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Converter Topology for PV System with Maximum Power Point Tracking

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Abstract: ***The rapid increase in the demand for electricity and recent change in global warming led to a need for a new source of energy. Mainly renewable energy sources like solar wind geothermal biomass etc plays a vital role in power generation and reduction of carbon footprint on global scale. Solar energy presents great applications in distributed power system. However it still presents a low energy conversion rate even at the maximum power point. The rest of the incident solar energy either becomes heat or reflected back to the atmosphere. The actual annual efficiency can be lower if the operating point is allowed to drift according to uncontrolled load and atmospheric conditions variations. . In order to maximize the energy conversion power electronics converter controlled MPPT algorithm like perturb and observation that consider the nonlinear output of PV can be used to obtain the maximum power from PV cell at all climatic conditions with the help of buck converter.***

Keywords: solar energy, MPPT, PV cell, buck converter, biomass, geothermal

1. Introduction

The rapid increase in the demand for electricity and recent change in global warming led to a need for a new source of energy. Mainly renewable energy sources, Renewable energy sources also called non-conventional type of energy are the sources which are continuously replenished by natural processes. Such as, solar energy, bio-energy - bio-fuels grown sustainably, wind energy and hydropower etc., are some of the examples of renewable energy sources. A renewable energy system convert the energy found in sunlight, falling-water, wind, sea-waves, geothermal heat, or biomass into a form, which we can use in the form of heat or electricity. The majority of the renewable energy comes either directly or indirectly from sun and wind and can never be fatigued, and therefore they are called renewable. Solar photovoltaic (PV) systems are used to utilize energy of sun in power generation during recent years. Photovoltaic's (PV) is a method of generating electrical power by converting solar irradiation into direct current electricity using semiconductors which exhibit Photovoltaic effect. Photovoltaic effect is the creation of voltage or current in a material upon exposure to light. Photovoltaic power generation employs solar panels composed of a number of solar cells made up of photovoltaic material. Photovoltaic materials include mono crystalline silicon, polycrystalline silicon, and amorphous silicon. When power required is more than delivered by a single cell, cells are electrically connected to form PV modules Again PV modules are grouped to form PV array for high power applications.[2][3]

The optimal operation of a PV system is important due to the low efficiency of solar panels. The output characteristic of a PV system is nonlinear and varies with ambient temperatures and solar irradiance levels. Therefore, a MPPT technique is required to obtain maximum power from a PV system. MPPT is used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and radiation conditions and of the load electrical characteristics with the use of DC-DC converter like buck converter, boost converter and buck-boost configurations.

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that "physically moves "the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power.[12]

Tracking the maximum power point (MPP) of a photovoltaic (PV) array is usually an essential part of a PV system. As such, many MPP tracking (MPPT) methods have been developed and implemented. The problem considered by MPPT techniques is to automatically find the voltage **VMPP** or current **IMPP** at which a PV array should operate to obtain the maximum power output **PMPP** under a given temperature and irradiance. [1]

Peak power is reached with the help of a DC-DC converter between the photovoltaic generator and the load by adjusting the duty cycle. The automatic tracking can be performed by utilizing various algorithms. Those algorithms are the heart of the MPPT controller. The algorithms are implemented in a microcontroller or a personal computer to implement maximum power tracking. The algorithm changes the duty cycle of the dc/dc converter to maximize the power output of the module and make it operate at the peak power point of the module. Algorithms that can be used are of the following types;

- Perturbation and Observation,
- Incremental Conductance
- Constant voltage algorithm

The problem considered by MPPT techniques is to automatically find the voltage VMPP or current IMPP at which a PV array should operate to obtain the maximum power output PMPP under a given temperature and irradiance. It is noted that under partial shading conditions, in some cases it is possible to have multiple local maxima, but overall there is still only one true MPP. Most techniques respond to changes in both irradiance and temperature, but some are specifically more useful if temperature is approximately constant.

