CONSTRUCTION & CHARACTERISATION OF SOLAR MOBILE CHARGER

PROJECT REPORT

Submitted by

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Submitted to the
Mahatma Gandhi University, Kottayam

In partial fulfilment of the requirements for the Award of
BACHELOR’S DEGREE OF SCIENCE IN PHYSICS

ST. TERESA’S COLLEGE (AUTONOMOUS)
ERNAKULAM, KOCHI-682011

ST. TERESA'S COLLEGE (AUTONOMOUS)
ERNAKULAM

CERTIFICATE

This is to certify that the project report entitled '**CONSTRUCTION & CHARACTERISATION OF SOLAR MOBILE CHARGER**' is an authentic work done by MARIA ROSE MOL, St. Teresa's College, Ernakulam, under my supervision at the Department of Physics, St. Teresa's College for the partial requirements for the award of Degree of Bachelor of Science in Physics during the academic year 2021-2022. The work presented in this dissertation has not been submitted for any other degree in this or any other university.

6/5/2022

Ms. Minu Pius	Dr. Priya Parvathi Ameena Jose
Assistant Professor	Assistant Professor
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PLACE: Ernakulam
DATE: 9/05/2022

ST. TERESA'S COLLEGE (AUTONOMOUS)
ERNAKULAM

B.Sc. PHYSICS
PROJECT REPORT

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Year Of Work : 2021-2022

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DATE: 9/05/2022

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Susan

DECLARATION

I, MARIA ROSE MOL, final year B.Sc. Physics student, Department of Physics, St. Teresa's College, Ernakulam do hereby declare that the project work entitled 'CONSTRUCTION & CHARACTERISATION OF SOLAR MOBILE CHARGER' has been originally carried out under the guidance and supervision of Ms. MINU PIUS, Assistant Professor, St. Teresa's College (Autonomous), Ernakulam in partial fulfillment for the award of the degree of Bachelor of Physics. We further declare that this project is not partially or wholly submitted for any other purpose and the data included in the project is true to the best of our knowledge.

Place : Ernakulam
Date : 9/05/2022 MARIA ROSE MOL

CONSTRUCTION & CHARACTERISATION

OF

SOLAR MOBILE CHARGER

ACKNOWLEDGEMENT

I express my sincere gratitude to all those who have helped me to achieve the moment of satisfaction. Firstly, I thank the lord almighty for the immense grace at every stage of this project. I am highly indebted to my project guide Ms. MINU PIUS, St. Teresa's College (Autonomous), for her valuable guidance and constant supervision as well as for providing necessary information regarding the project and for her support in completing the project. I would like to express my gratitude to all teachers and non-teaching staff, for their valuable guidance and suggestions for completing the project. My thanks and appreciation also goes for all those who have willingly helped me out.

ABSTRACT

Mobile phones have become an indispensable part in human being’s everyday life. But the availability of power for its charging is under question. Therefore, we attempted to construct a solar mobile charger powered by a solar panel. In solar mobile chargers, solar energy is used for the generation of voltage required to charge the mobile battery. Since, solar energy is one of the main sources of renewable energy, thus the abundance of solar energy can be guaranteed everywhere. In this work, we assembled a solar mobile charger and determined its efficiency, fill factor, and other key parameters from V-I characteristics. The performance of the panel is analysed by comparing its charging time upto 1% under AC mains and under direct sunlight. The charging of mobile phones is investigated for different tilt angles and intensities of light.

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CHAPTER I

1.1 INTRODUCTION

Energy has always been closely linked to man’s economic growth and development. Global energy demand is accelerating almost daily, resulting in an energy crisis and environmental pollution. The present strategies for development focused on rapid economic growth, have used energy utilisation as an index of economic development. This index however does not take into account the adverse long term effects of excessive energy utilization on society. Energy crisis is a broad and complex topic. Its overuse has resulted in depletion of natural resources and the higher consumption rates have severe effects on our environment. It’s high time that we switch to cleaner and more efficient energy resources.

1.1.1 Renewable Resources

Renewable energy resources are necessary and needed for the following reasons:

Renewable energy is reliable and plentiful and will be cheap once technology and infrastructure improves. Conventional sources cause pollution and degrade the environment whereas renewable energy produces only minute levels of carbon emissions and therefore helps combat climate change caused by fossil fuel usage. Energy efficiency and renewable energy policies can reduce the demand for and supply of energy generated from fossil fuels (natural gas, oil, and coal fired power plants). Geothermal energy, nuclear power, tidal and wave power, biogas, biomass energy, solar thermal electric power, photovoltaic energy, solar energy, hydroelectric power, are some of the widely used renewable sources of energy. Out of them Windmills, Solar energy, Hydro-electric power has been widely used for generating electricity.

The transition to an energy system based on renewable technologies will have very positive economic consequences on the global economy and development.

1.1.2 Solar Energy

Radiation from the sun is a source of energy suitable for initiating chemical reactions, production of heat and generation of electricity. In one hour, the sun pours as much energy onto the earth as we use in the whole year. If it were possible to harness this colossal quantum of energy, humanity would need no other source. It has the potential to satisfy all of our future energy needs. It’s inexhaustible and Non-polluting. Solar radiation can be converted either into thermal energy (heat) or into electrical energy, though the former is easier to accomplish.

Some of the common devices used to capture solar energy and convert it into thermal energy are flat plate collectors, solar ponds and solar ovens. Solar radiation may be directly converted into electricity by photovoltaic cells. There are different types of photovoltaic cells.

In our project, we have made a humble effort to construct a mobile charger powered by solar energy using polycrystalline solar panels of 10W(reference panel) and of 1.3W.

1.2 THEORY

A solar cell is an electrical device that converts light energy into electrical energy through photovoltaic effect. It’s basically a p-n junction diode although its construction is a bit different from that of conventional p-n junction diodes. A solar cell is composed of two types of semiconductors- n-type and p-type.

n-type semiconductor is formed by doping an intrinsic semiconductor with group V elements like phosphorus. These semiconductors have an excess of electrons and hence electrons are the majority carriers.

p-type semiconductor is formed by doping an intrinsic semiconductor with group III elements like Boron. These semiconductors have an excess of holes (vacancies due to lack of valence electrons) and hence holes are the majority charge carriers.

A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor.

At the junction of the two layers, the electrons in the n-side move into the holes in the p-side. As a result at the junction a depletion layer is formed. It’s so called because the region has no mobile charge carriers due to electron hole recombination.

On the p-side of the junction there are immobile negative ions and on the n-side of the junction there are positive immobile ions. These oppositely charged ions create an internal electric field that prevents electrons in the n-type layer from filling holes in the p-type layer. Hence a barrier potential is formed across the junction.

