Modeling and Simulation of MPPT Controlled Solar System Integrated with Grid

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Abstract: ***The world is becoming more and more dependent on renewable energy resources. Presently we have two major renewable energy resources including wind and solar. This project is an effort to make solar energy more efficient and controllable. The model is consists of solar-cell array, MPPT controller, dc-dc converter and grid interface inverter. The MPPT is a Power control strategy which helps to extract the maximum power. To obtain the output of photovoltaic power generation system at the maximum power output MPPT tracker control is an essential tool. The proposed model is having a 200-kW solar array connected to a 25-kV grid via a single 3-phase voltage source converter and two DC-DC boost converters. The "Perturb and Observe" technique is implemented to control the MPPT controller by means of a embeddable code in MATLAB Function block. The VSC inverter connected with grid transfers the energy drawn from the PV array to the grid by keeping common dc voltage constant. The simulation results show the performance and dynamic behavior of the MPPT controlled PV system.***

Keywords: Solar, MPPT, PV System, Perturb and Observe

1. Introduction

Due to the depletion of major industrial fuels including oil, gas, coal and others, the development of renewable energy sources is improving at a fast rate. The scarcity is the reason why renewable energy sources have become more important in today's world. There are other reasons also, include advantages like abundant availability in nature, eco-friendly and recyclable. We have various renewable energy sources like solar, wind, hydel and tidal. Out of all available renewable sources solar and wind energy are the world's rapidly growing energy resources. Energy conversion is done through wind and PV cells are having no emission of pollutants.

The demand for electricity is rapidly increasing every day, but the available base load plants are not able to match the demand. To bridge the gap between supply and demand during peak loads we can use these energy sources. This kind of small scale stand-alone power generating systems can also be used in remote areas where conventional power generation is impractical.

A photovoltaic power generation system model has been carried out in this model. The solar energy is abundantly available in nature which is used to power PV system in the model. A PV energy System is comprises of PV modules and maximum power point tracing systems. The PV cells are converting the incident light into electrical energy by solar energy harvesting means. The MPPT tracker system with Perturb & absorb algorithm is used, which extracts the maximum possible power from the PV modules. The DC-DC converters are used to boost the output voltage level and a DC-AC converter is used to obtain the 3-phase power from DC input.

The main objective of this paper is to implement a power system that is capable of giving a required performance from the purposed model. The step by step objectives are

- To study and PV cell model and PV array.
- To study the characteristic curves and effect of variation of environmental conditions like temperature and irradiation on them
- To trace the maximum power point of operation the PV panel irrespective of the changes in the environmental conditions

2. Photovoltaic Cell

A **solar cell**, or **photovoltaic cell**, is an electrical device which works on a physical and chemical phenomenon that converts the light energy directly into electricity by the photovoltaic effect, It is a form of photoelectric cell, defined as a device whose electrical characteristics such as voltage, current and resistance, vary when it is exposed to light. Photovoltaic modules are made up of solar cells known as solar panels.

Solar cell is basically made up of a p-n junction fabricated in a thin layer of semiconductor. The photovoltaic effect of solar cell converts the electromagnetic radiation of solar energy directly in to electricity and the photons of the semiconductor acquires energy greater than the band-gap energy on being exposed to the sunlight and create some electron-hole pairs. The numbers of electron-hole pairs thus generated are proportional to the incident irradiation. Photovoltaic cell is made up of semiconductor material such as silicon and germanium. Silicon is used because of its superior characteristics as compared to germanium. When photons strikes the surface of solar cell, the electrons and holes are generated and the covalent bond breaks inside the atom and in response electric field is generated by creating positive and negative terminals. Electric current starts flowing when these terminals are connected by any load.

The photovoltaic (PV) cell operation is designed to have three basic properties:

- The absorption of light energy and generating electron and hole pairs.

- The separation of charge-carriers of opposite kinds.
- The separation of those carriers to an external circuit.

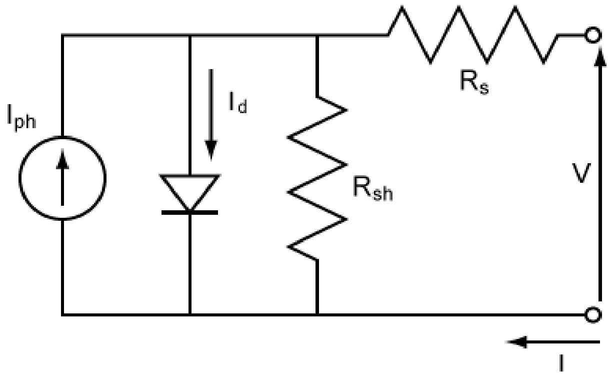

Figure 1: Solar Cell

Working Of PV Cell:
Working of PV cell is based on the Photoelectric effect according to which, when a photon particle hits a PV cell, after receiving a sufficient energy from sunlight the electrons get excited inside the semiconductor and moves to the conduction band from the valence band. This creates positive and negative terminal and with a potential difference across them. When a load is connected between them, the current starts flowing.
Thecharacteristic equation for a photovoltaic cell is given by

