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MAXIMUM POWER POINT TRACKING METHODS OF PV SYSTEM

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ABSTRACT

Compared to the traditional energy resources, photovoltaic (PV) system that uses the solar energy to produce electricity considered as one of renewable energies has a great potential and developing increasingly fast compared to its counterparts of renewable energies. Such system can be either stand-alone or connected to utility grid. While, the disadvantage is that PV generation depended on weather conditions. The major problem with photovoltaic (PV) systems is the amount of electrical power generated by solar arrays depends up on a number of conditions (i.e. solar irradiance, temperature and angle of incident light etc.). In order to maximize the output of a PV system, continuously tracking the maximum power point (MPP) is necessary. In this seminar there is a different types implementation of maximum power point tracking (MPPTs) algorithm for a PV system so as to extract maximum power from the solar arrays during unfavorable condition, also the effect on V-I and V-P characteristics of PV array module due to change in irradiance and temperature are delineated. MPPT algorithm plays an important role in increasing the efficiency of system. A proposed MPPT algorithm is implemented in boost converter and compared with various MPPTs Algorithm.Few comparisons such as efficiency, voltage, current and power output for each different combination has been recorded. Multi changes in irradiance, temperature by keeping voltage and current as main sensed parameter been done in the simulation. Matlabsimulink tools have been used for performance evaluation on energy point. Simulation will consider different solar irradiance and temperature variations.

INTRODUCTION

The rapid increase in the demand for electricity and the recent change inthe environmental conditions such as global warming led to a need for a new source of energy that is cheaper and sustainable with less carbon emissions. Solar energy has offered promising results in the quest of finding the solution to the problem. The harnessing of solar energy using PV modules comes with its own problems that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the PV modules.A great deal of research has been done to improve the efficiency of the PV modules. A number of methods of how to track the maximum power point of a PV module have been proposed to solvethe problem of efficiency and products using these methods have been manufactured and are now commercially available for consumers. As the market is now flooded with varieties of these MPPT that are meant to improve the efficiency of PV modules under various insolation conditions it is not known how many of these can really deliver on their promise under a variety of field conditions.

This research then looks at how a different type of converter affects the output power of the module and also investigates if the MPPT that are said to be highly efficient and do track the true maximum power point under the various conditions. A MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load. A dc/dc converter (step up/ step down) serves the purpose of transferring maximum power from the solar PV module to the load. A dc/dc converter acts as an interface between the load and the module. By changing the duty cycle the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power. Therefore MPPT techniques are needed to maintain the PV array's operating at its MPP. Many MPPT techniques have been proposed in the literature; example are the Perturb and Observe (P&O) methods, Incremental Conductance (IC) methods, Fuzzy Logic Method, etc. In this seminar two most popular of MPPT technique (Perturb and Observe (P&O) methods and Incremental Conductance methods) and three different DC-DC converter (Buck, Boost and Cuk converter) will involve in comparative study.Figure 2

