Performance Evaluation and Enhancement of Solar PV Panels

Abdul Quddus, Faizullah Khan, Fazal Muhammad, Muhammad Waleed Raza, Surat Khan, Imran Qureshi

Abstract— With the frightening rate of decrease of main energy resources such as fossil fuels, together with the environmental deprivation caused by the procedure of harnessing these energy sources, it has turned out to be an urgent need to spend in renewable energy resources that would adequately fulfil the growing energy requirements without degrading the environment. Solar energy is the direct conversion of solar radiations into Direct Current (DC) using solar cells and other solar technologies. Conversion of sunlight into electricity for industrial and domestic applications is both clean and environment friendly. The conversion efficiency of commercially available solar cells is in the range of 10% to 20% only. While recent advancements in solar technology has significantly improved the solar cell efficiency, but still the maximum efficiency falls in less than 20% range depicting enormous room for improvement. Solar cells accomplish better efficiency in cold weather than in hot climate. Solar panels are rated at 25 C˚ while panel temperature simply reaches to 70C˚ or more in the hot summer days. The deviation from the 25 C˚ temperature reduces the efficiency of the solar cell up to 25%. A 100W panel produces only 75W in the months of May-June in most parts of Pakistan where temperatures reach 45 C˚ and above in summer when electricity demand is high. The focus of this research work is to improve the efficiency of the solar cells by keeping the cell temperature within permissible limits. An experimental model is developed for two types of solar panels i.e. Monocrystalline and Polycrystalline. In the experimental model, both the solar panels were installed with a temperature sensor connected to Arduino. The temperature sensor measures the temperature of the solar panel. If the temperature of the solar panel is increased to a certain level the Arduino will generate a signal to a solenoid valve connected to it. The solenoid valve, connected to a water reservoir, would be turned ON and the water will be sprayed on the glass surface of the panel making a cooling effect. If the temperature increases further the Arduino will switch on the fan. The fan would turn ON making a cooling effect. The performance of both types of solar panels were analyzed by measuring the output power of the solar panel with and without cooling system. The results show that the efficiency of the solar panels were improved significantly by employing the dual cooling system.

Index Terms—Solar PV panel, Mono crystalline, Poly crystalline, Solar Irradiations, Cooling of Solar panel, Dual cooling system

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1 INTRODUCTION

With the disturbing decrease of conventional energy resources such as fossil fuels, it has become imperative to take advantage of renewable energy resources that would provide the energy needs of the future adequately without degrading the environment through greenhouse gas release. One of the renewable sources of energy is solar energy that has an utmost potential that if only a minute fraction of this energy is utilized, it would be extra than the whole world's necessity [1]. It utilizes sunlight to give heat, bright light and electricity to industrial and domestic users. The sun has immense energy potential, but due to a reduced amount of efficiency of the cells it is mainly a difficult task to extract electricity from it. Most of the solar cells in the market have efficiencies in the range of 10-20%. There is a huge room for improvement.

The performance of the solar cell is dependent on Irradiance and temperature of the cell. The parameters affected by the temperature are open circuit voltage, short circuit current and maximum power. The open circuit voltage decreases while short circuit current rises with rise in temperature [2].

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The Table-1 shows the changes in efficiency of monocrystalline silicone solar cell in the presence of different light intensities when temperature is increased from 25 C˚ to 60 C˚ [2]. Likewise, the efficiency of polycrystalline silicon solar cell is affected by environmental influences such as temperature and wind. The efficiency of polycrystalline silicon solar cells is less than mono crystalline silicon solar cell because of the less pure silicon crystal lattice and random alignment [3].

TABLE 1: THE EFFICIENCY OF MC-SI SOLAR CELL WITH CELL TEMPERATURE AT DIFFERENT CONSTANT LIGHT INTENSITY [2]

Efficiency (η %)				
Temperature	At 515W/m2	At 400W/m2	At 280W/m2	At 215W/m2
25	10.049	11.165	11.417	11.381
40	9.95	11.117	11.238	11.03
50	9.856	10.837	11.002	11.019
60	9.023	10.527	10.826	10.502

1.1 Types of Solar Cells

Though there are lots of different types of solar cells, crystalline silicon -which includes both monocrystalline and polycrystalline- and those made with thin film technology are the most common types [8].

1.1.1 Mono crystalline Silicon

Monocrystalline solar cells are made from cylindrical shaped silicon ingots [6]. Four edges are cut from the cylindrical bricks to make silicon wafer. Monocrystalline silicon solar cells can be distinguished from other types of solar cells because of the smooth appearance and even look due to high purity silicon. The efficiency of these PV cells is in the range of 20% [9]. These cells are the most space efficient. Monocrystalline solar panels are the most expensive type of solar panels as compared to other types of solar cell panels.

1.1.2 Polycrystalline Silicon

In 1981 polycrystalline or multi-crystalline silicon solar cells were introduced in the market. Uncooked silicon is changed from solid to liquid and emptied into a square shape. After chilling it is cut into flawless square wafers. The procedure used for making polycrystalline silicon is simple and cheap. Polycrystalline solar photovoltaic system operates at efficiency of 13-16% [10]. This is due to lower purity of the material. These types of solar cells are less space efficient so they require a lot of panels for small electrical power.

