태양광 시스템의 일사량과 모듈온도에 따른 I-V 및 P-V 특성에 관한 연구

논 문
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Characteristics of Photovoltaic I-V and P-V According to the Irradiation and Module Temperature

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Abstract - Photovoltaic (PV) energy is a renewable and harmless energy which offers many advantages. However, solar energy is an extreme intermittent and inconstant energy source. In order to improve the photovoltaic system efficiency and utilize the solar energy more fully, and the DC current and DC power vary with the irradiation and module temperature, it is necessary to study the characteristics of photovoltaic I-V and P-V according to the external factors. This paper presents the analysis of characteristics of photovoltaic I-V and P-V according to the irradiation and the module temperature. The results show that the DC current and the DC power of the photovoltaic system are increased along with the increasing values of irradiation and module temperature.

Key Words : Photovoltaic, I-V, P-V, Irradiation, Module Temperature

1. Introduction

In recent years, countries around the world are seeking and developing a new, clean, safe and renewable energy to satisfy the increasing and urgent demand for energy. Developing the renewable energy source is an important measure to increase the energy supply capacity, improve the energy structure, safeguard the energy security and to restore the natural environment gradually. It has very vital significance to construct the resource conservation and the environment-friendly society, and to realize the sustainable development of economic society. Meanwhile, when the technology is getting higher and higher in economical and military fields, the demand of photoelectron products and technology is growing unceasingly. Solar cell is a kind of device which using the interaction of sunlight and materials to generate electrical energy [1~4]. During the process of using solar energy, no exhaust gases release such as CO_2、NO_x and SO_x. The cost of photovoltaic energy is relatively high, but from a long-term point of view, along with the technology progress, as well as the gradual consumption, solar energy possibly becomes one of mainstream energy after 2030, has inestimable development potential. However, because solar energy is an extreme intermittent and inconstant energy source, the electric power generated by the PV panel varies with the solar radiation and temperature [5].

In order to improve the photovoltaic system efficiency and utilize the solar energy more fully, it is necessary to study the characteristics of photovoltaic I-V and P-V according to the external factors such as the irradiation and module temperature. The radiative energy output from the sun derives from a nuclear fusion reaction [6]. So the irradiation has an important impact to the output power of the solar cell.

The objective of this paper is to analyze the characteristics of photovoltaic I-V and P-V according to different irradiation which is from 100[W/m^2] to 800[W/m^2] and module temperature which is from 15[℃] to 55[℃]. What's more, from the results, we can know the factors effect the photovoltaic system efficiency and furthermore utilize the solar energy more fully.

2. Theory

Figure 1 show that there is a two-stage energy conversion system including a DC-DC boost converter, an inverter and the corresponding controllers connected between the PV array and the electrical power system. Theboost converter is used to increase the PV voltage

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for the inverter circuit and also plays a role in the intermediate circuit for tracking the maximum power point [7]. In the other hand, DC-DC converter is controlled to transfer energy to the batteries and inverter [8].

In addition, the inverter circuit is used to convert the direct current out from the PV array to the alternating current which flows into the utility or local loads. The inverter controller has two main functions. One is to synchronize the output current with the grid voltage, which means the power factor is equal to unity. The other function is to control the DC link voltage, namely, control the DC voltage in order to prevent the voltage of batteries charged from exceeding the voltage rating. To achieve the two goals, an inner current control loop and an outer voltage control loop are used [7,9].

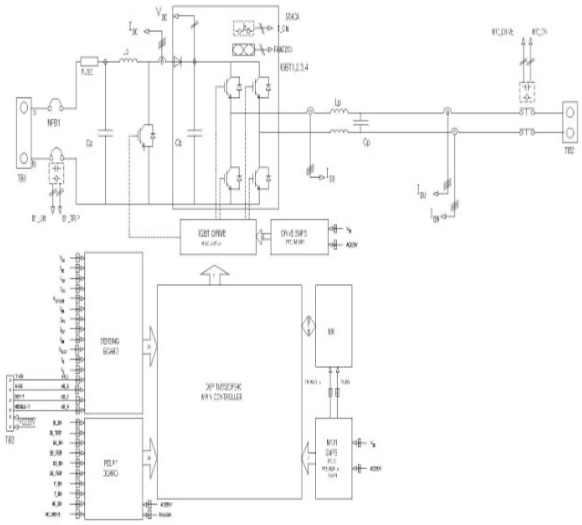


Fig. 1 Power circuit for PV system

The output power of $P_m(t)$ at MPP (maximum power point) is expressed as a function of the irradiation Q and the module temperature t.

$$P_m(t) = P_m \times Q \times [1 + \alpha(t - 25)] \tag{1}$$

where, P_m is the rated output power[W], and α is the temperature coefficient (-0.005/℃℃).

