Outline of the various MPPT methods used for photovoltaic power control

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Abstract - Considering the current energy situation, electricity generation & demand, acute energy crises, greenhouse effect, global climate control, constricted available non-renewable energy sources had created immense need for giving stress over the contingencies regarding transforming & maximum utilization of power generated via renewable energy sources against power generation from non-renewable sources so as to conserve the environmental equilibrium along with escalating human demands / needs. Amongst all renewable energy sources available with us, solar energy is a imperative & readily available untapped resource in tropical countries like ours. Solar energy can be transformed to useful electric energy through PV solar cells. However, being dynamic solar irradiance & temperature, the main interruption for the penetration and reach of solar PV systems is their low efficiency & hefty capital cost. Therefore, to trounce such issues, maximum power point tracking (MPPT) for solar arrays is indispensable in PV system. The non linear behaviour of PV system as well as variations of MPPT with solar irradiation & temperature resulted in MPPT mechanism a tedious one. To date a range of methods for MPPT are projected & implemented. In this paper a study of various methods with its pros & cons along with algorithms are presented.

Keywords: PV solar cell, P&O MPPT mechanism, solar irradiation, algorithm, MPPT methods, renewable sources.

I. INTRODUCTION

The installed capacity of energy sector in India is 298GW as on March 2016. Renewable Power plants constituted @ 28% of total installed capacity & Non renewable plants constituted @ 72% [18]. Thus, major involvement in the energy sector is being handled by the non renewable plants. However, due to uninterrupted use of fossil fuels the fossil fuels stock are depleting speedily day by day severely disturbing the environment depleting the biosphere & cumulatively totalling to global warming. Apart from rapidly decreasing reserve stock of fossil fuels, the major alarm for utilizing fossil fuels as a principal source is pollution allied with combustion. As early as 1896, the Swedish scientist Svante Arrhenius had predicted that human activities would interfere with the way the sun interacts with the earth, resulting in global warming and climate change. His prediction has become true and climate change is now disrupting global environmental stability. Many treaties, conventions, and protocols for the cause of global environmental protection were introduced during the recent past. Various conventions & protocols were established to maintain & safeguard the equilibrium of the earth. In June 1992, the “United Nations Framework Convention on Climate Change” (UNFCCC) was signed in Rio de Janeiro by over 150 nations & major stress was given over the human activities responsible for increase in greenhouse effect & climate change. Legal binding limitations or reductions in greenhouse gas emissions were introduced via Kyoto protocol. As per the United Nation climate change conference held at Paris during the year 2015, an agreement was signed to set the goal for restricting global warming to less than 2 degree Celsius compared to pre industrial levels. This agreement also includes the urge for zero net anthropogenic greenhouse emission to be reached during second half of the 21st century with restrictions to the increase in temperature up to 1.5 degree Celsius. Keeping all this perspective in mind maximum utilization of
renewable sources is the only option left with us to tackle the various issues stated above. Since India is a densely populated having high solar insulation, the utility of the solar power is an idealistic alternative to conventional power utility. Thus, utilization of solar power will play a pivotal role in achieving the various targets as decided & will trounce the various problems which will bind to take place in near future if a serious view or concern is not given over this issue. Solar energy being renewable source of energy bountifully available is a clean source of energy. The overwhelming problems of air, noise, water pollution, more maintenance activities, etc as faced in the conventional process will get eradicate up to much extent by using solar power as a principal source of energy for the electricity generation. Solar energy can be a separate generating unit or can be a grid connected generating unit depending on the accessibility of a grid nearby. Thus it can be used to power rural areas where the availability of grids is very low. Another advantage of using solar energy is the handy operation whenever wherever necessary. Looking into the value added advantages for utilizing the solar power, the Government of India projected to launch its Jawaharlal Nehru National Solar Mission under the National Action Plan on Climate Change with strategy to generate 1,000 MW of power by 2013 and up to 20,000 MW grid-based solar power, 2,000 MW of off-grid solar power and cover 20 million sq meters with collectors by the end of the final phase of the mission in 2020 [18]. To utilize / extract the maximum power from the solar radiation effective & efficient method has to be adopted. Generation of electricity through solar power is possible with the help of Solar PV cells. However, being dynamic solar irradiance & temperature, the main interruption for the penetration and reach of solar PV systems is their low efficiency & towering capital cost. The PV array is an uneven source of power since the peak power output depends on the temperature & irradiation level. The V-I and V-P characteristic curves indicate a distinctive operating point at which maximum possible power is delivered [12]. At the MPP, the PV operates at its peak efficiency. Therefore, to beat such issues, maximum power point tracking (MPPT) for solar arrays is obligatory in PV system. The non linear behaviour of PV system as well as variations of MPPT with solar irradiation & temperature resulted in MPPT mechanism a tedious one. To date a range of methods for MPPT are projected & implemented. The concept of PV cells was first invented during 1960’s. Ongoing Research & Development in this field have initiated maximum utilization & tapping of solar power. There are different techniques for MPPT such as Perturb and Observe (hill climbing method), Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control etc.

