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Investigating the effect of the frequency of incident light on the efficiency of a Solar Panel in Jaipur, Rajasthan

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Abstract
The world is suffering severely due to climate change and global warming. The maincause of such threats to humanity is the numerous non-renewable forms of energy we useevery day. Solar Energy is oneof the main forms of renewable energy that attempts to abatethe problem of the generation ofpower by harnessing the energy of the Sun. It is also gaining popularity with time as it becomes more efficient with recent technological developments and is therefore making an impression in the sector of renewable energy and power generation. This paper aims to provide a summary about the functioning of a solar panel and the way the type of light incident on the solar panel may play a major role in affecting the optimum usage of the technology. Moreover, this study aims to establishthe link between the frequency of incident light and how it affects the efficiency of the solar panels. After reviewing various existing literature on this, the research conducted analyses data samples from Jaipur, Rajasthan. The study uses the existing models and knowledge about Photovoltaic cells to the investigations and conclusions performed by the author, to determine the conditions which simulate the highest efficiency. This study aims to help increase the efficiency of power generation of solar panels at an industrial level in the future.

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I. Introduction

A paradigm change has occurred in the area of energy and electricity thanks to the development of solar panels and other renewable energy sources. One of the many advantages is the shift away from non-renewable energy sources, among many others. Mankind will be forced to turn to natural sources of energy due to the expected scarcity of resources like coal and biomass. The most effective source, though, is probably solar energy. Other alternatives include hydroelectricity and wind turbines. In principle, solar panels transform chemical energy into electrical energy through a series of processes that turns sun light into electricity. This process uses semiconductors to its advantage, as with their help,sunlight can activate free electrons. Bus bars collect these free electrons which create an electric current. This current is usually unidirectional therefore a solar panel produces Direct Current. This can, however, be converted to Alternate Current using DAC inverter.

To fully utilize the potential of an energy source so freely available to us, the efficiency of the solar panel must be optimized by controlling and altering various factors which directly or indirectly have an effect on it for example: technology, weather, temperature, angle of tilt, location etc. There are various research papers establishing the link between these factors to a solar panel's efficiency but there is sparse knowledge on the effect by the type of incident light on the power generated by a solar panel. This also elucidates how natural factors such as location and type of light may have a significant impact on the efficiency of a solar panel and how these too are factors which people should keep in their minds when setting up a solar panel for maximum efficiency. Therefore, it becomes advantageous to investigate the light conditions under which solar panels perform optimally.

II. Background

Only visible radiations can produce a photoelectric emission. Anything beyond the wavelength of red light does not produce any photoelectric emission. DC current is produced by photovoltaic cells using the energy carried by electromagnetic radiation in the visible spectrum.The photovoltaic cells in the solar panel are responsible for generating power.The photoelectric process that takes place is what gives the photovoltaic cell, also known as the PV cell, its name. When exposed to sunlight, the silicon in the photovoltaic cell generates an electric charge.

The photovoltaic effect, as it is also known as, occurs when photons hit the semiconductor material (silicon), causing them to gather energy and create an electric potential difference (voltage). The most used material for a photovoltaic cell is silicon because it has proven to be the most effective material available for use in these types of cells. A few of the reasons are:

1. Silicon is abundant in nature, and is easily extractable. Its production is relativelyinexpensive.
2. Silicon is an element with 4 valence electrons, due to which atoms of silicon combine insuch a way that they are equidistant at fixed and equal angles from each other, forming alattice structure.
3. It is a semi-conductor, meaning that as the temperature increases, the resistance to currentdecreases.

The present study was carried out in Jaipur,Rajasthan, India. Jaipur is the capital and largest city of the Indian state of Rajasthan in Northern India. The city today has a population of 3.1 million. Jaipur is known as the Pink City of India. Rajasthan is blessed with maximum solar radiation intensity in India with about 6-7kWh/Sq.m/day and more than 325 sunny days with very low average rainfall. The average sunshine period per day is about 10 hours per day during summers.

