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Design of solar panel intercooled by refrigeration system

Nader A. **Nader**

Mechanical Engineering Department, Prince Mohammad Bin Fahd University, P.O. Box 1664 Al Khobar 31952 KSA

Abstract. There is no denial that renewable energy is considered to be the most cost-competitive source of clean power in many parts of the world. Saudi Arabia's vision 2030 aims at achieving the best by using different sources of renewable energy such as solar energy, wind energy, and others. The use of solar energy in particular for power generation will decrease the dependency on oil and thus decrease the greenhouse gasses. The current study focuses on designing a cooling system in order to increase the efficiency of the photovoltaic panel for residential units. The design system provides enough energy by cooling the solar panels with pumping cool water from the refrigerator to the direct system. The results showed that for the Dhahran region, Saudi Arabia, the normal efficiency of the solar panels before cooling was between 10 to 15 % at 42 ^{o}C. After cooling, the temperature of solar cells decreased to 20 °C and the efficiency increased by 7%. Moreover, the output power was increased by 31% with maximum efficiency of 32% at noon time.

1 Introduction

Solar power is energy from the sun that is converted into thermal or electrical energy. Solar energy is the cleanest and most abundant renewable energy source available, and the U.S. has some of the richest solar resources in the world. Solar technologies can harness this energy for a variety of uses, including generating electricity, providing light or a comfortable interior environment, and heating water for domestic, commercial, or industrial use. The U.S. installed 2.3 gigawatts (GW) of solar PV capacity in Q2 2018 to reach 58.3 gigawatts (GW) of total installed capacity, enough to power 11 million American homes. This represents a 9% year-over-year decrease and a 7% quarter-over-quarter decrease. Total installed U.S. PV capacity is expected to more than double over the next five years, and by 2023, over 14 GW of PV capacity will be installed annually [1].

Even though the Kingdom of Saudi Arabia has an impressive natural potential for solar and wind power, and the local energy consumption will increase threefold by 2030, there is still a lack of competitive renewable energy sector at present. Indeed, more than 59 percent of the Gulf Cooperation Council's (GCC) surface area has potential for solar photovoltaic (PV) deployment. If only one percent is utilized from this area will result in 470GW of solar PV capacity [2]. This significant portion of the renewable energy value chain within the KSA can help to boost the economy, including research and development, and manufacturing, among other stages. From inputs such as silica and petrochemicals to the extensive expertise of the leading Saudi companies in the production of different forms of energy, there are all the raw ingredients for success. To put this into practice, the forthcoming launch initiative was issued by the King Salman Renewable Energy. A review of 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, public and private partnerships need to get involved. Finally to guarantee the competitiveness of renewable energy, a gradual liberalization of the fuels market is needed.

Solar energy has now proved to be an external beneficial source not only for the environment but also financially speaking. Additionally, due to the higher demand for renewable energy, our project aims to turn into an efficient source of clean energy. A solar sector is emerging as part of Saudi Arabia's economic diversifications plans under the vision 2030. Nowadays most of the countries have started to rely on solar energy in their future plans. The project aims to increase the efficiency of solar energy. The solar panel efficiency is normally affected due to extreme temperature conditions. The efficiency as specified by the manufacturer decreases by 0.5% for every one Celsius increase beyond 24 C. The main challenge of this project is to keep the solar panel from heating. In addition, the water is cooled using a refrigeration system. which is also partially powered by the PVC cell. The second challenge is to keep the water in the coil cold by circulating the water from the refrigerator to the panel using pump. This project is all about designing and manufacturing cooling system for solar panel intercooled by a refrigeration unit.

This project aims at reducing the use of fuel energy and to achieve one of the Saudi vision's objectives. The following explanation shows the mechanical process in details with the steps in operating the solar-powered refrigerator. In addition, economic benefits are achieved from using the refrigerator in the Saudi market with enough safety at a low cost as well. The project adds values to mechanical operation equipment and supports the environment with green energy and a suitable alternative to the fuel energy.