1.1.3 Thin Film:

Shrills of semiconductor material are placed on top of a substrate. This is how a thin film solar cell are made. Production on large scale is easy and cheaper than their counterparts. Their efficiencies lie from 7 to 13% [11]. Many experts say that their efficiencies will climb up to 16% in future models due to the research and advancement being done into them [12]. These solar panels are not space efficient which it's use for residential applications.

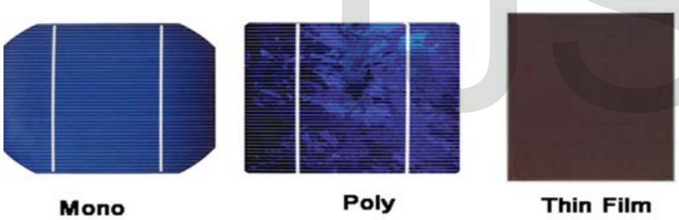

Figure 1 Different types of solar cells taken from [4]

1.2 Solar Energy Potential of Pakistan:

Pakistan is amid those countries in which sun shines the earth round the year and therefore solar power generation capacity is enormous [5]. Pakistan has a huge potential of renewable energy especially solar energy. Pakistan, therefore, being in the Sunny region, can preferably take advantage of solar energy technologies. This source of energy is extensive and accessible in abundance in the different regions of the country [7].

TABLE-2: MONTHLY AVERAGE SOLAR IRRADIATION OF CAPITALS OF FOUR PROVINCES OF PAKISTAN TAKEN FROM [5]

Provincial Capital	Irradiation (Min) KWh/m2	Irradiation (Max) KWh/m2
Quetta	3.6	7.56
Karachi	2.4	6.31
Peshawar	3.39	6.31
Lahore	2.8	6.28

This research is focused on performance enhancement of the solar PV panels using cooling techniques. Efficiency of monocrystalline and polycrystalline solar PV panels is analyzed at different cell temperatures and cooling techniques used to keep temperature of cell within limits. This work carried in this research not only improves the efficiency of solar PV panel but also helps in selecting the optimal solar panel type for Pakistan.

2. LITERATURE REVIEW

2.1 Structure of Solar Cell

A solar photovoltaic cell consists of two types of semiconductor materials having different conductivity levels. If semiconductor silicon is doped with phosphorus having five valence electrons, N-type material is formed. Similarly if Boron having three valence electrons is doped with Silicon, P-type material is formed. A single crystal made from N-type and P-type materials constitute a photovoltaic solar cell. The PN-junction is typically 0.2 μm to 0.5μm deep [15].

Solar panels contain solar cells which convert the sun light into Direct Current (DC).

2.2 Effect of Temperature on Solar PV Panels

2.2.1 Temperature:

The speed at which the electrons travel in an electrical circuit is dependent on the resistance of the circuit. The electrical resistance is affected by temperature. The increase in temperature increases the resistance and vice versa [13]. Solar cells are delicate to temperature like all other semiconductor devices. The band gap of a semiconductor material is reduced with an increase in temperature. By increasing the temperature of the semiconductor material, the electrons in the material has their energy increased. To break the bond lower energy is needed. The reduction in the bond energy also reduces the band gap. Decrease in band gap increases short circuit current while open circuit voltage decreases as shown in Figure- below.

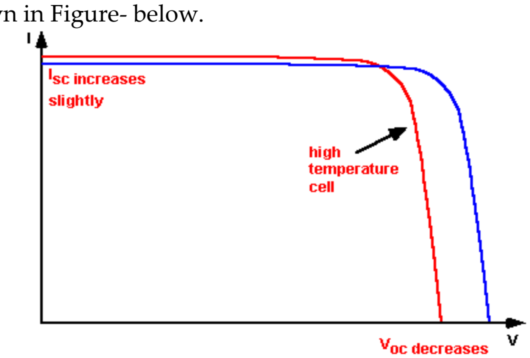

Figure 2 IV characteristic curve of solar cell with temperature [13]

Power production efficiency of the solar panel drops when the panel reaches high temperatures. According to a field experiment conducted in the UK, an increase of 1C° showed a drop of 1.1% of maximum power after the panel reached

42C°. Similar results were found in 2008 in Africa. After reaching a temperature of 44C° the power production dropped gradually [14]. The temperature of the cell is the key parameter to determine quality of a solar cell [2].

In the 1950s the efficiency of the monocrystalline silicon solar cell was 15% only but recently the efficiency has increased to 28%. The thin film type is amorphous silicon with efficiency of less than 10% but inexpensive and better light absorption than crystalline silicon. The PV modules are likely to give the greatest performance at standard test conditions (STC). Only controlled environment like laboratory setup can produce these conditions.