$$I_0 = (N_P * I_{ph}) - (N_p * I_{rs})\left(exp^{\left(\frac{q}{k}*T*A\right)}\right) * (V_o N_s - 1)$$
Eq- 2.1

Where
I_{ph} = $((I_{scr}+k_i*(T-T_r))*(s/100)$ Eq-2.2

$I_{rs} = I_{rr} * ((\frac{T}{T_r})^3) * e^{(q*\frac{Eg}{k*A})}*((\frac{1}{T_r}) - (\frac{1}{T})$ Eq- 2.3

$T_r = (T_{r1}-32) + 273$ Eq- 2.4

I_o & V_o : Cell output current and voltage;
I_{rs} : Cell reverse saturation current;
T : Cell temperature in Celsius;
k : Boltzmann's constant :1.38 * 10-23 J/K;
q : Electron charge: 1.6*10-19 C;
K_i : Short circuit current temperature coefficient at Iscr;
S : Solar radiation ;
I_{scr} : Short circuit current at 25 degree Celsius;
I_{ph} : Light-generated current;
E_g : Band gap for silicon;
T_r : Reference temperature;
R_{sh} : Shunt resistance;
R_s : Series resistance;

PV and IV characteristics of Solar cell
When a solar panel is operated under no load condition, the voltage measured is Voc and no current flows through the circuit. When it is operated under short circuit condition, the output voltage will be zero and short-circuit current ISC will flow in the circuit. Considering both the cases, power delivered by the solar panel is zero if any one component either voltage or current is zero. After connecting a load we need to consider the I-V curve of the panel and the I-V curve of the load to figure out how much power can be delivered to the load. The maximum power point (MPP) is the spot near the knee of the I-V curve, and the voltage and current at the MPP are designated as V_m and I_m. This maximum point is changing as the I-V curve is varying with the shading, isolation, and temperature for a particular load. We need to make solar panel to work at their maximum power conditions as solar power is relatively expensive.

For this purpose DC-DC converters are used so that the load resistance to the source resistance can be matched to draw the maximum power from the panel. These "smart" converters are often referred to as "tracking converters".

Solar arrays can provide a sufficient amount of electricity if its array performance is good, and to determine the performance of the array, following factors are to be considered;

1) Degradation factors
2) Characterization of solar cell electrical performance
3) Solar cell operating temperature and environmental conditions
4) Power output capability of an array

3. Maximum Power Point Tracking

Maximum Power Point Tracking, also known as MPPT is used to improve the efficiency of the solar panel. MPPT is an electronic system that operates the Photovoltaic (PV) modules to work close to their rating in a manner that allows the solar modules to produce all the power they are capable of. By adjusting source impedance equal to the load impedance as stated by maximum power point theorem, output power of any circuit can be maximized, so the MPPT algorithm is equivalent to the problem of impedance matching. In MPPT the duty cycle is calculated to obtain the maximum output voltage because power increases when output voltage increases. In this paper Perturb and Observe (P&O) and constant duty cycle techniques are used, because of the low cost and less hardware complexity requirements. MPPT is different from mechanical tracking system that physically moves the modules to make them directed more at the sun. MPPT is an electronic system that varies the electrical operating point of the modules so to deliver maximum available power from the modules.

Additional power obtained from the modules is then made available as increased battery charge current. Although MPPT can be used in combination with a mechanical tracking system, but the two systems are completely different.

A solar panels efficiency of converting irradiation into electrical energy is typically 30 to 40 percent only. MPPT is used to improve this efficiency to a higher level.

Maximum Power Transfer theorem states that the power output of a circuit is maximum when the source impedance of the circuit is equal to the load impedance. Hence our objective of tracking the maximum power point reduces to an impedance matching problem. In the source side a boost convertor is connected to a solar panel in order to increase the output voltage so that it can be used for different applications e.g. motor load. We can match the source impedance with that of the load impedance by changing the duty cycle of the boost converter appropriately.

