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Original Article

An Energy Efficient Battery Management System using Pulse Width Modulation and Maximum Power Point Tracking

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Abstract - *In a recent invention, a Wireless Sensor Networking (WSN) node with low energy is given access to solar energy harvesting as an alternative power source. The industrialised nations conducting research can offer these solutions for issues with sustainable energy producers, like China, Finland, Mexico, the United States, and others. The WSN nodes can be rendered entirely autonomous using an indefinite network lifespan by utilizing rechargeable batteries, low-power energy harvester circuits, tiny solar panels, and low-power energy harvester control systems. The performance of one or more battery modules can be tracked, managed, and optimized, which is a crucial component of electric garage equipment. Another opportunity is knowing how to take one or more modules out of the device in case of a malfunction. The BMS, which is named for this management approach, is one of the crucial components of electrical equipment. A BMS's primary function is to keep a battery within a safe operating range of voltage, current, and temperature when charged, discharged, or in certain situations, even when an open circuit is present. Both internal and external events have an impact on the BMS. The automatic detection of COVID-19 patients using DCNN with X-ray imaging was discussed. This study uses a novel technique to identify COVID-19 from X-ray pictures automatically. It has been suggested to take untreated chest radiographs. The suggested approach is made to offer precise detection in instances including both binary and multiclass classification. Pulse Width Modulation (PWM) and peak energy factor tracking (MPPT) are technologies developed to boost PV system performance. In this regard, a combinatorial MPPT method based on SEH-WSN node modelling is described in this study.*

Keywords - *Active balancers, MPPT controller, Passive balancers, Solar energy harvesting, Wireless sensor networking node.*

1. Introduction

Solar energy is one of the most likely energy sources for everyday use [1, 2]. With the development of Photovoltaic (PV) panels, solar energy that is absorbed and converted into electrical energy is being used more and more frequently, which is advantageous to various people and organizations [3-8]. That is also owing to the abundance of accessible solar radiation available all across the earth. As a result of increased worldwide energy, the number of PV systems is rapidly expanding. Active balancers use unidirectional or bidirectional DC/DC converters in their design. During the charging/discharging, they can transmit energy between the cells in the battery pack [9, 10].

Heat loss is significantly reduced when compared to passive balancers. If the active balancer is appropriately designed and the stored energy within the rechargeable battery is successfully utilized, the gadget's operational period is not limited by the weakest cell [11, 12].

In its most basic form, a Battery Management System (BMS) only charges the batteries when empty and discharges them as needed to ensure they function correctly. It limits battery usage solely for battery safety: fast charging and discharging processes and exceeding minimum and maximum State-of-Charge (SOC) limits are prohibited [13]. The projection of demand and PV generation profiles improves BMS management [14].

Accurate information about production profiles, typically lacking, is required in this situation. The BMS has many measurement capabilities, including measuring current, voltage, temperature, and coulomb count. These metrics allow the system to evaluate the battery's health and adjust activities to safeguard the package. For instance, a decline in cell voltage at a specific load can indicate high internal resistance. It might indicate dryness, corrosion, plaque separation, or another diagnosis. If the battery temperature rapidly increases, there may be heat loss in the battery assembly. The user may resolve any possible issues before they become out of control thanks to the BMS's ability to interrupt the energy flow and alert users to potential issues.

The adjustable width solar charge controller directly connects the solar panel and battery and only requires a "quick switch" to configure or regulate it. Process management. Battery, charger, and solar power. The switch (transistor) remains open until the battery reaches the absorbed charge voltage. To regulate the current and maintain a consistent Battery Voltage (BV) switches open and close quickly (hundreds of times per second) [15]. According to the Maximum Power Point Tracker (MPPT) monitor, a charge controller significantly more sophisticated than the controller, solar panels can operate only at grid-compatible voltages and currents. Typically, another test; more of it. An MPPT solar charge controller can be up to 30% more efficient than a traditional controller, depending on the solar panel's battery type and operational Voltage (Vmp) [16]. Coulomb counting is the quickest way to determine a battery's State of Charge (SOC) [17, 18]. The approximate Coulomb counting equation, shown in Figure 1, calculates SOC recursively. The Coulomb counting approach, however, is vulnerable to the following error: The first SOC error. Because it is recursion integration, any errors in the original SOC concept would continue to produce distortions [19, 20].