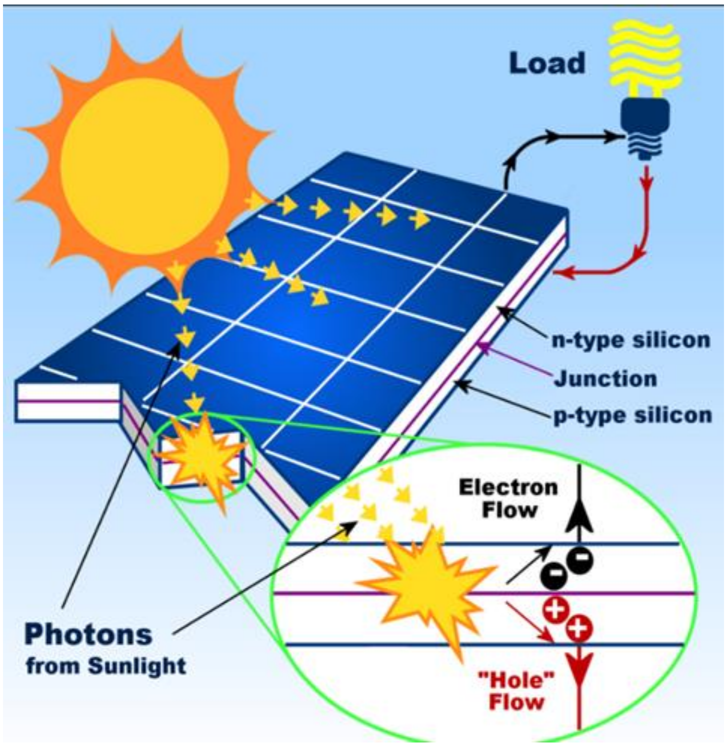


Fig 1.1 working of a solar cell

When light strikes the surface of the cell, electrons are ejected which is accompanied by the formation of holes. The electric field across the junction will move electrons to the n-type layer and holes to the p-type layer. Two charges build up on the opposite side of the junction, and hence we have a potential difference across the junction. If the n-type and p-type layers are connected with a metallic wire, the electrons will travel from n-type layer to p-type layer by crossing the depletion layer and then go through the external wire back to n-type layer, creating a flow of electricity. The more light that shines, the more electrons are ejected and the more current flows.

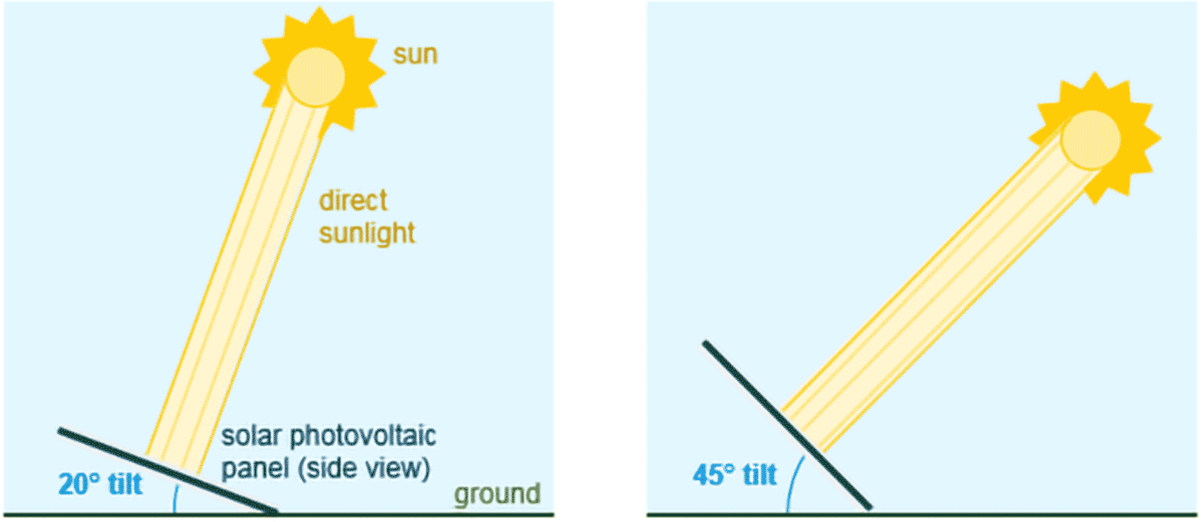


Fig 1.2 tilt angle

Solar panels work best when they face directly into the sun. But that task is complicated by the fact that the sun moves across the sky throughout the day. **Tilt angle** is the angle between the horizontal plane(ground) and the solar panel. The optimum tilt angle for maximum efficiency will depend on latitudes, seasons, etc.

There are a variety of solar cells. The three commonly used are mono crystalline, polycrystalline and thin film solar cells.

1.2.1 Mono crystalline solar cell

The cell is composed of a single crystal, the electrons that generate a flow of electricity have more room to move. Mono crystalline solar panels (mono-SI) are a pure type of solar panel made from mono crystalline silicon. They have a uniform dark appearance with rounded edges that make them easily recognizable. The purity of the silicon enables high efficiency rates, some reaching above 20%. These panels tend to be less affected by high temperatures compared to polycrystalline panels. These cells are longer lasting and space efficient. For these reasons they also tend to be the most expensive.

1.2.2 Polycrystalline solar cells

Polycrystalline solar panels are more eco-friendly than monocrystalline solar panels as they do not require individual shaping and placement of each crystal and most of the silicon is utilized during production. So, very less waste is produced. The acceptable maximum temperature of polycrystalline solar panels is 85 °C while the acceptable minimum temperature is -40 °C. Polycrystalline solar panels have lower heat tolerance than monocrystalline panels. So, at higher temperatures, these solar panels have lower efficiency than others.

These panels have high power density. They come with a structural frame of their own which makes mounting cheaper and simpler. Polycrystalline panels are suitable for roof mounted arrays. They are used in large solar farms to harness the power of the sun and supply electricity to nearby areas. They are used in standalone or self-powered devices such as traffic lights in remote areas, off-grid households, etc.

1.2.3 Thin film solar cells

They are very economical, require less material, contain no toxic components, generate less waste, and are very easy to manufacture. There are 3 types of solar Thin-Film cells: Amorphous silicon thin film, cadmium telluride thin film, copper indium gallium selenide.

They are more flexible and lightweight than the other types making them perfect to be used in portable devices. Thin-Film solar panels are less efficient and have lower power capacities than mono and polycrystalline solar cell types. The efficiency of the Thin-Film system varies depending on the type of PV material used in the cells but in general they tend to have efficiencies around 7% and up to 18%. Thin-Film solar panels have a better temperature coefficient than silicon-based panels. Meaning that they are less affected by high temperatures and will lose only a small portion of their performance when it gets too hot.