Different MPPT techniques

To track the maximum power point there are different techniques used. Most popular ones are as follows;

1) Perturb and observe (hill climbing method)
2) Incremental Conductance method
3) Neural networks
4) Fuzzy logic
5) Fractional open circuit voltage
6) Fractional short circuit current

The three major approaches for maximizing power extraction in medium- scale and large-scale systems are:

- Sun tracking,
- Maximum power point (MPP) tracking
- Sun tracking and MPP tracking (Both).

MPP tracking is popular for the small-scale systems as it is very economical. The algorithms that are most commonly used are the perturbation and observation method, incremental conductance algorithm [1] and the dynamic approach method. Photovoltaic (PV) generation systems are promoted on a high scale by various governments and organisations. PV generation systems have two big problems mainly (1) the efficiency is very low, especially in low radiation states and (2) the amount of electric power generated by solar arrays is weather dependent i.e., irradiation. Therefore, a maximum power point tracking (MPPT) control method to achieve maximum power output at real time plays a very important role in PV generation systems. Till date several MPPT techniques have been proposed and few among those have been successfully implemented on hardware platform.

The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power ΔP is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If ΔP is negative, we are going against the direction of MPP and the sign of perturbation supplied has to be changed.

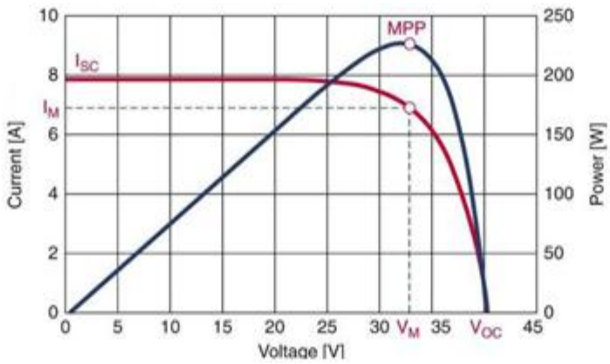

Figure 2: Solar panel characteristics showing MPP and operating points

Figure 2 shows the plot of module output power versus module voltage for a solar panel at a specific irradiation. MPP is marked as the Maximum Power Point, the theoretical maximum output which can be obtained from the PV panel. Therefore, if we want to move towards the MPP, it can be done by providing a positive perturbation to the voltage. On the other hand, point B is on the right hand side of the MPP. When we give a positive perturbation the value of ΔP becomes negative and thus it is imperative to change the direction of perturbation to achieve MPP.

4. Boost Converter

In this paper, the boost converter uses a MPPT system which automatically varies the duty cycle in order to generate the required voltage to obtain maximum power. This technique helps the converter to boosts DC voltage from 273.5 V to 500V.

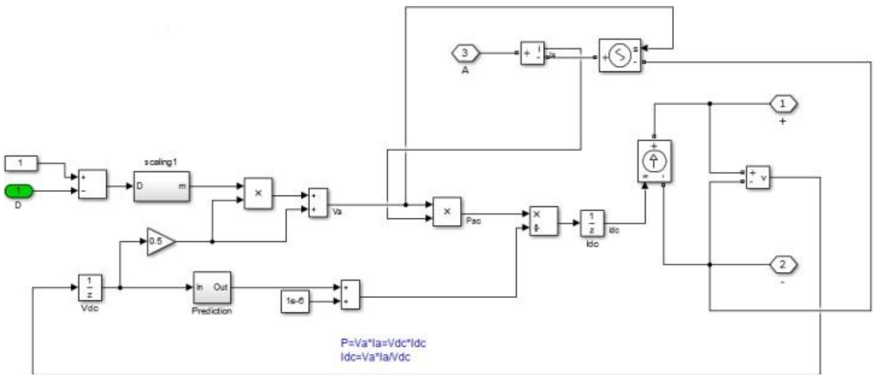

Figure 3: Simulation of Boost Converter

5. Inverter/VSC converter:

The purpose of three-level VSC is to regulate the DC bus voltage at 500 V keeping the power factor at unity.

The control system uses two control loops: an external control loop whose main purpose is to regulate the DC link voltage to +/- 250 V and another one is internal control loop whose main purpose is to regulate the Id and Iq grid currents. Id current reference is the DC voltage external controller output and Iq current reference is set to zero to maintain the power factor at unity. The voltage outputs of the current controller (Vd and Vq) are converted into three modulating signals Uref_abc used by the PWM three-level pulse generator.

The control system uses a sample time of 100 micro-seconds for voltage and current controllers and also for the PLL synchronization unit.