2. Mathematical Modelling Of PV Cell

The PV receives energy from sun and converts the sun light into DC power. The simplified equivalent circuit model is as shown in Figure.1.

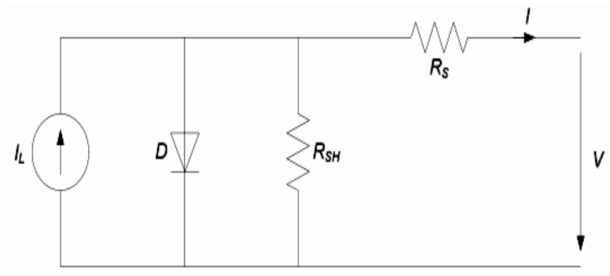

Figure 1: Simplified – equivalent Circuit of Photovoltaic Cell

The voltage-current characteristic equation of a solar cell is given as [9]

$$I = I_{PH} - I_S [\exp (q(V + IR_S) / kT_C A) - 1] - (V + IR_S) / R_{SH}$$

Where I_{PH} is a light-generated current or photocurrent, IS is the cell saturation of dark current, q (= 1.6 ×10−19C) is an electron charge, k (= 1.38×10−23J/K) is a Boltzmann's constant, TC is the cell's working temperature, A is an ideal factor, R_{SH} is a shunt resistance, and R_S is a series resistance. The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as;

$$I_{PH} = [I_{SC} + K_I (T_C - T_{Ref})]N$$

Where ISC is the cell's short-circuit current at a 25°C and 1kW/m2, KI is the cell's short-circuit current temperature coefficient, TRef is the cell's reference temperature, and N is the solar insolation in kW/m2. On the other hand, the cell's saturation current varies with the cell temperature, which is described as;

$$I_S = I_{RS} (T_C / T_{Ref})^3 \exp[qE_G (1/T_{Ref} - 1/T_C)/ kA]$$

Where IRS is the cell's reverse saturation current at a reference temperature and a solar radiation EG is the bang-gap energy of the semiconductor used in the cell. [9]

3. Block Diagram of Proposed Model

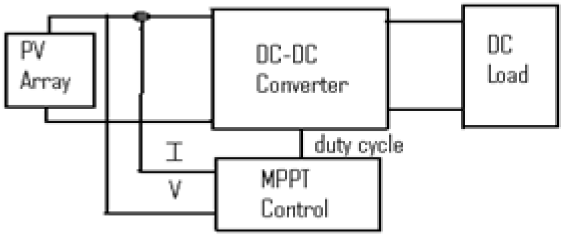

Figure 2: Block diagram of proposed model

The Figure 2 shows PV system block diagram with MPPT Technique. It consists of PV array, Boost converter, MPPT block, and finally load. Combination of Series and parallel solar cells constitute PV array. Series connection of solar cells boost up the array voltage and parallel connection increases the current. In order to change the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required. Buck converter is used to obtain more practical uses from solar panel. The input of buck converter is connected to PV array and output is connected to load. MPPT block receives V_{PV} and I_{PV} signals from PV array. The output of MPPT block is series of pulses. These pulses are given to buck converter. Converter works based on these pulses to make the PV system operate at Maximum power point (MPP) [4].

The heart of the model is MPPT block which helps in finding the maximum operating point of the solar panel. This can be done by using the MPPT algorithm. Which in turn gives the gating pulses to the buck converter which maintains the operating voltage at the maximum point irrespective of solar irradiance

4. Perturb & Observe MPPT Algorithm

The efficiency of solar cell is very low. In order to increase the efficiency methods should be undertaken to match source and load properly. One such method is the MPPT. MPPT technique used to obtain the maximum possible power from a varying source. In PV systems V-I characteristics is non linear, thereby making it difficult to be used to power a certain load. This is done by utilizing boost converter whose duty cycle is varied by using MPPT algorithm.

