NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 2, ISSUE 12, DEC.-2015

A REVIEW OF VARIOUS MPPT TECHNIQUES FOR PHOTOVOLTAIC SYSTEM

Miss. Dhanashri Prakash Dhande
(P. G. Student)
Department of Electrical Engineering,
S.S.G.B.C.O.E.T. Bhusawal, India

Prof. A.P. Chaudhari
HOD of .Electrical Engg.
S.S.G.B.C.O.E.T. Bhusawal, India

Prof. G.K. Mahajan
Asso. Prof. Electrical Engg Dept
S.S.G.B.C.O.E.T. Bhusawal, India

ABSTRACT

Solar PV system is becoming an important part of renewable energy, as more than 45% of required energy in the world will be generated by PV array. Hence it is necessary that concentration should be given in order to reduce application cost & to increment their performance. In this paper various techniques involving a comprehensive technique of MPPT applied to PV system is discussed which are available until June 2014. In an attempt to improve more efficient & effective energy extraction for a solar PV system, this paper investigates & compares typical MPPT control strategies used in solar PV industry. But as there will be confusion while selecting a MPPT, because every technique has its own existence, therefore a proper detailed study of different MPPT is essential. In this review paper a comprehensive study of MPPT technique with detailed explanation & classification based on features, such as number of control variable involved, different control strategies employed, types of circuitry useful for PV system & related commercial application. In this paper, atleast 15 distinct techniques have been reviewed with many variation on implementation, thus this paper would become a convenient reference for future work for PV power generation.

INDEX TERMS — Maximum power point tracking (MPPT), photovoltaic (PV) system.

INTRODUCTION

Worldwide concerns of changing climate have made human beings to thought over the use of conventional & depleting energy sources. This in turn pushes us to sustainable energy sources like renewable energy. Photovoltaic (PV) system is one of the promising energy source and its installations are increasing due to their environment-friendly operation & technological advantage over other sources. Photovoltaic power generation system (PVS) is becoming more popular technique for reducing fossil fuel consumption and carbon dioxide emission. However, large-scale penetration of PVSs may cause negative impacts on the existing electric power system because of its nature of fluctuation in power output. The apparent fluctuation in electrical load should be evaluated correctly and cost-effectiveness of this negative impact. Some primary reasons for the power output fluctuation of PVS includes the movement of the clouds and there would be the time-difference in the fluctuation pattern among PVSs in a particular area. Therefore, the total output fluctuation of all PVSs would be relaxed due to the so-called "smoothing effect". Taking this into consideration, this study examines the fluctuation property of apparent electricity load on utility power plants, considering the PVSs power output into account as negative electricity load. The multi-points observed data on insolation is used to estimate the fluctuation property of PVSs power output. [1,3]

PROBLEM OVERVIEW

Fig. 2 shows the characteristic power curve for a PV array. *F*or a certain temperature and irradiance, MPP tracker automatically ascertain the voltage (V_{MPP}) or current (I_{MPP}) to reach the maximum power output (P_{MPP})and accordingly operates PV array. In partial shading conditions possibly two or many local maxima exist, but overall there should be only one real MPP. Few MPPT techniques fits absolutely for constant temperature though many more techniques respond quickly for changing temperature and irradiance. Changes in the PV array due to aging effect would b responded by almost all techniques though some of it are open looped and periodically fine tuned. In our perspective, the variation in the output current of PV array is attended with the help of power converter. The forthcoming techniques are generally used MPPT techniques in applications such as space satellite, solar vehicle, and solar water pump, etc.