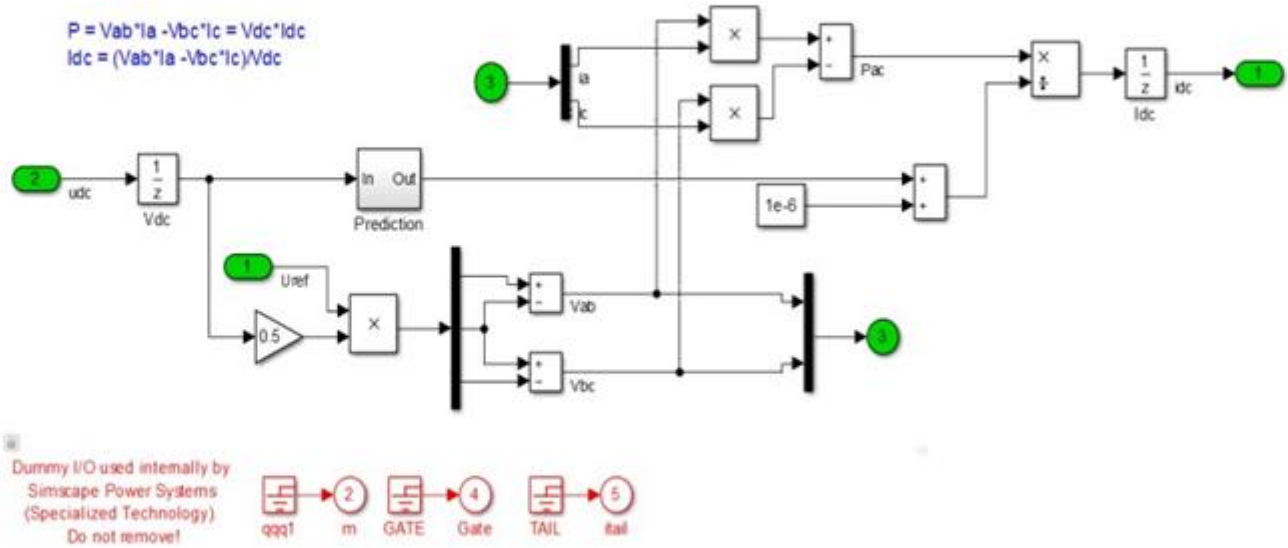

Figure 4: Simulation of VSC Converter

6. Simulation of Simulation of Solar Power Plant

The proposed model of a 200-kW solar array integrated with a 25-kV line grid via two DC-DC boost converters and a single 3-phase voltage source converter. A MATLAB function block is used that runs the code for MPPT control technique "Perturb and Observe". The proposed model contains:

- 2 Photo-Voltaic arrays delivering each a maximum of 100 kilo-Watt at 1000 sun irradiance.
- 2Boost converters increasing voltage from PV1 and PV2 voltages to 500 V DC. The two MPPT controllers use the "Perturb and Observe" technique.
- 1 Voltage source converter. which converts the 500V DC to 260 V AC at unity power factor.
- A capacitor bank rated 20-kvar for filtering harmonics produced by Voltage source converter.
- A 3-phase coupling transformer rated 200-kVA 260V/25kV.
- A 25-kV distribution feeder and 120 kV equivalent transmission systems forming the utility grid model.

In the proposed model the boost and Voltage source converters are represented by equivalent voltage sources generating the AC voltage averaged switching frequency as one cycle. Harmonics is not considered in this model, but the dynamics result from control system and power system interaction is kept. With this model we can use much larger time steps (50 micro-seconds) resulting in a much faster simulation.

In this model the two PV-array models contain an algebraic loop. Algebraic loop's main function is to get an iterative and accurate solution of the PV models when we are using large sample. These algebraic loops can be easily solved by Simulink.

7. Results of Simulation

Observe the performance of the two Perturb and Observe MPPTs under various irradiance changes. It can be seen that while keeping the irradiance constant, the MPPT controller tracks only the maximum power.

8. Conclusion and Future Work

A solar PV module is modelled and simulated with varying irradiation and temperature. A boost converter is designed and simulated. MPPT "P and O" algorithm is used to control the gate pulse of the high frequency switch off the boost converter.

A mathematical model has been presented of PV array and the program implemented in MATLAB function block to achieve the maximum power point using the MPPT technique. It has been demonstrated that the PV Array is able to deliver the maximum power to the load for the particular irradiance levels and the same is carried out with the variation in temperature.

It is a simple MPPT setup resulting in a highly efficient system has been modelled with a simple MPPT setup. It can be concluded that in the near future non-conventional energy sources will dominate the conventional sources of energy.
The greatest renewable energy source of all time is the solar energy obtained from sun's energy.

In future we can compare the same model with different control techniques and also can combine other hybrid system with this existing one like wind power, battery system and by using MATLAB it can be analyzed

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