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LabVIEW Based Simulator for Solar Cell Characteristics and MPPT Under Varying Atmospheric Conditions

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ABSTRACT

Though intermittent, solar energy is a clean and eternal source of energy. PV (Photovoltaic) cell is one of the technology to harness the solar energy and use it as electricity. In recent years rising cost of electricity and environmental concerns have made the solar PV technology a rising research field. In this research field the efficiency improvement is the focal point for the researchers. Because of intermittent weather conditions the output power of the solar cell varies directly to the irradiance level and inversely to the cell temperature and cell never operates at its maximum power. In this paper the characteristics of the sun power A-300 solar cell is simulated in a novel way in LabVIEW using MathScript RT Module along with a MPPT (Maximum Power Point Tracker) using variable step sized incremental conductance algorithm that operates the cell at its maximum power without oscillating at maximum power point. Impacts of changing solar insolation and cell temperature on output curves are also discussed graphically and numerically. The results of the simulation verify the data sheet parameters of sun power A-300 solar cell. Graphs of output power of MPPT indicate the accuracy of the variable step sized InC (Incremental Conductance) algorithm for constant and varying solar irradiance with fast tracking and elimination of steady state oscillations about the MPP which is comparatively better than the conventional MPPT algorithms as compared in the results.

Key Words: Solar Photovoltaic, LabVIEW, MathScript RT Module,Incremental Conductance, Maximum Power Point Tracke.

1. INTRODUCTION

Climate of the earth is exponentially being changed by the fossil fuel generated CO_2 that may bring the evolution as well as the eradication to the various species of the earth. Therefore, an alternative clean, green and non-exhaustible source of energy is the need of the hour in order to sustain and preserve each species of the ecosystem. Solar energy is one of the renewable energy that can be envisaged to be a greater part of the world energy in future. Solar power can be used either to generate electricity or steam that can further be used in various ways. Sun power has manufactured solar cell of maximum efficiency of about 21% [1]. In literature, the characteristics of the solar cell has been simulated in MATLAB/Simulink. This paper

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presents a novel way of simulation of the solar cell characteristics in LabVIEW using MathScript RT Module that provides a graphical platform to implement the programming language. A front panel presents the control and indicators as inputs and outputs respectively. First, output characteristic curves of solar cell are simulated and results verify the data sheet parameters such as the efficiency, fill factor, rated power, V_{mpp} and I_{mpp} of the sun power A-300 solar cell. Second, the impact of the changing insolation and cell temperature on I-V and P-V curve is simulated graphically and numerically. Third, maximum power point tracking technique using incremental conductance algorithm is applied to reach the maximum power point by adjusting the duty cycle of the boost converter. Boost converter is modeled in Multisim and exported to LabVIEW using co-simulation procedure [2]. Because of the variable seasonal pattern the output power of the solar cell is also variable.

Solar cells are made up of different semiconducting materials such as silicon and CdTe/CdS. We have a complete range of solar spectrum consisting of 59.6% visible light falling on the cell. Band gap energy for visible region is 1.5 eV-3.5 eV while for infrared region is 2.40eV-0.95eV. The band gap energy for silicon is 1.12eV [3] and for CdTe it is 1.47 [4]. So silicon solar cell absorbs all the light with band gap energy greater than 1.12 eV. The remaining part of the solar spectrum is useless and it only increases the temperature of the cell and deteriorates cell performance.

The deviation of the seasonal parameters such as irradiance and temperature from the STC (Standard Test Conditions) diminishes the cell efficiency and cell never operate at its maximum power [5]. Maximum power from the solar cell can be attained either by using solar tracker or MPPT. In recent years many MPPT algorithms have been adopted to operate the cell at maximum power point [6]. P&O (Perturb &Observe) and InC [7-9] are the efficient one but because of perturbation both generates oscillations about the MPP. In this paper InC algorithm is simulated with variable step size that greatly reduces the steady state oscillations and tracks the MPP accurately. In literature all the MPPTs were simulated in Matlab/ Simulink [10]. This paper presents a LabVIEW based solar simulator with MPPT which can also be connected to the hardware solar cell through DAQ (Data Acquisition) Assistance and by taking real time voltage and current can track the MPP.

2. MODELLING OF PV CELL

When sun light falls on the PV cell electrons are knocked off from the valence band to the conduction band leaving holes behind so both move in opposite direction that can be represented by a current source. In this paper a single diode model of PV solar cell shown in Fig. 1 and equivalent mathematical Equations (1-6) are used to acquire the output curves of the PV cell.

2.1 Photo current

Photo current also termed as short circuit current is the current generated by the solar irradiance falling on the PV cell presented as a current source I_{ph} in Fig. 1 and it is calculated by using Equation (4).