All types of solar cells' performance depend on the climate and they perform well in cold than in hot climate. Above 25 C° for every rise in 1C° the output power is reduced by 0.25% for amorphous silicon solar cells and 0.40% for crystalline solar cells [16]. In a hot summer day, the panel temperature can grasp up to 70C° and the panel will produce 25% reduced power compared to their maximum power. As a result, a 100W panel will produce only 75W in summer months when temperature reaches 45C° [16]. The main environmental parameter to decide the quality and performance of a solar cell is the temperature.

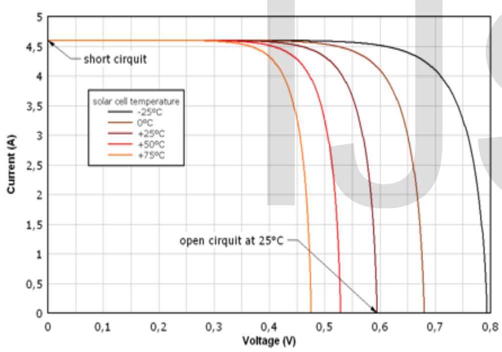

Figure 3 V-I characteristics of solar cell under different temperature [19]

2.6 Cooling of Solar Panels

Photovoltaic panel directly converts solar radiations to DC electric power. PV solar panel contains solar cells that have series and parallel connections. A solar cell contains layers of semiconducting materials. Falling of light over the surface of PV panel creates potential which further creates pair of holes and electrons to maintain flow of electric current and temperature of the light affect the efficiency of the solar PV panel. Power output and efficiency of the solar PV panel linearly depends on the operating temperature. Higher the temperature the lower will be efficiency and the power output. The basic principal to cool down the PV panel is evaporation that lowers the temperature. When a dry and hot air is passed through a wet pad evaporation will take place to cool down the panel. So water spray over the surface of PV panel will reduce temperature. Addition of forced air over the surface of wet panel will create humidifying conditions that will enhance the cooling effect so, finally the power output and efficiency will increase. Water spray and forced air will increase heat of vaporization. There are five factors which control the rate of vaporization the five factors support relative humidity and water vapor. Relative humidity plays vital role if its value is high. The rate of vaporization will be low at cooling effect will be low. Light temperature stimulates evaporation rate that increase humidity in air that produce the evaporation rate. So humid air near surface of PV will cause to decrease evaporation, passing forced air will remove humid air in ambient of PV panel.so that arrangement of forced air, water spray over the surface of PV panel and water reservoir will help to reduce the surface temperature of solar panel. Cooling of the PV panel will increase the power output and efficiency of the Photovoltaic panel.

2.7 Water cooled PV panels

Water is a good cooling medium because of its heat absorbing properties. The thermal transmittance coefficient between fluid and metal is very good. However, at higher temperatures it cannot be used because under liquid form its use involves higher pressure [17]. An additional drawback is that it offers oxidation. Lastly, below zero degrees, it can damage the system. All solar panel parameters, like short circuit current, open circuit voltage, fill factor and efficiency are altered because of altering the amount of light and temperature.

The solar radiation that falls on a PV panel is converted to heat rather than electricity; this increases the temperature of the solar panel thus decreasing its efficiency [17]. Many researchers have proposed different techniques to cool the solar panel and improve the output power of the panel. Sandhya [17] investigated experimentally and showed that a PV panel that is cooled by water using a thin water film on the surface of the PV panel reduces the temperature of the panel thus increases the overall output of the panel. The research of Bahaidarah [18] experiential that the panel temperature reduces up to 35 C° because of water cooling of the panels. Elnozay [19] investigated experimentally the performance of PV panels that were cooled by water flow on the surface of PV panel and saw a 45% and 39% reduction in temperature of the frontage and backside surface of the PV panel respectively. Furthermore, the panel that was cooled had an efficiency of 11.7% to that of 9% for the module without cooling. Sabri [20] investigated the cooling of PV panels using a spiral pipe as a heat exchanger so as to offer cooling. The PV panel that was cooled had an efficiency of 13%, whereas the conventional PV panel had an efficiency of 10%.

TABLE 3 VARIATION OF POWER GENERATED AND REDUCTION IN EFFICIENCY

Panel Temperature (℃)	*Power generated (Watts)*	*Reduction in efficiency (%)*
35	34.3	0.2
40	33.5	4.3
45	32.8	6.3
50	31.9	8.9
55	31.1	11.2
60	30.3	13.7
65	29.4	16

2.8 Air cooled photovoltaic panel

Another way of cooling the PV panel is by means of air which absorbs the heat from the panel and therefore cools it.

The model that was cooled using air was simpler in working than the PV panel that was cooled with water. The air that is passing all the way through the PV panel provides cooling of the PV panel by absorbing its heat and then improves the power output of the panel. Taken as a whole the air cooled PV panel were less efficient than the PV panels that were cooled using water.

3. METHODOLOGY

The methodology used for this research work is to design a dual cooling system for two types of solar PV panels, Monocrystalline silicon and Polycrystalline silicon that work in intense heat scenarios to improve efficiency of these. The necessary steps in this regard are as follows.

