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Performance of solar modules integrated with reflector

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ABSTRACT

This study investigates experimentally the performance of two-dimensional solar tracking systems with reflector using commercial silicon based photovoltaic module, with open and closed loop control systems. Different reflector materials were also investigated. The experiments were performed at the Hashemite University campus in Zarqa at a latitude of 32º, in February and March. Photovoltaic output power and performance were analyzed. It was found that the modified photovoltaic module with mirror reflector generated the highest value of power, while the temperature reached a maximum value of 53 ºC. The modified module suggested in this study produced 5% more PV power than the two-dimensional solar tracking systems without reflector and produced 12.5% more PV power than the fixed PV module with 26º tilt angle.

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1. INTRODUCTION

Jordan confronts critical challenges in the energy sector due to increased demands on energy. The major challenge is to provide and produce more energy at reasonable cost to meet the growing demands of the consumers. Jordan imports more than 95% of its energy needs [1]-[3]. Thus, the energy sector in Jordan depends mainly on oil products, and natural gas. Energy bill has put a heavy burden on Jordan's economy. Furthermore, extra burden is caused by the interruption of the natural gas coming through the pipeline from Egypt. This forced the energy sector to convert to oil to produce electricity, which causes extra expenses on Jordan's economy. Moreover, oil shale development utilization is still facing serious problems.

In this regard, renewable energy sources present important alternative to generate electric power. Thus, new projects have been constructed to get benefit of the available renewable energy sources such as wind and solar energy. Solar energy is considered a clean, non-polluting and an inexhaustible energy source [4]. Several systems have been developed to use the solar energy, such as flat-plate solar panels [5] or concentrated solar power (CSP) systems [6]. In order to encourage others to switch from using fossil fuel energy sources to renewable energy sources, the PV panel performance should be improved. The potential lies in the method and the techniques used for the maximum efficiency possible. The power generated by the PV panel depends on the sun radiation and angle of incidence on the PV panel surface. If a reflector is incorporated in the PV system, the collective area will be increased. On the other hand, using solar tracker, will reduce the angle of incidence to minimum value. Hopefully, this will increase the power output of the two-axis photovoltaic tracking PV-system with reflector (modified solar tracking system). Eventually, this will decrease the number of PV panels needed to maintain certain amount of energy, which means reducing the initial cost.

PV is one of the fastest growing solar energy technologies in the world. Therefore, there is a good potential for PV application in Jordan due to available high rates of solar radiation. Furthermore, increasing the contribution of renewable energy sources in Jordan energy sector will reduce energy bill and improve current economic status. There are many methods used to enhance the performance of solar panel system. The most common one is to track sun motion [7]-[12]. Air-cooling, liquid-cooling and immersion are examples of methods to increase the efficiency of solar cell [13]-[16]. In spite of the improved energy extraction from solar tracking system, these systems are less preferred due to their higher installation and maintenance costs and their additional power requirement for the moving parts [17]-[20]. PV augmented mirroring affects positively the performance of PV systems [21]-[25]. In this work, a fixed PV panel mounted towards south, a two-axis photovoltaic tracker panel without reflector and a two-axis photovoltaic tracking system with reflector were built, studied and investigated. The performance and generated power were experimentally analyzed for the three systems. This research aims to provide a PV tracking system, which can reduce the power generation cost and to get the maximum output power from a PV solar system using a simple reflector on the PV module. Previous studies either used a two-axis photovoltaic tracking system or a reflector to enhance the performance of a PV system. This work combines both techniques to study the potential of enhancing the power output of the PV system under Jordanian climate conditions.

2. EXPERIMENTAL WORK

The experimental setup used in the study is installed at Hashemite University campus in Zarqa at a latitude of 32º. The experimental setup consists of three Mono-crystalline silicon PV panels of 310 W maximum output power. The first PV panel was fixed towards south and mounted at 26º tilt angle, which is the optimum tilt angle for a fixed PV panel. For the second PV panel, a two-axis photovoltaic tracker was installed. A two-axis photovoltaic tracking system and mirror reflector were installed to the third panel. The technical specifications of the PV panels used are given in Table 1.