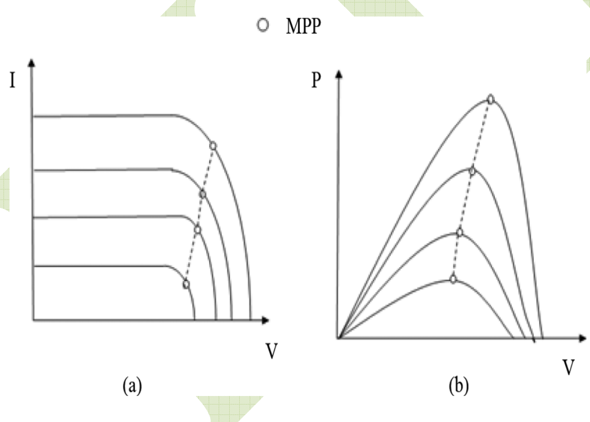

Fig. 1. (a) I–V and (b) P –V characteristics of PV panel at different environmental conditions.[7]

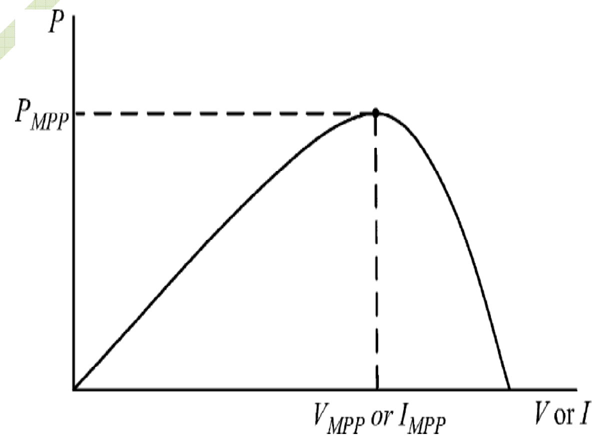

Fig 2. Characteristic of PV array power curve [5]

MPPT TECHNIQUES

1. Curve-Fitting Technique

MPP is the peak value of the P –V characteristic of a PV panel, hence at first the P–V characteristic of a PV panel is predicted in this technique. For the Prediction of this P–V characteristic, the modeling of PV panel is done offline based on mathematical equation or numerical approximation. To achieve an accurate P–V curve fitting, a third-order polynomial function as,

$$P = aV^3 + bV^2 + c\,V + d$$

Where, the coefficients a, b, c, and d are determined by sampling of PV voltage and power in intervals. Differentiation of above equation gives,

$$\frac{dP}{dV} = 3aV^2 + 2bV + c \qquad \text{At MPP,} \quad \frac{dP}{dV} = 0$$

Thus, the voltage at MPP can be calculated as,

$$V_{mpp} = \frac{-b \pm \sqrt{b^2 - 3ac}}{3a}$$

In this technique a, b, c and d are repeatedly sampled in a span of few milliseconds using mathematical equations defined in and then V_{mpp} is calculated [2].

2. Fractional Short-Circuit Current (FSCI) Technique

There exists a single operating point P (V_{mpp}, I_{mpp}) called MPP at which the power of the panel is maximum (P_{mpp}) at a given environmental condition shown in fig 1. However, if any one of V_{mpp} or I_{mpp} are tracked by some way, then the corresponding P_{mpp} can be tracked. In the FSCI technique, depending on a wide range of environmental conditions and degradation level of PV panels, the nonlinearity of V–I characteristics of PV system is modeled using mathematical equation or numerical approximation. And Based on those V–I characteristics, a mathematical relation between I_{mpp} and I_{sc} is constructed as I_{mpp} is linearly dependent on I_{sc} by an empirical relation shown as follows:

$$I_{mpp} \approx K_{sc}\, I_{sc}$$

The value K_{sc} in above relation generally varies between 0.64 and 0.85. And K_{sc} can be calculated by analyzing range of solar radiations and temperatures.

3. Fractional Open-Circuit Voltage (FOCV) Technique

In this technique, V_{mpp} can be calculated from the empirical relationship shown as follows:

$$V_{mpp} \approx K_{oc}\, V_{oc}$$

It is found that the value of K_{oc} varies between 0.78 and 0.92. K_{oc} can be calculated by analyzing the PV system at wide range of solar radiations and temperatures. In this method, the V_{mpp} is calculated by open-circuiting the PV system at load end for a fraction of second and V_{oc} is measured. Then repeating this process, V_{oc} is sampled repeatedly in every few seconds and value of V_{mpp} is updated.