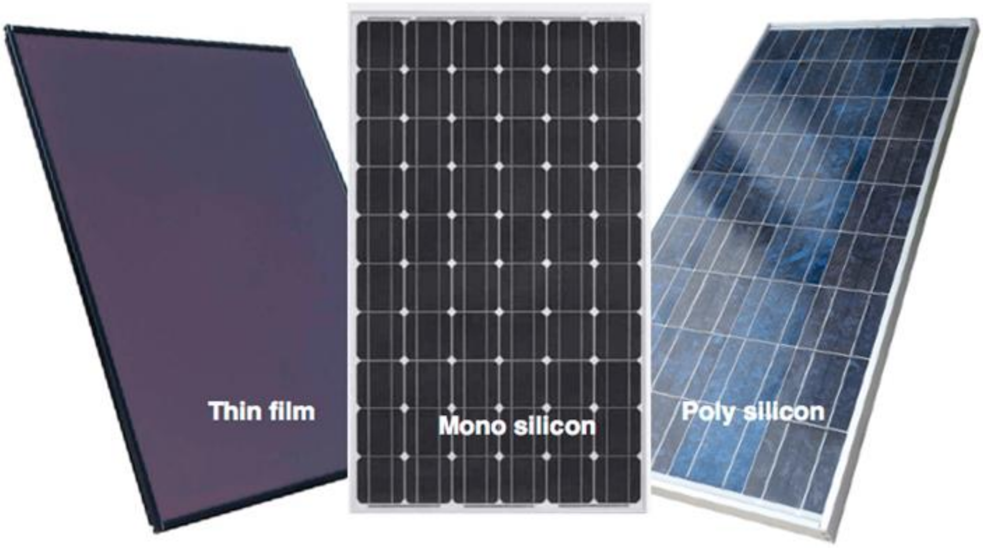


Fig 1.3 types of solar cells

1.2.4 V-I Characteristics of A Solar Cell

The voltage current relation in a solar cell is given below:

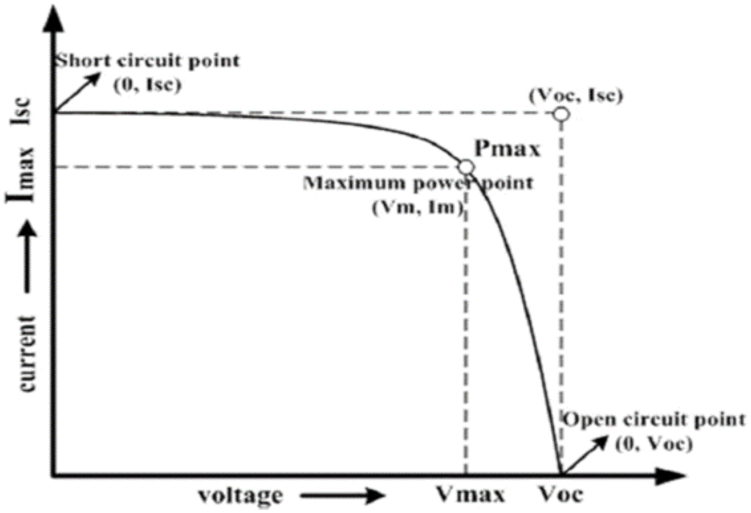


Fig 1.4 V-I characteristics

- I_{sc} is the short circuit current and it is measured by short circuiting the terminals.
- V_{OC} is the open circuit voltage and it is measured when no load is connected.
- I_{max} is maximum current.
- V_{max} is maximum voltage and it occurs at the bend of the characteristic curve.
- P_{max} is maximum power.

$$P_{max} = I_{max} \times V_{max}$$

- Fill Factor (FF)

  The fill factor gives an idea of the maximum output withdrawn from the solar cell for a given V_{oc} and I_{sc}. Mathematically it is given by the equation given below. The value of FF under ideal conditions is unity. Deviations from the ideal gas values are due to defects and contact resistance. The lower the value of FF, the less sharp will be the V-I curve. For a silicon solar cell, the maximum value of FF is 0.88.

$$\text{FF} = \frac{Imax \times Vmax}{Voc \times Isc}$$

$$= \frac{Pmax}{Voc \times Isc}$$

- Efficiency:

Solar cell power conversion efficiency given as

$$\eta_{cc} = \frac{Pmax}{Pin}$$

CHAPTER II

2.1 COMPONENTS

2.1.1 Polycrystalline solar panel-7V

Polycrystalline or Multi crystalline solar panels are solar panels that consist of several crystals of silicon in a single PV cell. Panels absorb energy from the sun and convert it into electricity. This panel has a voltage of 7V.

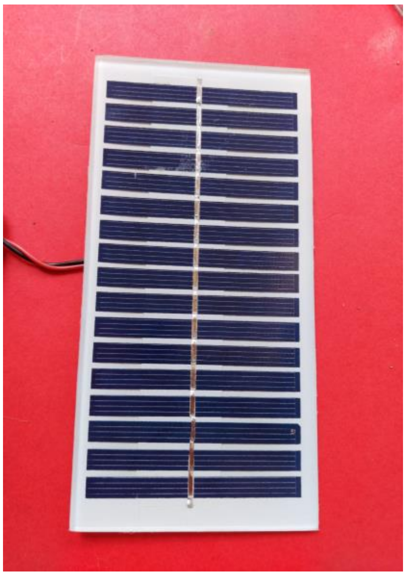


Figure 2.1.1 solar cell

2.1.2 IC7805

IC7805 is a 5V voltage regulator that restricts the output voltage to 5V for various ranges of input voltages. It acts as an excellent component against input voltage fluctuations for circuits, and provides an additional safety to the circuitry. It is inexpensive, easily available and very much commonly used. With few capacitors this IC can build a pretty solid and reliable voltage regulator in no time.