III. Methodology

The variable being investigated is the efficiency of the solar panel. Therefore, the dependentvariable of this investigation is the efficiency of the solar panel.The frequency of light has been hypothesised as the variable on which the efficiency isdependent, and Iam also varying the frequency of the incident light. Therefore, ourindependent variable is the frequency of incoming light.To make my experiment more accurate, I kept a certain factors (which otherwise might have affected my readings) constant. The factors are enlisted and further explained in Table 1:

Sr No	Name of Variable	Description of Variable	Reasons
1	Time and Location where the procedure is carried out	From 11:45 a.m. to 12:45 p.m. in an arid and dry location	The time and location have a major impact on the sun's relative position to the ground. The following times were chosen to allow for the maximum exposure to sunlight as the sun is directly perpendicular to the ground at noon.
2	Temperature of the Surroundings	32.5±0.5°C	According to Mahindra Teqo. the temperature coefficient of a solar panel is -0.258% per degree Celsius. So, for every degree rise, the maximum power of the solar panel will fall by 0.258% and for every degree fall it will increase by the same percentage.
3	Same thickness and quality of films used	$2.7 \times 10^{-5} m$	The thickness of filter has a direct impact on the intensity of the sunlight which it allows to pass
4	Same experimental apparatus with negligible systematic errors	Same solar panel with the same maximum power (and corresponding voltage and current at that power). The details of the solar panels I used are present after this table.	With different solar panels having varied efficiency levels, the type of solar panel being used was kept constant.
5	Angle of Solar Panel	0° to the horizontal axis	It has been proven by previous research work that the angle of the tilt of a solar panel can have an impact on the efficiency of the solar panel, this was kept constant for all trials
6	Height of solar panel from sea level	431m from the sea level	This is the altitude of Jaipur, Rajasthan
7	Intensity of sunlight incident on the solar panel	20000 lux. This value was calculated experimentally.	A difference in input intensity would create a difference in the output power as well. This difference may not be linear which would lead to errors with the experiment. Therefore the incident intensity of the different frequencies of light was kept constant.

Table 1

Specifications of the solar panel being used:

i. P_{max} – 19.8W
ii. V_{mp} – 17.56V
iii. I_{mp}– 1.13A
iv. V_{oc} – 21.96V
v. I_{sc} – 1.36A
vi. Surface Area : 0.203m^2

Before the experiment was carried out, a lux-meter was used to measure the intensity of natural (white) light from the sun. This came out to be 61000 lux. This was the maximum intensity and it would be used in final calculations of efficiency. Each filter allowed for a certain amount of light to pass through which caused variations in the intensity incedent on the solar panel. To ensure that this was uniform, for a certain colours varied amounts of filter films were used. This amount is summarized in Table 2.

Colour	No. of filter films used	Approximate incident intensity / lux
Blue	2	20000
Green	3	19890
Yellow	3	20100
Red	1	20000

Table 2

Table 3 shows the data which summarizes the input power, maximum voltage and current, and output power with natural light. Average Frequency of visible light ranges from4E+14Hz to 8E+14Hz.

Data Collection

Outside Temperate	35°C
Time	12:00pm
Incident Intensity	61000lux
P_{in}	126.357 W
V_{out}	17.1 V
I_{out}	0.88 A
P_{out}	15.134 W

Table 3

The same was repeated for the other colours. The results are summarized in Table 4.

Colour	Average Frequency / Hz	Incident Intensity / lux	Luminous efficacy/η	Incident Intensity / Wm^{-2}	V_{out} / V	I_{out} / A	P_{in} / W	P_{out} / W	Efficiency / %	No. of sheets used
Blue	6.33E+14	20000	98	204.082	14.3	0.51	41.429	7.36	17.8	2
Green	5.61E+14	19890	98	202.959	13.7	0.48	41.201	6.59	16.0	3
Yellow	5.11E+14	20100	98	205.102	13.6	0.37	41.636	4.98	12.0	3
Red	4.28E+14	20000	98	204.082	16.2	0.53	41.429	8.61	20.8	1
Visible Light	4 - 8E+14	61000	98	622.449	17.1	0.89	126.357	15.134	12.0	0

