Grid Connected Photovoltaic using multi level inverter

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Abstract: This paper presents Photovoltaic (PV) connected to single phase grid based on maximum power point tracking paper related with how to solve problems caused by unconformity phenomena as like partial shading condition (PSC) which the photovoltaic always be in most time. In order to enhancing the efficiency of tracking global maximum power point under partial shading condition (PSC) particle swarm optimization MPPT technique is approached. The paper studies photovoltaic (PV) cell which is modeled as two diodes under the variation of irradiation and temperature (partial shading conditions) by using two different MPPT methods called particle swarm optimization (PSO) and incremental conductance method (IC). The particle swarm optimization is one of the artificial intelligence method used to detect MPPT. The efficiency of PSO is higher than any traditional method such as IC. The efficiency of each method are shown in matlab simulation to show the advantage of detecting the optimal power point in all cases. The particle swarm optimization represent lower energy losses and reach max power point more quicker than incremental conductance method specially in the partially shading conditions. Both of two MPPT methods feed the input of the grid tied inverter with the determined DC bus voltage.

Keywords: photovoltaic (PV), Maximum power point (MPPT), particle swarm optimization (PSO), Incremental conductance (IC), Partial shading condition (PSC).

I. INTRODUCTION

The solar cell radiation seems to be one of the most promising renewable energy sources and can be directly converted into electricity using the photovoltaic (PV) devices. This subject causes to make a great deal of investments in different energy solutions to enhance the energy performance and power quality problems. The renewable energy cost are lower than oil energy and have a good environment affect. In order to get the maximum benfit of this energy many researchers try to reach maximum power point of PV cells by many methods.

The PV array connect to the utility grid not directly but through few devices to be ready to connect [1-13]. The output voltage from PV is not enough and not stable to enter to the inverter DC/AC which delivery power produced by PV into the grid [5-8]. To overcome this problem a DC/DC chopper (Boost converter) is used [7-13]. Then the PV array connected to the utility grid through a boost converter and a full bridge inverter. Choppers are mainly employed in regulated switch mode power supplies where the input voltage of these converters changes in wide range especially in the Photovoltaic (PV) supply source due to sudden and unpredictable changes in the solar Irradiation level like the cell operating temperature. The dependency of the solar system characteristics to the temperature and
insolation level variations gets the issue worse. Hence, the maximum power point (MPP) and operating point of the solar cells get mismatch. To achieve the maximum power from the PV panel source it should be capable to track the solar panel unique maximum power point which varies with temperature and irradiance. To do this, MPPT can be employed by using any one of the algorithms proposed in [14]. One of the oldest MPPT methods is Incremental Conductance [15,16],

In the recent years the artificial intelligence techniques (soft computing methods) for MPPT are proposed in [17-20]. Particle swarm optimization is one of advanced MPPT methods proposed in [21-23] which can solve problems of partial shading condition. In this paper theoretical comparison between Incremental conductance MPPT method and particle swarm optimization (optimized MPPT algorithm) under two different solar irradiation functions [24-25]. The presented MPPT algorithm based on PSO is used to tracking the global maximum power point (GMPP) of the photovoltaic cells. On the contrary of the incremental conductance method (IC) which depend on the local maximum power point (LMPP). So that the PSO algorithm reduce the shadow condition affect and improve the performance of the whole system. The PSO algorithm function enhance the dynamic response of the system under the sudden radiation changes and the other environmental effects. Also the PSO function is used to find the duty cycle for the boost converter. The PSO method needs iterations to get the global peak (GB). It is based on a lagrange interpolation (LI) formula. Once it finds the MPP the steady state oscillation are reduced to be approximately zero. The tracking speed is being faster and the efficiency of the presented method is increased. This paper is arranged as following section 2 presents the pv system description. Section 3 presents comparison between MPPT algorithms IC & PSO. The performance and feasibility of the grid-tied PV system are evaluated by means of simulations, as well as by using a laboratory prototype for experimental validation in section 4. Finally, the conclusions are presented in Section 5.

