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Comparative study of the Solar Cell

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Abstract

This study focuses on one of the most efficient forms of renewable energy called as solar energy, which is highly abundant in nature. Solar energy is widely considered as a primary form of Green Energy because it generates electricity and heat without polluting the nature and separating it from the fossil fuels and resulting in the Solar energy as Sustainable Technology. This research paper mainly focuses on solar panel preparation, design, and performance analysis of a low-cost solar panel using the photovoltaic (PV) cells suitable for the small-scale application like domestic energy requirements. Our research mainly emphasizes the comparative study of the solar cell. Testing of solar panel was done under various circumstances and I-V characteristics, Fill Factor are studied. Taking all the things into consideration, the final result indicates that the low-cost solar panels can generate the feasible amount of electrical energy through which small household devices such as fan, light bulb, or other devices, can be run on the basis of the solar panel. This contributes to better energy management and promotes the advancement of sustainable technologies and focuses on high use of renewable energy sources for the human mankind and future.

Keywords: Solar cell, renewable energy, green energy, sustainable technologies.

Introduction

A solar cell is also known as photovoltaic cell[1] which converts sunlight into electricity using the photovoltaic effect. It is made up of semiconductor materials like silicon. Light is made up of photons. When sunlight incidents on the solar cell, electrons absorbs the kinetic energy of photons and thus releasing the electrons from silicon atom to which they are bound to it. Now these electrons are mobile so their movement causes the electricity generation.

Solar cells consist of N-type and P-type semiconductors and through doping we can enhance the semiconductor. Doping is done in N-type and P-type with phosphorus and boron respectively because phosphorus contains more electrons and boron contains more holes. Hence, doping increases the number of the charge carriers i.e. electrons and holes in N-type and P-type respectively and when combined together they form a P-N junction. Electrons and holes diffuses across the junction which causes recombination and results into the formation of ions. This creates an internal electric field and a depletion region, which controls the further movement of charge carriers.

At equilibrium, diffusion current and drift current balances and resulting into complete stopping the net charge flow. A single solar cell produces limited energy at low scale. For large scale multiple cells are connected to form the solar panels and solar arrays. Since Solar panels generate direct current, which is converted into alternating current with the help of the inverters to run the domestic appliances.

Batteries stores the energy in the form of direct current and acts as the power backup-up during power failure or night time.

Objective of the research: To study about the designation and preparation of the solar panel, working process and analysis of shift in current and voltage, conversion process i.e how light is converted into electrical energy. Impact on environment and benefits from it such as reducing the carbon in air and minimizing pollution and promoting the sustainable renewable sources of power generation. Challenges regarding solar panel such as high installation cost which is less affordable and requires wide area to install, energy storage issue, maintenance, repair and provide protection to it from being damaged.

Research Gaps: Since, solar panel don't generate constant power for that battery systems are installed but current battery systems are not efficiently integrated. Hence more research is needed on combined solar panels with the power storage systems; this is called as energy storage integration. Recycling technology[2] for solar panel is very limited and more progress needs to be done on it. Power grids always struggle to handle solar panel's power variation. Research is needed on energy management technologies like smart grids, etc. High initial cost and time to time maintenance and lacks stability and long term durability are the major gaps which limits the use of solar panels. More research is needed on affordable and scalable solutions.

Components of solar panel and power system: Solar panels - It converts the sunlight into electrical energy. Inverter - It

converts the DC electricity into AC electricity. Battery - It stores electrical energy and acts as a power backup system during power failure or night time. Charge controller - It regulates the charging of a battery and prevents it from overcharging. Mounting structure - It supports and positions the solar panel towards the maximum exposure of sunlight. Voltage boosting circuit - It enhances the output DC voltage.

Factors affecting solar panel performance: High sunlight intensity[3] increases the electrical generation which results the battery to be overcharged. Due to the high sunlight the temperature significantly increases and can reduce the efficiency of solar panel. Dust and dirt accumulation over the panel can block sunlight and reduces power output. Incorrect panel angle can lead to the less sunlight absorption and bad quality of semiconductor material can decrease the conversion efficiency.

Application of solar panel: In residential areas, solar panels are used for powering homes, lighting systems, fans, refrigerators and charging systems. In industries, solar systems are used for the machinery, heating, cooling, and electrical generation. In agriculture, solar energy is used for water pumping, irrigation systems etc. Solar panels are also installed on satellites and spacecraft and uses sunlight as their primary energy source. In modern time, EV charging stations also uses solar systems.

Advantages and limitations of solar panel: It is renewable and sustainable energy source depends i.e. on sunlight for power generation but efficiency decreases with high temperature. It has low maintenance cost but high initial installation cost. It reduces electricity bills but the energy storage system's cost increases. Reduces the greenhouse effect and gases but performance depends on weather conditions. Best useful in Industrial areas for machineries, power generation but occupies large installation area.

