

DESIGN, MODELING AND CONTROL OF SOLAR PV BASED MICROGRID WITH BATTERY ENERGY STORAGE

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Abstract - The renewable energies are the new trend and sustainable technologies are starting to play a big role in the society in order to eliminate the dependence on fossil fuels, finding the way to collect these clean energies. And to convert them into electricity at their highest performance is without any doubt essential. Nevertheless, the way to link the power generated from these renewable sources to the main grid is as well significant. The paper studies step by step the design, modeling, control and simulation of a Microgrid based on several elements with a special focus to the Photovoltaic (PV) System and to the Voltage Source Converters.

Modeling of the equivalent electric circuit model to simulate the working principle of a PV cell is studied in detail and a Maximum Power Point Tracking (MPPT) control algorithm to force the PV system works at its highest operation point is applied. The operation and behavior of the entire Microgrid is checked using software MATLAB Simulink and the results show a proper performance.

Key Words: solar, grid connectivity, PV system, voltage source converter, maximum power point tracking (MPPT), SPWM,

1. INTRODUCTION

The radiation continuously showered by sun represents the most basic and inexhaustible source of energy. The non-renewable energy resources, including coal, petroleum, natural gas, etc. are gradually declining. Therefore development and proper utilization of the renewable energy resources is very important. Due to the environmental and economic incentives, renewable energy generation is gaining a lot of attention, such as solar power, fuel cell power, wind power, tidal power etc. Among them, solar energy is now experiencing fast development. There are two major types of Solar Energy Production. One of them is solar electrical photovoltaic system that uses solar panels to convert sunlight directly into power. The other is the Concentrated Solar Power (CSP) also called "concentrated solar thermal". This technique uses solar thermal energy to create steam that is reborn into electricity by a rotary engine thereafter.

Throughout the last years, the expansion of electrical photovoltaic phenomenon has been study worldwide. With the aim of moving towards small carbon economy,

every country has its target at For example, the Renewable Energy Directive sets rules for Europe to achieve 20% energy from renewable source, target by 2020. In 2017, international solar photovoltaic capacity achieved 227GW whereas CSP energy reached 480GW among 785GW of total renewable power capability. By the end of 2018, installed international electrical photovoltaic capacity increased to 303GW. The covered demand proportion might seem low. However, back in the year of 2000 the overall capacity of photovoltaic installed was low about 170MW.

2. EQUIVALENT MODEL OF PHOTOVOLTAIC SYSTEM

The performance of a cell can be demonstrated by using its current versus voltage characteristics (IV curve -Figure 1). The IV curve given in figure is the superposition of the IV curve of the cell diode within the dark with the light-generated current.

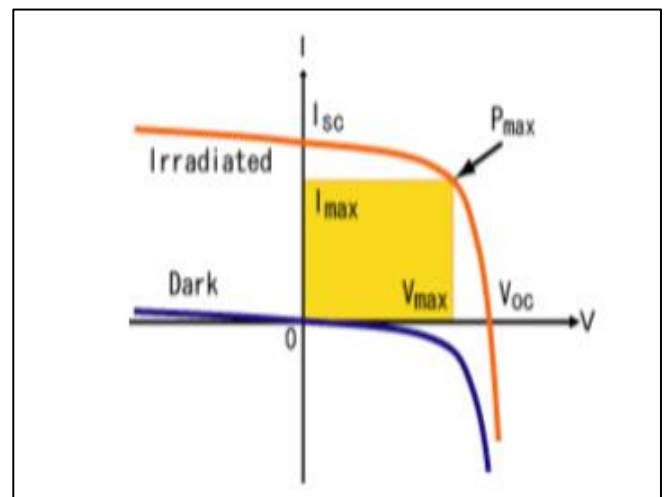


Figure 1. Common IV curve of a solar cell

In the dark, the IV curve of a cell has an exponential characteristic same as that of a diode under no illumination.

$$I_D = I_{dark} = I_0 (qV/kBT)$$

The solar cell blocks current below reverse bias conditions and it will generate current under forward bias conditions.

Under illumination, the silicon cell conducts extra current associated with the light excited charge carriers and so, the IV curve shifts because the cell begins to generate power.

