DESIGN AND SIMULATION OF GRID CONNECTED PV SYSTEM USING MPPT ALGORITHM

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Abstract

This paper describes a method of modelling and simulation photovoltaic (PV) module with power converter to connect the grid system that implemented in Simulink/Matlab. In order to define a circuit-based simulation model for a PV cell to allow the interaction with a power converter. In this project the PV array is modelled and its voltage-current characteristics and power-voltage characteristics are simulated and optimized. However the characteristics of PV cells that are affected by varying irradiation and temperature. In order to continuously harvest maximum power from the solar panels, they have to operate at their MPP despite the inevitable changes in the environment. Here we are using the MPPT algorithm. The concept of Maximum Power Point Tracking is to be implemented which results in appreciable increase in the efficiency of the Photovoltaic System. MPPT algorithm such as P&O method studied and simulated. The MPPT algorithm connected to the boost converter in this paper boost converter model studied and simulated. The boost converter model is connected to the inverter grid connected is simulated and observed the estimated results. Here we performed the FFT analysis of the different systems and observed the harmonic distraction of the model.

Keywords— Boost converter, Grid, maximum-power-point-tracking (MPPT) method, photovoltaic (PV) system, PWM Inverter, solar cells

Introduction

The energy which is harvested from the natural resources like sunlight, wind, tides, geothermal heat etc. is called Renewable Energy. As these resources can be naturally replenished, for all practical purposes, these can be considered to be limitless unlike the tapering conventional fossil fuels. The global energy crunch has provided a renewed impulsion to the growth and development of Clean and Renewable Energy sources. Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. The sun creates its energy through a thermonuclear process that converts about 650,000,000 tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation [1]. The harnessing of solar energy using PV modules comes with its own problems that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the PV modules [2-4].
Electricity generated from sunlight is called solar electricity and the process of converting solar light into electricity is known as the photovoltaic process. In this process direct current (DC) electricity is produced [5]. In this project we need connect the power to grid supply. So we convert the DC to AC voltage. Before converting we need to increase the voltage from solar cells. So we are using boost converter.

Therefore MPPT techniques are needed to maintain the PV array’s operating at its MPP [6]. Many MPPT techniques have been proposed in the literature; example are the Perturb and Observe (P&O) methods [4, 6-9], Incremental Conductance (IC) methods [7, 10-12], Fuzzy Logic Method [2, 4, 6, 11], etc. In this paper most popular of MPPT technique Perturb and Observe (P&O) method and DC-DC converters Boost converter will involve in comparative study.

The solar cells are affected by temperature and irradiance levels [14]. Moreover, the solar cell V-I characteristic is nonlinear and varies with irradiation and temperature. In general, there is a unique point on the I-V or P-V characteristic, called maximum power point (MPP), at which the entire PV system (array, converter, etc…) operates with maximum efficiency and produces its maximum output power so we need to maximize the power [4,6]. So MPPT algorithm techniques are needed to maintain the PV array’s operating point at its MPP. In MPPT algorithms we are using P&O method to obtain the maximum power [13].

The boost converter of the system is connected to inverter circuit and the inverter system is connecting to the grid system. To remove the harmonics distortion a LC filter circuit is connected to the both converter systems.

**PV MODULE**

Solar cells are the building blocks of a PV array. These are made up of semiconductor materials like silicon etc. A thin semiconductor wafer is specially treated to form an electric field, positive on a side and negative on the other. Electrons are knocked loose from the atoms of the semiconductor material when light strikes upon them. If an electrical circuit is made attaching a conductor to the both sides of the semiconductor, electrons flow will start causing an electric current. It can be circular or square in construction [14, 18].

The power produced by a single module is not sufficient to meet the power demands for most of the practical purposes. PV arrays can use inverters to convert the dc output into ac and use it for motors, lighting and other loads. The modules are connected in series for more voltage rating and then in parallel to meet the current specifications.

To validate the model and simulation results, we compare by solar panel datasheet. The table shows the 270-watt poly-crystalline solar panel data sheet from Suntech Company.
TABLE I
Electrical data for suntech STP 270-24/VB

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal output power (P_{mp})</td>
<td>270 [watt]</td>
</tr>
<tr>
<td>Max. power tolerance</td>
<td>+/- 3 [%]</td>
</tr>
<tr>
<td>Max. Voltage system</td>
<td>1000 [V]</td>
</tr>
<tr>
<td>Nominal Voltage (V_{mp})</td>
<td>35 [V]</td>
</tr>
<tr>
<td>Nominal current (I_{mpp})</td>
<td>7.71 [A]</td>
</tr>
<tr>
<td>Open circuit voltage (V_{oc})</td>
<td>44.8 [V]</td>
</tr>
<tr>
<td>Short circuit current (I_{sc})</td>
<td>8.14 [A]</td>
</tr>
<tr>
<td>Temperature coefficient of open circuit Voltage</td>
<td>-0.34 [% / °C]</td>
</tr>
</tbody>
</table>

The fig.1 shows the V-I and V-P curves that were published by manufacturer. The three curves that pass through the origin are power curves and the rest are current curves [15].

