Comparative Analysis of Different MPPT Algorithms for Photovoltaic Application

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Abstract—Photovoltaic based distributed generation system has seen a wide spread interest in research community because of growing energy needs. For efficient distributed generation system, a PV cell is connected with a DC-DC converter and DC-AC inverter. Maximum power point tracking (MPPT) algorithm is used to extract maximum power from the PV cell. There are different MPPT algorithms such as perturb and observe algorithm and incremental conductance algorithm. This paper provides a comparative analysis of different MPPT algorithm.

Keywords—MPPT, PV cell, DC-DC Converter

I. INTRODUCTION

The rising energy need of human being has forced the mankind to look for alternate energy sources. Therefore, there is a significant research is going on in renewable energy sources. Renewable energy sources such as PV, fuel cell and wind energy has been widely studied. Grid integration of renewable energy sources and development of standalone application for renewable energy sources has been widely studied areas in electrical engineering.

There are significant research works towards sustainable energy. A comparative study of different MPPTs used in photovoltaic power system is reviewed in [1-3]. Development of different control algorithms for photovoltaic power system is discussed in [4-8]. Analog MPPT technique for distributed PV application has been discussed in [4]. Single stage grid connected inverter for PV application with a single current sensor has been discussed in [5]. Adaptive auto tuned MPPT for PV application with FPGA based real time application has been discussed in [6]. Partial shading of PV array using colony of flashing fireflies has been discussed in [8].

Not only in photovoltaic systems have other renewable energy system such as fuel cell found widespread application in generation of green energy. During rapid load changes there is a significant change in output energy therefore; research has been carried out to study the changes in voltage during rapid change in load profile [9]. Control and grid interfacing of solid oxide fuel cell has been discussed in [10]. FPGA based real time implementation of DC-DC converter connected to solid oxide fuel cell has been discussed in [11].

This paper provides a detailed comparison of two of the most widely used MPPT algorithms i.e P&O MPPT and incremental conductance MPPT. Extensive simulation of PV cell and MPPT algorithm has been discussed. MPPT with DC-DC boost converter is analyzed in this paper.

This paper consists of seven sections. Section II comprises of discussion about PV system for distributed generation system. Section III provides mathematical model of different PV cells. Section IV presents different MPPT algorithm. Section VI provides modeling of boost converter with PV cell. Section VI comprises of simulation results and Section VII concludes the paper.

II. PV SYSTEM FOR DISTRIBUTED GENERATION

Fig. 1 shows the grid integration of PV array. PV array provides a low voltage unregulated DC voltage which has to be converted in to utility AC voltage. DC-DC converter is used for regulating unregulated voltage of PV array and is used to step up the voltage to a certain level. Maximum power point technique (MPPT) is used to extract maximum power from the PV array. There are several well-known MPPT algorithms. DC-AC inverter is used to invert the voltage and feed it to the utility grid. Feedback control of converter and inverter is used for proper grid integration.

III. MATHEMATICAL MODEL OF PV SYSTEM

The mathematical model of PV cell is discussed in this section. The equivalent circuit diagram of PV cell is shown in Fig. 2. PV cell is a combination of current source with a diode in reverse bias mode. The physical structure of PV cell is equivalent to PN junction subject to irradiance and change in temperature.
The current of the PV cell can be represented as,

\[ I = I_L - I_D - I_{sh} \]  

(1)

Here \( I_L \) is the current generated by the light, \( I_D \) is diode current and \( I_{sh} \) is the shunt current.

Diode current \( I_D \) can be expressed using Shockley equation such as

\[ I_D = I_o \left( \frac{qV_D}{nkT} - 1 \right) \]  

(2)

The shunt current is defined as

\[ I_{sh} = \frac{V + IR}{R_{sh}} \]  

(3)

Substituting the values in eq(1),

\[ I = I_L - I_o \left( \frac{qV_D}{nkT} - 1 \right) \frac{V + IR}{R_{sh}} \]  

(4)

IV. MAXIMUM POWER POINT TRACKING

MPPT is a method that compensates for changing voltage and current characteristic of solar panel and maximum utilization of solar energy from panel. Maximum power point tracking, or MPPT, is the automatic adjustment of the load of a photovoltaic system to achieve the maximum possible power output. PV cells have a complex relationship between current, voltage, and output power, which produces a non-linear output. This output is expressed as the current-voltage characteristic of the PV cell. Constant fluctuations in external variables such as temperature, irradiance, and shading cause constant shifts of the I-V curve upwards and downwards. A change in temperature will have an inversely proportional effect on output voltage, and a change in irradiance will have a proportional affect on output current.