- Selection of monocrystalline and polycrystalline solar panels for experimental analysis.
- Designing of water cooling source, water source pump and water piping for the purpose of water spray over the surface of the both solar panels in intense heat scenario.
- Installing the LM-35 Temperature sensors to the monocrystalline and polycrystalline panels to measure the critical temperature of both the panels.
- Undertaking the task of schematic wiring arrangement of the Arduino with Temperature sensors, voltage sensors and current sensors to measure the temperature, voltage and current of both mono crystalline and polycrystalline panels.
- Measuring the efficiencies of both mono crystalline and polycrystalline panels at critical temperature without dynamic cooling arrangement.
- Measuring the efficiencies of both mono crystalline and polycrystalline panels with the help of all sensors of the panels at critical temperature using only water as a source of cooling for the panels.
- Measuring the efficiencies of both mono crystalline and polycrystalline panels with the help of all sensors of the panels at critical temperature using air as a source of cooling for the panels.
- Measuring the efficiencies of both monocrystalline and polycrystalline panels with the help of all sensors of the panels at critical temperature using both water and air as a source of cooling for the panels.
- Comparing the efficiencies of both monocrystalline and polycrystalline panels in scenario without cooling arrangements and with cooling of both air and water to analyze the efficiency of the PV solar panels.

3.1 Specification of the monocrystalline and polycrystalline cells

The specifications of both solar PV panels are: rated power150 Watt; short circuit current of 10.01A; rated current of 8.57A; Maximum system voltage 600V; Open circuit voltage 21.90 V and rated voltage of 17.5 V. Solar cells of both monocrystalline and polycrystalline having fire rating of class C and having series fuse of 10A.

3.2 Design of the cooling system

Water is used as source to cool down both monocrystalline and polycrystalline solar cells along with water pump. A water reservoir contains water for cooling purpose as coolant. DC pump of operating voltage of 12volts is used to carry water from water reservoir to the piping. A pipe of 24 cm length and half inch diameter is used at the upper side of monocrystalline and polycrystalline solar panels for the purpose of the water spray smoothly to cool down the panel in critical temperature. The entire pipe along the length has bored and holes are created for the water spray over the surface of both monocrystalline and polycrystalline solar panel. A pipe with diameter of 4 inches is installed at the lower side of both the panels which carries the water used for cooling back to the water reservoir forming a closed cycle loop for reuse of the cooling water.

Figure 1 Lower side view of the solar panel installed with piping

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3.3 Installation of the temperature sensors

For measurement of the temperature of both monocrystalline and polycrystalline solar panels LM-35 is used. LM-35 sensor is a precise temperature device with output voltage linearly proportional to centigrade temperature. LM-35 temperature sensor does not require any external calibration and provides accuracies of 0.25 C° over a full range of temperature from -55 C° to 150 C°.

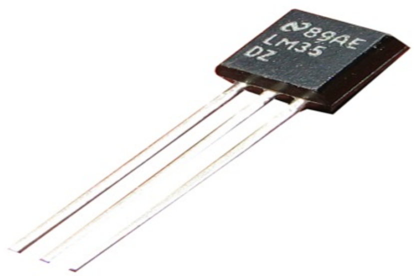

Figure 2 LM 35 temperature sensor

The LM-35 temperature sensor is installed on the back side of both the monocrystalline and polycrystalline solar panels at center for correct measurement of the temperature. LM-35 temperature sensor is connected to Arduino board for the measurement of temperature. An LCD display is also connected to the Arduino board to display the measured temperature of both the monocrystalline and polycrystalline solar panels.

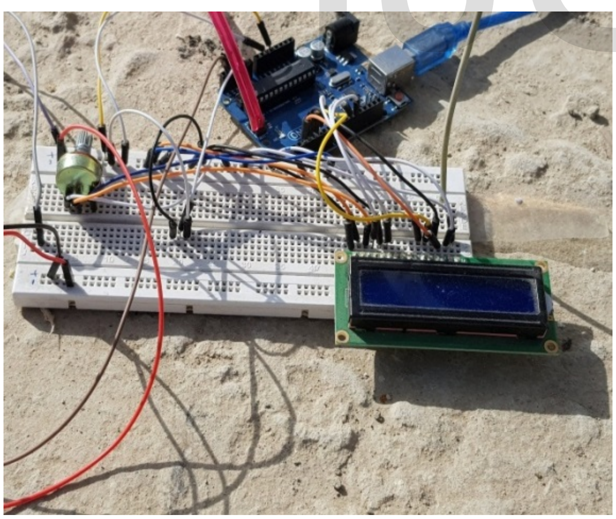

Figure 6 View of the Arduino connected with LCD Display

Current sensor ACS712-BA is used to sense the current of both the monocrystalline and polycrystalline solar panels which they are supplying to the load. This sensor is connected to Arduino board and LCD display.