Similar work had been done before by previous researcher where solar energy was used to supply enough power to a refrigerator with a simple mechanical operation. In this project, it is normal to have appropriate specifications for the vapor compression refrigerator. There are basic electrical and mechanical principles that support the mechanical operation for the advantages of using a high-quality solar-powered refrigerator. That work depended on the quality of making use from the evaporator compression in the refrigeration cycle. This may require appropriate percentage from the pressure needed to operate the mechanical system for both of the pumps and the operating system for the compression [3].

The schematic system is used for the advantages of vapor compression cycle where the compression system can be fixed in the low and high amount of liquid needed for the refrigeration system (Fig. 1). Most of the previous works related to the refrigeration system using vapor compression need professional items in each step of the cycle to get the planned amount of energy to complete the refrigeration functions. The same system that was used in refrigeration cycle can be provided to the required cooling system in order to decrease the temperature of the solar panel and thus improve its efficiency. There is a strong relationship in the previous solar-powered refrigerator and the current mechanical operations for conventional cooling system depending on the quality of using solar panels. There is a separate function in the vapor compression system to provide energy depending on the high pressure. It is also to enter a condenser for exchanging heat to the cooling system in the values of the refrigerator functions for cooling benefits [4].

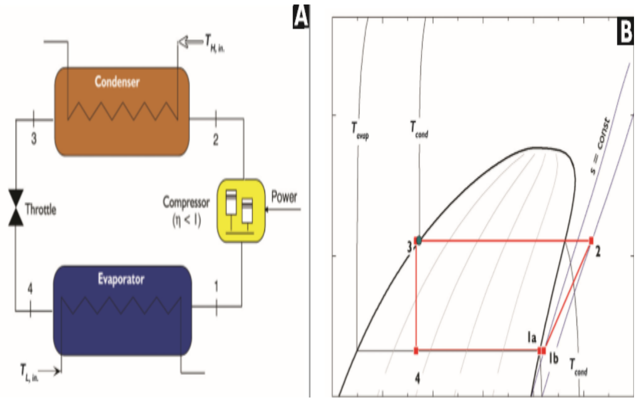

Fig. 1. Schematic of a vapor compression refrigeration [4]

1.1 Comparative Study

It is considered to have more innovation about the importance of using different types from solar-powered refrigeration. Using the different machines to get the absorption refrigeration type can support the process of solar refrigeration in general. This type is considered one of the heat driven types that support the refrigeration process and increases the options of using solar refrigeration. It is important to mention that our project is not a new invention in this field. However, there is a big development in the field of refrigeration in terms of energy and economic benefits. It is also considered to use the heat driven system as little as possible from a mechanical power which provides more than enough solar energy for other purposes. While the absorption system in refrigeration uses ammonia over using refrigerant and absorbent, it is necessary to accept the output mechanical power [5].

Throughout the scope of this work, an electrical power was needed for starting the compressor and the water pump which were supplied partially by the solar panels. The compressor comes in the place of the absorption system to use three heat exchangers. One of those exchangers is the regenerating intermediate heat and another exchanger is the absorber with the last one which is the generator. The pumping process in this project is one of the main parts to send cold water for the mechanical part in the solar panel to reduce its heat and to average the level of temperature in the refrigerator. The solar-powered refrigerators seem complicated and costly while some others find the conventional vapor compression systems are more complicated and costlier because of using electricity and other types of non-environmental energy. It may be necessary to have the quality of using solar energy in appropriate methods like the project of using solar energy and simple items with simple electrical support. There are some procedures to keep enough solar energy to operate the refrigerator from the similar shapes that collect solar energy for mechanical power in the mechanical system in the solar refrigerator. In addition, it is considered to examine the ability of a solar refrigerator system under the process of solar energy and the quality of the mechanical power in the whole system.

The main idea of the discussion is to use an alternative energy such as solar energy to power refrigerator mainly the compressor which consumes a lot of power. The major advantage of solar refrigeration is that it can be designed to operate independently of a utility grid. Applications exist in which this capability is essential, such as storing medicines in remote areas [6].

2 Theoretical Calculations

Solar Panel Calculation:

The performance of a PV cell is defined by the IV-curve (Fig. 2), which shows how the current inside the cell varies as a function of the voltage for a given solar irradiance. The current is proportional to the incident solar irradiance.