2.2 Forward Biased Diode

If the PV cell is not connected to the external load then there is open circuit voltage that allows a full current to

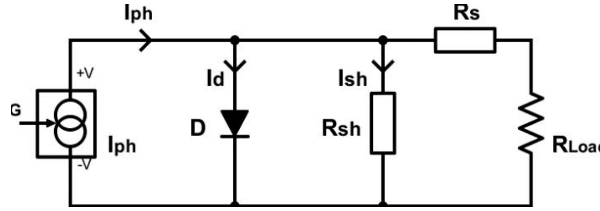


FIG. 1. SINGLE DIODE MODEL OF SOLAR CELL

flow effectively through a P-N junction acting like a forward biased diode. But when a load is in action, though the voltage is reduced but still there is a voltage that causes the flow of current through the forward biased diode so a diode is in parallel to the current source I_{ph} as shown in Fig. 1.

2.3 Series Resistance

The sum of all the resistances encountered by the current as it passes through the PV cell to the external metal contacts through bulk material and to the load, is termed as series resistance as it appears in series to the load as shown in **Fig. 1.**

2.4 Shunt Resistance

As the light falls on the PV cell electrons are knocked from the holes and entered to the conduction band. But before they flow out of the PV cell, some of the electrons and holes recombine causing the decrease in the originally generated current I_{ph}.

$$I_o = I_{or}\left[\frac{T_c}{T_r}\right]^3 \exp\left[\frac{q.E_g}{nk}\left\{\frac{1}{T_r}-\frac{1}{T_c}\right\}\right] \quad (1)$$

$$I_{or} = \frac{I_{scr}}{\exp\left(\frac{qV_{ocr}}{nkT_r}\right)} - 1 \quad (2)$$

$$V_{oC} = \ln\left(\frac{I_{SC}}{I_o}+1\right)\left(\frac{nkT_c}{q}+1\right) \quad (3)$$

$$I_{SC} = \frac{G}{1000}\left[I_{SCr} + K_i\left(T_c - T_r\right)\right] \quad (4)$$

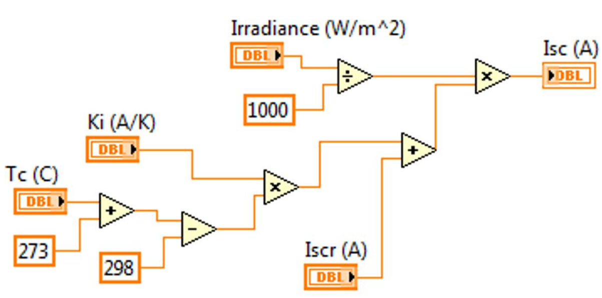
$$FF = \frac{I_m \times V_m}{I_{SC} \times V_{OC}} \quad (5)$$

$$\eta = \frac{P_m}{P_{in}} = \frac{I_{SC} \times V_{OC} \times FF}{P_{in}} \quad (6)$$

3. SIMULATION OF PV CELL IN LABVIEW

To simulate the characteristics curves of a solar cell, its parametric Equations (1-6) are used. In LabVIEW simulation of these complex equations have been done in literature in a more complex way. Jaleel [11], Srinivas [12] and Pradeep [13] have used the complex way of simulation of PV cell. As a reference the complex way of simulating the short circuit current using Equation (4) is shown in Fig. 2. To simulate the solar cell characteristics Equations (1-6) are implemented on a single pallet to calculate saturation current, reverse saturation current, open circuit voltage, short circuit current, fill factor and efficiency that makes the whole circuit complex enough to understand and debug. While the easiest and the simplest way of simulation using MathScript RT Module used in this paper is shown in Fig. 3 to simulate short circuit current as a reference. In MathScript RT Module you only need to put inputs to the calculator and take outputs. No complex circuit or flow diagram is needed.

Each parameter of the solar cell is calculated and simulated individually using Equations (1-6) [14-16] in MathScript RT Module as shown in Fig. 4. MathScript RT Module has many different ways of implementing given equations such as formula, math script, formula node and script node. Having various modules LabVIEW makes it easy to simulate any technical project either in flow diagram



(a) Conventional way of simulation of PV cell equations

FIG. 2. CONVENTIONAL COMPLEX WAY OF SIMULATION FOR I_{SC}

mode or using code. LabVIEW provides a user friendly platform with a block diagram view and a front panel view. Front panel accepts various inputs from the user and shows the numerical as well as the graphical outputs calculated by the block diagram. In this paper front panel exhibits the PV cell's input and output parameters like open circuit voltage, short circuit current, maximum power, voltage at maximum power, current at maximum power, fill

