International Journal for Modern Trends in Science and Technology
Volume 10, Issue 05, pages 20-29.
ISSN: 2455-3778 online
Available online at: http://www.ijmtst.com/vol10issue05.html
DOI: https://doi.org/10.46501/IJMTST1005005

A Review: Design of Solar Photovoltaic Based Sustainable Power Generating System

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To Cite this Article
Vivek Kumar Mehta and Dr. Deman kosale, A Review: Design of Solar Photovoltaic Based Sustainable Power Generating System, International Journal for Modern Trends in Science and Technology, 2024, 10(05), pages. 20-29. https://doi.org/10.46501/IJMTST1005005

Article Info
Received: 16 April 2024; Accepted: 04 May 2024; Published: 10 May 2024.

ABSTRACT

Global energy problems and environmental concerns caused by the depletion of conventional fossil fuels have pushed for an increase in renewable energy production throughout the world. Solar power contributes more to clean power generation than other renewable energy sources, making it an important factor in meeting electricity demand. However, one of the most pressing concerns in solar power is the effective integration of photovoltaic energy resources into existing electrical distribution networks. A steady supply of energy is the most important necessity for the world's fast industrial and economic progress. As a result, it is critical to develop and execute an efficient power conversion system using renewable energy sources in order to create a sustainable environment.

The primary goal of this study is to develop and deploy efficiency enhancement approaches for solar photovoltaic production systems. There are several flaws in the power conversion of renewable energy sources. The changes in output power are caused by the nonlinear nature of the photovoltaic system, the kind of power electronic interface utilized, and the nature of the load, which can lead to poor performance. A summary of problems in grid-connected solar photovoltaic generation system is listed as nonlinear I-V characteristics of photovoltaic system affecting the operating point, low power conversion efficiency due to changes in climatic conditions, poor dynamic response and low efficiency due to improper power electronic interface, the DC-DC converters suffer drawbacks such as lower efficiency, increased stress, cost, size, etc., and the conventional inverter take more time.

As a result, in this study, a strategy based on an enhanced maximum power point tracking algorithm, a high step-up DC-DC converter ii, and grid synchronization is proposed and tested for a grid-connected solar photovoltaic generating system. This method is highly successful for efficient power conversion in a solar photovoltaic power production system. The power output of a solar photovoltaic panel is primarily determined by its performance, sun irradiation, and temperature. Maximum power point tracking is the fundamental operation for increasing solar system efficiency. Based on the sun irradiation model, this study created an improved dP P&O maximum power point tracking approach. This approach seeks to overcome tracking direction uncertainty caused by rapidly changing solar irradiation.

1.INTRODUCTION

1.1 Generation of Power

Natural energy resources serve as the backbone of every country's ability to maintain itself in a period of climate change. Global energy demand has been increasing as a result of population increase, industrialization, and urbanization. A country's economic growth is more dependent on its industrial expansion, which consumes the majority of energy. Among the many energy resources, 80% of the energy is produced by the combustion of fossil fuels, raising major environmental problems. Unfortunately, fossil fuels may become exhausted over the next six decades (Ashourian et al. 2013). Taghvaee et al. (2013) forecast that oil fuels will run out in 2040, coal in 2030, and natural gas in 2060. The emission of carbon dioxide (CO_2) produces Natural energy resources are the backbone of every country's ability to maintain itself in a period of climate change. CO_2 emissions cause the greenhouse effect, which contributes to global warming. Global warming is predicted to raise the earth's temperature, which is dependent on coal; as a result, CO_2 emissions are expected to rise in the future. CO_2 emissions from power generation sectors account for around 38% of overall CO_2 emissions in India, which contributes 4% of total world CO_2 emissions.

1.2 Renewable Energy Power Generation

There are several renewable energy sources accessible across the world. India is a tropical country with an abundance of natural resources such as wind, solar, tidal, and geothermal to supply the power needs of both rural and urban regions. The sort of renewable energy source used relies on the location, accessibility, and availability of sources. However, of all the renewable energy sources, PV power generation is the most suited. Since the series and parallel connection of solar panels may provide electricity ranging from a few Killo Watts (KW) to several Megawatts (MW) depending on the voltage and current requirements.