A perturb and observation (P&O) method is the most frequently used algorithm to track the maximum power due to its simple structure and high reliability[7]. Which moves the operating point toward the maximum power point periodically increasing or decreasing the PV array voltage by comparing power quantities between in the present and past.[8]

If the power increased, the perturbation is continuous in the same direction in the next perturbation cycle; otherwise the perturbation direction is reversed. This way, the operating point of the system gradually moves towards the MPP and oscillates around it in steady-state conditions. This means the array terminal voltage is perturbed for every MPPT cycle.[6]

Table 1: summary of perturb and observation algorithm

Perturbation	Change in Power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

The logic of this algorithm and the flowchart are explained in Figure 3. The operating voltage of the PV system is perturbed by a small increment of ΔV, and this resulting change inΔP. If ΔP is positive, the perturbation of the operating voltage needs to be in the same direction of the increment. On the contrary, if ΔP is negative, the obtained system operating point moves away from the MPPT and the operating voltage needs to move in the opposite direction of the increment.[5]

The variations of the output voltage & power before and after changes are then observed and compared to the reference for increasing or decreasing the load in the next step. The advantage of the perturb & observation method are simple structure easy implementation and less required parameter. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs around the maximum power at MPP.

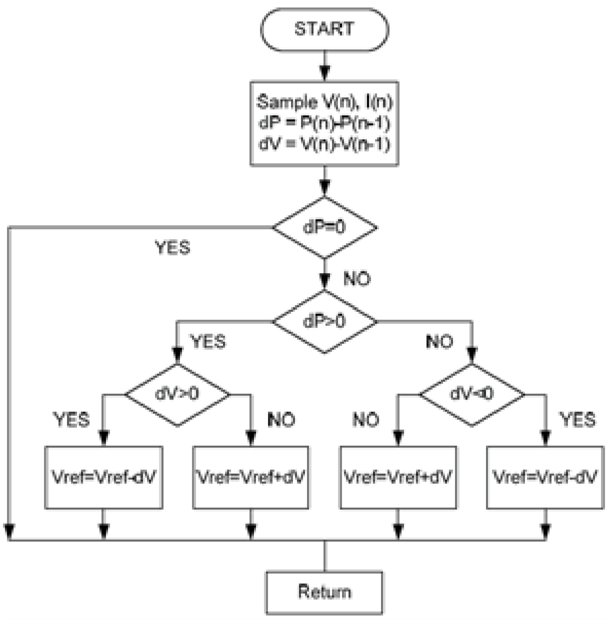

Figure 3: flow chart for perturb & observe method

5. Simulation Model in PSIM

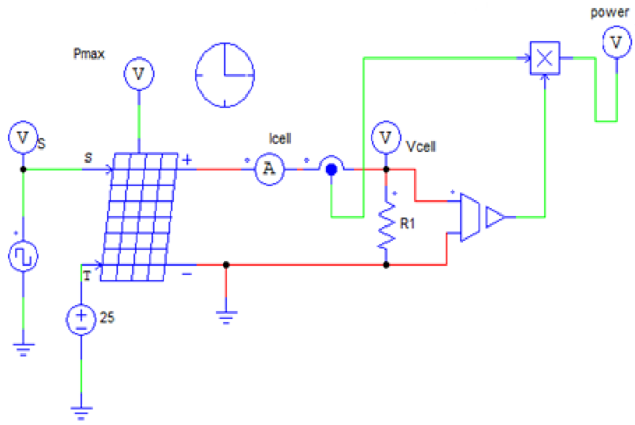

Figure 4: solar panel without MPPT block

Simulation of solar panel without MPPT is as shown in the figure 4. It consists of the solar panel, ammeter, voltmeter, resistance, current sensor and voltage sensor as shown in the figure. Solar irradiance is given to the solar panel with the help of square wave signal block. This block is connected to the input terminal S of solar panel. Similarly temperature is given to the solar panel with the help of voltage source block. This block is connected to the input terminal T of the solar panel. Standard temperature of 25 degree Celsius is maintained for this simulation block. Irradiance can be varied from 500 w/m^2 to 1000 w/m^2. Simulation control block is added to control the simulation time. Current sensor is connected in series with resistance which acts as a load to sense the current in the circuit. Similarly voltage sensor is connected across the resistance or load to measure the voltage across the circuit.