Fig.1 P-V and I-V curves of solar panel from datasheet

A. Simscape model

In the Simscape, the sun irradiation is considered as a parameter. To make the PV module we are connecting 72 solar cells in series. We simplifying the model by make a block with 6 cells, so there are 12 blocks connected in series.

Fig.2 solar cells connected in simulink
These six solar cells are creating to a block. Like 12 blocks combined as shown in fig

![Fig.3 72 solar cell model](image)

**MPPT algorithm**

As we have seen in the above section, the operating point at maximum power in systems based on PV modules depends on solar-radiation level, operating temperature and load current. So that’s the reason to develop control algorithms in order to ensure that operating point achieves its optimal value. MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array.

**A. Perturb & Observe technique**

The perturb & observe (P&O) algorithm, also known as the “hill climbing” method, is very popular and the most commonly used in practice because of its simplicity in algorithm\[8, 9, 11\]. The algorithm flow chart is shown in the figure.

In this control algorithm PV-output voltage (V<sub>K</sub>) and PV output current (I<sub>K</sub>) are sensed. Then power is calculated (P<sub>K</sub>) and compared with the power value calculated in the previous sample (P<sub>K-1</sub>) in order to get ΔP<sub>K</sub>. If the result of ΔP<sub>K</sub> is zero the system is working in MPP. Otherwise and according to the sign of ΔP<sub>K</sub> and to the sign of ΔV<sub>K</sub> the command voltage to control the duty cycle (δ) of the converter (let’s say the perturbation), will be decreased or increased in order to force the working point of the PV module towards the MPP [16].
Boost converter

In the boost converter model the gate pulses is connected from MPPT algorithm. The duct cycle of the MPPT algorithm is connect to gate pulses of the IGBT as shown in figure.

A simple boost converter consists of an inductor, a switch, a diode and a capacitor as shown in Fig. 11. Boost converter circuit can be divided into two modes. Mode 1 begins when the switch SW is turned on at $t = T_{on}$. The input current which rises flows through inductor $L$ and switch SW. During this mode, energy is stored in the inductor. Mode 2 begins when the switch is turned off at $t = T_{off}$. The current that was flowing through the switch would now flow through inductor $L$, diode D, capacitor C, and load $R$. The inductor current falls until the switch is turned on again in the next cycle. Energy stored in the inductor is then transferred to the load. Therefore, the output voltage is greater than the input voltage and is expressed as in equation [17].

$$V_{OUT} = \frac{1}{1-D} V_{IN} \quad (1)$$

Fig.5 simulink model of boost converter

In order to operate the converter in continuous conduction mode (CCM), the inductance is calculated such that the inductor current $I_L$ flows continuously and never falls to zero.

$$L_{min} = \frac{(1-D)^2 * D * R}{2 * f} \quad (2)$$

Where $L_{min}$ is the minimum inductance, $D$ is duty cycle, $R$ is output resistance, and $f$ is the switching frequency of switch SW. The output capacitance to give the desired output voltage ripple is given by equation

$$C_{min} = \frac{D}{R * f * V_r} \quad (3)$$

Where $C_{min}$ is the minimum capacitance, $D$ is duty cycle, $R$ is output resistance, $f$ is switching frequency of switch SW, and $V_r$ is output voltage ripple factor. $V_r$ Can be expressed as equation

$$V_r = \frac{\Delta V_{out}}{V_{out}} \quad (4)$$
**Simulation and results**

The solar module is connected to the boost converter. The gate pulses are connected from MPPT algorithm. The boost converter is connected to the inverter circuit. The inverter circuit is connecting to the grid system. For inverter we generating PWM pulses as connected to gate circuit.