3. Experiment

The experimental solar array consists of 8EA modules which are made of single crystal silicon. The efficiency of the module is 16[%]. The specifications of the experimental device are as follows: the device rated power is 800[W], the maximum power P_{MPP} is 100^{+} W_p±5[%], the voltage at MPP (maximum power point) is 34.5[V], the current at MPP is 2.90[A], the open-circuit voltage is 42.5[V], the short-circuit current I_{sc} is 3.20[A]. The measured data include DC current[A], DC voltage[V], AC current[A], AC voltage[V], AC power[W], power generation[Wh], module temperature and ambient temperature.

4. Results and Discussion

4.1 I-V characteristics according to the irradiation

Fig. 2 presents the I-V characteristics according to the irradiation which is from 100[W/m^2] to 800[W/m^2]. Fig. 2 (a) shows the I-V characteristics according to the irradiation of 100[W/m^2]. In this case, along with the increase of DC voltage from 225[V] to 267[V], the value of module temperature decreases from 32[℃] to 19[℃].

Fig. 2 (b) shows the I-V characteristics according to the irradiation of 200[W/m^2]. In this case, along with the increase of DC voltage from 247[V] to 279[V], the value of module temperature decreases from 38[℃] to 21[℃].

Fig. 2 (c) shows the I-V characteristics according to the irradiation of 300[W/m^2]. In this case, along with the increase of DC voltage from 240[V] to 269[V], the value of module temperature decreases from 38[℃] to 33[℃].

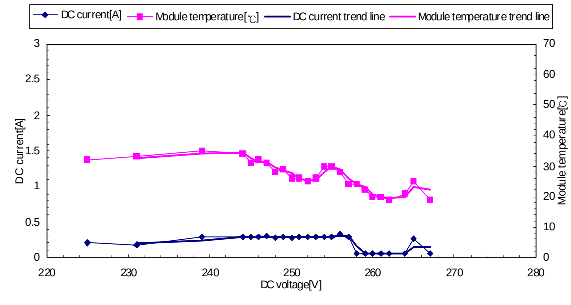
Fig. 2 (d) shows the I-V characteristics according to the irradiation of 400[W/m^2]. In this case, along with the increase of DC voltage from 241[V] to 275[V], the value of module temperature decreases from 48[℃] to 32[℃].

Fig. 2 (e) shows the I-V characteristics according to the irradiation of 500[W/m^2]. In this case, along with the increase of DC voltage from 239[V] to 272[V], the value of module temperature decreases from 50[℃] to 33[℃].

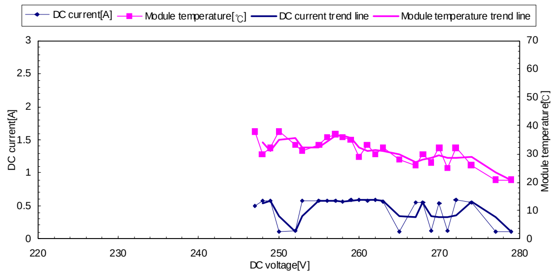
Fig. 2 (f) shows the I-V characteristics according to the irradiation of 600[W/m^2]. In this case, along with the increase of DC voltage from 244[V] to 269[V], the value of module temperature decreases from 49[℃] to 35[℃].

Fig. 2 (g) shows the I-V characteristics according to the irradiation of 700[W/m^2]. In this case, along with the increase of DC voltage from 242[V] to 263[V], the value of module temperature decreases from 57[℃] to 42[℃].

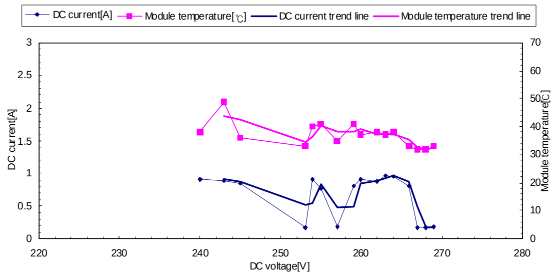
Fig. 2 (h) shows the I-V characteristics according to the irradiation of 800[W/m^2]. In this case, along with the increase of DC voltage from 233[V] to 257[V], the value of module temperature decreases from 61[℃] to 47[℃].