Power output:

$$P = V \times I \tag{1}$$

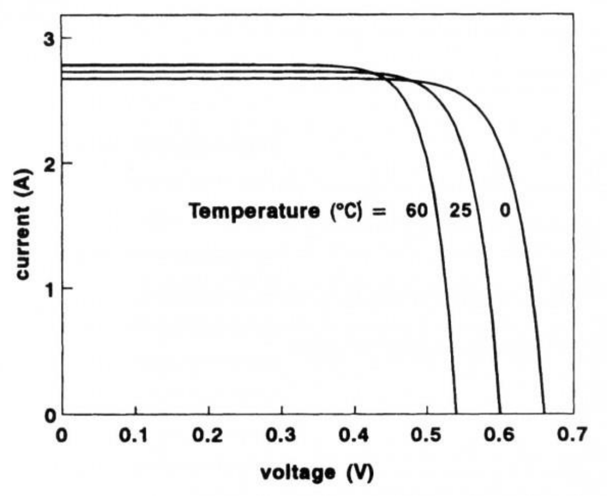

Fig.2. IV-curves for different Temperatures [8]

Heat input:

$$Q_{in} = C_v \,.\, m \,.\, \Delta T \quad (2)$$

$$Q_{solar} = \Phi \,.\, A \,.\, t \quad (3)$$

where Q_{in} is the amount of heat generated in the cooling process of the solar panel and Q_{solar} is the amount of solar heat obtained during the day. Φ is the coefficient of heat transfer of the heating device (W/m²); A is heat transfer surface area of the heating device (m²); ΔT is the temperature difference (°C), and t is the time in seconds [8].

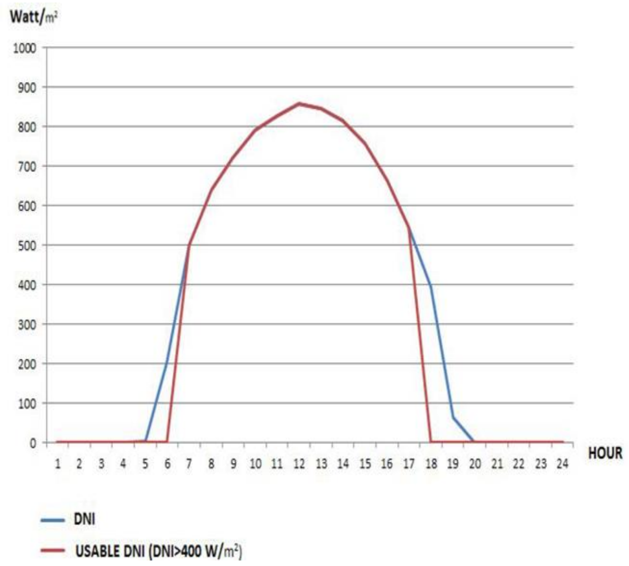

Fig. 3. Coefficient of radiation in Dhahran

Figure 3, shows the coefficient of radiation that have been done in Dhahran, Saudi Arabia for 24 hours on a summer session, because the problem which the project solves happens in summer more than any other sessions.

Table 1. Calculation for the rest of points

		$\eta = 10\%$	$\eta = 15\%$	$\eta = 20\%$	$\eta = 25\%$
	Q_{solar}	$Q_{electric}$	$Q_{electric}$	$Q_{electric}$	$Q_{electric}$
10 to 11	405.92	40.59	60.89	81.18	101.48
11 to 12	418.23	41.82	62.73	83.65	104.56
12 to 13	413.31	41.33	62.00	82.66	103.33
13 to 14	396.08	39.61	59.41	79.22	99.02

Table1 shows sample calculations of efficiencies at different times for example at time from 9-10

$$Q_{solar} = \emptyset \cdot A \cdot t = (0.355 \cdot 0.385)(3600)(795) = 391.1639\ kJ$$

Efficiency (η): Efficiency is defined as ratio of energy output from solar cell to input energy from sun [9].