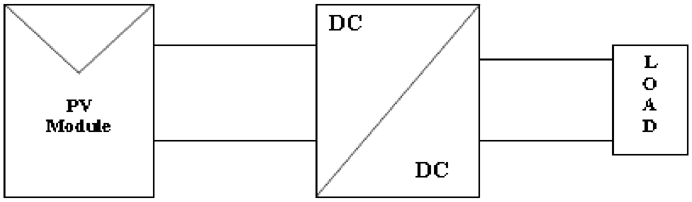

Fig. 1: Block diagram of Typical MPPT system

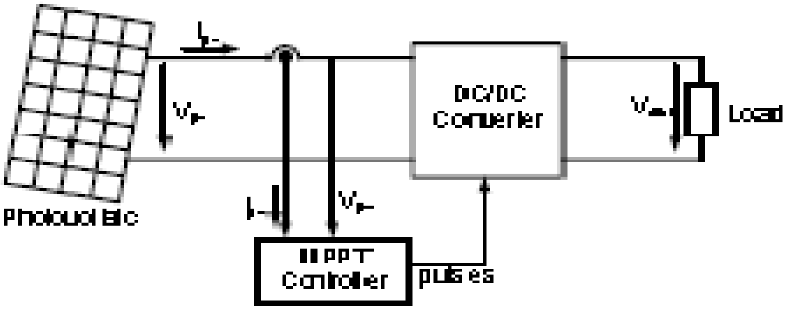

Fig. 2: DC – DC converter for operation at the MPP

Few comparisons such as voltage, current and power output foreach different combination has been recorded. Multi changes in duty cycle, irradiance, temperature by keeping voltage and current as main sensed parameter been done in the simulation. The MPPT techniques will be compared, by using Mat lab tool Simulink, considering the variant of circuit combination.

PROBLEM OVERVIEW

The problem considered by MPPT techniques is to automatically find the voltage *VMPP* or current *IMPP* at which a PV array should operate to obtain the maximum power output *PMPP* under a given temperature and irradiance. It is noted that under partial shading conditions, in some cases it is possible to have multiple local maxima, but overall there is still only one true MPP. Most techniques respond to changes in both irradiance and temperature, but some are specifically more useful if temperature is approximately constant. Most techniques would automatically respond to changes in the array due to aging, though some are open-loop and would require periodic fine tuning. In our context, the array will typically be connected to a power converter that can vary the current coming from the PV array.

DIFFERENT TYPES OF MPPT CONTROL ALGORITM

A. Hill Climbing/P&O

Among all the papers, much focus has been on hill climbing and perturb and observe (P&O) methods. Hill climbing involves a perturbation in the duty ratio of the power converter, and P&O a perturbation in the operating voltage of the PV array. In the case of a PV array connected to a power converter, perturbing the duty ratio of power converter perturbs the PV array current and consequently perturbs the PV array voltage. Hill climbing and P&O methods are different ways to envision the same fundamental method. From Fig. 2, it can be seen that incrementing (decrementing) the voltage increases (decreases) the power when operating on the left of the MPP and decreases (increases) the power when on the right of the MPP. Therefore, if there is an increase in power, the subsequent perturbation should be kept the same to reach the MPP and if there is a decrease in power, the perturbation should be reversed. This algorithm is summarized in Table I. In [9], it is shown that the algorithm also works when instantaneous (Instead of average) PV array voltage and current are used, as long as sampling occurs only once in each switching cycle. The process is repeated periodically until theMPP is reached. The system then oscillates about the MPP. The oscillation can be minimized by reducing the perturbation step size. However, a smaller perturbation size slows down the MPPT. A solution to this conflicting situation is to have a variable perturbation size that gets smaller towards the MPP. In fuzzy logic control is used to optimize the magnitude of the next perturbation. In a two-stage algorithm is proposed that offers faster tracking in the first stage.and finer tracking in the second stage. On the other hand, bypasses the first stage by using a nonlinear equation to estimate an initial operating point close to the MPP. Hill climbing and P&Omethods can fail under rapidly changing atmospheric conditions as

TABLE I
SUMMARY OF HILL CLIMBING AND P&O ALGORITHM

Perturbation	Change in Power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

illustrated in Fig. 3. Starting from an operating point A, if atmospheric conditions stay approximately constant, a perturbation ΔV in the PV voltage V will bring the operating point to B and the perturbation will be reversed due to a decrease in power.

