COMPARATIVE ANALYSIS OF MPPT BASED TWO INPUT BOOST CONVERTER

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Abstract: In order to tackle the present energy crisis, one has to develop an efficient method for extracting maximum power from the incoming solar radiations which is abundance, clean and green energy among other renewable sources of energy. For such purposes, different MPPT techniques such as P&O, Incremental conductance algorithm are applied to DC-DC converter to boost the output voltage based on the duty cycle of power converter switch. The novelty of this paper is the use of constant voltage and Incremental conductance with variable step size for multi-input DC-DC converter to increase the convergence speed and efficiency. MATLAB Simulink tool is used for the performance evaluation of different MPPT algorithms under different solar irradiance.

Key words: Maximum Power Point Tracker(MPPT), Perturb and Observe(P&O), Incremental conductance (INC), Constant Voltage-Incremental Conductance Algorithm(CV-INC)

1. Introduction.

With increase in energy demand all over the world, studies of renewable energy indicate that the global energy demand will almost triple by the year 2050[1]. Moreover, renewable energy can play a significant role on the reduction of environmental problems and delay the depletion of fossil fuel [2] and consequently increase the use of green energy sources. Nowadays researchers are concentrating on renewable energy sources, such as solar, biomass, wind and tidal energies as a clean alternative of conventional energy sources. However, solar power generation has significant advantages such as no rotating parts, hence low maintenance cost and clean green energy with pollution free atmospheric environment [3]. The PV system installation cost has been reducing due to the mass production techniques. However, the drawback of the PV system is its ineffectiveness during the nights or low illumination periods or during partially shaded conditions that leads to lower the conversion efficiency. PV array is made with series and parallel combination of PV cells to get a specific current and voltage rating. Solar array has non-linear I-V characteristic and output power depends on the environmental conditions such as solar irradiation and temperature. So, most of PV’s researches conducted to improve the conversion chain by using Maximum Power Point Tracker Techniques There is an intersection point on I-V, P-V characteristic curve of solar array called as Maximum Power Point (MPP), where the PV system produces its maximum output power[4]. Location of MPP changes with change in atmospheric environmental condition. The main purpose of MPPT is to adjust the solar operating voltage close to MPP under changing environmental conditions. In order to continuously collect the maximum power from the PV array, it has to operate at its maximum power point despite of the inhomogeneous change in environmental conditions. The solar panel is interfaced to the load by a dc-dc converter to attain the maximum power point. The structure of the proposed Multiple Input Converter (MIC) is simpler when compared to the several other available single input converters for each source[5]-[9]. The photovoltaic (PV) power generation systems have very many popular commercial and residential areas. For low input voltage from PV panel cannot make higher efficiency at PV inverter [10]. Several converter topologies are proposed to increase PV output voltage as required. The single phase buck converter reduces the output voltage which in turn decreases the efficiency of converter and buck-boost converter requires input filter as input current is pulsating due to switching of power switch, even though buck converter is able to step up or step down input voltage it gives negative output voltage, while boost converters gives high output voltage, low operating duty cycle and also lower voltage across switch[11]-[14]. It also provide less input current ripple, which in turn decreases the conduction loss of the switch. The output efficiency of solar array depends on many factors such as irradiation, temperature, spectral characteristics of shadow, sunlight, etc. During cloudy season due to changing insolation levels the output of the array keeps differing. The
efficiency of the photovoltaic system may be increased by using maximum power point tracker (MPPT) to track the point, at which maximum current and voltage can be obtained[15]. There are two ways to get maximum output from PV panel is mechanical tracking and electrical tracking. The Mechanical tracking is obtained the direction of PV panel is aligned in such a way that to get maximum power from the sun. The electrical tracking is obtained by manipulating the load to get maximum output power under changing condition of irradiation and temperature. The choice of the algorithm depends on the time to reach maximum power point, cheaper and simpler. There are different types of MPPT techniques based on different topologies and varying complexity, cost and production efficiency, are perturb and observation, incremental conductance, constant reference voltage or current, these techniques are used for increase the efficiency of PV system[16]-[19]. Among them P&O and Incremental conductance algorithm can track maximum power point, easy to implement and cost effective method [20]-[22]. Among these two techniques incremental conductance algorithm gives good dynamic response and also it incorporates sudden change in temperature and irradiation. Hence Incremental conductance MPPT algorithm is suggested.