Future scope of solar energy: Solar energy is the sustainable technology[4] and there will be a huge energy demand in future because it uses one of the renewable energy sources is sun i.e. light. Governments will support such sustainable technologies and also invest and upgrade them. This will lead to the technological advancements and growth of electric vehicles and smart grids. Researchers continue to improve photovoltaic efficiency and energy storage systems to make solar panel more reliable and affordable.

Materials and Methods

The experimentation is carried out in different combination of solar cells which are connected in series and parallel, and tested to see which one is more prominent for electrical generation. The first experiment was done on the single solar cell under the strong sunlight. The positive and negative terminal of the solar cell are directly connected to the digital multimeter (DMM) to measure the voltage and current. As a result, 4V - 4.9V of voltage and 0.5mA current was generated by the single solar cell under strong sunlight. But to run high power appliances, solar cells are connected in series or parallel to increase the output voltage and current respectively. Second experimentation was done in which 4 solar cells are connected in series and 4 solar cells are connected in parallel and shouldered nicely. In series connection, the opposite terminals of solar cells are connected while in parallel connection, all the same terminals of solar cells are connected. After connection and shouldering was done, an experimentation set-up for solar cell was made to measure the increment in voltage and current. Apparatus required for the set-up such as voltmeter, Ammeter (mA), resistance box, source of light (lamp), connecting wires, solar panel (cells connected in series and parallel) etc.

Connection: First we started the experiment with series in which positive and negative terminals of the solar cells are connected with the voltmeter. Voltmeter's positive terminal is connected to the one end of the resistance box and its other end is connected with the ammeter's positive terminal and its negative terminal is connected with the voltmeter's negative terminal.

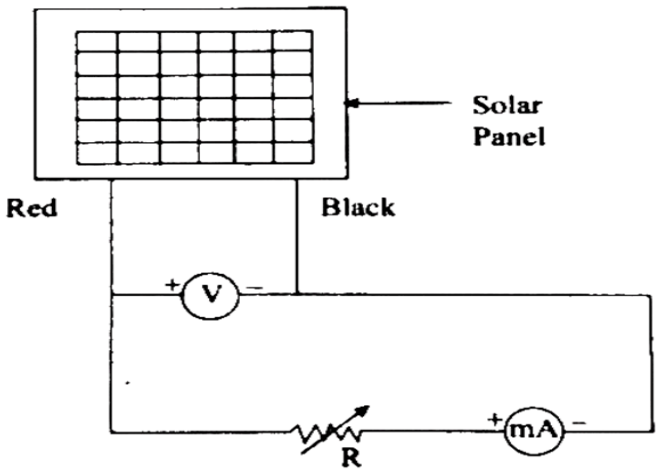


Figure-1: Diagram.

Aim: Our main aim is to find the fill factor of the solar panel connected in series and parallel through I-V graph. For that, open circuit voltage (Voc) and short-circuit current (Isc) is to be known. After completing the connection when the setup is ready. Open circuit voltage means maximum voltage can be gained when the circuit is open means no current is flowing (I=0). Short circuit current means current is maximum when voltage is zero i.e (V=0).

Through this set-up we will find the values of open circuit voltage and short circuit current. With the help of Voc and Isc, an I-V graph can be made, by plotting the graph we can get ideal power and maximum usable power. Ideal power is the maximum theoretical power which uses maximum voltage and current or the values of Voc and Isc. Maximum useful power is

the actual power we can get, taken at maximum power point at curve of I-V graph.
Ideal power = Voc x Isc
Maximum useful power = Vm x Im
By dividing maximum useful power to the ideal power, we can get the fill factor.

To find the Voc, the resistance must be infinity so that the circuit will be open and current is zero. For Isc, the resistance must be very negligible such that value of current obtained will be maximum and voltage is zero.

Table-1: Series.

Volt (V)	Current (mA)	Resistance
6.4	0	infinity
0	0.05	1

Table-2: Parallel.

Volt (V)	Current (mA)	Resistance
3.4	0	Infinity
0	1.8	1

To obtain the maximum useful power, the values of open-circuit voltage (Voc) and short-circuit current (Isc) are required. Using these values, a curve can be drawn from Voc to Isc. The maximum useful power is determined using (Vm) and (Im), which can be obtained from this curve.
We know that, Maximum useful power = Vm x Im

To find Vm, we take a value from Voc. For example, if Voc = 6.4V, dividing it by 2 gives Vm = 3.2V. To find Im, locate the point where the horizontal line corresponding to Vm (3.2V) intersects the curve. The corresponding value on the X-axis at this point gives Im. The point where Vm touches the curve represents the maximum power point. To calculate the maximum useful power, multiply Vm by Im.

Calculation: Series and Parallel are as follows
Series: Vm = 3.2 Voc = 6.4
Im = 0.041 Isc = 0.05
Ideal power = Voc x Isc
= 6.4 x 0.05 = 0.32
Max Useful Power = Vm x Im
= 3.2 x 0.041 = 0.13
Fill Factor = Max useful power / Ideal power
= 0.13/0.32 = 0.406
Therefore, Fill factor of solar panel in series is 0.4.
Parallel: Vm = 1.7 Voc = 3.4
Im = 1.2 Isc = 1.2
Ideal Power = Voc x Isc
= 3.4 x 1.2 = 4.08
Max Useful power = Vm x Im
= 1.7 x 1.2 = 2.04
Fill Factor = Max useful power / Ideal power
= 2.04/4.08 = 0.5
Therefore, Fill factor of solar panel in parallel is 0.5.
Therefore, from the Table-1 and 2 we can prove that, in series the voltage increases and in parallel, the current increases.