Table 1. PV panel specifications

Specification	Detail
Maximum output power, Pmax (W)	310
Open circuit voltage, Voc (V)	45.79
Short circuit current, Isc (A)	8.99
Nominal operating cell temp. (℃)	45
Cell type	Mono-crystalline
Dimension (mm)	1956x992x40

Two flat reflectors were fitted at the shortest side of the PV panel in order to increase the sun intensity on the panel surface by reflecting the sun radiation that has missed the panel surface. In other words, they increase the surface area of the panels. The reflector has an optimum angle to gain the greatest exposure to sun radiation that can be reflected to the PV panel surface. The reflector tilt angle (Ө) is defined as the angle between the reflector surface and the PV panel surface. The dimension of the reflector is (1000x500) mm. The reflector size is identical during all experiments. The optimum tilt angle and the material of the reflector will be determined in this study. There are two reflectors for the PV panel: The north reflector and the south one. The optimum tilt angle for each one will be estimated separately. The tracking system used in these experiments is the two-axis type tracking with both open and close loop systems. The micro-controller circuit diagram and board of the tracking system are shown in Figures 1 and 2.

The micro controller consists of software and hardware components. The software may be programmed by using micro basic language that decodes the input signals and sends it to control the motors status. The hardware executes these signals or commands. Every tracking system have two DC motors. One motor is used for E-W motion, while the second one is used for S-N motion. DC motors can be controlled with the polarity of their inputs. For polarity alternation, we have used a simple SPDT relay (5 V) arrangement. The motor terminals are connected to the two common poles of the relay in the circuit. For various ranges of input voltage, the IC 7805 controls the output voltage to be 5V. During a circuit's operation, it serves as an excellent component against voltage fluctuations, adding an additional layer of safety. The LM358 IC is used as a transducer standard amplifier. It can handle voltages from 3V to 32V DC supply and currents up to 20mA per channel. Signals from sensors are usually small, so this amplifier was used.

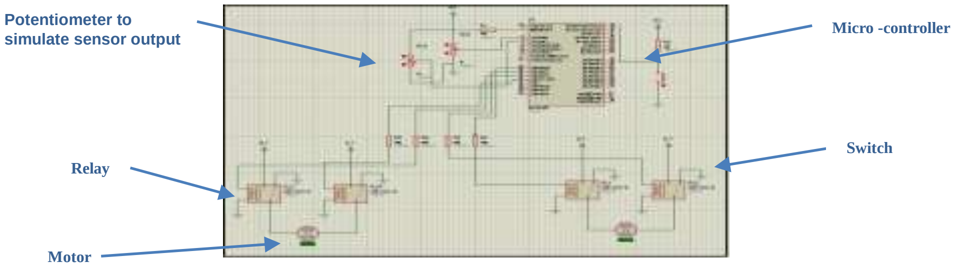

Figure 1. Micro-controller circuit diagram

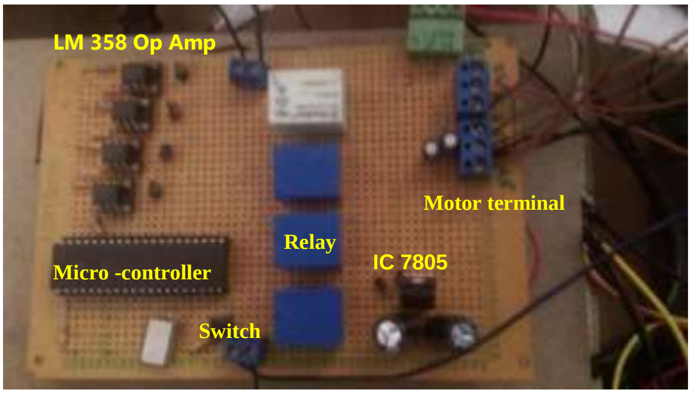

Figure 2. Micro-controller board

To ensure accurate and reasonable comparison between the three solar systems, those three systems have same PV specifications. They are located near each other oriented towards south with an adequate distance between them; to avoid any shadow effect on the PV panels. A weather station was mounted near the three systems. The two PV panels with their tracking systems are moving simultaneously having same controller, but each one has its own control board. The data collected from the three systems was analyzed.

The experimental work was conducted daily for 2 months (February and March); from 9:30 AM to 2:30 PM. The total rotation angle that the PV system will cover (solar azimuth angle) will be around 70^o each day. The controller sends a signal to the DC motor each time period (30 minutes) ordering it to operate for a certain angle. This angle is calculated by dividing the total angle of rotation on the number of time periods. A potentiometer is mounted on the main joint to acquire the required rotation angle. The panel motion reference was the solar noon time. At solar noon time, the three solar PV panels should be oriented towards the sun. This was verified by placing a small piece of wood vertical to the PV panel surface to ensure that no shadow exist for the moving panels. This method can be used any time of the day to make sure that the calculated angles are correct. The PV tilt angle may be stored in the controller software all over the year. To achieve an exact tilt angle, a sensor was used. A potentiometer was mounted on a joint to acquire the required tilt angle during experimental work. This is an open loop control system that operates on time basis, that needs sensors to achieve the required time basis motion. Two micro-controller boards were built, one for each PV tracking system. Each PV tracking system needs two DC motors: One motor for the E-W motion, and the second for the S-N motion. As mentioned earlier, a simple weather station consisting of an anemometer, two pyranometers, and four thermocouples of K-type was used in this study. Three temperature sensors were used for the three PV panel's surfaces, while the fourth temperature sensor was used to determine the ambient temperature. A micro inverter is connected to each one of the PV panels. Three micro inverters were used to convert the DC current into AC current and compute the output energy for each PV panel.