$$\eta = \frac{Q_{Solar}}{Q_{in}} \quad (4)$$

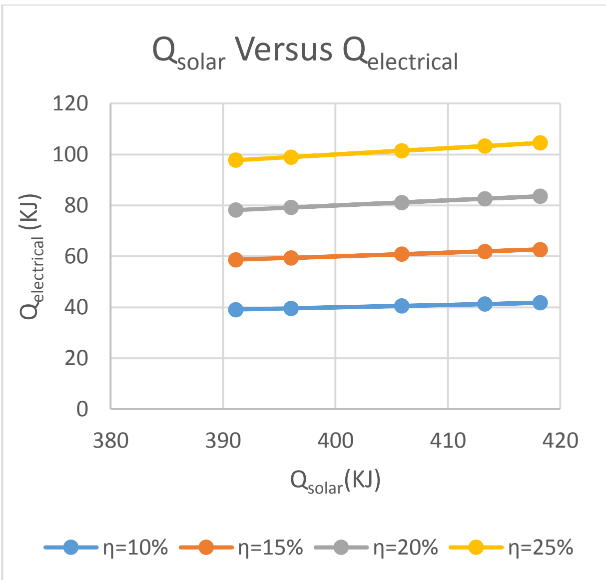

Fig. 4. Input power versus Output power different efficiencies

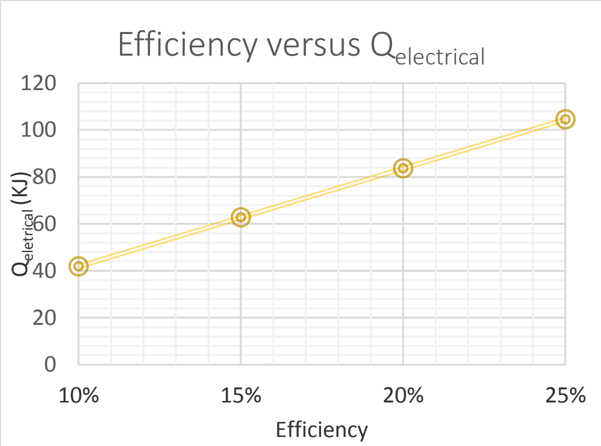

Fig. 5. Different efficiencies versus output power between 9 - 10 Am

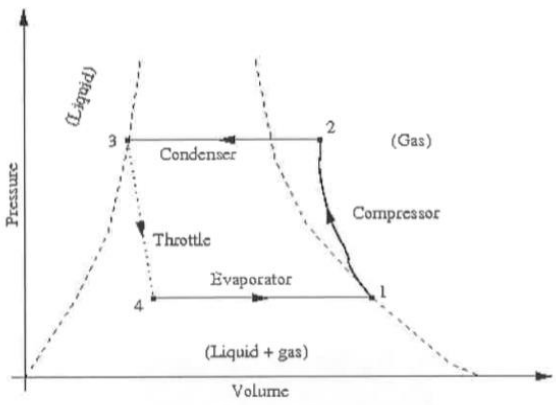

Fig. 6. Diagram of vapor compression refrigeration cycle [8]

The vapor compression refrigeration cycle has four components: evaporator, compressor, condenser, and expansion (or throttle) valve. The most widely used refrigeration cycle is the *vapor-compression refrigeration cycle.* In an ideal vapor-compression refrigeration cycle, the refrigerant enters the compressor as a saturated vapor and is cooled to the saturated liquid state in the condenser. It is then throttled to the evaporator pressure and vaporizes as it absorbs heat from the refrigerated space [10].

Refrigeration Effect:

$$Q_{in} = h_1 - h_4 \quad (5)$$

Q_{in} is the amount of heat inputted to the system from the cold body

$$W_{in} = h_2 - h_1 \quad (6)$$

W_{in} is the amount of work done to the system to accomplish this cycle. The coefficient of performance, COP, of a refrigerator is defined as the heat removed from the heat input Q_{in}, (i.e. inside a refrigerator) divided by the work W_{in} done to remove the heat (i.e. the work done by the compressor)

$$COP = \frac{Q_{in}}{W_{in}} \quad (7)$$

Finally, the pressure and temperature gauges were inserted at each stage of the refrigeration system in order to find the enthalpies by using steam table [11]. The performance of a PV cell is defined by the IV-curve, which shows how the current inside the cell varies as a function of the voltage for a given solar irradiance. The current is proportional to the incident solar irradiance.

