

Lifecycle Maintenance Strategies for Solar PV Systems: A Focus on Rooftop and Ground-Mounted Installations

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India is the world's third-largest producer and consumer of power and the country's energy sector is becoming more and more dependent on renewable energy. India's installed power capacity was 442.00 GW as of March 31, 2024. India has made tremendous strides in the field of renewable energy. The fluctuating price of fossil fuels is one of the factors contributing to the rise in importance of renewable energy in India. India hopes to improve energy security, lessen its reliance on imported fossil fuels and lessen its environmental effect by diversifying its energy mix and depending increasingly on renewable sources. The term "solar energy" describes the energy obtained from the radiation of the Sun. It is a sustainable and renewable energy source that can be harnessed and transformed into electricity or used straight away for lighting, warmth, and other uses. As far as working of solar panels is concerned, it is a well known and well accepted truth that the environmental impact considerably affects the working of solar panels. Therefore, for improving the overall performance of panels, it is important to look at the maintenance strategies for solar PV systems. Solar panels can have roof top or ground mounted installations and for getting the constant and maximized output, it is important to precisely monitor the surface conditions of solar panel to determine impact of varying weather conditions. The accumulation of dust, sticky surface, rainy season, fog etc. can affect the output and hence lifecycle maintenance strategies are important to consider for solar photovoltaics.

Keywords: Solar Panel, Environmental Impact, Dust, Renewable Energy, Solar PV, Pedagogy, Solar Radiation.

1. Introduction

Effective energy conversion is made possible by the transparent glass surface of solar PV panels, which absorbs and reflects solar radiation. However, the absorption rate drops and the conversion efficiency is reduced if the glass's transparency is damaged, for example, by physical damage. It might be difficult to clean solar panels after installation because dust particles prevent solar energy from entering the panel efficiently, decreasing conversion efficiency and lengthening battery charging time. Because of the panel's mounting and mechanics, conventional cleaning techniques like vacuuming or hand washing aren't always feasible. An accumulation of dust on the panel results in an inefficient conversion because it blocks the appropriate penetration of solar energy into the PV panel receiver. To guarantee optimum performance, solar panels must be frequently maintained and cleaned. By preventing sunlight from reaching the photovoltaic cells on the panel's surface, these materials drastically lower solar performance and total efficiency. Using chemicals and cleaning solutions on the panel surfaces might cause dirt to build up and hasten the deterioration process, which will harm the PV panel's attractiveness and main purpose.

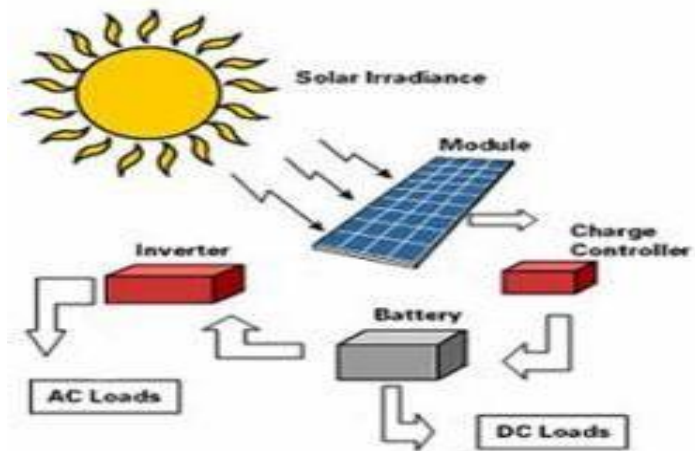


Fig1: Block Diagram of the developed Solar System

2. CLEANING OF SOLAR PANELS

Cleaning the solar panels is an essential maintenance task to keep the solar system operating at peak performance and efficiency. Dust, dirt, trash, bird droppings and other environmental factors can build up on solar panels, making it more difficult for them to absorb sunlight. The following are guidelines for solar panel maintenance:

- Safety first: Put the safety first before attempting to clean solar panels. During the cleaning procedure, make sure the solar panels are not in use and are exposed to sunlight.
- Manufacturer's recommendations: For detailed cleaning recommendations, consult the solar panel manufacturer's instructions. To preserve warranty coverage, some manufacturers can have particular guidelines or limitations on cleaning supplies and

techniques.