II. PV System Description

![Block Diagram of the PV System and Topology.](image)
2.1 Main Photovoltaic Technologies

2.1.1 PV array

The principle of Photovoltaic System is simple: it is a direct conversion of light to electricity. Since the 1950's, and the first crystalline silicon PV, many material have been put into solar cells as crystalline silicon and amorphous silicon, Cadmium telluride (CdTe) and cadmium sulphide (CdS).

This large variety of PV technologies provides great opportunities as each material has a different light absorption capability, especially regarding the incident light spectrum.

The solar energy conversion into electricity takes place in a semiconductor device that is called a solar cell. The solar cell is the basic unit of a PV system.

In order to use solar electricity for practical devices, which require a particular voltage or current for their operation, a number of solar cells have to be connected together (in series/parallel combinations) to form a PV module, also called a PV panel. To increase the voltage, modules are connected in series and to increase the current they are connected in parallel.

For large-scale generation of solar electricity the solar panels are connected together into a solar array.

So the PV array consists of a number of PV modules or panels and the PV module is an assembly of a large number of interconnected PV cells.

![Diagram of PV Cell, Module, String, and Array]

Fig. 2 Description of PV Cell, PV Module, PV String and PV Array.

2.1.2 PV Cell Equivalent Circuit

For simplicity in analyzing characteristics of solar cells, electrical equivalent circuits are realized and are hence modelled using simulation softwares. It helps in predicting behavior under various environmental conditions, and further in obtaining (I-V) and (P-V) characteristic curves.

The common approach is to utilize the electrical equivalent circuit, which is primarily based on a light generated current source connected in parallel to a p-n junction diode. Many models have been proposed for the simulation of a solar cell or for a complete photovoltaic (PV) system at various solar intensities and temperature conditions.
The most commonly used models are single diode and two diode model.

### 2.1.2.2 Double-Diode PV Cell

![Double Diode PV Cell Diagram](image)

**Double Diode PV Equations**

\[
I = I_{PV} - I_D1 - I_D2 \\
\text{Where} \ I_D1 = I_{O1}[\exp\left(V/A1VT\right)-1] \\
I_D2 = I_{O2}[\exp\left(V2/AVT\right)-1]
\]

The Inclusion of additional parameters \( R_S, R_{SH} \) the Eq 1 becomes:

\[
I = I_{PV} - I_{O1}[\exp\left(V+R_S*I/A1VT\right)-1] - I_{O2}[\exp\left(V+R_S*I/A2VT\right)-1] - [V+R_S*I/R_{SH}]
\]

### 2.2-Boost converter

The Boost converter is a simple power electronic converter and basically consists of a voltage source, an inductor, a high frequency switch (usually a MOS-FET or an IGBT) and a diode. Boost converter steps up the input Voltage magnitude to a required output voltage magnitude without the use of a transformer. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change.

![Boost Converter Diagram](image)

**Boost converter consists of input voltage source, switch, inductor, diode, capacitor and resistor which acts as a load. The switch can be closed or open depends on the output requirement. The output voltage across the load or resistor is always greater than that of input voltage. Due to a single switch, it has a high efficiency. The input current is continuous.**

If the switch is turned on and off repeatedly at very high frequencies and assuming that in the steady state the output will basically be DC (large capacitor).
MODES OF OPERATION

There are two modes of operation of a boost converter. Those are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation.

Charging Mode

In this mode of operation; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying [11]. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor.

Discharging Mode

In this mode of operation; the switch is open and the diode is forward biased [11]. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation.

2. 3- MULTI LEVEL INVERTER

Fig. 5 showed Inverters are power electronic circuit which converts the DC voltage into AC voltage. The DC source is normally a battery or output of the controlled rectifier. The output voltage waveform of the inverter can be square wave, quasi-square wave or low distorted sine wave. The output voltage can be controlled with the help of drives of the switches. The pulse width modulation techniques are most commonly used to control the output.