1.3 Renewable Energy Power Generation in India

India is one of the countries that generates the most electricity from renewable sources. Renewable energy accounts for 34.6% of the total installed power capacity. The huge hydro project was installed with a capacity of 45.399 GW as of March 31, 2019, accounting for 13% of total electricity capacity. The remaining renewable energy sources accounted for 22% of total installed power capacity (77.641 GW) as of March 31, 2019. As of March 31, 2019, India's wind power capacity was around 36,625 MW, ranking it as the world's fourth-largest generator. The country has a significant manufacturing base in wind power, with 20 manufacturers producing 53 distinct wind turbine models of world quality up to 3 MW in size, with exports to Europe, the United States and other countries (source: Government of India, Ministry of New & Renewable Energy, 2019-20).

Wind or solar PV combined with four-hour battery storage systems is already cost competitive as a source of dispatchable electricity in India, even without subsidies, in comparison to new coal and gas facilities. The government's goal of constructing 20 GW of solar power by 2022 was met four years ahead of schedule in January 2018, using both solar parks and roof-top solar panels. India has set a new target of 100 GW of solar electricity by 2022. India has four of the world's top seven largest solar parks, including the second largest solar park in the world, Kurnool, Andhra Pradesh, with a capacity of 1000 MW. Bhadla Solar Park, in Rajasthan, is the world's biggest solar power facility. Its capacity of this solar power plant is 2255 MW.

TYPE OF GENERATING POWER	TOTAL INSTALLED CAPABILITY (MW)	2024 AIM (MW)
WIND POWER	35626	60000
SOLAR	28181	100000
SMALL HYDROPOWER PROJECTS	4593	5000
BIOMASS POWER & GASIFICATION	9103	10000
WASTE TO POWER	138	10000
TOTAL GRID CONNECTED POWER	77641	185000

Table 1.1 Renewable energy installed capacity in India

1.4 Solar PV Power Generation System

The solar PV power generating system is intended to provide electricity to electrical loads. The load can be DC or AC, and depending on the application, it may demand power just during the day, at night, or even 24 hours a day. Because a PV panel provides electricity only during sunlight hours, certain energy storage systems are required to power the load during non-sunny hours. PV systems are roughly classified into the following categories:

• Stand-alone PV System (not linked to the grid)
• Grid-connected PV System (connected to the grid) • Hybrid PV System (contains other source than PV).

1.5 Photovoltaic Cell and Its Electrical Characteristics

A semiconductor diode known as a PV cell features an exposed p-n junction. PV cells are made by combining several semiconductors and production processes. Monocrystalline and polycrystalline silicon are the only silicon cells available for commercial use today. Photovoltaic cells consist of a thin layer of Si film linked to electrical connections. The p-n junction is formed by doping one side of the Si layer.

A thin metallic grid covers the surface of the semiconductor facing the sun. Figure 1.2 depicts the general physical composition of a solar cell. If the cell is shorted, the light incident on it generates charge carriers, resulting in an electric current. When the incident photon's energy is sufficient to separate the semiconductor's covalent electrons, charges are created; this occurrence is dependent on both the semiconductor material and the wavelength of the incident light [7].

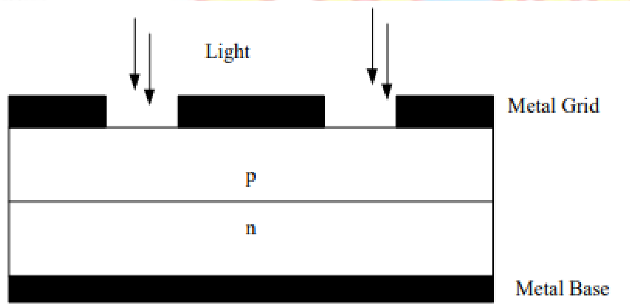

Figure.1.2 "PV cell structure"

When incoming light strikes the solar cell which is made up of semiconducting material, light photons of specific wavelengths are absorbed by it, resulting in the generation of charge carriers, electrons, and holes. These carriers pass through the junction, they create a strong electric field. 3 The electric field separates holes and electrons in the external circuit, an electric current flow. This electric current also known as photo current, is determined by the intensity of light photons and the type of semiconductors that make up the junction device.

