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PV Characteristics and Their Maximum Power Point Tracking Algorithms using LabVIEW

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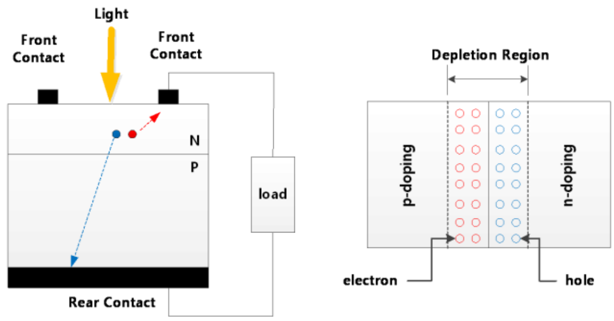
Abstract

We have examined the photovoltaic (PV) fundamentals, characteristics and maximum power point tracking (MPPT) of solar cell modules by using laboratory virtual instrumentation engineering workbench (LabVIEW) program. The idea of the proposed method is to enhance the PV cell performance. The improved efficiencies were 0.91% when the step size was 0.1V and 1.12% when 0.5V for sunny day while the efficiency were 0.59% when 0.1V and 0.69% when 0.5V for partial shading day. The PV cell models are simulated by the mathematical equations. The simulation and experiment of PV cell model are described to modify the characteristics of PV cell and study the maximum power point tracking (MPPT). To improve the performance of MPPT on both steady and transient dynamic state, we proposed the control step size method. The comparative study between fixed step size and control step size methods are described by the simulation and experiment results.

Keywords: PV cell, MPPT, LabVIEW, P&O, Step Size.
UCTION

Renewable energy is generated from unexhausted and constantly renewed resources. The renewable energy which is continuously replenished includes sunlight, geothermal heat, tides, water, wind, and various forms of biomass. The photovoltaic (PV) energy is one of the important roles of renewable energy. The demand of solar energy is significantly increasing because it does not pollute or cause any harmful function to the environment.

To enhance the PV cell performance, power control is needed. In solar system, the power generation depends on irradiance, temperature, and other conditions. Therefore, maximum power point tracking (MPPT) algorithm is essential to control the PV power under the real situation. Most of the researcher used matrix laboratory (MATLAB) simulation which is very effective to simulate the PV systems[1-3]. In this paper, we utilize the laboratory virtual instrumentation engineering workbench (LabVIEW) program. It is useful not only for simulation but also for implementing an automation system. Abdul et al. have reported the analysis of solar photovoltaic module at different temperature irradiation, series resistance and shunt resistance by using LabVIEW[4]. They have described the effect of resistance to the maximum power point and used Newton Raphson algorithm for finding the root of a nonlinear function[4]. Berrera et al. has compared seven different maximum power point tracking algorithm and their performance under the presence of solar irradiance variations[5]. Revankar et al. have published for the complete and effective utilization of the available energy from the PV[3]. They have discussed the tracking position of the sun and positioning of PV panel to operate at the maximum power point[3]. Esram et al. have reported the computation technique of maximum voltage and current measurements under different the irradiance and the temperature using a model of the PV module[6]. Most of the algorithm depended upon the starting point of the algorithm. Mei et al. have proposed a novel improved variable step size incremental resistance maximum power point tracking method[7]. They have described the proposed method is more suitable to practical operation conditions[7].



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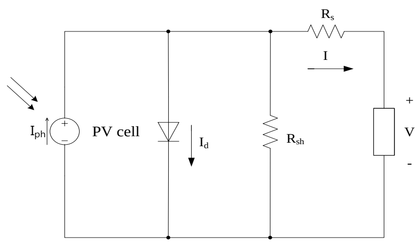

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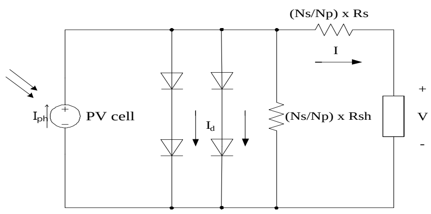

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Figure 1. Scheme and equivalent circuits of photovoltaic cell. (a) PV cell operating principle, (b) PV cell equivalent circuit, and (c) PV module and array equivalent circuit.

The various kind of MPPT algorithms are reported. Among them, the popular hill climbing methods are selected in this paper. For the hill climbing method, 'Perturb and Observe' (P&O) and 'Incremental Conductance' (IC) are simulated and experimented by using LabVIEW. It is also modified the effect of step size to P&O because the traditional MPPT method can not control speed and oscillation under steady and dynamic state simultaneously. To improve the performance of MPPT on both steady and transient dynamic state, we proposed the control step size method to enhance the PV performance.

