An investigation of photovoltaic system with maximum power point tracking method

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Abstract : ***Nowadays, renewable energy resources play an important role in replacing conventional fossil fuel energy resources. Photovoltaic energy is one of the very promising renewable energy resources which grew rapidly in the past few years. The variation of the operating conditions of the Photovoltaic cell array has one major problem Due to this variation, the voltage at which maximum power can be obtained, is also alter. Solar photovoltaic (PV) systems are distributed energy sources that are an environmentally friendly and renewable source of energy. The objective of this paper is to study and analyze PV systems. In this paper, a PV model is used to simulate PV arrays behavior, and then a Maximum Power Point tracking method using variable step size Perturb and observe (P & O) is proposed in order to control the non inverted buck boost DC-DC converter. Each subsystem is modeled and simulated in a Matlab/Simulink environment. Simulation results shows that the proposed variable step size Perturb and observe (P & O) maximum power point tracking method with non inverted buck boost DC-DC converter gives faster response than the conventional perturb and observe method under rapid variations of operating conditions.***

IndexTerms - PV technology, MPPT, DC-DC converters, Perturb and observe; Variable step-size.

I. INTRODUCTION

The majority of the energy generated globally utilizes fossil fuels which involves the emission of hazardous green house gases like carbon dioxide. Further fossil fuels have limited reserves. The continuous variation of fossil fuel prices has added a major concern on its sustainable use for future energy supplies [1]. In order to minimize the environmental degradation due to emissions of hazardous gases during the energy production process, the utilization of renewable energy resources can be beneficial which provides clean energy with sustainability [2, 3]. Due to a constantly increasing demand of clean energy, a gradually rise in the utilization of naturally available solar energy has been observed. Consecutively to effectively utilize the solar power system, we need to know about the technology with its suitability according to the power requirements and nature of its usage [4, 5, 6].

Solar energy refers to the use of the sun's energy to produce thermal and electric power. Solar thermal systems provide hot water whereas solar photovoltaic (PV) and concentrating solar power (CSP) systems are used for electricity generation. These systems installed around the world over the last few decades [7, 8, 9, 10]. Photovoltaic already has a billion dollars industry. It is experiencing rapid growth as concerns over fuel supplies and carbon emissions mean that governments and individuals are increasingly prepared to ignore its current high costs. Among all the renewable energy resources, it is found that the solar energy is the most abundant, unlimited and clean. Because, the power from sun intercepted by the earth is about 1.8×1011 MW, which is much more than the present rate of all the kind of energy consumption. Photovoltaic technology is one of the most incredible ways to make the use of solar power [11, 12, 13, 14].

The photovoltaic cell transforms solar light in electrical energy and the phenomenon is named as 'Photovoltaic effect'. A solar PV cell is a small electricity generation device. Hence in order to generate electricity at a larger scale, solar cells are connected to form a module of multiple cells. After that these modules are assembled into a PV array of several meters length. The cells are assembled in series-parallel configuration to form a solar PV array for required energy. There are many operating and field conditions such as the sun's geometric location, irradiation levels and ambient temperature, which affect the electric power generated by a solar PV array [15]. The current PV market consists of a variety of technologies like wafer based silicon and thin-film technologies. Solar cells are composed of different kind of photovoltaic materials. The most commonly used materials are silicon (mono and polycrystalline), Cadmium telluride (CdTe), Gallium arsenide (GaAs). PV technologies are generally divided into three generations. But the overall efficiency and performance of these PV generations differ significantly, because of the use of different types of semi-conductor materials. The 1st and 2nd generation PV becomes more commercially mature and yield large scale production whereas 3rd generation is in pre-mature and R&D phase [16, 17].

Photovoltaic devices are robust and simple in design, entail scanty maintenance. It can be constructed as stand-alone systems to give outputs from microwatts to megawatts, which is the biggest advantage of it. Hence they are used in many applications such as backup power generation, water pumping, powering remote buildings, in solar home systems, in communications, satellites, space vehicles, reverse osmosis plants, and even for megawatt scale power plants. By means of this variety of applications, the demand for photovoltaic is increasing gradually [18, 19]. In this paper, modeling and simulation of maximum power point tracking for photovoltaic system using MATLAB/SIMULINK has been discussed. Modeling and simulation present a great potential to understand photovoltaic systems design, which often results in savings in design cycle time and cost, with better construction and operation.