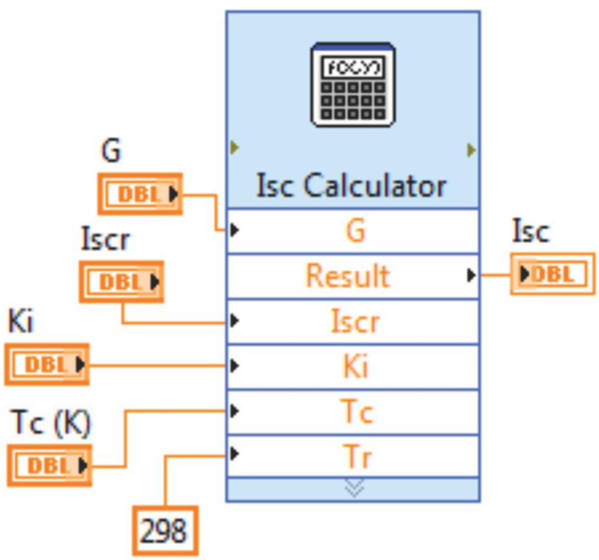


FIG. 3. SIMPLEST SIMULATION OF I_{SC} USED IN THIS PAPER

factor, efficiency, PV and Equations (1-6) curves. The results of the simulation are compared with the data sheet values of Sun Power A-300 solar cell and verifies the validation of the simulation as shown in Table 2.

4. SIMULATION RESULTS

The output characteristics curve of Sun Power A-300 solar cell at standard test conditions (G=1000 W/m^2, T=25^{0}C) are shown in **Fig. 5(a-b)**.

Front panel view with input and output parameters of the solar cell is shown in Fig. 6. Input parameters are taken from the data sheet of the chosen sun power A-300 mono crystalline silicon solar cell and the simulated output results are shown in front panel in Fig. 6. Table 1 indicates the data sheet of the sun power A-300 solar cell which are given at standard test conditions STC (G=1000 W/m^2, T=25^{0}C). When STC were put into the front panel of the solar cell in Fig. 6, the simulated results V_{oc}, I_{sc}, V_{mpp}, I_{mpp}, P_m, fill factor and efficiency were found to be very close to the data sheet values of sun power A-300 solar cell given in Table 1 and compared in Table 2.

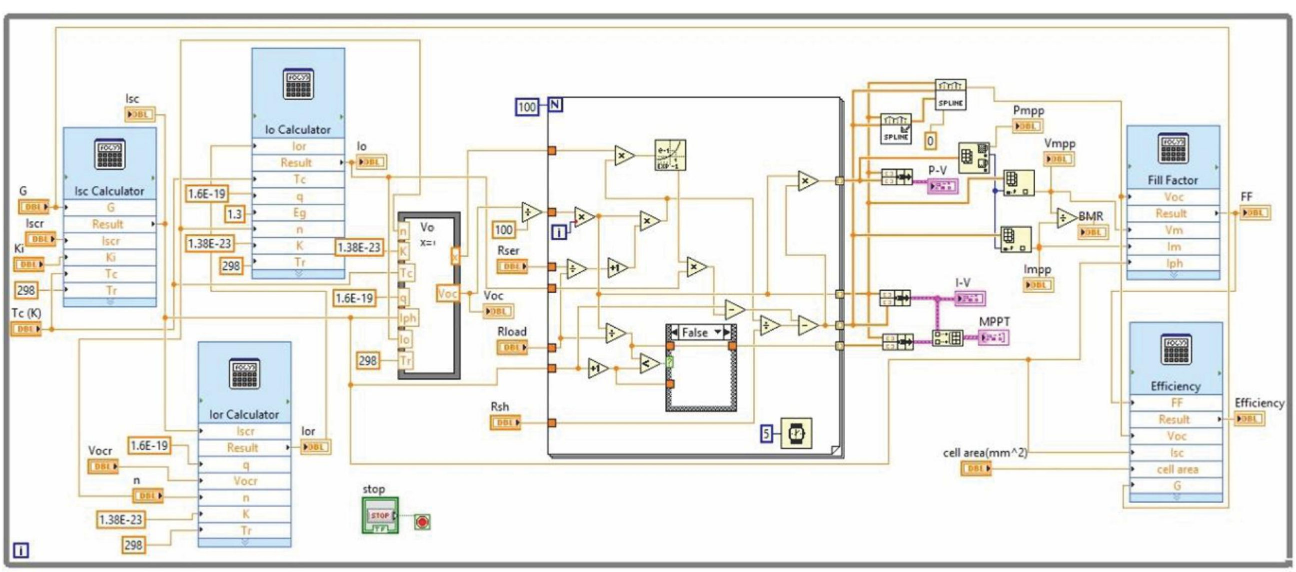


FIG. 4. LABVIEW BASED SIMULATION OF PV SOLAR CELL

4.1 Simulation at Constant Cell Temperature and Varying Solar Irradiance

Throughout the year, continuously changing seasonal pattern affects the solar cell performance negatively. Because of the absence of solar tracker the number of suns falling on the cell is maximum once a day for a short duration generating maximum power of its capacity. The rest of the day PV cell operates below its rated power because of low irradiance level. P-V and Equations (1-5) curves are simulated for a wide range of irradiance levels at constant cell temperature 25^{0}C explaining the effect of irradiance on output power as shown in Fig. 7. Fig. 7(a) shows the PV curves and Fig. 7(b) indicates Equations (1-5) curves for a wide range of irradiance levels at constant STC temperature.