A solar cell's important properties are short-circuited current (Isc), open-circuit voltage (Voc), fill factor (FF), and solar energy conversion efficiency (η) [8-9]. Figure 1.3 depicts the equivalent electrical circuit of a solar cell, which uses series and shunt resistors to serve as both a voltage and current source. These cells are linked in series and parallel to provide the required voltage and current, respectively. This series and parallel arrangement of cells creates a module. Furthermore, for large power generation, these modules are joined in series and parallel forms.

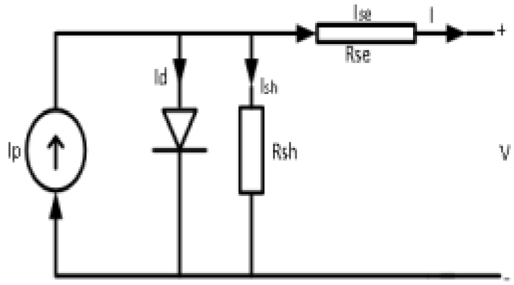

Figure.1.3 "Equivalent circuit of the solar cell"

The I-V Characteristics and parameters related to PV model is defined with the help of equation given below [10].

$$I = N_p I_p - N_p I_d - I_{sh} \qquad (1.1)$$

$$I_d = I_s\left[e^{\frac{q\left(\frac{V}{N_s}+\frac{IR}{N_p}\right)}{\mu\lambda T}} - 1\right] \qquad (1.2)$$

$$I_s = I_{rs}(T/T_r)^3 e^{\frac{q\eta}{\mu\lambda}\left(\frac{1}{T_r}-\frac{1}{T}\right)} \qquad (1.3)$$

$$I_{rs} = \frac{I_{sc}}{e^{\frac{qV_{oc}}{N_s \mu\lambda T_r}}-1} \qquad (1.4)$$

Where Ip= Photo current at a given irradiance and temperature. Id = Diode current. Ish = shunt resistance due to leakage current through p-n junction.

Is= A series resistance due to the combined resistances of contacts, metal grid p-n junction.

q= count on electron (1.6 *10 -19 C).

λ =Boltzmann's constant.

T= Temperature in Kelvin.

μ= Diode Ideality factor.

Tr= Reference temperature.

η= Energy band gape

Figure 1.3 depicts the behavior of current, voltage, and power when the voltage across the load is swept from 0 to Voc, with a fixed illumination on the solar cell/module. When the voltage reaches 0V, indicating a short circuit, the current reaches its maximum, and the state is known as short circuit current condition. In contrast, when there is no load, the terminal voltage is at its highest and is referred to as open circuit voltage. Thus, under both cases, the power transfer is zero. As a result, the PV cell operates at a position between Voc and Isc. Maximum power point refers to the operational point at which power is at its peak (Pmax). The voltage and current associated with Pmax are known power (VMP) and current at maximum power (IMP) [11-12] respectively as shown in Figure 1.4