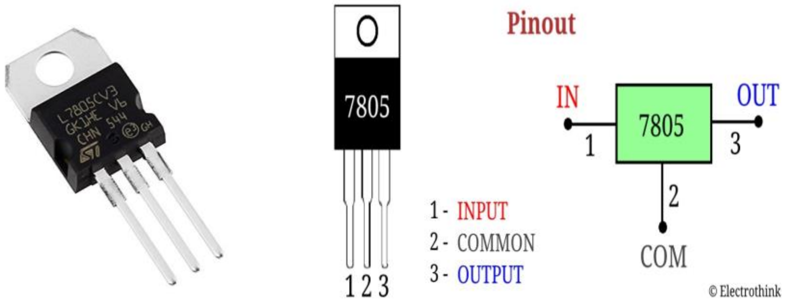


Figure 2.1.2 Voltage regulator - IC7805

2.1.3 Capacitors

A capacitor is a device that stores electrical energy in an electric field. It is a passive electronic component with two terminals. We use 100µF capacitors for constructing solar mobile chargers. The capacitor is used to suppress the mini voltage spikes inside the phone. It helps keep the voltage constant when it is fluctuating up and down at times. When the phone is almost about to discharge, the capacitor helps in providing a boost power to the mobile phone for a short duration of time.

Figure 2.1.3 capacitor 100µF

2.1.4 USB module

USB stands for Universal Serial Bus. USB port allows USB devices to be connected to each other with and transfer digital data over USB cables. They can also supply power across the cable to devices that need it.

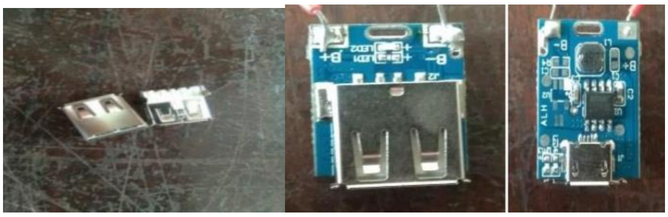


Figure 2.1.4 USB Port Printed USB Port

2.1.5 Multi-meter

Multimeter is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter can measure voltage, current, and resistance. Analog multimeters use a microammeter with a moving pointer to display readings. Digital multimeters have a numeric display, and may also show a graphical bar representing the measured value. Digital multimeters are now far more common due to their lower cost and greater precision.

Figure 2.1.5 digital Multimeter

2.1.6 Soldering device

The basic purpose of a soldering iron is to create a bond between two workpieces using electronically heated soft metal. The soldering iron supplies heat to the soldering tip, which is used to melt the solder. The melted solder forms a bond in the joint between two work pieces. 18 Solder is made up of soft metal alloys, usually composed of a combination of different materials. Typically, this includes a low percentage of a soft metal alloy (such as zinc or copper) and a high percentage of tin. Tin is also a relatively soft metal, but it helps make the bond between the workpieces stronger. Another major component of solder is flux. Flux is a chemical agent that comes in gel form which is used as a catalyst for soldering. It is used to transfer the heat from the soldering iron to the metal so that the solder can form a chemical bond with the metal.

Figure 2.1.6 Soldering device and Soldering iron

2.1.7 Intensity metre

A lux metre is a device for measuring brightness, specifically, the intensity with which the brightness appears to the human eye. A lux metre works by using a photocell to capture light. The metre then converts this light to an electrical current, and measuring this current allows the device to calculate the lux value of the light it captured.

Figure 2.1.7 intensity metre

CHAPTER III

In this chapter, the details of the experiment such as the construction of the solar mobile charger and its performance analysis are discussed.

3.1 V-I CHARACTERISTICS OF SOLAR CELL

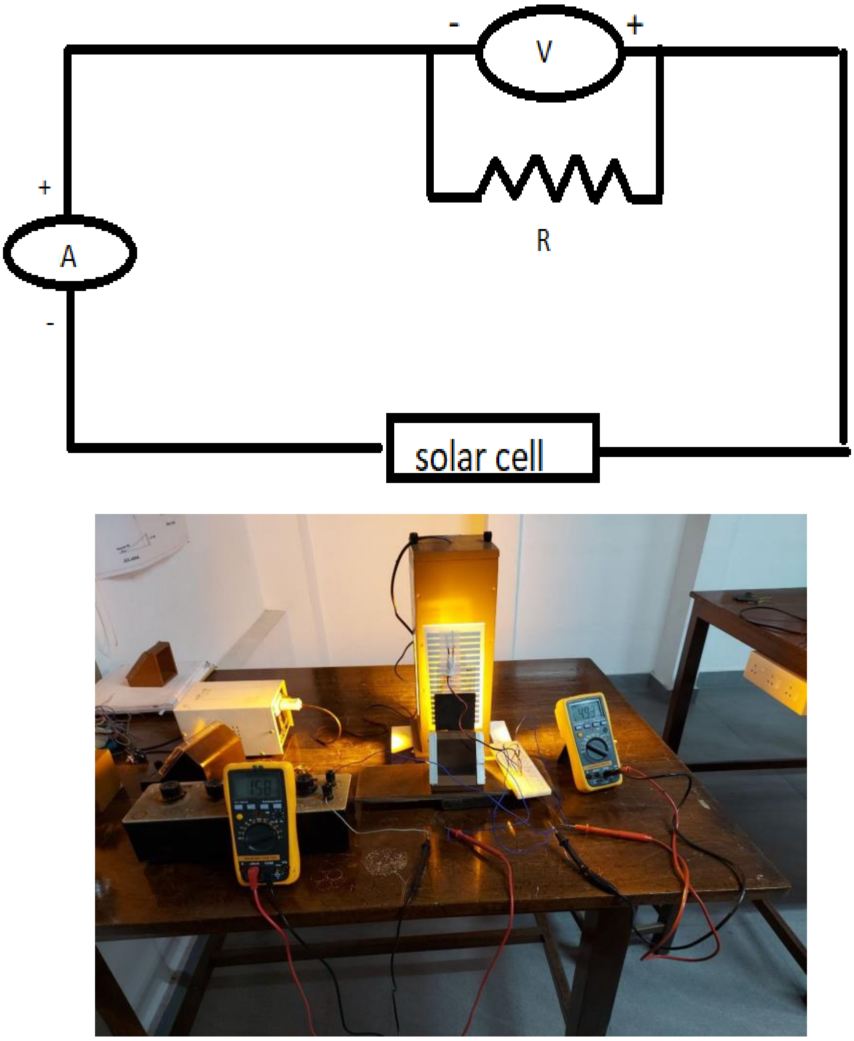


Fig 3.1 circuit diagram

V-I characteristics stand for voltage-current characteristics of an electrical component or device. The V-I graph yields valuable information about the resistance and breaks down an electronic component. From the V-I characteristics Isc is the short circuit current and it is measured by short circuiting the terminals. Voc is the open circuit voltage and is measured when no load is connected, Pm is the maximum power. Im is the maximum current. Vm is maximum voltage and it occurs at the bend of the characteristics curve.