This behavior can be represented as an electrical circuit. The photo generated current is diagrammatic by a current source (I_{PH}) and also the diode of the cell within the dark is diagrammatic by triangle form symbol (I_D). Both parameters, V_{OC} and I_{SC} , outline the IV curve. Then, the power of solar cell can be easily determine by using voltage and current values from the IV curve. With the IV curve it is attainable to see the Maximum Power Point (MPP). Figure 2 shows the voltage versus current characteristics of a solar cell. At the point of maximum power, two parameters, voltage and current that shape the properties of the solar module. It can deliver maximum power to the load side. Therefore, it is essential that the solar module operates at the maximum power point.

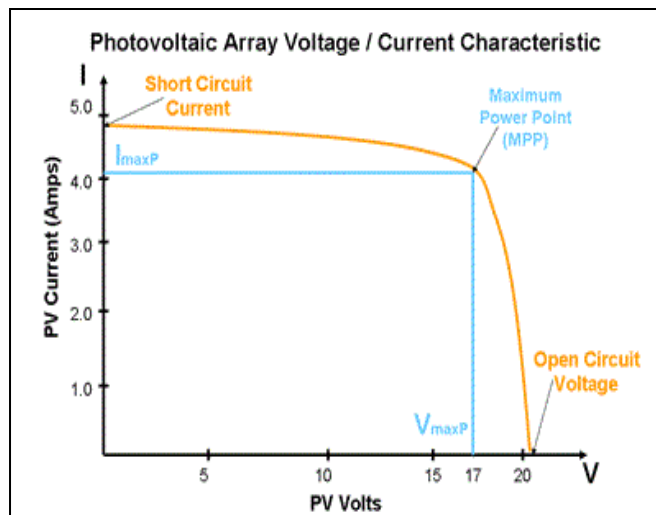


Figure 2. IV curve of solar cell

A more accurate equivalent circuit of a solar cell is represented in figure 3 with the parasitic resistances. This circuit is necessary to take under considerations while modeling of a photovoltaic system.

By using Kirchhoff's law,

$$I = I_L - I_D - I'$$

By using above equation,

$$I = I_L - I_0 \exp \left[\frac{(V + IR_s) nkT}{q} \right] - \frac{(V + IR_s)}{R_{sh}}$$

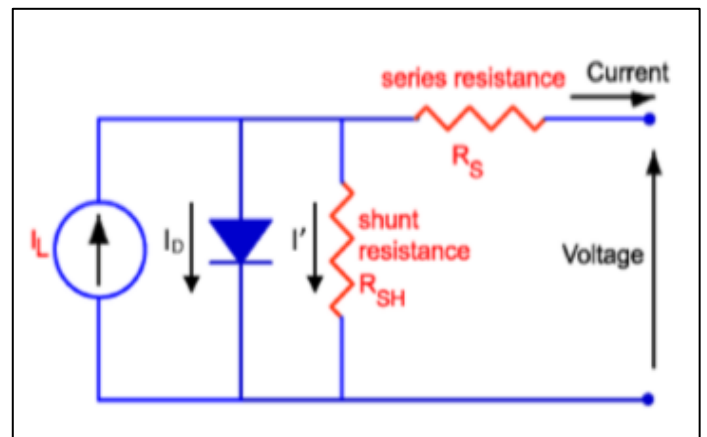


Figure 3. Equivalent circuit of a non-ideal electric cell

3. PHOTOVOLTAIC SYSTEM MODELING

The renewable generation system, as mentioned, consist photovoltaic solar panels connected either in series or in parallel, all of them building a photovoltaic system controlled by a central electrical converter. A simplified scheme of the renewable generation system is showed in Figure 4.

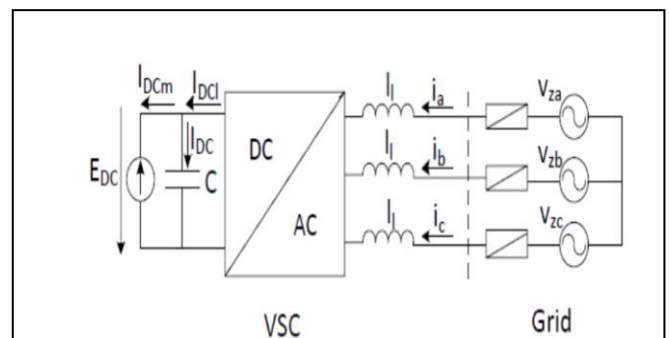


Figure 4. Simplified scheme of the renewable generation system

Photovoltaic system showed as a current source, connected to the VSC by means that of an electrical shunt capacitor. The connection between the photovoltaic modules and the DC side of the device referred as DC bus current. A shunt capacitor is introduced to make the voltage constant and thus making the power balance between the grid DC photovoltaic side and AC side. As observed, the renewable generation system during this case is modeled as a current source and the shunt capacitor.