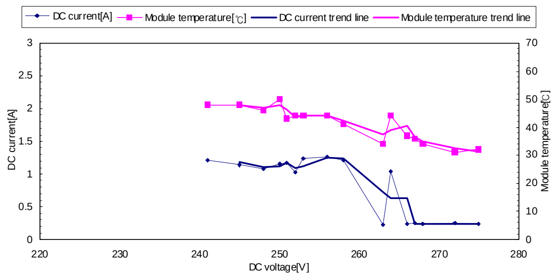
(a) 100[W/m^2]



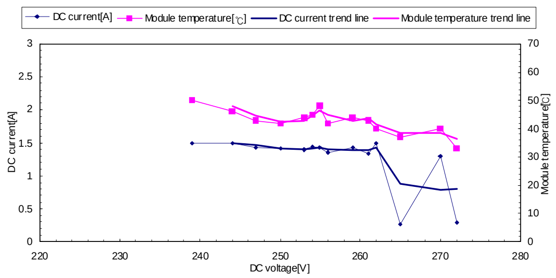
(b) 200[W/m^2]



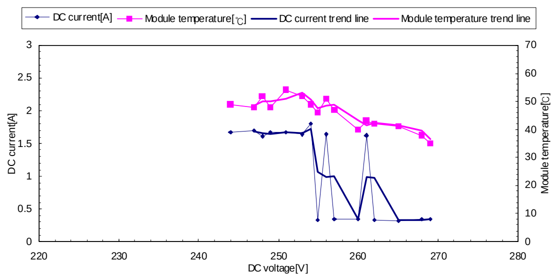
(c) 300[W/m^2]



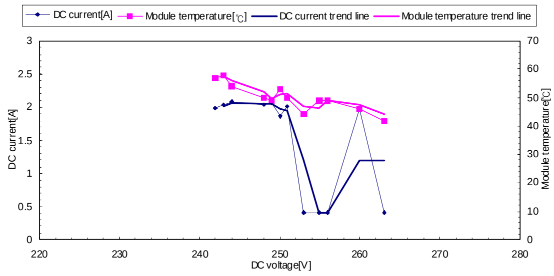
(d) 400[W/m^2]



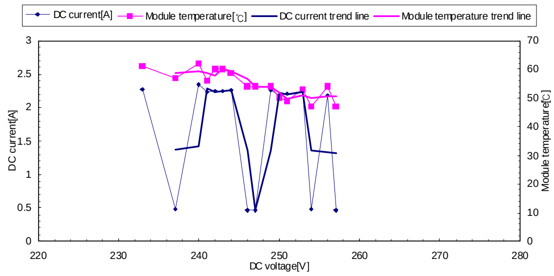
(e) 500[W/m^2]



(f) 600[W/m^2]



(g) 700[W/m^2]



(h) 800[W/m^2]

Fig. 2 I-V characteristics according to irradiation

Fig. 2 indicates that when the irradiation increases, the DC current increases. The area under the line of DC current presents the DC power, so it can be obtained that when the irradiation increases, the DC power is also increasing. The result is matched with the equation (1).

4.2 P-V characteristics according to the irradiation

Fig. 3 presents the P-V characteristics according to the irradiation which is from 100[W/m^2] to 800[W/m^2]. Fig. 3 (a) shows the P-Vcharacteristics according to the irradiation of 100[W/m^2]. In this case, along with the increase of DC voltage from 225[V] to 267[V], the value of module temperature declines from 32[℃] to 19[℃].

Fig. 3 (b) shows the P-V characteristics according to the irradiation of 200[W/m^2]. In this case, along with theincrease of DC voltage from 247[V] to 279[V], the value of module temperature declines from 38[℃] to 21[℃].

Fig. 3 (c) shows the P-V characteristics according to the irradiation of 300[W/m^2]. In this case, along with the increase of DC voltage from 264[V] to 291[V], the value of module temperature declines from 32[℃] to 14[℃].

