Algorithm to harvest maximum solar energy for improved performance and efficiency of solar PV plants

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Abstract: Jawaharlal Nehru National Solar Mission has targeted 20,000 MW of grid connected solar power by 2022. Solar energy is available abundantly and solar PV technology can be used to generate electricity. Currently, this technology is very expensive and hence its optimum utilization is necessary. Maximum Power Point Tracking (MPPT) helps in harvesting maximum solar energy and plays an important role for optimum utilization of Solar PV technology.

MPPT is an algorithm which tries to balance the load resistance with the Solar panel resistance such that there is maximum flow of power from Solar panels to the load according to the maximum power transfer theorem.

Output of solar PV panel mainly depends on various factors like solar irradiation, temperature of PV panel and load conditions which does not remain constant throughout the day. Moreover, the PV cells are made up of non-linear diode. All these parameters affect the internal resistance of the PV panels and hence an impedance matching circuitry is needed between PV panels and load. This impedance matching circuit is termed as DC to DC converter. The duty cycle of the switch used in DC to DC converter is to be varied in a manner so as to match the input resistance of PV with that of the load so as to enable maximum power flow from solar PV to the load and hence achieving maximum efficiency of the system. The logic for controlling the triggering pulse of the switch is done by MPPT algorithm.

There are numerous algorithms for MPPT like Perturb and Observe (P&O), Incremental Conductance (IC), fuzzy logic control, fractional method, etc. P&O method is the widely used method and cost effective method for MPPT. A hardware prototype for DC to DC converter for solar PV system was designed and developed at ERDA. Programming for MPPT algorithm was done in DSC 28335 controller. Hardware results are presented.

This paper is divided into sections comprising of comprehensive explanation of Perturb and Observe method for MPPT, basics of DC to DC converter, simulation results of MPPT algorithm for boost converter and hardware results of the developed prototype.

1.0 INTRODUCTION:

Solar inverter also called as Power Conditioner Unit (PCU) act as interfacing media between PV panels and utility grid or directly to load. The basic structure of PCU is shown in figure 1. PCU basically consists of DC to DC converter and DC to AC converter as power electronic interface between PV panels and utility grid / load.

