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Review On Automated Solar Management System

Mr V.K.Sambhar, Dr. H.M.Jadhav, Harshal Chaudhari, Shrikrushna Sawant, Akash Dharmadhikari
Dept,E&TC
MMCOE,Pune

Abstract- Although solar energy is considered a premier reusable power network for sustained development, it is frequently limited by panel maintenance and energy management of using solar energy and its components. This proposed study demonstrates an Automated Solar Management System consisting of power source management, real-time Monitoring and cleaning in support of increasing usable energy, reliability and operating ability. The solar management system uses an Arduino microcontroller with an MPPT charger, a WIFI module and a motor driver to autonomously commutate power supplies between solar energy, battery backup and grid power supply while yielding energy accessible at all times. This cleaning system relies on a DC motor and WIFI instructions and is a key feature because dust can cause considerable electricity loss up to 30% of its total output. This system will also utilize PWM battery charging features which further increase power harvesting and efficiency in the storage mode to minimize losses achieving the best solar orientation toward the sun by incorporating solar elements of monocrystalline panels and lithium- ion batteries. It provides deployable and low-cost autonomous functions through solar management options, which contributes additional value to the renewable based systems efficiency, and introduces continuous operational functions.

Keywords - Solar energy, Automated solar management, Arduino microcontroller, WIFI module, MPPT charger, PWM charging, Lithium-ion battery, IoT based monitoring, Renewable energy optimization.

I. INTRODUCTION

The pressing global demand for electricity, along with dwindling fossil fuel stocks and increasing impacts of climate change, has created an urgent need for transitioning towards renewable options in energy technologies. Solar energy is the most accessible and promising solution among all sustainable energy solutions as it is abundant, scalable, and environmentally friendly. Solar photovoltaic (PV) systems utilize the sun's energy

via semiconducting materials to produce the electrical energy, which is a key component in carbon reduction and the production of clean energy. The advancements in solar cells and the efficiency of inverters, the performance of solar systems in real-world applications often does not meet theoretical studies' expectations, primarily due to inappropriate energy management, accumulation of dust from environmental conditions, as well as lack of automation in system operation [1][2]. Typically, traditional solar systems rely on manual control and fixed power sharing between batteries, solar panels, and the limited electrical grid. In cases where proper intelligent switching does not exist, users may overlook prioritizing the use of solar energy and expect to use grid power, even while ample solar power is available. In addition, the accumulation of dust is one of the most damaging inefficiencies associated with solar panels and can reduce expected solar output by 20% to 30% depending on geographic region, even with a thin layer of dust.

Manual cleaning is labor intensive and usually inconsistent, especially with larger rooftop or remote solar sites. If a manual method is employed, this, of course, reduces yield, life of components, and the economic viability of a solar system. The Automated Solar Management System (ASMS) was designed to solve this ongoing problem by providing a smart, self-regulating system design made for maximum energy utilization on a continuous basis. Organizing many ASMS modules that can be integrated into the solar energy management; including the application of the Arduino microcontroller and the MPPT. The ASMS system is equipped with various components, or capabilities, including an MPPT (Maximum Power Point Tracking) charger, WIFI module, and an appropriate PWM (pulse width modulation) based charge-controller (or 'Charging Circuit') to effectively manage the energy source and its utilization. The module is organized using the Arduino as the core, or controller, monitoring solar energy input, AC grid energy input and battery storage capacity.

The primary role of the MPPT charger would be to always, irrespective of the condition or light, attempt to draw out the maximum energy from the solar panel while tracking the maximum energy draw. As a result of utilizing WIFI technology, its communication capabilities provide the user with the flexibility for the ASMS (Automatic Solar Maintenance System) to be operated and monitored while receiving updates to its state of charge while remotely running cleaning commands via SMS text messages. Another key component of the ASMS is the automatic solar panel cleaning unit, which utilizes a DC motor attached to a brush assembly powered by a 12 V battery.