4. One-Cycle Control (OCC) Technique

OCC MPPT technique is based on nonlinear control. Maximum power extraction is achieved by the use of single stage inverter in which inverter output current is linked to with PV array voltage . MPPT control & inversion of DC- AC both are realized using single power conversion stage . The OCC system is shown in Fig.3. The (L,C) parameters involved in this system should be correctly tuned as their values greatly affect the accuracy of OCC technique.

5. Hill Climbing/P&O Technique

Hill climbing or perturb and observe (P&O) methods are most focused MPPT techniques. Hill climbing does perturbation in the duty ratio of the power converter, where as P&O does perturbation in operating voltage of the PV array. Perturbations in PV array current and voltage are obtained by changing power converter duty ratio.

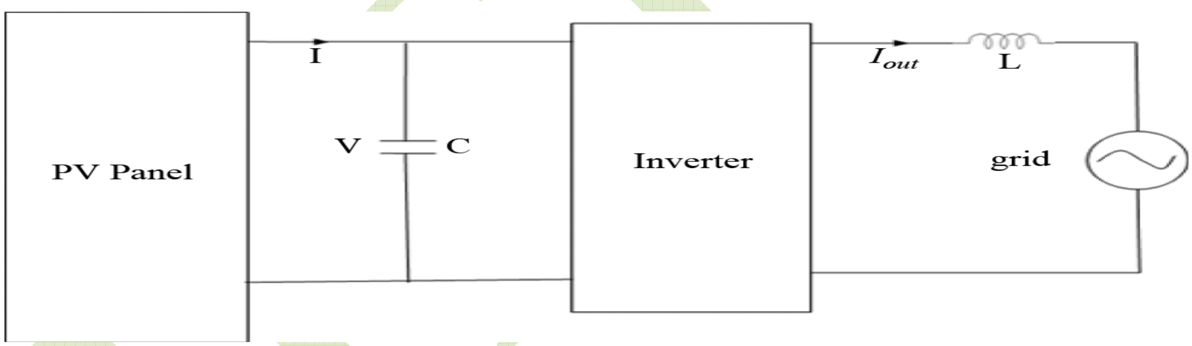

Fig. 3. Block diagram of OCC technique.[7]

Fig. 2 depicts, on left of the MPP increasing (decreasing) the voltage increases (decreases) and on right of the MPP decreasing (increasing) the voltage decreases (increases) . Therefore, if there is an increase in power, the following perturbations should be kept the same to reach the MPP and vice-versa. Algorithm in table I. Also works for instantaneous (instead of average) PV array current and voltage values when sampling occurs once in each switching cycle .

The process is repeated periodically until the MPP is reached, then system oscillates about the MPP to minimize oscillation perturbation step size may be reduced. However, a smaller perturbation size slows down the MPPT. Having a variable perturbation size that gets smaller towards the MPP, avoids the situation. However, rapidly changing environmental conditions, such as broken clouds causes occasional deviation from MPP which is major drawback of the P&O/hill-climbing. Also, correct perturbation size is significant in providing good performance in both dynamic and steady-state response [7].

Table 1: Summary of Hill Climbing& P&O algorithm

Perturbation	Change in power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

6. Load Current/Load Voltage Maximization Technique

Operation of the PV array at MPP may not be ensured at constant load when it is directly connected to load. Thus even a tunable matching network may not achieve operation at the MPP which interfaces the PV array to load. The main components of the MPPT circuit are its power stage and the controller (Fig.6). As the power stage is realized by means of a switched mode power converter, the control input is the duty cycle.