In this paper, a new algorithm is proposed for the constant voltage incremental conductance with variable step size. The proposed algorithm is compared with P&O and incremental conductance MPPT algorithm techniques under different solar irradiations in order to optimize the efficiency of the solar PV system. The proposed technique is well adjusting to the duty cycle of the boost converter switch based on variable step size to track the maximum power and increase the efficiency of a solar PV array .The proposed method is simulated by using Matlab/Simulink. The Simulation of different MPPT Algorithm with boost converter are also presented.

2. Mathematical Model Of Photovoltaic Panel

A photovoltaic cell is a semiconductor device that converts light energy incident on it to electrical energy by photovoltaic effect. If the energy of photon in light energy is higher than the band gap then the electron is emitted and causes the flow of electrons to create current. However a photoelectric cell is always biased.

The PV array is made-up of solar cell, which is basically a p-n semiconductor junction as shown in Fig.2. The characteristic of a solar array is given by Eq. (1), the main equation of output module.

\[ I_o = Np \cdot I_{ph} - Np \cdot I_{rs} \cdot \left( \exp \left( \frac{K_{ov} \cdot N_s}{N_s} \right) - 1 \right) - (1) \]

Where:
- V and I are voltage and current across solar panel terminal.
- rs is reverse saturation current.
- Iph is the light-generated current.
- Irs is the reverse saturation current.
- Io is the reverse saturation current.
- k is the Boltzman constant.

![Fig 2. Single diode equivalent circuit](image)
The solar panel DS-100M is simulated with following specifications as shown in table I.

<table>
<thead>
<tr>
<th>NAME</th>
<th>DS-100M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power (Vmp)</td>
<td>100 W</td>
</tr>
<tr>
<td>Voltage at maximum power (Vmp)</td>
<td>18 V</td>
</tr>
<tr>
<td>Current at maximum power (Imp)</td>
<td>5.55 A</td>
</tr>
<tr>
<td>Open circuit voltage (VOC)</td>
<td>21.6 V</td>
</tr>
<tr>
<td>Short circuit current (ISC)</td>
<td>6.11 A</td>
</tr>
<tr>
<td>Total no. of cells in series (NS)</td>
<td>36</td>
</tr>
<tr>
<td>Total no. of cells in parallel (NP)</td>
<td>1</td>
</tr>
<tr>
<td>Maximum system voltage</td>
<td>1000 V</td>
</tr>
<tr>
<td>Range of operation temperature</td>
<td>-40 °C to 80 °C</td>
</tr>
</tbody>
</table>

The P-V and I-V curve for different solar irradiance is simulated.

![Fig 3. P-V Curve under Different Solar Irradiance](image)
3. MPPT Techniques

3.1 P&O algorithm

The P&O algorithm (Fig. 5) is most commonly used because of its simplicity and little parameters comparison. In this algorithm, small perturbation is introduced which causes solar output power to change with perturbation to reach maximum power point. If power increases then perturbation continues in same direction otherwise it reverses in opposite direction [23][24]. Once the maximum point is reached the perturbation decreases to reduce the output power. This algorithm oscillates around maximum point when the steady state is reached.

![P&O Algorithm](image)

3.2 Incremental Conductance Algorithm

In this method (Fig. 6) direction to reach MPP is based on the relationship between power \( \frac{dP}{dV} \) and incremental \(-\frac{dI}{dV}\). When \( \frac{dP}{dV} \) is equal zero, the algorithm knows the maximum power point and it terminates. When \( \frac{dP}{dV} \) is less than zero then it is at the left of MPP which increases the duty cycle. Otherwise duty cycle must be decreased to reach maximum power point from right of MPP. This algorithm tracks rapidly changing irradiation conditions more accurately than P&O method [25]-[26].