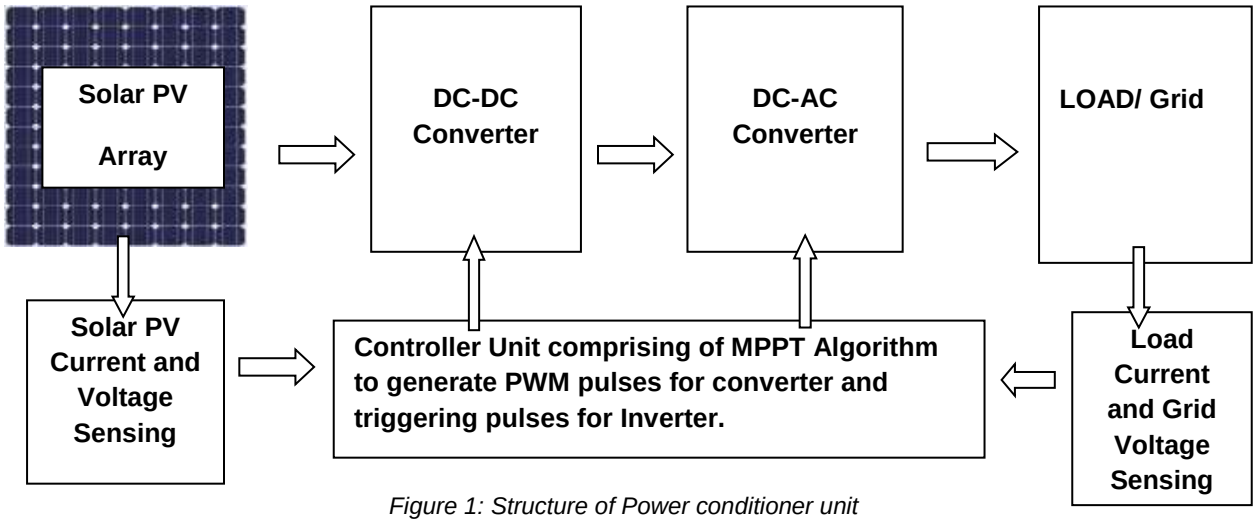

Figure 1: Structure of Power conditioner unit

PV cell has non-linear voltage current characteristics. The power delivered by the PV panel increases, to a point, as the current drawn from PV increases. The Maximum power point (MPP) is at the knee of the power voltage curve of PV panel. Any additional current drawn from the PV panel beyond this point would result in rapid fall in the solar PV voltage, thus reducing the PV panel output power.

PV panel is the most expensive component in solar PV system and its optimum utilization is critical. This calls for importance of identifying the particular point on the voltage current characteristic of PV panel at every instant so as to enable PV panel to deliver maximum power. This point is called Maximum power point (MPP). MPP is the point on the voltage – current characteristic of the PV panel where the PV panel is most efficient in converting the solar energy into electrical energy. Moreover, the voltage – current characteristic of the PV panel varies with solar radiation, ambient temperature and solar cell temperature which in turn varies the power delivered by PV panel. Thus MPP is not a fixed point and it actually moves throughout the day with changing atmospheric conditions.

A dc-dc (step up/ step down) converter serves the purpose of transferring maximum power from the solar PV module to the load. A dc-dc converter acts as an interface between the load and the PV module. By changing the duty cycle of the switch of the dc-dc converter, the load impedance as seen by the PV panel is varied and matched at the point of the peak power with the source so as to transfer the maximum power.

Many MPPT algorithm are there to obtain the maximum power point of PV cell as listed below [5]:

- Perturb and observation method
- Incremental conduction method
- Fractional open circuit voltage method
- Fractional short circuit current method
- Fuzzy logic method

In this paper DC to DC converter using Perturb and observe (PO) algorithm has been designed, simulated and hardware results based on simulation are presented. Programming of the algorithm has been developed in DSC 28335.

2.0 SIMULATION

2.1 PV panel modeling

A solar cell basically is a p-n semiconductor junction. When exposed to light, a dc current is generated. The generated current varies with the solar irradiance and temperature. The standard equivalent of the PV cell is shown in figure 2. Non-linear I-V characteristic of a solar PV panel is shown in figure 3 [1]. The output of solar PV panels mainly depends on solar irradiation, temperature of panel and the load conditions. The basic equation that describes the I-V characteristics [2] of the PV model is given by equation 3.

$I_D = I_O[\exp \frac{q(V+R_S I)}{KT} -1]$ ----------equation 1

$I = I_L - I_D - I_{Sh}$----------equation 2

$I = I_L - I_O[\exp \frac{q(V+R_S I)}{KT} -1] - \left(\frac{V+IR_S}{R_{Sh}}\right)$ ------equation 3

where,

I = Solar cell current (A)

I_L = Light generated current (A)

I_O = Diode saturation current (A)

I_D = Current through Diode (A)

q = Electron charge (1.6×10-19 C)

K = Boltzman constant (1.38×10-23 J/K)

T = Cell temperature in Kelvin (K)

V = solar cell output voltage (V)

R_S = Solar cell series resistance (Ω)

R_{Sh} = Solar cell shunt resistance (Ω)