II. PHOTOVOLTAIC TECHNOLOGY

A photovoltaic power generation system consists of multiple components like cells, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output. A typical PV system is shown in figure 1, which consists of PV moduleor panal which generates electric energy from solar energy; DC-DC converter to transfer the maximum power according to the load requirements; MPPT controller that generates the maximum power from the PV with the help of DC-DC converter; and electric Load [20].

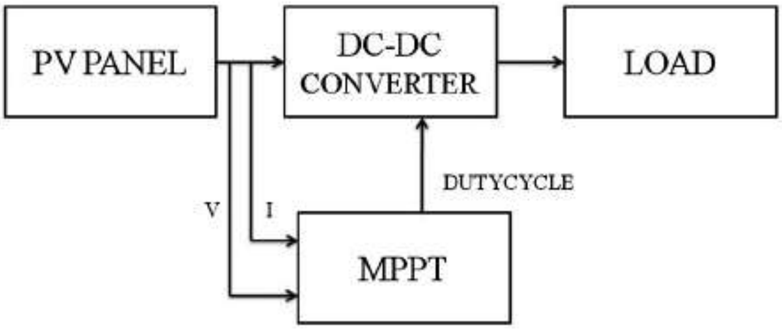

Figure 1: Block diagram of a typical photovoltaic system.

DC–DC voltage converters are used for matching the characteristics of the load with those of the solar panels. DC–DC voltage converters are classified into three categories, namely boost converters, buck converters and buck-boost converters. Selection of the type of DC–DC voltage converter depends on the voltage levels involved [21, 22, 23, 24]. The MPPT ensures that the maximum power generated by the solar PV array is extracted at all instants while the charge discharge controller is responsible for preventing overcharging or over discharging of the battery bank required to store electricity generated by the solar energy during sunless time [25, 26, 27]. In simple PV systems, where PV module voltage is matched to the battery voltage, use of MPPT electronics is generally considered unnecessary, since the battery voltage is stable enough to provide near-maximum power collection from PV module.

III. MODELING OF PV MODULE

A photovoltaic panel includes Ns cells placed in series and/or Np cells in parallel which are modeled by current source coupled in parallel with a diode according with series and shunt resistor Rs and Rp. The characteristic current-voltage of a photovoltaic array conducts as a function of cell temperature and solar irradiance. A practical model of PV module is shown figure 2. It consists of current source Ipv, which depends on irradiance and temperature; Diode, D; Rp, parasitic resistance; and Rs, series resistance.

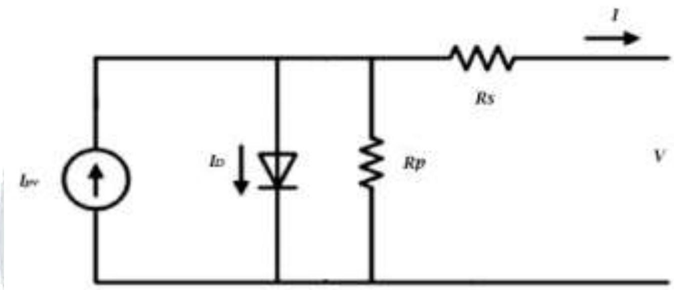

Figure 2: Single diode model of a PV cell

The circuit of Photovoltaic model is described using equations of schottky diode incorporated with quality factor in account of the recombination effects in space-charge region, which are given by equations 1, 2, 3, 4, 5 and 6

$$I = I_{pv} - I_D - I_{Rp} \quad (1)$$

where I is the PV module output current, Ipv is current generated by PV cell and is directly proportional to the irradiance, ID is the diode current and IRp is the current through shunt resistance.

$$I_{pv} = \left(\frac{G}{G_{STD}}\right)(I_{pv,STD} + K(T - T_{STD})) \quad (2)$$

where G is the current irradiance level, G_{STD} is the irradiance at standard conditions, $I_{pv,STD}$ is the current generated by solar cell at G_{STD} and T_{STD}, K is the Boltzmann constant, T is the p-n junction temperature and T_{STD} is the standard p-n junction temperature.

$$I_D = I_0\left(exp\frac{q(V + R_s I)}{\gamma k T} - 1\right) \quad (3)$$

where I_0 is the diode reverse saturation current.

