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Experimental Study of Increasing PV Efficiency by Hydro-Cooling Method Under High Loading

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ABSTRACT- *This study has two methods, which are applied to the PV system to protect it and cool it from overheat. PV system in Saudi Arabia faces high temperatures and dust which is available at the most days of the year. In addition, a high weather temperature affects the efficiency of the PV system; the method of cooling PV panels will improve and increase the efficiency of the PV system. Two methods were used to PV system, the first method, is hydro-cooling by using water to cool PV panels and the second method, is the Nano Ceramic isolation. The results show that hydro-cooling module is suitable for PV systems in KSA, and it can increase the efficiency of the PV systems on one side, and decrease the temperature of the system on the other side. Nano isolation is protecting the PV systems and would be suitable for weather condition in KSA but would reduce the efficiency of the PV system as a side effect, which is not suitable for mass production or industrial production.*
Keywords- *PV system, Water cooling-cleaning, Nano ceramic isolation, Digital Multi Meter (DMM), Vision 2030.*

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I. INTRODUCTION

The sun is an average star comparing to other stars in the universe. It has been burning for more than 4-billion years, and it will burn at least that long into the future before erupting into a giant red star, engulfing the earth in the process [1], which means infinite source of light and thermal energy production from the sun.

The sun's light looks white because it is made up of many different colors that, combined, produce a white light. Each of the visible and invisible radiations of the sun's spectrum has a different energy. Within the visible part of the spectrum (red to violet), red is at the low-energy end and violet is at the high-energy end having half again more energy as red light. Light in the infrared region (which we can't see but feel as heat) has less energy than that in the visible region.

Light in the ultraviolet region (which is invisible but causes the skin to tan) has more than that in the visible region. The peak intensity of sunlight at the surface of the earth is about 1 kW/m2. However, not all areas of the earth get the same average amounts of sunshine throughout the year. The most intensely bathed areas lie between 300 north and 300 south latitude, since these areas have the least cloud cover. There also are, of course, seasonal radiation variations caused by the tilt of the earth with respect to the sun. Thus, the winter sun will daily provide less than 20% of the summer sun's energy at some locations because it is lower in the sky and the days are shorter [2].

The solar irradiance, i.e. amount of power that the sun deposits per unit area that is directly exposed to sunlight and perpendicular to it, is 1 368 watts per square meter (W/m2) at that distance. This measure is called the solar constant. However, sunlight on the surface of earth is attenuated by the earth's atmosphere so less power arrives at the surface — about 1 000 W/m2 in clear conditions when the sun is near the zenith [3].

In the last 10 years, the efficiency of average commercial wafer based silicon modules increased from about 12 % to 17 % (Super mono 21 %). At the same time, module efficiency increased from 9 % to 16 %. In the laboratory, best performing modules are based on monocrystalline silicon with about 23% efficiency. Record efficiencies demonstrate the potential for further efficiency increases at the production level. High concentration multi-junction solar cells achieve an efficiency of up to 46.0 % today. With concentrator technology, module efficiencies of up to 38.9 % have been reached [4].

World demand for energy is projected to more than double by 2050 and to more than triple by the end of the century. Incremental improvements in existing energy networks will not be adequate to supply this demand in a sustainable way. Finding sufficient supplies of clean energy for the future is one of society’s most daunting challenges.

As the world is shifting to the renewable energy today, countries as Saudi Arabia is having big renewable resources, as it has big areas of deserts which receive high amount of sun light, and has sunny days for the most days of the year.

Vision 2030 focused on the topic of renewable energy as reported on vision:

“Even though we have an impressive natural potential for solar and wind power, and our local energy consumption will increase three fold by 2030, we still lack a competitive renewable energy sector at present. To build up the sector, we have set ourselves an initial target of generating 9.5 gigawatts of renewable energy. We will also seek to localize a significant portion of the renewable energy value chain in the Saudi economy, including research and development, and manufacturing, among other stages.

From inputs such as silica and petrochemicals, to the extensive expertise of our leading Saudi companies in the production of different forms of energy, we have all the raw ingredients for success. We will put this into practice with the forthcoming launch of the King Salman Renewable Energy Initiative. We will review the legal and regulatory framework that allows the private sector to buy and invest in the renewable energy sector. To localize the industry and produce the necessary skill-sets, we will also encourage public-private partnerships. Finally, we will guarantee the competitiveness of renewable energy through the gradual liberalization of the fuels market."(vision 2030)" [5].

