Design and Simulation of a Grid Tied Single Phase SPWM Inverter Using Matlab

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Abstract. The work objective is to design and simulate grid tie photovoltaic module with Simulink software, to investigate the characteristics of photovoltaic module as well describe the maximum power point tracking using the single diode equivalent circuit. As well as developing single phase H bridge inverter a control circuit which generates output of a pure sine wave and voltage of alike frequency and magnitude such as the voltage of the grid. Sinusoidal pulse width modulation signal (SPWM) a common PWM method to achieve perturb and monitor (P&O), the maximum power point tracking (MPPT) method.

1. INTRODUCTION

In the last years the electricity demand grows exponentially. The major causes for the growing energy demand are economic growth, increasing the world population, and the fast exhaustion of traditional fuel reserve (fossil) [1]. Which become imperative to find an alternative power source. Solar energy is one of these sources which have great potential and no impact on the environment. Off grid PV system utilize photovoltaic array with battery banks to collect its produced solar energy, which provide a comprehensive independent solar energy system. Yet, this kind of solar systems perform good if solar irradiance is sufficient throughout the day to recharge the battery bank for usage throughout the night. Standalone solar systems are independent and stationary or movable, photovoltaic systems that are not linked to utility grid are usually utilized in remote areas. Unlike from standalone PV system, on grid PV system are linked to and feed produced electricity into the national grid [2]. Grid connected solar energy systems. PV array could occasionally generate excess electricity than is really required or consumed; this excess electricity is either stored in battery banks or fed back to the grid as in many on grid photovoltaic systems [3]. The power generated from solar panels is direct current (DC) and the need for inverter is essential to generate alternating current (AC) which is utilized to operate electrical appliances. Most the available inverters are costly as well as the output voltage is not pure sinusoidal, which may cause damage to the operated electrical appliances. SPWM switching technique is utilized to produce a pure sine wave. The technique needs a specific configuration of switching utilized in DC to AC power inverter. The technique of SPWM is broadly utilized in power electronics devices like motor driver, uninterruptible power source (UPS), and renewable energy. The technique of SPWM switching is regarded as steady amplitude pulses with diverse duty cycle at every period. In this study investigate the conversion of PV output to sinusoidal by using an inverter.
2. System Modeling
The photovoltaic system modeled as in figure 1 show the elements of photovoltaic module; DC boost converter, voltage source converter (DC- AC), low pass filter and a power distribution grid.

![Figure 1. on grid photovoltaic system component.](image)

The following is step by step description of the main component of the system:

2.1. Solar panel
Figure 2 shows the equivalent circuit of one-diode type of PV cell. One-diode solar panel model is adopted for this work as shown in figure 3, standard equation can be used to obtain PV cells characteristic [4]. In this paper the PV module that is used consist of 36 cells connected in series is supply short circuit current (Isc) = 3.74 Amps and open circuit voltage (Voc) = 21Volt.

![Figure 2. One–diode equivalent circuit for model of theoretical PV cell and a practical PV cell.](image)
These equations represent voltage current properties of PV cell:

\[ I = I_L - I_S \left\{ \exp \left( \frac{q(V + IR_S)}{kT_cA} \right) - 1 \right\} - V + IR_S/R_{sh} \]  

(1)

Where:

- \( I \) generated current
- \( q = 1.6 \times 10^{-19} \text{ C} \) charge of electron.
- \( R_{sh} \) shunt resistance,
- \( k = 1.38 \times 10^{-23} \text{ J/K} \) Boltzmann’s constant.
- \( T_c \) temperature of cells
- \( R_s \) series resistance
- \( A \) ideality factor,

The photocurrent is defined as

\[ I_{L=} = [I_{sc} + K_1 T_c - T_{ref}] \cdot \lambda \]  

(2)

Where: \( I_{sc} \) current of the cell short circuit
- \( K_1 \) short circuit current temperature coefficient.
- \( T_{ref} \) reference temperature
- \( \lambda \) the solar radiation in kW/m².

While the current of saturation of cell differs with the temperature of cell, which is defined as:

\[ I_s = I_{RS} T_c / T_{ref} \cdot 3 \exp \left[ q E_G \left( \frac{1}{T_{ref}} - \frac{1}{T_c} \right) / k A \right] \]  

(3)

Where:

- \( I_{RS} \) the reverse saturation current,
- \( E_G \) the energy bang gap.

The scientific equations of the model formed can be defined as

\[ I = N_p I_{ph} - N_p I_s \left[ \exp \frac{q(V / N_s + I_{RS}/ N_pk T_c A - 1)}{k A} \right] \]  

(4)

2.2. DC-DC Boost Converter

DC-DC boost converter is connected between the photovoltaic module and the load so as to
assist the module operation at maximum power at the entire time.

The output characteristics of the photovoltaic module that are shown by power, voltage and current voltage curves subject to the influence of various values of the solar radiation and temperature are simulated by Matlab. The proposed PV characteristics module are presented in figure 4. It was observed that the maximum power output is 74 W, open circuit voltage is 21 volts with short circuit current is 3.74 Amps. The Simulink model depends on the solar irradiance and cell temperature. At the point where the derived curve is power at its maximum. Current, Voltage and power are variety with temperature. Voltage is most sensitive to temperature changes.