$$I_0 = \frac{I_{pv,STD} + K_i(T - T_{STD})}{exp\left(\frac{qV_{oc} + K_v(T - T_{STD})}{\gamma V_t} - 1\right)} \quad (4)$$

where q is the electron charge, V_{oc} is the PV open circuit voltage, V_t is the PV module thermal voltage, K_i is the short circuit coefficient, K_v is the open circuit voltage coefficient and γ is the diode ideality factor.

$$I_{Rp} = \frac{V + R_s I}{R_p} \quad (5)$$

The equation for complete PV module is

$$I = N_p\left(I_{pv} - I_0\left[exp\left(\frac{V + R_s I}{\frac{N_s kT}{q}\gamma}\right) - 1\right]\right) - \frac{V + R_s I}{R_p} \quad (6)$$

V is the output voltage, Rs is the series resistance due to metal contact joining the PV cells, Rp is the parasitic resistance due to the p-n junction leakage current, Ns is the number of cells connected in series and Np is the number of cells connected in parallel.

IV. MODELING OF NON-INVERTING BUCK BOOST CONVERTER

A typical PV system is shown in Fig. 3.1, which consists of PV module which generates electric energy from solar energy; DC-DC converter to transfer the maximum power according to the load requirements; MPPT controller that generates the maximum power from the PV with the help of DC-DC converter and electric load. DC–DC voltage converters are used for matching the characteristics of the load with those of the solar panels. DC–DC voltage converters are generally classified into three categories, namely boost converters, buck converters and buck-boost converters. Selection of the type of DC–DC voltage converter depends on the voltage levels involved. The buck converter is a commonly used in circuits that steps down the voltage level from the input voltage according to the requirement. A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. The output of the buck-boost converter can be either higher or lower than the input voltage. The inverting buck-boost converter does not serve the needs of applications where a positive output voltage is required. Hence non inverting converters are required to fulfill the requirements.

In the presented work, a non-inverted buck-boost converter is used. The basic circuit diagram of the non-inverted buck-boost is shown in figure 3. It consists of input voltage from PV (Vpv), insulated-gate bipolar transistor switches (S_1 &S_2), inductor (L), diodes (D1 & D2) and capacitor (Ci & C), load (R). It is assumed that the converter is operating in continuous conduction mode. There are two operating modes of the converter i.e. mode 1, in which the switches are on and mode 2, in which the switches are off. In mode 1, both transistor switches (S1 &S2) are ON, diode (D1) is reverse biased and load is disconnected due to the closed path by switch (S2). Inductor (L) is charged from PV through switch (S1) in this mode.

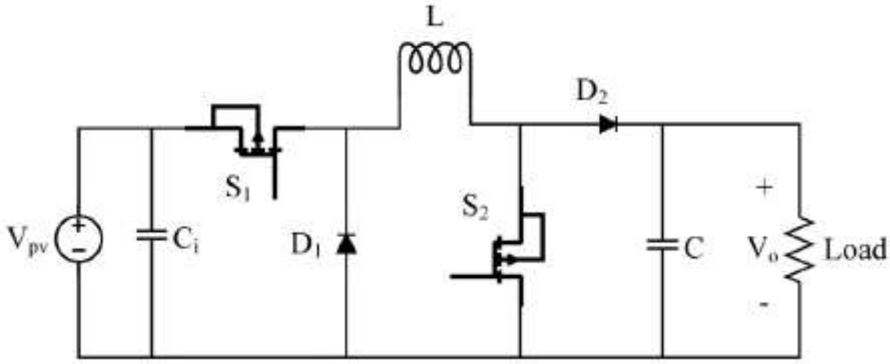

Figure 3. Block diagram of non-inverted buck-boost converter system

Using Kirchhoff's voltage and current law, we can write as

$$i_{c_i} = i_{pv} - i_L \quad (7)$$

$$\frac{dV_{pv}}{dt} = \frac{i_{pv}}{C_i} - \frac{i_L}{C_i} \quad (8)$$

As $V_L = V_{pv}$, hence

$$\frac{di_L}{dt} = \frac{v_{pv}}{L} \quad (9)$$

Whereas,

$$i_c = \frac{-v_O}{R} \quad (10)$$

$$\frac{dv_O}{dt} = \frac{-v_O}{RC} \quad (11)$$

In mode 2, both switches (S_1 &S_2) are off and the load is connected to inductor (L) through diode (D_2). Hence from Kirchhoff's laws $i_{ci}=i_{pv}$ and $V_L= -V_O$