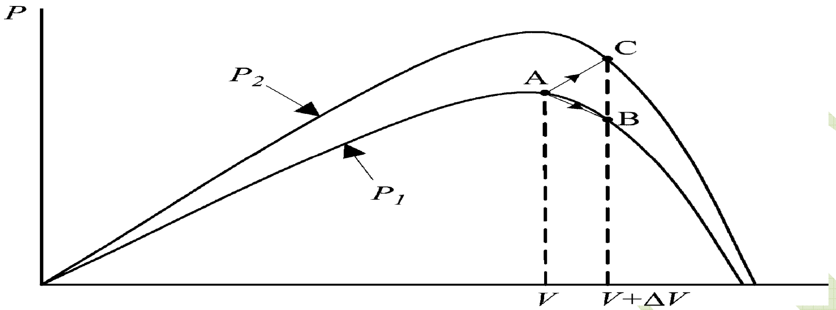

Fig. 3. Divergence of hill climbing/P&O from MPP as shown in

However, if the irradiance increases and shifts the power curve from *P1* to *P2* within one sampling period, the operating point will move from A to C. This represents an increase in power and the perturbation is kept the same. Consequently, the operating point diverges from the MPP and will keep diverging if the irradiance steadily increases. To ensure that the MPP is tracked even under sudden changes in irradiance,uses a three-point weight comparison P&O method that compares the actual power point to twopreceding ones before a decision is made about the perturbation sign. In the sampling rate is optimized, while in, simply a high sampling rate is used. In toggling has been done between the traditional hill climbing algorithm and a modified adaptive hill climbing mechanism to prevent deviation from the MPP. Two sensors are usually required to measure the PV array voltage and current from which power is computed, but depending on the power converter topology, only a voltage sensor might be needed. In the PV array current from the PV array voltage is estimated, eliminating the need for a current sensor. DSP or microcomputer control is more suitable for hill climbing and P&O even though discrete analog and digital circuitry can be used.

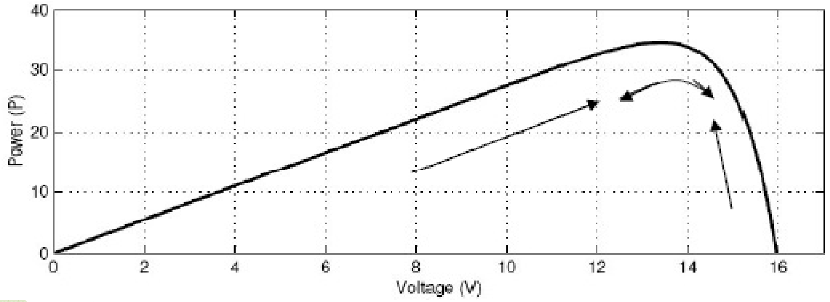

Fig. 3: Graph Power versus Voltage for Perturb and Observe Algorithm

The MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe. One disadvantage of this algorithm is the increased complexity when compared to P&O.

B. Incremental Conductance (IC)

The disadvantage of the perturband observes method to track the peak power under fast varying atmospheric condition is overcome by IC method. The IC can determine that the

MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V. This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached.