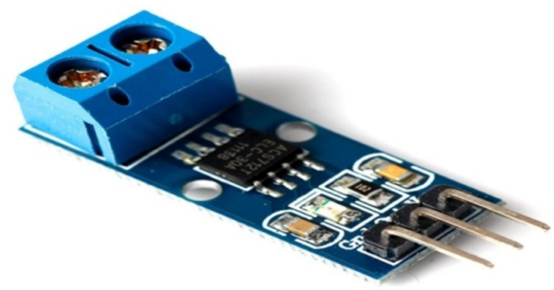

Figure 3 ACS712-BA Current sensor

In parallel the voltage sensor is installed to measure the voltage of both monocrystalline and polycrystalline solar panels and it is connected to the Arduino to display voltage at LCD.

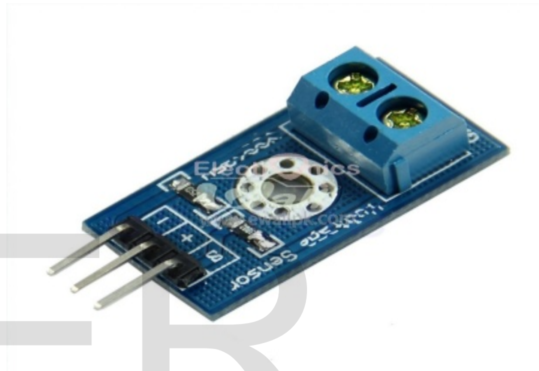

Figure 4 Arduino voltage sensor

3.4 Temperature measurement from LM35 temperature sensor

The LM-35 temperature sensor is connected to Arduino and displays the critical temperature of both the monocrystalline and polycrystalline solar panels on the LCD. The temperature of both the panels was measured with an interval of 5 minutes on different days between 9:00 AM to 04:00 PM in the month of November.

3.4.1 Temperature readings on 2nd November:

The readings of the temperature of the solar panel were taken on the 2nd day of November. The temperature shown is average temperature of the hours shown in the table.

Time	Monocrystalline (C°)	Polycrystalline (C°)
9-10	28.22	31.22
10-11	38.33	40.25
11-12	45.33	48.39
12-1	44.33	45.39
1-2	45.39	47.39
3-4	42.01	43.33

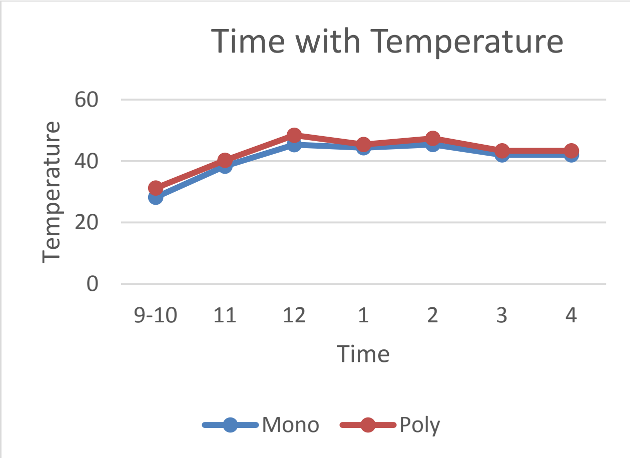

Figure 5 Temperature at different times of Poly and Mono

From 9:00AM to 10:00AM the maximum temperature reached by the monocrystalline solar panel was 34.81C° and 36.19C° for Polycrystalline solar panel.

Between 10:00AM and 11:00AM the temperature raised to higher values of 43 C° for monocrystalline solar panel and 47.62 C° for polycrystalline solar panel.

The highest temperature of 53.66 C° for monocrystalline and 54.987 C° for Polycrystalline was observed between 11:00AM and 12:00PM.

The temperature of both the solar panels varied at other times lowering a little from 3:00PM to 4:00PM.

3.4.2 Critical Temperature of Both the panels on different days:

TABLE 4: TEMPERATURE OF MONOCRYSTALLINE AND POLYCRYSTALLINE AT DIFFERENT TIMES OF DAY READINGS TAKEN ON 4/11/17

Time	Monocrystalline (C°)	Polycrystalline (C°)
9-10	32.89	34.41
10-11	44.51	46.51
11-12	46.94	48.38
12-1	46.43	49.55
1-2	52.08	53.86
3-4	46.08	50.40

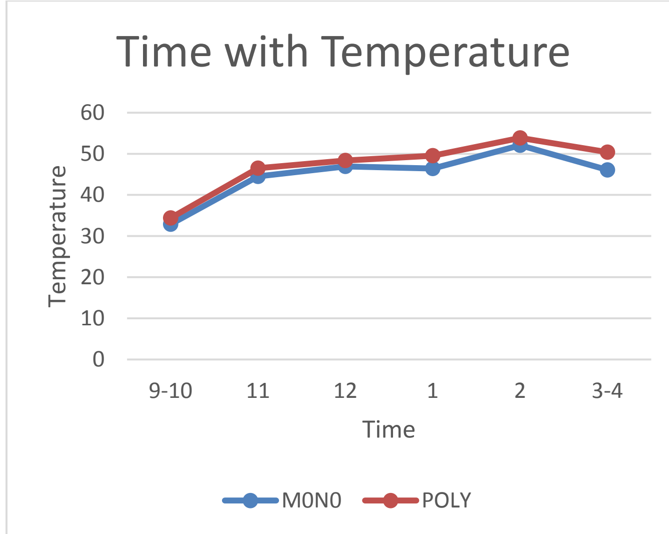

Figure 6 Temperature at different times of Poly and Monocrystalline readings taken on 4/11/17