![Figure 4. I-V and P-V curves.](image)

Boost converter is created from four electronic elements as illustrated in figure 5; which are inductance, capacitor, MOSFET, and diode. Just like the name of the converter indicates, it boosts the input voltage which increases the output voltage compared to the input voltage, that will results in rising the system efficiency. The converter is control via MOSFETs which perform like a switch. On /off of the MOSFET manage the output voltage by varying the inductance voltage, which enable the photovoltaic power the load at maximum voltage.

![Figure 5. DC to DC boost converter.](image)

### 2.3. MPPT Algorithm
The sum of maximum power which could be extracted from PV array at a certain period is a function of irradiance and ambient temperature. Meanwhile irradiance and ambient temperature are always
varying, an MPPT algorithm is essential to track the MPP. Among the available MPPT algorithms, is the P&O MPPT algorithm which is illustrated in figure 6 as a flow chart.

A MPPT is utilized to extract the maximum power from the photovoltaic and direct that power to the load. DC boost converter (step up) assists in the purpose of directing maximum power from the solar photovoltaic to the load. DC boost converter performs as an connection between the load and the module. By varying the load impedance and the duty cycle. Thus, a MPPT method is essential to get maximum power from a photovoltaic system. MPPT is utilized in solar systems to exploit the photovoltaic output power, regardless of the temperature and irradiance situations and the load electrical characteristics with the use of DC boost converter. MPPT is an electrical system that runs the Photovoltaic module in a method that permits the PV to generate maximum power they are able of. MPPT varies the modules electrical functional point so that the PV is able to provide the available maximum power.

2.4. DC to AC Inverter
Modeling of Inverter is a vital part of a grid tie photovoltaic system [6], as well as the control part for grid synchronization. Figure 7 shows the Simulink system of inverter and grid synchronization.

Full H-bridge inverter is utilized as shown in figure 8, for the first half sequence MOSFET 1 and 2, are off, and MOSFET 3 and 4 are off for the negative half cycle, MOSFET 1 and 2 are opened. For a resistive load, the output current is calculated by:
Voltage of the grid is uncontrollable; the best actual way of controlling the operation of the system is by controlling direct current that is flowing to the grid [7]. As active power is reliant on the current. The current output controller is served into the switching pulses by SPWM generator to produce the inverter gate pulses [8].

Tight synchronization with the grid is essential for seamless delivery of excess power by grid tied photovoltaic system. Grid synchronization depends on control of the inverter’s full bridge output stage used to generate the needed AC waveform.

### 2.5 Low Pass filter

As shown in figure 9 low pass filter is utilized to eliminate any ripple and harmonics. To simulate a DC source which is connected to DC side of an inverter model to get AC source then a filter is utilized to get sinusoidal output [9].

### 3. Simulation and Results

The presented setup detailed in figure 1 is simulated by Matlab. Figure 9 describe the photovoltaic in Simulink. The PV output power is illustrated in figure 10. The PV output voltage at starting conditions of 800 W/m² and 20°C the output voltage at 13.1 volts after 0.05 sec of simulation the irradiance was 1000W/m² with temperature of 40°C the output voltage reached to 16.7 volts, which
the peak output voltage at the mentioned operation condition and continue till 0.1 sec (end of simulation).

![Figure 10. PV output voltage.](image1)

The output of the photovoltaic will pass through the DC boost that will help to reduce losses of the system when the output voltage of the boost is near the maximum power point. As noticed from figure 11 the output voltage of the MPPT is at 25 volts and input current of 2.1 amps and output power of 55 W when simulation parameters of irradiance of 800 W/m² and temperature of 20 °C, which started at time zero to 0.05 sec. When simulation parameters of solar irradiance at 1000 W/m² and temperature at 40 °C started from time 0.05 sec to 0.1 sec (end of simulation) the output voltage of MPPT reached 40 volts and input current of 2.7 amps with output power of 75 W.

![Figure 11A. MPPT output voltage. B: Input current of MPPT. C: Output power of MPPT](image2)

A generator of PWM wave is employed with the circuit of the inverter, this PWM wave produces one pulse for each MOSFET switch. The output pulse of the PWM wave is as presented in the figure 12.

![Figure 12. PWM pulse waveform generation.](image3)
Figure 13 illustrates the grid voltage and compares it with the output of the inverter without transformer on the inverter voltage.

![Grid Voltage vs Inverter Voltage](image1.png)

Figure 13. Grid voltage compared to inverter output.

Below in figure 14 is the output of system after using transformer which boosted the system output voltage up to same level as the grid voltage, which is of maximum 320 V, which is the desired outcome of the system. The next figure will illustrate the system output and how is it in synch with the grid.

![System Output After Transformer](image2.png)

Figure 14. System output after transformer.

Figure 15 shows the grid voltage and the system output which is in complete synchronization, this outcome illustrate the system ability to generate a voltage waveform that is in synchronism with the national grid without any ripples and harmonics.

![Transformer Output vs Grid](image3.png)

Figure 15. Output of transformer.
4. Conclusion

This paper presents the model of grid tied solar panel system. A practical case developed in MATLAB/SIMULINK R2015 environment. The system comprise of a PV module, boost converter, voltage Source Inverter, Utility grid and MPPT controller by using Perturb and Observe algorithm, which gives output with less ripple voltage.

5. References

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