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Indoor Test Performance of PV Panel through Water Cooling Method

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Abstract

The purpose of this paper is discussed about how to increase the electrical efficiency of the photovoltaic (PV) panel in indoor test. The performance of PV panel depends on the environmental factors, which is solar radiation and operating temperature. These environmental factors will be reduced the electrical efficiency of PV panel due to increase in operating temperature of PV panel. The solar simulator is set up on a steel frame is used to lift all the halogen lamp bulbs. The halogen lamp bulbs act as a natural sunlight. Four sets of average solar radiation at the test surface of the solar simulator are measured as 413, 620, 821 and 1016 W/m². A DC water pump is used to overcome the problem of low efficiency of PV panel with water flow over the front surface of PV panel. This water cooling mechanism is one way to enhance the efficiency of PV panel for maintaining a low operating temperature during its operation period. The experimental results mentioned that the decrement of operating temperature and increase the power output of the PV panel with water cooling mechanism based on different fixed of solar radiation. The water spraying can be reduced heat on the front surface of the PV panel.

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Keywords: PV panel; electrical efficiency; water cooling mechanism; operating temperature; indoor test

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1. Introduction

All over the world, energy is an essential issue for human. Energy is classified into two different categories, which are non-renewable energy and renewable energy. As development outcomes of world economy, the world cannot continue to depend for long on fossil fuels (natural gas, oil and coal). Most of the world's energy is generated from fossil fuels. The reserves of fossil fuels are limited lead to the price of fossil fuels is continued increasing.

Renewable energy sources are becoming important as significantly benefits. Among all the renewable energy sources, PV energy is a very effective solution for renewable energy because of no pollution, abundance and completely free of cost. PV energy is energy that comes from the sun converts into electricity. Nowadays, the PV system is likely recognized and widely using in electric power applications. This is because it can be produced direct current electrical energy without any environmental harm when is exposed to solar radiation.

One of the main obstacles that face the operation of the PV panel is very low PV cell conversion electrical efficiency. This is also a key obstacle of scientists and researchers to enhance the electrical efficiency of PV cells. The power output yield by the PV system depends on several climatic factors [1] such as the solar radiation, the operating temperature and the state of the PV panels (ageing, cell material, cleanliness, etc.) [2]. The efficiency of PV plant is not only strongly depended on solar radiation, but also depends on the operating temperature of PV panels [3]. The cause of low PV cell conversion electrical efficiency is overheating due to excessive solar radiation and high operating temperatures. This is because the PV panel only 15 % of sunlight energy converts into electricity to the rest converted into heat.

To obtain increased electrical efficiency, the PV panel needs to be cooled by removing the excess heat from the cell assembly in some manner. Much different research and studies have been present to increase the electrical efficiency of PV panel. The common PV panel cooling methods are water cooling, air cooling, and heat pipe cooling [4]. Tiwari and Sodha [5] developed a thermal model of an integrated PV/T water cooled system and validated with experimental results. The experiments showed that the maximum thermal energy is caught up the circulating the fluids, and it has the minimal impact on temperature along with a general thermal efficiency. Hosseini et al. [6] stated that an experimental study to compare the performance of a PV system combined with a cooling system consisting of a thin film of water running on the top surface of the panel with an additional system to use the hot water produced by the system. The result of the combined system displayed that this system obtained increase power output efficiency and decreased the ambient temperature compared to the traditional PV system.