II. LITERATURE SURVEY

An overview of the different MPPT techniques is described. Each technique is evaluated on its ability to detect multiple maxima, convergence speed, ease of implementation, efficiency over a wide output power range, and cost of implementation [1]. A comparative study of ten widely-adopted MPPT algorithms; their performance is evaluated using the simulation tool Simulink [2]. A review on various MPPT methods for variable environmental conditions (i.e. variable temperature and irradiation level), their difficulty while tracking and how those difficulties can be overcome efficiently by the other techniques [4]. A focus on the state of the art of various MPPT methods and their evolution to apply under partial shading conditions. The recent developments and modifications are analyzed through a comparison based on design complexity, cost, speed and the ability to track the MPP under rapid environmental variations and partial shading conditions [5]. A comparative simulation study of two important MPPT algorithms specifically perturb and observe and incremental conductance are evaluated or elaborated [6]. Conventional P&O with adaptive perturb and modified P&O with adaptive perturb are elaborated [7]. A comparison between the ‘perturb and observe’ control method and the ‘incremental conductance’ control method are given, analyzed and discussed [8]. A comparison and DC-DC converter used in solar PV MPPT systems are described [9]. Various MPPT methods along with problem overview & algorithm is elaborated [10]. A detailed description and then classification of the MPPT techniques have made based on features, such as
number of control variables involved, types of control strategies employed, types of circuitry used suitably for PV system, transient response and practical/commercial applications are explained [11]. Significance of MPPT in all PV power systems for getting better energy conversion efficiency during steady & dynamic state using Perturb & Observe algorithm is elaborated [12]. The design and implementation of DC-DC boost converter operating in uninterrupte d conduction mode with a Maximum power point tracker using a Microcontroller linking a 555 timer circuit to generate Pulse Width Modulation (PWM) signal to set up a constant output voltage is elaborated. Also PSIM and Pspice software were used to simulate DC-DC boost converter and compare simulation results with the practical operation of the design system [13]. Simple and quick calculation methodology to obtain a solar panel model, based on the manufacturer’s datasheet, to perform MPPT simulations, is described [14]. Optimal efficiency for converter using DC-DC converters is explained [15]. A relative study of widely-adopted MPPT algorithms; their performance is calculated on the basis of energy generation capability in most effective way, by using the simulation tool Matlab/Simulink, taking into account different solar irradiance variations [16].

III. MPPT METHODS
The MPPT is responsible for extracting the maximum possible power from the photovoltaic to achieve maximum power output. PV cells are having very tedious bond between current, voltage & power output and are important factor for producing non linear power output. The power output is expressed as the current – voltage characteristics of the cell.

The trend of I-V curve in upward-downward direction is observed due to fluctuations in external variables such as temperature, irradiance & shading. A change in temperature will have an inverse relation with the output wherein change in irradiance will have direct relation.

There are different techniques for MPPT are implemented todate. However, the details of the commonly & important techniques such as Perturb and Observe (hill climbing method), Incremental conductance, Modified P&O method, Short Circuit Current, Open Circuit Voltage, Constant voltage, Fuzzy Control and Neural Network Control are described below:-

A. Perturb and Observe (hill climbing method)
If the power extracted from PV arrays rises then the operating point will shift towards the MPP resulting into the perturbation of the PV arrays input voltage in a desired or same direction.