The most recent calculation was inaccurate; measuring noise contaminates power sensors; simple, affordable current sensors are likely to be noisy and probably erroneous, presenting integration mistakes. A straightforward [21, 22] rectangular approximation is used for current integration in Coulomb counting methods. As the load fluctuates quickly, such an approximation produces mistakes that worsen the sampling interval [23, 24]. The current capacitor performance, which is susceptible to temperature variations, how it is used, and how much time has passed (battery age), is assumed to be ideal by the Coulomb counting approach [25]. If there is any inaccuracy or drift in the timing oscillator, the measured Coulombs will change.

The following are the research article's significant contributions and innovations:

- Using the Pulse Width Modulation (PWM) control technology, MATLAB/Simulink is used to construct a new 3.6-volt concentrated solar power battery charger.
- PWM control technology is used to implement a unique solar battery charger hardware.
- The invention declaration is based on solar panels or PWM-driven DC-DC converters in conjunction with a Commercial WSN Trainer Kit.
- The use to develop a solar energy harvester system that charges a 3.6-volt bank is claimed to be creative. This battery is rechargeable, and it powers the WSN node.

The remainder of this paper is organized as follows: A brief review of the literature is presented in Part II. The proposed framework is described in Part III, experimental results and comparative analysis are presented in Part IV, and our proposed work is concluded in Part V.

2. Literature Review

A new wireless sensor network architecture was presented by [26] to enhance the power management of IIoT (Industrial Internet of Things) devices that run on heat rather than batteries. These IIoT gadgets will aid major energy-intensive businesses in digitization by helping them be environmentally friendly [27]. The finest fusion technology for utilizing industrial waste heat to build battery-free, maintenance-free IoT devices is the combination of energy harvesting with IoT. I have reviewed several energy extraction techniques for low-power wide area networks. The advancement of IoT architecture and associated advantages have accelerated the development of wireless technologies for machine-to-machine communication.

A review based on Battery Management System (BMS) advances and industry standards was presented. A BMS responds to both internal and external events. With the appropriate safety precautions within a system, it is used to enhance battery performance. As a result, operating an electrical system requires a safe BMS [28, 29]. It covers various BMS-related topics, concerns with BMS safety, component functionality, topology, operation, and operation. A low-cost, open-source BMS prototype that can track variables such as voltage, current, temperature, and charge state for batteries with up to 10 serially connected cells was proposed by [30]. The development process considers the hardware and software needed for fundamental BMS activities. The lithium-ion 18650 and sodium-nickel chloride cells are the two cell types utilized in the proposed BMS. The BMS's versatility is highlighted by its flexibility in using these two technologies.

A standard framework for a cloud-based BMS using an end-to-end cloud architecture was put forth, along with descriptions of the design and functionality of each link. Cloud-based BMS uses a STRAIN (Decentralized Network and Interoperability Network) structure to distribute information at various scales. More advanced and effective algorithms can carry out the X-state estimation, heat management, cell balancing, diagnosis of fault, and other functions of conventional BMS systems [31, 32]. By allowing on-the-fly data storage to provide insights into micro-evolution and effective visualization, smart battery monitoring and management platforms can aid in creating control methods-battery power. [33, 34] developed a reliable non-linear equivalent circuit mathematical model for a hybrid system connected to photovoltaic cells. The suggested nonlinear controllers are produced using the sliding mode techniques [35].

Load limitation, battery management control, and maximum power extraction are all features of the proposed control algorithm for the slip collector. In order to get as much energy out of the photovoltaic system as feasible, the reference current is produced. The suggested controller is optimized using several operating modes by preset or defined battery charge limits, discharge current limitations, and State of Charge (SoC).

There is a different control algorithm for every mode. This study suggests an MPPT-based pulse width modulation and battery management system. It uses Pulse Width Modulation (PWM) control technology to construct a brand-new 3.6-volt concentrated solar battery charger. One hardware version of the solar battery charger is made using the PWM control approach.