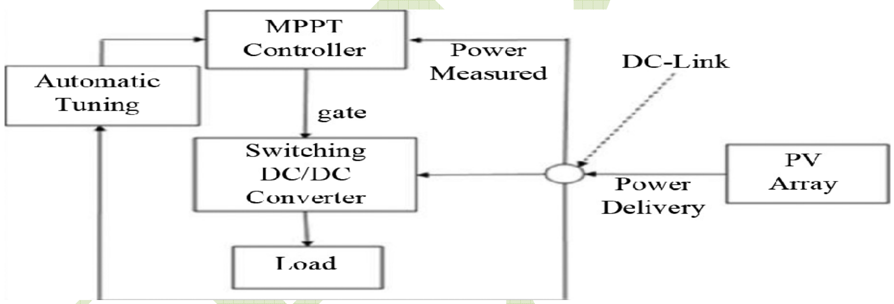

Fig. 4. Block diagram of adaptive Hill-climbing technique [7]

7. Incremental Conductance (Inc-Cond) Technique

For a PV system, the derivative of panel output power with its voltage is expressed as

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} = I + V\frac{\Delta I}{\Delta V} \quad , \text{ at MPP } \frac{dP}{dV} = 0$$

The above equation is zero at MPP, positive on the left of the MPP and negative on the right of the MPP. So, it can also be given as,

i) $\frac{\Delta I}{\Delta V} = \frac{-I}{V} \quad at\ MPP$

ii) $\frac{\Delta I}{\Delta V} > \frac{-I}{V} \quad at\ left\ of\ MPP$

iii) $\frac{\Delta I}{\Delta V} < \frac{-I}{V} \quad at\ right\ of\ MPP$

Thus, MPP can be tracked by comparing the instantaneous conductance $\frac{I}{V}$ to the incremental conductance $\frac{\Delta I}{\Delta V}$. It is as efficient as P&O technique, good yields under rapidly changing atmospheric conditions. Here, also the same perturbation size problem as the P&O exists and an attempt has been made to solve by taking variable step size . But, it requires much complex and expensive control circuits [1,3].

8. Ripple Correlation Control (RCC) Technique

Imposition of voltage and current ripple on PV array is caused due to switching action of converter, when PV array is subjected to power converter. This ripple is the subjected to the generated power of the PV system. In the RCC technique, this ripple is used by the PV system to perform MPPT. As the ripple is naturally available by using a switching converter, no artificial perturbation is required. RCC correlates dp/dt with either di/dt or dv/dt and hence by using following eq. the value of voltage and current of PV system are recognized whether that value is more or less than that of MPP. The role of RCC is to force this ripple to zero and eventually drag the PV panel voltage and current to that of MPP[3].

$$\frac{dv}{dt} > 0 \; or \; \frac{di}{dt} > 0 \; and \; \frac{dp}{dt} > 0 \; \rightarrow V < V_{mpp} \; or \; I < I_{mpp}$$

$$\frac{dv}{dt} > 0 \; or \; \frac{di}{dt} > 0 \; and \; \frac{dp}{dt} < 0 \; \rightarrow V > V_{mpp} \; or \; I < I_{mpp}$$

RCC technique can be applied to any switching power converter topology. This adjustment of I (current) can be done by using a boost converter. Here, the inductor current I_L is equal to the array current (I). At a given temperature and irradiance, I_L is adjusted together with $P = VI_L$ .Whenever there is any change in environmental condition, MPP is also shifted. Then referring to Fig.2 & above eq. can be modified as follows:

$$\frac{di_L}{dt}\frac{dp}{dt} > 0 \rightarrow i_L < I_{mpp}$$

$$\frac{di_L}{dt} > \frac{dp}{dt} < 0 \rightarrow i_L > I_{mpp}$$

Adjusting the duty ratio d , the value of i_L can be adjusted. The value of d can calculated using the following relation,

$$d = k \int \frac{di_L}{dt}\frac{dp}{dt}\, dt$$

Where, K is constant.

