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Efficiency Analysis of Solar Photovoltaic Panels for Water Lifting Pump

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***Abstract*—Solar technology is mainly used for lifting water in regions where electricity grid has not reached yet. The objective of this research work is to perform the efficiency test of solar panels used for the water lifting projects. A suitable location was chosen for the test and arrays of solar panels were used for the operation of the pump. The efficiency of panel was calculated using the output power supplied by the solar panel to the motor. The delivery discharge of motor was noted for the operation of motor. It was seen the solar panel used for the testing had the maximum efficiency of 18 % only. The shading effect was also considered for the verification of power production of solar panels.**
***Keywords*—Solar panel, efficiency, water lifting, and shading.**

I. INTRODUCTION

SOLAR panel technology has evolved significantly over the past few decades, driven by advancements in materials, design, and operational methodologies. Solar panels are photovoltaic systems that convert sunlight into electricity through the photoelectric effect. They are typically made from semiconductor materials like silicon, with various types of silicon wafers available [1]. Monocrystalline silicon panels are known for their high efficiency rates, often exceeding 20%, due to their single-crystal structure that allows for better electron mobility [2]. In contrast, polycrystalline panels, while generally less efficient, are more cost-effective and have seen improvements in their performance through advancements in manufacturing techniques [2], [3].

A. Factors affecting the solar PV efficiency

Solar panel power output is influenced by various environmental and technical factors. Temperature has an inverse relationship with panel efficiency, as higher temperatures reduce power output [4]. Research indicates that photovoltaic (PV) cells experience a 0.5% decrease in efficiency and a voltage drop of 2.2 mV for every 1 °C rise in operating temperature [5]. Radiation levels directly affect panel performance, with higher levels increasing power generation [4]. To generate more power, PV modules should be directly facing the sun. (reference) Partial shading, caused by nearby trees or objects, can significantly impact panel efficiency [6] . Studies show that 2% shaded panel area can reduce panel performance by 70% [7] while 5-10% shaded area can reduce array performance up to 80% [8]. Dust accumulation on panels also degrades their performance [6],[9]. When testing a 100-watt photovoltaic (PV) panel, it is expected to produce around 93 watts because of dust buildup [10]. Additionally, research revealed that the voltage of PV panels decreased by 80% in an area with a cement dust deposit of 73 g/m² [10]. Other factors affecting solar panel efficiency include humidity, wind velocity, altitude, and air pressure [9]. The choice of PV cell technology and peripheral devices also plays a role in overall system performance [11]. To enhance solar power efficiency, it is crucial to consider these factors during system design and implementation. Ongoing research aims to improve PV cell technology and develop strategies to mitigate the negative impacts of environmental factors on solar panel performance [11].

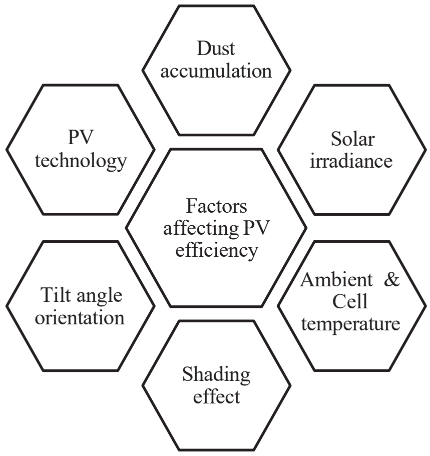

Fig. 1. Factors affecting solar PV efficiency

The efficiency of the module technology has a significant impact on the performance of PV systems [12]. More energy can be produced by modules with greater efficiency both in terms of energy production per square meter of roof space and over the system's lifespan. Increased module efficiency also results in lower per-watt costs for the remaining system components [13].

Table I displays the efficiency for the most popular module technologies. As noted, the efficiencies of mono- and poly-Si surpass those of thin-film technologies.