The current innovation is based on solar cells, PWM-controlled DC-DC converters, and commercial WSN actuators. Using a solar harvester to build a 3.6-volt bank would be wise. An external battery that may be recharged powers the WSN node.

2.1. Solar Energy Harvest Wireless Sensor Network

In order to enhance battery performance and maintain maximum power production, a novel Solar Energy Harvest Wireless Sensor Network (SEH-WSN) is proposed in this section. Using silicon Photovoltaic (PV) cells as a renewable energy source, charging stations and solar chargers with energy storage systems and battery banks have been built. and batteries as sources of energy.

In order to operate at their maximum power under all irradiance and temperature conditions, the PV modules are connected to a Maximum Power Point Tracker (MPPT). Battery temperature, DC, and voltage are all measured by the BMS. The BMS prevents abnormal battery degradation due to improper charging patterns, overcharging, undercharging, and abnormal temperatures by continuously calculating the SOC to estimate the remaining charge of the store.

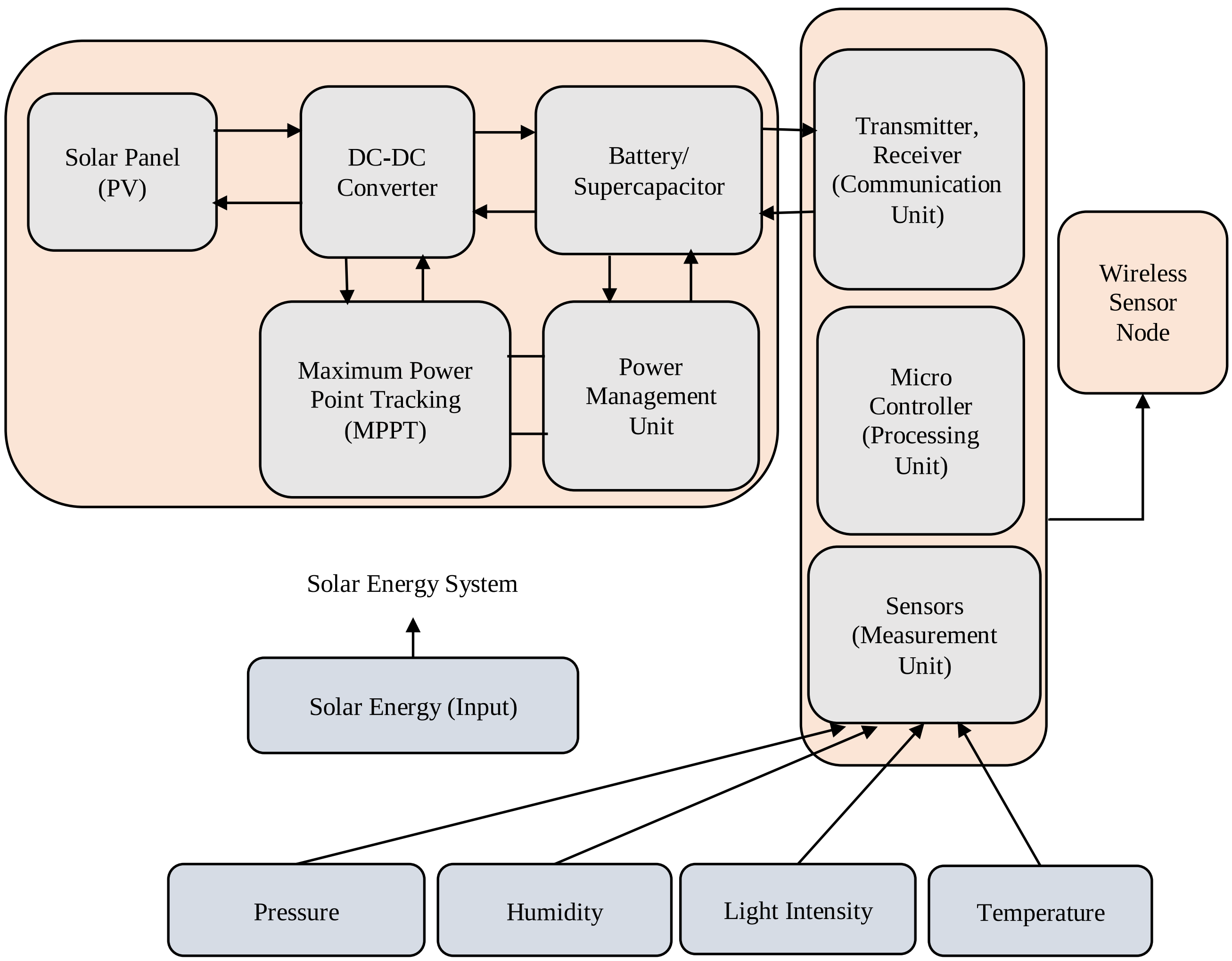


Fig. 1 Solar energy harvest wireless sensors network

Figure 1 depicts the internal schematic diagram of a SEH-WSN module. The WSN module gets a DC power source from the solar energy-harvesting system (Tektronix, Inc., Beaverton, OR, USA, 3.6 volts). Solar panels are used to gather this electricity from background sunlight. The solar cell converts power instantly from the sun into DC electricity. In addition to recharging batteries, the DC-DC converter adjusts the voltage level [36, 37]. A transmitter unit wirelessly sends the measurable or detected data based on data packets to a neighbouring network node. Cluster head nodes transmit data from the end nodes to the USB gateway node.

In a future city, the user will eventually be able to monitor and control the enrollment process remotely, such as manufacturing boiler plant control, temperature monitoring, forest monitoring, controlling the cooling system of an air conditioner, glacier monitoring, volcano supervising, battlefield monitoring applications and traffic signal management [38].