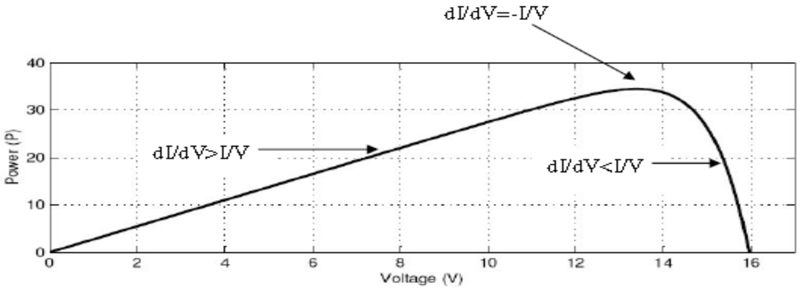

Fig. 8(a): Graph Power versus Voltage for IC Algorithm

dP/dV= 0, at MPP

dP/dV>0, left of MPP(1)dP/dV<0, right of MPP

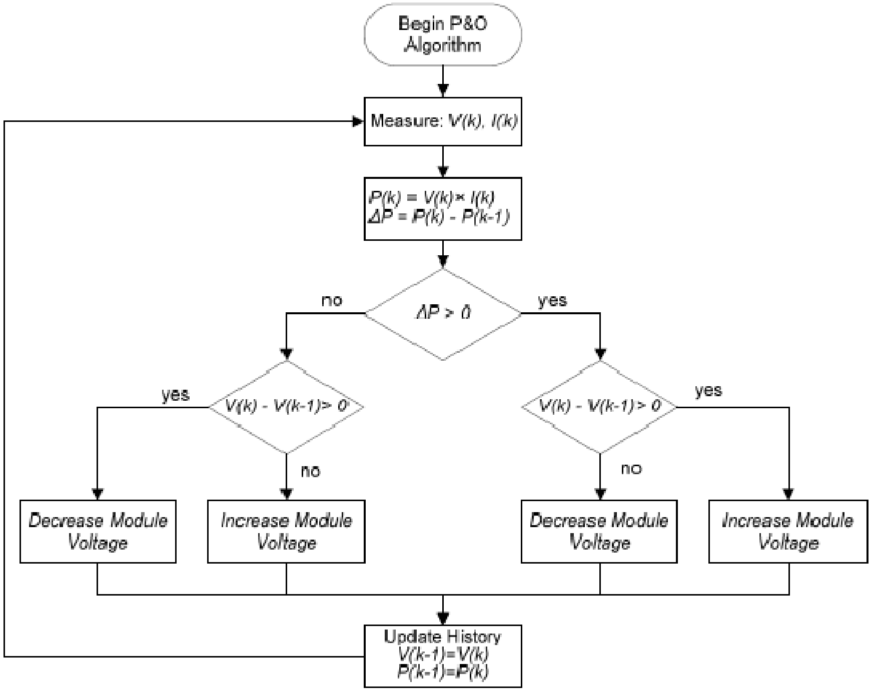

Fig. 7(b): Perturb and Observe Algorithm

Since

$$dP/dV = d(IV)/dV = I + VdI/dV \sim= I + V\Delta I/\Delta V \qquad (2)$$

(1) Can be rewritten as

$$\Delta I/\Delta V = -I/V, \text{ at MPP}$$

$$\Delta I/\Delta V > -I/V, \text{ left of MPP}$$

$$\Delta I/\Delta V < -I/V, \text{ right of MPP.} \qquad (3)$$

TheMPP can thus be tracked by comparing the instantaneous conductance (*I/V*)to the incremental conductance (Δ*I*/Δ*V*)as shown in the flowchart in Fig. 4. *Vref*is the reference voltage at which the PV array is forced to operate. At the MPP, *Vref*equals to *VMPP*. Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in Δ*I* isnoted, indicating a change in atmospheric conditions and theMPP. The algorithm decrements or increments *Vref*to track the new MPP.The increment size determines how fast the MPP is tracked. Fast tracking can be achieved with bigger increments but the system might not operate exactly at theMPP and oscillate about it instead; so there is a tradeoff. In a methodis proposedthat brings the operating point of the PV array close to the MPP in a first stage and then uses Inc Cond to exactly track theMPP in a second stage. By proper control of the power converter, the initial operating point is set to match a load resistance proportional to the ratio of the open-circuit voltage (*VOC*) to the short-circuit current (*ISC*) of the PV array. This two-stage alternative also ensures that the real MPP is tracked in case of multiple