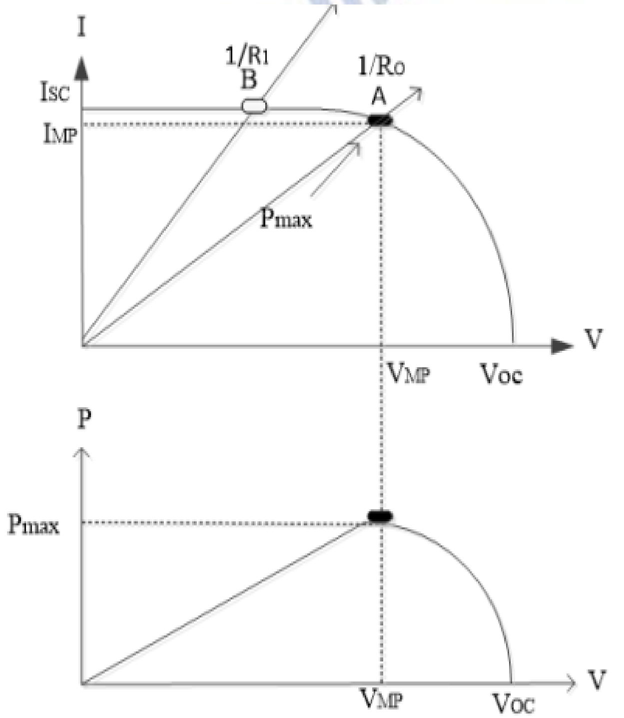

Figure 1.4 "V-I and P-V characteristic of a photovoltaic cell"

1.6 Effect of Insolation/Irradiance and Temperature on Current, Voltage and Power

The photo current is directly proportional to the intensity of radiation. Isc approximately equal to photocurrent Ip. With increase in temperature photo current will increase. As the temperature of the cell rises, the band gap narrows This increases the rate of photon generation as more free electrons are released. This results in more photo current, thereby higher value of Isc [13]. The increases in Isc with temperature is a very small value of 0 .1%/ °K. For a given temperature Voc is calculated as

$$V_{oc} = nV_T \ln\left\{\left(\frac{I_{sc}}{I_o}\right) + 1\right\} \quad \text{as } I_{sc} = I_P \qquad (1.5)$$

$$V_{oc} = nV_T \ln\left\{\left(\frac{I_P}{I_o}\right)\right\} \qquad (1.6)$$

Where $I_O = T^m e^{\frac{-V_{GO}}{\eta V_T}}$ is leakage current and V_T is thermal equivalent of voltage. Curves have been drawn after simulation in Matlab Simulink.

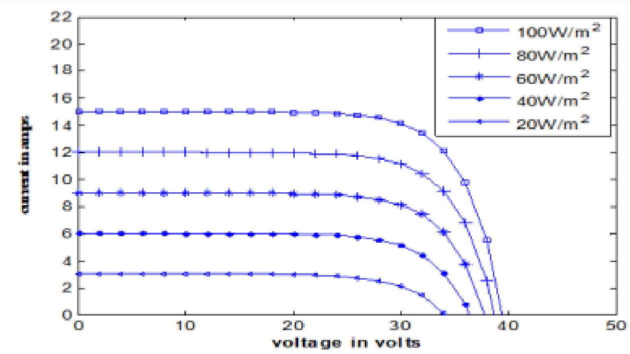

Figure 1.5 "Effect of irradiance on I-V curve

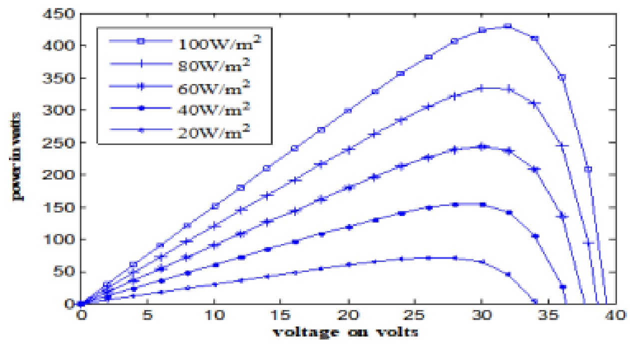

Figure 1.6 "Effect of solar irradiance on P-V curve"

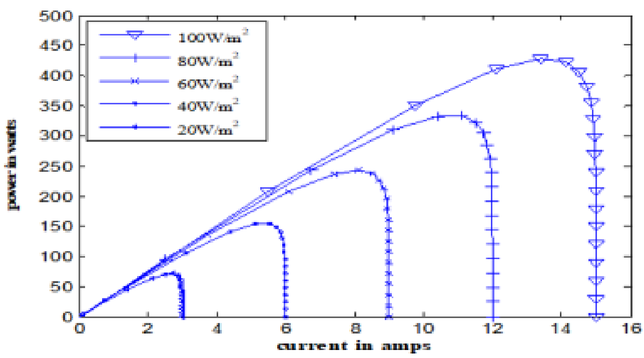

Figure 1.7 "Effect of irradiance on I-P curve"