Connections are made as shown above in the diagram. The solar cell is connected in forward bias. Positive of the cell is connected to the positive of the voltmeter, and the negative of the cell is connected to the negative of the ammeter. A load resistance is connected across the voltmeter. The experiment is done by varying the values of resistance. In each step, take both ammeter and voltmeter readings. The cell is kept in maximum intensity position. A graph is plotted taking voltage along X-axis and current along Y-axis. The V-I characteristics parameters are determined from the graph.

3.2 SOLAR MOBILE CHARGER

The objective of this project is to make a mobile charger unit using a solar panel, determine V-I characteristics of the solar panel, deduce parameters such as fill factor, power density, determine optimum inclination for charging, and also compare time of charging under mercury vapour lamp and under direct sunlight. The block diagram for solar mobile charger is shown in Fig. 3.1.

BLOCK DIAGRAM

Figure 3.2 Block Diagram of Mobile Charger.

Solar mobile charger consists of a panel and a fixed voltage Regulator. The solar panel is a voltage source, the output of which varies based on the intensity of sunlight falling on the solar panel. It works on the principle that when light falls on the solar cell, electron -hole pairs are created in the n-type emitter and in the p-type base. The generated electrons (from the base) and holes (from the emitter) then diffuse to the junction and are swept away by the electric field, thus producing current. Most cell phone charger’s output voltage is between 5 and 12 volts. IC7805 is a voltage regulator IC which is used to provide a constant output voltage of 5V.

3.2.1 Circuit Diagram

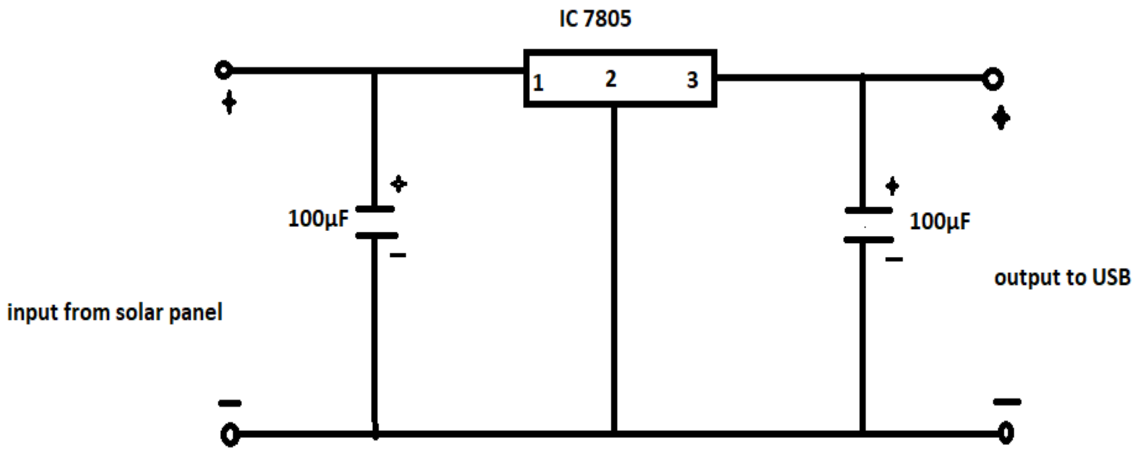


Figure 3.2.1 Basic circuit Diagram

This is the basic circuit diagram of a solar mobile charger. In the circuit IC7805 is connected to two 100µF capacitors. Input voltage is provided by the solar panel and output is taken from the USB port connected across the IC7805 and capacitor 100µF. Then the USB port is connected to the mobile phone.

3.2.2 Breadboard Connections

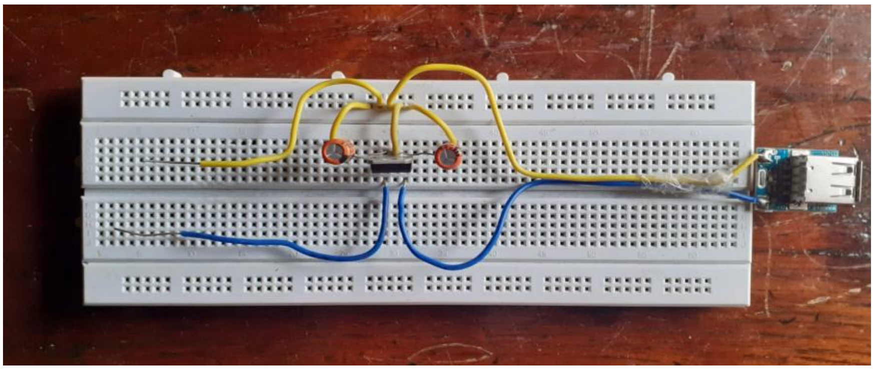


Figure 3.2.2

The preliminary basic circuit of the mobile charger is done in the bread board. This is tested to ensure that it gives the sufficient voltage and current required for charging the mobile. Then this circuit is converted to a printed circuit board.

3.2.3 Mobile charger Printed Circuit Diagram

A printed circuit board (PCB) mechanically supports and electrically connects electrical or electronic components using conductive tracks or pads. Components are generally soldered onto the PCB to both electrically connect and mechanically fasten them to it. The basic mobile charger circuit is converted into PCB, since it is easier to handle than the connections done in the breadboard.

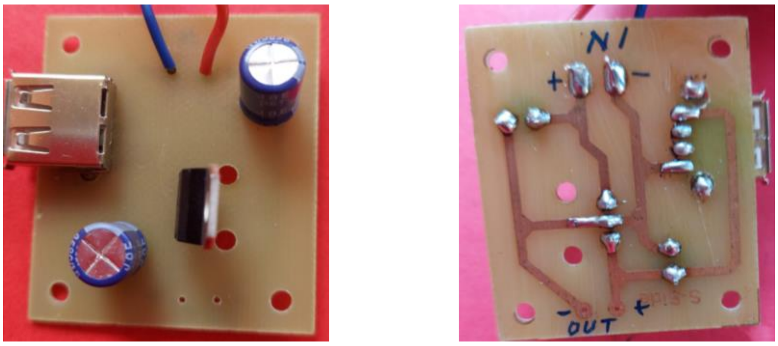
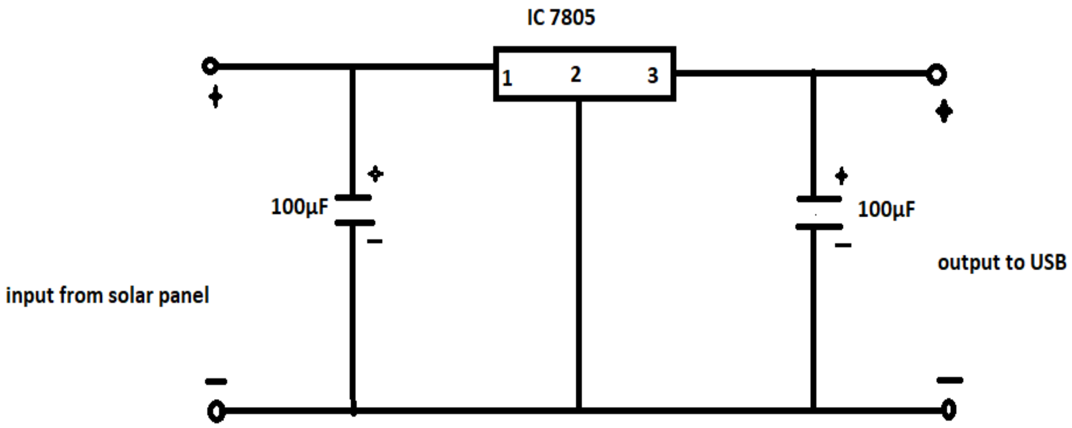