PV CELL OPERATION & MODEL, PARAMETERS & EFFECTS, AND MAXIMUM POWER POINT TRACKING

A. PV Cell Operation & Model

The basic principle of PV cell is the PN junction diode and it generates the electricity by the photovoltaic effect. The equivalent circuit of solar cell is shown in Fig. 1[8]. When the sun shines on the Earth, only the photon of which energy is higher than the band gap can generate electron-hole pair in the solar cell. The electron and hole are separated by the electric field existing at the p-n junction. Electric field forces the electrons to get free and across the n-side and move to the bottom of the cell across the load. Flowing of electrons create electricity through the connecting wire. Complete circuit occurs when the hole moves across the junction toward the p-side by the electric field and recombines with the electron (See Fig. 1(a)).

Table.1. Geometric value and specification of SP 20-12M. The specification data are measured under standard test condition (STC) (irradiance 1 kW/m^2 and temperature 25°C and 1.5AM).

Variable	Definition	Value
I_{ph}	light-generated current or photocurrent	
I_s	cell saturation of dark current	
q	electron charge	1.6×10^{-19} C
κ	Boltzmann constant	1.38×10^{-23} J/K
T	cell working temperature	
A	ideal factor	1.5
R_{sh}	shunt resistance	
R_s	series resistance	
G	solar insolation	
K_1	cell short-circuit current temperature coefficient	0.003
T_r	cell reference temperature	25°C
V_m	Optimum operating voltage	18V
V_{oc}	Open circuit voltage	21.24V
I_{sc}	cell reverse saturation current	1.22A
I_m	Optimum operating current	1.11A
I_{rs}	cell reverse saturation current	
E_g	band-gap energy of the semiconductor	1.5eV
N_s	number of cells in series in module or array	36
N_p	parallel in module or array	1

In a general model the I-V characteristics of a PV cell can be written as [8]:

$$I = I_{ph} - I_s\left[\exp\left(\frac{q(V+IR_s)}{\kappa TA}\right) - 1\right] - \frac{(V+IR_s)}{R_{sh}} \quad (1)$$

$$I_{ph} = G[I_{sc} + K_1(T - T_r)] \quad (2)$$

$$I_s = I_{rs} \times \left(\frac{T}{T_r}\right)^3 \exp\left[qE_g \frac{\left(\frac{1}{T_r} - \frac{1}{T}\right)}{kA}\right] \quad (3)$$

$$\mathrm{I_{rs}} = \frac{\mathrm{I_{sc}}}{\exp\left[\frac{\mathrm{qV_{oc}}}{\mathrm{N_s\,kAT}}\right] - 1} \quad (4)$$

$$I = I_{ph} - I_s\left(exp\left[\frac{qV}{kTA}\right] - 1\right) \quad (5)$$

The notation of the equations is shown in Table 1 (See Fig. 1(b)). As well-known, PV cell produces low power. Therefore, solar modules in series or parallel array are needed to produce enough power to electrical appliances (See Fig. 1(c)). Solar array and module can be described as in Eq. (6)[8].

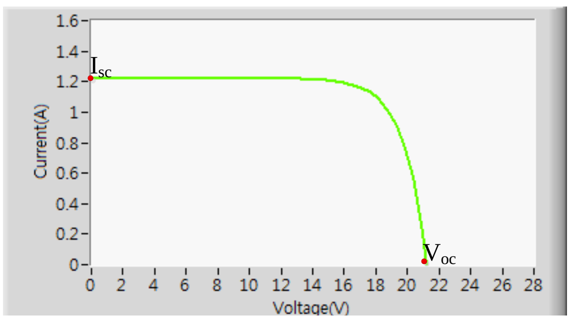
$$I = N_p I_{ph} - N_p I_s\left(\exp\left[\frac{q\left(\frac{V}{\mathrm{N_s}} + \frac{I\mathrm{R_s}}{\mathrm{N_p}}\right)}{kTA}\right] - 1\right) - \frac{\left(\frac{V\mathrm{N_p}}{\mathrm{N_s}} + IR_s\right)}{R_{sh}} \quad (6)$$

For ideal module and array equation can be written as following[8].

$$I = N_p I_{ph} - N_p I_s\left(\exp\left[\frac{qV}{N_s kTA}\right] - 1\right) \quad (7)$$

B. PV Cell Parameters & Effects

Figure 2 shows PV cell parameters and effects. The short circuit current (I_{sc}) is the main current which may be drawn from the solar cell and depends upon the area of solar cell, light intensity, the spectrum of the incident light, the optical properties and the collection probability. The open circuit voltage is the maximum voltage of the PV cells.