The annual solar radiation level reaches over 2400 kWh/m2 as shown in Figure 1 [6]. Despite such a rich potential and having initiated a sizeable solar village electrification project as early as 1981, the country is yet to make a meaningful utilization of solar energy. Under the Vision 2030, however, solar energy is being planned to contribute the most of the 9.5 GW renewable target.

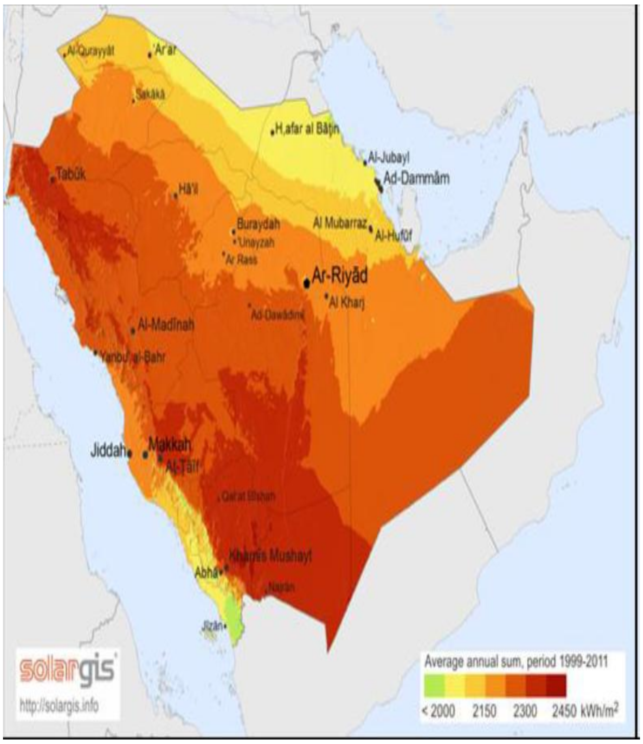

Figure 1: Global horizontal irradiation map of Saudi Arabia.

This study measured the efficiency of the two systems comparing to normal module with no addition systems. The systems were tested for 7 days in July and August, once each hour from 9 PM to 5 PM. The measurement was compared to the regular system with no additional systems and the efficiency is compared as decreased or increased according to the normal module. The results showed increased efficiency in power production in the system using Water Cooling system by over than 60%. At the peak hours of the day, the system using Water Cooling gave the highest and best results. The module using Nano isolation gave low results and decreased the efficiency of the PV system by 50%.

The major advantages of solar energy are:

1) Solar energy is a clean and renewable energy source.
2) Solar energy causes no pollution.
3) Once a solar panel is installed, solar energy can be produced free of charge [7].

The major disadvantages of solar energy are:

1) The amount of sunlight that arrives at the earth's surface is not constant. It depends on location, time of day, time of year and weather conditions.
2) Because the sun doesn't deliver much energy to any one place at any one time, a large surface area is required to collect the energy at a useful rate [7].

This reviews updated literature and presents highlights of important studies. The aim is to identify the research gaps and follow up research areas which can improve the current status of progress of the technology.

Electricity generation using photovoltaic are promising techniques that can meet the current energy challenges but the problem of overheating of the panels affect the energy conversion efficiency as well as the life of the module. Increased temperature raises the charge carrier concentration which raises the short circuit current due to reduced band gap but the open circuit voltage drops. This occurs due to increased recombination rates thereby reduces the overall power output from the cell. Thermal regulation of the PV panels is therefore important.

Different methodologies are found in literature on PV cooling where most of the works are focused on passive cooling systems using air flow and water circulation. These systems however could not maintain the cell temperature to an appropriate level. Active systems affect the system economics remarkably, primarily due to the large pumping costs involved in circulating air and water for effective PV cooling. The highlights of the various reviews on cooling by water circulation of PV panels are:

1) Improving photovoltaic's efficiency by water cooling: Modeling and experimental approach [8].
2) Enhancing the performance of photovoltaic panels by water cooling [9].
3) Experimental Setup to Increase the Efficiency of Solar Panel by using the water Circulation [10].
4) Indoor Test Performance of PV Panel through Water Cooling Method [11].
5) Rooftop PV Potential in the Residential Sector of the Kingdom of Saudi Arabia [12].