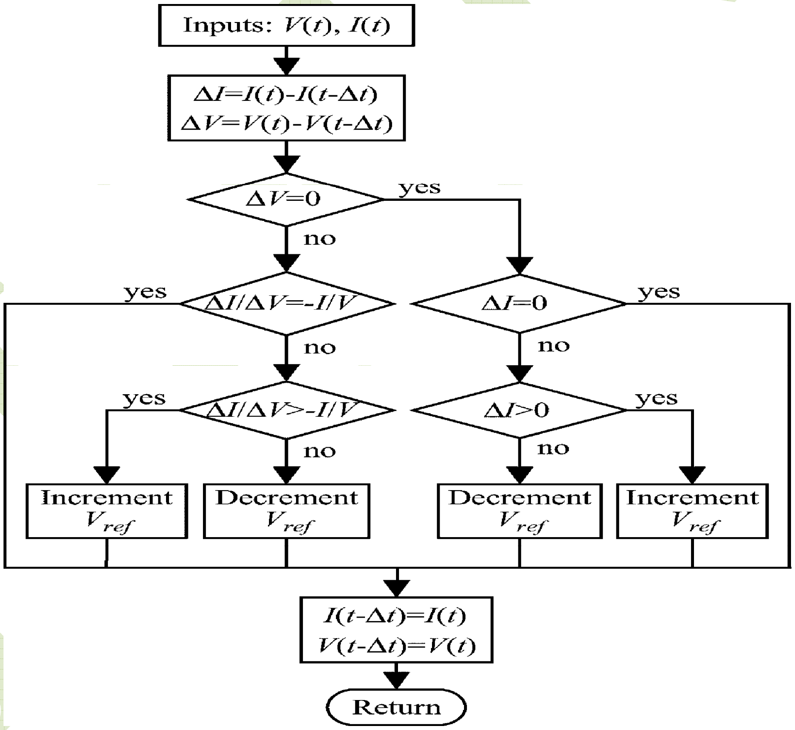

Fig. 4.IncCond algorithm as shown in

Local maxima. In a linear function is used to divide the *I–V* plane into two areas, one containing all the possibleMPPs under changing atmospheric conditions.Theoperating point is brought into this area and then IncCond is used to reach the MPP. A less obvious, but effective way of performing the IncCondtechnique is to use the instantaneous conductance and the incremental conductance to generate an error signal

$$e = I\ V + dIdV(4)$$

we know that e goes to zero at the MPP. A simple proportional integral (PI) control can then be used to drive e to zero. Measurements of the instantaneous PV array voltage and current require two sensors. IncCond method lends itself well to DSP and microcontroller control, which can easily keep track of previous values of voltage and current and make all the decisions.

C. Fractional Open-Circuit Voltage

The near linear relationship between $VMPP$ and VOC of the PV array, under varying irradiance and temperature levels, has given rise to the fractional VOC method.

$$VMPP \approx k1VOC(5)$$

where$k1$ is a constant of proportionality.

Since $k1$ is dependent on the characteristics of the PV array being used, it usually has to be computed beforehand by empirically determining $VMPP$ and VOC for the specific PV array at different irradiance and temperature levels. The factor $k1$ has been reported to be between 0.71 and 0.78. Once $k1$ is known, $VMPP$ can be computed using (5) with VOCmeasured periodically by momentarily shutting down the power converter. However, this incurs some disadvantages, including temporary loss of power. To prevent this, uses pilot cellsfrom which VOC can be obtained. These pilot cells must be carefully chosen to closely represent the characteristics of thePV array.
It is claimed that the voltage generated by pn-junction diodes is approximately 75% of VOC. This eliminates the need for measuring VOC and computing $VMPP$. Once $VMPP$ has been approximated, a closed-loop control on the array power converter can be used to asymptotically reach this desired voltage. Since (5) is only an approximation, the PV array technically never operates at the MPP. Depending on the application of the PV system, this can sometimes be adequate. Even if fractional VOC is not a true MPPT technique, it is very easy and cheap toimplement as it does not necessarily require DSP or microcontroller control. However, points out that $k1$ are no more valid in the presence of partial shading (which causes multiple local maxima) of the PV array and proposes sweeping the PV array voltage to update $k1$. This obviously adds to the implementation complexity and incurs more power loss.

E. RCC

When a PV array is connected to a power converter, the switching action of the power converter imposes voltage and current ripple on the PV array. As a consequence, the PV array power is also subject to ripple. Ripple correlation control (RCC) makes use of ripple to perform MPPT. RCC correlates the time derivative of the time-varying PV array power $p^{\cdot}$ with the time derivative of the time-varying PV array current $^{\cdot}i$or voltage $v^{\cdot}$ to drive the power gradient to zero, thus reaching the MPP.Referring to Fig. 2, if v or i is increasing ($v^{\cdot}$ >0 or $i^{\cdot}$ >0)and p is increasing ($^{\cdot}p$ >0), then the operating point is below the MPP ($V < VMPP$ or $I < IMPP$). On the other hand, if v or i is increasing and p is decreasing ($p^{\cdot}$ <0), then the operating point is above the MPP ($V > VMPP$ or $I > IMPP$).
Combining these observations, we see that $^{\cdot}\ p\ ^{\cdot}\ v$ or $^{\cdot}\ p^{\cdot}i$are positive to the left of the MPP, negative to right of the MPP, and zero at the MPP. When the power converter is a boost converter as in, increasing the duty ratio increases the inductor current, which is the same as

