An improved P&O MPPT control algorithm for increasing power extraction efficiency of solar PV module

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Abstract. The extraction of solar energy is done by using power point tracking techniques. The solar PV cells available have low efficiency in the order of 15-20%. The extraction efficiency depends on solar insolation, cell temperature, angle of incidence and the load current. These factors resulting a non linear V-I characteristics for a PV cell. A Perturb & Observation MPPT is developed to operate the PV cell at a reference voltage corresponding to maximum power point in the characteristic curve. This algorithm is incorporated to improve the performance and thereby increasing the efficiency of PV cell. A 225W solar PV module at different cell temperatures and solar insolation is simulated in MATLAB environment. The simulated results shows the deviation of output power of solar module at maximum power point with ideal PV power is about 12% for different cell temperature and solar insolation.

1. Introduction

Solar energy is the most emerging alternate source for electricity generation. It generates environmental friendly energy. The reform made by the nations on global warming the solar power generation is increasing day by day. India’s installation capacity is about 29.42GW as of May 2019. The government has set its target to reach 40GW by 2020 [1].

The energy available in the solar spectrum can be utilized directly for generation of electricity and indirectly in the form of thermal to produce steam to drive the steam turbines [2, 3]. Solar photovoltaic cells are made up of semiconductors will generate electrons when the light energy packets known as photons are absorbed. The efficiency of conversion of solar energy to electric energy depends on the factors such as solar irradiance or solar insolation level available at particular time, cell temperature and the load current. The available solar PV cell in the market has an efficiency of 10-25%. This brings the necessary to improve the performance by incorporating power tracking techniques thereby ensuring better utilization of solar energy and decreasing the cost of investment.

Many MPPT methodologies are suggested in the literature but they depend on the factors like dynamic irradiance, low convergence speed and hardware implementation. The MPPT methods include open voltage, constant voltage, short current, incremental conductance(IC) and perturb & observe (P&O) methods [4].The design simplicity and good performance of P&O MPPT method has made to use widely in solar Photovoltaic applications[5,6].
This paper focuses on the extraction efficiency of solar PV array under different irradiance and temperature conditions. A 225W solar PV module acting as source to an inverter for isolated electric system is simulated in MATLAB environment. The performance is analyzed by using P&O MPPT algorithm. The simulates results will validate its efficiency of P&O MPPT algorithm in terms of percentage deviation with ideal PV panel output power.

2. Photovoltaic model

The commonly known PV cell is configured as a semiconductor p-n junction made of silicon. The photons in sunlight hit the solar panel and are absorbed by the semiconducting materials. This phenomenon will make the electrons to loose from their atoms when excited. The materials used in the solar cell allow these electrons to move only in single direction resulting direct current (DC) electricity. The electrically equivalent model is useful to understand the characteristics of solar cell. The solar cell is modelled as photo generated current source \( I_{ph} \) in shunt with a diode \( D \). In practical a series \( R_s \) and shunt \( R_{sh} \) resistances are added. The circuit model of a solar cell is given in figure 1. These cells are combined together in series and in parallel to form PV modules and PV arrays.

![Electrically equivalent model of solar PV cell](image)

From the equivalent circuit \( V_{pv} \) is output voltage and \( I_{pv} \) is the output current of PV cell. Applying Kirchhoff’s current law for the current generated by the PV cell.

\[
I_{pv} = I_{ph} - I_D - I_{sh}
\]  

\( I_D \) is diode current given as

\[
I_D = I_0 \left\{ \exp \left( \frac{V_j}{nV_T} \right) - 1 \right\}
\]

and

\[
V_T = \frac{kT}{q}
\]

Where

\( V_j \) is the voltage across the diode and shunt resistor

\( I_0 \) is reverse saturation current
$n$ is ideality factor
$T$ is absolute temperature
$V_T$ is thermal voltage at $25^\circ C$ approximately given as $0.025V$
$K$ is Boltzmann’s constant
$q$ is elementary charge

Therefore the current generated by the PV cell from equation (1) is given as

$$I_{pv} = I_{ph} - I_0 \left( e^{\frac{V_f}{nV_T}} - 1 \right) - \frac{V + IR_s}{R_{sh}}$$  \hspace{1cm} (4)

The above equation (4) gives a non linear characteristic curve for a solar PV cell. When the solar cell is open circuited $I_{pv} = 0$, and the voltage across the diode and shunt resistance is termed as open circuit voltage $V_{OC}$. Similarly, when the solar cell is short circuited, the voltage $V_{pv}$ becomes zero and $I_{SC} \approx I_{ph}$ which is termed as short circuit current.

A 225W solar array with three modules consisting of 34 cells in series is considered at different solar irradiance and cell temperatures to obtain non linear characteristics. The parameters and test conditions of the solar module at solar irradiance 1200W/m$^2$ are listed in the below table 1.

| Parameters                      | Notation | Value  |
|---------------------------------|----------|--------|
| Maximum rated power             | $P_{MP}$ | 225W   |
| Rated Voltage at maximum power  | $V_{MP}$ | 45V    |
| Rated current at maximum power  | $I_{MP}$ | 5A     |
| Open circuit voltage            | $V_{OC}$ | 52V    |
| Short circuit current           | $I_{SC}$ | 5.502A |
| Solar cells in series           | $N_s$    | 110    |
| Solar cells in parallel         | $N_p$    | 1      |

The solar PV model with the given specifications is simulated to obtain its I-V and P-V characteristics at 20$^\circ C$ for different irradiances of 1200W/m$^2$, 800W/m$^2$ and 600W/m$^2$.