TABLE I: EFFICIENCY OF COMMON SOLAR TECHNOLOGY [12]

Module technology	Efficiency (%)
Mono-Si	18-22
Poly-Si	16-20
CdTe	14-18
CIGS	14-16
a-Si	8-12

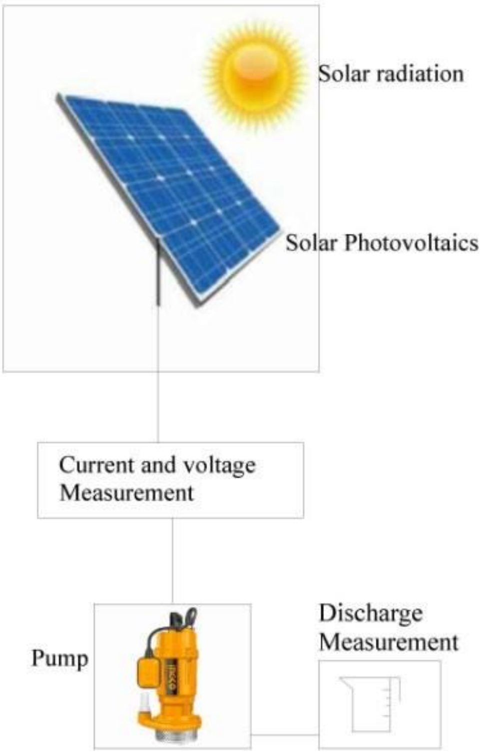

Fig. 1. System designed for the analysis

Using quantum effects to produce several electron-hole pairs per absorbed photon is another interesting approach that might increase the theoretical efficiency limit from 30% to 43% [14]. Although these theoretical bounds seem encouraging, real-world application is still difficult. Commercial solar panels usually have lower efficiencies; however, in 2012, SunPower Corp. announced that its crystalline silicon cell production had reached a 24% efficiency [15]. The main objective of this research work is to check the efficiency of solar panels used for lifting water.

II. MATERIALS AND METHODS

The performance of solar photovoltaic system was tested at Centre for Energy Studies, Institute of Engineering, TU, Lalitpur premises. The panel were set up as shown in figure 1. Other assumptions are as follows:

a. The tilt angle of 26 was chosen as it gives maximum efficiency [16].
b. The wind velocity was negligible.

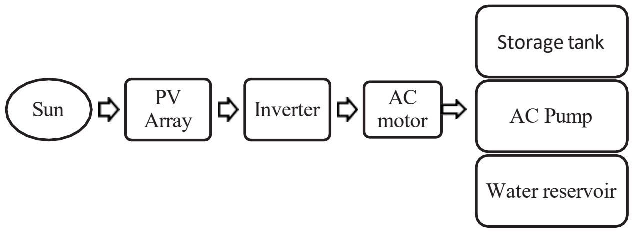

Fig. 2. Block diagram of a directly coupled Photovoltaic water pumping system.

c. Panel surface temperature was 60^{o} C.
d. The sensitivity of measuring instruments is assumed to be working fine within acceptable range.

A. Voltage and Current measurement

Voltage and current were measured using multimeter. For current measuring, 1 hp water pump was used as a load. The multimeters used for the project was digital type. With 2 people being standby the readings were noted at the panels side.

B. Radiation measurement

The solar irradiation measuring device was used for measuring the radiation of sun. The device had the working range of 200 to 1000 W/m2. The solar PV power is given by equation 1.

$$P = A_p G \quad (1)$$

where Ap is area of panel and G is solar irradiation. The value of G varies due to location of site and amount of sunlight received by panel. The site for the testing of the project was chosen at Centre for Energy studies (CES) premises. The power produced by the pump was calculated using the equation 2.

$$P_p = VI \quad (2)$$

where P_p is the power supplied (W) to the pump by the solar panels, V is the voltage supplied in volts and I is the current supplied in A.

The panel efficiency can be calculated using the power supplied by the panel to the pump.

C.PV Module

The PV Module used for the testing was the Genius Polycrystalline GI335F72 Model with the specifications in Table 2. Total 3 panels were used for the testing. The motor was directly connected to the supply box without the battery storage systems. Therefore, the system took certain interval before starting the pump. The water lifting pump used in the project was the ac type submersible pump with the capacity of 1 hp. The pump had the capacity to lift the water to the height of 40 m. But for the simplicity of calculations, the delivery head was kept constant of 2 m.