Figure 3 shows the block diagram representation of perturb and observe MPPT and figure 4 shows the block diagram of incremental conductance MPPT. Figure 5 shows MPPT with reference voltage control.
Fig. 5. Block diagram of MPPT with reference voltage control

V. DC-DC BOOST CONVERTER

DC-DC boost converter regulates and steps up the unregulated voltage of PV cell. Figure 6 shows boost converter with PV cell.

Fig. 6. Boost Converter with PV cell

In this paper, state space average model of boost converter is used to model the boost converter. In state space average model, the dynamics of the converter changes with the instantaneous change in status of the switch i.e S = ON or S = OFF. The state space representation of system when S = ON is represented by

\[
\begin{align*}
\dot{x}_1 &= A_1 x_1 + B_1 u_1 \\
y_1 &= C_1 x_1 + D_1 u_1
\end{align*}
\]

(5)

Here the state variables are \( x = \begin{bmatrix} I_L \\ V_c \end{bmatrix} \)

When S = ON, the state space representation of boost converter is represented as

\[
A_1 = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{RC} \end{bmatrix}, \quad B_1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}, \quad C_1 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}
\]

When S = OFF, the state space representation of boost converter is represented as

\[
\begin{align*}
\dot{x}_2 &= A_2 x_2 + B_2 u_2 \\
y_2 &= C_2 x_2 + D_2 u_2
\end{align*}
\]

(6)

\[
A_2 = \begin{bmatrix} 0 & -1 \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}, \quad B_2 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}, \quad C_2 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}
\]

The state space representation of boost converter is shown by combining the two stages. It can be represented as

\[
\begin{align*}
\dot{x} &= Ax + Bu \\
y &= Cx + Du
\end{align*}
\]

(7)

\[
A = A_1 d + (1-d) A_2 \\
B = B_1 d + (1-d) B_2 \\
C = C_1 d + (1-d) C_2 \\
D = D_1 d + (1-d) D_2
\]

\[
\begin{bmatrix} I_L \\ \dot{V}_c \end{bmatrix} = \begin{bmatrix} 0 & -(1-d) \\ \frac{1}{L} & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} I_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in}
\]

(8)

\[
\begin{bmatrix} V_o \\ I_{in} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} I_L \\ V_c \end{bmatrix}
\]

(9)

VI. RESULTS AND DISCUSSION

This section shows the simulation results obtained from MATLAB-Simulink.

A. PV Cell characteristics

Different characteristics of PV cell are simulated in this paper. Voltage and current of PV cell are plotted with varying irradiance level. The V-I characteristics of PV cell with varying irradiance is shown in Figure 7.
The power and voltage of PV cell i.e P-V characteristics of PV cell with varying irradiance level is shown in Figure 8. Power and current of PV cell i.e P-I characteristics of PV cell with varying irradiance level is shown in Figure 9.

B. MPPT

MPPT plays a vital role in PV cell as it calculates the point where maximum power from the PV cell is obtained. Table I provides a comparative analysis of output voltage of PV cell with and without MPPT technique. Table II provides a comparative analysis of two MPPT techniques i.e P&O method and incremental conductance method. Figure 10 and Figure 11 shows the voltage of MPPT and boost converter respectively. The boost converter steps up the voltage output of PV-MPPT which is evident from the graph.

<table>
<thead>
<tr>
<th>Irradiance (W/m^2)</th>
<th>Without MPPT (V)</th>
<th>With MPPT (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>19.5</td>
<td>42.8</td>
</tr>
<tr>
<td>600</td>
<td>40.5</td>
<td>58.2</td>
</tr>
<tr>
<td>800</td>
<td>71.2</td>
<td>92.4</td>
</tr>
</tbody>
</table>
TABLE II: Comparison of different MPPT techniques

<table>
<thead>
<tr>
<th>MPPT Algorithm</th>
<th>( V_{pv} )</th>
<th>( V_{in} )</th>
<th>( V_o )</th>
<th>( I_{in} )</th>
<th>( I_o )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perturb and Observe</td>
<td>21.8</td>
<td>38.28</td>
<td>37.67</td>
<td>1.87</td>
<td>1.87</td>
</tr>
<tr>
<td>Incremental Conductance</td>
<td>21.8</td>
<td>38.33</td>
<td>28.92</td>
<td>172.3</td>
<td>1.48</td>
</tr>
</tbody>
</table>

The MPPT controller is accompanied by DC-DC boost converter which steps up the unregulated voltage to a certain voltage. Extensive simulation results are obtained and discussed.

REFERENCES