Multilevel inverters are a source of high power, often used in industrial applications and can use either sine or modified sine waves. Instead of using one converter to convert an AC current into a DC current, a multilevel inverter uses a series of semiconductor power converters (usually two to three) thus generating higher voltage. Therefore multilevel inverters are the preferred choice in industry for the application in high voltage and high power application.
2.3.1 TOPOLOGY OF MULTILEVEL INVERTERS
Multilevel inverters have an arrangement of power switching devices and capacitor voltage sources. Multilevel inverters are suitable for high-voltage applications because of their ability to synthesize output voltage waveforms with a better harmonic spectrum and attain higher voltages with a limited maximum device rating.

2.3.2 Types of Multilevel Inverters:
The classification of multilevel inverter is described in (Fig.6)

III. MPPT TECHNIQUES
In this section the descriptions of MPPT techniques based on PSO and IC methods are presented. In addition, the mechanism for determining the DC-bus voltage reference are also presented.

3.1-MPPT based on Incremental conductance method (IC): 
Maximum power point is obtained [9,10] when \( \frac{dP}{dV} = 0 \) where \( P = V*I \)
\[
\frac{d(V*I)}{dV} = I + V\frac{dI}{dV} = 0 
\]
\[
\frac{dI}{dV} = -\frac{I}{V} 
\]
dI, dV = fundamental components of I and V ripples measured with a sliding time window T_{MPPT}
I, V = mean values of V and I measured with a sliding time window T_{MPPT}
The integral regulator minimizes the error (dI/dV + I/V)
Regulator output = Duty cycle correction
This method needs many sensors to work so it is not cheap.

3.2-MPPT based on PSO:
PSO is one of well known search techniques which be famous in the engineering fields recently. PSO was proposed first time in 1995 by Kennedy and Ebrahat. PSO is quoted from the birds swarms behavior. The idea of PSO algorithm is tracking the MPP and improve the efficiency of the MPPT controller under PSCs.[16,17].

The PSO theory depend on finding a large solution area where the solution of the problem may be exist in any place in this area. The PSO starts procedure with initial random particles. In this method there are three main steps called initialization, movement and evaluation.

In the Initialization step PSO start with a population which take random values and the algorithm generates random particles which are considered solutions based on the reference voltage value which is closed to the MPP value.

In the Movement step each particle has a velocity and search to the better position by the influence of neighboring particle position.

In the Evaluation step each particle fitness is evaluated in the new position and be saved to improve the future particle movements in the next iterations until a particle reach to the best position which in our case the voltage of the greatest power generated (Fitness function) all particles will be influenced by it.

That is will done after number of iterations are predefined and the determination of the MPP still is not ensured. The stopping condition can be set to ensure the determination of the MPP and not related to the predefined iterations.

The process of MPP based on PSO is applied to the PV output power conversion and represented in (Fig.7).
IV. RESULTS

Table 1 shows the simulation parameters used in PSO. PV represented as electrical circuit with a series resistance and a shunt resistance. The PV output voltage and current depend on the input irradiation and temperature. Temperature is used as 25°C and irradiation is a
function presents sudden variation shape (1000 W/m² and decreased to 600 W/m² at instant 1 sec then be 950 W/m² at instant 7 sec). Boost converter parameters as capacitance and inductance equal 100 micro farad and henry. All the MPPT algorithms have a perturbation period of 400 µs, while the perturbation amplitude is 1 V for the IC algorithm and the initial perturbation amplitudes is 0.8 V for the PSO algorithm.

The chopper voltage increases rapidly until 0.1 sec to reach steady state (S.S) value 160 volt then be constant value until 1 sec it began to decrease slowly to reach 158 volt and continue until 7 sec increase again to reach steady state value 160 V and continue. That's as result of affect of partial shading condition (PSC) and the variation of the presented radiation.