![Simulink model of entire system with PV module, boost converter and PWM inverter](image)

**TABLE III**  
Output value of PV panel at different irradiance levels

<table>
<thead>
<tr>
<th>Irradiance (w/m²)</th>
<th>Output voltage (v)</th>
<th>Output current (A)</th>
<th>Output power (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>43.11</td>
<td>0.0863</td>
<td>3.721</td>
</tr>
<tr>
<td>750</td>
<td>42.5</td>
<td>0.0856</td>
<td>3.66</td>
</tr>
<tr>
<td>500</td>
<td>41</td>
<td>0.0821</td>
<td>3.367</td>
</tr>
<tr>
<td>250</td>
<td>38.87</td>
<td>0.0778</td>
<td>3.024</td>
</tr>
</tbody>
</table>
Here the output values of photovoltaic modules at different irradiance levels. In this table we showed the output voltage, current and power of the PV module. In the simulation of model we are taking irradiance at 100w/m².

The figure 7 shows the 72 solar cells output wave forms. The voltage of the solar module is nearly 44 V. we can also observe the P-V and I-V plots of the solar module. Here the constant irradiation is given.

![Fig.7 output wave of PV module voltage, current and power](image)

The current and voltage (I-V), power and voltage (P-V) characteristics are shown in the figure 8&9. These are taken at 1000w/m².

![Fig.8 I-V characteristics](image)

![Fig .9 P-V characteristics](image)
The pulses are generated from MPPT algorithm. These pulses are connected to boost converter.

![Fig.10 pulses to the gate](image)

Fig.10 pulses to the gate

The figure 11 shows the input voltage of PV module and output voltage of Boost converter without filter.

![Fig.11 PV module voltage and boost converter voltage](image)

Fig.11 PV module voltage and boost converter voltage

The output of the boost converter is noises and harmonic distortions. So we want to remove these contents. By using L-C filter we are reduced the harmonics.

<table>
<thead>
<tr>
<th>TABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output of the boost converter with and without filter</td>
</tr>
<tr>
<td>Input voltage (v)</td>
</tr>
<tr>
<td>43.11</td>
</tr>
</tbody>
</table>

The boost converter is connected to the PWM inverter. The inverter converts the DC voltage to AC voltage. The inverter is connected to L-C filter and grid.
Figure 12 shows the output waveforms of the inverter.

![Waveforms of Inverter](image12.png)

Fig.12 shows input DC- supply, output of inverter, and load voltage and modulation index with MPPT algorithm.

The figure 13 shows the output of the inverter without using MPPT algorithm. The output voltage of model is less than with MPPT algorithm.

![Waveforms of Inverter without MPPT](image13.png)

Fig.13 shows input DC- supply, output of inverter, and load voltage and modulation index without MPPT algorithm.

The figure 14 shows the active and reactive power of the inverter load without using MPPT algorithm. There are fluctuations in the power. The active and reactive power is varied.

![Active and Reactive Power](image14.png)

Fig.14 active and reactive power without MPPT algorithm
In this model we determine the active and reactive power of the AC supply. In this model we are using the MPPT algorithm. The active and reactive power is shown in figure 15. The active and reactive power is settled constant after few seconds.

![Fig.15 active and reactive power with MPPT algorithm](image1)

Here we analyze the Fast Fourier Transform (FFT) analysis of boost converter $V_{DC}$ and inverter system finds the Total Harmonic Distortion (THD). The figure 16 shows the boost converter voltage. There is more THD level.

![Fig.16 FFT analysis of boost converter voltage $V_{DC}$](image2)
The figure 17 shows the inverter at voltage $V_{AB}$. The Total Harmonic distortion is 67.5% at this level with the fundamental frequency of 59.82 Hz’s.

The figure 18 shows the load voltage of the inverter. The Total Harmonic Distortion is very less that is 4.58% with the fundamental frequency of 67.5 Hz’s.

Fig.18 FFT analysis of the inverter at load
Conclusion

The concepts of a PV cell and its characteristics have been studied and obtained through its characteristic equation. The open circuit P-V, I-V curves we obtained from the simulation of the PV array designed in MATLAB environment explains in detail its dependence on the irradiation levels. The entire energy conversion system has been designed in MATLAB-SIMULINK environment. The boost converter and P&O MPPT algorithm is designed in MATLAB. We get the esteemed results in the simulation. FFT analysis of the different systems and observed the Total harmonic Distortion (THD %) in the AC system.

References

[1] figure from Asimov, Isaac; Understanding Physics: The Electron, Proton, and Neutron; pg. 208
[14] Bibek Mishra, Bibhu Prasanna Kar "MATLAB BASED MODELING OF PHOTOVOLTAIC ARRAY CHARACTERISTICS "