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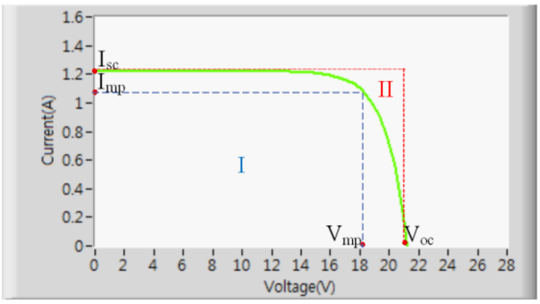

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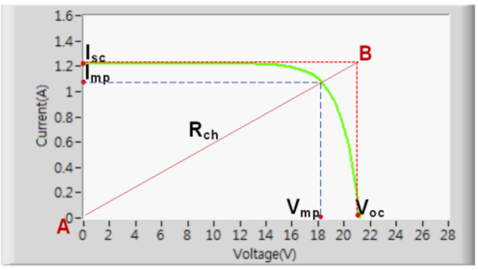

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Figure 2. PV parameters and effects. (a) open-circuit voltage and short-circuit current, (b) fill factor, and (c) resistance effect.

Open circuit voltage (V_{oc}) depends upon the saturation current and light-generated current. The ratio of the maximum power from the PV to the product of open circuit voltage and short circuit current is called fill factor. The maximum current and voltage from PV cell is short circuit current and open circuit voltage but that conjugate is not a maximum power because the operation power of PV is zero at that point. The maximum power can be calculated by the product of maximum power voltage (V_{mp}) and maximum power current (I_{mp}). The higher value of area I that I-V curve is squareness has high fill factor as shown in Fig. 2(b). Generally, PV efficiency measured under the standard conditions such as AM1.5, temperature, and irradiance. The efficiency is directly proportional to the fill factor. There are two kinds of resistances for the photovoltaic cells. One is the characteristics resistance which is the output resistance of the solar cell at the maximum power point. To achieve maximum power point, the load should be equal to the characteristic resistance. In Fig. 2(c), the inverse of the slope AB is the characteristics resistance of the PV cells. The characteristic resistance is one of the important factors for controlling the maximum power point of PV cells. Higher photo-generated current is due to increased irradiation because it is directly proportion to the incident radiation. The short circuit current is linearly proportional to the irradiation whereas exponentially increasing the open circuit voltage. Solar cell is a kind of semiconductor device that why it is impacted by the temperature. The most effected by the temperature is the open-circuit voltage that is increased when increasing the temperature but short circuit current is exponentially decreased.

C. Maximum Power Point Tracking

As already reported, P&O and IC methods are used to find MPP because of easy implementation and good performance[8].

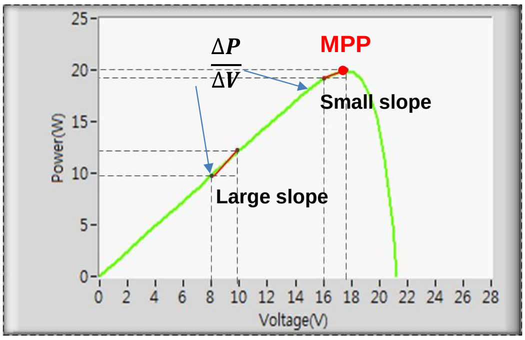


Figure 3. Maximum power point.

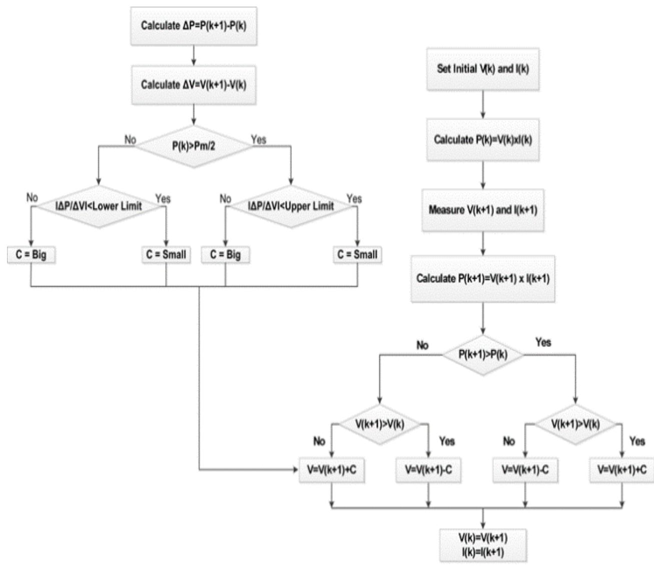
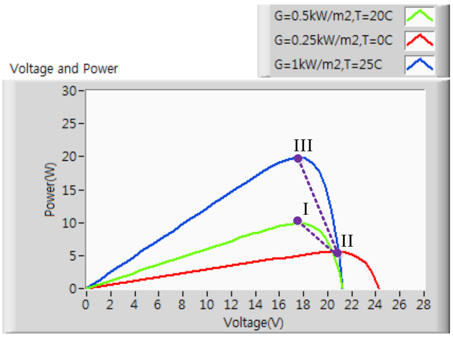