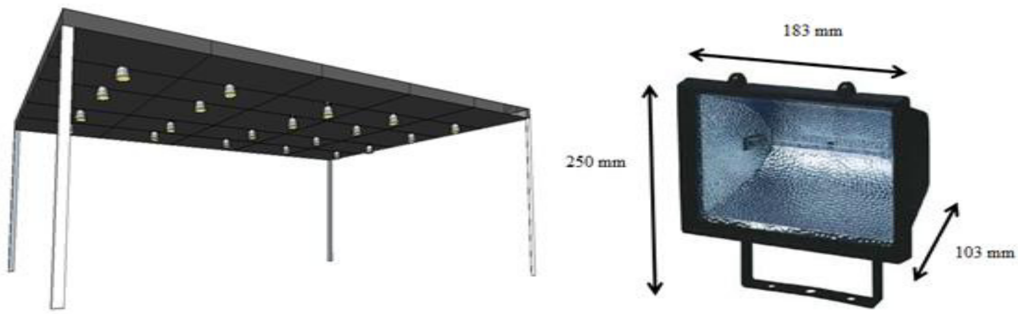
Solar simulator is very helpful in the solar energy experimental. This is because many scientists can be simulated the performance of PV panel under controllable indoor test facility. Solar simulators are a supply of light providing illumination in close proximity to the natural sunlight. They are applied for manipulating indoor testing of various elements and equipment, but more frequently for solar cell research, characterization; quality manipulates, and performance confirmation of completed modules. With a solar simulator, tests of PV panel performance can be carried out any chosen time, continued for 24 hours a day, and controlled for humidity and the other aspects of a local environment [7]. The type of lamp and the usage time can be affecting the change of the solar radiation of a general solar simulator light source. Kohraku and Kurokawa [8] developed a small solar simulator for PV cell measurements and it was found that the unevenness was about 3 % for testing a small illuminated area of 100 x 100 mm^2 of PV cells. One very high-power array was built at the NASA Glenn (formerly Lewis) Research Center, and consists of nine 30 kW arc lamps [9]. The total electrical power of this system is 270 kW that to test the space, power equipment in a thermal vacuum environment. A simple, low-cost solar simulator for indoor testing using 14 quartz halogen lamps of 1000 W followed in 1985 [10]. The solar radiation is in the range of 400 and 1500 W/m^2.

This paper describes the comparison of the performance of the PV panel with and without the water cooling mechanism by using solar simulator. The DC water pump is attached on the front side of the PV panel to spray water over the surface of PV panel. Moreover, the effect of spraying water over the PV panel on reduces the operating temperature of PV panels and reflection of PV panel. This water cooling mechanism has been used for measuring the performance of PV panel for different parameters such as operating temperature, voltage output, current output and power output.

2. Methodology

The arrangement of halogen lamp bulb with the solar simulator is displayed in Fig. 1 (a). The solar simulator is set up on a steel frame with the dimension is 183 cm by 183 cm by 183 cm is used to lift all the halogen lamp bulbs. This steel frame can be moved horizontally to adjust the solar simulator. Twenty units of halogen lamps with built in reflector is attached on the solar simulator. The lamp bulbs are located in four rows consisting of five lamp bulbs. All the lamps can be controlled separately or in groups, to various total amounts of solar radiation. The solar radiation can be regulated via a combination of amounts of lamp bulbs and height above the target. The center of halogen lamp bulb to another center of halogen lamp bulb spacing is close to 32 cm. The space distance between the PV panels and halogen lamps is approximately 67.3 cm, 82.5 cm, 95 cm and 119.38 cm for testing the various amounts of solar radiation, respectively.

From the exiting researches, several kinds of lamps were frequently used as the light source of the solar simulator, such as halogen lamps, metal halide lamp, mercury vapor lamps, incandescent spot, argon arc lamp and xenon arc lamps. The halogen lamp bulb is inexpensive, uncomplicated and convenient to operate and require only easy power supply units. The halogen lamp bulb is widely used in solar beam experiments (SBE) for solar simulator applications because it provides a very stable and smooth spectral output as illustrated in Fig. 1 (b) [7]. The color temperature of the lamp is the temperature of an ideal black body radiator with the peak irradiance at the same wavelength of the test source. The selection lamps used in this fabrication are high-efficiency lamps, with coiled-coil filament, giving white halogen light and manipulate at 230 V, Philips Halogen 500 W. However, it is inexpensive and excellent light output, maintenance, and improved consistency [11] makes it widely used as the infrared light source in multi-source solar simulators and the solar simulators with fewer spectrum requirements.