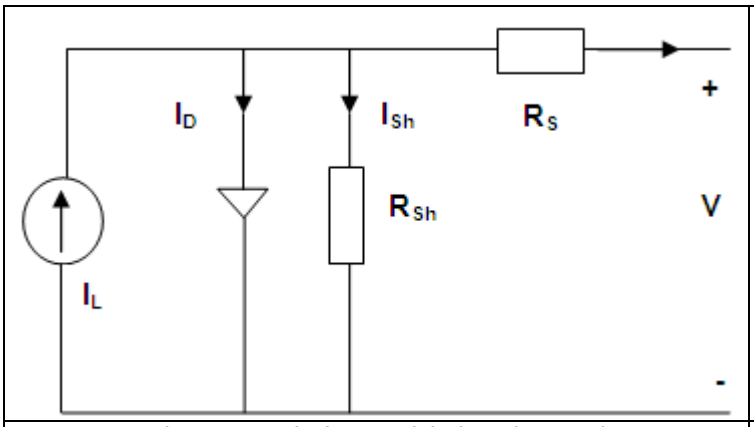

Figure 2: Equivalent model of a solar panel

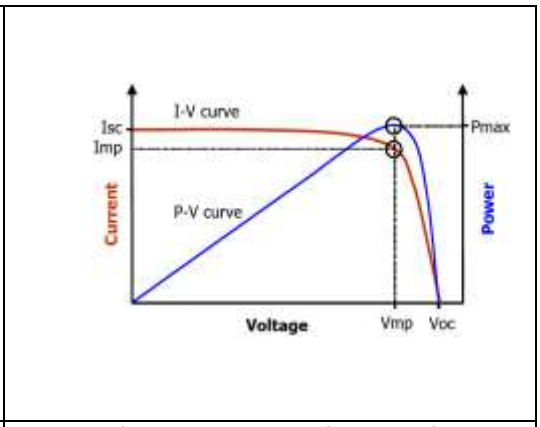

Figure 3: I-V curve of PV Panel

The PV cell is modelled in Matlab Simulink using the equation 3 and is shown in figure 4.

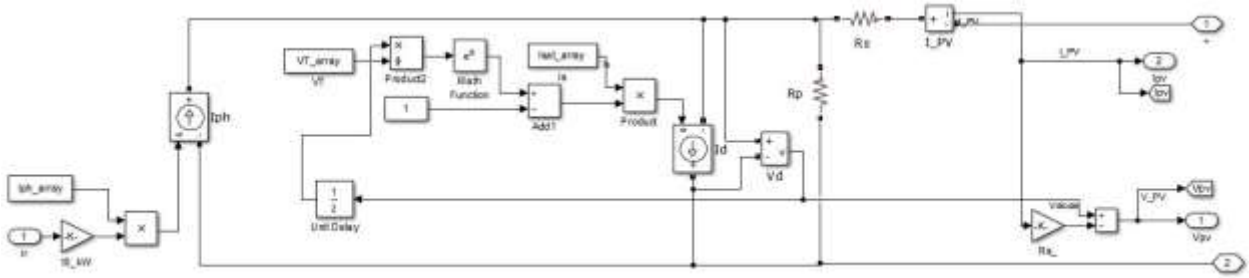

Figure 4: Matlab Simulink model of solar PV Module

2.2 MPPT method analysis

If a load is directly connected to a PV panel at maximum solar irradiation, without boosting its voltage and calculating its Maximum Power point, it will not operate at its maximum power point and hence will be unable to fetch maximum power needed by load even if it is capable at maximum solar insolation. Therefore to make PV panels operate at its maximum power point at given load and solar insolation, MPPT algorithm along with DC-DC Boost converter is essential [7].

MPPT stands for **M**aximum **P**ower **P**oint **T**racking**.** As the PV Panel's characteristic is non linear, it needs an algorithm to track its optimum operating point at which it will deliver maximum current and voltage in accordance to the load. There are numerous methods to track MPP like Perturb and Observe, Incremental Conductance, Fuzzy logic control, fractional methods etc [5]. In this paper, PO method is selected for simulation and hardware.

Perturb and Observe Method

P&O method is one of the most simple and cost effective method for implementation as it only requires sensing of the PV panel parameters. This algorithm is responsible for matching the impedance of the PV panel to that of the load in order to transfer maximum power. This impedance matching is given by the equation 4:

$R_{in} = (1\text{-}D)^2 R_{out}$----------equation 4

where, R_{in} is the input resistance of the solar PV, R_{out} is the load resistance and D is the duty cycle.