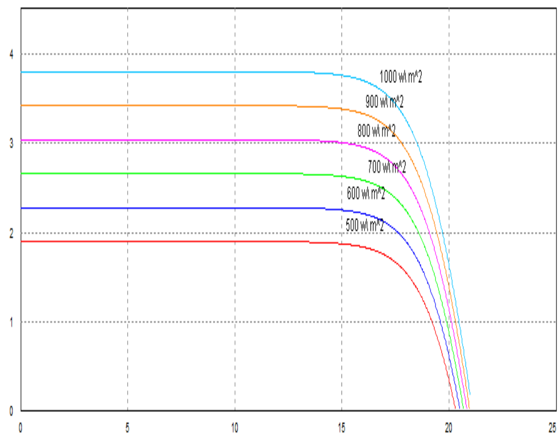

Figure 5: Icell versus Vcell characteristics curves wrt different values of irradiance

Characteristics curves of solar panel ie I_{cell} versus V_{cell} characteristics to solar irradiance is as shown in figure 5 . Power versus V_{cell} and with respect to solar irradiance is shown in fig 6 . The output power of solar panel of solar panel without MPPT block with respect to solar irradiance level is as shown in the fig 7. It is clear from the figure that the output power of the solar panel varies with the irradiance. Solar power is high at high value of solar irradiance & it starts decreasing as the solar irradiance value decreases.

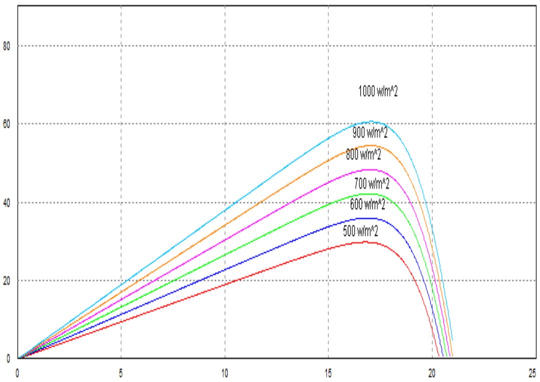

Figure 6: power versus Vcell characteristics curves wrt different values of irradiance