![Incremental Conductance Algorithm](image)

3.3 Constant Voltage Incremental Conductance Algorithm

An attempt to combine some good characteristics of the IC method under rapidly changing weather conditions and the effectiveness of the CV method at low insolation levels can be performed to yield a two-stage MPPT control algorithm with variable step size which in turn capable of maximizing the tracking efficiency of the whole PV power generation system [27]. The MPPT algorithm usually uses a fixed iteration step size to change the duty cycle of converter. The step ratio size for the INC MPPT determines how fast the MPP can be tracked. Fast tracking can be achieved with bigger increments, but the system might not run exactly at the MPP and oscillate around it; thus, there is to be a comparatively low efficiency. The inverse operation when the MPPT is operating with a smaller increment. Therefore, interpose between the dynamics and oscillations has to be made for the constant fixed step-size MPPT. To solve this problem, CV INC MPPT(Fig.7) with variable step size is proposed. In this, PV output power directly controls the power converter duty cycle which in turn reduce the complexity of the system. \( N \) is the scaling factor which is adjusted at the design stage to adjust the step size. The performance of the MPPT system is decided by the scaling factor \( (N) \) for the variable step-size MPPT algorithm. To update rule of MPPT, the variable step rule Eq.(3) must meet the following inequality.

![Constant Voltage Incremental Conductance Algorithm](image)
\[ N \times \frac{dP}{dV} < D_{\text{max}} - (3) \]

where \( \Delta D_{\text{max}} \) is the largest step size for fixed step-size MPPT operation and is chosen as the upper limit for the variable step size INC MPPT method. Therefore, the scaling factor can be obtained as

\[ N < \frac{dP}{dV} \times D_{\text{max}} - (4) \]

If Eq. (4) cannot be satisfied, the variable step size INC MPPT algorithm will work with a fixed step size of the previously set upper limiter \( \Delta D_{\text{max}} \). This method may increase convergence speed and also reduce oscillation in steady state, but it brings a major problem for wider operation range in practice.

A fast tracking approach is achieved by the modified CV method when the variation in the output current of the PV panel is less than 33% and a fine tracking approach is achieved by means of the IC method, when the variation in output current is more than 33%. For the modified CV method on the right side, the power is calculated consecutively at previous and current states with the help of current measurements and voltage equation.

\[ V_{\text{ref}} = k \times V_{\text{oc}} - (5) \]

A test is then conducted to assess the variation of power and voltage respectively; finally, a decision is made to increase or decrease the voltage according to whether the variation of voltage is positive or negative respectively.

For the IC method on the left side, the current and voltage are measured at previous and current states, then a test is performed to assess either if the variation of voltage and current is equal to zero respectively or if the variation of voltage is equal to zero and the balancing condition are

- \( dI/dV + I/V > \text{err} \) greater than MPP
- \( dI/dV + I/V < \text{err} \) less than MPP

The CV-INC algorithm with variable step size is implemented to increase the convergence speed with lesser oscillations. The equation for variable step size is

\[ C = \left( \frac{N}{I} \right) \times \text{abs} \left( \frac{dP}{dV} \right) - (6) \]

The value of \( N \) must be higher to increase convergence speed, the values of current, power are taken according to solar irradiations at particular time to calculated step size. Therefore now, the slope of V-P curves is being compared with a variable coefficient that changes by output current of PV module.

Fig 8. CV-INC variable step size representation

4. Two Input Modified Boost Converter Operation

The modified two-input boost converter with voltage multiplier cell is shown in Figure 9. The circuit is derived from the standard Boost converter. Two boost converters are duplicated in parallel for the two inputs and a two stage voltage multiplier cell is inserted as common between the output sides of both converters.

A. First Operation Mode 1: In this mode both switches S1 and S2 are turned ON. Both the inductors are charged from their input sources Vin1 and Vin2. Both the inductors current rise linearly. The diodes in different voltage multiplier stages are reverse biased and do not conduct. The VM voltages across capacitor remain unchanged and the output diode Do is reverse biased which makes isolation between source and load. Thus the load is supplied by the output capacitor Co.

B. Second Operation Mode 2: In this switch S1 is OFF and S2 is turned ON. All the odd numbered
diodes are forward biased and the inductor current $I_{L1}$ flows through the voltage multiplier capacitors charging the capacitors (C2, C5) and discharging the capacitors (C1, C4). If the count of voltage multiplier stages is odd, then the output diode Do is open circuited and the load is supplied by the output capacitor. However, if it is an even stage of VM, then the output diode is forward biased charging the output capacitor and supplying the load.

C. Third Operation Mode: In this mode switches S1 and S2 are turned ON and resonant inductor $L_r$ and the output diode Do current reduce slowly to zero with also reduction in the reverse recovery current of the output diode is also minimised.

D. Fourth Operation Mode: In this mode S1 and S2 are turned OFF, when diode at output is blocked, DM2 conducts and transfers the energy stored in the capacitor CM1 to CM2. When there is unequall balance of energy between the multiplier capacitors, the diode DM2 is blocked with low $di/dt$. During the turn on time of switch the input inductor stores some energy as the classical boost.