Table 3 shows clearly the effect of solar irradiance on various parameters of the solar cell such as I_o, I_{or}, V_{oc}, I_{sc}, V_{mpp}, I_{mpp}, P_m, efficiency and fill factor. As the solar irradiance goes on decreasing, P_{mpp}, efficiency and fill factor are also decreased which degrades the performance of the solar cell. If some arrangement is made to collect maximum irradiance on the cell by using solar tracker or Fresnel lens, efficiency of the cell can be increased.

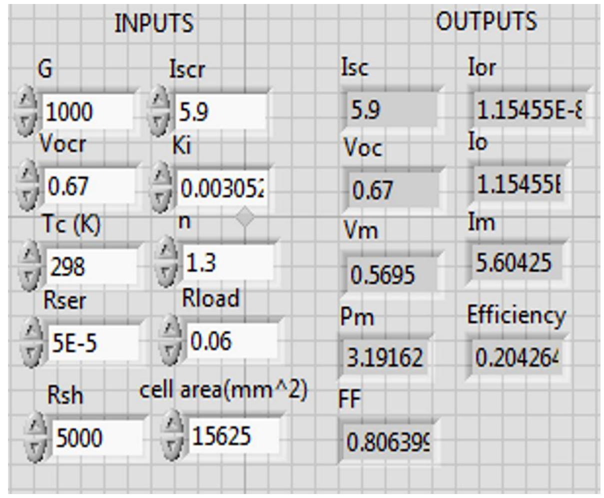


FIG. 6. FRONT PANEL VIEW OF FIG. 2

TABLE 1. SUN POWER A-300 SOLAR CELL DATA SHEET [1]

Parameters	Data Sheet Values
V_os (V)	0.670
I_sc (A)	5.90
P_mpp (W)	3.10
V_mpp (V)	0.560
I_mpp (A)	5.54
η%	21.5
Area (mm2)	125×125

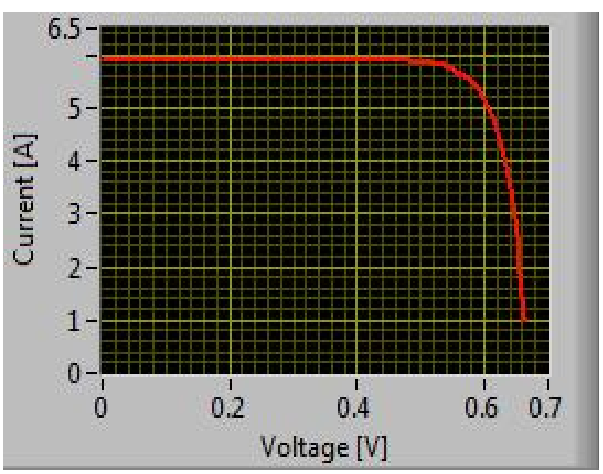


FIG. 5(a). I-V CURVE

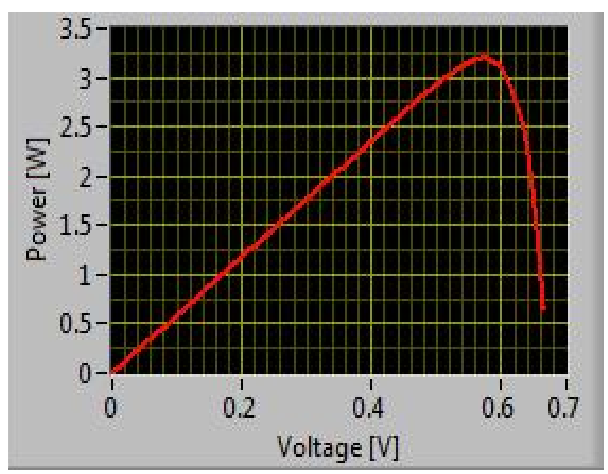


FIG. 5(b). PV CURVE OF SUN POWER A-300 SOLAR CELL

4.2 Simulation at Constant Solar Irradiance and Varying Cell Temperature

With the increase of solar cell temperature, the resistance of PV cell is increased and hence the mitigation of current increases the voltage drop. The output power of the PV solar cell is reduced shown in Fig 8(a) that deteriorates the performance of the PV cell. P-V and Equations (1-5) curves of the PV cell is simulated for a wide range of temperatures as depicted in Fig. 8(a-b) respectively. LabVIEW provides the concatenation function of graphs that holds the graph for one value and then shows the output for that range of input values. Table 4 shows the different parameters of PV cell such as I_o, I_{or}, V_{oc}, I_{sc}, V_{mpp}, I_{mpp}, P_{mpp}, efficiency and fill factor for varying temperatures at constant irradiance level of 1000 W/m^2.