In PO method, PV panel's voltage and current are sensed continuously and power is computed. Based on the past P(k-1) and present P(k) values of power, reference voltage is changed by incrementing or decrementing the duty cycle. The Duty cycle is assigned an initial value and the step size of duty cycle is a constant value. When the operating voltage is incremented and power also gets incremented, then the operating point is on the left side of the MPP and it needs to be perturbed in the same direction. If the reference voltage is increased and the power decreases, then it implies that the operating point is on the right side of the MPP of the curve and the direction need to be changed [6]. The flowchart of the Perturb and Observe method to change the direction of increment and decrement of reference voltage by varying the duty cycle is shown in figure 5.

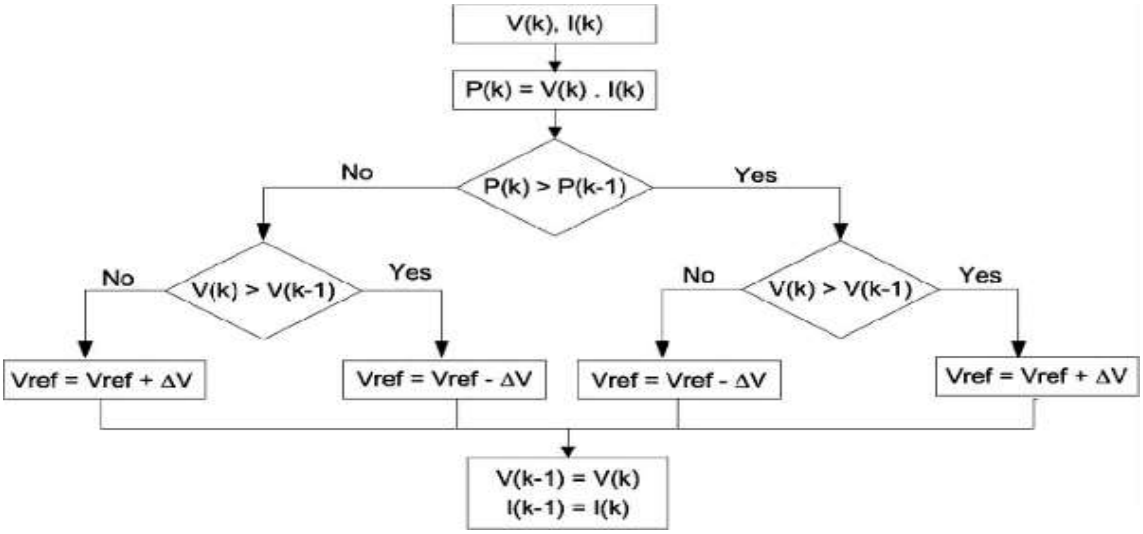

Figure5: Flowchart of Perturb and Observe

2.3 Operation of DC to DC Boost converter

The dc-dc boost converter is a switched mode converter that is capable of producing a DC output voltage greater in magnitude than the input voltage. Boost converter consists of an IGBT (which acts as a switch) and the gating pulses given to the gate of IGBT according to the calculated Duty cycle [3]. The two states of the switch are depicted in figure 6 .

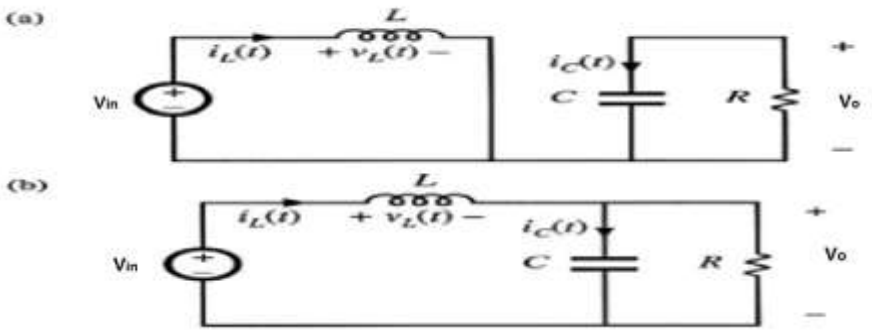

Figure6: (a) Switch in ON state (b)Switch in off state

Operation for state a: When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive [4].