Ventilated air based cooling is found ineffective during peak hours. Water cooling has been found to outperform air based cooling. Other cooling techniques are at the primary stage of research.

II. METHODOLOGY

The purpose of the study was to find a way to reduce the temperature and clean the panel from dust. Therefore, the performance (voltage and current) of the module will increase. Two modules were used and compared to a basic module which did not use cooling or the added method of isolation.

Used Methods

1) Nano ceramic isolation technology.
2) Water cooling-cleaning system.
3) Normal module to be compared to.

Nano ceramic isolation technology.

This technology is considered as the biggest technological advance in insulation, Nano-ceramic films are not dark, shiny or reflective. The spectrally selective coatings on Nano-Ceramic films filter out 65%–99% of the infrared heat normally transmitted through insulated double pane glass. The Nano ceramic isolation technology is now used in isolating the vehicle glass to keep the vehicle interior under low temperature.

A 6mm glass covered with Nano-ceramic film is used to cover the module, to separate the thermal spectrum from the light spectrum, both first and second module are inclined on holder at an angle of 21.5^0 which is the angle of the study city, Makah.

The Nano ceramic sheet was established on a thin sheet of glass and had been put at 0.5-centimeter distance over the PV, also no distance was applied, and the results are to be discussed later on.

Water cooling-cleaning system

As known the specific heat of the water is high enough and considered as the best safe cooling liquid. To keep the module surface temperature as low as it should to keep the performance as high as possible. The holder of the PV panel was designed to carry the PV panel and to allow the water passing over the panel.

The holder is designed at the same angle of the no modified and the Nano ceramic sheet covered which is 21.5^0 , the water is pumped through a DC pump submerged inside the tank and automated according to the temperature reading, the water flows over the module with flow rate of 4000L/h = 1.1L/s, the surface temperature is measured during different interval times for different weeks during the study period. First module is with Nano-ceramic sheet, the Second module is with water cooling-cleaning system and last module is without any addition.

Power comparison between three modules

The comparative of Power between the three modules using variable resistance, the same resistance is applied to the three modules at the same time, voltage and current readings after each load is recorded.

The three modules were measured for 7 days from 17/7/2018 to 23/8/2018 (only 7 days chosen). The modules were measured at different hours during the day, measuring the peak hours of 12 pm and 1 pm, till 5 pm which measured the lowest performance for the solar panels of every module. The two main modules testing are compared to the PV system using no cooling or isolation systems.

All measurement will be conducted for each module on each day, every hour once starting from 9 pm till 5 pm. The results will be collected and compared to the basic module using no cooling or isolation methods at the highest performance and the lowest performance for each module. The comparison between the highest performance and the lowest for each module with the module using no methods of cooling and isolation showed the difference of negative or positive performance added due to the use of the cooling or isolation system.

The highest performance showed added value because of the use of any module on the basic system, comparing it to the basic module using no method of cooling or isolation.

III. EQUIPMENT AND ERROR ANALYSIS

Equipment used

A Digital Multi Meter (DMM) is a test tool used to measure two or more electrical values of voltage (volts), current (amps) and resistance (ohms). It is a standard diagnostic tool for technicians in the electrical/electronic industries.

Digital multi meters long ago replaced needle-based analog meters due to their ability to measure with greater accuracy, reliability and increased impedance. Fluke introduced its first digital multi meter in 1977.

Digital multi meters combine the testing capabilities of single-task meters—the voltmeter (for measuring volts), ammeter (amps) and ohmmeter (ohms). Often they include a number of additional specialized features or advanced options. Technicians with specific needs, therefore, can seek out a model targeted for particular tasks.

The face of a digital multi meter typically includes four components:

- Display: Where measurement readouts can be viewed.
- Buttons: For selecting various functions; the options vary by model.
- Dial (or rotary switch): For selecting primary measurement values (volts, amps, ohms).
- Input jacks: Where test leads are inserted.

Test leads are flexible, insulated wires (red for positive, black for negative) that plug into the DMM. They serve as the conductor from the item being tested to the multi meter. The probe tips on each lead are used for testing circuits.