- Visual Inspections: Examine the solar panels frequently to look for any obvious dirt, debris, or blockages. While you're at it, look for any loose connections or damage.
- Time to perform cleaning: Make plans to clean on a chilly day or early in the morning when the panels won't be overheated from the sun.
- Cleaning methods: To start, remove any loose dirt or debris with a long-handled sponge or soft brush.

3. COMPARISON BETWEEN DIFFERENT CLEANING TECHNIQUES:

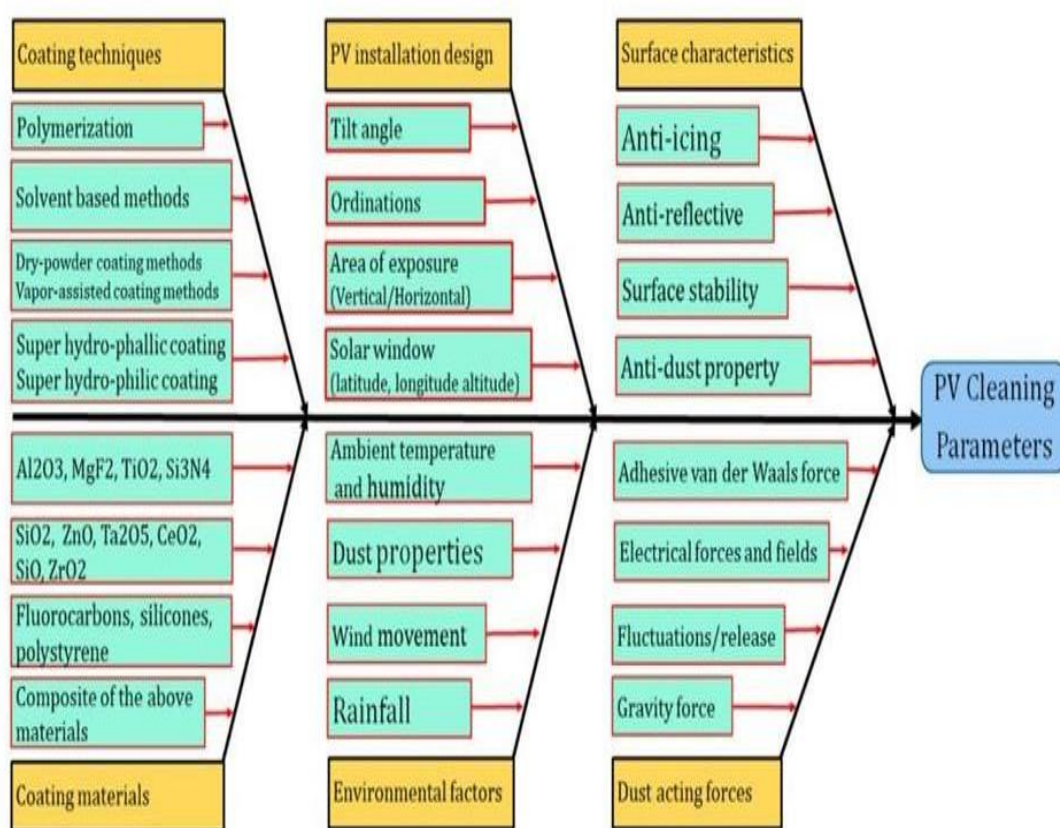


Fig2: Block Diagram of Cleaning Parameters

(a) Manual Cleaning:

The term "manual cleaning" describes the act of organizing a place by hand, without the use of mechanical or automated equipment. Brooms, mops, dusters, brushes, and cleaning solutions are some of the tools and methods used to clean surfaces of dirt, dust, stains, and debris. With this technique, the surfaces are physically cleaned by a human operator utilizing wipers and suitable support structures, as shown in Figure 6.

The operator evaluates the surface's cleanliness visually and keeps cleaning until all dust particles have been removed or the required level of cleanliness is reached. This procedure is laborious and difficult, though, especially in solar power plants where many panels are positioned at heights of 12 to 20 feet or more.