Figure 4. P&O with CSS method.

The P&O method has the large oscillation near the maximum power point when we use the large step size. On the other hand, the tracking speed is slow with the small step size because both directly depend on voltage step size. The control step size based on the slope of (ΔP/ΔV) is shown in Fig. 3. The larger the slope, the power is more far away from the MPP whereas the larger step size will be needed. The comparison states are divided into two, the power and the slope (ΔP/ΔV). By the simulation result the power is greater than 10W, the limit value is 0.5 and other is 0.2. The control method provides a larger step size when the operating point is far away from the MPP to obtain efficient tracking speed and changes to small step size when the slope is under the limit for the better steady-state performance. P&O with control step size method (CSS) is the combination of control step size method[8] and P&O MPP under the same conditions in Fig. 4. The control system modifies the step value and P&O tracks of the actual MPP.

SIMULATION & EXPERIMENTAL RESULTS

The study of PV module characteristics based on the mathematical model which are shown in Eq. (1) ~ (7)[8]. Ideal equation is preferred for easy implementation of both PV module modelling and MPPT simulation.



Case	Temperature(℃)	Irradiation(kW/m²)	Time(min)
I	20	0.5	8.3
II	0	0.25	8.3
III	25	1	8.3

Figure 5. Condition of simulation.

The PV module (SP20-12M) used for simulation, experiment, and their specifications are described in Table 1. The simulation setup is divided into two parts which are PV cell characteristics and MPPT algorithms. The simulation and experimental setups were described well at the previous report[8]. The whole system has been modeled on LabVIEW 2012 which is the powerful programing language to simulate the solar system. The conditions of simulation I to II (decreasing the power) and II to III (increasing the power) and their scenarios are shown in Fig. 5. Figure 6 shows the comparison of FSS P&O (0.1V) and CSS P&O simulation results. The duration time is 2.5 min under the sunny day and partial shading conditions. To study about dynamic performance of proposed MPPT, we intentionally created partial shading on the solar module during the testing time.

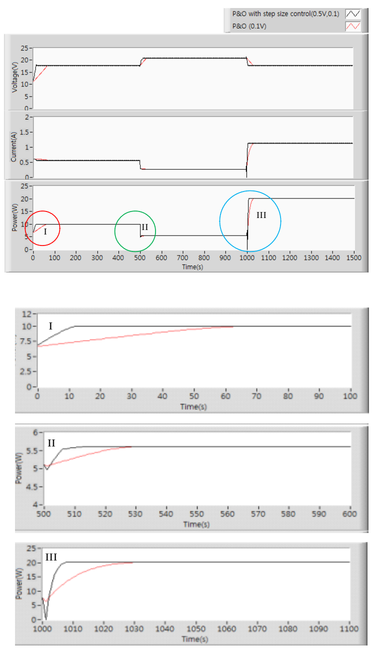


Figure 6. Comparison of FSS P&O (0.1V) and CSS P&O simulation results.