The terms counts and digits are used to describe a digital multi meter's resolution—how fine a measurement a meter can make. By knowing a multi meter's resolution, a technician can determine if it is possible to see a small change in a measured signal [13].

Error Analysis

During working on the study many measurements and readings were taken. These results were taken from two multi meter devices. Each device has percentage of error which is built in the device. This part is trying to analyze this error occurring by measuring devices. All measurements have some degree of uncertainty.

Table 1 Error Analysis

Error source	Value	Distribution	Divisor	Standard uncertainty
DC Voltage resolution	100mV	Rectangular [B]	$\sqrt{3}$	57.7mV
DC current resolution	10 mA	Rectangular [B]	$\sqrt{3}$	5.77 mA
Temperature resolution	1 °C	Rectangular [B]	$\sqrt{3}$	0.577 °C

IV. RESULTS AND ANALYSIS

The results recorded for 2 months, are recorded for different days in each day starting in 17 JULY as the following:

The results of the first day as shown in Figure 2 showed the following: high performance of Water cooling system at all hours during the day, then the system using no method which is the compared system. The lowest performance was for the system using Nano ceramic isolation.

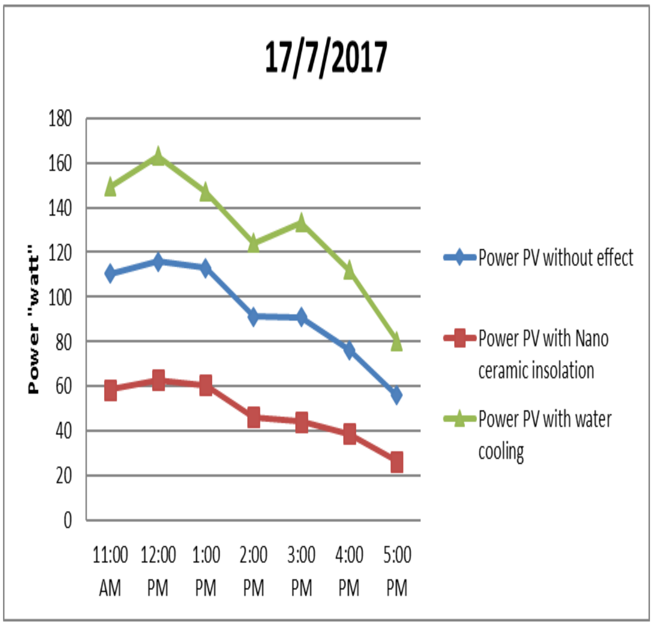

Figure 2: Results of the three systems at (17 July).

The results of second day as shown in Figure 3 showed the following: high performance of Water cooling system at all hours during the day, then system using no method which was the compared system. The lowest performance was for the system using Nano ceramic isolation. The result of the first two days showed better performance for Water cooling system compared to the two other systems at all hours of the day at the same dates.

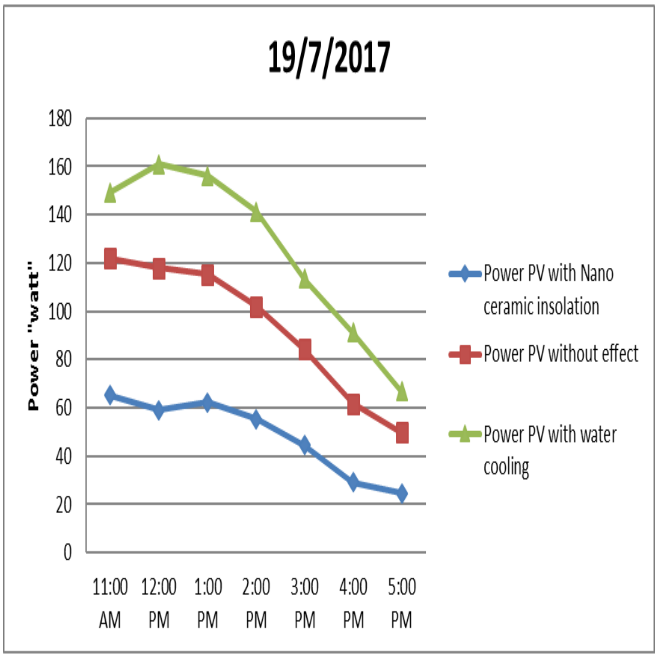

Figure 3: Results of the three systems at 19 July.