The rate of change of open circuit voltage with respect to temperature is given by eq. 1.7.

$$\frac{dV_{OC}}{dT} = \frac{V_{OC} - (V_{GO} + mnV_T)}{T} \qquad (1.7)$$

m=1.5 for Silicon

n=2 for silicon

$V_T = 0.026V$
T=300O K
Voc =O.6V

$$\frac{dV_{OC}}{dT} = -2.1mV/°K$$

The temperature coefficient of Isc=.045%/°K, Voc = -0.34%/°K and Pmax = -0.47%/°K. As both Voc negative temperature coefficient and Isc have positive temperature coefficient therefore Power=V× I =Pm decreases with increase in temperature. The maximum power production for a particular environmental situation decreases as temperature rises. Only a small portion of the irradiance received by illuminated PV cell is converted into electrical energy; the remaining is transferred to heat, raising the temperature of the cell. If insulation remains the same while the temperature rises, there will be a noticeable decrease in cell voltage and a slight increase in current. The effect of temperature on the output of the solar cell is depicted in figure 1.8

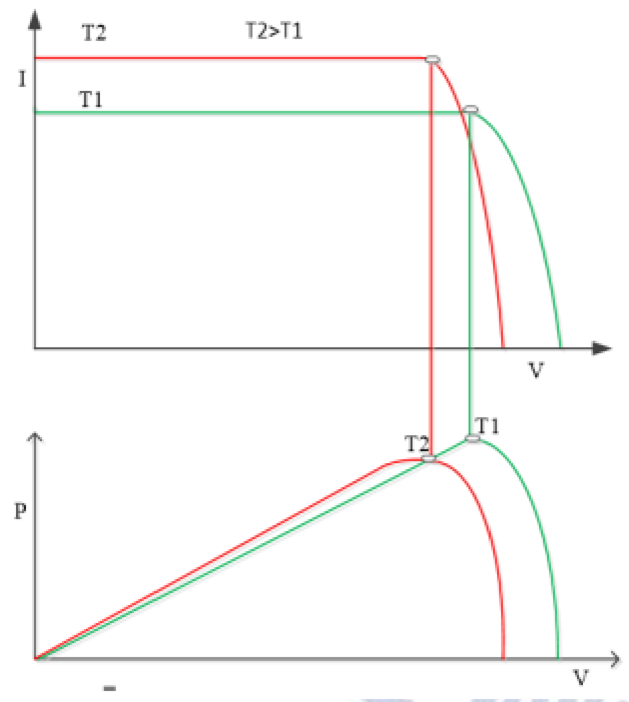

Figure.1.8 "Effect of Temperature on solar cell performance"

1.7 FILL FACTOR AND EFFICIENCY OF PV CELL

The fill factor, which is fraction of maximum P(power) to ideal P(power), is expressed as:

$$\text{Fill Factor (FF)} = \frac{V_{MP} \times I_{MP}}{I_{SC} \times V_{OC}} \quad (1.8$$

Thus, in view of the preceding discussion the FF must always be less than unity and usually it ranges between 0.7- 0.8. Higher the value of FF better is the performance of cell [14].

The efficiency of the PV cell is given as under:

$$\text{Efficiency}(\eta) = \frac{P_{max}}{P_{in}} = \frac{V_{MP} \times I_{MP}}{\text{Insolation}(E) * \text{Area of Panel/Cell}}$$

At Standard Test Conditions (STC)
E =1000Watt/m2 Temp.
(T)=25°C.
Air Mass (AM)=1.5
The Fill Factor can be related to efficiency as

$$\eta = \frac{V_{OC} \times I_{SC} \times FF}{E \times A_C} \quad (1.9)$$

1.8 MAXIMUM POWER POINT TRACKING (MPPT) CONTROLLER:

As previously stated, the power (P=V×I) is zero in both open and short circuit states. The maximum power transfer theorem states that maximum power may be transmitted when the load and source impedances are properly matched. Thus, without correct impedance matching, electricity generated by the PV cell/module cannot be delivered directly to the load. To guarantee optimal power transfer, an interface between the PV module and the load is required. This is accomplished using the Maximum Power Point Tracking (MPPT) Controller [15]. Figure 1.9 depicts the components of an MPPT controller, which include an algorithm and a DC-DC converter.