Fill Factor: The fill factor (FF)[5] of a solar panel (more precisely, a solar cell) is a measure of how "good" the cell is at converting sunlight into usable electrical power. It tells you how close the actual power output is to the ideal maximum.
Typical values of good solar cells: 0.70 to 0.85 (70% – 85%).

Meanwhile our solar cells connected in series = 0.4 and in parallel = 0.5. It means 40% to 50% our solar cell is converting sunlight into usable electrical power.
Fill factor directly affects Efficiency[6]
Efficiency $\propto$ FF × Voc x Isc
Efficiency is directly proportional to the Fill factor, Open circuit voltage, Short circuit current. So, Higher FF means more power output.

There are several factors which affects the solar cells and simultaneously lowering the fill factor such as internal resistance in the cell, Temperature (higher temp usually lowers FF), Material quality, Manufacturing defects, etc. These are the reasons due to which lowers the Fill factor of solar panel. Modern solar panels[7] have the fill factor of (0.8 - 0.85) means 80% to 85% conversion rate.

Voltage boosting circuit as an application with solar panel: A voltage boosting circuit[8] (also called a DC-DC boost converter) is an electronic circuit that takes low DC voltage from a solar panel and converts it into a higher DC voltage. It is very important application used with solar panels because the voltage produced by a solar panel is often low or variable. To make it usable (for charging batteries or powering devices), we increase it because it using a boost converter.

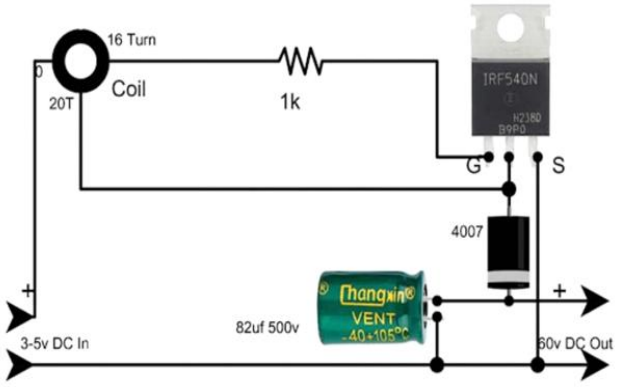


Figure-2: Circuit Diagram.

Apparatus: Inductor (L) - stores energy. Switch (Transistor/MOSFET) - controls the current flow. Diode (D) - allows current to flow in one direction. Capacitor (C) - it smoothes the output voltage. Load - battery or devices (here, voltage boosting circuit is directly connected with the solar panel).

Working of voltage boosting circuit: Start (Power ON) - You give 3–5V to the circuit. A small current flows through the resistor into the MOSFET. MOSFET turns ON - The MOSFET starts conducting (like a switch closing). Current flows through the 20-turn coil. This creates a magnetic field in the coil. Feedback winding kicks in - The 16-turn coil sends feedback to the MOSFET gate. This makes the MOSFET turn ON even harder (positive feedback). So current increases quickly. Sudden switch OFF - After a moment, the MOSFET suddenly turns OFF. The magnetic field in the coil collapses. When this happens, the coil produces a high voltage spike (much higher than 5V). Diode + Capacitor capture the energy. The diode (4007) directs this high voltage to the capacitor. The capacitor stores this energy. Repeats very fast - This ON/OFF cycle happens thousands of times per second. Each time, more energy is added to the capacitor. From 4V input voltage increases upto the 60V in the form of direct current.

Results and Discussion

The research shows that how voltage and current generated by the solar cells in series and parallel respectively affects them. Voltage booster circuit is a small circuit (consist of diode, capacitor, inductor, resistor, and MOSFET switch) directly connected with solar cells providing continuous constant current under the strong sunlight and simultaneously increasing the voltage with the help of voltage boosting circuit. Thus in this way by connecting few solar cells together we can develop upto 50V - 65V easily in the form of direct current.

Conclusion

Solar panel plays a very important role in clean and green energy systems. The Photovoltaic technology which converts sunlight into the electricity in the form of direct current without releasing harmful greenhouse gases and also it is eco-friendly energy source.

This research paper concludes that solar cells connected in series and parallel increase s voltage and current respectively. Electricity obtained from solar cells is in the form of direct current of low voltage but to enhance this voltage, we used the voltage boosting circuit instead of using inverter and transformer.

Despite of many challenges such as high initial installation cost, weather dependency and efficiency reduction at high temperatures, the advantages of solar panel always outweigh its limitations[9]. Therefore, solar panels are expected to become one of the major sources of electrical generation in future.

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