WSN stations can be powered by an energy-harvesting device that converts solar radiation into electricity. Understanding the schematic of a typical solar energy harvesting system is necessary to recognise the effectiveness and functionality of solar-powered network elements in Figure 2. The DC-DC conversion, Power converter control unit, power storage unit (rechargeable batteries or strong capacitor), solar panel, and energy storage unit protective circuit are the main components of solar energy harvesting [39]. For obtaining maximum solar power under all illumination situations, MPPT would be a commonly used method in solar energy [40, 41].

Depending upon that current and real-time voltage from the solar panel, the MPPT controller decides the duty cycle to apply to the DC-DC converter's switching mechanism. The Perturb & Observe (P&O) method is a widely used algorithm for the MPPT mentioned above techniques in all sun harvesting applications [42-45].

By comparing the extracted power, this approach adjusts the voltage level. An application calculates electricity by detecting the voltage and current of solar panels at predetermined intervals. After a long time, power is calculated using the same process as previously.

2.2. PWM Efficiency

The optimum wattage of the solar panel in our scenario was set to 4W. When using PWM control, a specific solar panel can only create 3.5W of power at its peak. As a result, its PWM efficiency can be calculated using the following formula:

$$\eta_{PWM} = \frac{P_{PWM}}{P_m} \tag{1}$$

DC/DC Buck Converter Efficiency is,

$$\eta_{buck} = \frac{P_0}{P_0 + P_{loss}} \tag{2}$$

Overall energy harvester systems efficiency using PWM and DC/DC Buck is as follows,

$$\eta_{sys} = \frac{(\eta_{buck}) + (\eta_{PWM})}{2} \tag{3}$$

The efficiency of the MPPT controller is defined as,

$$\eta_{MPP} = \frac{P_{MPP}}{P_m} \tag{4}$$

Overall energy harvester systems efficiency using MPPT and DC/DC Buck is as follows,