(a) (b)

Fig. 1. (a) Schematic of experimental set-up of solar simulator and (b) Halogen lamp bulb used for solar simulator.

Two units of 50W Monocrystalline PV panels were used to convert solar energy into electrical energy in this investigation. One of the PV panels is attached to a DC water pump to spray water over the front surface of the panel and the other panel is a traditional PV as a reference panel as shown in Fig. 2. A digital solar power meter, manufactured TES Electrical Electronic Corp. TES solar power meter is used to measure the solar radiation at the test surface of the solar simulator. Four sets of average solar radiation at the test surface of the solar simulator were measured as 413,620, 821 and 1016 W/m². PROVA 200 solar module analyzer was used to measure the performance of both PV panels with and without water cooling mechanism.

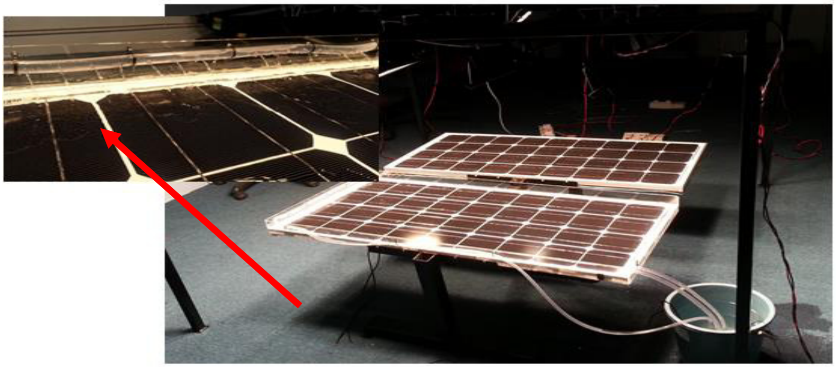


Fig. 2. PV panel with and without water cooling mechanism by using solar simulator.

3. Results

The fabricated solar simulator is capable of generating repeatable ranges of solar radiation at any time any weather in the indoor test. Four sets of average solar radiation have been measured by using the solar meter. The solar radiation in the test area of the solar simulator was assumed to be constant during measurement performance of PV panels under constant operation. Table 1 shows the space distance between the PV panels and halogen lamps is approximately 67.3 cm, 82.5 cm, 95 cm and 119.38 cm for testing the various amounts of solar radiation, respectively.

Table 1. Distance between PV Panels and Halogen Lamp

Average Solar Radiation	Distance between PV panels and halogen lamps
413 W/m²	119.38 cm
620 W/m²	95 cm
821 W/m²	82.5 cm
1016 W/m²	67.3 cm

One of the most difficult characteristics for a solar simulator to meet is the uniform of solar radiation. In the specific test requirement, the solar radiation area under the solar simulator is must be larger than the test area required. For the design requirements, a rectangular solar radiation area from the center of the test area that has a non-uniformity of less than 5 % was designated as the effective test area [12]. Non-uniformity is defined by

$$Non-uniformity\ (\%) = \frac{Emax-Emin}{Emax+Emin} \times 100\ \% \tag{1}$$

Where E_{max} is the maximum solar radiation that detected by a solar power meter over the target test area and E_{min} is the minimum solar radiation that detected by a solar power meter over the target test area, both solar radiation is measured in W/m².

The height of solar simulator is 67.3 cm; the solar radiation of the simulator is 1016 W/m². The non-uniformity of illumination is 3.85 %, thus it is considered as an effective test area. While the height of solar simulator is 82.5 cm, 95 cm and 119.38 cm, the solar radiation that measured by solar power meter under the solar simulator is 821, 620 and 413 W/m², respectively. The non-uniformity of the illuminations is 3.39 %, 3.16 % and 4.97 %, relatively. Thus, the variations of solar radiation over the test area depend on the height of solar simulator changes.