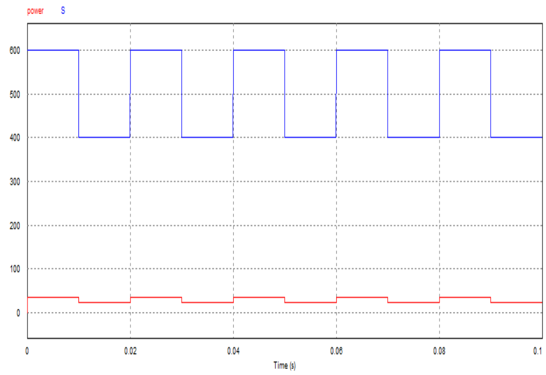

Figure 7: output power of solar panel wrt irradiance without MPPT block

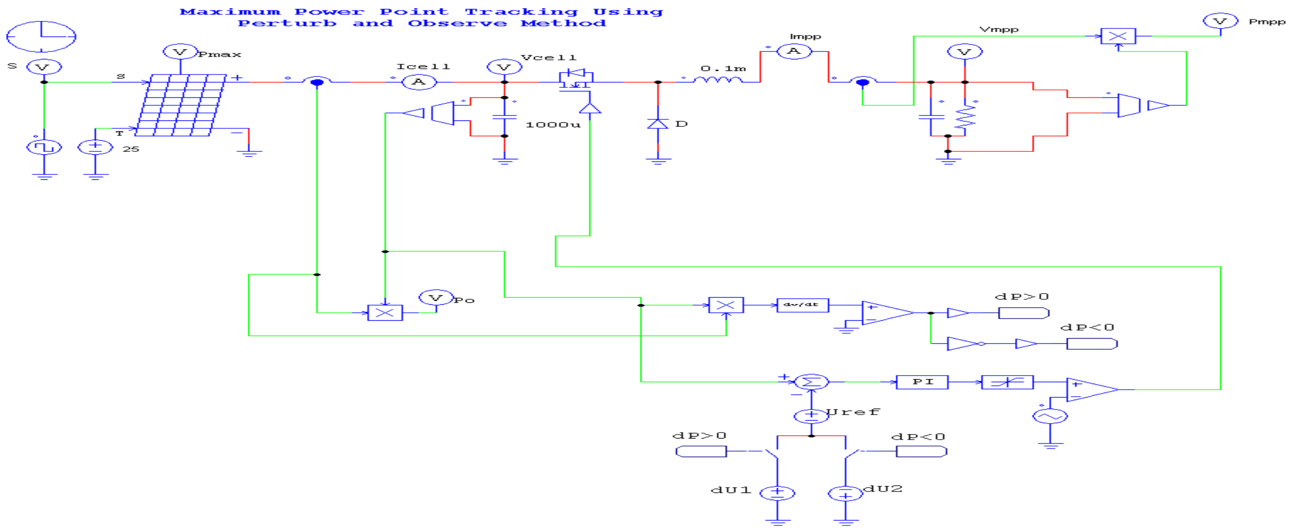

Figure 8: simulation circuit of solar panel with MPPT block

Simulation of solar panel with MPPT block is as shown in figure 8. It consists of solar panel block, buck converter circuit and MPPT block. Solar irradiance is given to the solar panel with the help of square wave signal block. This block is connected to the input terminal S of solar panel. Similarly temperature is given to the solar panel with the help of voltage source block. This block is connected to the input terminal T of the solar panel. Standard temperature of 25 degree Celsius is maintained for this simulation block. Irradiance can be varied from 500 w/m^2 to 1000 w/m^2. Simulation control block is added to control the simulation time. Current sensor is connected to measure in series with the solar panel to measure the current in the panel. The output of this is connected to current terminal of MPPT block. Similarly voltage sensor is connected across the solar panel to measure the voltage across the solar panel. The output of sensor is connected to voltage terminal of MPPT block. The buck converter is connected between the solar panel and the load. The output of the MPPT block controls the switching cycle of the MOSFET used in buck converter which acts as a switch.

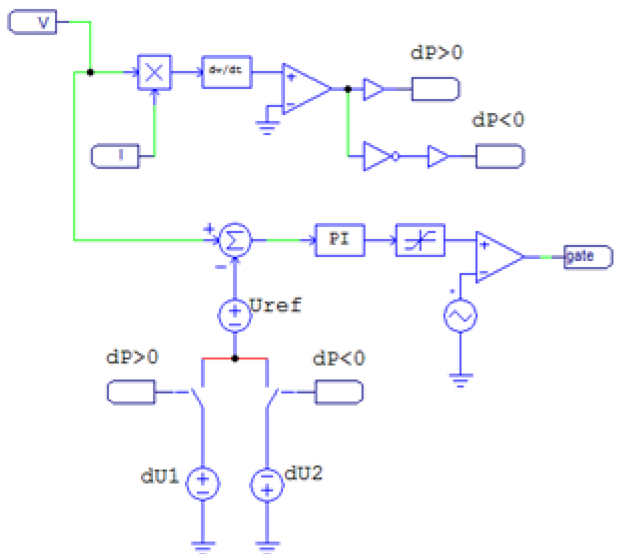

Figure 9: perturb and observation simulation block

The Perturb and Observation simulation block diagram is as shown in figure 9. It consists of comparator, proportional integrator and limiter, not gate, reference voltage block, differentiates. Initially the voltage and current measured by the voltage sensor and the current sensor are used as a input to the perturb & observe block. Multiplier block is used for multiplication purpose and then pass it to integrator block to check dv/dt. Then output of this is checked whether the change in power is greater than zero or not. Reference voltage is set at 16v. if dP/dV is greater than zero then reference voltage is equal to V_{ref} – dv. Otherwise reference voltage equal to V_{ref} +dv. Later it is compared with triangular wave signal. If output of the comparator is high then it sends the gating signal to turn ON the MOSFET. Similarly when output of the comparator is low it sends the gating signal to turn OFF the MOSFET. Which acts as a switch in buck converter helps in charging and discharging of inductor.