the PV array current, but decreases the PV array voltage. Therefore, the duty ratio control input is. Controlling the duty ratio in this fashion assures that the MPP will be continuously tracked, making RCC a true MPP tracker. The derivatives and are usually undesirable, but shows that ac-coupled measurements of the PV array current and voltage can be used instead since they contain the necessary phase information. The derivatives can also be approximated by high-pass filters with cutoff frequency higher than the ripple frequency. A different and easy way of obtaining the current derivative in (10) is to sense the inductor voltage,which is proportional to the current derivative. The non-idealitiesin the inductor (core loss, resistance) have a small effect since the time constant of the inductor is much larger than the switching period in a practical converter. Our present undocumented work has shown that (10)can fail due to the phase shift brought about by the intrinsic capacitance of the PV array at high switching frequencies. However, correlating power and voltage as in (9) is barely affected by the intrinsic capacitance. Simple and inexpensive analog circuits can be used to implement RCC. An example is given in. Experiments were performed to show that RCC accurately and quickly tracks the MPP, even under varying irradiance levels.
The time taken to converge to the MPP is limited by the switching frequency of the power converter and the gain of the RCC circuit. Another advantage of RCC is that it does not require any prior information about the PV array characteristics, making its adaptation to different PV systems straightforward. There are other papers in the literature that use MPPT methods that resemble RCC. For example, integrates the product of the signs of the time derivatives of power and of duty ratio. However, unlike RCC, which uses inherent ripple present in current and voltage, disturbs the duty ratio to generatea disturbance in power.a hysteresis-based version of RCC is used. A low frequency dithering signal is used to disturb the power. In a 90◦ phase shift in the current (or voltage) with respect to power at the MPP is discussed, just like in RCC. The difference in that the injection is an extra, low-frequency signal and not an inherent converter ripple.

G. DC-Link Capacitor Droop Control

DC-link capacitor droop control is an MPPT technique that is specifically designed to work with a PV system that is connected in parallel with an ac system line as shown in Fig. 7.The duty ratio of an ideal boost converter is given by

$$d = 1 - VVlink$$

Where V is the voltage across the PV array and *Vlink*is the voltage across the dc link. If *Vlink*is kept constant, increasing. Different load types. 1: voltage source, 2: resistive, 3: resistive and voltage source, 4: current source,.the current going in the inverter increases