4. BATTERY SYSTEM

Batteries are the electrochemical device that converts chemical energy into current (electrical energy). A battery system of constant DC voltage is assumed for the present

work. Therefore, the battery has been modeled as an easy controlled voltage source. The constant load is modeled as three resistances connected to the main grid. Therefore, the load solely consumes active power.

The storage system consist a battery. In this case, the battery system is connected to the DC facet of the device because of constant voltage supply.

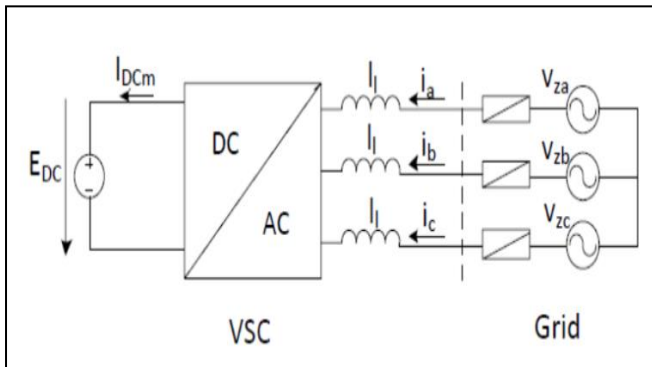


Figure 5. Simplified scheme of the storage battery system modeled as a voltage source

5. SYSTEM CONTROL

This section will explain the control methodologies applied to the various elements modeled in the upper section. The control of the photovoltaic system and its converters are primary. The control of the battery system and its converters are secondary.

- Photovoltaic System control

The control of the VSC on the PV side permits to control the power generated from the photovoltaic modules, this is the power that may be transferred to the VSC on the DC side and latterly injected to the grid.

As mentioned earlier, the performance of a photovoltaic cell depends on two variables factors: irradiance and temperature. The opposite factors referring the standard of the cell or the size of the photovoltaic system are fixed variables once getting installed. As seen in section, the IV curves of a cell changes with the sunshine intensity (G) and temperature (T). However, solely the modification of temperature changes the electrical open circuit voltage. Therefore, it is essential to create the photovoltaic system work to point of maximum power for every temperature that is the knee of the IV curve. The answer is to implement a MPPT algorithm, track the voltage from the IV curve that provide maximum power and having the voltage at maximum power the photovoltaic module will confirm automatically the current at maximum power.

Summarizing, the control of the VSC on the PV aspect is sketched in Figure 6, wherever the inputs to the PV

models are the irradiance (G), temperature (T) and voltage from the DC aspect and also the output is the current flowing through the cell ($-I_{DCM}$). The input to the MPPT block is the temperature (T) and its output is the voltage at maximum power (V_{mpp}) that is the required voltage for the DC aspect (E_{DC}^*).

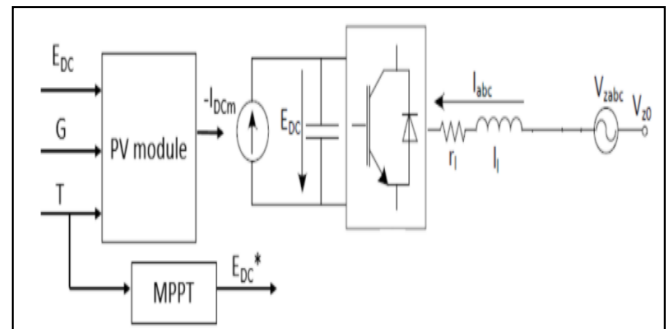


Figure 6. PV VSC converter control scheme

6. SIMULATION AND RESULTS

DC- DC converter was having input voltage of 274 V and output of 787.29 V with duty ratio of 0.65. The results will be seen within the graph below during which the input voltage is same as calculated however there was slight difference within the output voltage.