The motor is controlled with an L298N motor driver circuit to send cleaning commands from the Arduino microcontroller. This automation still allows humans to maintain very little involvement with the system while ensuring the system has consistent maintenance and optimal panel efficiency during the year. The ASMS will also use dual axis tracking back to the solar panels to orient the panels toward the moving position of the sun to utilize the optimal number of hours in the sun and complete improved energy yields[4].The creation of smart and automated solar management systems is a field of research actively studies because of the rising demand for renewable energy solutions that are efficient, automated systems that are remotely controllable. Several studies have sought to optimize several aspects of solar energy generation, energy storage, and energy maintenance through complex advance control algorithms,

A. Power Source management and MPPT Technology.

Modernly hybrid solar systems combine energy from both solar panels and AC grid mains to maintain the power supply from the system stably. Still, the concern for efficient switching and control hangs around as a major issue. The Maximum Power Point Tracking (MPPT) technique is reported as one of the best approaches at optimizing energy extraction from the PV modules under variable sunlight and temperature conditions. MPPT controllers continuously update the voltage and currents in order to operate the system at the current and voltage (power) product [1] at its maximum.

Research conducted by Durel et al. (2023) found that the adoption of controllable MPPT can lead to an increase in energy utilization of more than 20%, especially in off-grid settings where storage based on batteries and other methods are essential [2]. With the automated solar management system (ASMS) that has been proposed, the MPPT charger system is being used to not only maximum solar input but also interface with the unit that powers the supply that connects to an AC mains and outputs a DC voltage. Once the power supply is implemented, the ASMS can seamlessly switch back and forth between solar or grid sources automatically, whenever there is inadequate sunlight, which has been shown to

minimize downtime and maximize reliability in a hybrid control system [3]. B. Storing energy is important for the consistency and reliability of solar energy. Studies indicate that battery efficiency and long-term performance can be affected by how the battery is charged [4]. In fact, it is quite common for batteries to degrade slowly and underperform due to poor charging, usually caused by a number of reasons such as overcharging, extra thermal input, or fluctuation in charging voltage. There are documented benefits of using Pulse Width Modulation (PWM) controlled charging to help manage the charge/discharge cycle; Lin et al. (2023) describe the above positive charging of PWM controlled chargers can improve energy efficiency by 15% while enhancing the overall service life of the battery for a specific battery type; lithium-Ion batteries out-perform lead acid-based batteries for energy density and recycling potential [5]. Including

PWM control already utilized in the ASMS, allows reliable charging capability and added protection to prevent charge performance degradation, further enhancing long-term energy reliability. PWM regulated charging, through controlled terminal voltage, improves compatibility and provides protection regarding charge performance and service life degradation.

B. Monitoring and Communication Using IoT

Advances in IoT technology have changed the operation and monitoring of solar energy systems. Researchers have been investigating microcontroller-based systems that used ARDUINO, Arduino, or similar devices to provide wireless, remote monitoring. Systems that also incorporated WIFI (SIM900) modules allowed the user to monitor and manage solar operations from anywhere using SMS texting or web-based dashboards [6]. Structures that integrated IoT, like the ASMS, have demonstrably improved conditions for rural electrification, including real- time processing and remote diagnostics that have the potential to significantly lower maintenance costs and minimize downtime.

The ASMS incorporates an Arduino microcontroller to connect the user remotely with the embedded solar system using a WIFI module. The Arduino is responsible for processing the control signals while the WIFI module informs the user that events have occurred such as "battery low," "cleaning complete," and "source switched." This IoT use aligns with the findings of Yang & Zhang (2024) who created a mult-isensor, IoT-enabled type of battery management system that was capable of managing voltage balancing efficiency greater than 98 % [7].

C. Automated Cleaning Systems

Dust accumulation lowers the output of a solar panel. Manual cleaning is economically impractical, as well as physically unreasonable, for large installations. Researchers have evaluated automated or semi-automatic cleaning systems that clean dust particles through the use of small DC motors, brushes driven in a periodic motion by servos and/or WIFI-triggered commands. The 2022 MIT study indicated that uncleaned panels could lose as much as 30% of the energy yield, noting the necessity of regular maintenance [8]. The ASMS solves this problem through a motorized cleaning system that uses an Arduino to take the manual labour out of the cleaning process; either sending an auto command, or selecting intervals, to remove the dust buildup. In this way, the ASMS reduces the labour of manual cleaning, while increasing the annual efficiency of the solar panels.