3 Design Methodology

The design consists of two main parts. Manufacturing of portable refrigeration powered by the solar system and designing a solar panel intercooled by the refrigerator. A copper coil was installed in the back of the solar panel in order to cool it down in case of excessive heat due to rise in the ambient temperature. That will help the efficiency of a solar panel to increase as the surface of the panel is cooled to nominal 24 °C. The copper coil is extended from the panel to refrigerator. Inside the refrigerator, there is a water tank connected to a water pump which elevate the water to the solar panel using the copper coil. The cooling processes occurs between the solar panel and coil by conduction that causes an exchange of heat between the coil and the solar panel. Then the water goes back to the tank to be cooled down again.

In this study a different setup for the calculation is used. The first one was done for calculating the internal heat coming from the sun to the solar and the second one to find the voltage and current to find out the power output. In addition, the first test was done by placing the solar above the refrigerator at 45° angles and pointing out the leaser gun to various areas of the solar panel surface. A voltmeter was used to calculate the current and voltages values and by using the ohm's law $(P = IV)$ the power output from the solar panel can be found.

4 Experimental Work

The prototype setup consisted of a stand, solar panel, battery, controller, inverter, coil, compressor, condenser, expansion valve, evaporator, and refrigerator case. The solar panel was installed above the stand in which the coil was installed directly behind the surface of the solar panel. Moreover, the cooling tank was inserted inside the refrigerator. The first step was to calculate the internal heat coming from the sun and second to find the voltage and current for the current power output. The coil that circulates the water to the panel was made of copper (7408 Copper Wire). The refrigerator body was made of fiberglass to insulate the heat from going inside. In the refrigeration cycle a reciprocating compressor (R134A 220V/50Hz 1/5HP 173W Huaguang) was used. In addition, to circulate the water passing through the panel there was a use of (Uniclife 80-550GPH Submersible Water Pump). Moreover, the expansion valve that was connected to the evaporator use (CTV(E), DTV(E) series thermostatic expansion valve) [12].

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5 Results and Discussion

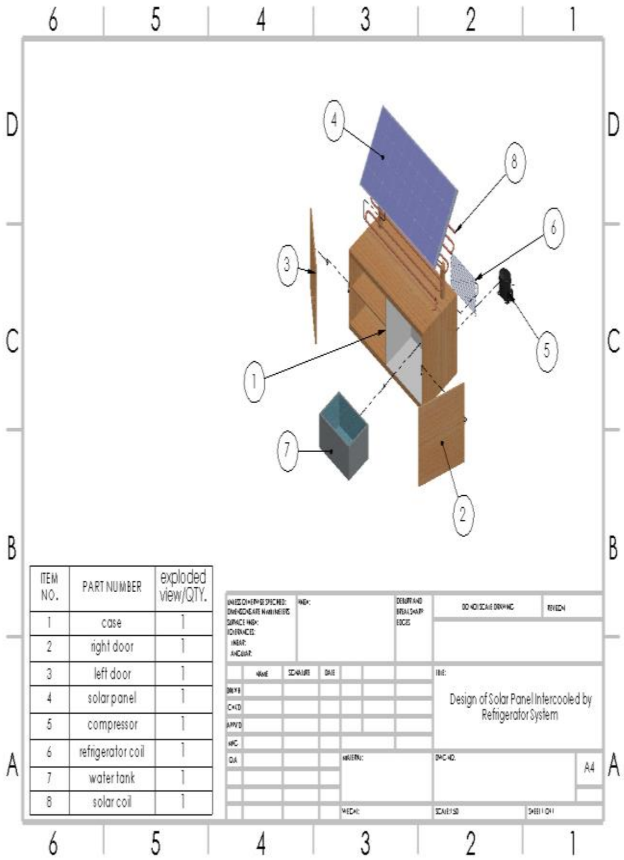

Fig. 7. Assembly drawing of major parts used in this experiment

Table 2. The result of solar performance without cooling system

Time	Ø	A	t	Q_{solar}	$Q_{electric}$
9 to 10	795	0.034706	3600	993.28572	129.127
10 to 11	825	0.034706	3600	1030.7682	129.815
11 to 12	850	0.034706	3600	1062.0036	132.7505
12 to 13	840	0.034706	3600	1049.50944	131.1886
13 to 14	805	0.034706	3600	1005.77988	129.7456

Table 3. The result of solar performance with cooling system.