- Results of DC-DC Boost converter

The inductance current initially rose then stays stable for whole simulation period.

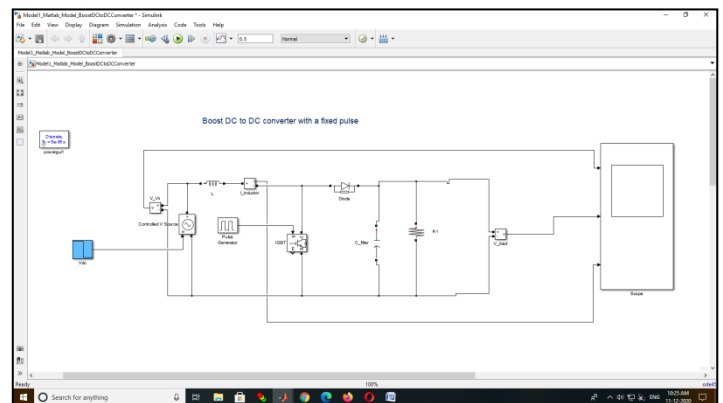


Figure 7. Simulation model of Boost Dc to Dc converter

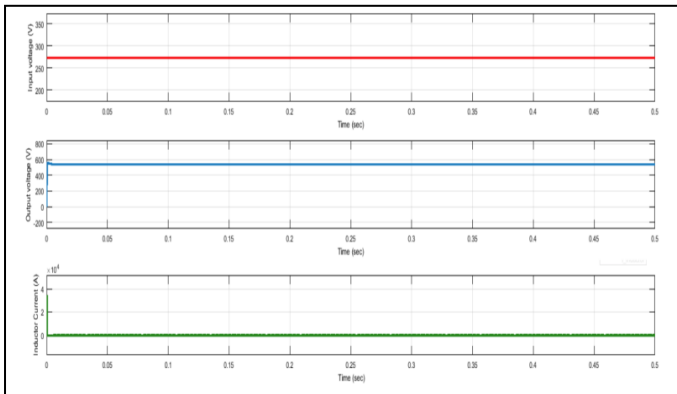


Figure 8. Scope response

Table 1 Boost converter specifications

Number of boost converters	Input voltage V	Power rating kW	Output voltage V	Duty ratio D
1	274	75	797.28	0.65

• Results of DC – AC device or Inverter

The inverter used should be rated that it should stand up to the output voltage of the boost converter and will be able to provide the desired power. Selecting an inverter rated at 25kw, then the no. of inverters required to method he generation of 75kW is given by

$$\begin{aligned}
 NI &= PV \text{ Generation} / \text{power of one inverter} \\
 &= 75 / 25 \\
 &= 3
 \end{aligned}$$

Hence three inverters are going to be needed to attach in parallel to produce the load of 75kW. Selecting a switching frequency of 4500 Hz, the frequency index modulation is given as

$$\begin{aligned}
 M_f &= f_s / f_e \\
 &= 4500 / 50 \\
 &= 90
 \end{aligned}$$

Table 2. Inverter specifications

Number of inverters	Input voltage (V)	Power rating (kW)	Output voltage (V)	Amplitude modulation index M_a	Frequency modulation index M_f
3	787.28	25	415	0.85	90

Inverter employed in the circuit has 787.28 V as DC input voltage and 415 V AC as an output voltage. Three inverters of 25kW each can offer the AC voltage. The amplitude modulation index is 0.85 and also the frequency modulation is 90. The output waveforms of the voltage and current are given below in figure 8. It is ascertained that the peak value of the current is 25 ampere and also the peak value of the output voltage is close to 525 V that are according the expected values per calculations. The voltage output is step waveform and may be created sinusoidal wave by the use of the filter if required.