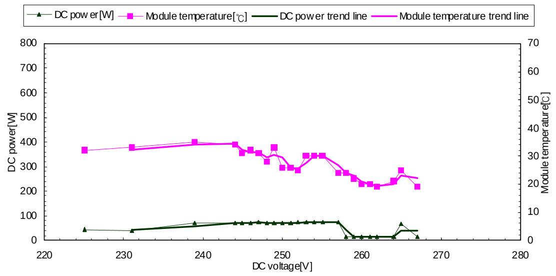
Fig. 3 (d) shows the P-V characteristics according to the irradiation of 400[W/m^2]. In this case, along with the increase of DC voltage from 263[V] to 296[V], the value of module temperature declines from 38[℃] to 12[℃].

Fig. 3 (e) shows the P-V characteristics according to the irradiation of 500[W/m^2]. In this case, along with the increase of DC voltage from 257[V] to 292[V], the value of module temperature declines from 43[℃] to 12[℃].

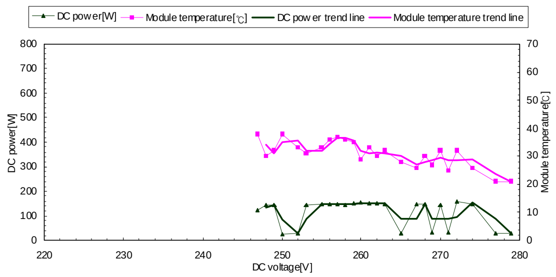
Fig. 3 (f) shows the P-V characteristics according to the irradiation of 600[W/m^2]. In this case, along with the increase of DCvoltage from 252[V] to 291[V], the value of module temperature declines from 43[℃] to 17[℃].

Fig. 3 (g) shows the P-V characteristics according to the irradiation of 700[W/m^2]. In this case, along with the increase of DC voltage from 250[V] to 284[V], the value of module temperature declines from 53[℃] to 20[℃].

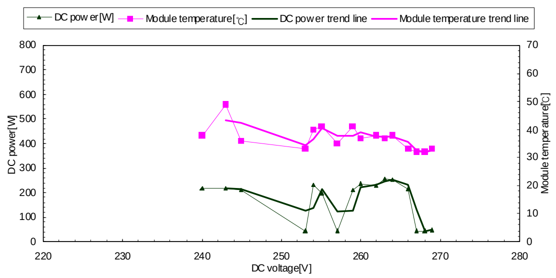
Fig. 3 (h) shows the P-V characteristics according to the irradiation of 800[W/m^2]. In this case, along with the increase of DC voltage from 242[V] to 277[V], the value of module temperature declines from 47[℃] to 27[℃].



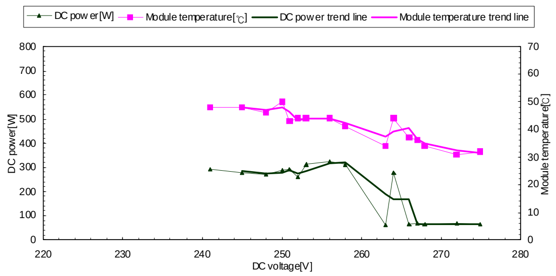
(a) 100[W/m^2]



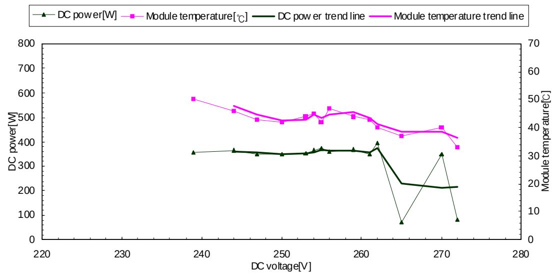
(b) 200[W/m^2]



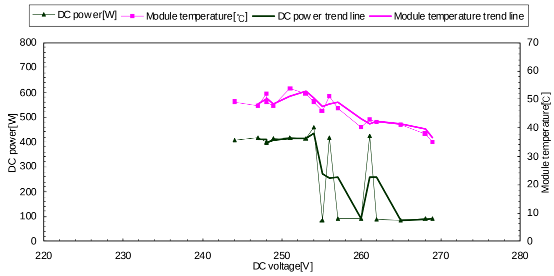
(c) 300[W/m^2]