Table 4 is a self-evident that the increase in temperature of the cell badly reduces the efficiency of the cell. If the solar cell is operated in a controlled environment where the temperature of the cell is kept constant at STC by letting fall on the solar panel only that part of the solar spectrum whose band gap energy matches the band gap of the cell material, efficiency of the solar cell can be increased.

TABLE 2. COMPARISON OF DATA SHEET AND SIMULATION RESULTS

Parameters	Data Sheet Values	Simulated Results
V_os (V)	0.670	0.670
I_sc (A)	5.90	5.90
P_mpp (W)	3.10	3.19
V_mpp (V)	0.560	0.56
I_mpp (A)	5.54	5.60
η%	21.5	20.4

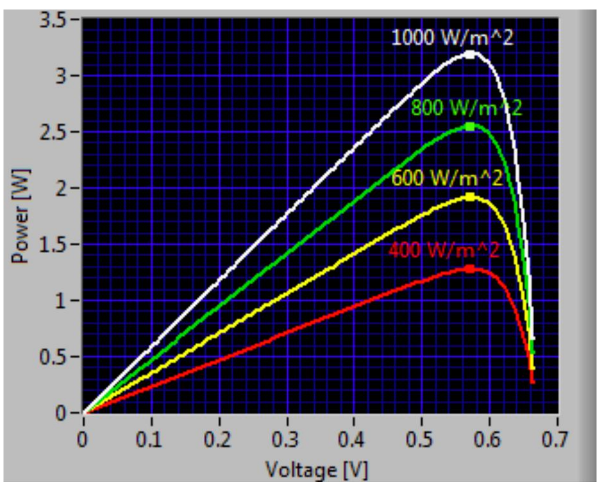


FIG.7(a). PV CURVES AT VARYING IRRADIANCE LEVEL

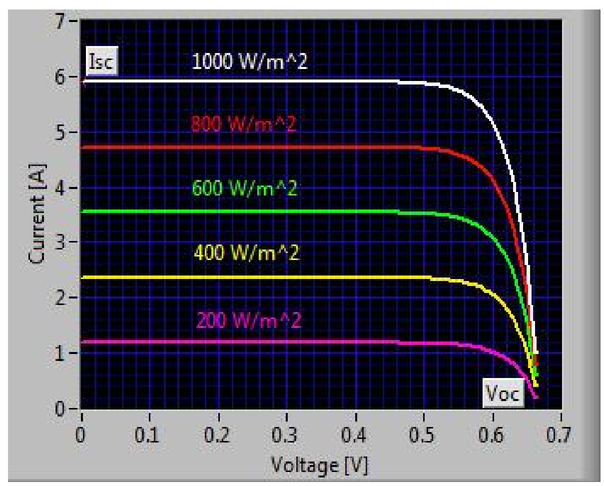


FIG.7(b). I-V CURVES AT VARYING IRRADIANCE LEVEL

TABLE 3. SIMULATION RESULTS AT CONSTANT CELL TEMPERATURE AND VARIANT SOLAR IRRADIANCE

G (W/m^2)	I_o (A)	I_{or} (A)	V_{oc} (V)	I_{sc} (A)	V_{mpp} (V)	I_{mpp} (A)	P_m (W)	η %	FF
1000	1.15E-8	1.15E-8	0.67	5.90	0.56	5.60	3.19	20.4	0.806
800	9.23E-9	9.23E-9	0.66	4.72	0.56	4.48	2.55	19.5	0.805
600	6.92E-9	6.92E-9	0.64	3.54	0.56	3.36	1.91	18.2	0.804
400	4.61E-9	4.61E-9	0.60	2.36	0.56	2.24	1.27	16.8	0.764

5. MAXIMUM POWER POINT TRACKER

Fig. 7(a-b) clearly indicates that the output power of the solar cell is reduced by irradiance and temperature and hence the efficiency of the cell is declined as stated by Equation (6). To let the cell function at maximum power a MPPT controller is used that follows an algorithm to extract the duty cycle for the power converter.