6. Simulation Results

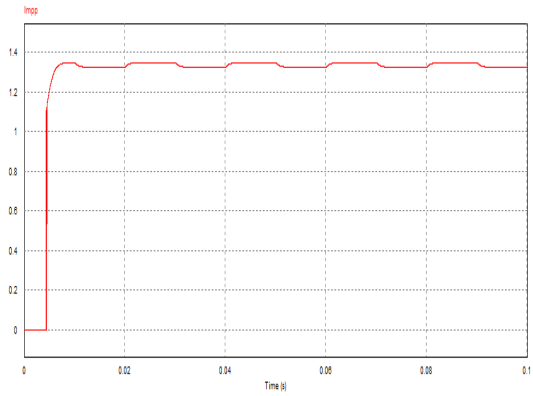

Figure 10: maximum current versus time

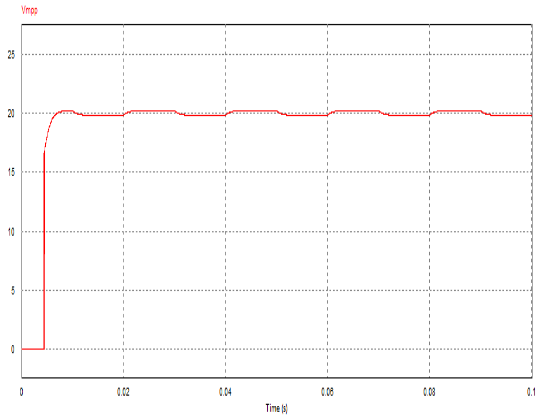

Figure 11: maximum voltage versus time

Maximum current versus time is as shown in the figure 10. Here initially current is zero as the switch is closed the inductor is in charging mode. As soon as switch opens the current appears across the load & there is a sudden increase in the current value. As the solar irradiance varies the variation in the current is very less.

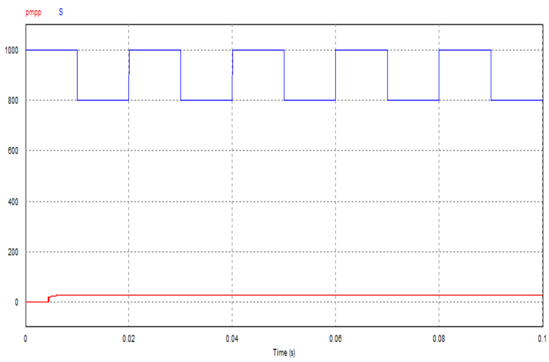

Figure 12: maximum power, irradiance versus time

The output power versus time with respect to irradiance is as shown in figure 12. It is clear from waveform that even though solar irradiance varies output remains constant. This is because of buck converter and perturbs and observe MPPT algorithm.

7. Conclusion

Photovoltaic cell simulation model is established in this paper, and output characteristics of photovoltaic array is studied and analyzed. The maximum power point tracking techniques are used to deliver maximum possible power from the solar array. Mainly perturb and observation MPPT algorithm is used to obtain the maximum power point of solar array. Buck converter is used to obtain this maximum power point which helps in step down the array voltage to the maximum operating point voltage. So by using MPPT algorithm and buck converter solar array is operated at maximum power point irrespective of solar irradiance. Further we can also design the inverter circuit which converts the DC power into AC power. And this can be connected to grid with the help of inverter.

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