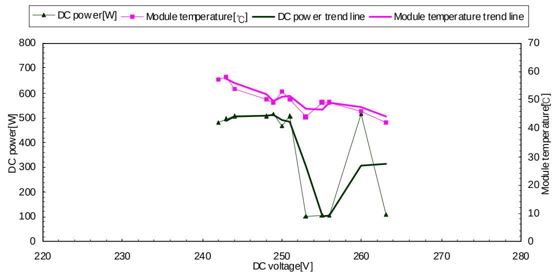
(d) 400[W/m^2]



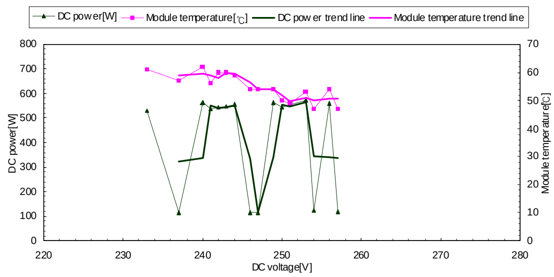
(e) 500[W/m^2]



(f) 600[W/m^2]



(g) 700[W/m^2]



(h) 800[W/m^2]

Fig. 3 P-V characteristics according to irradiation

Fig. 3 (i) shows the P-V characteristics according to the irradiation of 900[W/m^2]. In this case, along with the increase of DC voltage from 240[V] to 277[V], the value of module temperature declines from 58[℃] to 25[℃].

Fig. 3 shows that when the irradiation increases, the DC power increases. That means, there is a positive correlation between the PV DC power and the irradiation. The result is matched with the equation (1).

4.3 I–V characteristics according to the module temperature

Fig. 4 presents the I–V characteristics according to the module temperature which is from 15[℃] to 55[℃]. Fig. 4 (a) shows the I–V characteristics according to the module temperature of 15[℃]. In this case, along with the increase of DC voltage from 193[V] to 313[V], the value of irradiation increases from 11[W/m^2] to 757[W/m^2] and the value of DC current increases from 0.012[A] to 2.026[A].

Fig. 4 (b) shows the I–V characteristics according to the module temperature of 15[℃]. In this case, along with the increase of DC voltage from 192[V] to 302[V], the value of irradiation increases from 25[W/m^2] to 811[W/m^2] and the value of DC current increases from 0.07[A] to 2.144[A].

Fig. 4 (c) shows the I–V characteristics according to the module temperature of 20[℃]. In this case, along with the increase of DC voltage from 188[V] to 300[V], the value of irradiation increases from 16[W/m^2] to 513[W/m^2] and the value of DC current increases from 0.038[A] to 1.386[A].

Fig. 4 (d) shows the I–V characteristics according to the module temperature of 25[℃]. In this case, along with the increase of DC voltage from 209[V] to 287[V], the value of irradiation increases from 30[W/m^2] to 557[W/m^2] and the value of DC current increases from 0.094[A] to 1.512[A].

Fig. 4 (e) shows the I–V characteristics according to the module temperature of 30[℃]. In this case, along with the increase of DC voltage from 260[V] to 286[V], the value of irradiation increases from 181[W/m^2] to 640[W/m^2] and the value of DC current increases from 0.408[A] to 1.796[A].

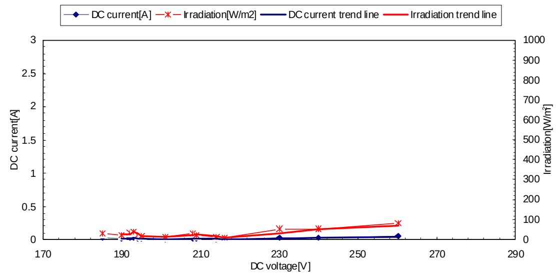
Fig. 4 (f) shows the I–V characteristics according to the module temperature of 35[℃]. In this case, along with the increase of DC voltage from 254[V] to 278[V], the value of irradiation increases from 636[W/m^2] to 881[W/m^2] and the value of DC current increases from 1.868[A] to 2.482[A].

Fig. 4 (g) shows the I–V characteristics according to the module temperature of 40[℃]. In this case, along with the increase of DC voltage from 249[V] to 281[V], the value of irradiation increases from 554[W/m^2] to 862[W/m^2] and the value of DC current increases from 1.516[A] to 2.256[A].