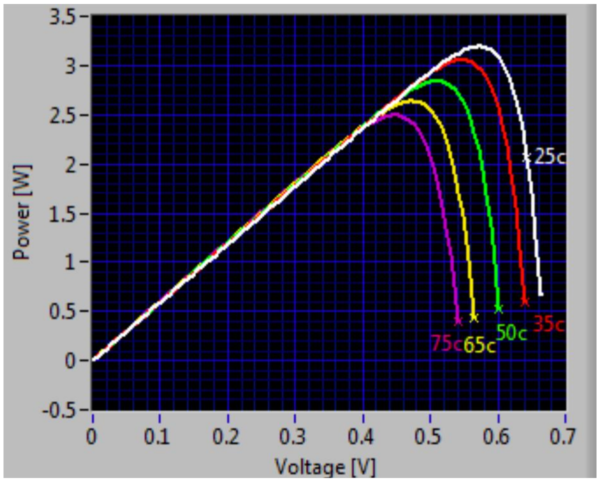


FIG. 8.(a). PV CURVES AT VARYING CELL TEMPERATURE

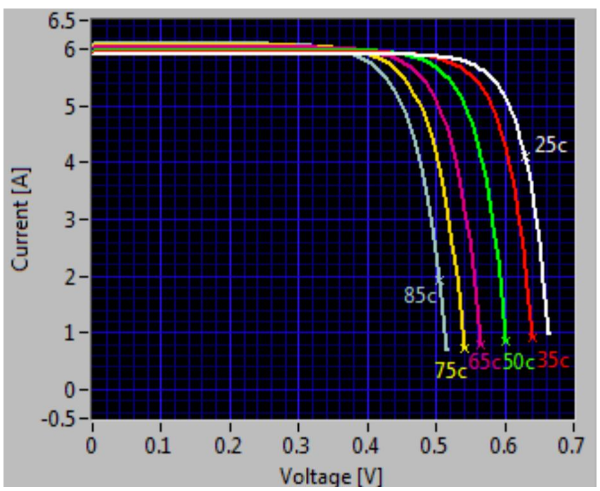


FIG. 8.(b). I-V CURVES AT VARYING CELL TEMPERATURE

5.1 Incremental Conductance Algorithm

In this paper InC algorithm with variable step is simulated for the Sun power A-300 solar cell. This algorithm compares the incremental conductance (dI/dV) with instantaneous conductance Equation (1/5) and decides the operating point of the cell according to Equations (7-9) [10,14].

$$\frac{dI}{dV} = -\frac{I}{V} \text{ At MPP} \tag{7}$$

$$\frac{dI}{dV} > -\frac{I}{V} \text{ Left of MPP} \tag{8}$$

$$\frac{dI}{dV} < -\frac{I}{V} \text{ Right of MPP} \tag{9}$$

The Equations (7-9) decide whether to increment or decrement the duty cycle to reach the maxima. Increment and decrement are calculated by Equation(10) called variable step size [17]. Flow chart of the InC algorithm is shown in Fig. 9.

$$step = N.\left[\frac{dP}{dV}\right] \tag{10}$$

MPPT controller takes voltage and current from the output of the solar cell as simulated in Fig. 4 and then implements the InC algorithm according to flow chart shown in Fig. 9. LabVIEW provides shift registers that hold V(K) and I(K) and use them in next iteration as V(K-1) and I(K-1) to compare the dI/dV with Equations (1/5) determining the operating point and deciding whether to increment or decrement the duty ratio. Simulated block diagram of the InC algorithm is

TABLE 4. SIMULATIONRESULTS AT CONSTANT SOLAR IRRADIANCE AND VARIABLE CELL TEMPERATURE

T_c (C°)	I_o (A)	I_{or} (A)	V_{oc} (V)	I_{sc} (A)	V_{mpp} (V)	I_{mpp} (A)	Pm (W)	η %	FF
25	1.15E-8	1.154E-8	0.67	5.90	0.56	5.60	3.19	20.4	0.806
35	4.53E-8	1.160E-8	0.64	5.93	0.54	5.56	3.05	19.5	0.796
50	3.02E-7	1.169E-8	0.60	5.97	0.51	5.564	2.84	18.2	0.781
65	1.71E-6	1.178E-8	0.57	6.02	0.47	5.552	2.62	16.8	0.764
75	5.05E-6	1.184E-8	0.54	6.05	0.44	5.560	2.49	15.9	0.752
85	1.40E-5	1.190E-8	0.52	6.08	0.42	5.562	2.34	15.0	0.740

shown in Fig. 10. The duty cycle calculated by InC. was fed to the DC-DC boost converter imported from multisim using co-simulation method as described in [2].