Figure 3.2.3 (A) PCB module **(B) PCB circuit board**

3.3 CONNECTIONS AND WORKING



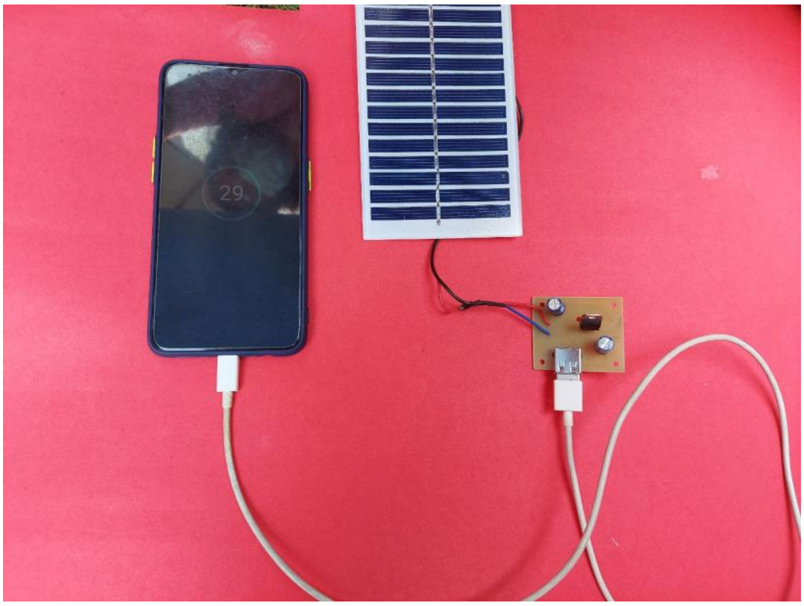


Figure 3.3 Circuit Diagram

The input terminal of IC7805 is connected to the positive terminal of a 100µF capacitor. IC7805 will regulate the output voltage at 5V. The output terminal of IC7805 is connected to the positive terminal of the other capacitor 100µF. The capacitor is used here to suppress the mini voltage spikes inside the phone. It helps keep the voltage constant when it is fluctuating up and down at times. When the phone is almost about to discharge, the capacitor helps in providing a boost power to the mobile phone for a short duration of time. The negative terminals of these capacitors are grounded. The input voltage is supplied through the solar panel. Positive and negative terminals of the solar panel are connected across the corresponding terminals of the capacitor 100μF. The output goes to the USB port. This USB port is connected to the mobile phone. Once connections are done, the sunlight is allowed to fall on the solar panel. This is then converted to electrical energy, the voltage corresponding to this energy is regulated using voltage regulator and capacitors and then it is used to charge the mobile device.

3.4 PROCEDURE

3.4.1 Determination of tilt angle for maximum efficiency.

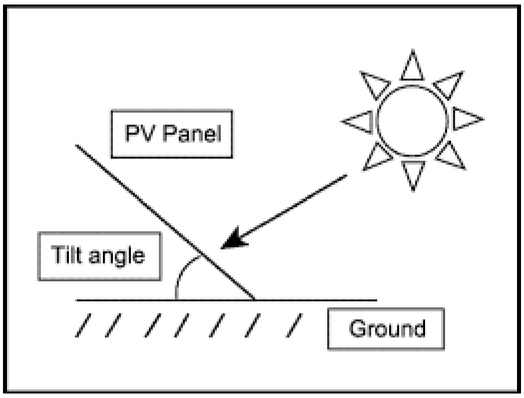


Fig 3.4 Tilt angle

Initially, the mobile phone is charged with the solar panel at 0 degree inclination to the ground. The time taken for charging the phone by 1% is noted.

The experiment is repeated for different tilt angles and in each case the time taken for charging the phone by 1% is noted.

Since the optimum tilt angle for the panel is dependent on seasonal variations we use a software to determine the optimum tilt angle at a particular latitude.

The time taken to charge the phone by 1% corresponding to the optimum tilt angle is also noted.

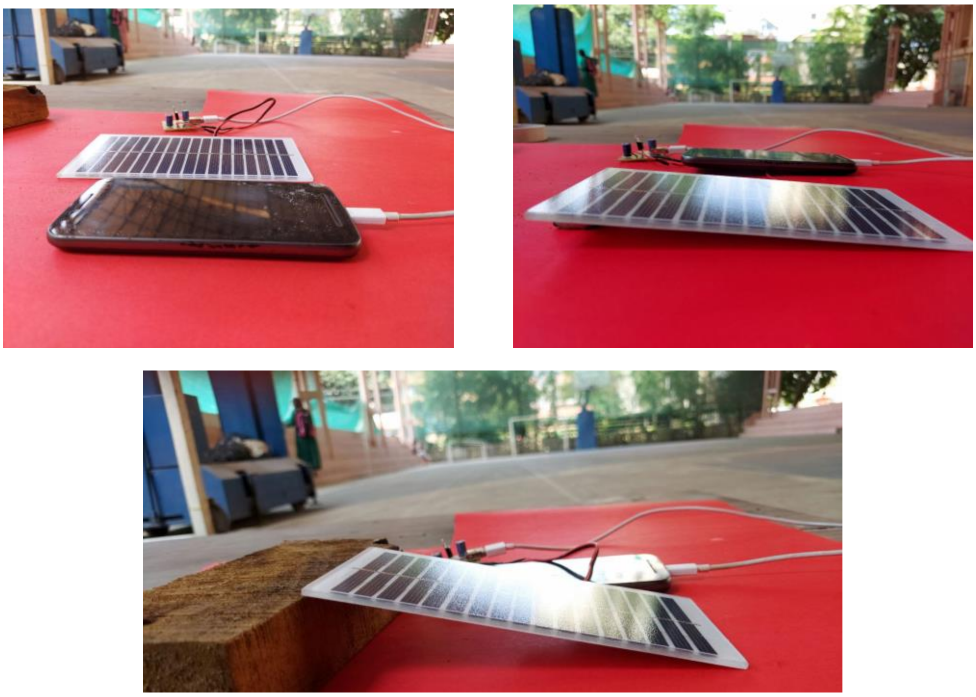


Fig 3.4 solar panels at different tilt angles

3.4.2 Mercury vapour lamp and Sun light comparison

In order to understand how the intensity of the light affects the time taken for charging the phone, the experiment is done first using a mercury lamp and then by exposing the solar panel to sunlight. The time taken for charging the phone by 1% during each case is noted. The intensity of each of the sources are measured using a lux metre.