9. Current Sweep Technique

Sweep waveform is used in current sweep technique for the PV array current such that the I–V characteristic of the PV array is obtained and updated at a constant time interval. The V_{MPP} can then be computed from the characteristic curve at the same interval. The function chosen for the current sweep waveform is directly proportional to its derivative as

$$i(t) = k_1 \frac{di}{dt}$$

ISSN: 2394-3696
VOLUME 2, ISSUE 12, DEC.-2015

The solution of above is

$$i(t) = k_2 e^{t/k1}$$

Here K_2 is taken as I_{MPP} . Again at MPP

$$\frac{dp(t)}{dt} = \frac{d(v(t)i(t))}{dt} = i(t)\frac{dv(t)}{dt} + v(t)\frac{di(t)}{dt} = 0$$

Using above two equation

$$\frac{dp(t)}{dt} = \left(k_1\frac{dv(t)}{dt} + v(t)\right)\frac{di(t)}{dt} = 0$$

Here, the reference point is frequently updated in a fixed time interval and hence the technique yields accurate results if proportionality coefficients K_1 and K_2 are properly chosen.

10. DC-Link Capacitor Droop Control Technique

DC-link capacitor droop control is an MPPT technique which is particularly designed to work for a PV system that is connected in parallel with an ac system line as shown in Fig.5. The duty ratio of an ideal boost converter is given by:

$$d = 1 - \frac{V}{V_{link}}$$

Where, V is the voltage across the PV array and V_{link} is the voltage across the dc link. If V_{link} is kept constant, increasing the current going in the inverter increases the power coming out of the boost converter which leads to increase in power coming out of the PV array. With the increase in current , the voltage V_{link} may be kept constant as long as the power demanded by the inverter doesn't exceed the power availability from the PV array. And if the situation is not alike , *Vlink* starts decreasing. Exactly 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 V_{link} from drooping and d is optimized to bring *Ipeak* to its maximum, thus achieving MPPT. This control scheme can be easily implemented with analog operational amplifier & decision making logic units.

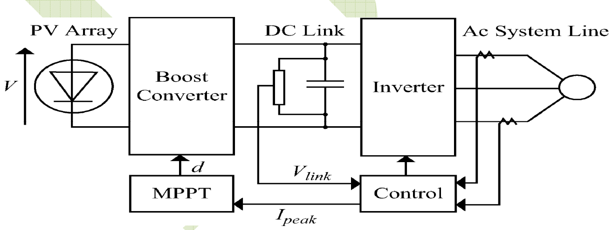

fig 5. topology for dc –link capacitor droop [5]

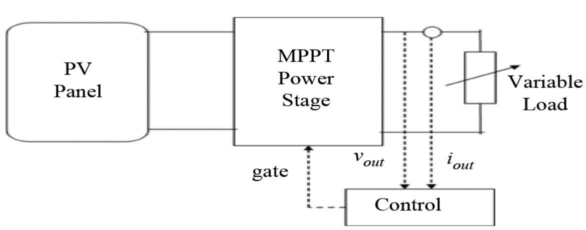

Fig 6. Experimental set up for load current/voltage maximization technique of PV panel [7]

11. Intelligence MPPT Techniques

a) Fuzzy Logic (FL)-Based MPPT Technique: FL-based MPPT do not require the knowledge of the exact PV model & it has two inputs and one output. The two input variables are error (e) and change in error (C_e) at the k^{th} sampled time are defined as follows:

$$e(k) = \frac{dP}{dV}(k) - \frac{dP}{dV}\,(k-1)$$
$$C_e\,(k) = e(k) - e(k-1)$$

Where e(k) implies if the error of position of operating point of load at the K^{th} instant, while $C_e\,(k)$ expresses the moving direction of this point. The fuzzy inference is carried out by using Mamdani' method and the defuzzification uses the centre of gravity to compute the output (duty ratio, d) of this fuzzy logic-based MPPT.

b) Artificial Neural Network (ANN)-Based MPPT Technique: The link between the *i*th and jth nodes has weight W_{ij} .For MPPT, ANN input can be PV array parameters like PV voltages and currents, environmental data like irradiance and temperature, or any combination of these, whereas the output signal is the identified maximum power or the duty cycle signal used to drive the electronic converter to operate at the MPP. The ANN input and output data are obtained from experimental measurement or model-based simulation results. After learning relation of V_{MPP} with temperature and irradiance, ANN can track the MPP online.