Time	Ø	A	t	Q_{solar}	$Q_{electric}$
9 to 10	795	0.034706	3600	993.28572	168.8585
10 to 11	825	0.034706	3600	1030.7682	173.169024
11 to 12	850	0.034706	3600	1062.0036	176.29266
12 to 13	840	0.034706	3600	1049.50944	177.367021
13 to 14	805	0.034706	3600	1005.77988	171.98838

The tables 2 and 3 show the input power to solar panel (Q_{solar}) and output power ($Q_{electric}$) in different times in the Dhahran region, Saudi Arabia. The temperature of the panel was measured from 9 am to 2 pm. In addition, the temperature of the cooling water was recorded as shown in tables 2, and 3.

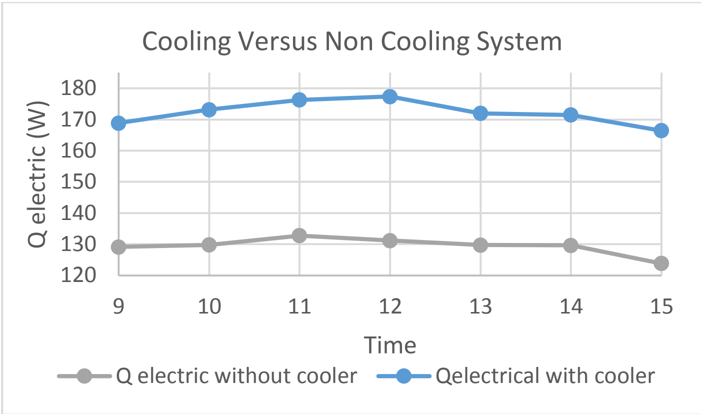

Fig. 8. The difference performance of solar panel before and after system

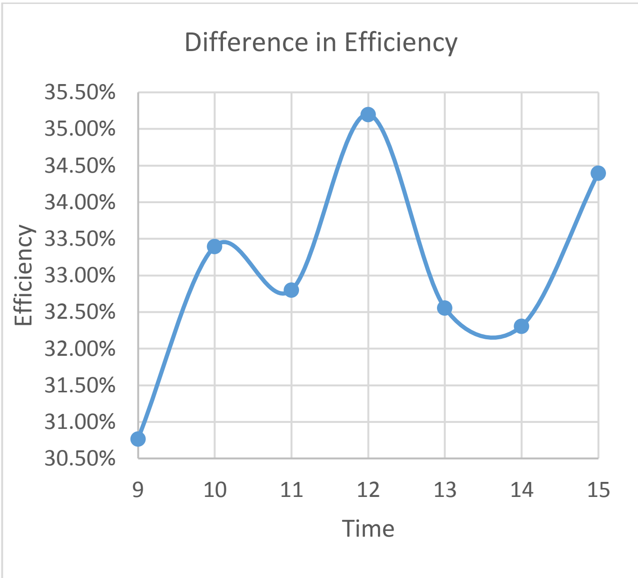

Fig. 9. Efficiency increases after operation

The performance of solar panels before and after cooling was shown in figure 8. The results showed that the normal efficiency of solar panels systems is between 10 to 15 %. After the cooling system is applied in the solar panel, the temperature of solar cell decreased around 20 $°C$ and the efficiency increased around 7%. For example, the output power between 9 to 10 a.m. was around 129W and it increased in next day after ran the system to 169W. Figure 9 showed how the efficiency increased after running the system. The efficiency increased around 32% and the biggest change of efficiency was at 12 P.M since the temperature was very high at that time.

4 Conclusion

The objective of this research was to cool the PV panels using water. The design of cooling system for solar panels has numerous advantages in environmental, social, commercial and industrial sectors. An experimental setup had been developed to the cooling rate system. Moreover, the study involving the influence of cooling on the performance of PV panels was conducted. In general, cooling the surface temperature of solar cell to 20 ºC increased the efficiency of the panels by 7%. The output power was increased by 31% with maximum efficiency of 32% at noon time.

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