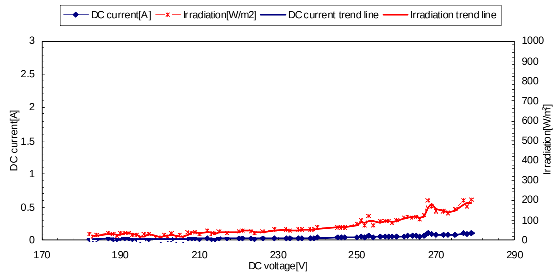
Fig. 4 (h) shows the I–V characteristics according to the module temperature of 45[℃]. In this case, along with the increase of DC voltage from 246[V] to 261[V], the value of irradiation increases from 610[W/m^2] to 935[W/m^2] and the value of DC current increases from 1.78[A] to 2.698[A].

Fig. 4 (i) shows the I–V characteristics according to the module temperature of 50[℃]. In this case, along with the increase of DC voltage from 230[V] to 256[V], the value of irradiation increases from 724[W/m^2] to 899[W/m^2] and the value of DC current increases from 2.13[A] to 2.55[A].

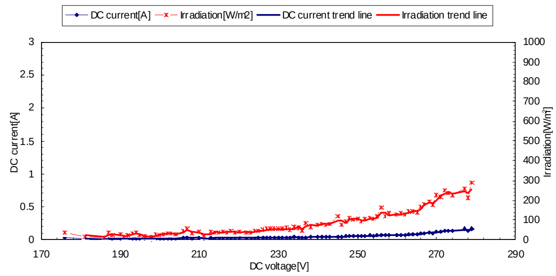
From Fig. 4, we could find that when the module temperature increases, the DC current increases.



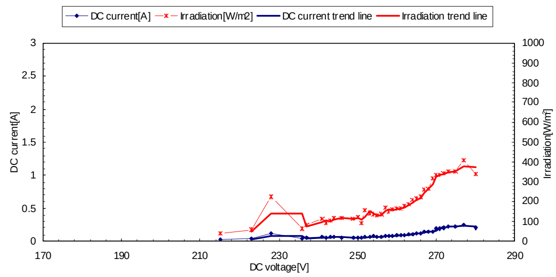
(a) 15[℃]



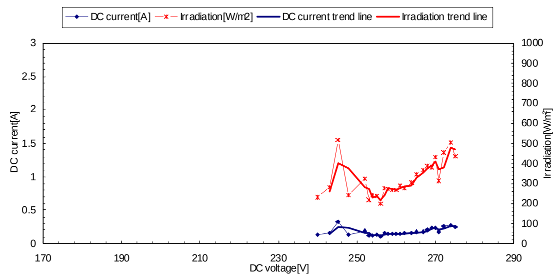
(b) 20[℃]



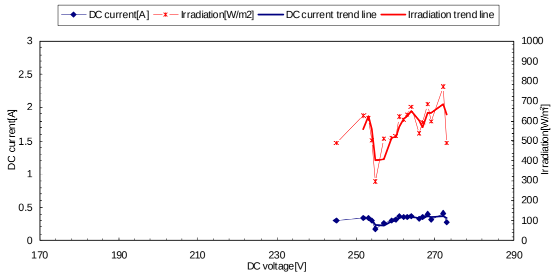
(c) 25[℃]



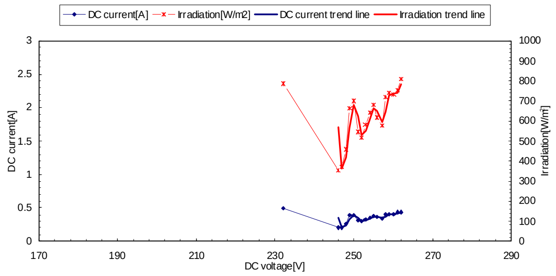
(d) 30[℃]



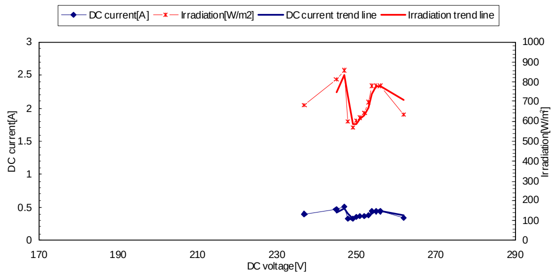
(e) 35[℃]