By using particle swarm optimization MPPT technique can reduce the affect of partial shading condition (PSC) and make the output voltage more smooth and approximately pure DC which presented to the full bridge inverter.

<table>
<thead>
<tr>
<th>PV panel</th>
<th>Boost Converter</th>
<th>MPPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vpv = 120 V</td>
<td>C = 100 µF</td>
<td>Ta = 400 µs</td>
</tr>
<tr>
<td>Ipv = 390 A , Rsh = 10000 Ohm</td>
<td>L = 100 µH</td>
<td>ΔV = 1 V (IC)</td>
</tr>
<tr>
<td>Rs = 0.001 Ohm.</td>
<td>VConverter = 300</td>
<td>ΔV0 = 0.8 V (10 p.) LPF@5 kHz</td>
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**Table 1. Simulation Parameters.**

**4.1 - SIMULINK RESULTS FOR INCREMENTAL CONDUCTANCE METHOD:**

The simulation of MPPT algorithm is done based on incremental conductance method with perturbation amplitudes of 1 V.

Fig.8 and Fig.9 show the performance of the IC algorithm with a perturbation amplitude of 1 V. The time to reach the maximum power point is close to 50 ms, while the steady-state error is 1.6% and energy losses during 100 ms are 150 mJ. The zoom of the voltage sub-figure shows the settling time designed.
Figure 9 power extraction from Boost Converter. (IC MPPT)

Fig10 and Fig.11 show voltage and power output from PV cell.

Figure 10. Profile of PV Panel Voltage. (IC MPPT)

Figure 11. Profile of PV Panel Power Extraction. (IC MPPT)

4.2- SIMULINK RESULTS FOR PARTICLE SWARM OPTIMIZATION ALGORITHM:
The simulation of PSO MPPT method of two iterations with 10 particles were made. This method does not guarantee the best solution. Fig12 and Fig.13 show the performance of the
PSO algorithm with a perturbation amplitude of 0.8 V. The time to reach the maximum power point is close to 50 ms, while the steady-state error is 0.11% and energy losses during 100 ms are 95 mJ. The zoom of the voltage sub-figure shows the settling time designed .Fig.14 and Fig.15 show voltage and power output from PV cell.

Fig. 12 MPPT based on PSO. Profile of the chooper voltage

Fig. 13 MPPT based on PSO. Profile of the chooper power extraction.

Fig.14 MPPT based on PSO. Profile of the pv panel voltage
Fig. 15 MPPT based on PSO. Profile of the pv panel power extraction.

Table 2. Main simulation results used to compare the performance of the MPPT techniques based on IC and PSO.

<table>
<thead>
<tr>
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<th>With partial shading</th>
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<tbody>
<tr>
<td></td>
<td>IC</td>
</tr>
<tr>
<td>time to reach the MPP (s)</td>
<td>150</td>
</tr>
<tr>
<td>power oscillation in steady state (%)</td>
<td>0.06</td>
</tr>
<tr>
<td>PV power extracted at MPP (W)</td>
<td>1384</td>
</tr>
<tr>
<td>tracking efficiency (%)</td>
<td>71.93</td>
</tr>
</tbody>
</table>

V. CONCLUSION

This paper proposes on the effect of the sudden change in input radiation for photovoltaic PV on the output current and voltage and how to solve it by two different MPPT method. We find that the particle swarm optimization PSO is faster in response than incremental conductance IC. This is due to that particles search to the best position automatically in the different weather changes when particles are initialized correctly around the MPP. This make the tracking time which particles waste in the wrong direction is reduced as result the system tracking efficiency is raised and the fluctuation around the MPP is reduced. The power loss in steady state oscillation in incremental conductance method IC is higher than its by the particle swarm optimization PSO. From the obtained results it was found that the PSO based MPPT exhibits superior performance compared to incremental conductance IC. Tracking the global MPP using PSO algorithm is making the controllers system independent, robust and fast under partial shading conditions (PSC).

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