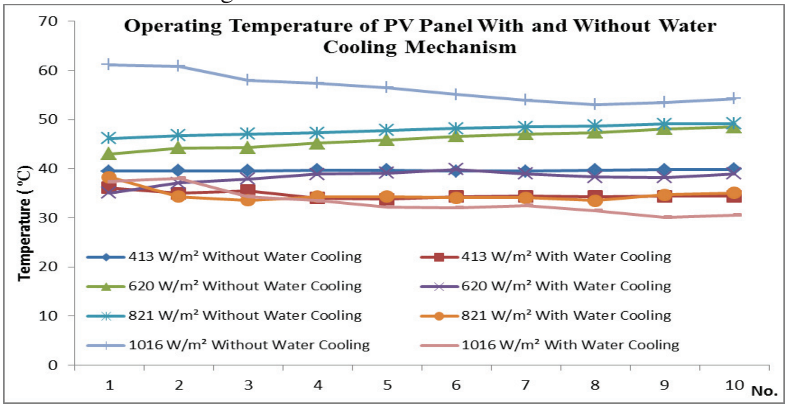


Fig.3. Operating temperature of PV panel with and without water cooling mechanism.

Fig. 3 shows the variation of the operating temperature of PV panel with and without the water cooling mechanism in the different fixed solar radiation. The variation of the operating temperature of PV panel with water cooling mechanism and PV panel reference was tested in the 413 W/m², 620 W/m², 821 W/m² and 1016 W/m², respectively. From the figure above, it can be seen that the average operating temperature of PV panel with water cooling mechanism is lower than the average operating temperature of traditional PV panel in the different fixed solar radiation. This is because the operating temperature of PV panel can be decreased by using water pump spray water over the front surface of PV panel. In the solar radiation of 413 W/m² and 620 W/m², the decrement of the operating temperature of PV panel is 5.03 ºC and 7.78 ºC by using the water cooling mechanism. On the other hand, the operating temperature of PV panel with water cooling mechanism can be decreased 13.26 ºC and 23.17 ºC compared to traditional PV panel in the solar radiation of 821 W/m² and 1016 W/m², respectively. It can be observed that the PV panel faced higher operating temperature when the solar radiation is in excess condition. This is due that the rest of solar radiation that absorbs by PV panel converted into heat. Thus, the operating temperature of PV panel can be decreased by using the water cooling mechanism.

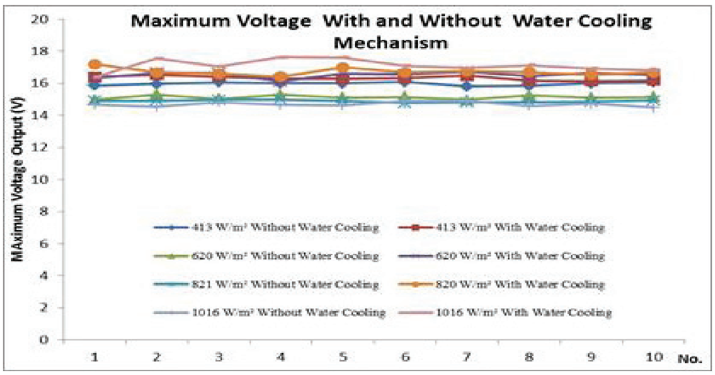


Fig.4. Maximum voltage output of PV panel with and without air cooling mechanism.