12. Sliding-Mode-Based MPPT Technique

In Increasing Conductance technique, ratio of PV array current and voltage is compared with change in ratio of current and voltage term. Let h be a constant term and defined as h=$I/V + \Delta I/\Delta V$. At MPP, h=0 . This concept is used in sliding mode-based MPPT technique. The dc/dc converter is designed such that its switching control signal is generated as shown as,

$$u = \begin{cases} 1, h < 0 \\ 0, h > 0 \end{cases}$$

Where u=0 means the converter-switch is opened while it signs to closing of the switch when u=1. In this way, the converter is forced to operate at MPP. SMC-MPPT is compatible with a wide range of processors such as DSP, microcontroller, FPGA, etc. Conventional SMC-MPPT has limitations like variable operating frequency and presence of nonzero steady state error. These problems are overcome to large extent by using discrete sliding mode controller and PWM-based integral sliding mode controller. Another problem in SMC-based MPPT is the measurement of V and I. Since, I is dependent on inductor current, estimation I of needs a state observer.

13. Beta Technique

The beta method is the approximation of the point of maximum power through the equation of an intermediate variable β,as given in the following equation:

$$\beta = In\frac{I_{pv}}{V_{pv}} - c \times V_{pv}$$

Where $c = (q/(\eta \cdot KB \cdot T \cdot Ns))$ is a constant that depends on the electron charge (q), the quality factor of the junction panel (η), the Boltzmann constant (KB), temperature (T), and amount of series PV cells (Ns). Moreover, as the operating conditions change, the value of β at the optimum point remains almost constant. Thus, β can be calculated at every instant using the voltage and current of the panel and inserted on a conventional closed loop with a constant reference. However, it is mandatory to know the PV electrical parameters, for optimal performance which can reduce the attractiveness of this method. The implementation of this method is shown in Fig.7. [8]

14. Hybrid MPPT (HMPPT) Techniques

It is found that the P&O technique is the most extensively used in commercial MPPT systems because it is very straight forward, accurate, and easy to implement. Its accuracy and tracking time depend on the perturbation size. Hence, hybrid control techniques are essential. In a recent proposed hybrid MPPT technique with both P&O and ANN, the perturbation step is continuously approximated by using ANN. Using this P&O-ANN hybrid MPPT on-line MPP tracking is possible. It is accurate and fast. Once tuned, it does not depend on atmospheric conditions.

15. MPPT Techniques for Mismatched Conditions

Mismatched conditions impact strongly on the shape of the P–V characteristics of the PV arrays and therefore the energy productivity of mismatched strings can drop down to 20% -30% of that of the none mismatched strings. Additionally, in case of mismatch, the P –V characteristic of the PV field may have more than one peak. Hence, MPPT algorithms may fail causing a drastic drop in the overall system efficiency. The above mismatched problems is alleviated by Distributed Maximum Power Point Tracking DMPPT), because in the DMPPT technique, each module uses a single MPPT.

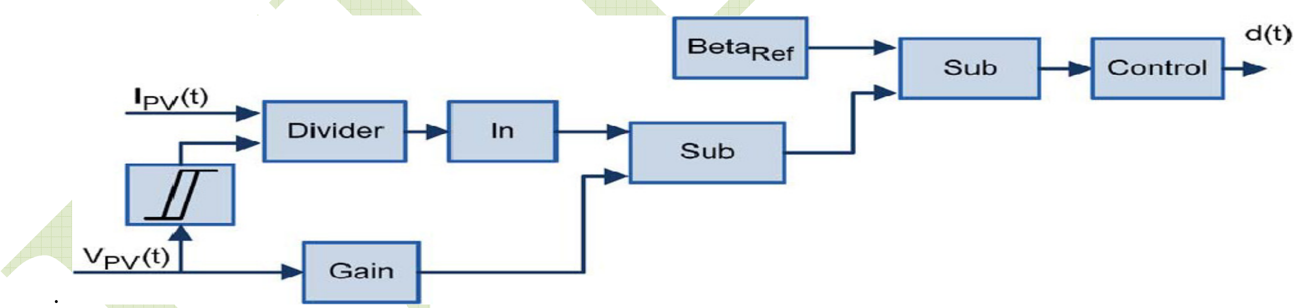

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Fig 7 Implementation of beta method.