Conversely if the power extracted from PV arrays decreases then operating point will shift away from MPP resulting into the perturbation of the PV arrays input voltage in an opposite direction. The function of the MPP tracker is to track the change in behaviour of the solar arrays i.e incrementing or decrementing time to time & to compare the power output with the preceding perturbation cycle. After reaching to P & O, the algorithm will move to & fro ultimately resulting into the loss of PV power. This phenomenon is predominant in cases of constant or gradually varying atmospheric conditions. Hence, to overcome this issue certain modifications in the designed algorithm were made, by which MPP tracker will compare PV output power with the parameters of the two previous perturbations instead of single cycle so as to check whether P&O is reached or not & consequently bypass the perturbation stage.
B. Modified dP P&O method
The modified dP P&O method is introduced in line with the conventional P&O method with certain modifications to trounce the drawbacks evident in conventional P&O method such that the incorrect control phenomenon during frequent varying solar irradiation is eradicated completely. Initially it is presumed that only PV voltage perturbation is responsible for power variation. However, later on it is evident practically that beside PV voltage perturbation a significant contribution for power variation of solar PV array output is contributed by the ambient condition like solar irradiation. The conventional P&O method will fail to track maximum power during varying irradiance condition from irradiance\(_1\) at time (t) to irradiance\(_2\) at time (t+1). Hence, to eradicate the irradiance disturbance as evident in conventional P&O method, the modified P&O method is introduced so as to distinguish power variation resulted due to irradiance change & PV voltage perturbation. At the mid-point of the MPPT control period an additional PV array power is measured in modified P&O mechanism & PV power is computed by taking the average. Thus, the power difference \(dP_{0.5}\) measured between the mid-point power \(P(K - 0.5)\) and the staring power \(P(K - 1)\) of MPPT control includes both power variation caused due to MPPT control & change in irradiation respectively and the power \(dP_1\) contains power variation caused only due to change in irradiation. Hence, a power difference \(dP\) caused solely due to MPPT control is computed as below:-

\[
\begin{align*}
    dP_{0.5} & = P\left(k - 0.5\right) - p(k - 1) \\
    dP_1 & = P\left(k\right) - p(k - 0.5) \\
    dP & = dP_{0.5} - dP_1
\end{align*}
\]
C. **Constant Voltage**

Solar output voltage is matched to a constant reference voltage by properly regulating it, so that the PV array is retained near the MPP. The reference voltage value $V_{ref}$ is adjusted equal to the voltage at the maximum power point $V_{mpp}$ of the characteristic photovoltaic array. The algorithm assumes that PV panel variations, such as temperature and irradiation, are not momentous, and the constant reference voltage is adequate to accomplish performance close to the MPP. Due to this, the CV algorithm may never exactly locate the MPP. Hence before installation it is essential to collect the changes from location to location. In low insolation conditions having constant or low varying atmospheric condition the constant voltage technique is more effective than either the perturb and observe, or the incremental conductance algorithm [2].
D. Incremental Conductance (IC) method
The incremental conductance (IC) algorithm seeks to overcome the limitations of the perturbation and observation algorithm by using the incremental conductance of the photovoltaic. In this method a voltage operating point is track such that the conductance is equivalent to the incremental conductance & consequently after tracking the exact point, the set up stops perturbing the operating point. The value added advantage of this method is that it has a potential to discern the relative distance to the MPP such that information regarding whether MPP has reached or not can be identified or determined. In addition to this, as compared to optimized P & O method, the ability of tracking the MPP is more precise during varying environmental conditions & also shows marginal oscillating behaviour around the MPP. However, due to utilization of derivative operation in algorithm resulted into the instability of the system. During the instances of low solar irradiations the differentiation process got tedious & consequently desired results may not be reflected. Thus, the IC tracking system is successful using constant iteration step size, which is determined by the accuracy and tracking speed requisite. With increase in step size the improvement in tracking speed is observed while inverse phenomenon is observed for the accuracy it got depleted. To overcome such problem a technique with variable step size has been introduced by which the step size automatically fiddle with the solar array operating point. During the instances when the operating point is away from the MPP, the algorithm increases the step size to facilitate the algorithm to reach the operating point towards the MPP rapidly & vice versa.
Thus, the difference of the value obtained from the above equation

\[ V_{mpp}(T) = V_{mpp}(T_{ref}) + U_{mpp}(T - T_{ref}) \]  

(4)

Where:

- \( V_{mpp} \) – Voltage at MPP
- \( T \) – Measured temperature through sensors
- \( T_{ref} \) – Reference temperature
- \( U_{mpp} \) – Temperature coefficient of \( V_{mpp} \)

This, the difference of the value obtained from the above equation \( V_{mpp} \) with the measured PV voltage is then utilized for determining the incremental duty cycle (D). This method for its successful operation requires the datasheet information regarding the PV array.