3. RESULTS AND DISCUSSION

All the readings in these experiments were taken simultaneously to get accurate comparison. The experimental results are summarized in Table 2. Figure 3 shows the output power with daytime. In this experiment, the reflector material is aluminum. The figure reveals that PV system with reflectors produces more power than the other 2 systems. Another experiment was done to specify the optimum tilt angle. Figure

4 indicates that the optimum reflector tilt angle is 125º. In the optimum south reflector experiments, the difference is less than the difference in the optimum north reflector experiments.

Table 2. Summary of experimental results

Reflector material: aluminum (Optimum north reflector tilt angle, South reflector angle 180)											
Time		9:30-10:00	10:00-10:30	10:30-11:00	11:00-11:30	11:30-12:00	12:00-12:30	12:30-1:00	1:00-1:30	1:30-2:00	2:00-2:30
Ambient Temp. [ºC]		16	17	17	18	19	21	21	22	23	22
Solar intensity [W/m²]/Tracking		850	910	930	943	958	970	961	950	940	919
Without Reflector	Panel Temp. [ºC]	41	41	43	43	43	545	43	44	44.5	45
	Power output [W]	259	262	261	263	280	288	279	274	272	260
with reflector	Panel Temp. [ºC]	41	41	44	42	44	45	42	43	44	44
	Power output [W]	260	264	279	270	284	286	280	274	272	261
Reflector Material: Aluminum (Optimum south reflector tilt angle, North reflector angle 180)											
Ambient Temp. [ºC]		19	20	22	22	24	24	24	25	26	23
Solar intensity [W/m²]/Tracking		953	940	935	930	921	732	547	850	690	771
Without Reflector	Panel Temp. [ºC]	39	39	41	43	46	47	34	42	46	47
	Power output [W]	280	278	270	270	280	220	140	268	244	216
With reflector	Panel Temp. [ºC]	39	39	41	44	46	49	33	42	46	47
	Power output [W]	280	277	277	279	284	220	142	270	245	215
Reflector Material: Aluminum (Optimum Performance)											
Ambient Temp. [ºC]		20	21	22	22	23	23	24	26	25	26
Solar intensity [W/m²]/Tracking		934	957	960	962	980	985	985	984	960	956
Without Reflector	Panel Temp. [ºC]	46	45	48	47	46	44	48	49	48	49
	Power output [W]	270	278	274	279	280	283	280	274	268	269
With reflector	Panel Temp. [ºC]	48	45	47	47	46	45	50	52	50	52
	Power output [W]	280	290	289	288	289	296	293	290	284	277
Reflector Material: Stainless Steel (Optimum Performance)											
Ambient Temp. [ºC]		22	21	22	22	22	24	25	25	25	26
Solar intensity [W/m²]/Tracking		953	955	955	931	984	1000	993	995	973	946
Without Reflector	Panel Temp. [ºC]	36	39	39	40	43	44	45	46	45	45
	Power output [W]	275	283	285	279	286	289	282	283	278	273
With reflector	Panel Temp. [ºC]	38	40	40	41	45	46	48	48	47	45
	Power output [W]	285	294	297	291	297	303	296	297	290	283
Reflector Material: Mirror (Optimum Performance)											
Ambient Temp. [ºC]		16	18	17	19	19	19	20	20	21	21
Aolar intensity/ Fixed		924	967	1003	1010	1036	715	980	1050	940	871
Solar intensity [W/m²]/Tracking		935	980	1010	1045	1195	780	1020	1050	1000	1013
Fixed System	Panel Temp. [ºC]	39	39	40	43	44	40	43	46	45	43
	Power output [W]	248	267	271	279	286	210	272	270	253	240
Without Reflector	Panel Temp. [ºC]	40	41	42	45	45	41	43	47	46	47
	Power output [W]	283	290	288	282	292	206	289	290	283	279
With reflector	Panel Temp. [ºC]	42	46	47	50	51	44	46	52	51	53
	Power output [W]	295	304	306	300	309	221	294	310	294	288