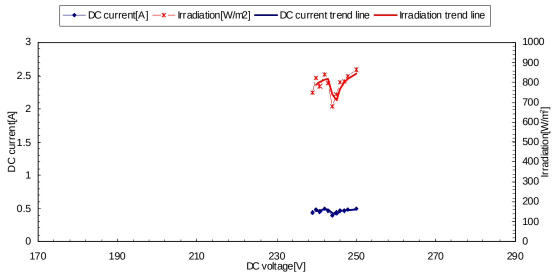
(f) 40[℃]



(g) 45[℃]



(h) 50[℃]



(i) 55[℃]

Fig. 4 I-V characteristics according to module temperature

4.4 P-V characteristics according to the module temperature

Fig. 5 presents the P-Vcharacteristics according to the module temperature which is from 15[℃] to 55[℃]. Fig. 5 (a) shows the P-V characteristics according to the module temperature of 10[℃]. In this case, along with the increase of DC voltage from 193[V] to 313[V], the value of irradiation increases from 11[W/m^2] to 757[W/m^2] and the value of DC power increases from 2.316[W] to 634.138[W].

Fig. 5 (b) shows the P-V characteristics according to the module temperature of 15[℃]. In this case, along with the increase of DC voltage from 192[V] to 302[V], the value of irradiation increases from 25[W/m^2] to 811[W/m^2] and the value of DC power increases from 13.44[W] to 647.488[W].

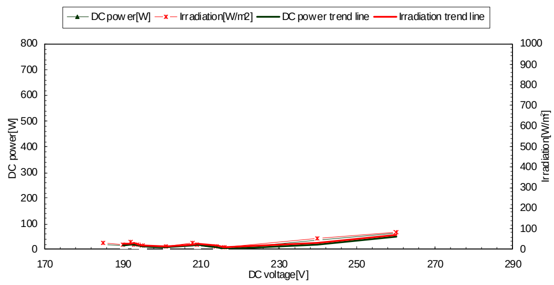
Fig. 5 (c) shows the P-V characteristics according to the module temperature of 20[℃]. In this case, along with the increase of DC voltage from 188[V] to 300[V], the value of irradiation increases from 16[W/m^2] to 513[W/m^2] and the value of DC power increases from 7.144[W] to 397.782[W].

Fig. 5 (d) shows the P-V characteristics according to the module temperature of 25[℃]. In this case, along with the increase of DC voltage from 209[V] to 287[V], the value of irradiation increases from 30[W/m^2] to 557[W/m^2] and the value of DC power increases from 19.646[W] to 433.944[W].

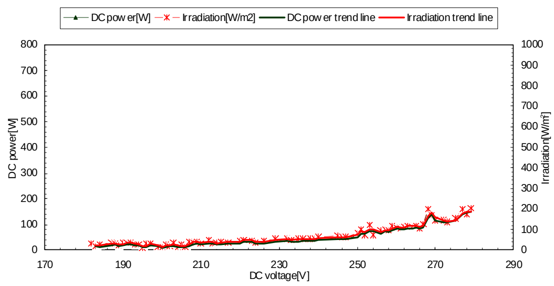
Fig. 5 (e) shows the P-V characteristics according to the module temperature of 30[℃]. In this case, along with the increase of DC voltage from 260[V] to 284[V], the value of irradiation increases from 181[W/m^2] to 703[W/m^2] and the value of DC power increases from 106.08[W] to 477.548[W].

Fig. 5 (g) shows the P-V characteristics according to the module temperature of 40[℃]. In this case, along with the increase of DC voltage from 249[V] to 281[V], the value of irradiation increases from 554[W/m^2] to 890[W/m^2] and the value of DC power increases from 389.612[W] to 677.808[W].

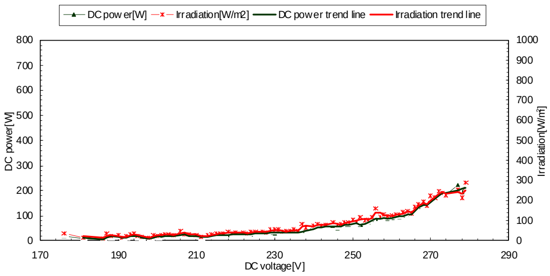
Fig. 5 (h) shows the P-V characteristics according to the module temperature of 45[℃]. In this case, along with the increase of DC voltage from 246[V] to 261[V], the value of irradiation increases from 607[W/m^2] to 935[W/m^2] and the value of DC power increases from 423.3[W] to 701.48[W].



