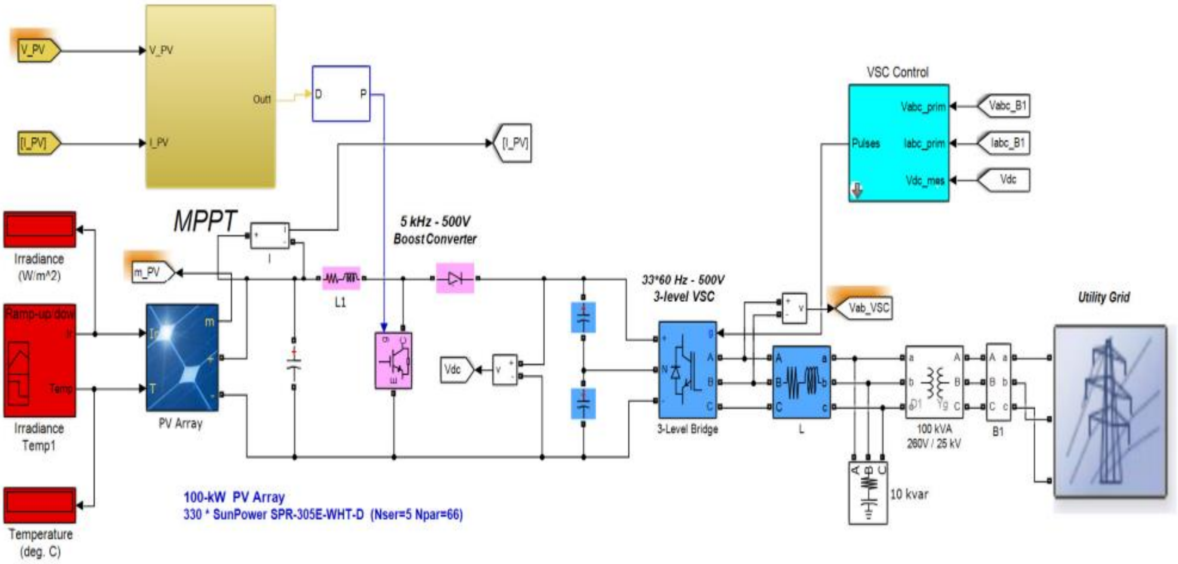

Fig. 1 PV system with grid connection using Incremental Conductance

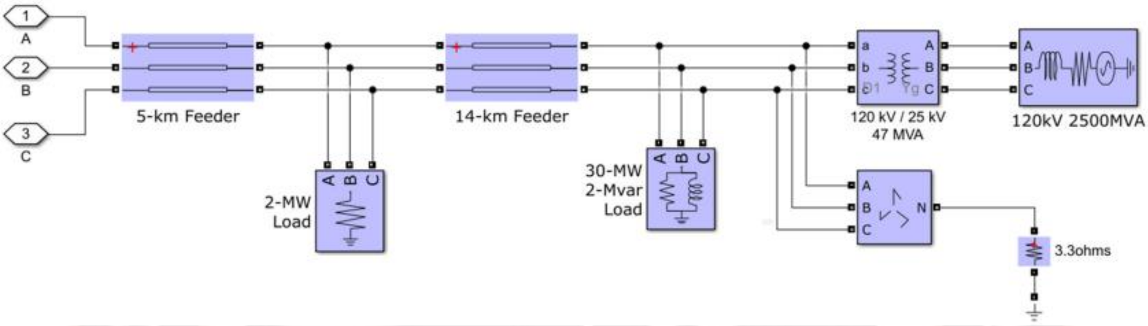

Fig: 2 Grid framework

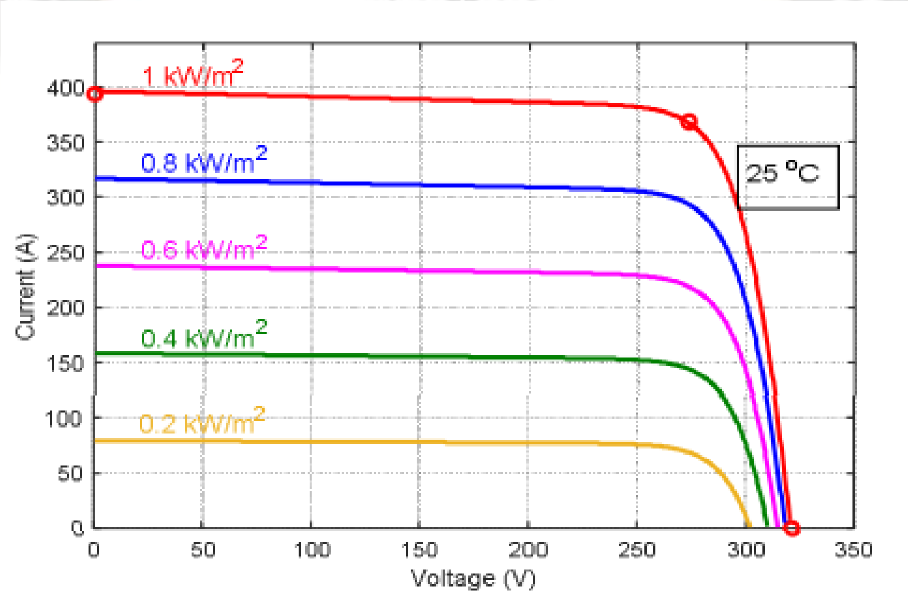

Fig. 3 PV module I-V characteristic at constant temperature and variable intensity of illumination