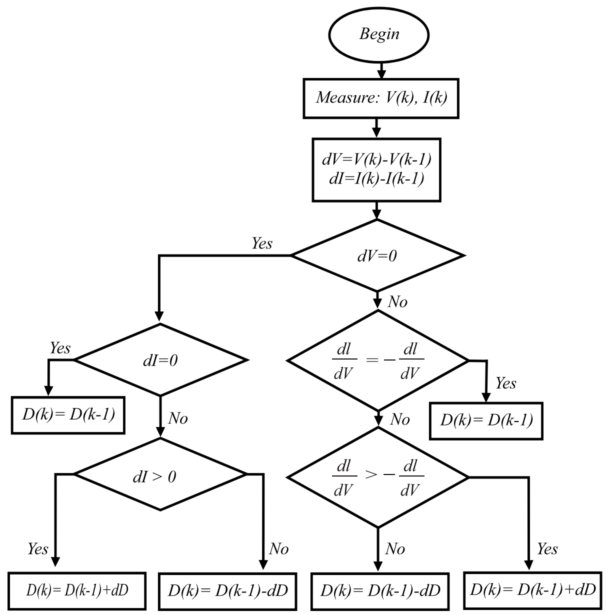


FIG. 9. FLOW CHART OF INC ALGORITHM

5.2 Results

Fig. 7(a) shows that at 1000 W/m^2 maximum power point is 3.19W which continues to change with change in voltage and current. In order to let the cell operate at this MPP, our implemented InC algorithm performed well and tracked the MPP efficiently and accurately without steady state oscillation at MPP at constant irradiance. First the MPPT was implemented for a constant irradiance 1000 W/m^2 to track the MPP of 3.19 W and stay there till the irradiance is constant as shown in Fig. 11. Then the irradiance level was changed from 1000 W/m^2 to 800 W/m^2 to 600 W/m^2 and it was observed that the chosen InC algorithm performed its duty well and accurately tracked the MPP for varying solar irradiance with minute oscillations as given in Fig 12. In Fig 7(a) MPP at 800 W/m^2 is 2.55W and at 600 W/m^2 it is 1.91W which was accurately tracked by the implemented InC algorithm as shown in Fig. 12. Ishaque [18] and Joshi [19] have implemented HC (Hill Climbing) and P&O conventional algorithms respectively for tracking the maximum power point

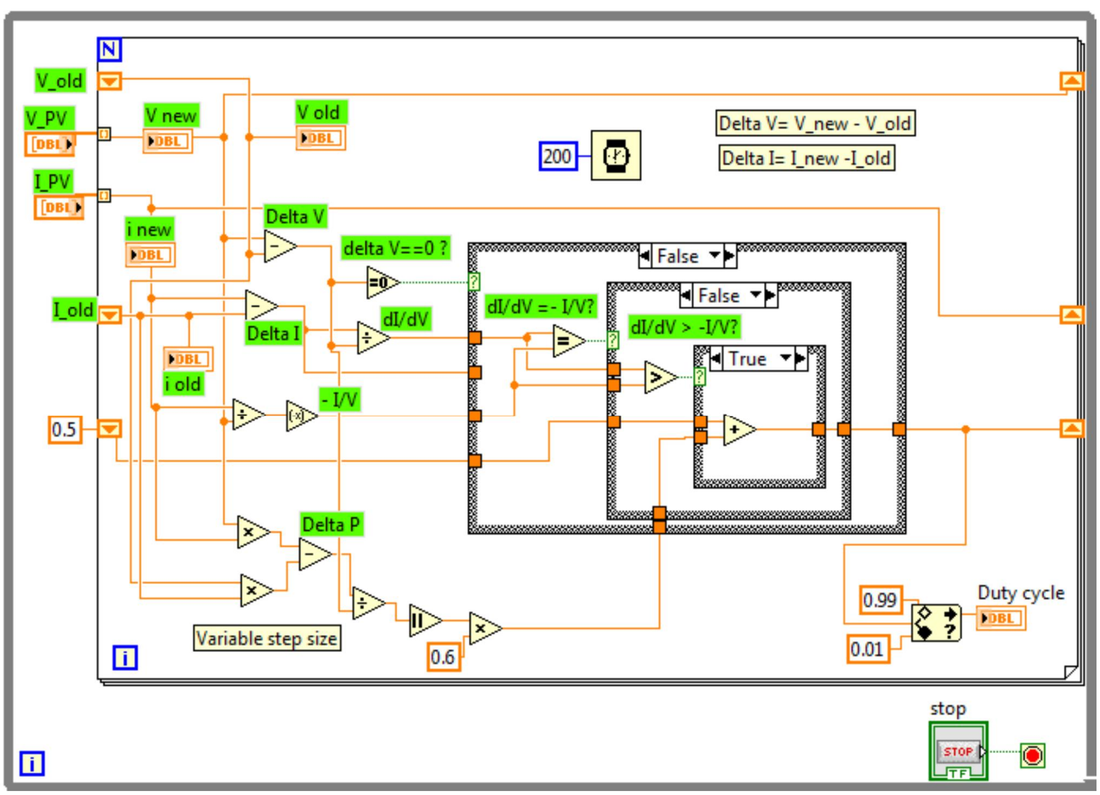


FIG. 10. SIMULATED BLOCK DIAGRAM OF INC ALGORITHM

of the solar panel. Both of these algorithms have been extensively used because of simplicity but both have the problems of oscillations at the maximum power point and hence the power at load is degraded. Fig. 13 shows the output power of solar panel with HC algorithm under varying solar irradiance that does track the maximum power but generates steady state oscillations at MPP. Fig. 14 depicts the PV output power using P&O algorithm under constant irradiance tracking the maximum power and having the same problem of steady state oscillations at MPP.