Fig. 4 illustrates the maximum voltage output of the PV panel with and without the water cooling mechanism at different fixed solar radiation. In the 413 W/m², the average maximum voltage output of the PV panel with water cooling mechanism is 16.32 V. While the average maximum voltage output of traditional PV panel is 15.97 V. Based on the results of both PV panels, it can be observed that the maximum voltage output of PV panels can be decreased is approximately 2.15 % by using the water cooling mechanism. By using a water cooling mechanism, the PV panel can be increased 8.41 % and 10.89 % compared to traditional PV panel in the 620 W/m² and 821 W/m², respectively. In the comparison result of both PV panels in the 1016 W/m², the increment of the average maximum voltage output of the PV panel is 14.14 % by using the water cooling mechanism. It can be clear that higher operating temperature is one of the impacts of environmental factors that can affect the performance of PV panel. The flow of current in the PV cell under different resistance of each cell may create temperature deviations within the module [13]. When the level of temperature is above the maximum point in PV panel, thus the electrical energy efficiency production was reduced. The dissipated heat energy will be changed the performance of PV panel. This is because the heat that stored in PV panel will be reducing the band gap of semiconductor material, whereby affecting parameter of semiconductor materials.

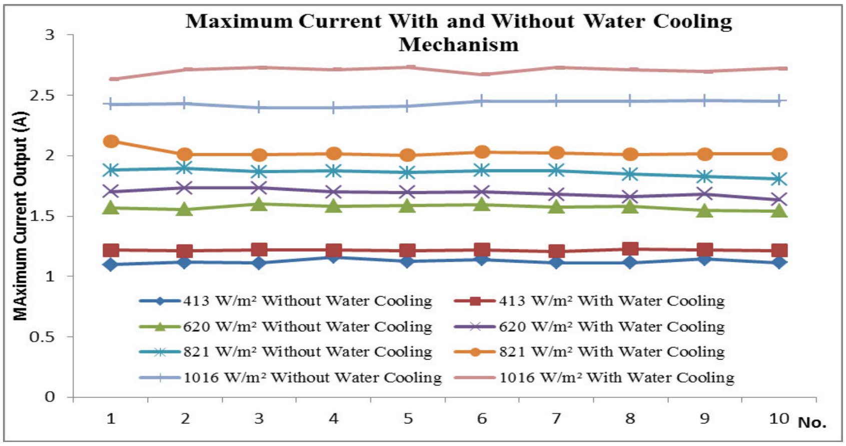


Fig.5. Maximum current output of PV panel with and without water cooling mechanism.

Fig. 5 displays the variation of maximum current output of the PV panel with and without the water cooling mechanism in different fixed solar radiation. The variation of maximum current output of the PV panel with water cooling mechanism and traditional PV panel were tested in the 413 W/m², 620 W/m², 821 W/m² and 1016 W/m², respectively. In the 413 W/m², the average maximum current output of the PV panel with water cooling mechanism is 1.22 A while the average maximum current output that generated by traditional PV panel is 1.12 A. In the comparison between both PV panels, the PV panel with water cooling mechanism can be generated more current output compared to traditional PV panel. It is clear that the increment of the maximum current output of the PV panel is approximately 8.2 % when apply DC water pump to spray water over the front surface of PV panel. On the other hand, the average maximum current output of the PV panel with water cooling mechanism is 1.69 A and 2.05 A in the 620 W/m² and 821 W/m², respectively. While the average maximum current output of traditional PV panel is 1.57 A and 1.86 A in the solar radiation of 620 W/m² and 821 W/m², correspondingly. It can be analytically that the maximum current output of PV panels can be increased by using the water cooling mechanism. Also, it is obvious that the percentage of increment in the maximum current output of the PV panel is 7.1 % and

9.27 % for the 620 W/m² and 821 W/m², respectively. Besides that, the average maximum current output of the PV panel with water cooling mechanism is 2.71 A and the average maximum current output of traditional PV panel is 2.43 A in the 1016 W/m². It can be observed that the average maximum current output of the PV panel with water cooling mechanism is higher than the traditional PV panel. The increment of the maximum current output of the PV panel is 10.33 % by using a DC water pump. It can be concluded that the performance of PV panel decreases as the operating temperature increases. Therefore, the water cooling mechanism is important to cool down the operating temperature of PV panel in order to increase the electrical efficiency of PV panel. Jianqing et al. [14] investigated that used water as cooling agent for cooling of the PV panel to reduce PV panel operating temperature in order to increase the electrical yield.