TABLE 5: TEMPERATURE OF MONOCRYSTALLINE AND POLYCRYSTALLINE AT DIFFERENT TIMES OF DAY READINGS TAKEN ON 9/11/17

Time	Monocrystalline (C°)	Polycrystalline (C°)
9-10	24.16	26.98
10-11	28.66	29.86
11-12	33.54	31.66
12-1	40.66	42.20
1-2	48.23	50.123
3-4	42.36	44.36

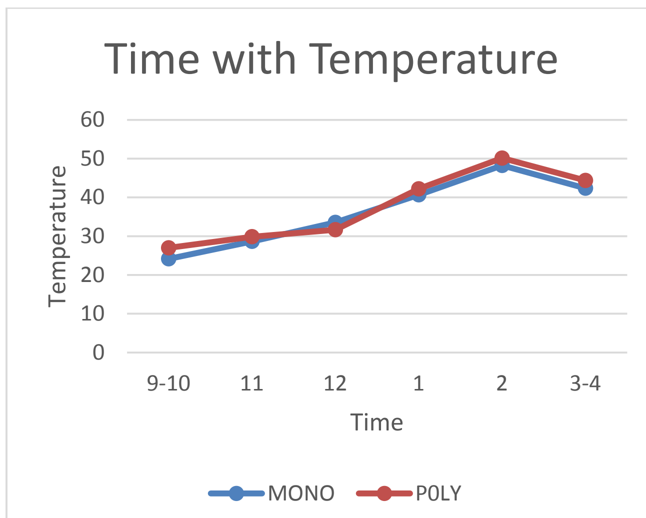

Figure 7 Temperature at different times of Poly and Monocrystalline readings taken on 9/11/17

TABLE 6 TEMPERATURE OF MONOCRYSTALLINE AND POLYCRYSTALLINE AT DIFFERENT TIMES OF DAY READINGS TAKEN ON 11/11/17

Time	Monocrystalline (C˚)	Polycrystalline (C˚)
9-10	24.16	26.98
10-11	28.66	29.86
11-12	33.54	31.66
12-1	40.66	42.20
1-2	48.23	50.123
3-4	42.36	44.36

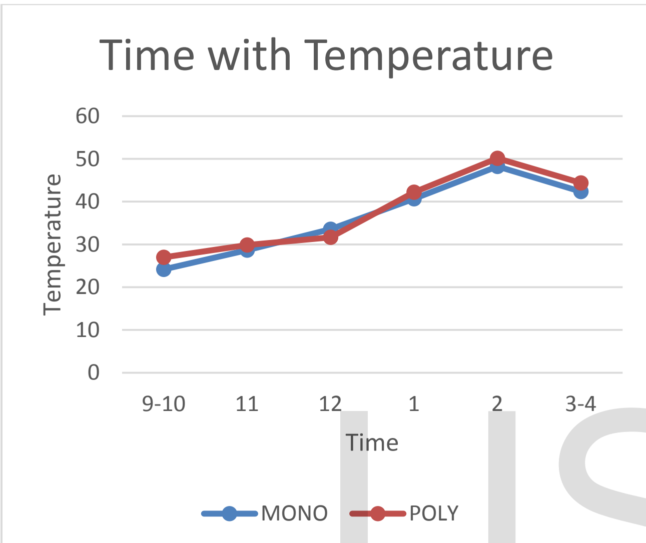

Figure 8 Temperature at different times of Poly and Monocrystalline readings taken on 11/11/17

3.5 Power output measurement of both Monocrystalline and Polycrystalline Solar panel

To measure the efficiency of both the panels the monocrystalline and polycrystalline panels are connected to Arduino. It measures the short circuit current and open circuit voltage provided by the panels by using voltage sensor and current sensor. This gives the power output of the solar panel at the critical temperature. The input power of the solar panel depends on the size of the panel. The input power for efficiency calculations is 1 kW/m^2.

3.6 Measurement of Temperature before Water cooling

3.6.1 Monocrystalline

The temperature of the monocrystalline solar cell was measured before applying any cooling techniques. The results are tabulated below:

TABLE 7: TEMPERATURE WITH POWER OF MONOCRYSTALLINE

Temperature (C˚)	Power (W)
45.4	31.7
45.5	31.8
46.4	31
47.1	30.6
47.3	30.5
47.4	29.8
47.5	30.6
47.8	30.5
47.8	30.7
48.3	26.5
49.5	22.5
50.3	22.6