3.4.3 Charging and Discharging time in AC mains and solar panels of different power

The mobile phone is charged using AC mains(5V), a reference solar panel of 10W and a solar panel of 1.3 W. The time taken for charging the phone by 1% is noted in each case. The time taken for discharging is also noted.

CHAPTER IV

4.1 RESULTS AND DISCUSSIONS

4.1.1 V-I characteristics of solar cell and determination of efficiency, maximum power and fill factor.

SI. NO	VOLTAGE (V)	CURRENT (A)
1.	5.32	0
2.	5.09	0.26
3.	5.03	0.27
4.	4.98	0.29
5.	4.94	0.30
6.	4.86	0.32
7.	4.75	0.34
8.	4.55	0.37
9.	4.18	0.40
10.	3.62	0.43
11.	2.86	0.46
12.	1.72	0.49
13.	1.60	0.5
14.	1.47	0.51
15.	0.916	0.55
16.	0.216	0.63
17.	0	0.64

Short circuit current, Isc = 0.64 A

Open circuit voltage, Voc = 5.32 V

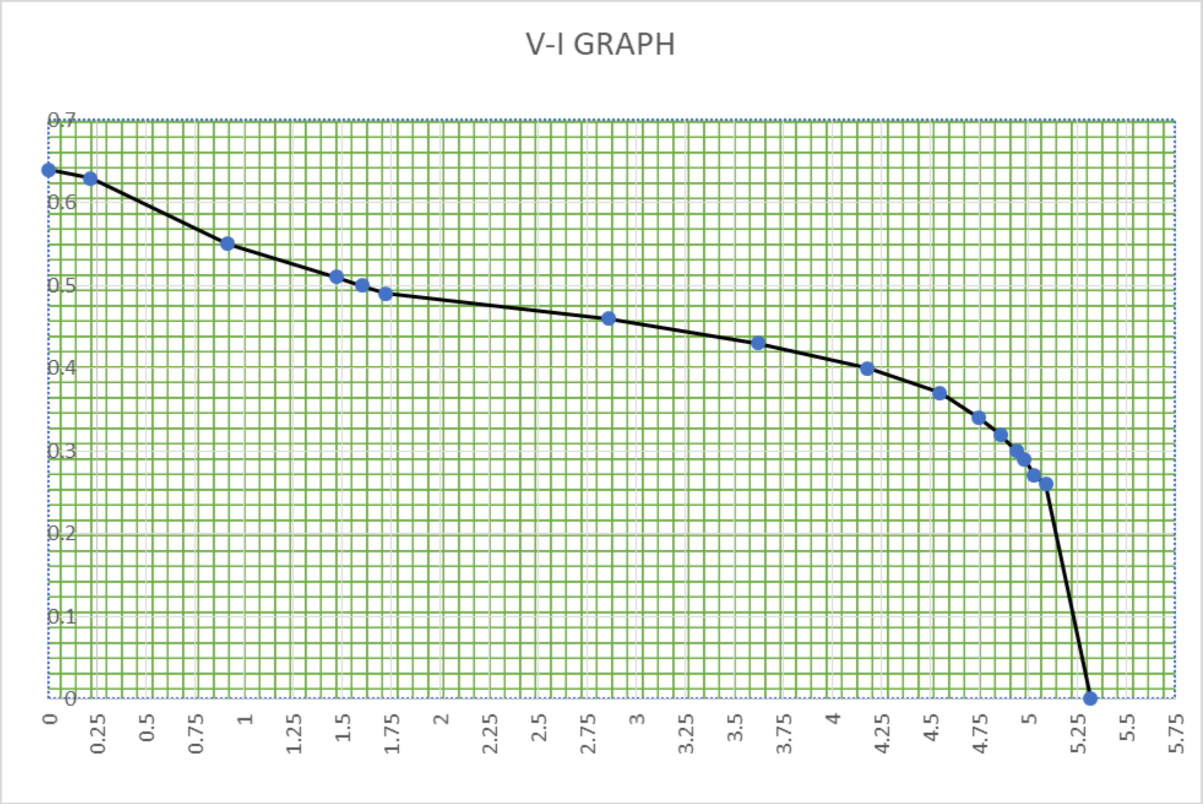
Maximum current, Imax = 0.37 A

Maximum voltage, Vmax = 4.55 V

Maximum Power, Pmax = 4.55 V × 0.37 A= 1.68 W

Fill factor = $\frac{Imax \times Vmax}{Isc \times Voc} = \frac{0.37 \times 4.55}{0.64 \times 5.32}$ = 49.4%