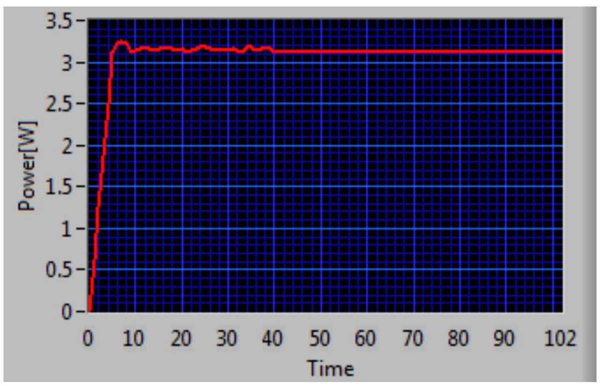


FIG. 11. TRACKED MPP AT CONSTANT IRRADIANCE 1000 W/M²

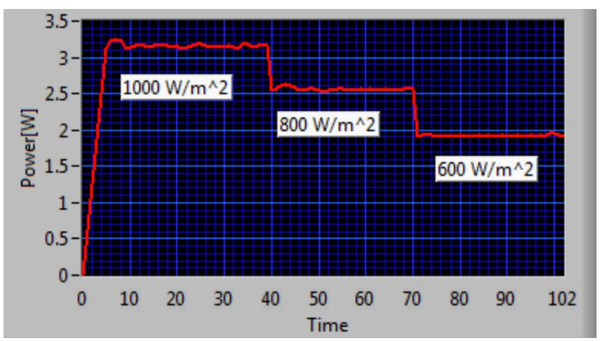


FIG.12. TRACKED MPP AT VARYING SOLAR IRRADIANCE

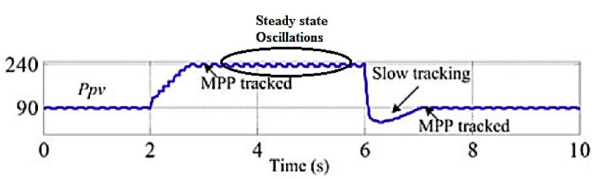


FIG. 13. PV OUTPUT POWER WITH HC ALGORITHM FOR VARYING IRRADIANCE [18]

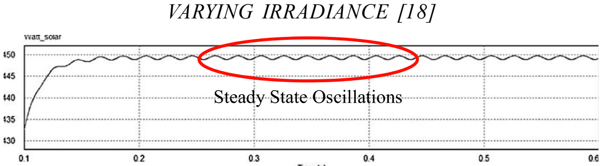


FIG. 14. PV OUTPUT POWER WITH P&O ALGORITHM FOR CONSTANTS IRRADIANCE [19]

6. CONCLUSION

In this paper output characteristics of a monocrystalline silicon solar cell were obtained by simulating single diode model. By varying solar irradiance and temperature different P-V and Equations (1-5) curves were obtained and various parameters were analyzed under varying atmosphere conditions. The results were compared with the data sheet of sun power A-300 solar cell data sheet. MPPT was implemented using InC algorithm that accurately and speedily tracked the MPP without oscillation at MPP for constant and varying solar irradiance. All the simulation was done on LabVIEW platform by National Instrument NI using various modules.

7. NOMENCLATURE

I_0	Saturation current (A)
I_{or}	Reverse saturation current (A)
$I_{SC} \approx I_{ph}$	Short circuit current (A)
V_{oc}	Open circuit voltage (V)
I_{scr}	Short circuit current at T_r (A)
V_{ocr}	Open circuit voltage at (A)
Q	Electron charge (1.602E-19 C)
E_g	Band gap energy
N	Ideality factor(1.3 for mono crystalline)
K	Boltzmann's constant(1.381 E"23 J/K)
T_c	Cell temperature (K)
T_r	Reference temperature (298 K)
G	Solar irradiance (W/m^2)
R_{sh}	Shunt resistance (&!)
R_s	Series resistance (&!)
I_d	Diode current (A)
I	Output current of cell (A)
I_{sh}	Current through Rsh (A)
I_m	Maximum current (A)
V_m	Maximum voltage (V)
P_m	Maximum power (W)
P_{in}	Input power (W)
FF	Fill factor
η	Efficiency

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