3. **P&O MPPT control technique**

In order to improve the solar PV module efficiency at different irradiance conditions a P&O MPPT was developed. This algorithm finds the reference voltage corresponding to maximum power point in the characteristic curve. The control block diagram is shown in the below figure 2.
The power circuit comprises a DC-DC boost converter. The load impedance is matched by varying converter duty cycle ($D$). The P&O MPPT algorithm is utilized for duty cycle to obtain the reference voltage corresponding to maximum power point. The flow chart corresponding to P&O MPPT algorithm is shown in figure 3. First the voltage and current are measured to obtain the output power. The obtained power is verified with voltage. If the voltage of PV panel is increased the output power is also increased in the same way duty cycle is also increased else the duty cycle is decreased by one step of $\Delta D$. This is continued till the maximum point is tracked and the output voltage is maintained at that point.

The duty cycle will maintain the DC-DC boost converter output voltage as constant. The output voltage of solar PV panel is fed to the input voltage of converter which is given as
\[ V_{in} = V_{PV} = V_0(1 - D) \]  

(5)

Where \( V_0 \) is output voltage corresponding to the duty cycle \( D \)

For any small change in solar irradiation and temperature resulting in change of output voltage and output power of a solar PV panel. These variations are given as

\[ \Delta V_{PV} = (\Delta D)V_D \]  

(6)

Where \( \Delta V_{PV} \) is change in output voltage and \( \Delta D \) is change in duty cycle which is chosen as 0.0005.

\[ \frac{V_{in}}{V_{out}} = 1 - D \]  

(7)

The inductor and capacitor expression are given with respect to duty ratio

\[ L = \frac{V_{in}D}{f_D \Delta I_L} \]  

(8)

\[ C = \frac{V_{out}D}{f_D \Delta V_{out}} \]  

(9)

Where \( \Delta V_{out} \) and \( \Delta I_L \) are ripple voltage and currents respectively.

| Parameters               | Notation | Value   |
|--------------------------|----------|---------|
| Input voltage            | \( V_{in} \) | 48V     |
| Output voltage at \( D=0.5 \) | \( V_{out} \) | 95V     |
| Resistive load           | \( R_L \) | 38.6Ω   |
| Inductor                 | \( L_1 \) | 550μH   |
| capacitor                | \( C_0 \) | 110μF   |
| Switching frequency      | \( f_s \) | 5KHz    |

4. Simulation results and analysis

The simulink model of solar PV array with P&O control algorithm shown in figure (3) is developed in MATLAB environment to understand its performance characteristics at different irradiation and cell temperatures. The MATLAB is shown in figure (5) was developed for the specifications listed in table 1 and table 2. The results taken for solar output power at 1200W/m², 800W/m² and 600W/m² operating at 20°C, 45°C and 70°C. Duty cycle and PV power outputs are shown in figure (6) and figure (7). The I-V and P-V curves are shown in figure (8) and figure (9). It is observed that as the duty cycle has been decreased and the output power is decreased with the decrease in solar
irradiance from 1200W/m² to 600W/m² with the increment in cell temperature from 20°C to 70°C. The percentage
deviation of P&O MPPT solar PV array with PV maximum power output at different irradiations and cell
temperature are presented in the table 3 & 4 given below.

![Simulink model of solar PV module with P&O MPPT method.](image1)

![Duty cycle for different T and constant G](image2)

![PV power for different T and constant G](image3)

![I-V characteristics of PV panel](image4)

![P-V characteristics of PV panel](image5)

| Table 3. comparison at constant cell temperature of 20°C |
|------------------------------------------------------|
| Solar irradiance (W/m²) | PV Maximum output power(W) | Output power of PV with P&O MPPT(W) | Percentage deviation (%) |
|------------------------|-----------------------------|------------------------------------|--------------------------|
| 1200                   | 221.42                      | 214.31                             | 3.211                    |
| 800                    | 173.86                      | 155.49                             | 10.56                    |
| 600                    | 126.83                      | 114.67                             | 9.58                     |
Table 4. Comparison at constant solar irradiance of 1200 W/m²

| Cell temperature (°C) | PV Maximum output power (W) | Output power of PV with P&O MPPT (W) | Percentage deviation (%) |
|-----------------------|----------------------------|-------------------------------------|--------------------------|
| 20                    | 221.42                     | 214.31                              | 3.211                    |
| 45                    | 186.43                     | 175.23                              | 6.007                    |
| 70                    | 150.64                     | 138.94                              | 7.766                    |

5. Conclusion

An improved P&O MPPT algorithm is incorporated with the solar PV array was developed to increase its power extraction efficiency at different solar irradiance 1200W/m², 800W/m² and 600W/m² operating at cell temperatures of 20°C, 45°C and 70°C. The technique used for obtaining maximum power effectively which is very nearer to PV Maximum output power. The comparison results will validate that percentage deviation of output power of PV with P&O MPPT with ideal PV output power is about 10% when operated at different irradiance and temperature conditions.

References

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