The third result recorded for the third testing day as shown in Figure 4 showed the same performance of the first and second day, and higher performance for system using Water Cooling, which was reduced after 1 pm as for all systems. All systems have the lowest performance at 5 pm with 50 W for Water Cooling system and 25 W for system using no cooling system. The lowest of the three systems at 5 pm was for the Nano ceramic isolation and recorded 20 W only of power generated.

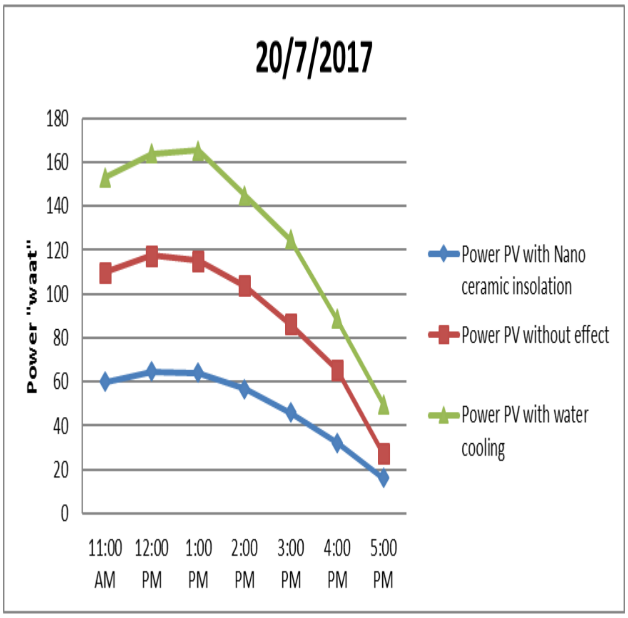

Figure 4: Results of the three systems (20July).

On the fourth day as shown in Figure 5 of the testing systems showed the following: the system using Water Cooling had the highest performance. The second high performance was the system using no method of cooling. The lowest performance was for system using Nano ceramic isolation.

The result of the fourth day of experiment in July as shown in Figure 5 showed the same results of the previous days, with better performance of Water Cooling system, with peak power of 157 at 12 pm. The results showed that the higher performance of the PV system reduced the temperature of the system when using Water Cooling system. It also showed that the lowest performance at all hours of the day was for the system of the Nano ceramic isolation.

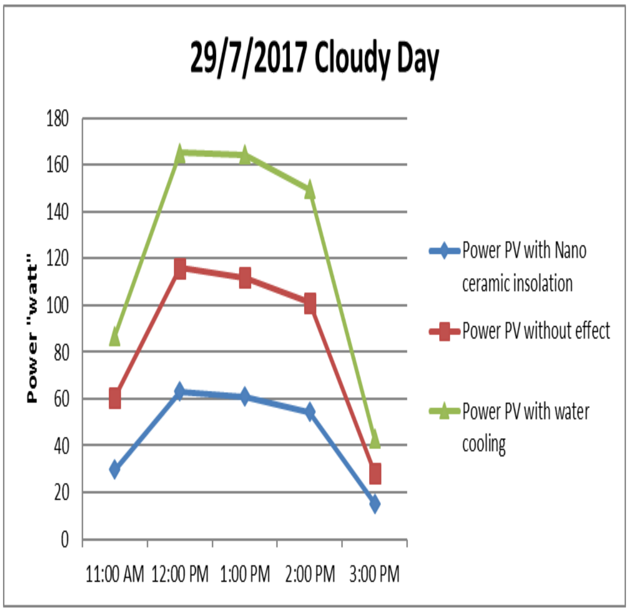

Figure 5: Results of the three systems at (29 July).

The first of August testing results as shown in Figure 6 recorded best performance for system using water cooling, then for system that didn't use any method, and finally the system using sheet as cooling system. The highest performance was for Water Cooling system at 12 pm(peak hour), and recorded 155W which is higher than all other systems at the same hour, as it is 55 W for system using Nano ceramic isolation, and 110 W for basic PV system using no Cooling System.