Operation for state b: When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D [4].

2.4 Simulation results

The simulation of DC-DC Converter along with MPPT (P&O) was done in MATLAB Simulink for 250 W PV system and is as shown in figure7. The system was simulated for varying irradiance from 1000W/m^2 to 400 W/m^2.Switching frequency of the controller circuit is kept as 2.5 KHz with minimum step size as 0.0001.

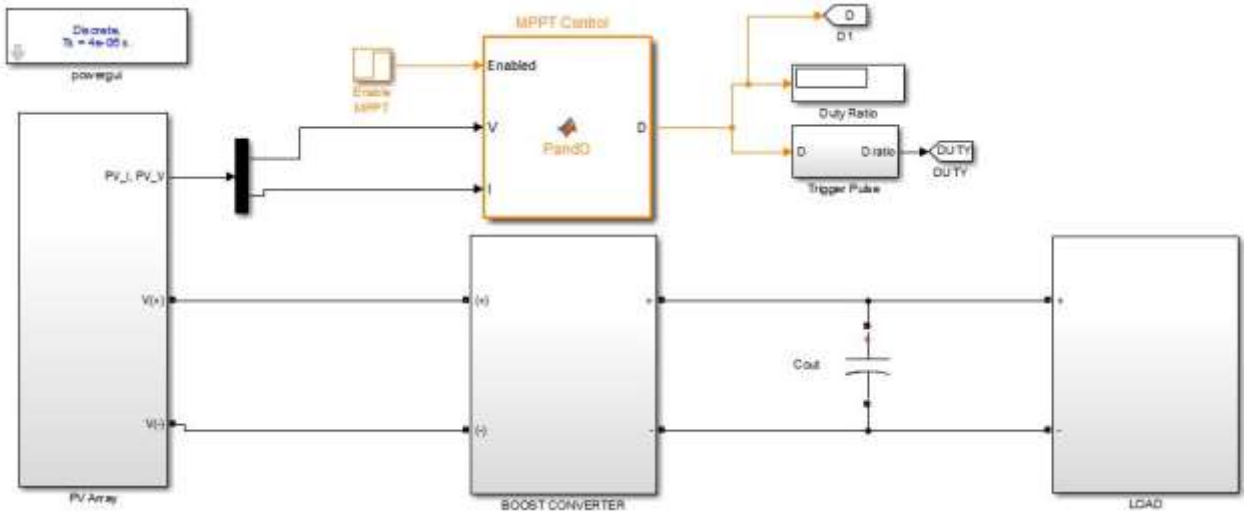

Figure7: Matlab Simulink model of DC-DC converter with MPPT (PO)

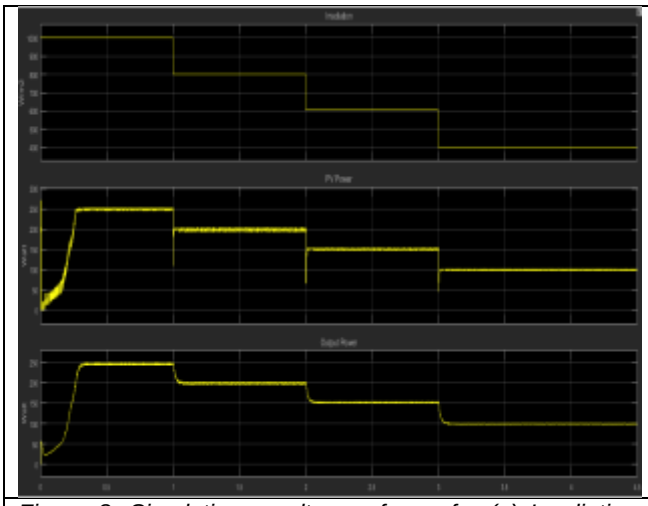

Figure 8: Simulation result waveforms for (a) Irradiation (b) PV Power (c) Output Power