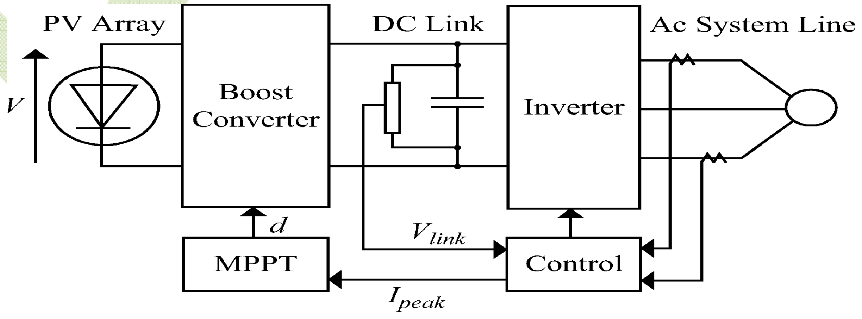

Fig. 7. Topology for dc-link capacitor droop control as shown in

The power coming out of the boost converter and consequently increases the power coming out of the PV array. While the current is increasing, the voltage *Vlink*can be kept constant as long as the power required by the inverter does not exceed the maximum power available from the PV array. If that is not the case, *Vlink*starts drooping. Right before that point, the current control command *Ipeak*of the inverter is at its maximum and the PV array operates at the MPP. The ac system line current is fed back to prevent *Vlink*from drooping and *d* is optimized to bring *Ipeak*to its maximum, thus achieving MPPT. DC-link capacitor droop control does not require the computation of the PV array power, but according to , its response deteriorates when compared to a method that detects the power directly; this is because its response directly depends on the response of the dc-voltage control loop of the inverter. This control scheme can be easily implemented with analog operational amplifiers and decision-making logic units.

H. Load Current or Load Voltage Maximization

The purpose of MPPT techniques is to maximize the power coming out of a PV array. When the PV array is connected to a power converter, maximizing the PV array power also maximizesthe output power at the load of the converter. Conversely,maximizing the output power of the converter should maximize the PV array power , assuming a lossless converter. In it is pointed out that most loads can be of voltage source type, current-source type, resistive type, or a combination of these, as shown in Fig. 8. From this figure, it is clear that for a voltage-source type load, the load current *iout*should be maximized to reach the maximum output power *PM*. For a current-source type load, the load voltage *vout*should be maximized. For the other load types, either *iout*or *vout*can be used.

Therefore, for almost all loads of interest, it is adequate to maximize either the load current or the load voltage to maximize the load power.Consequently, only one sensor is needed. In most PV systems, a battery is used as the main load or as a backup. Since a battery can be thought of as a voltage-source type load, the load current can be used as the control variable. In positive feedback is used to control the power converter such that the load current is maximized and the PV array operates close to the MPP. Operation exactly at the MPP is almost never achieved because this MPPT method is based on the assumption that the power converter is lossless.

K. dP/dV or dP/dI Feedback Control

With DSP and microcontroller being able to handle complex computations, an obvious way of performing MPPT is to compute the slope (*dP/dV*or *dP/dI*) of the PV power curve (Fig. 2) and feed it back to the power converter with some control to drive it to zero. This is exactly what is done in. The way the slope is computed differs from paper to paper. In*dP/dV*is computed and its sign is stored for the past fewcycles. Based on these signs, the duty ratio of the power converteris either incremented or decremented to reach the MPP.A dynamic step size is used to improve the transient response of the system. In a linearization-based method is used to compute dP/dV. In sampling and data conversion are used with subsequent digital division of power and voltage to approximate dP/dV. In $dP/dI$is then integrated together with an adaptive gain to improve the transient response. In the PVarray voltage is periodically incremented or decremented and $\Delta P/\Delta V$ is compared to a marginal error until the MPP is reached. Convergence to the MPP was shown to occur in tens of milliseconds.

L. Parasitic capacitances

The parasitic capacitance method is a refinement of the incremental conductance method that takes into account the parasitic capacitances of the solar cells in the PV array**.** Parasitic capacitance uses the switching ripple of the MPPT to perturb the array. To account for the parasitic capacitance, the average ripple in the array power and voltage, generated by the switching frequency, are measured using a series of filters and multipliersand then used to calculate the array conductance**.** The incremental conductance algorithm is then used to determine the direction to move the operating point of the MPPT. One disadvantage of this algorithm is that the parasitic capacitance in each module is very small, and will only come into play in large PV arrays where several module strings are connected in parallel. Also, the DC-DC converter has a sizable input capacitor used filter out small ripple in the array power. This capacitor may mask the overall effects of the parasitic capacitance of the PV array.

M. Voltage control maximum point tracker

It is assumed that a maximum power point of a particular solar PV module lies at about 0.75 times the open circuit voltage of the module. So by measuring the open circuit voltage a reference voltage can be generated and feed forward voltage control scheme can be implemented to bring the solar PV module voltage to the point of maximum power. One problem of thistechnique is the open circuit voltage of the module varies with thetemperature. So as the temperature increases the module open circuit voltage changes and we have to measure the open

DIFFERENT PARAMETERS OF MPPT

With so many MPPT techniques available to PV system users, it might not be obvious for the latter to choose which one better suits their application needs. The main aspects of the MPPTtechniques to be taken into consideration are highlighted in the following subsections.