$$\eta_{sys} = \frac{(\eta_{buck}) + (\eta_{MPP})}{2} \tag{5}$$

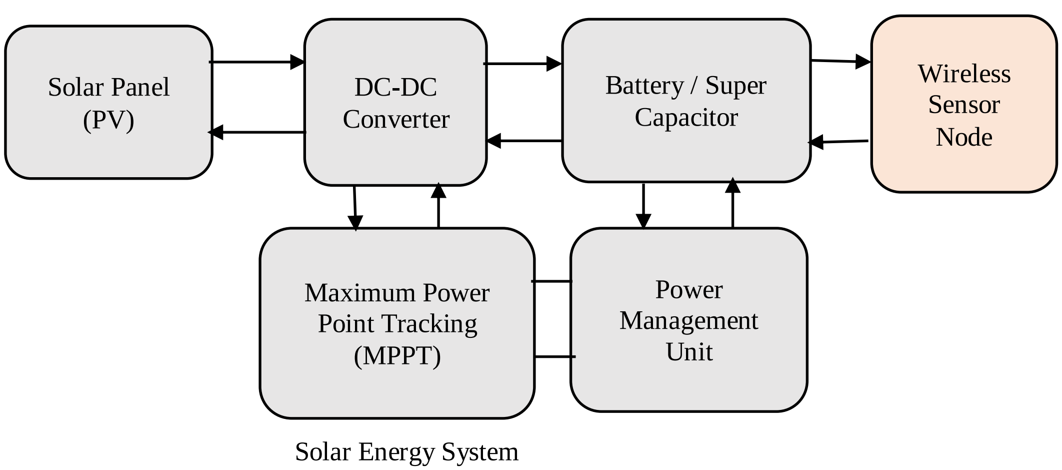


Fig. 2 SEH system components

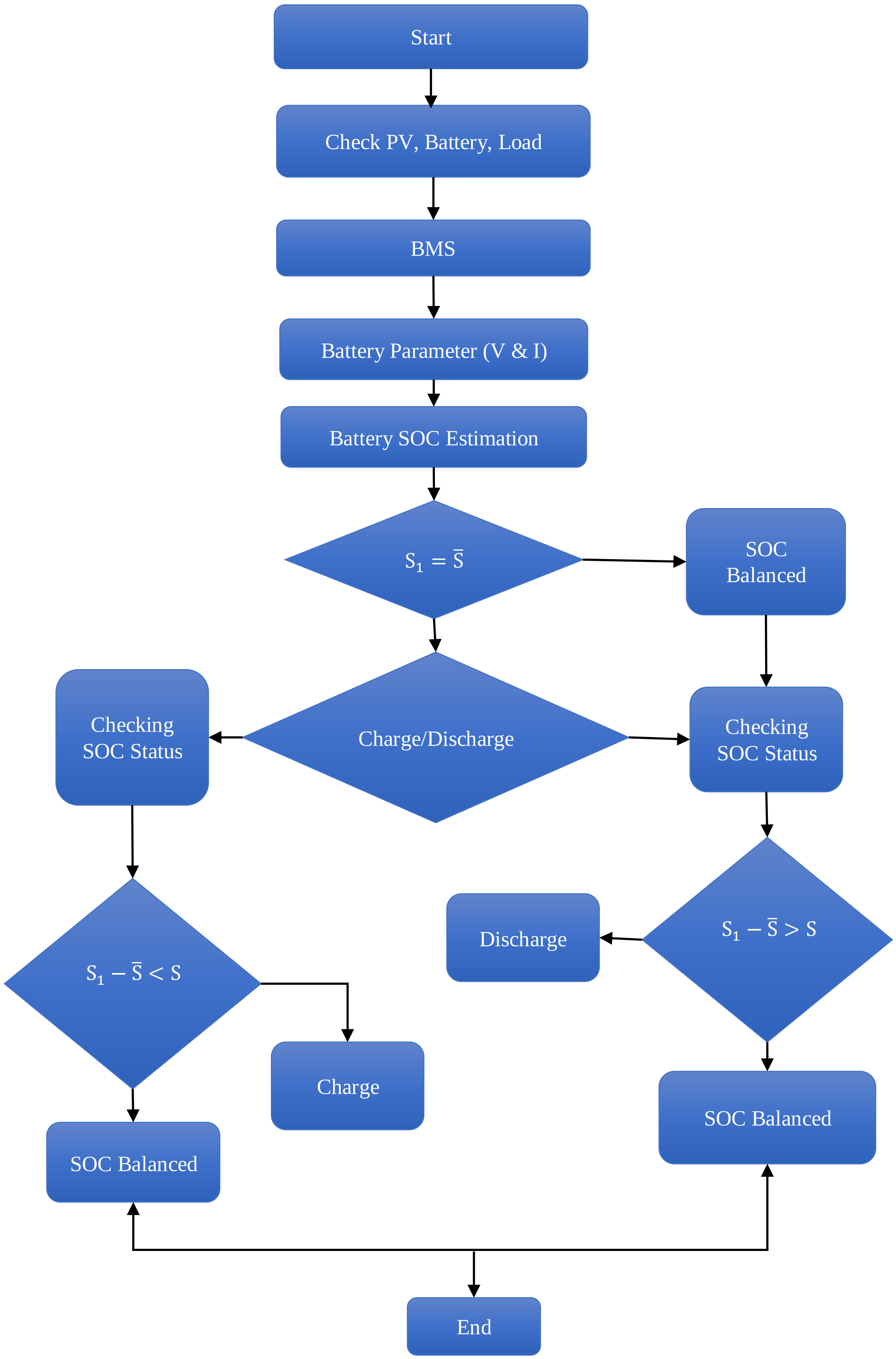


Fig. 3 Planned BMS flowchart

2.3. Efficiency of P&O MPPT

When using P&O MPPT, a solar panel's output can reach a maximum of 2.9 watts. The following equation is currently used to calculate the P&O maximum power point tracking's overall effectiveness:

The effectiveness of maximum power point tracking is,

$$(\eta_{MPP}) = \frac{P_{MPP}}{P_m} \quad (6)$$

Overall energy harvester systems efficiency using MPPT and buck is as follows.

$$(\eta_{sys}) = \frac{(\eta_{buck})+(\eta_{MPP})}{2} \quad (7)$$

Figure 3 exposes the flow chart for the planned BMS.

3. Results and Discussions

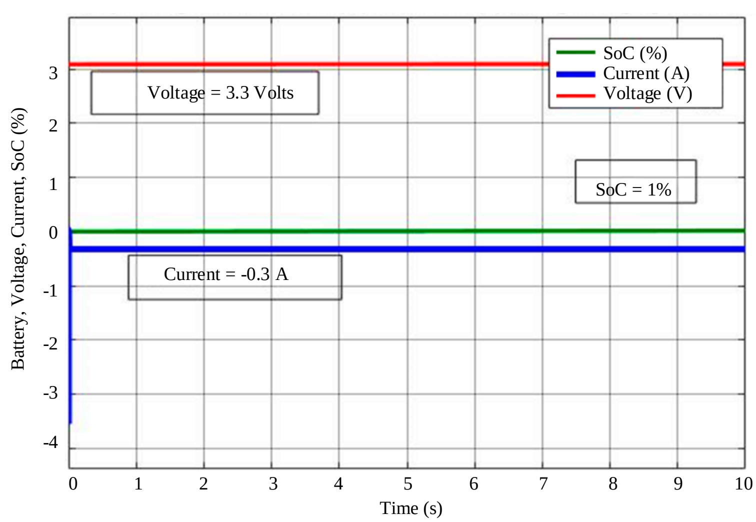
The proposal offers a practical solar energy harvesting solution towards the WSN nodes' limited energy storage issue. This method makes use of solar photovoltaic energy that is already there. The SEH-WSN nodes will never stop functioning in a perfect world. For WSN nodes, we provide a brand-new, effective MPPT and pulse width modulated solar energy collecting method in this work (PWM). Figure 4a shows the charge State of Charge (SoC), storage power, and voltage level for the PWM-controlled SHE battery charger throughout one simulated time of 10 s. Batteries have a SoC that varies between 0% and 1%. Comparatively, Figure 4b displays the battery current and voltages for the solar energy harvesting battery charger SoC with MPPT control during a simulated period of 10 seconds.