The first system and the basic system gave the same results at 4 pm with 90 W and 85 W respectively. The lower temperature at 4 PM made the two systems giving the same results as Water Cooling system used give the higher performance at high temperature at the peak hours with high temperature degrees.

The lowest results recorded was of system using Sheet system at 5 pm with only 25 W , where other systems recorded 40 W for system using no methods , and 50W for system using Water Cooling system.

The result showed high performance of Water Cooling system at all hours during the day, then system using no method which was the compared system. The lowest performance was for the system using Nano ceramic isolation. The result showed best performance of the Water Cooling system at high temperature hours, as the system was designed to reduce temperature of the PV system. The Nano Ceramic isolation failed to make positive difference on the PV system compared to the basic system using no cooling methods.

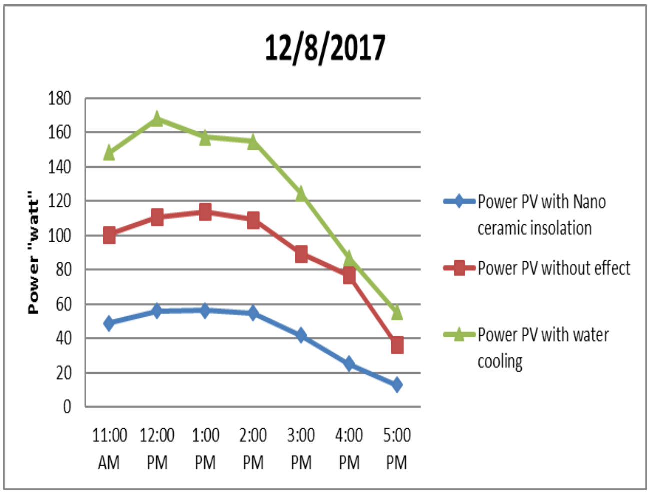

Figure 6: Results of the three systems at (12 August).

At the second day of testing in August, the day was cloudy, so the results didn't match to the previous results, as the peak hour of the day has clods, and so the performance of the three systems gave the lowest performance compared to all other testing days as shown in Figure 7.

The highest result of PV system using Water Cooling system was at 2 PM which gave 140W, and then the performance decreased at 3 PM with 110 W, to reach 15 W at 5 pm which was the lowest of this system at all testing days. Other systems gave highest performance at 2PM also with 90 W for the basic system using no cooling system, and 40W for the system using Nano ceramic isolation which was the lowest compared to all other days of testing.

This result also showed the advance performance of PV system using Water Cooling system, with high performance at peak hours, which include high temperatures, thus making the difference of power as it reduce temperature and increase performance. All systems gave almost the same result at 5PM as the following:

- Water Cooling PV = 15W
- No cooling system = 13W
- Nano ceramic isolation = 8 W

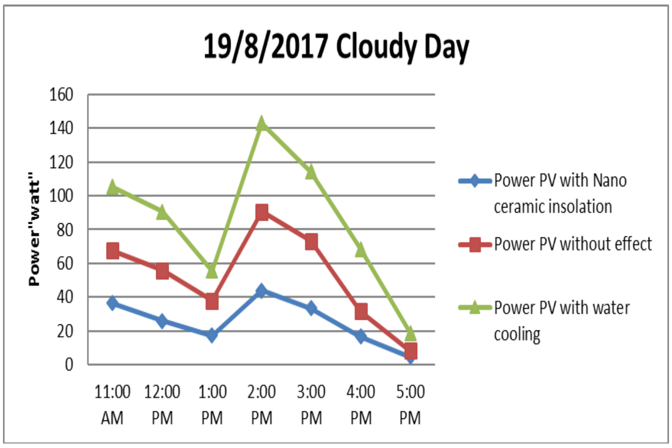

Figure 7: Results of the three systems at (19 August).

On the last day of testing, the PV system using Water Cooling still recorded the highest performance, as it recorded power up to 185 W at 1 PM, and 175 W at 12 PM, and the lowest of 110 W at 4 PM.

The other testing systems using Nano ceramic isolation and system using no cooling systems, recorded similar results as previous days of the test. The highest power generated by the second system (compared system) using no cooling system was at 1 pm of 125 W and the lowest of 50 W at 4 PM. the third system using Nano ceramic recorded highest power at 1 PM of 65 W and the lowest of 40 W at 4 PM.

