Implementation of a novel P&O MPPT Controller for Photovoltaic System at Standard Test Conditions

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Abstract. This paper gives an ample idea of a novel P&O MPPT controller implementation to a DC-DC boost converter for a photovoltaic system at standard test conditions (STC) to track Maximum Power Point (MPP). The novel P&O MPPT controller implementation accompanies that initialization of duty cycle and calculation of power at the starting of the algorithm. Photovoltaic (PV) model is designed for lighting applications with a single diode. The PV system output is connected to a DC-DC boost converter to regulate the voltage up to a desired level. The novel P&O MPPT algorithm is implemented in a feed forward manner. The steady state condition reached at less than 0.05sec time, and tracks 10% more power at STC. The novel P&O MPPT controller results are compared with conventional P&O MPPT controller; the models are simulated in MATLAB/SIMULINK.

Keywords: DC DC boost converter, MPP, P&O Controller, PV, STC

1 Introduction

Photovoltaic’s has an exceptional potential as a sustainable energy source due to large availability of solar power and resulting the free generation of direct current. The PV system generates DC current, when the sun rays falls on the PV material. The solar power generation is based on the principle of the photovoltaic effect [1]. Due to silicon p-n junctions, the photovoltaic current can produce power with internal voltage drop across the p-n junction; such power generation is suitable for nonlinear relationship between the current and the voltage of a PV cell [2]. The solar cell produces maximum power at a particular point. At that point, the rate of change of power with respect to the voltage is zero. There are several power management patterns regarding the enrichment in the conversion efficiency of a PV array to maximize the PV power output. The PV output current changes with solar irradiations, and voltage changes with temperature of the PV array [3]. Therefore, the fundamental challenge in a PV system is to ensure that the maximum energy is generated from the PV array with a dynamic variation of its output characteristic when connected to a variable load [4]. Connecting a converter in between the load and PV array is the solution for this problem, and then the impedance of the circuit is varied by using a control algorithm [5]. A step up converter is used in this work, which has a potential of providing excess output voltage than the input voltage.

The proposed novel P&O MPPT approach is one of the useful and robust controllers for non linear applications operating at STC. The novel P&O MPPT has implemented with fixed step size and with varied duty cycle. The proposed P&O MPPT controller is to employ the changes in PV array current and voltage to predict the effect of voltage change. It can track the MPP in a faster manner and changes its direction to repeat the same process again. MPP is located at the knee of the I-V curve [3].

The conventional P&O MPPT controller with fixed step size has been developed by using MATLAB/SIMULINK. The implementation of this control algorithm is easy to track Maximum Power Point [6]. This technique measures the changes in PV array current and voltage to predict the effect of voltage change. P&O technique repeats the process till MPP occurs; then it will change the direction and repeats the process [7].

Section II of this paper presents about mathematical modeling of a PV cell explanation and results. Section III is devoted for state space analysis of a DC-DC boost converter and results. Section IV is committed for the implementation of a novel P&O MPPT controller for a step up converter. Section V shows the
implementation of a conventional P&O MPPT controller. Section VI summarizes the comparison and discussion on simulation results and section VII concludes the paper.

2 Modeling of a PV cell

PV is one of the processes of generating renewable energy mechanisms. Here, generating electrical power by converting solar irradiation into direct current [3]. The circuit of a PV cell is shown in Fig. 1. When the sun rays fall on PV panel, that irradiation converts into direct current. A series connected resistor determines the downward slope of I-V curve in PV cell nearer to V_{oc} represents the internal resistance of the cell. A resistor connected parallel, which determines the slope of the line at a top of I-V curve near I_{sc} [2], controls the leakage current from cell to ground, and is usually small enough to be neglected. The diode current equation expressed [3] is as follows:

\[ I_d = I_0 \left[ e^{\frac{qV}{nkT}} - 1 \right] \]  
\[ I_{pv} - I_d = I_L \]

After solving all the equations, the final expression of PV cell is computed and shown below:

\[ V_L = \frac{nkT}{q} \left[ \ln \left( \frac{I_{pv} - I_L}{I_0} \right) + 1 \right] - \frac{V_L + I_L R_S}{R_p} - I_L R_S \]

Simulation of PV cell is done in MATLAB/SIMULINK after modelling and obtained PV characteristic curves. The waveforms are calculated at STC is shown in Fig. 2. The simulated PV model extracted 23V voltage and 3.4A current. For STC, the temperature is 25°C and irradiation level is 1000 W/m² respectively.

![Fig. 1. PV cell circuit with a single diode model](image1)

![Fig. 2. PV characteristic ((a) I-V and (b) P-V) curves at STC](image2)
3 Controller based DC-DC Boost Converter

The DC-DC boost converter is called as step up converter; it has a potential that provides excess output voltage than input voltage [5], and the circuit diagram of DC-DC boost converter is shown in Fig. 3. The functioning of a boost converter depends on the switch “ON and OFF”. The diode ‘D’ blocks the reverse flow of current when the switch is turned ON. The current flow is marked with green arrows is shown in Fig. 3.