Fig3: Manual Cleaning of Solar Panel

(b) Vacuum Suction Cleaning:

A Hoover suction cleaner is a device that uses a motor to create suction, which allows it to remove dust and filth from a variety of surfaces, including windows and floors. Even while the vacuum cleaner's power consumption is measured, this does not always indicate how efficient it is. Airflow, which is measured in air watts, is produced from the input power. Even while the vacuum cleaner can clean most surfaces well, as Figure 7 illustrates, it sometimes need to be handled by hand in tight spaces like corners. To guarantee that the operator can operate the cleaner on the surface efficiently, it is crucial to give them the right training.



Fig4: Vacuum Cleaning of Solar Panel

(c) Automatic Wipe Cleaning:

The term "automatic wiper-based cleaning" describes a method or device intended to clean surfaces, usually with a water spray and a rubber wiper. In many different applications, this technique is frequently used to clean windows, windshields, and other smooth surfaces. A rubber wiper and a water pot that sprays water with cleaning agents and additives are part of the automatic wiper-based cleaning system that is discussed in corporates. It works in a manner akin to that of car glass washing. The technology is dependent on a battery-operated automated mechanism. The automatic cleaning procedure is guaranteed by the control mechanism. The effects of this approach are similar to those of the prior system you cited, which was perhaps a previous iteration or an alternative strategy with comparable results.



Fig5: Auto Wipe Cleaning of Solar Panel

(d) Drones equipped with sensors and mapping cameras:

The creation of a drone-based solar panel cleaning system is a creative way to deal with the difficulties of keeping solar panels clean, especially in isolated or difficult-to-reach areas. In this configuration, a waterproof docking station close to the solar panels houses a quadcopter drone. The cleaning procedure is predetermined and mechanized. The weatherproof docking station opens its top doors at regular intervals, enabling the drone to ascend on a motorized platform and take off. The drone can accurately line itself over each solar panel thanks to its sophisticated technology, which include mapping cameras and Lidar (Light Detection and Ranging) sensors.

The drone efficiently removes accumulated dust, filth, and debris from the panel surface by spraying cleaning solution onto it after it is positioned correctly. The drone cleans one panel before moving on to the next, cleaning the entire array. The drone returns to the docking station

and safely settles there after doing the cleaning job.



Fig6: Drone Cleaning of Solar Panel

(e) Internet of Things based cleaning:

Using an Arduino-based system, the suggested system seeks to monitor the parameters of a 10-watt solar panel and send the power output to an Internet of Things (IoT) platform. This system's objectives are to continuously monitor the operation of the solar panel, identify any connection or circuit failures, and alert users for prompt repairs. Monitoring the solar power plant helps to guarantee maximum power output, spot malfunctioning panels or connections, find dust buildup on panels that could reduce output, and take care of other problems that could impair solar performance.

The system collects data from the solar panel and keeps track of its properties using Arduino, a well-known microcontroller platform. An interface for gathering voltage, current, temperature, and other pertinent data is offered by Arduino. The Arduino-based system then analyzes this data to find any irregularities or departures from the predicted values. The system sends information to an IoT system via the internet as soon as it finds a malfunction or other performance issue.

The data collected from several solar panels is gathered, examined, and visualized centrally via the Internet of Things system. It allows the solar power plants to be remotely monitored and controlled from any location with an internet connection.