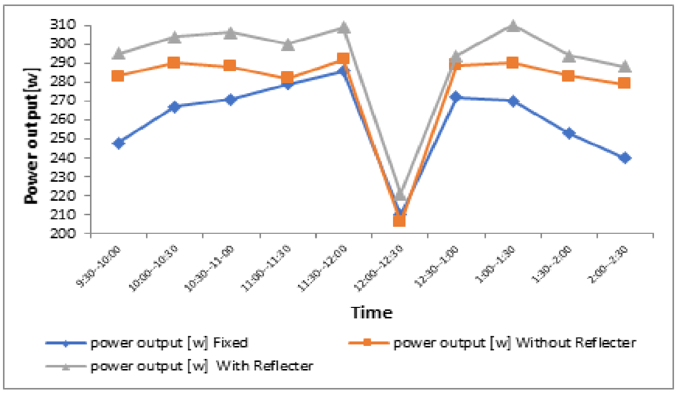

Figure 3. Output power vs. daytime

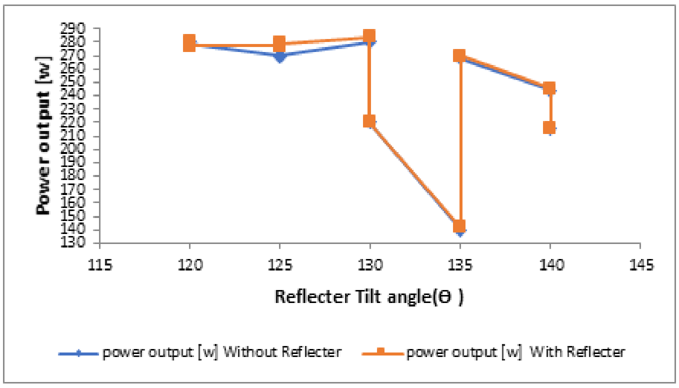

Figure 4. Output power vs. reflector tilt angle

When Aluminum material was used for reflector material, with a reflector tilt angle of 125º, the output power for both solar tracking systems with daytime is presented in Figure 5. The power output difference between the two systems is about 12W. The same experiment was repeated with replacing the Aluminum reflector with stainless steel reflector. The tilt angle of 125º was kept as before. The obtained results are presented in Figure 6. The power output difference between the two systems was around 12W. When a mirror was used as a reflected material, the power output difference between the two systems in average is about 14.3W as shown in Figure 7. The experiments were done at the same tilt angle of 125º

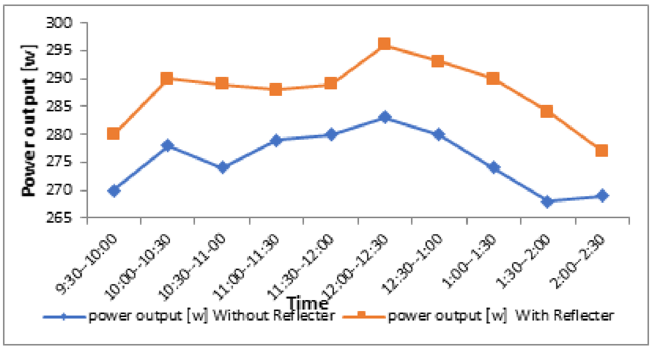

Figure 5. Output power using aluminum as a reflector material

Thus, the modified solar tracker with mirror as a reflector material achieved the highest power output. The optimum reflector tilt angle is 125º. Comparing the solar tracker with reflector, the solar tracker without reflector and the fixed solar panel with the optimum tilt angle 26º power output shows an increase in output power of 14W when a reflector is used and 18.6W when the the solar system with reflector is compared with the fixed solar panel. The results show that solar cells can produce more power by about 12.5% with a reflector. According to our estimates, the reflectors will add 10 US dollars to a 310 Wp PV module. This additional cost needs to be added to the sale price. At the same time, by adding reflectors, 38.75 Wp of additional power can be generated. In other words, the new module is capable of producing 348.75 Wp. Using the USD 0.5/Wp market price of flat plate PV modules, the gain thus represents 19.375 US dollars which exceeds the added 10 US dollars due to the reflectors.