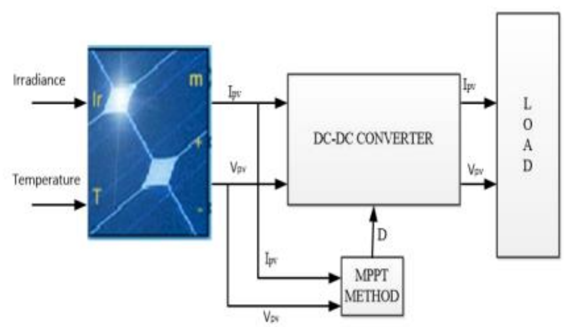

Figure.1.9 "Block diagram of PV system along with MPPT controller"

Depending on the PV voltage generation and voltage needed load, the DC-DC converter may be a Buck, Boost, or Buck-Boost. The algorithm's task is to keep track of the change in irradiance level caused by changing weather conditions and dynamically changing loads. Several MPPT approaches have been proposed in the literature. Some often used terms are Constant Voltage (CV), Perturb and Observe (P&O), Incremental Conductance (IC), Open Circuit Voltage (OCV), Short Circuit Current (Isc), Artificial Neural Network (ANN), and Fuzzy Logic Controller (FLC). However, P&O is the most often utilized because of its simplicity and ease of implementation. However, the fundamental disadvantage of this technology is the existence of oscillations at the output, which causes power loss [16]. In this thesis, P and O will be discussed thoroughly along with its limitations.

1.9 PARTIAL SHADING:

Partial shading from adjacent objects such as trees, buildings, and leaves falling on solar panels has a substantial influence on PV system production. When solar cells are shaded, the current produced decreases, significantly reducing the solar array's output power, efficiency, and complexity. When solar irradiation is uniform, there is just one point where power is at its peak, which may be easily identified using the perturb and observe approach or the incremental conductance technique. However, under Partial Shading Conditions (PSC), these approaches are useless because partial shading produces a large number of Maximum Power Points (MPP) [17-18]. As seen in Figure 1.10 indicates P1, P2, and P3 are the three power peaks, although the greatest power is accessible at P3, which is known as the Global greatest Power Point (GMPP) of the solar module under PSC, while P1 and P2 are known as Local Maximum Power Points (LMPP). Conventional MPP approaches fail to reliably measure Global Maximum Power Point (GMPP). Many recent MPPT methods based on PSC have been developed to track the GMPP.

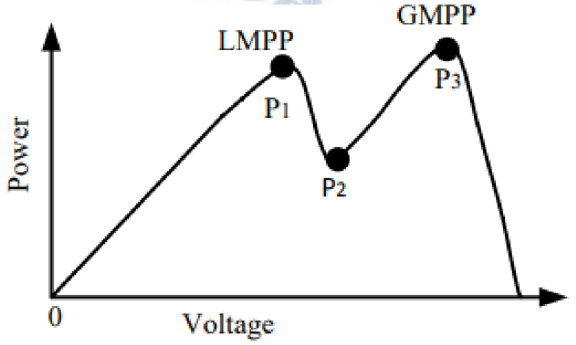

Figure 1.10 "PV curve of solar module under partial shading"

1.10 CONTROLLERS

The major duty of the controller in a DC-DC converter is to keep the output voltage at its rated value while keeping the input current within limits. Voltage control (VC) and current mode are the main control techniques used in DC-DC converters. Typically, a DC-DC converter's input is unregulated DC voltage. The uncontrolled DC input is caused by diodes, inadequate rectification, and fluctuations in line voltage and load. These differences cause the output to become uncontrolled. DC-DC converters turn these uncontrolled DC input voltages into regulated DC outputs at the specified voltage level 10 [19]. The primary purpose of a DC-DC converter is to maintain a constant output voltage despite variations in input voltage or load. There are multiple DC-DC converters available with a variety of control schemes. These approaches are designed to improve the efficiency of DC-DC converters [20-21]. Because of the revolution in power electronics, accurate and reliable regulation for DC-DC converters is now required, necessitating the construction of dependable DC-DC converter controllers. The buck converter has been constructed, and its average has been calculated. Using the K-Factor approach, the converter's output voltage is stabilized independent of line voltage or load fluctuations. Waveforms from the mathematical analysis and MATLAB simulation of the proposed approach are utilized to ensure that the output voltage remains constant despite variations in line voltage and load.