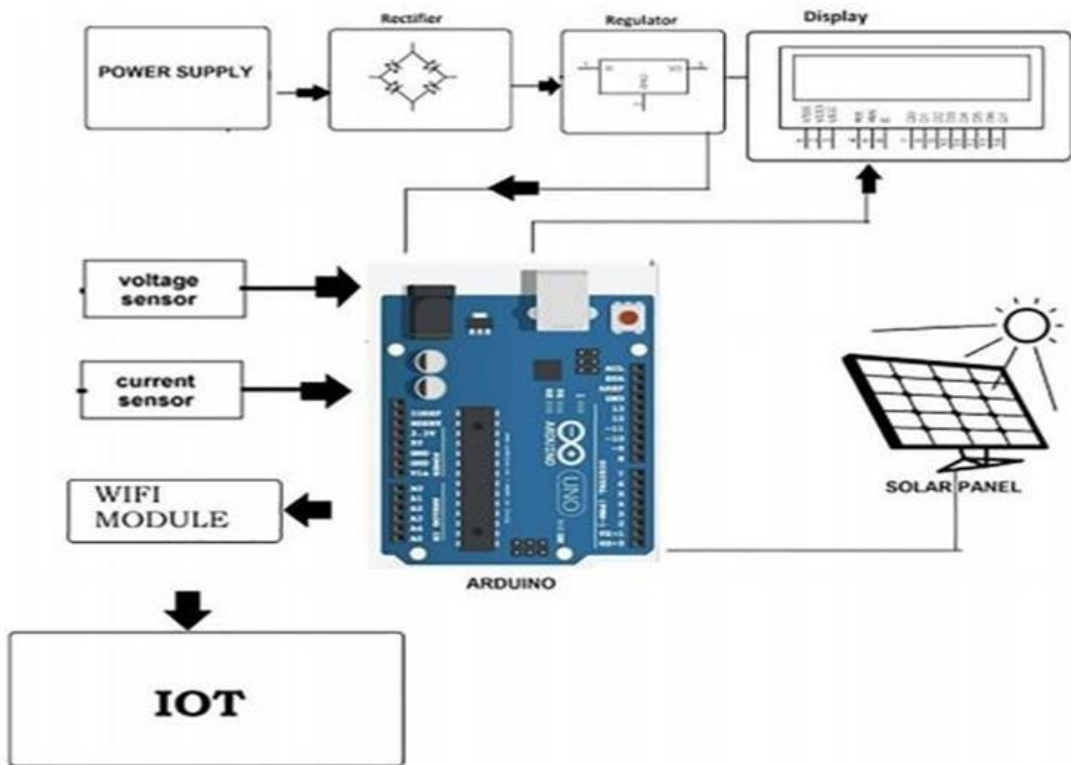


Fig7: IoT Based System of Solar Panel

4. EFFICIENCY OF SOLAR PANELS:

A solar cell's overall performance and competitiveness in the market for renewable energy are greatly influenced by its efficiency. It is defined as the ratio of the electrical energy output of the solar cell to the solar energy input (irradiance) it receives from the sun. Scientists and researchers have concentrated on a number of technological developments and inventions to increase the efficiency of solar cells. These include creating new materials, refining the manufacturing and design procedures, and enhancing the solar cell's energy conversion systems.

One important consideration in solar cell efficiency is the solar radiation intensity, also known as irradiance or insolation. Irradiance represents the amount of solar energy per unit area that reaches the solar cell. It is influenced by factors such as the angle and position of the sun, atmospheric conditions, and any shading or obstructions that may reduce the amount of sunlight reaching the solar cell. Higher irradiance levels generally result in increased electrical output from the solar cell. From an average of 15% to 20% conversion of sunshine into useful energy in recent years, solar panels' efficiency has increased substantially. High-efficiency solar panels can have an efficiency of around 23%.

Type of solar Panel	Conversion efficiency	PV cell material	Panel efficiency	Area needed for 1KWp
Copper Indium Gallium Selenide	10-13%	Monocrystalline silicon	13-16%	7m ² (75 sq ft)
Cadmium Telluride	9-12%	Polycrystalline silicon	12-14%	8m ² (86 sq ft)
Organic photovoltaic cell	7-12%	Amorphous silicon	6-7%	15m ² (161 sq ft)

Fig8: Solar PV Materials and Its Efficiency

5. PROBLEM ASSOCIATED WITH PRESENT TECHNOLOGY:

While solar panel technology has seen significant advancements in recent years, there are still a few challenges associated with it, some of the key problems include:

- (1). only a small amount of the sunlight that passes through solar panels is normally converted into useable electricity. Although solar panels have become more effective over time, it is still difficult to maximize conversion efficiency and absorb as much sunlight as feasible.
- (2). The cost of manufacturing solar panels can be relatively high due to the materials used, especially high grade silicon and low efficiency. This can lead to a limited supply of high-grade silicon, which affects the scalability of solar panel production.
- (3). Designing a solar panel system that meets the specific needs of a property can add to the overall cost. Factors such as roof size, orientation, shading, and energy consumption patterns need to be considered during the design phase. Customization to accommodate these factors may increase the cost of the system.
- (4). Solar panels are exposed to various weather conditions, including extreme heat, cold, and humidity, which can affect their performance and lifespan.
- (5). Cleaning solar panels manually can involve working at heights or on rooftops, increasing the risk of falls and injuries. If proper safety measures are not followed, there is a potential for accidents.
- (6).Manual cleaning of solar panels can be a time-consuming process, especially for large-scale solar installations. It requires significant manpower and effort to clean each panel individually, which can be inefficient and costly.
- (7). Some solar panels may be installed in remote or inaccessible locations, such as rooftops or elevated structures. This can make manual cleaning challenging and may require additional equipment or resources to reach these areas.
- (8). Manual cleaning may not be able to effectively remove all types of dirt, grime, or stubborn stains from the solar panels. This can lead to decreased panel performance and reduced energy generation.
- (9). Shading from nearby objects, such as trees, buildings, or other structures, can significantly

impact the performance of solar panels. Even partial shading on a small portion of a panel can result in a disproportionate reduction in power output. It is crucial to position solar panels in locations with minimal shading or use techniques like bypass diodes to minimize the impact of shading.

(10). Solar panels can be exposed to a wide range of temperatures, including extreme heat or cold. High temperatures can cause a decrease in panel efficiency, while rapid temperature fluctuations can lead to thermal stress and potential damage to the panels over time. Proper ventilation and thermal management systems can help mitigate the effects of temperature extremes.

(11). Moisture can penetrate into the solar panels if proper sealing measures are not in place, leading to corrosion and electrical malfunctions. High humidity levels, especially in coastal areas, can also accelerate the degradation of materials used in the solar panels. Ensuring proper sealing and using high-quality materials can help mitigate these issues.

(12). Solar panels installed in coastal areas or regions with high levels of saltwater or corrosive pollutants face an increased risk of corrosion. This can degrade the performance of the panels and affect their life span. Regular inspections, appropriate coatings, and corrosion-resistant material can help combat this problem.

(13). Depending on the location, solar panels can be susceptible to damage from hailstorms, heavy winds, or other severe weather conditions. Hailstones can cause physical damage to the panels, including cracks or shattered glass.

6. THE LATEST ADVANCEMENTS IN SOLAR TECHNOLOGY:

Ultra-light Fabric Solar Cells: Engineers at MIT have created ultra-light fabric solar cells that can transform any surface into a source of power. These flexible and durable solar cells are extremely thin, measuring less than a human hair, and are attached to a lightweight fabric, allowing for easy installation on various surfaces. The cells are highly versatile and can be used as wearable power fabric or quickly deployed in remote areas during emergencies. Compared to traditional solar panels, they are 100 times lighter, produce 18 times more power per kilogram, and are manufactured using scalable printing processes with semiconducting inks. Due to their lightweight nature, the solar cells can be laminated onto different surfaces such as boat sails, tents, tarps, and even the wings of drones, enabling power generation in various settings. This technology can be seamlessly integrated into existing structures with minimal installation requirements.

Emerging solar panel Materials and their properties:

(a) **Perovskite:** Due to their high efficiency and low production costs, perovskite materials have become more popular in the field of solar panels. They are less expensive to produce than conventional silicon-based solar cells and have the potential for greater efficiency. The stability and longevity of perovskite solar cells are being improved, according to research.

(b) **Organic polymers:** Also known as plastic solar cells, organic polymers offer advantages such as light weight, flexibility, and low production costs. However, their current efficiency levels are lower compared to silicon-based solar cells. Ongoing research aims to enhance the

stability and efficiency of organic solar cells to make them more competitive in the market.

(c) Quantum dots: Small semiconductor particles called quantum dots can be used to make highly efficient solar panels. They have the potential to increase solar energy absorption, especially in the infrared region, where conventional silicon-based solar cells perform less well. Research is ongoing to incorporate quantum dots into solar cell technology.