(12)

$$\frac{dv_{pv}}{dt} = \frac{i_{pv}}{C_i}$$
$$\frac{di_L}{dt} = \frac{-v_0}{L} \quad (13)$$

Whereas,

$$i_c = i_L - \frac{v_0}{R} \quad (14)$$
$$\frac{dv_c}{dt} = \frac{i_L}{C} - \frac{v_0}{RC} \quad (15)$$

By assuming ideal power transfer i.e. Pi= Po, we can write

$$v_o = \frac{D}{1-D} v_{pv} \quad (16)$$

V. SIMULATION RESULTS

The complete architecture of the PV system is built in MATLAB (Simulink and Simscape) with the aim of simulating the proposed tracking method. The PV array used in this work consists of 36 cells. The specification of the single PV module is shown in Table 1. The Photovoltaic model simulation is shown in Fig 2.2.

Table 1. Typical Electrical Characteristics of PV panel.

Characteristics	Specifications
Typical peak power (Pm)	60 W
Peak power voltage (Vm)	34.1 V
Peak power current (Im)	2.5 A
Current at short-circuit (Isc)	3.8 A
Voltage at open-circuit (Voc)	21.1 V
Coefficient temp. of OC voltage	73mV/°C
Coefficient temp. of SC current	3mA/°C
Approx. power by temp.	0.38W/°C

In order to verify the model under different operating conditions, several tests have been performed at various solar irradiance values. The figure 4 and 5 shows the IV curves and PV curves for various solar irradiance G (400 W/m^2, 600 W/m^2, 800 W/m^2 and 1000 W/m^2 at standard cell temperature of 25 ^{o}C. From the curves it is seen that, PV curve has negligible effect on the open circuit voltage, due to the variation of irradiation and mainly affects short circuit current.

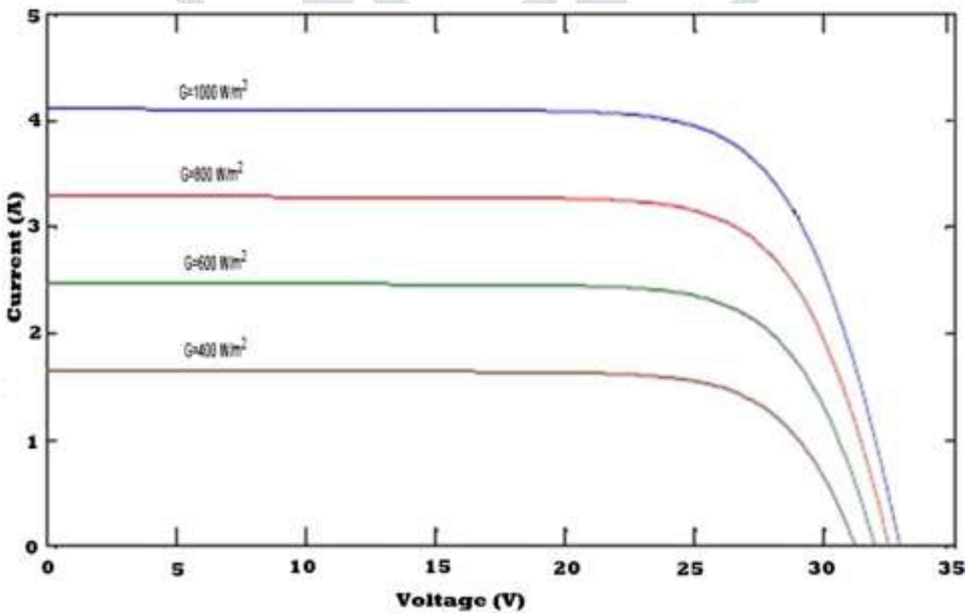

Figure 4. Variation of IV curve with different irradiances.