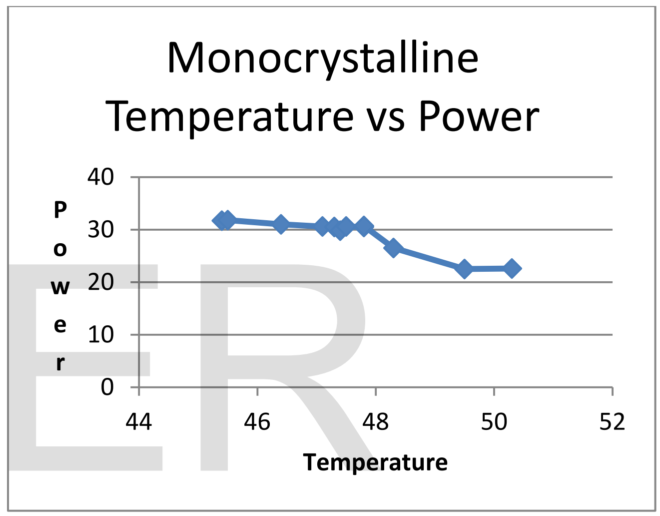

Figure 9 Temperature with power of Monocrystalline before cooling

The figure above shows the temperature and power curve. As the temperature increases the power output of the solar panel decreases. It is the minimum at 50 C˚.

3.6.2 Polycrystalline

The temperature of the polycrystalline solar cell was measured before applying any cooling techniques. The results are tabulated below:

TABLE 8: TEMPERATURE WITH POWER OF POLY

Temperature (C˚)	Power (W)
45.41	32.05
45.55	32.04
46.38	31.38
47.11	31.1
47.29	30.22
47.36	30.03
47.39	29.15
47.85	29.14
47.89	28.84
48.34	27.94
49.83	21.77
50.36	20.79

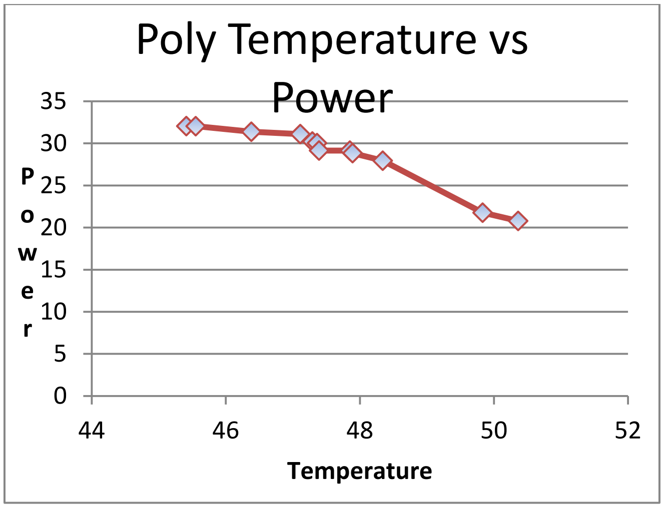

Figure 10 Temperature with power of Polycrystalline before cooling

The power output of the polycrystalline solar cell decreases with the increase in temperature. It is at the lowest value at the highest temperature of 50.36 C˚. The power output of the polycrystalline solar panel decreases at the same rate as the power output of the monocrystalline solar panel.

3.7 Measurement of Power after water cooling

3.7.1 Measurement of Power after water cooling monocrystalline solar panels

TABLE 9 TEMPERATURE WITH POWER OF MONOCRYSTALLINE AFTER WATER COOLING

Temperature (C˚)	Power (W)
50.3	22.6
49.4	22.9
48.2	24.5
47	26.3
46.4	27.4
45	28.6
43.2	29.7
40.1	30.5