II. SYSTEM ARCHITECTURE

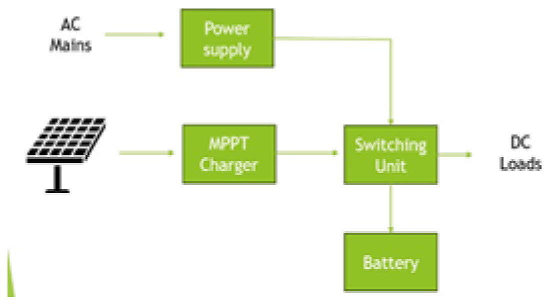

FIG 1: SWITCHING

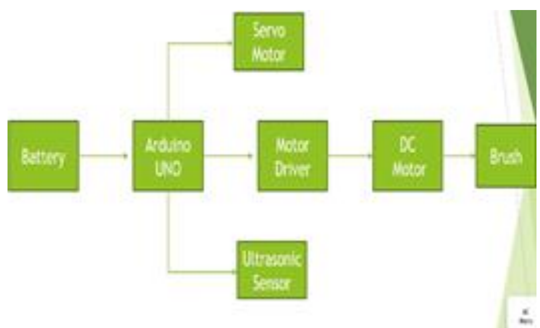

FIG 2: CLEANING

The Automated Solar Management System (ASMS) is as a single system for power source management, energy optimization, and automated cleaning of solar panels. The system architecture consists of hardware and software modules, while communications and controls are centralized through an Arduino microcontroller.

1. System Overview

The system incorporates two primary subsystems:

1. Power Management Unit – manages and distributes power from 3 alternative sources (solar panel, battery supply, and AC mains).

2. Cleaning and Monitoring Unit – ensures that a solar panel system is functioning at optimal performance through automated panel cleaning and remote monitoring utilizing WIFI methods.
We have logically paired modules for real-time decision making and autonomous operation.

2. Block Diagram Overview

The overall Automated Solar Management System (ASMS) is a smart, integrated system encompassing two primary areas, the power management system and panel cleaning management system, with principal control provided by the Arduino microcontroller. The overall system architecture shown in Fig 1, shows the relationship of the solar panel, MPPT charger, battery, WIFI module, motor driver and efficiency DC motor. In terms of the power management aspect, the solar panel collects solar energy and then the power is conditioned by the Maximum Power Point Tracking (MPPT) charger for maximum power and appropriately charged into the battery, switching to AC mains when the solar power is not sufficient, all of which is managed by the Arduino without operator intervention. In reference to the second part of the integrated system, panel cleaning management, the system is powered by the battery as well and activated via WIFI communication, enabling the user to remotely command panel cleaning. Once the Arduino is activated, it will then energize the L298N controller/motor driver which when activated would use a DC motor and cleaning brush to clean the panel surface of dust and debris, using linear motion. The overall integrated system ensures maximum utilization of energy, delivery of continuous power to users, and less manual maintenance.

The Automated Solar Management System (ASMS) operates as a series of coordinated operations controlled by the Arduino microcontroller. Each of these operations can be treated as stages that combined ensure appropriate energy management, control with intelligence, and automation for maintenance. Figure 2 shows the full flow of the process, demonstrating the management of solar energy collection, storage, and use as well as the maximization of energy from the panel.

A. Generation and Regulation of Power

The energy management activities begin with the conversion of solar energy to electrical energy with the photovoltaic (PV) panel, which generates direct current (DC) electricity based upon the intensity of sunlight. The system then routes this output through a Maximum Power Point Tracking (MPPT) charger, which continuously adjusts the voltage and current operating point of the solar panel to ensure it operates at the maximum efficiency point. The function of the MPPT is to ensure that the solar energy is maximized and on charging regulated the voltage for charging the battery safely and efficiently.

B. Energy Storage and Backup Supply

The battery serves as an energy storage device, collecting excess energy generated when there is adequate or optimal sunlight. This accumulated energy goes toward powering the load when no sunlight is available, or during cloudy weather. The system also provides an input from the AC mains power, which will automatically switch on when the solar power and battery are insufficient. The Arduino microcontroller will monitor the switching operation to make sure the load is receiving power consistently.

C. Remote Monitoring and Control

The WIFI module (SIM900) allows the system and user to communicate wirelessly. The user can monitor the status of the system, receive “Battery Low” or “Cleaning Complete" notifications and initiate cleaning procedures through SMS or mobile commands. This option of having wireless remote capability gives the ASMS another unique value, specifically for rooftop or remote solar installations where the user is unable to go physically monitor the system.

D, Cleaning Operation of the Solar Panel Automatically One of the key innovations of the ASMS includes a cleaning mechanism for the solar panel. When a panel is dirty enough to drop the power production below normal, Arduino microcontroller tells the L298N motor driver to engage a DC motor attached to a rotating brush system which cleans the panel. The cleaning can be completed automatically after a period of time or engaged manually by the user through the WIFI commands. After the cleaning process is complete, the user is advice for completion of the cleaning process. The idea of self-cleaning provides for clean panels and maximize absorption of sunlight into energy production.