**E. Temperature (T) method**

The short circuit current \( I_{sc} \) of the solar array is proportional to the irradiance level & is generally steady when the PV cell temperature changes wherein the open circuit voltage of solar panel is directly proportional to the PV array temperature [2]. In this method two sensors are affixed on the PV array for temperature & voltage measurement respectively. The temperature & voltage are both measured simultaneously by these sensors. The measurement recorded from these sensors is then utilized for evaluating the value of the MPP voltage \( (V_{mpp}) \) with the following equation [2]:

\[ V_{mpp}(T) = V_{mpp}(T_{ref}) + U_{mpp}(T - T_{ref}) \]  

Where:

- \( V_{mpp} \) – Voltage at MPP
- \( T \) – Measured temperature through sensors
- \( T_{ref} \) – Reference temperature
- \( U_{mpp} \) – Temperature coefficient of \( V_{mpp} \)

Thus, the difference of the value obtained from the above equation \( V_{mpp} \) with the measured PV voltage is then utilized for determining the incremental duty cycle (D). This method for its successful operation requires the datasheet information regarding the PV array.
“Figure 5. Temperature algorithm”

F. Open voltage (OV) method

It is based on the assumption that MPP voltage is nearer to fixed percentage of the open circuit voltage for most of the time. As per the temperature & solar irradiation level the MPP is adjusted within 2% tolerance band. Around 76% of the open circuit voltage $V_{ov}$ is considered as optimum operating voltage $V_{mpp}$ at which the maximum output power can be delivered. The relationship between the maximum operating voltage $V_{mpp}$ and open circuit voltage $V_{ov}$ is given by:

$$V_{mpp} = kV_{ov}$$  (5)

Where $k(0.71-0.78)$ is proportionality constant for commonly used crystalline silicon panel. Thus from $V_{mpp}$ can be determined by sensing $V_{ov}$. A static switch in series with the PV array is a pre requisite for this MPPT so as to facilitate for measurement of the open circuit voltage $V_{ov}$ as per the demand. However, at the same time during measurement of open circuit voltage, the current of the PV panel ($I_{pv}=0$) is zero & hence no power is delivered during this period & consequently resulted in power loss for that particular span of time.
G. **Short circuit current (SCC) method**
The Short circuit current (SC) method is based on the assumption that the linear relation exist between the PV array current $I_{pv}$ corresponding to the maximum power $I_{mpp}$ and the array short circuit current $I_{sc}$. In fact, short circuit current $I_{sc}$ under diverse conditions of irradiance level exist an direct relation with the maximum operating current IMPP for maximum output power & is enumerated below: —

$$I_{mpp} = k I_{sc}$$  \hspace{1cm} (5)

where $k(0.78-0.92)$ is a current factor. Thus, by sensing $I_{sc}$, $I_{mpp}$ can be determined. Hence, to sense or measure the $I_{mpp}$, a static switch in parallel with the PV array is a pre requisite requirement so as to generate the short-circuit condition. The voltage across PV panel $V_{pv}$ is zero while measuring the short circuit current. When $V_{pv} = 0$ no power is supplied by the PV system and consequently no energy is generated.
H. Feedback voltage (current) method
This method is used to fasten the bus voltage at a constant level. In this method the PV voltage is compared with the constant voltage & accordingly the duty cycle (D) of the converter is adjusted so as to operate the PV array at a point nearer to MPP. Being single feedback control loop is used in this system, it is comparatively economical & simple to use. However, major disadvantage of this method is that it is non operative during the frequent varying environmental conditions.

I. Fuzzy logic control method
In this method the microcontrollers are used for its operations. Fuzzy logic controllers have three stages, fuzzification, rule base table lookup, and defuzzification. During fuzzification, as per the defined membership functions the numerical input variables are converted into linguistic variables. The accuracy of the controller operation is directly proportional to the number of membership functions used. Thus more the number of membership functions used more is the accuracy of the controller. Error signal “E” & the change in error signal “ΔE” are the inputs given to the fuzzy logic.