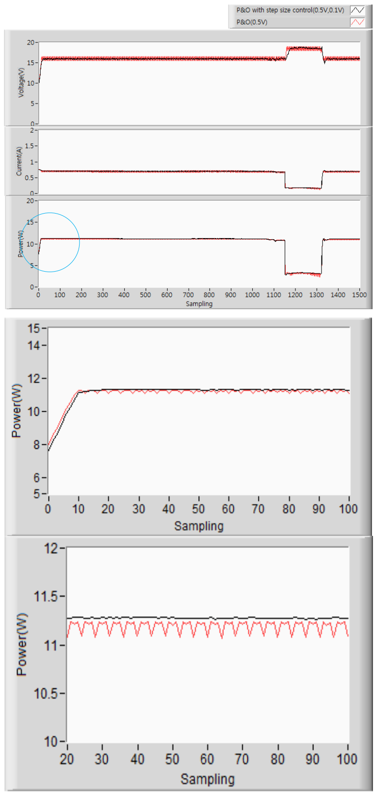
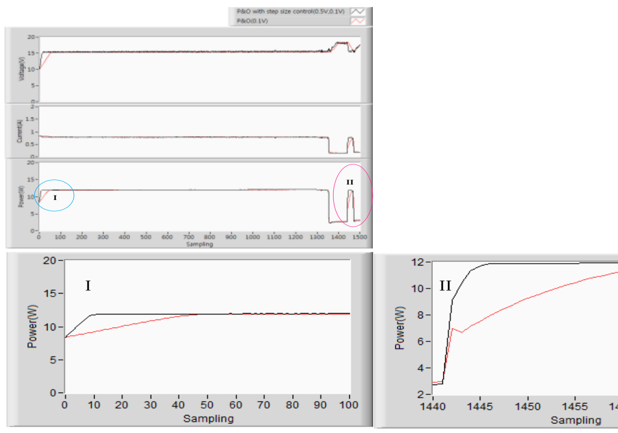


Figure 7. Comparison of FSS P&O (0.5V) and CSS P&O under partial shading experimental results.

The P&O with control method and traditional P&O is tested under sunny condition to investigate the steady state performance. Firstly, the fixed step size using large step size (0.5V) for efficient tracking speed. And then, small fixed step size is provided for investigate the performance of steady state. The large fixed step size P&O method have the good performance of tracking but the drawback of oscillation is occurred at steady state. The control step size modifies the step size depend upon the condition of slope. So, it can track quickly and also enhance the steady state ability.



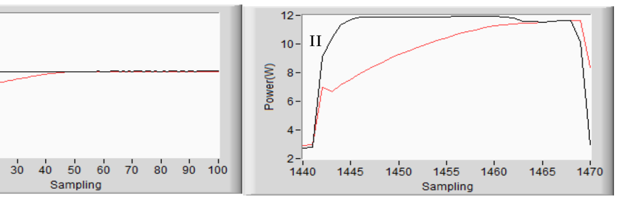


Figure 8. Comparison of FSS P&O (0.1V) and CSS P&O under partial shading experimental results.

Table 2. Comparison of P&O algorithm with control step size and fixed step size between sunny day and under partial shading day

	Sunny day		Partial shading day	
Step size	0.1V	0.5V	0.1V	0.5V
P&O with CSS	1907.46 [J]	2017.32 [J]	1537.95 [J]	1689.36 [J]
P&O	1890.29 [J]	1995.02 [J]	1528.92 [J]	1677.83 [J]
Improved efficiency	0.91 [%]	1.12 [%]	0.59 [%]	0.69 [%]

The small fixed step size can reduce the oscillation but the tracking time is increased. The control step size method can track like large fixed step and reduce the oscillation as small fixed step. Under sunny day, the small step size is better than the large step size. However, the proposed method is more advantageous than both large and small step size. Under partial shading study are described the following. The control step size is more advantage than the large fixed step P&O (0.5V) under the partial shading condition. The proposed method can perform well under the dynamic weather conditions in Fig. 7. The control step size reduces the energy losses under the dynamic state more than small fixed step size. The energy and efficiency can be calculated by the equation (8) and (9).

$$\text{Energy} = \sum p(k) \times \Delta t(k) \quad (8)$$

$$\text{Improved Efficiency} = \frac{P_{css} - P_{fss}}{P_{fss}} \quad (9)$$

Where p(k) is power, t is time, Pcss is power under control step size, and Pfss is fixed step size.

The control step size reduces the energy losses under the dynamic state more than small fixed step size. Figure 8 clearly shows the proposed method is more efficient than the small fixed step size. The comparative results are summarized in the Table 2. The experimental results clearly show that the control step size is more effective than the fixed step size. Therefore, it is more advantageous than the fixed step size P&O.

CONCLUSIONS

PV energy is the important role for the future energy plan. In this paper, we modified the PV and their maximum power point tracking by using LabVIEW. We simulated the PV model using mathematical equations and experimented the PV characteristics for study of the PV fundamentals. For simplicity and actual maximum power point tracking, the hill climbing methods, P&O with CSS algorithm, were tested. By the simulation and experimental results, the two methods are similar properties. Considering the optimize power of PV, P&O with step size control method is superior compared with traditional one under steady state as well as dynamic condition.

ACKNOWLEDGMENTS

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