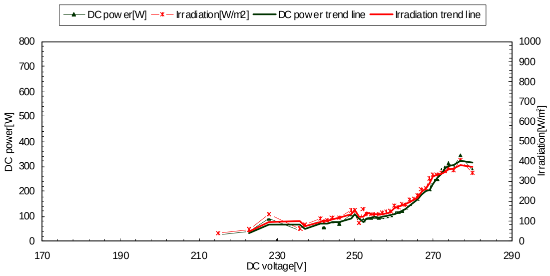
(a) 15[℃]



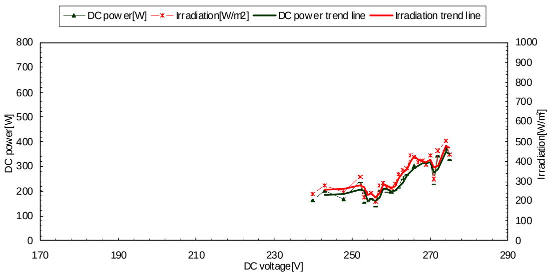
(b) 20[℃]



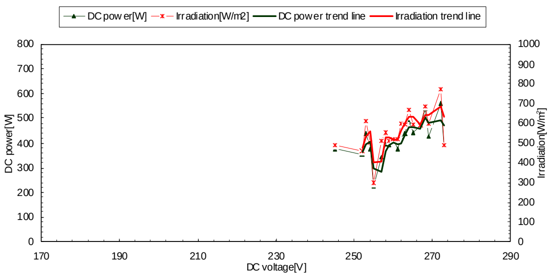
(c) 25[℃]



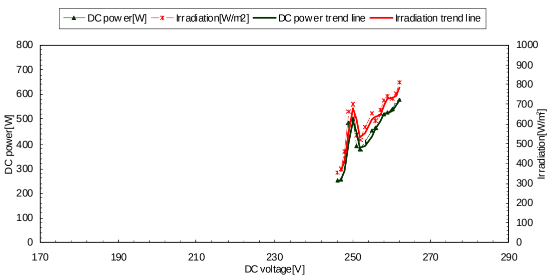
(d) 30[℃]



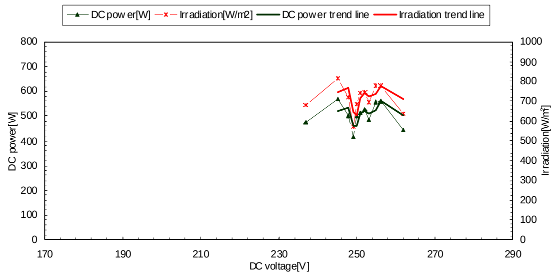
(e) 35[℃]



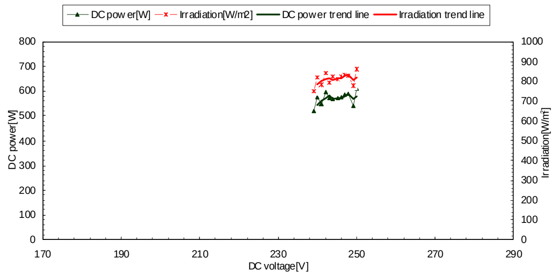
(f) 40[℃]



(g) 45[℃]



(h) 50[℃]



(i) 55[℃]

Fig. 5 P-V characteristics according to module temperature

Fig. 5 (i) shows the P-V characteristics according to the module temperature of 50[℃]. In this case, along with the increase of DC voltage from 230[V] to 256[V], the value of irradiation increases from 724[W/m^2] to 899[W/m^2] and the value of DC power increases from 515.46[W] to 647.7[W].

From Fig. 5, we could find that when the module temperature increases, the DC power is also increasing.

5. Conclusions

Characteristics of photovoltaic I-V and P-V according to the irradiation and module temperature have been presented in this paper. It indicates that when the irradiation increases, DC current and DC power are all increased. So it can be obtained that increasing the irradiation is an available method to increase the PV output power, furthermore, to increase the efficiency of PV system.

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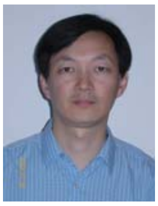

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