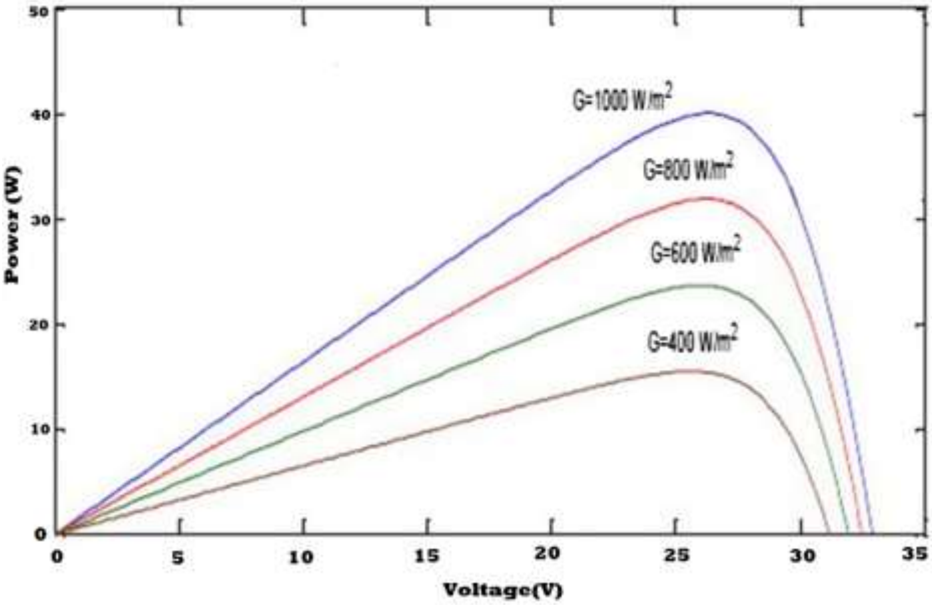

Figure 5. Variation of PV curve with different irradiances.

The non-inverted buck-boost converter has been selected for matching the panel curve with output load in order to extract maximum power from PV panel. The specifications of the controller parameters and the non-inverting buck-boost converter is shown in Table 2. From the simulation results shows that the Converter produces non inverted output. The output voltage waveforms of both converters are shown in figure.6 and 7.

Table 2: Converter Parameters

Characteristics	Specifications
L	1107µH
Ci	518 µF
C	518 µF
Power	25 W
Vs	12 V
Vo	14 V
fs	10 KHz

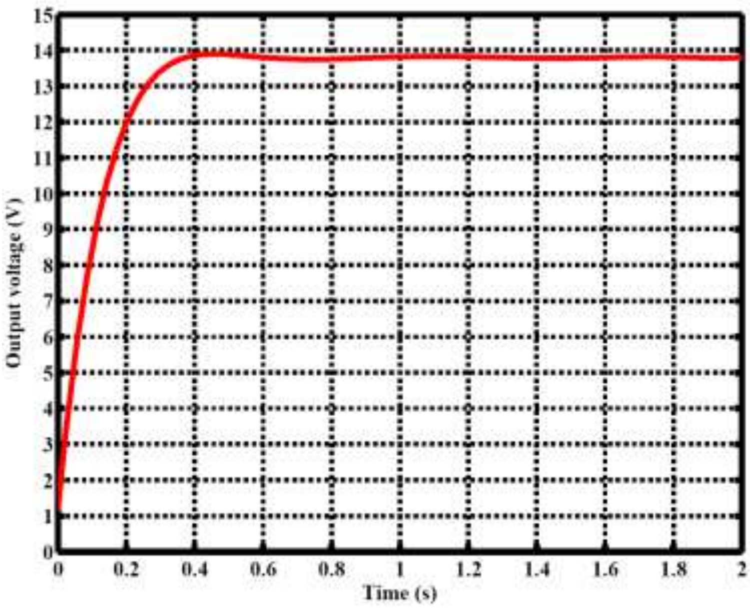

Figure 6. Output voltage of noninverting Buck-Boost converter.