1.11 ANALYSIS OF MPPT METHODS:

The Comparison in terms of complexity, convergence speed, the efficiency and the oscillations around MPP of different MPPT topology are discussed are given in the table.

Method	Convergence speed	Complexity	Tracking Range	Tuning required	Oscillations around MPP	Sensed Parameter
P&O	Varies	Low	Wide	No	Yes	V&I
IC	Varies	Medium	Wide	No	Yes	V&I
CV	Fast	Low	Narrow	Yes	No	V
NN	Fast	High	Wide	Yes	No	V
FLC	Fast	High	Wide	Yes	No	V
V_{oc}	Medium	Low	Narrow	Yes	No	V
I_{sc}	Medium	Medium	Narrow	Yes	No	I

Table 1. Comparison of MPPT methods.

Various modifications in P&O operations are proposed in the literature. Review of some of the in the recent literature is as under:

With combine of P&O and constant voltage method was proposed by Cristinel et al [39] for tracking efficiently maximum power point under high and low insolation conditions. In this algorithm the operation is increased till the terminal voltage of PV module is close to its Voc, which in turn is used as the initial condition for tracking power at maximum power. The current output is evaluated by the algorithm and if it is found more than 0.7, the algorithm adopts the P&O method (if it is less it change to the CV method). The results reveal that more power can be recovered from the module than the usual P&O approach. However, the algorithm has a difficulty with the complexity of integrating two approaches.

This typical P&O approach has problems, such as sluggish or erroneous monitoring of the highest power point, because the P&O method is prone to unpredictable behavior under rapidly changing insolation [40].

To address the aforementioned issue, a modified technique was developed in [41–42], in which an insolation-changing estimate process is introduced to each perturbation process to assess the amount of fluctuation in power caused by changing circumstances. The results demonstrate improved performance compared to the standard Perturb & Observe. However, tracking speed is roughly half that of the typical P&O system. Tracking speed enhancement C. Lui et al. [41] suggested an estimate P&O approach that uses one estimating step for every two perturbations. Compared to modified P&O, this algorithm provides quicker tracking speed while maintaining same tracking accuracy [42]. It is evident that oscillations around MPP cause power loss in the PV system. [41-42] demonstrate how P&O settings may be improved based on the dynamic behavior of a certain converter. A standard P&O algorithm may follow maximum power point in the wrong direction under rapidly shifting insolation.Nicola Femia [43] demonstrates how the P&O parameters may be optimized for the dynamic behavior of the specific power converter under examination. During rapidly changing irradiation, the conventional P&O algorithm may become confused and follow the MPP in the incorrect direction [44]. To address this issue, a method was proposed in [45], which requires an extra measurement of PV power. The identical procedure is carried out in the middle of the sample period. The suggested strategy was evaluated experimentally and compared to standard P&O, and the findings demonstrate that this method can prevent MPP from being tracked in the erroneous direction under rapidly changing insolation circumstances while also increasing tracking speed.

In [46], a modified P&O approach is presented to eliminate the drift problem by integrating the knowledge of change in current (ΔI) in the decision process, in addition to the change in power (ΔP) and voltage (ΔV). A single-ended primary inductance converter is used to validate the proposed drift-free P&O MPPT with direct duty ratio control. The adaptive strategy has a greater influence on drift compared to standard P&O due to the high value of ΔD. However, the suggested method is free of drift.