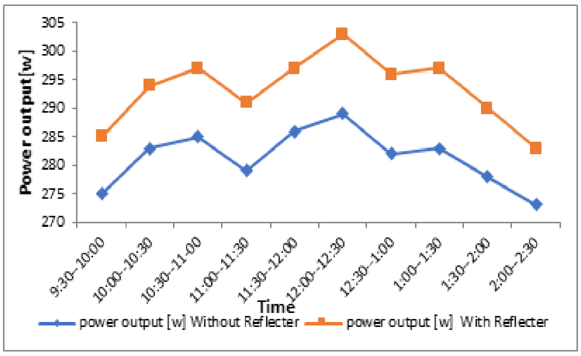

Figure 6. Output power vs. daytime with stainless steel as a reflector material

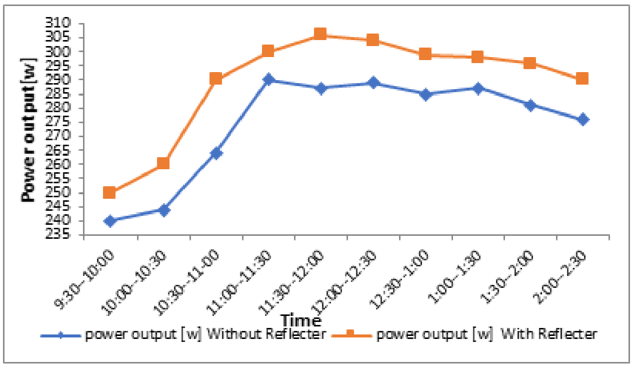

Figure 7. Output powers using mirror as a reflector material

4. CONCLUSION

There are many methods used to enhance the performance of PV solar panel systems. Tracking the sun is the most common method but requires high cost. This work proved that using other techniques to increase the power output, with lower the cost compared with installing tracking system, is possible. In this research, the optimal condition for reflector material and reflector integration angle is studied experimentally. The improvement in the system power output shows that the proposed system is effective. It can be concluded from the experimental outcome that the system with reflector is capable in producing 5% power output from the solar tracker without reflector. The only limitation observed in the system with reflector is the increase in temperature which increases the degradation of the panel. More research work needs to be carried out to study power mismatch of PV panels and degradation factors for the integrated reflectors with the help of I–V curves.

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Jamil Al Asfar received his Ph. D in Mechanical Engineering from the University of Jordan in 2007, from which he also obtained his M. Sc. in 1996. He received his B.Sc. in Mechanical Engineering in 1985 from Yarmouk University in Jordan. He worked as Head of engineering department at the National College (intermediate university college) for engineering and management careers in Amman till 1995. Then, he joined the Jordanian Ministry of Trade and Industry (Jordan Investment Board) as Head of planning and studies department, and director of a UNDP project for capacity building, from 1995 to 2007. Currently, he works as Professor at the University of Jordan-School of Engineering/ Mechanical Engineering Department. His current research interests include CFD, Energy, Combustion, Hybrid renewable energy systems, Alternative Fuel. He also worked as visiting professor in Tabuk University/KSA, Philadelphia and Al Zaytooneh University. **Prof. Al Asfar** has published more than **40 articles** in many ISI/Scopus journals.

Prof. Sakhrieh joined the department of Mechanical and Industrial Engineering at the American University of Ras Al Khaimah, UAE in fall 2015. Prior to that he was the chairman of the mechanical engineering department at the University of Jordan. Prof. Sakhrieh is the author and coauthor of more than 60 papers in international journals and conferences. Prof. Sakhrieh served as a co-president of the Arab German Academy for Science and Humanities (AGYA) in 2016. He is a reviewer several for International Journals such as Applied Thermal Engineering, Energy Conversion & Management, Sustainable Cities and Society and Journal of Energy. He chaired the organizing committee of several conferences and workshop such as the International Conference on Energy, Water & Environmental Sciences (ICEWES) conference in 2018; boosting opportunities awareness for women in STEM education and career pathway: Boosting Opportunities and Awareness workshop; Energy and Water in the Gulf Cooperation Council Countries (EWGCC) workshop; Entrepreneurship and innovation challenges in the 21st-century students Forum.

Waleed Al-Nayfeh experienced mechanical and industrial engineering laboratory teaching and conducting experiments with a demonstrated history of working in the work shops as a training and production engineer and as a renewable energy center supervisor for research purpose. Skilled in operating and programming the lathe and milling CNC machines. Strong research professional with a Master’s Degree focused on Energy management from the University of Jordan.

Ahmed Ghandour is a Jordanian scientist, solar energy expert and a professor of industrial engineering at the Hashemite University. The Association of Energy Engineers has rated it as the Energy Manager of the Year for the Middle East. Dr. Ghandour was honored by King Abdullah II Bin Al Hussein among the Jordanian Stars of Science for his contributions to his field of specialization during the World Science Forum 2017.