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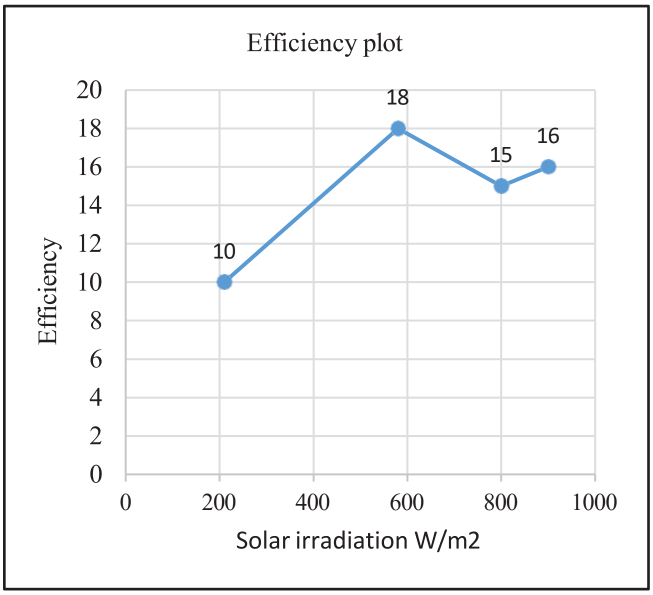
TABLE II: SOLAR PANEL SPECIFICATIONS

SPECIFICATIONS	VALUE
MAXIMUM POWER (PMAX)	335 W
MAXIMUM POWER VOLTAGE (VMP)	39.34 V
MAXIMUM POWER CURRENT (IMP)	8.58 A
OPEN CIRCUIT VOLTAGE (VOC)	46.18 A
SHORT CIRCUIT CURRENT (ISC)	9.05A
MAXIMUM SYSTEM VOLTAGE	1000 VDC
POWER TOLERANCE	±2%

Fig. 3. Solar panels used for testing.



All the testing was conducted in a single cloudy day. The variation of sun's radiation was only due to clouds. The solar panels were faced towards south direction with an inclination of 26° . The panels were thoroughly cleaned before performing the experiment.

III. RESULTS AND DISCUSSION

A. Testing of panels

The pump was switched on manually and time for filling a 25 litre bucket was checked using a stop watch. The current consumed by motor was noted and subsequent voltage supplied to motor was also noted which can be seen in Table III. The power produced by panels can be seen in Table 3. The power produced was based on amount of solar irradiation that stroked the solar panel. As it can be seen maximum solar irradiation observed during the test was 900 W/m^2 and power produced during this time was 5130 W. The lowest radiation that was observed was 210 W/m2 and power produced during this time was 1197 W. The efficiency of solar panel at various solar irradiation is plotted at figure 4. It can be seen that maximum efficiency of 18 % is achieved at 580 W/m2 solar irradiation and with 210 W/m2 solar irradiation the efficiency achieved is only 10%. The efficiency is greatly affected by the temperature as 70-80% absorbed irradiance is a rejected as waste heat and remaining 20% is used for converting into electricity [17].

TABLE III: MEASURED DATA AT SITE

Global irradiance (W/m^2)	Area of Panel (m^2)	Voc (V)	Condition	Input Power (W)
210	5.7	128	No shedding	1197
580	5.7	113	No shedding	3306
800	5.7	116	No shedding	5130
900	5.7	119	No shedding	5130
900	4.4	128	3 cell shedding	5130
900	3.8	117	6 cell shedding	5130

TABLE IV: CALCULATION OF EFFICIENCY

Global irradiance (W/m^2)	Vmp (V)	Imp (A)	Condition	Output power (W)	Efficiency
210	72	1.7	No shedding	122.4	10.2
580	98	6.2	No shedding	607.6	18.0
800	80	8.0	No shedding	640.0	13.8
900	93	9.0	No shedding	837.0	16.3
900	84	8.4	3 cell shedding	705.6	13.7
900	84	4.5	6 cell shedding	378.0	7.3

IV. CONCLUSION

The Efficiency of solar panel directly depends on the solar irradiance. The efficiency varies from 10% to 18%, this can be explained as at the early morning and late afternoon the efficiency will be significantly low to nearly 10 %. It also shows significant loss in power from 16.3% to 7.3 % due to shading in the solar panel at peak irradiance. We can conclude from this research that; the solar pump performance is significantly affected by the shading and also other factors.

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