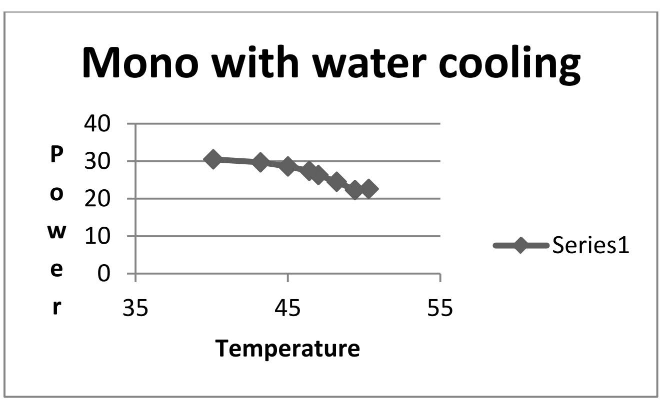

Figure 11 Temperature with power of Monocrystalline with water cooling

3.7.2 Measurement of Power after water and air cooling monocrystalline solar panels

TABLE 10 TEMPERATURE WITH POWER OF MONOCRYSTALLINE AFTER WATER AND AIR COOLING

Temperature (C˚)	Power (W)
40.1	30.5
39.6	30.9
39	31.8
38.5	32.5
38	33.09

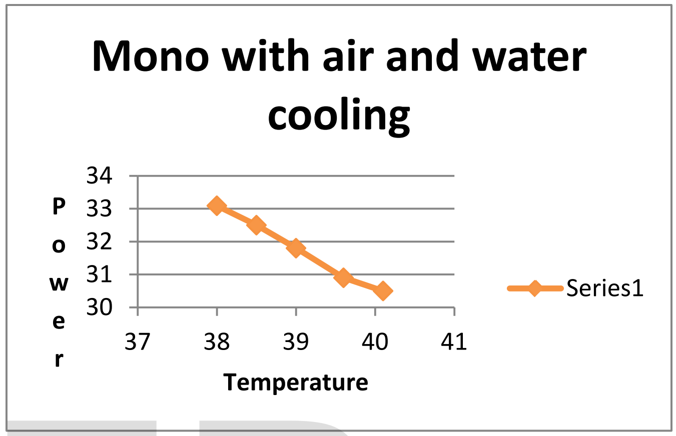

Figure 12 Temperature with power of Monocrystalline with air and water cooling

3.7.3 Measurement of Power after water cooling polycrystalline solar panels

TABLE 11 TEMPERATURE WITH POWER OF POLYCRYSTALLINE AFTER WATER COOLING

Temperature (C˚)	Power (W)
50.4	20.8
48.9	21.6
47.7	23.5
4747.1	25.9
46.6	27.8
45.1	29.3
43	31.4
40.4	32

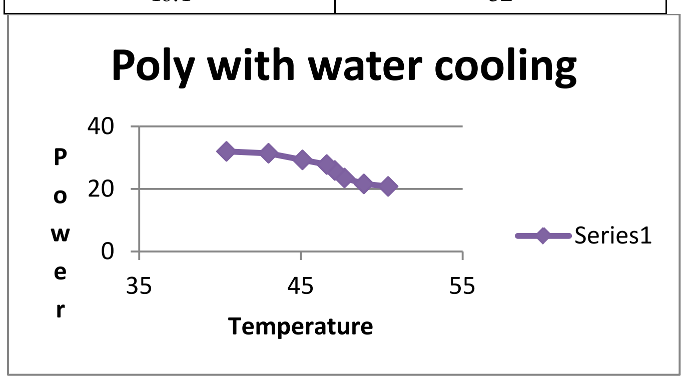

Figure 13 Temperature with power of Polycrystalline with water cooling

3.7.4 Measurement of Power after water and air cooling polycrystalline solar panels

TABLE 12 TEMPERATURE WITH POWER OF POLYCRYSTALLINE AFTER WATER AND AIR COOLING

Temperature (C°)	Power (W)
40	31.9
39.8	32.6
39	33.2
38.5	33.8
38	34.04

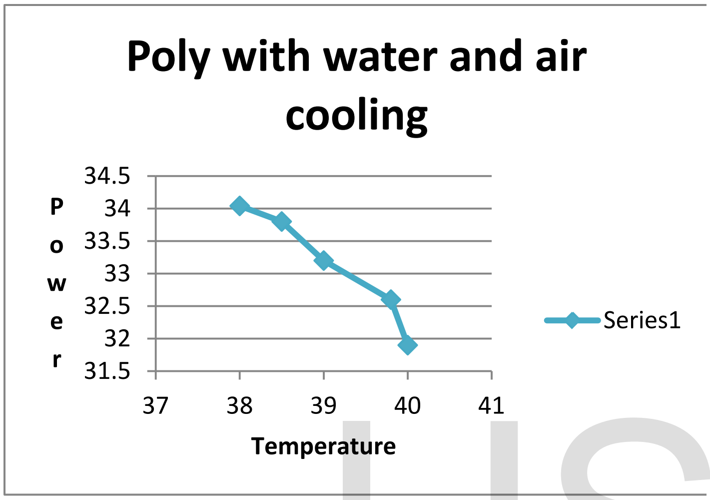

Figure 14 Temperature with power of Polycrystalline with air and water cooling

4. CONCLUSION

This research has analyzed the efficiency of both monocrystalline and polycrystalline solar PV panels using experimental evaluation method with both water spray cooling method and water spray and air combined cooling method using LM-35 temperature sensor in addition with Arduino. Both mono crystalline and polycrystalline solar PV panels were having the same power rating of 150 Watt and same batch and company. During this research water spay is made over the surface of the solar panel as a source of cooling medium for the solar panel during critical temperature. In this research both monocrystalline and polycrystalline solar panel's power output without using any cooling medium has determined. Then water alone used as cooling medium during the critical temperature as a cooling source for both the panels and results were measured. Finally both monocrystalline and polycrystalline solar panels were treated with combined air and water as a cooling source. From results it is clear that when only water was used as a cooling medium little efficiency of both monocrystalline and polycrystalline solar cells got improved and when water plus air combined used as a source of cooling the efficiency has got much more improved. Further the efficiency of polycrystalline was increased more than that of the monocrystalline solar PV panel. This research has been performed systematically to measure the temperature of both the monocrystalline and polycrystalline solar cells using LM-35 temperature sensor, voltage and current sensors accordingly. After performing this experimental cooling method it is concluded that the efficiency of the polycrystalline solar panel got much improved than that of monocrystalline solar PV panel.

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