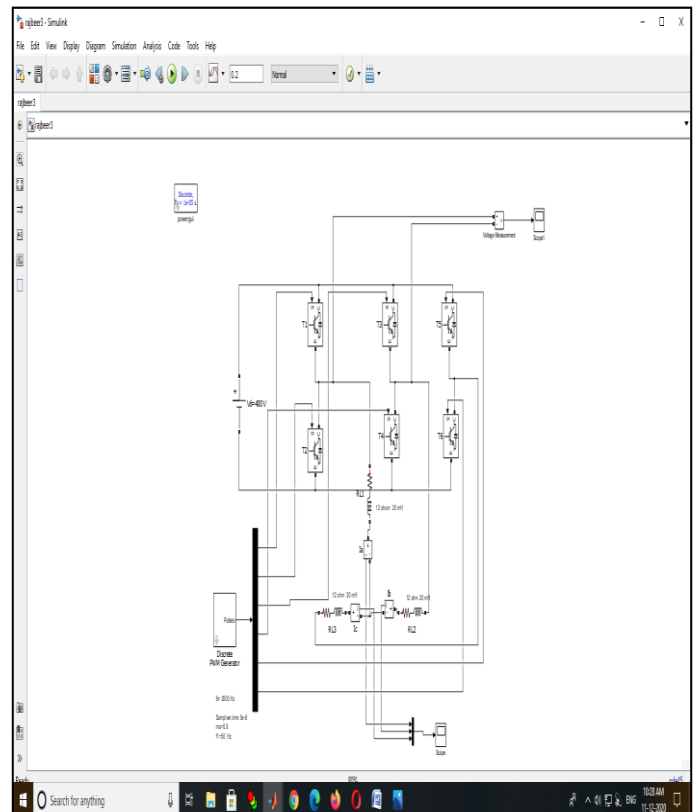


Figure 8. Simulation model of inverter circuit

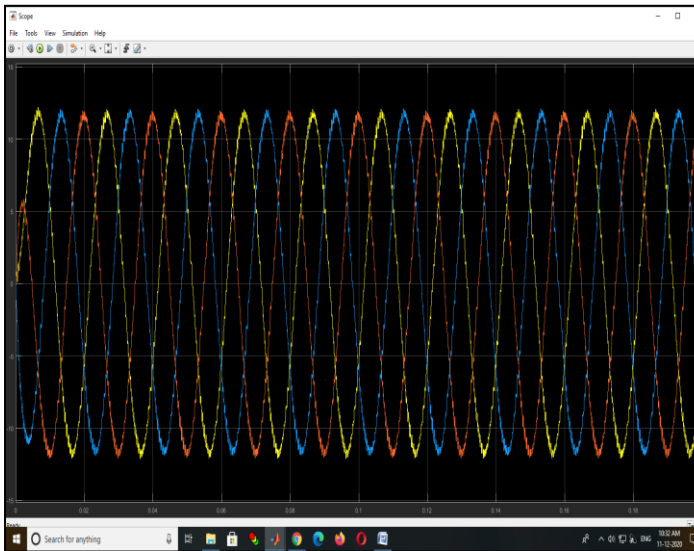


Figure 9. Scope response

Results of PV System Model

The detailed model of PV system connected to the grid is shown in figure 10. This model contains multiple components which are integrated to extract 75kW power which is supplied to the grid. Consider description of important parts with their role in the system. PV array is converting sun light into electrical energy. From the study of literature and mathematical calculations we have selected the size of this array. The output power is dependent upon the irradiance and temperature. Due to non-uniform behavior of these factors we need some circuitry to maintain the constant voltage. The role of boost converters comes here, using boost converter and by using PWM controllers we can set the duty cycle which maintains constant voltage at its output. Figure 11 shows PV scope explains the effect of irradiance and temperature on output power and how this change is compensated. Graph shows that with the decrease in irradiance the output current decreases significantly. However, the change in voltage is not that much significant. Also, the output power is dependent upon the value of temperature. In figure 11 the temperature is kept constant for that reason there is no change in output power. However, an increase in temperature decreases voltage significantly which reduces the power.

The value of voltage is constant in the presence of change of irradiance this is because of the controllers connected to the converters. For each change in current and voltage a reference signal is created and required PWM signal is produced to generate a gate pulse with the required duty cycle. There is difference in voltage between the mathematically calculated value and the one we get in simulations. This change is due to value of L_{min} , however this change is contributed by the current and hence overall power remains same i.e. 75 kW. Then, the output signal

received from the boost converter is added in the inverter, where the signal is modulated and filtered to remove ripples, as there is a requirement for output ripple in the signal for connecting it to the grid. Also, the relative change in the output load and the variable input we use battery backup and capacitor bank to store excess energy and use in the time of peak demand.