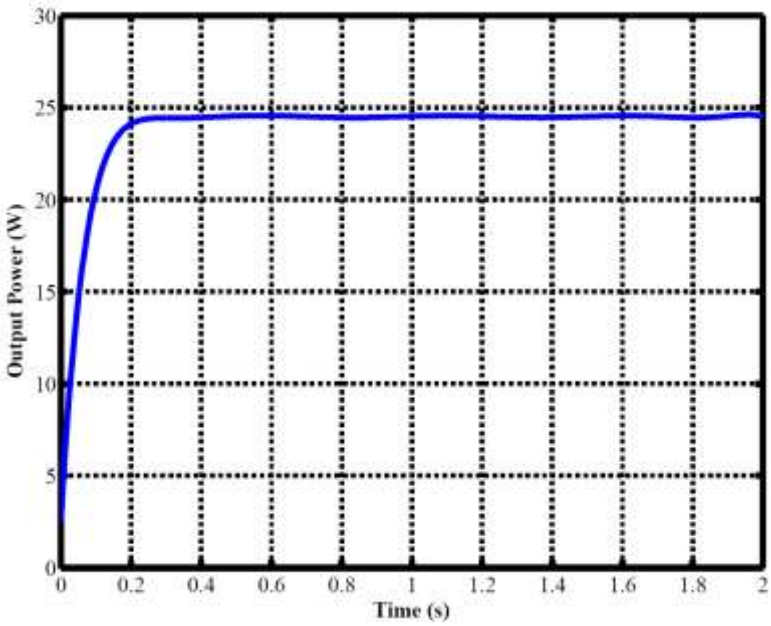

Figure 7. Output power of noninverting Buck-Boost converter.

A model of PV panel and dc–dc non inverted buck boost converter with different variable step-size P&O MPPT method was simulated using MATLAB software (figure 8). Before applying the variable step-size P&O method, its scaling factor needs to be determined. The abrupt variations of irradiation are estimated: from 1000 W/m^2 to 200 W/m^2 (at 1 s) and from 200 W/m^2 to 1000 W/m^2 (at 2 s) at 25 ^{o}C. The sampling period is set to be 50 ms. The duty cycle maximum step ΔD is set to be 20%. When the irradiance level is 200 W/m^2, the maximum scaling factor (M) is 4.46 and is selected as 3 in observations. However, when the irradiance level is 1000 W/m^2, the maximum M is 0.89 and is selected as 0.7. Figure 9 shows the MPPT response of the variable step-size P&O method with M=0.7, where the irradiance levels are 200 W/m^2 and 1000 W/m^2. It can be observed that under these two different irradiance levels, the transient time are 43 steps and 10 steps, respectively. In both conditions, neither one oscillates near the MPP. Figure 10 shows the system response of the variable step-size P&O method with M = 3 when the irradiance levels equal 200 W/m^2 and 1000 W/m^2, respectively. However, under the irradiance level of 1000 W/m2, the steady-state operating point exhibits large oscillations. The thing worth mentioned is that although the optimal value of M is not the same under different irradiation levels. However, as mentioned in Pandey et al. (2008), the value of M needs to be kept constant. As a result, M is selected to be fixed at 3 and 0.7, respectively for these two observations to avoid oscillation. The variable step-size methods have stable output power due to the smaller steps around the MPP, but the tracking time is not as good as with the fixed step-size method.

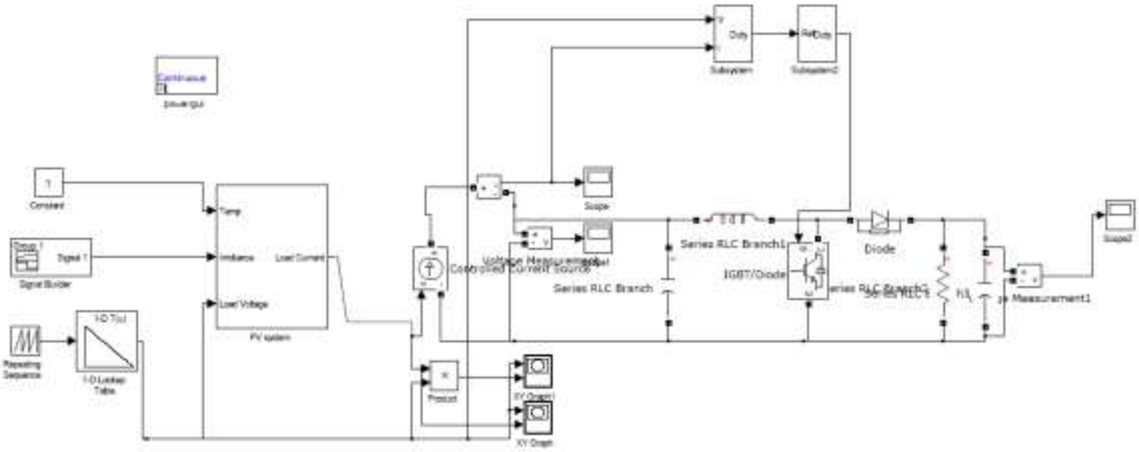

Figure 8. Simulation of PV system with mppt.