These inputs are given by:
\[ E(k) = \Delta I/\Delta V + I/V \]  
\[ \Delta E(k) = E(k) - E(k - 1) \]
The facility is made available such that error signal & change in error signal can be computed externally. These signals are then converted to linguistic variables which define how the system is to be controlled. The major advantage of fuzzy logic is that it does not need precise mathematical model & also capable to operate during the non-linearity system. However, the successful operation of this system is predominantly depends on the knowledge & competency of the user for computing the error signal value along with affixing suitable rule base table based on the chosen membership functions.

J. Neural network method

For operation of Neural network with the PV array and adjust for time varying characteristics of the system the proper training to neural network is mandatory so as to have confirmed accurate MPPT operation. Neural network after getting trained does not depend on the detail information about the PV systems & operates like a black box model. The neural network has three layers: input layer, hidden layer, and output layer. The number of nodes in each layer varies and is user dependent. The PV array Voc and Isc are used as the input variables. The output is usually represented by one of several reference signals, or the duty cycle signal used to drive power converter. The hidden layers act to achieve the MPP; the performance of the system is heavily dependent on how well a neural network has been initially trained [2].
### Table 1. Comparison of various MPPT methods

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>MPPT mechanism</th>
<th>PV array dependant?</th>
<th>Tracking speed</th>
<th>Tracking accuracy in steady state or low solar irradiation</th>
<th>Tracking accuracy in varying condition</th>
<th>Implementation Parameters to be sensed</th>
<th>Dataseet required regarding environmental condition?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P&amp;O</td>
<td>No</td>
<td>Slow</td>
<td>Algorithm Oscillates around MPP during steady environmental condition</td>
<td>Low</td>
<td>simple</td>
<td>Voltage, Current</td>
</tr>
<tr>
<td>2</td>
<td>Modified P&amp;O</td>
<td>No</td>
<td>Fast</td>
<td>High &amp; show marginal oscillation</td>
<td>High</td>
<td>simple</td>
<td>Voltage, current, extra PV array voltage at mid-point of the MPP</td>
</tr>
<tr>
<td>3</td>
<td>Incremental conductance</td>
<td>No</td>
<td>Fast with increase in iteration step size with sacrifice of accuracy &amp; vice versa</td>
<td>Unstable and Improper results</td>
<td>High &amp; show marginal oscillation</td>
<td>Medium</td>
<td>Voltage, current</td>
</tr>
<tr>
<td>4</td>
<td>Open Voltage (OV)</td>
<td>Yes</td>
<td>Low</td>
<td>Medium, based on the assumption that MPP voltage is nearer to fixed percentage of the open circuit voltage</td>
<td>Medium</td>
<td>voltage</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>SCC</td>
<td>Yes</td>
<td>Low</td>
<td>Medium, based on the assumption direct relation exist between $I_{PV}$,$I_{MPP}$,$I_{SC}$</td>
<td>Medium</td>
<td>current</td>
<td>NO</td>
</tr>
<tr>
<td>6</td>
<td>Feedback Voltage (Current)</td>
<td>No</td>
<td>Fast in steady state</td>
<td>High Non operative</td>
<td>Complex</td>
<td>Voltage, current</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>Fuzzy logic</td>
<td>Yes</td>
<td>High</td>
<td>High Depends on the number of membership functions used &amp; input error &amp; change in error signal given.</td>
<td>Complex</td>
<td>varies</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>Neural network</td>
<td>Yes</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Voltage, current</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>Temperature</td>
<td>Yes</td>
<td>Medium</td>
<td>Varies as per the solar irradiation &amp; temperature</td>
<td>Simple</td>
<td>Voltage, current</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>Constant Voltage</td>
<td>No</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>simple</td>
<td>Voltage, Yes</td>
</tr>
</tbody>
</table>
IV. CONCLUSION

An outline of various MPPT methods for photovoltaic power control is presented in this paper. Individual MPPT are having their own characteristics & shows different behavior accordingly with certain pros & cons. Thus, the selection of MPPT method varies situation to situation & is mostly applicant dependant. However, keeping perspective of simplicity, reliability, fast tracking speed with accuracy & economy in mind & imperatively MPPT should be capable of minimizing the ripple around the MPP, it is evident that amongst all the methods presented in this paper the two methods – Incremental conductance & P&O method are suitable for implementation.

REFERENCES

[18] www.wikipedia.com