(d) CIGS: A thin-film solar panel material called copper indium gallium selenide (CIGS) has the potential for low manufacturing costs and excellent efficiency. CIGS panels are lightweight, flexible, and can be produced in a variety of colors and forms. Ongoing research aims to optimize CIGS technology for large-scale production and further improve its efficiency.

(e) Graphene: Graphene, a two-dimensional material with exceptional electrical and optical properties, holds promise for solar panel technology. Researchers are investigating ways to integrate graphene into solar panels to enhance their effectiveness.

These novel materials offer exciting possibilities for improving the efficiency, cost-effectiveness, and versatility of solar panels. Ongoing research and development in these areas are crucial to unlocking their full potential and driving the advancement of solar energy technology.

Reverse Solar Panels: Australian researchers have unveiled a groundbreaking study outlining the integration of standard-grade night-vision goggles with a power-harnessing mechanism. Although the initial prototype only generated limited amounts of electricity, its demonstrated capacity holds great potential for viable solutions that could complement the widespread adoption of solar panels. The newly developed device has the capability to seamlessly integrate with photovoltaic similar to solar cell devices, enabling the generation of electricity from photons present in the surrounding environment. An outstanding advantage of this night time energy collector is its ability to capture surplus heat from solar panels that have been operating continuously throughout the day.

Nano particles self-assemble to harvest solar energy: Designing a solar harvester with enhanced energy conversion capabilities is a significant step towards improving renewable energy technologies. The utilization of a quasi-periodic Nano scale pattern combined with self-assembling Nano particles in the fabrication process demonstrates innovative approaches in materials science and engineering. The self-assembling Nano particles in the fabrication process provide a means to create an organized material structure without the need for external instructions. This self-assembly process simplifies manufacturing and reduces the complexity associated with traditional fabrication techniques. It allows the Nano particles to arrange themselves in the desired pattern, enabling precise control over the material's properties and enhancing the device's performance.

Double-sided panels: Bifacial solar panels, with their ability to capture sunlight from both sides, have great potential to enhance solar energy production. The new method developed by the leading laboratory in photonics and renewable energy at the University of Ottawa could be a significant advancement in measuring the solar energy generated by these panels. Traditionally, measuring the energy output of bifacial solar panels has been challenging due to the need to account for the light received on both the front and back sides of the panels. The

new method developed by the laboratory could address this issue and provide more accurate measurements. The proposed characterization method, known as the scaled rear irradiance method, aims to enhance the measurement and modeling of bifacial devices in indoor environments, offering representation of outdoor environmental conditions. The method enables researchers and manufacturers to better understand and optimize the performance of bifacial devices, leading to improved efficiency and reliability.

7. CONCLUSION:

Solar panels have proven to be a highly viable and sustainable solution for generating clean and renewable energy. Solar panels harness energy from the sun, a virtually limitless and clean source of power. By converting sunlight into electricity, solar panels help reduce greenhouse gas emissions, air pollution, and reliance on fossil fuels, reducing the effects of climate change in the process. The cost of solar panels has been decreasing steadily over the years, making solar energy more affordable and accessible. The return on investment for solar panel installations can be significant, with long-term energy savings offsetting the initial installation costs. Ongoing research and development efforts have led to significant advancements in solar panel technology, resulting in higher efficiency levels and improved performance. This has further contributed to the cost reduction and increased the overall effectiveness of solar energy systems. Solar panels are designed to withstand various weather conditions and have a long lifespan, typically ranging from 25 to 30 years or more. Proper maintenance and regular inspections can ensure their optimal performance and extend their lifespan even further. Solar panels can be installed on various scales, from small residential systems to large-scale solar farms. They can be integrated into existing infrastructures, such as rooftops or solar carports. Many governments and organizations worldwide offer incentives, subsidies, and tax credits to promote the adoption of solar energy. These incentives help reduce the upfront costs of solar panel installations and encourage more individuals and businesses to embrace renewable energy solutions. Despite the numerous benefits, solar panel adoption faces challenges such as intermittency (as sunlight is not available 24/7), limited energy storage capabilities, and the need for suitable installation locations with ample sunlight exposure.

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