A NEW APPROACH OF MODELLING, SIMULATION OF MPPT FOR PHOTOVOLTAIC SYSTEM IN SIMULINK MODEL

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ABSTRACT

This paper presents the design and simulation for maximum power point tracking (MPPT) for photovoltaic system, which includes a high-efficiency dc-dc boost converter with a modified incremental conductance algorithm. The converter can draw maximum power from the PV panel for a given solar insolation and temperature by adjusting the duty cycle of the converter. The modelling procedure for the circuit model was presented using MATLAB/Simulink Sim-power. The MPPT system has been tested with solar panel ICO-SPC 100 W module under various operating conditions. The obtained results prove that the proposed MPPT can track even under sudden change in sunlight conditions and loading level.

Keywords: dc-dc boost's converter, maximum power point (MPP), maximum power point tracking (MPPT), photovoltaic (PV).

INTRODUCTION

Due to the world energy crisis and coupled with growing demand for energy has resulted in conventional energy sources unable to cope with the expected world energy demand soon. Therefore, developments in renewable and alternative energy systems are expected to increase. Thus, it is important to explore more and better means of alternative energy sources like solar, wind and biomass. Photovoltaic energy is a source of interesting means of alternative energy sources like solar, wind and biomass. Photovoltaic energy is a source of interesting energy; it is renewable, inexhaustible and non-polluting, and it is more and more intensively used as energy sources in various applications. In regard to endless importance of solar energy, it is worth saying that solar energy is a unique perspective solution for energy crisis. Meanwhile, despite all these advantages of solar energy, they do not present desirable efficiency (Abdulkadir, et al., 2012), (Adbullah, et al., 2012).

The efficiency of solar cells depends on many factors such as temperature, insolation, and spectral characteristics of sunlight; dust, shading, which result in poor performance. In addressing the poor efficiency of photovoltaic systems, various methods were proposed among which a concept is called “maximum point power tracking” (MPPT) is implored. The photovoltaic has an optimum operating point to extract the maximum power called the maximum power point (MPP), which varies depending on cell temperature, insolation level, the nature of load, the technology of the photovoltaic cells (Safari, 2011), (Zegaoui et al., 2011). The variation in solar irradiation and temperature causes the tracker to deviate from the maximum power point, thus the tracker needs to respond within a short time to these variations to avoid energy loss. A variety of maximum power point tracking (MPPT) method is developed. The methods vary in implementation complexity, sensed parameters, convergence speed and cost, range of operation, popularity and their application. (Zegaoui et al., 2011; Kakosimos, 2011; Samosir, 2010; Lin et al., 2011; Moacyr et al., 2011; Zhang, et al., 2011).

Presently, the most commonly used algorithm is the perturbation and observation method (P and O), the incremental conductance method (INC) and Hill climbing. P and O method easily leads to erroneous judgment and oscillation around the maximum power point; it generally needs to combine one or several improvements for normal use. INC methods overcome these shortcomings of P and O methods but require relatively harsh detection devices and the choice of the step and threshold is also more stressful (Liu, et al., 2008).

For implementing the MPPT, there is a need to include the dc-dc converter into the system. The dc-dc converter can be either buck or boost converter. The buck converters are step-down switching-mode, and the boost converters are step-up power converters. They are popular because of their high efficiency and compact size (Walker, 2001). In this paper, the boost converter is chosen where the duty cycle of the boost dc-dc converter is controlled by PWM signal from controller implementing Incremental Conductance and integral regulator algorithm. Therefore, whatever the weather (irradiation and temperature) and the load conditions, the control system of the converter will ensure the operating point is optimized for maximum power transfer.

The Simulink model of the PV system under different temperature and irradiation is simulated and tested. The operating point of the PV on the I-V curve is dynamically modified by the controller so that the MPPT obtained the maximum power point at any sunlight conditions and maintain PV power in the neighbourhoods of this point to produce power with the higher efficiency. The whole system is as shown in Figure-1.

Figure-1. Block diagram of the proposed scheme.
MODEL VALIDATIONS OF THE PV SYSTEM

Photovoltaic cell models have long been a source for the description of photovoltaic cell behaviours for researchers and professionals. The most common model used to predict energy production in photovoltaic cell modeling is the single diode circuit model (Kashif et al., 2011), (Pandiarajan et al., 2011; Aissa Choudter et al., 2011). The ideal photovoltaic module consists of a single diode connected in parallel with a light generated current source \(I_{SC}\) as shown in Figure-2.

![Figure-2. Solar cell model using single diode.](image)

In this model, a current source \(I_{SC}\) which depends on solar radiation and cell temperature; a diode in which the inverse saturation current \(I_D\) depends mainly on the operating temperature; a series resistance \(R_s\) and a shunt resistance \(R_P\) which takes into account the resistive losses was considered.