The result was similar to other days of testing as the PV system using Water Cooling gave the best performance, with the best performance at peak hours (12 . 1 PM) which indicated high performance of water cooling system used in the system of PV as shown in Figure 8.

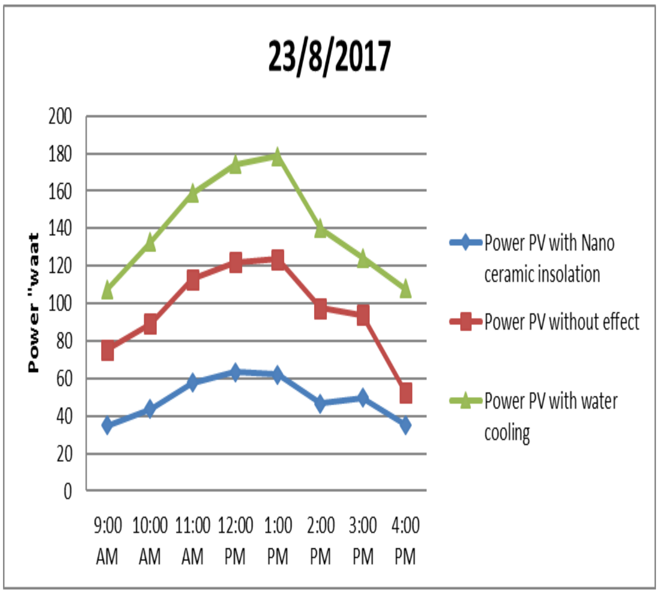

Figure 8 results of the three systems at (23August).

V. DISCUSSION

Figure 9 compared the highest performance of the three systems for 7 testing days, which showed the difference in performance between the three systems, as the highest performance was recorded at peak hour for the PV system using Water Cooling of 185 W. PV system using Nano Ceramic recorded high performance of 65 W which is the best performance recorded for the system on any giving day. The compared system which using no added systems for cooling or isolation recorded the highest performance of 125 W, on any giving day of testing.

The difference of performance between the two systems to the original system at the highest performance of the 7th day gave the following result:

- System using Water Cooling registered adding value of 60 W at peak hours.
- System using Nano Ceramic isolation gave negative value (decrease) of 60 W at peak hours.

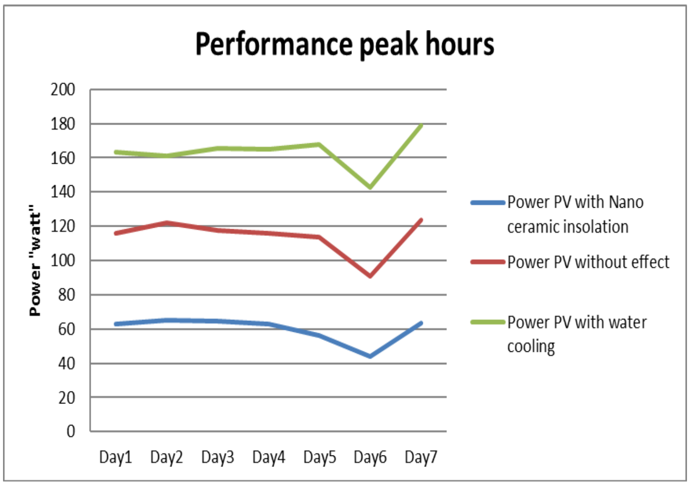

Figure 9: Comparing the three systems at peak hours.

Figure 10 showed the lowest performance of the three systems for the three testing days with the best lowest performance is for the system using Water cooling at the 7th day with the value of 110 W.

The worst value came from the system using Nano isolation with the value of 8 W. The performance decreased from day one to day 6 for the three systems, with better performance for the system using Water Cooling. All performances increased on the 7th day because the value decreased sharply on the 6th day due to cloudy day which prevent the sun light to reach for the solar panels, which decreased the performance of all systems.

Comparing the lowest performance of all systems at the first day, the result was as the following:

- Water cooling module: 80 W
- Nano ceramic isolation: 25 W
- Basic module: 55 W

The difference of the value of performance compared to the basic module was as the following:

1) Positive difference of 25 W by using Water Cooling system.
2) Negative difference of 20 W by using Nano Ceramic isolation.