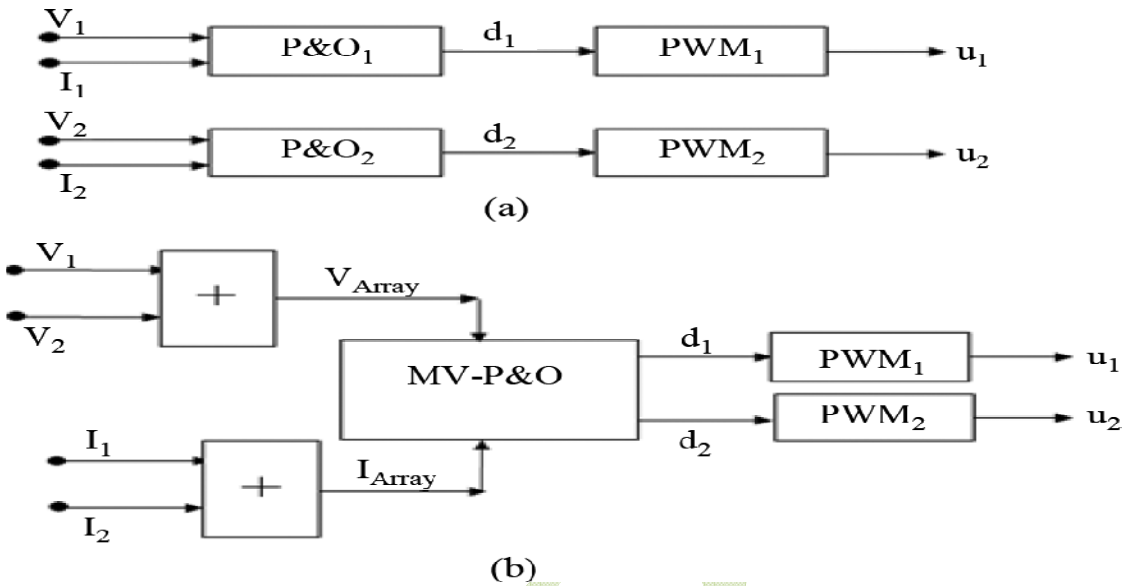

Fig.8. Comparison between (a) traditional P&O and (b) multivariable P&O Structures [7]

(DMPPT ensures higher energy efficiency than other discussed MPPTs in presence of mismatching conditions. Further, a multivariable MPPT (MVMPPT), as shown in Fig.8(b),
As shown in Fig.8(a), the control unit of this MVMPPT takes the current and gives the signal for the controlled switches of the dc/dc boost converters. As shown in Fig.8(a), in the P&O-based MPPT technique, the number of required P&O blocks is equal to the number of switching control variables (d_1, d_2) whereas as shown in Fig.8(b), one block of MV-P&O is sufficient to generate multiple control variables. MV-P&O has less number of control stages compared to that of P&O, this leads to considerably less power loss in the whole MPPT system, maximizing the PV power at the output of the converter [9].

CONCLUSION

This review article provide a detailed classification of available MPPT technique based on no. of control variable involved type of control strategies & type of circuitry which will surely help the reader while selecting an MPPT technique for particular application. It also gives an idea about grid tied or stand alone mode of operation & types of preferable converters for each MPPT techniques. This review investigates many recent hybrid MPPT techniques along with their merits. Further the review shows MPPT technique for different atmospheric condition such as partial shedding, non-linearity or PV panel temperature, dust effect, damages of panel glass etc. Hence this article will surely be a very useful tool for not only the MPPT user but also the designer and commercial manufacturer of PV system.

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