![Figure-3. Solar cell model using single diode with \(R_s\) and \(R_P\).](image)

The equations that describe the, I-V and P-V characteristics of the circuit in Figure-3 are given by;

\[
I_{SC} - I_D - \frac{V_D}{R_p} = I_{PV} = 0
\]

Thus,

\[
I_{PV} = I_{SC} - I_D - \frac{V_D}{R_P}
\]

And the reverse saturation current \(I_{rs}\) is given as

\[
I_{rs} = \frac{I_{SC} e^{-\frac{q V_{SC}}{N_A k T_{ref}}}}{N_A k T_{ref}} - 1
\]

The module saturation current \(I_D\) varies with the cell temperature which is given by;

\[
I_D = I_{rs} \left(1 + \left(\frac{N_A k T_{ref}}{q V_{SC}}\right) \frac{1}{T_{ref}} - \frac{1}{T}\right)
\]

Where \(I_D\) is the diode saturation current (A). The basic equation that describes the current output of the photovoltaic (PV) module \(I_{PV}\) of the single-diode model is as given in equation (8).

\[
I_{PV} = N_P I_{SC} - N_P I_D \left[\exp \left(\frac{q V_{PV}}{N_A k T}\right) - 1\right] - V_{PV} + \left(\frac{I_{SC} - I_D}{R_P}\right)
\]

Where \(k\) is the Boltzmann constant \((1.38 \times 10^{-23} \text{ J K}^{-1})\), \(q\) is the electronic charge \((1.602 \times 10^{-19} \text{ C})\), \(T\) is the cell temperature (K). \(A\) is the diode ideality factor, \(R_s\) the series resistance (\(\Omega\)) and \(R_P\) is the shunt resistance (\(\Omega\)). \(N_P\) is the number of cells connected in series, \(N_P\) is the
The number of cells connected in parallel, \( V_{F} = \frac{V_{G}}{N_{p}} = 21.06\Omega \) (Pandiarajan et al., 2011).

The nonlinear and implicit equation given by Eq. (4) depends on the incident solar irradiance, the cell temperature, and on their reference values (Abdulkadir, et al., 2012; Adbullah, et al., 2012).

These reference values are generally provided by manufacturers of PV modules for specified operating condition such as STC (Standard Test Conditions) for which the irradiance is 1000W/m\(^2\) and the cell temperature is 25\(^\circ\) C. Real operating conditions are always different from the standard conditions, and mismatch effects can also affect the real values of these mean parameters (Aissa Chouder et al., 2011; da Silva et al., 2010; Dell Aquila et al., 2010).

The use of the simplified circuit model in this work makes it suitable for power electronics designers to have an easy and effective model for the simulation of photovoltaic devices with power converters. Based on the above equations and using the electrical specifications presented in Table-1, the PV system model has been developed using MATLAB/Simulink as shown in Figure-4.

**Table-1. Parameter specification of ICO-SPC 100 W PV module.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power</td>
<td>( P_{m} )</td>
<td>100W</td>
</tr>
<tr>
<td>Maximum voltage</td>
<td>( V_{m} )</td>
<td>17.3V</td>
</tr>
<tr>
<td>Current at max power</td>
<td>( I_{m} )</td>
<td>5.79A</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>( V_{oc} )</td>
<td>20.76V</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>( I_{sc} )</td>
<td>6.87 A</td>
</tr>
<tr>
<td>Total No. of cells in series</td>
<td>( N_{s} )</td>
<td>36</td>
</tr>
<tr>
<td>Total No. of cells in parallel</td>
<td>( N_{p} )</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure-4. Simulink model of the PV system.**

**Figure-5. I-V Characteristic-constant irradiance.**

**Figure-6. P-V characteristic-constant irradiance.**

### MPPT IN PHOTOVOLTAIC SYSTEMS

Photovoltaic (PV) modules are semiconductor's devices that are able to directly convert the incident solar radiation into electrical energy. On the I-V curve, there is a point called MPP (maximum power point) which always occurs in the knee of the curve, where the generated PV power is maximized as shown in Figure-5. Most of the maximum power point tracking (MPPT) algorithms searches the maximum power point (MPP) by comparing the output power of the PV module before, and after the duty cycle of the converter is changed (Issam Houssamo et al., 2010).

In this paper, the maximum power point tracking is achieved by Incremental Conductance method with the inclusion of an integral regulator. The theory of the incremental conductance method is to determine the variation in direction of the terminal voltage for PV modules by measuring and comparing the incremental conductance and instantaneous conductance of PV modules (Houssamo, et al., 2010; Luo et al., 2009; Wu, et al., 2009; Peftitsis, et al., 2008).

If the value of incremental conductance is equal to that of instantaneous conductance, the power delivered will be at its maximum point. This point can be obtained from the voltage and/or current measurements, and the
MPPT algorithm calculates the optimal duty cycle D in order to maximize the power flow. Since the irradiance and temperature are dynamic in nature, the MPPT algorithm must work practically in real time, updating the duty cycle D constantly and maintaining the accuracy and speed of tracking.