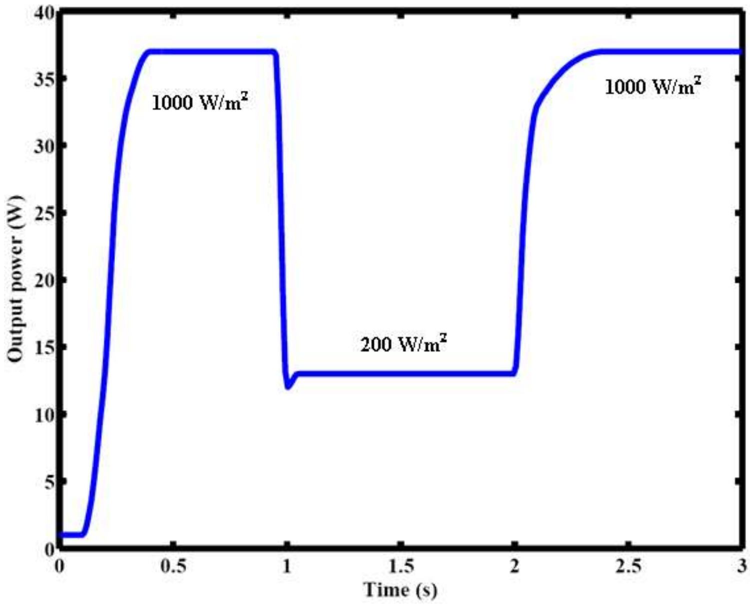

Figure 9. MPPT response of the variable step-size P&O method (M=0.7) under different irradiance levels (200 W/m^2 and 1000 W/m^2).

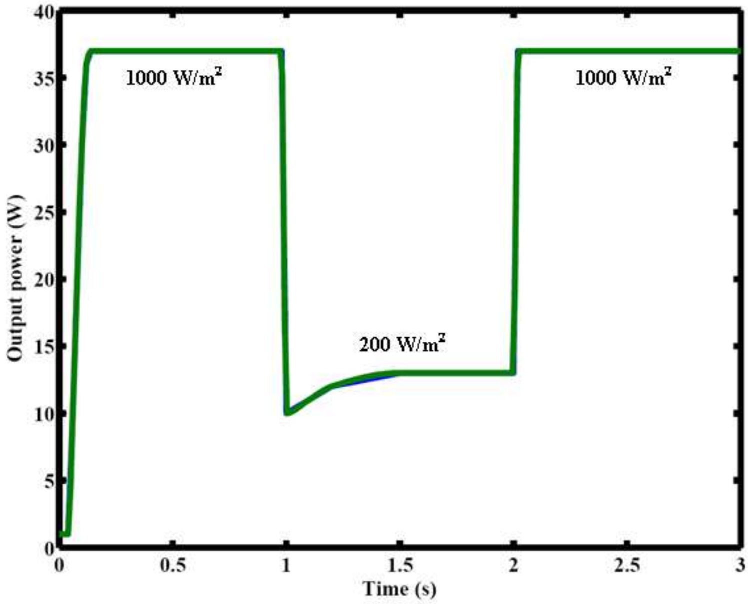

Figure 10. MPPT response of the variable step-size P&O method (M=3) under different irradiance levels (200 W/m^2 and 1000 W/m^2).

VI. CONCLUSION

The fast growing demands and increasing awareness for the environment, PV systems are being rapidly installed for numerous applications. In this chapter the modeling of non-inverted buck boost DC-DC converter has been done. Converter is an essential part of any PV system regardless of load type. The main role of converter is conditioning the produced power of PV cells in order to meet the load requirements. However, it can be used for matching the panel curve with output load in order to extract maximum power from PV panel. The result shows the fast response of the simulated converter. In this chapter, variable step-size perturbation step Perturb and observe (P&O) maximum power point tracking (MPPT) algorithm have been presented with non-inverting buck boost converter. It is observed that the proposed method improved the transient and steady-state performances of the outcome of the dc source. The simulation results show that variable step-size P&O have the fast transient response, In terms of tracking energy loss, the results indicate that variable step-size P&O performs well.

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