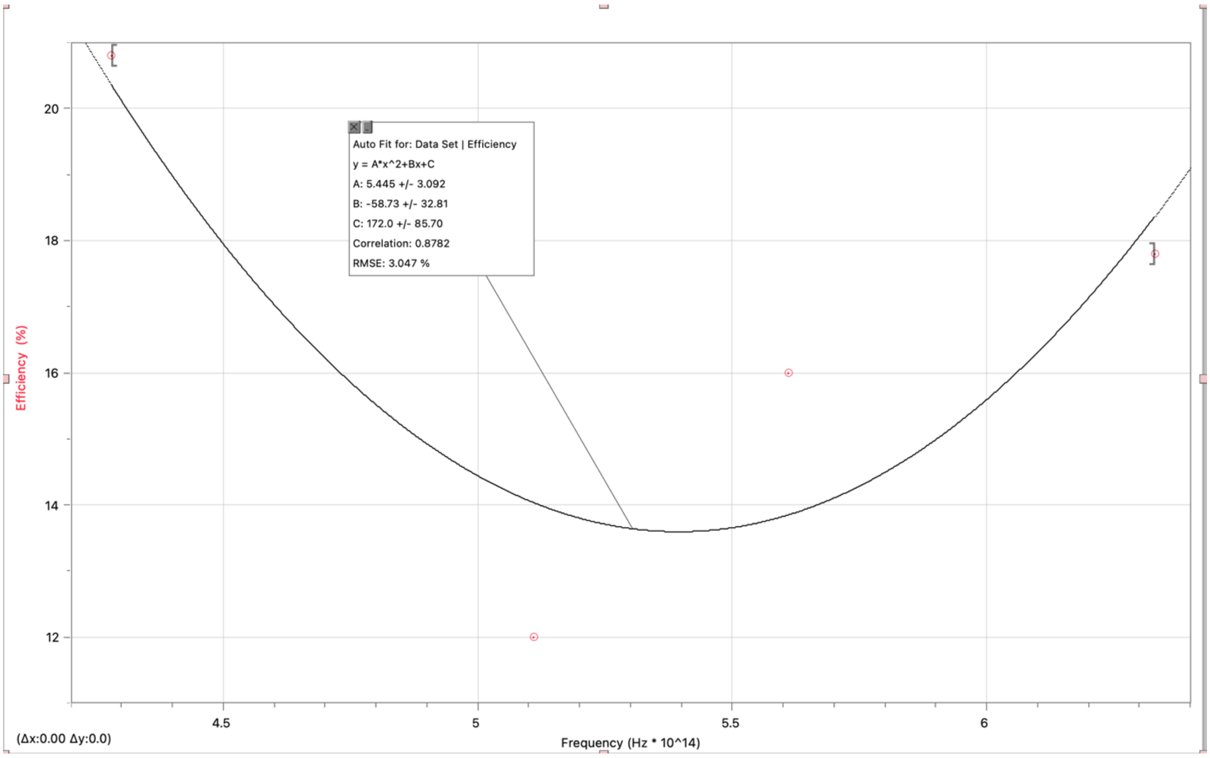
Table 4

* Luminosity (Lux) was converted into Luminosity (Watts) using the following formula where $L_{(w)}$ is luminosity in watts, $L_{(lux)}$ is luminosity in lux, A is the surface area of solar panel which is facing the sun – In this case it is $0.203m^2$ because the solar panel is directly perpendicular to the sun rays), and η is luminous efficacy.

$$L_{(w)} = \frac{(L_{(lux)} \times A)}{\eta}$$

The $L_{(w)}$ can be further divided by the surface area of the solar panel to find the Incident Intensity in Wm^{-2}.

Graph 1 presents the findings of Table 4 in a graphical manner to look for any trends:



Graph 1

The function obtained was fairly accurate with a relation coefficient of 0.8782 and was quadratic in nature with the equation:

$$f(x) = 5.445x^2 - 58.73x + 172.0$$

The following observations have been made from the analysis of the tables and the graph above:

1. The graph between the frequency and the efficiency is not linear. The graph is at its peakat the frequency of the red colour, but it drops to its minimum at the frequency of yellow colour. The graph gradually rises up, passing through the green frequency and stopping atthe blue colour frequency, at a value of lesser efficiency than red.

2. The efficiency of the least frequency is the greatest, but as the frequency increases, the value first decreases and then increases.

3. These values have been achieved in low-brightness levels of light i.e., even though theday was bright and the sky was clear during the investigation, the intensity of sunlightreceived was much lesser than the average value of sunlight at standard conditions (1000Wm^{-2} compared to 622Wm^{-2} in this experiment)

4. A relationship was established between the frequency of incident light and the resulting efficiency of the solar panel.

IV. Conclusion

The importance of solar panels cannot be emphasized more. The crucial importance of this technology is increasing exponentially day by day. There are a plethora of factors which may influence the efficient use of solar panels to generate electricity. This study focuses on one particular variable: the frequency of the incident light on a solar panel.

To conclude this experiment, it can be inferred from the observations above that underlow-intensity light conditions, the red spectrum of visible light provides the maximum efficiencyand the yellow spectrum of light provides the minimum efficiency. Therefore it can be reasonably concluded that theenergy of each frequency does not play such a major role, but the shunt resistance of the solarpanel's internal circuitry does. Shunt resistance is an internal manufacturing fault within a solarpanel that provides the electric current with an alternative path for current to flow through thecircuit, reducing the output current and voltage. The effect of shunt resistance is especiallypronounced during low light intensity intervals. The shunt resistance, during low-light conditionshas a minimal effect on the red frequency of light, but increases with an increase infrequency.The difference between the colours is not constant.

Thus, this exploration has come to the conclusion that due to shunt resistance in low-intensity conditions of light, the solar panel provides a maximum efficiency of power output when red light is incident on it.

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