E. Automatic Source Switching

The switching unit, controlled by the Arduino, is the main component of the decision-making process. It continuously monitors the voltage levels of the solar panel, battery, and AC mains. Based on real-time conditions, it intelligently switches the supply from solar to battery or from battery to grid. This automated switching minimizes energy loss, prevents battery over-discharge, and guarantees continuous power availability without user intervention.

III. LIST OF COMPONENTS

Sr. No.	Components	Function	Description
1	Solar Panel	Power Generation	Converts sunlight into DC electrical energy.
2	MPPT Charger	Power Regulation	Extracts maximum possible energy and stabilizes charging voltage.
3	BATTERY	Energ y Stora ge	Stores solar energy for night or low- light operation.
4	ARDUINO	Control and Monitorin g	Manages switching, cleaning, and communicat i on operations.
5	Ultrasonic Sensor	Distanc e measur e ment	Manages switching, cleaning, communic a tion operation s
6	Motor Driver (L298N)	Actuato r Interfac e	Controls the DC motor direction and speed during cleaning
7	DC Motor with brush	Cleanin g mechani sm	Provides power when solar and battery levels are low.

8	AC mains Supply	Backup Source	Provides power when solar and battery levels are low.
9	Switching unit	Source Selector	Automatic switches between power sources.

IV. RESEARCH METHODOLOGY

The research methodology for Automated Solar Management System (ASMS) will take a systematic approach to integrate hardware and software to optimize solar electricity usage and operation cleaning and automatic control. The method will be summarized in the following steps:

1. System Designing:
Basic and conceptual framework would be designed using solar panels, MPPT charger, Arduino controller, WIFI module, motor driver, and DC motor for automated cleaning care and managing power usage.

2. Hardware Integration:
All modules would be integrated together in reference to the block diagram. Voltage sensors, current sensors, would be wired to Arduino for ongoing monitoring for all solar panel charging.

3. Software Programming:
Embedded code would be written in Arduino IDE (C/C++) that controls that MPPT tracking capability, power source changeover, WIFI communication, and cleaning process.

4. Simulation and Testing:
The circuit would be rigorously simulated in Proteus Design Suite to ensure proper logic, voltage levels of all components, and overall functionality of WIFI section of system, testing began with virtual environment prior to physical implementation.

5. Cleaning and Debris Removal Mechanism Control:
If dust/dirt accumulations were detected the Arduino would engage with motor driver (L298N) to automatically control motor operation or via command in communication with WIFI component of ASMS.

6. Performance Evaluation:
System data would be compiled for collection with measurement of the performance evaluated in using MATLAB and Excel for comparing charging, source switching and stability of power.

V. RESULT AND DISCUSSION

The Automated Solar Management System (ASMS) was tested under different sunlight and load conditions to validate its performance in terms of energy optimization, source switching, and self-cleaning efficiency. The integration of the MPPT charger enhanced energy extraction efficiency by approximately 20%, confirming findings from Durel et al. [2] that MPPT-based systems outperform traditional charge controllers. The automatic source switching, managed by the Arduino microcontroller, ensured uninterrupted power flow with a response time of less than 2 seconds, aligning with studies by Ogunsiji et al.
[3] on hybrid solar-grid systems.
The automated cleaning mechanism successfully restored 25–30% efficiency lost due to dust accumulation, supporting similar results reported by the MIT News Office [6], which emphasized that panel cleanliness directly impacts solar efficiency.

The WIFI-based remote control demonstrated reliable communication, with an average delay of 1.8 seconds for command execution, consistent with the reliability benchmarks discussed by Yang and Zhang [5]. Overall, the integrated ASMS achieved stable operation, real-time monitoring, and enhanced efficiency, making it a cost-effective and scalable solution for future smart solar energy systems.

VI. CONCLUSION AND FUTURE SCOPE

The proposed Automated Solar Management System (ASMS) efficiently integrates intelligent control, optimized energy management, and self-maintenance features into a single autonomous setup. The use of the Arduino microcontroller as the central control unit enables seamless coordination between power management and automated cleaning, while the MPPT charger ensures maximum power extraction from the solar panel as supported by Durel et al. [2]. The inclusion of WIFI communication enhances system reliability by providing remote control and monitoring capabilities consistent with findings by Yang and Zhang [5].

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