![Fig. 3. Conventional DC-DC boost converter with IGBT as switch](image)

The mathematical model of a DC-DC boost converter at switch ON can be expressed in state space [3] is as follows

\[
\begin{bmatrix}
\frac{dI_L}{dt} \\
\frac{dV_o}{dt}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 \\
0 & -\frac{1}{C_o R_o}
\end{bmatrix}
\begin{bmatrix}
I_L \\
V_o
\end{bmatrix} +
\begin{bmatrix}
\frac{1}{L} \\
0
\end{bmatrix} V_{ref}
\]

(4)

\[
V_o = \begin{bmatrix}
0 \\
-\frac{1}{C_o R_o}
\end{bmatrix}
\begin{bmatrix}
I_L \\
V_o
\end{bmatrix}
\]

(5)

The inductor generates a high voltage at switch OFF to maintain the current \(i_L\) in the same direction and now the diode D is forward biased and it starts conducting. The current flow is marked with red arrows is shown in Fig. 3. Therefore the output voltage can be expressed as

\[
V_o = V_{ref} + L \frac{di_L}{dt}
\]

(6)

The mathematical modeling of DC-DC boost converter at switch OFF can be expressed in state space is as follows

\[
\begin{bmatrix}
\frac{dI_L}{dt} \\
\frac{dV_o}{dt}
\end{bmatrix} =
\begin{bmatrix}
0 & \frac{1}{L} \\
\frac{1}{C_o} & -\frac{1}{C_o R_o}
\end{bmatrix}
\begin{bmatrix}
I_L \\
V_o
\end{bmatrix} +
\begin{bmatrix}
I_k \\
0
\end{bmatrix} V_{ref}
\]

(7)

\[
V_o = \begin{bmatrix}
\frac{1}{C_o} \\
-\frac{1}{C_o R_o}
\end{bmatrix}
\begin{bmatrix}
I_L \\
V_o
\end{bmatrix}
\]

(8)

The results of step up converter have taken from different parts of the circuit is shown in Fig. 4. These results are exactly matched with the functioning of a DC-DC boost converter.

4 Proposed P&O MPPT Controller

Fig. 5 shows the flowchart of the proposed P&O MPPT controller algorithm. Implementation of the algorithm is quite simple, and all variables are initialized at the beginning. The algorithm changes the duty cycle according to the maximum power point tracking. In proposed algorithm, the MPP occurs based on calculations of variation in power (dP) and variation in voltage (dV). At the end of the algorithm, duty cycle values will be changed. The proposed P&O algorithm perturbs the voltage in one direction and calculates the corresponding difference of the power [6]. If the power is increasing, then the algorithm will move the voltage in the same direction till the peak power. After the peak power occurred, the perturbation will reverses the direction, which means, the P&O MPPT algorithm can track the maximum power...
point (MPP) in the wrong direction also. The P&O algorithm is optimized with respect to the change in step size, $\Delta D$ in order to follow certain irradiance.

Fig. 4. Results of Boost converter (a) Diode current,(b) Gate voltage,(c) Inductor current, (d) Switch current and (e) Switch voltage.

Here, value of step size is chosen directly by different initializations at the starting of the algorithm, therefore, no more calculations are required to set duty cycle within the range. The main advantage in this algorithm is that the duty cycle varies with respect to the change in temperature. The algorithm execution steps are follows:

1. Initialization of different conditions duty cycle such as $D_{\text{start}}$, $D_{\text{high}}$, $D_{\text{low}}$ and calculate the change in duty cycle ($\Delta D$) with the initial values. Fix the $V_{\text{prev}}$ and $P_{\text{prev}}$ as zero and $D_{\text{prev}}$ as $D_{\text{start}}$. Calculate power, change in power ($dP$) and change in voltage ($dV$) when the algorithm start its execution.

2. Check the condition of change in power, if it is equal to zero, then no change in the duty cycle, otherwise, check the change in power is positive or negative.

3. If the change in power is positive, then checks the change in voltage too (either positive or negative) and then fixes the duty cycle. Similarly, check the condition for “$dP$” is negative and then check for “$dV$” is positive or negative and then fix the duty cycle.

4. The algorithm repeats the process when the duty cycle is not in the given range. If it is not, then change the duty cycle with initial conditions and repeat the same process till completion.

The simulation results are shown in section VI of this article.

5 Conventional P&O MPPT Controller

The conventional P&O algorithm operates in a periodic manner for perturbing the control variable and comparing the PV output power immediately. The adjustment can be made through the duty cycle “$D$”. Note that $P(j)$ and $V(j)$ are the output power and voltage of PV. The power can be calculated from $V(j) \times I(j)$ at $j^{th}$ time. $\Delta D$ is change in duty ratio. The PV power can be denoted is as follows

$$\Delta D = \alpha \beta [P(j) - P(j-1)] \quad (9)$$

Where $\alpha$ and $\beta$ are the constant value to control the movement towards MPPT and sign step, it depends on perturbation direction.
6 Results and Discussion

A P&O MPPT controller is an open loop controller. This algorithm is developed with change in duty ratio. Here the outputs of proposed P&O and conventional P&O controllers are presented and verified that, proposed P&O response time is faster and tracks excess power than the conventional one. Simulated results of proposed and conventional P&O controllers are shown in Fig. 6
7 Conclusion

In this paper, proposed P&O MPPT controller for boost converter is implemented, and it is tracking PV voltage promptly and reaches steady state condition before 0.05s. The outputs of proposed and conventional P&O MPPT controllers are compared. Mathematical modeling of a PV cell is analyzed and the output of PV array is connected to a step up converter for voltage regulation. State space analysis of a DC-DC boost converter is derived and eventually a boost converter based P&O is developed. With proposed P&O, the reference voltage level and steady state conditions occurred quickly.

References