Efficiency = $\frac{Pmax}{Pin} = \frac{1.68}{35}$ × 100 = 4.8%


V-I GRAPH
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
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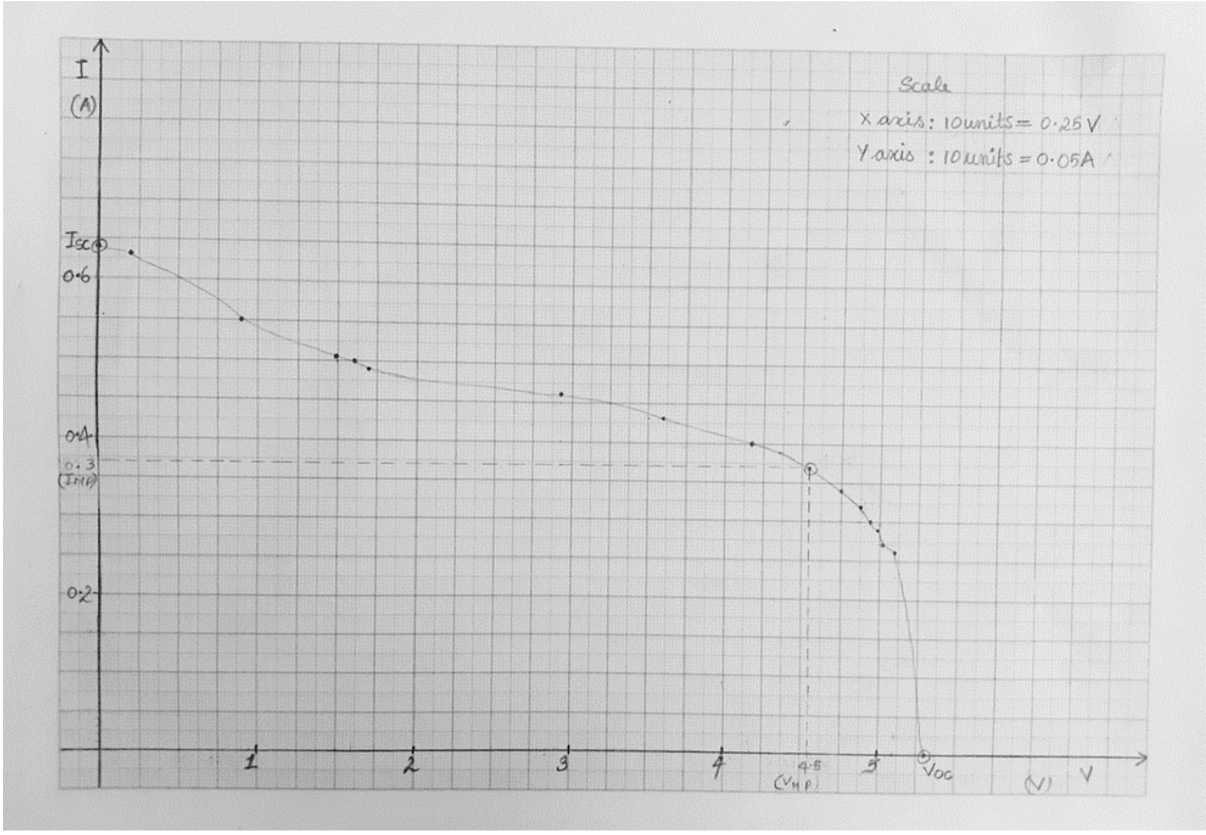
I
(A)
Scale
X axis: 10units = 0·25 V
Y axis : 10units = 0·05A
Isc
0·6
0·4
0·3
(IMP)
0·2
1
2
3
4
4·5
(VMP)
5
Voc
(V)
V

4.1.2 Determination of tilt angle for maximum efficiency

Date: 07/04/2022

Tilt angle obtained as per software: 3.2 degree

(Latitude: 9 deg 58 min 34 sec)

Today's Tilt Angle: 3.2°

Date: 04/07

Latitude: 9° 58' 34"

Vertical distance (cm)	Angle (degree)	Time taken for charging 1 %
0	0	33 min 22 sec
1	3.2	31 min 33 sec
3.7	12	35 min 40 sec
6.4	20	38 min 11 sec
8	26	44 min 25 sec
18	90	No charging

We get maximum efficiency for a tilt angle of 3.2 degree which is also the same according to the software.

4.1.3 Mercury vapour lamp and Sun light comparison

Angle of inclination: 0 degree

Power of mercury lamp: 35W

Intensity of the light from sodium vapour lamp as measured by a lux meter: 7,600 lux

Intensity of sunlight as measured by the lux meter: 40,000 to 70,000 lux (during peak time)

Source	**Time taken for charging 1%**
Sodium vapour lamp	1 hr 13 min
Sun	31 min 33 sec

Hence higher the intensity, lesser the time taken for charging the phone.

4.1.4 Charging and Discharging time in ac mains and solar panels of different power

We successfully designed a solar mobile charger using IC 7805 and capacitors. Here, we have used a Motorola mobile phone having battery capacity 3500 mAh to determine charging and discharging time.

Reference solar panel

Power: 10W (voltage at maximum power 16.032 V and current at maximum power 0.640 A).

Solar panel 2

Power: 1.3W

Charging and discharging time of the above devices were measured and are tabulated in the table below.

When mobile is connected to	**Time taken for charging 1%**	**Time taken for charging 100%**	**Time taken for discharging 1%**	**Time taken for discharging 100%**
AC main **5V, 1A**	1.41 minutes	2.35 hours	8.43 minutes	12.65 hours
Solar panel 1 (Reference 10W)	1.7 minutes	2.833 hours	8.43 minutes	12.65 hours
Solar panel 2 (1.3W)	31.55 minutes	52.58 hours	8.43 minutes	12.65 hours

4.2 ADVANTAGES AND DISADVANTAGES

4.2.1 Advantages:

- No pollution associated with it.
- It must last for a long time - solar panels last for over 30 years.
- No maintenance cost.
- Utilise renewable resources.
- Useful in remote areas and portable for travellers.
- Save electricity bill in the long run.
- No external power source required for charging.
- It can be used for all types of mobile phones and other gadgets too with a USB port as charging point.
- Solar mobile phone charger is compact in size and easy to carry around.

4.2.2 Disadvantages:

- Initial cost is high.
- Low efficiency and dependence of efficiency on tilt angle.
- Difficulties caused due to weather and also at night we will not get solar energy.
- Solar chargers have no capacity to store energy.

4.3 CONCLUSION

We have constructed a solar assisted mobile charger using a solar panel of 1.3W, IC7805 and capacitors. V-I characteristics of the solar panel were initially studied. A maximum power of 1.68W, efficiency of 4.8% and fill factor of 49.4% were determined. The tilt angle for maximum efficiency was found to be 3.2 degree. Charging and discharging time were noted and tabulated. Relation between intensity of light and time taken for charging was also found by charging the mobile phone in mercury vapour lamp and sunlight. Charging occurred in both cases, but faster charging was observed in sunlight.

From our project it was found that, using a solar panel of 1.3 W, it takes 31.55 minutes to charge a mobile phone by 1%. Hence, it takes a total of 52.58 hours for complete charging. So, the solar mobile charger takes more time for charging a mobile phone than direct electricity. For faster charging, the panel must be aligned at the optimum tilt angle and the charging must be done in the noon time because the rays from the sun are the strongest and give the brightest light at noon. We can improve the efficiency in charging by bringing modifications like increasing the panel power. Solar panels can be wired in parallel to increase the output current keeping the output voltage constant and hence faster charging. Climate is also important for the efficient working of the solar mobile charger. This issue can be tackled using a power bank set up. Also, the technology is advancing each second and there is a great future for the project.

4.4 REFERENCES:

- Handbook of solar energy- G.N Tiwari, Arvind Tiwari, Shyam
- Solar photovoltaics(third edition)- Chetan Singh Solanki
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