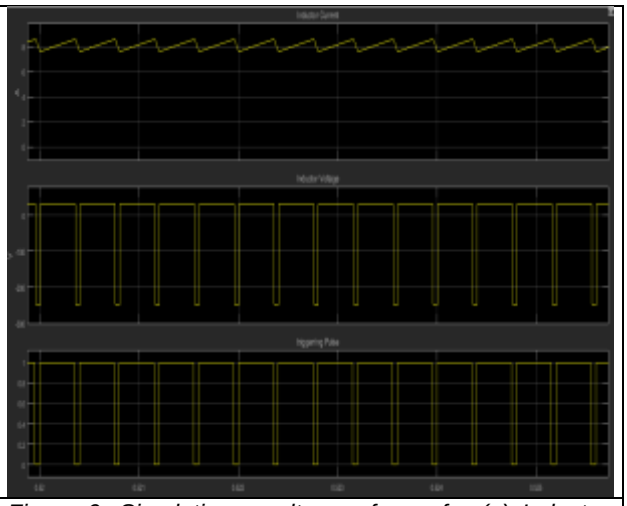

Figure 9: Simulation result waveforms for (a) Inductor current (b) Voltage across inductor (c) Triggering pulses

Figure 8 displays the change in power from PV and change in output power with the change in irradiation from 1000 W/m^2 to 400 W/m^{2}in steps of 200 W/m^{2}at every 1 second. The maximum power at different irradiation is fetched by the PO algorithm and is delivered to the load. Figure 9 displays the inductor current and voltage across inductor and triggering pulses at 1000 W/m^2.

3. HARDWARE RESULTS

Based on simulation values, hardware model of the dc-dc boost converter was developed at ERDA, Vadodara and programming for the logic is done in DSC 28335 controller. Figure10 shows the waveforms of voltage across inductor and current through the inductor.

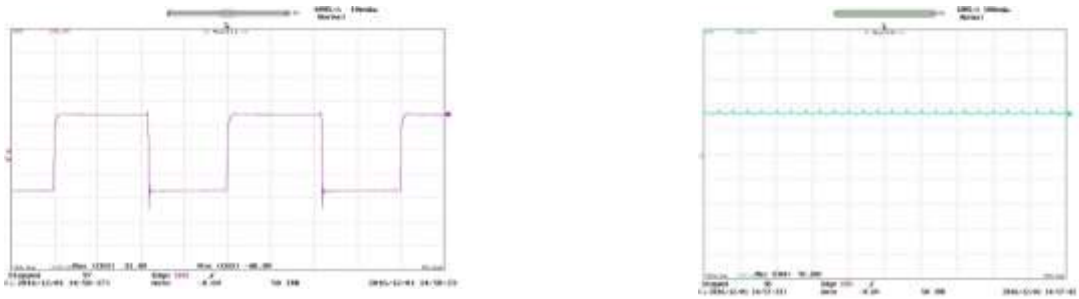

Figure 10: hardware result waveform for a) voltage across inductor b) current through inductor

4. RESULTS AND DISCUSSION

The efficiency of solar PV panel can be increased by using the MPPT techniques. Perturb and observe method of MPPT is the simplest and inexpensive method among all the other available methods. In this method, the MPP is tracked by comparing power and voltage at a particular instant and its previous instant. For the simulation of MPPT algorithm Matlab Simulink software is used. Hardware model is prepared based on simulation design and the programming is done in DSC 28335 controller.

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