A. Implementation

The ease of implementation is an important factor in deciding which MPPT technique to use. However, this greatly depends on the end-users' knowledge. Somemight be more familiar withanalog circuitry, in which case, fractional *ISC* or *VOC*, RCC, and load current or voltage maximization are good options. Others might be willing to work with digital circuitry, even if that may require the use of software and programming. Then, their selection should include hill climbing/P&O, IncCond, fuzzy logic control, neural network, and *dP/dV*or *dP/dI*feedback control. Furthermore, a few of the MPPT techniques only apply to specific topologies. For example, the dc-link capacitor droop control works with the system shown in Fig. 7 and the OCC MPPT works with a single-stage inverter.

B. Sensors

The number of sensors required to implement MPPT also affects the decision process. Most of the time, it is easier andmore reliable to measure voltage than current. Moreover, currentsensors are usually expensive and bulky. This might be inconvenient in systems that consist of several PV arrays with separate MPP trackers. In such cases, it might be wise to use MPPT methods that require only one sensor or that can estimate the current from the voltage. It is also uncommon to find sensors that measure irradiance levels, as needed in the linear current control and the *IMPP* and *VMPP* computation methods

C. Multiple Local Maxima

The occurrence of multiple local maxima due to partial shading of the PV array(s) can be a real hindrance to the proper functioning of an MPP tracker. Considerable power loss can be incurred if a local maximum is tracked instead of the real MPP. As mentioned previously, the current sweep and the state based methods should track the true MPP even in the presence of multiple local maxima. However, the other methods require an additional initial stage to bypass the unwanted local maxima and bring operation to close the real MPP.

D. Costs

It is hard tomention the monetary costs of every singleMPPTtechnique unless it is built and implemented. This is unfortunately out of the scope of this paper. However, a good costs comparison can be made by knowing whether the technique is analog or digital, whether it requires software and programming, and the number of sensors. Analog implementation is generally cheaper than digital, which normally involves a microcontroller that needs to be programmed. Eliminating current sensors considerably drops the costs.

E. Applications

Different MPPT techniques discussed earlier will suit different applications. For example, in space satellites and orbital stations that involve large amount of money, the costs and complexityof the MPP tracker are not as important as its performance and reliability. The tracker should be able to continuously track the trueMPP in minimum amount of time and should not require periodic tuning. In this case, hill climbing/P&O, IncCond, and RCC are appropriate. Solar vehicles would mostly require fast convergence to the MPP. Fuzzy logic control, neural network, and RCC are good options in this case. Since the load in solar vehicles consists mainly of batteries, load current or voltage maximization should also be considered. The goal when using PV arrays in residential areas is to minimize the payback time and to do so, it is essential to constantly and quickly track the MPP. Since partial shading (from trees and other buildings) can be an issue, the MPPT should be capable of bypassing multiple local maxima. Therefore, the two-stage IncCondand the current sweep methods are suitable. Since a residential system might also include an inverter, the OCC MPPT can also be used. PV systems used for street lighting only consist in charging up batteries during the day. They do not necessarily need tight constraints; easy and cheap implementation might be more important, making fractional *VOC* or *ISC* viable. For all other applications not mentioned here, we put together Table III, containing the major characteristics of all the MPPT techniques. Table III should help in choosing an appropriate MPPT method.

CONCLUSION

Several MPPT techniques taken from the literature are discussed and analyzed herein, with their pros and cons. It is shown that there are several other MPPT techniques than those commonlyincluded in literature reviews. The concluding discussion and table should serve as a useful guide in choosing the right MPPT method for specific PV systems. In this comparison show that buck converter will give the best simulation result, follow by boost converter and last is cuk converter. All of this converter will be used in comparing two basic controllers in MPPT.

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