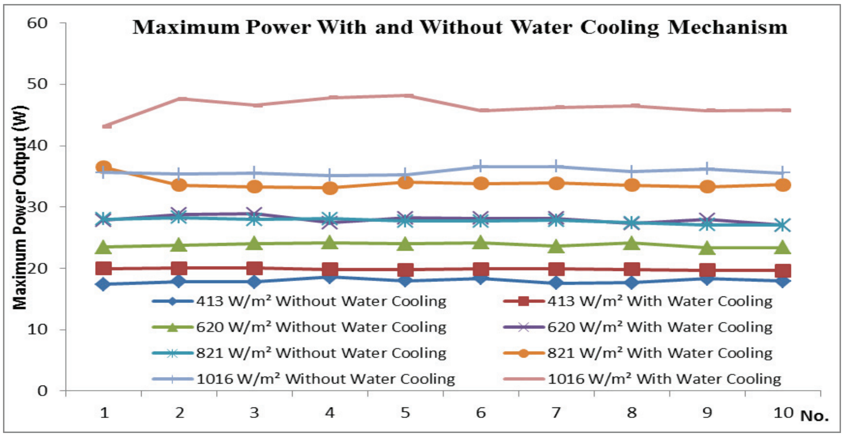


Fig.6. Maximum power output of PV panel with and without water cooling mechanism.

Fig. 6 presents the maximum power output of the PV panel with and without the water cooling mechanism. In the solar radiation of 413 W/m², the average maximum power output of the PV panel with water cooling mechanism is 19.87 W while 17.93 W is the average maximum power output for traditional PV panel. The increment of maximum power output is approximately 9.76 % by using a DC water pump. Besides that, 27.97 W, 33.87 W and 46.33 W are the average maximum power output of the PV panel with water cooling mechanism in the 620 W/m², 821 W/m² and 1016 W/m², respectively. Whereas, the average maximum power output of the traditional PV panel in the 620 W/m², 821 W/m² and 1016 W/m² are 23.81 W, 27.71 W and 35.76 W, correspondingly. The increment of maximum power output is 14.87 %, 18.19 % and 22.81 % in the 620 W/m², 821 W/m² and 1016 W/m² by using water cooling mechanism, respectively. Thus, the DC water pump was used to cool down the operating temperature in order to enhance performance of PV panel. Kordzadeh [15] carried out cooling of PV cells with a thin film of water flow over the PV surface. This main objective of this research is to overcome the increment of operating temperature with the increase the energy conversion efficiency of PV panel.

4. Conclusion

The solar simulator system with halogen lamp bulbs has been successfully designed and fabricated in this experiment. With a solar simulator, tests of PV panel performance can be carried out any chosen time, continued for 24 hours a day. The main objective of the solar simulator is to analysis the performance of PV panel with and without the water cooling mechanism in indoor test. The electrical efficiency of PV panel depends on many environmental factors, one of which is the operating temperature of PV panels. The increase in operating temperature of PV panel significantly decreases the electrical yield of PV panels. DC water cooling mechanism was used to solve this problem. A DC water pump will be spraying water over the PV surface for cooling of PV panel. Water has an ability to exhaust more heat out of the PV panel when it is operating at high temperatures. The reflection of solar radiation that absorbs by PV panel also will be reduced by using water flow over the front surface of PV panel. The water cooling mechanism is designed and constructed to keep the panel within certain temperatures. In the comparison between performance of PV panels with and without water cooling mechanism, water flow over the front surface of PV panel can be reduced the operating temperature of PV panel, which results in increased the electrical energy efficiency. The experimental results mentioned that the decrement of operating temperature is around 5 - 23 ˚C increase the power output of the PV panel with a water cooling mechanism by 9 - 22 %. The increment of power output will have a significant contribution to the PV system applications. An increase in efficiency of PV panel, investment payback period of the system can reduce and the lifespan of PV panel will also be longer.