Riby John et al suggested a variable step size (VSS)-P&O to solve the constraints of the fixed P&O algorithm [47], which improves tracking speed while minimizing oscillations. This method produces a big step value if the operating point is far away from the maximum power point, and a small step value if the operating point is closer to the maximum power point. The author studied two separate scenarios in which VSS-P&O was operated at various duty cycle levels. In example 1, VSS P&O has duty cycles of dDbig = 0.025 and dDsmall = 0.005. In example 2, dDbig = 0.02 and dDsmall = 0.005 have been chosen. The dDbig operates with 27 points to swiftly reach the maximum.

Power Point Dsmall minimizes the oscillation. When compared to standard P&O MPPT, this results in an improvement in oscillation reduction around the peak power point. Furthermore, under varying insolation conditions, a fixed step size P&O algorithm takes longer to achieve the desired peak power, but the suggested MPPT method tracks faster and with less oscillations.

In [48], Vibhu Jately et al. suggested a technique for precisely tracking the MPP under rapid changes in load and insolation. This technique consists of three sections: voltage perturbation, current perturbation, and a step-size reduction approach. The usage of dual perturbation parameters, which use the first two, ensures a high tracking speed. The step size reduction method, on the other hand, reduces the perturbation step size of these two, which helps to reduce oscillations at the MPP. However, the method for the technique is lengthy and complex.

2. DESIGN AND ANALYSIS OF FEEDBACK CONTROL FOR DC-DC BUCK CONVERTER:

Controllers are required to keep a DC-DC converter's output voltage controlled. To create the switching pulse for DC-DC converters, controllers process the error signal between the desired and actual output voltages. The error signal is often compared to a triangle wave to create a PWM signal. Figure 1.11 shows the fundamental construction of a feedback-controlled DC-DC converter.

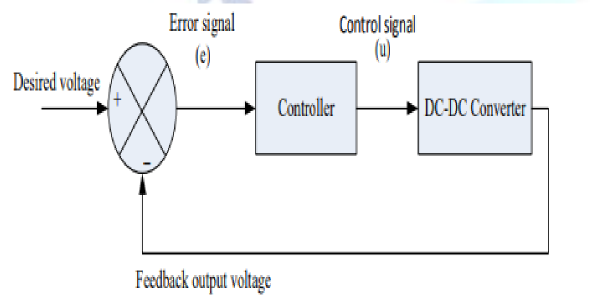

Figure. 1.11 "DC-DC converter with feedback"

There are multiple DC-DC converters available with different control topologies. These schemes are designed to improve the efficiency of DC-DC converters. Because of the revolution in power electronics, accurate and reliable regulation is now required for DC-DC converters, necessitating the construction of dependable DC-DC converter controllers [85]. Voltage control, current control, proportional integral (PI), and proportional-integral-derivative (PID) control are some of the most commonly mentioned controllers in literature.

A buck converter's output is affected by fluctuations in supply voltage, load, and component non-ideality. Averaging is utilized to derive the transfer function for the DC-DC buck converter; moreover, using the K-factor approach, the compensator is constructed to increase the phase margin of the closed loop buck converter. The simulation results show that the output voltage is stable and reaches steady state quickly despite dynamic fluctuations in line voltage and load. A good controller may be constructed using sophisticated control theory by analyzing the frequency response of the DC-DC converter to make it resilient against disturbances in load and supply voltage.

3. FUTURE SCOPE AND CONCLUSION

The demand for the PV energy system increases day by day worldwide, and it became a most important source for the power electronic based converters in the conditioning system to become more economical and efficient. The microinverter has superior MPPT tracking ability than the string and centralized inverters which harvests maximum power for the same array of PV panels. This is due to the module level converter and MPPT technique. However, the poor performance and high cost are associated with the microinverter due to the two-stages of the power electronic converter. The work in this paper proposed a new converter/inverter topology which has the features of high efficiency and less cost.

In conclusion, a new non-isolated dc-dc converter topology and a new transformer less single-phase inverter topology with a wide input range, high voltage gain, galvanic isolation, a smaller number of devices, and high-power efficiency. These converter/inverter topologies are great circuit schemes for implementation in the solar PV module level power conditioning systems such as the front-end dc-dc converter, and back-end inverter transformer less inverter.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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