PROPOSED MPPT METHOD

In order to operate a photovoltaic (PV) system within its MPP, and considering the irradiance and temperature variation, a maximum power point tracking algorithm is needed to search and maintain the peak power (Walker, 2001). The Incremental Conductance comes from the fact that it uses the derivative of the PV system conductance, in order to determine the operating point position in relation to MPP. In this work, the algorithm was modified in order to include an integral regulator. The integral regulator minimizes the error \( \frac{V_{pv}}{I_{pv}} \) and the regulator output will be equal to duty cycle correction. The power output from the solar PV modules is:

\[
P = V I
\]  

Maximum power point is obtained when \( \frac{\partial P}{\partial V} = 0 \)

\[
\frac{\partial P}{\partial V} = \frac{\partial (V \cdot I)}{\partial V} = I + V \frac{\partial I}{\partial V}
\]

\[\frac{\partial P}{\partial V} = 0 \quad \text{if} \quad \frac{\partial I}{\partial V} = -\frac{V}{I} \quad \text{on the left of MPP} \]

\[\frac{\partial P}{\partial V} = 0 \quad \text{if} \quad \frac{\partial I}{\partial V} = \frac{V}{I} \quad \text{at the MPP} \]

\[\frac{\partial P}{\partial V} < 0 \quad \text{if} \quad \frac{\partial I}{\partial V} > -\frac{V}{I} \quad \text{on the right of MPP} \]

\[
\frac{\partial I}{\partial V} = \frac{-I}{V}
\]

Thus, the PV module voltage must be increased to reach the MPP. Similarly, if \( \frac{\partial P}{\partial I} = 0 \), then \( \frac{\partial I}{\partial V} > 0 \) and the PV module operating point lies to the right of the MPP on the P-V curve, showing that the voltage must be reduced to reach the MPP. In this work, a small marginal error could be added to the maximum power conditions such that the MPP is assumed to occur if

\[
\left( \frac{\partial P}{\partial V} + \varepsilon \right) < 0
\]  

The value of \( \varepsilon \) was determined with consideration of the trade-off between the problem of not operating exactly at the MPP and the possibility of oscillating around it. This also depends on the chosen perturbation step size.

The implementation of this method can be done adding a controller to improve the incremental conductance method minimizing the error between the actual conductance and the incremental conductance, because the compensator can be adjusted and updated according to the system necessity. Besides, this controller can reduce the ripple oscillations in steady-state minimizing the issues involving digital resolution implementation. This method can be seen as an adaptive solution once it presents large step sizes when the PV operating point is far from the MPP, then the step sizes are reduced according to the distance of MPP and finally when the MPP is achieved the system operation point is not changed, unless the climate conditions are also changed. The controller can control the duty cycle (d) of the converter directly to find the MPP. Figures 8 (a) and (b) show the Matlab/Simulink of the modified Incremental Conductance with integral regulator.

![Flow chart of the INC algorithm.](image-url)
SIMULATION RESULTS AND ANALYSIS

Based on the modified algorithm, the simulation was conducted using dc-dc boost converter system implemented with SimPower Systems toolbox of MATLAB/Simulink model. The simulation system consists of photovoltaic module, dc/dc boost converter circuit, resistive load and control module as shown in Figure-9. An algorithm based on Incremental Conductance, and integral regulator method has been developed for real time tracking. This method uses the slope of the derivative of the current with respect to the voltage in order to reach MPP. From the voltage V and the current I measurements, the algorithm calculates the photovoltaic output power and its derivative as a function of the voltage.

The simplified flow chart of this method is given in Figure-7. Figure-10 to Figure-12 presents the PV output voltage, current, power across the dc/dc converter with MPPT and without MPPT. An MPPT enable was incorporated into the algorithm set at initialized time and in this paper, the enabled time was set to 0.02ms. After the transient response, it is noted that the PV voltage V is established exactly on the MPP voltage and in consequence, the power flow is optimized. Two different load conditions R1 and R2 were incorporated with a switch to test the variation in load at different time.

From the graph, this proved that the MPPT algorithm was able to track the MPP. Thus with this simulation tool, it has highlighted the fact that the advantages of the incremental conductance to other algorithms by a faster achievement of the MPP which is carried out immediately in the good direction without additional oscillations when the MPP is reached in case of sudden change in load.
CONCLUSIONS

This paper has presented all procedure to the development of maximum power point algorithm based on modified incremental conductance. The modelling and simulation of the maximum power point tracking algorithm was implemented in Matlab/simulink environment. The role of the maximum power point tracking, was to match the load power required with a maximum of the available power that can be generated from a photovoltaic module. The simulation result prove that the modified incremental conductance MPPT reaches the intended maximum power point. Beside the tracking elapsed time of the incremental conductance method, it has advantage of exact perturbing and tracking direction and steady perturbing period.

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