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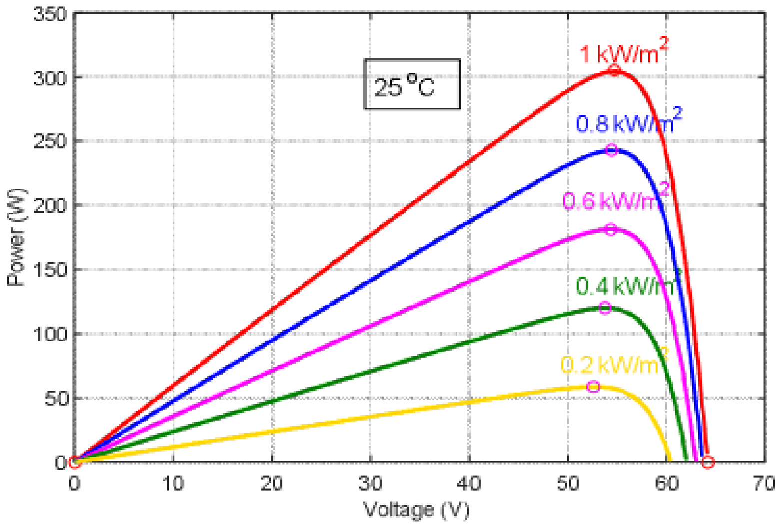

Fig: 4. P-V PV module characteristics under constant temperature and variable irradiation

An MPPT tracking method for grid-connected PV panels is tested in this paper to determine its feasibility and effectiveness. Figure 3 shows the simulation of the overall system performed in Matlab/Simulink. In this comparative study, the following MPPT methods are considered: P&O, FLC, CS, and Beta.
There are 64 strings in the PV array, which are connected to the boost converter and operated by the MPPT controller. Positive Big (PB), Negative Big (NB), and Zero (ZE) are the linguistic variables in this study. The grid details associated with the PV are shown in Figure 4. A constant 25oC temperature was maintained in the cells to examine the effect of solar irradiation on module characteristics.
A comparison of the Beta method to other known MPPT techniques is made, namely P&O, which introduces considerable oscillations near the MPP, resulting in power losses. In contrast to the results presented, the FLC and CS algorithms presented large oscillations around the MPP. As a confirmation of the efficacy of the proposed method, two comparisons were conducted: Power efficiency and settling time: MPPTs in PV systems are evaluated primarily on the basis of power efficiency and settling time. With 98.8% efficiency and 0.0254 seconds settling time, this paper proves the efficacy of the Beta technique. THD comparative study: The rate of distortion of the network currents (THD) is another factor considered in evaluating the performance of the control algorithms. Validation was done by comparing and contrasting the results of the FFT analysis.

5 Conclusion and Scope

A By comparing the pulse signal generated by the PWM generator with the signal generated by the MPPT device, the gating signal was generated for the switch. The duty cycle would have been entered by the user if MPPT had not been used. Changes in solar irradiation cause the maximum power point for the model to change, thereby changing the required duty cycle. By using constant duty cycles, the system is unable to track its maximum power point, reducing its efficiency. Plotting various waveforms in MATLAB was possible thanks to its plot mechanism. According to estimates, the boost converter loses a small amount of power to the solar panel. A boost converter's switching losses, as well as inductor and capacitor losses, may explain this phenomenon.
Parameters such as inductance, DC gain (kv), and timing constant (tv) of the inverter model greatly impact the dynamics of the system at switchover, and should be carefully chosen to ensure a stable periodic behavior. As long as both current and voltage are harmonically shaped, the voltage waveform is quite similar to that of a reference voltage when connected to a DC source rather than a PV source. Grid-connected PV systems are measured by their efficiency, which is an essential indicator of their power. An important indicator is MPPT performance. Tracking the operating point with the highest output requires using an MPPT algorithm. As part of this project, four MPPT algorithms were presented and compared: P&O, FLC, CS, and Beta, in regards to the injection of sinusoidal current into the electrical grid. Based on the simulation results, the Beta algorithm provided the best performance in following the MPP with minimal oscillations and the highest speed during a rapid change in solar irradiance.

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