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References

[1] M. Wasfi, Solar Energy and Photovoltaic Systems, *Cyber Journals, Journal of Selected Areas in Renewable and Sustainable Energy (JRSE)*, Vol. 1, No. 2, February 2011, pp. 1-8.

[2] II-Song-Kim, Robust Maximum Power Tracker Using Sliding Mode Controller for Three Phase Grid-Connected Photovoltaic System, *Solar Energy*, Vol.81, No. 3, 2007, pp. 405-414.

[3] S. Chokmaviroj, R. Wattanapong and Y. Suchart, Performance of A 500 kWp Grid Connected Photovoltaic System At Mae Hong Son Province, Thailand, *Renewable Energy*, Vol.31, No.1, 2006, pp. 19-28.

[4] Araki K, Uozumi H, Yamaguchi M. A Simple Passively Cooling Structure and Its Heat Analysis for 500x Concentrator PV Module. *In: Proceeding of the 29th IEEE Photovoltaic Specialists Conference*; 2002. Pp. 1568-71.

[5] Tiwari A, Sodha MS. Performance Evaluation of Solar PV/T System: An Experimental Validation. *Solar Energy*, Vol.80, 2006, pp.751-9.

[6] Hosseini R, Hosseini N, Khorasanizadeh H. An Experimental Study of Combining a Photovoltaic System with a Heating System. *World renewable energy congress* 2011 Sweden, 8-13th may 2011.

[7] Mahmoud Shatat, Saffa Riffat, Francis Agyenim, Experimental Testing Method For Solar Light Simulator With An Attached Evacuated Solar Collected, *International Journal of Energy And Environment*, Vol.4, Issue 2, 2013, pp.219-230.

[8] Kohraku S. and Kurokawa K., New Methods for Solar Cells Measurement by Led Solar Simulator, *Energy Conversion*, 2003, pp.1977-1980.

[9] Jawaorkse, D., K. Jefferies, and L. Mason. Alignment and Initial Operation of an Advanced Solar Simulator. *Journal of Spacecraft and Rockets*, Vol. 33, 1996, pp.867-869.

[10] Garg, H. P., and Shukla, A. R., 1985, Development of Simple Low-Cost Solar Simulator for Indoor Collector Testing, New Delhi, India, *Applied Energy*, 21, pp. 43–54.

[11]E. J. G. Beeson, The CSI Lamp as a Source of Radiation for Solar Simulation, *Lighting Research and Technology*, Vol.10, 1978, pp. 164-166.

[12] Qinglong Meng, Yuan Wang, LinHua Zhang, Irradiance Characteristics and Optimization Design of a Large-Scale Solar Simulator, *Solar Energy* Vol.85, 2011, pp. 1758-1767.

[13] Jiang, J.-A., Wang, J.-C., Kuo, K.-C., Su, Y.-L., Shieh, J.-C. and Chou, J.-J., Analysis of The Junction Temperature And Thermal Characteristics of Photovoltaic Modules Under Various Operation Conditions, *Energy*, Vol. 44, No. 1, (2012), 292-301.

[14] Gao Jianqing, Zhang Ying, Liu Yanfeng, Gao Xin, Study on the Temperature Variation of the Water-cooled Photovoltaic Solar Template, *2010 International Conference on Intelligent System Design and Engineering Application*, Changsa/ China, 10/13/2010, pp. 502-505.

[15] Azadeh Kordzadeh, The Effect of Nominal Power of Array and System Head on the Operation of Photovoltaic Water Pumping Set With Array Surface Covered by a Film of Water, *Renewable Energy*. 35, 2010, pp. 1098 – 1102.