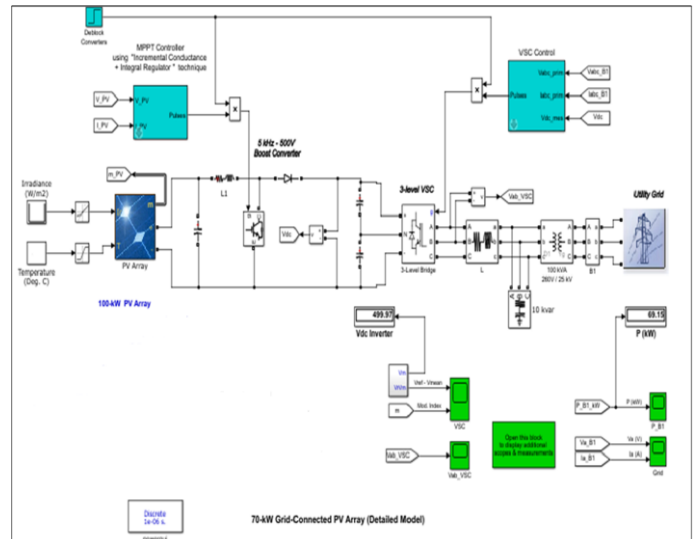


Figure 10. Solar PV Based Microgrid with battery energy storage

Table 5.3 PV System Parameters

Output Power	Modules per string	Strings per array	DC Inverter Voltage	M_a / M_f
75 kW	5	49	500	0.85/90

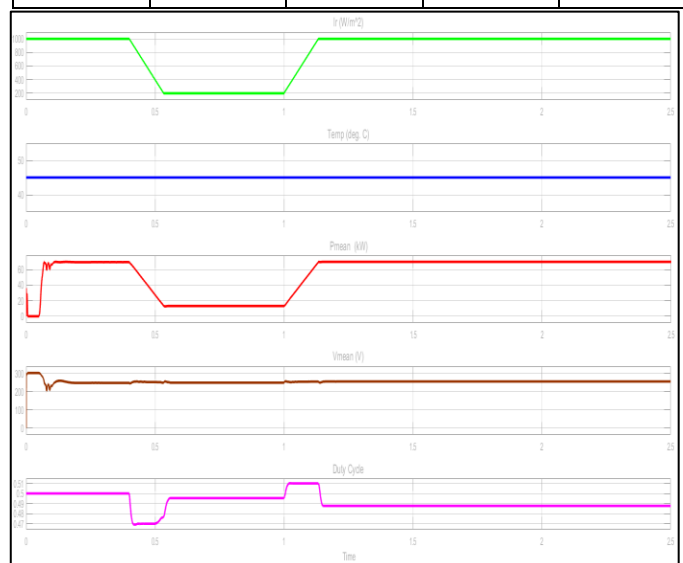


Figure 11. PV scope response

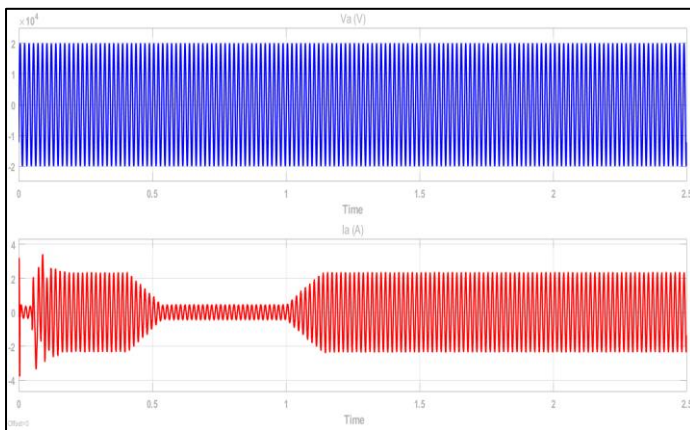


Figure 12. Va and Ia connected to grid

Conclusion:

In this paper, it has been evaluated that the use of PV based Microgrid system is the most viable alternative to existing conventional sources of energy production. The modern MPPT algorithms and high rated converters give incentive to tolerate high changes and high switching FETs. With a storage of super capacitor bank and battery storage system mitigates demand of load requiring high energy and power density.

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