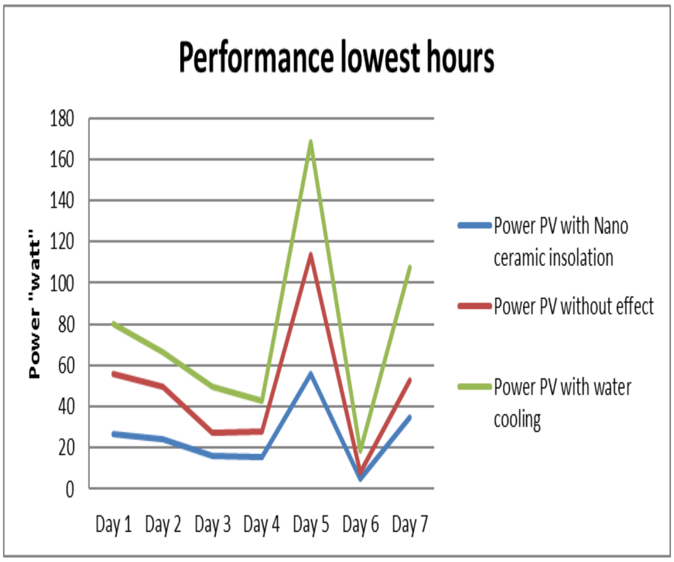

Figure 10: Comparing the three systems at lowest hours.

VI. CONCLUSION

The current report focused on the solar power systems and the need for increasing sufficiency of the systems. The kingdom has its own environment which has main features of hot climate most of the year, and high temperature on most of the areas of the kingdom. PV systems used in the kingdom will face high temperature and dusty weather for the most of the year, which needs temperature controlling and reducing, in addition to protection system from the dust and dirt which can affect the efficiency of the system. Accumulation of dust and other pollution from the outdoor environment on the solar collectors can reduce the system efficiency.

This study used both isolation system (Nano ceramic), and Water Cooling system for the purpose of reducing temperature and protecting the solar panels used in KSA. The systems used on normal solar panels and tested for 7 days during August and July. The results showed differences between the performances of the two systems compared to the basic module used with not any additional systems.

The purpose of using of the additional two systems is to protect the solar panels and reduce the temperature, but keeping the efficiency of the system or increase it.

One of the main obstacles that faced the operation of photovoltaic panels (PV) is overheating due to excessive solar radiation and high ambient temperatures. This study used the water cooling system on PV modules and measured the efficiency of the system.

The results showed increase in the efficiency of the module using Water cooling system and a positive difference of 60 W, on the peak hours and the higher performance of the systems. The Water Cooling system used in the first module increased the efficiency of the PV system by reducing the temperature of the system. The high temperature of the PV system reduces the performance of the system, which indicates the need for a module that can reduce the temperature of the system, and doesn’t reduce the overall of the PV system.

Increasing efficiency of the PV system is achieved by 60 W on high performance on peak hours, and 25 W, on the lowest performance of the system compared to the basic module using no additional system.

The second system used was the module with Nano ceramic coating, which is used for protecting the PV system in the climate of KSA. The results showed that using the Nano coating reduced the efficiency of the system on both peak hours and low performance hours. The system showed lowest performance compared to other systems using Water cooling and PV system using no methods of protection.

According to the results, the best system used for PV systems in KSA with the consideration of the climate and high temperature of the weather was to be Water Cooling System, as it was reducing temperature and increasing performance.

For using the Nano Ceramic coating, the results showed low performance and decrease of the efficiency of the system after applying the Nano coating by over than 60% at the peak hours. Finally we can conclude the following statements:

1) For the PV systems in KSA, heat and dust were the main problems that faced the panels after installation.
2) Reducing the temperature of the PV system can increase the efficiency of the system.
3) Temperature reduction of the PV system can be achieved by Water Cooling system added to the solar panels.
4) Efficiency of the PV system can be increased by 50% and more by using Water cooling system.
5) Protecting the PV system by Nano ceramic isolation will reduce the efficiency of the system by more than 60%
6) Nano Ceramic isolation can protect the PV system, but will affect the efficiency of the system and reduce it.

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