![Fig 9. Modified two input Boost Converter](image)

5. Comparison between different MPPT Techniques

5.1. Comparison between P&O and Incremental Conductance Algorithm

The P & O and INC MPPT algorithms are simulated and compared with each other. The output parameters of P&O and incremental conductance algorithm are compared and are shown in fig 10,11,12.

When atmospheric conditions changes which causes to change the insolation levels. The P&O MPPT oscillates near to MPP but the INC finds the MPP accurately at changing atmospheric conditions. The incremental conductance algorithm tracks MPP at 0.083s which has better performance than P&O algorithm. Boost converter with incremental gives better output power for rapidly changing atmospheric conditions.

5.2. Comparison between Proposed CV-INC and Incremental Conductance Algorithm

When the solar panel is subjected to rapid irradiance changes as shown in Figures 13 and 14 and that the waveforms at steady state of the solar panel voltage for two algorithms are quite different. The boosted output
voltage waveforms in the PV system using the two-mode CV-IC algorithm provides fewer fluctuations compared to those in the PV system using the INC algorithm. This steady state behavior is further seen in the waveforms at steady state of the solar output power in Figures 18.

These simulation results demonstrate that the MPPT using the two-stage CV-IC method gives stable and small oscillations around the maximum power point MPP; thus the proposed MPPT using the two-stage method gives better, steadier performance than the MPPT using the IC method.

During a rapid increase in insolation of the PV system from 500W/m² to 1000W/m², the MPPT using the two-stage algorithm gives a faster response, since it reaches its optimal value at 0.173ms than the MPPT using the IC algorithm, which requires (0.256ms) much more time to track the maximum power point. Therefore, the MPPT using the two-stage algorithm reduces the convergence time taken to track the MPP and improves...
The tracking speed response. It is quite efficient during the transitional state and performs much better in cloudy weather scenario when compared to the standard INC method. The tracking speed of the MPPT using the two mode algorithm is faster when subjected to a rapid decrease and increase in insolation seen in Figures 18. This means that the PV system using a two-stage CV-IC method with variable step size loses less solar energy than the standard IC method with fixed step size. Furthermore, the simulated tracking output power waveforms displayed in Figures 15, 16 & 17 show that the MPPT using a two-stage CV-INC method generates fewer oscillations around the maximum power point MPP than the conventional IC method under rapid irradiance changes.

The simulated results of the combined Simulink PV model demonstrate that the PV system using the two-stage CV-IC algorithm yields lower power fluctuations and shorter tracking times than the PV system using the standard IC and P&O algorithm. The simulated tracking output power waveforms displayed in Figures 15, 16 & 17 show that the MPPT using a two-stage CV-INC method generates fewer oscillations around the maximum power point MPP than the conventional IC method under rapid irradiance changes.

### Table 2: Comparison between INC and CV-INC Algorithm

<table>
<thead>
<tr>
<th>ALGORITHM</th>
<th>SOLAR OUTPUT CURRENT (A)</th>
<th>SOLAR OUTPUT VOLTAGE (V)</th>
<th>SOLAR OUTPUT POWER (W)</th>
<th>OUTPUT CURRENT (A)</th>
<th>OUTPUT VOLTAGE (V)</th>
<th>OUTPUT POWER (W)</th>
<th>CONVERGENCE SPEED (μs)</th>
<th>EFFICIENCY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INC</td>
<td>32</td>
<td>19</td>
<td>196</td>
<td>0.9</td>
<td>182</td>
<td>165</td>
<td>0.256</td>
<td>84</td>
</tr>
<tr>
<td>CV-INC</td>
<td>31</td>
<td>18</td>
<td>154</td>
<td>0.55</td>
<td>189</td>
<td>180</td>
<td>0.173</td>
<td>90.7</td>
</tr>
</tbody>
</table>

In conclusion, the simulated results of the PV system using a two-stage CV-IC algorithm with variable step size shows good performances in both steady-state and transient operations. Hence, by implementing the two-stage algorithm in the current PV system, the disadvantages of long tracking time and increase in PV panel output power fluctuations when using the IC algorithm can be overcome and also proposed MIC structure lower the volume by integrating two forward converter with one output inductor.

### References