The battery SoC is between 0 and 5%, higher than the results of 10 seconds of PWM control (i.e., 1 percent only). In Figure 5a, 10% of the total value of the battery SoC is reached. for a longer simulation time (T = 100 s). However, in Figure 5b, the MPPT results for a 100-second simulation duration show the battery SoC at 50% instead of the outcomes achieved for PWM control in Figure (i.e., 10 percent only). When the battery is being charged, the current is negative, signifying that the battery's electrochemical cells are oxidising. However, as the battery is being discharged, the current is positive, signifying that the battery's electrochemical cell is going through a reduction process.

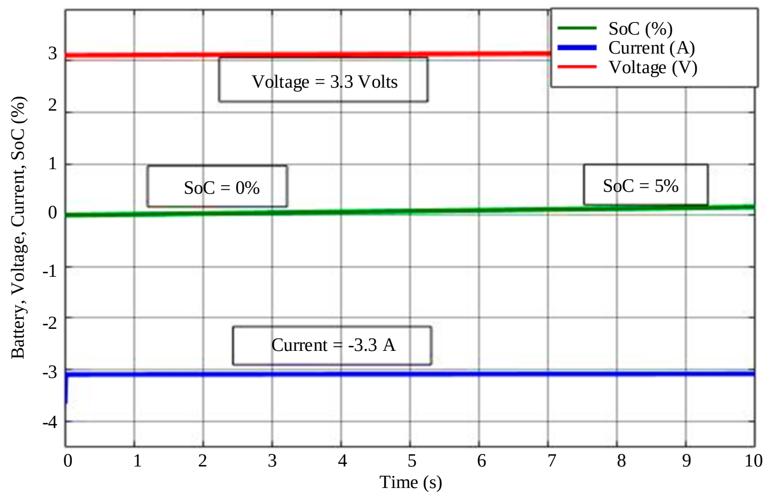
Last but not least, in Figure 6a, the battery SoC could only achieve 30 percent in the 200 s simulation. However, the SoC battery in Figure 6b achieves 95 percent of its capacity in fewer than 200 simulation seconds. As a result, battery charge duration is dynamically extended via installing MPPT-controlled SE gathering equipment for WSN nodes. By controlling the energy of the photovoltaic system connected to the grid (Ali et al. 2022), an overall efficiency of 88% has been achieved.

In hybrid microgrid environments, using innovative battery-supported energy management systems for the Efficient Management of Weak Power [20] achieved 91.23% efficiency. [33] achieved a 92.4% efficiency using a Sliding mode control with robust nonlinear controller architecture for improved battery performance in photovoltaic battery-tied hybrid systems.

[36] achieved 93.81% efficiency using intelligent battery management system algorithms and control strategies such as development, issues, and prospects. The efficiency would be increased widely from 88% to 95.21% by various researchers. We have achieved a new peak efficiency of 96.06% in our proposed system using PWM and MPPT in an energy-efficient battery management system.

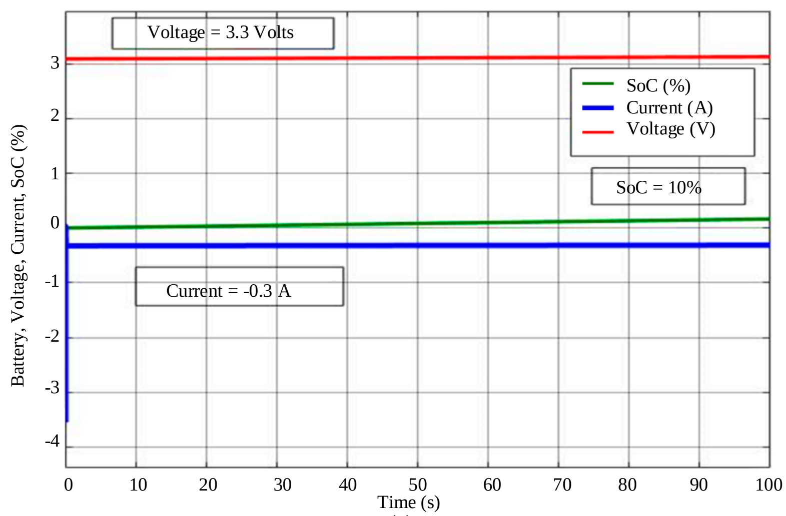


(a)

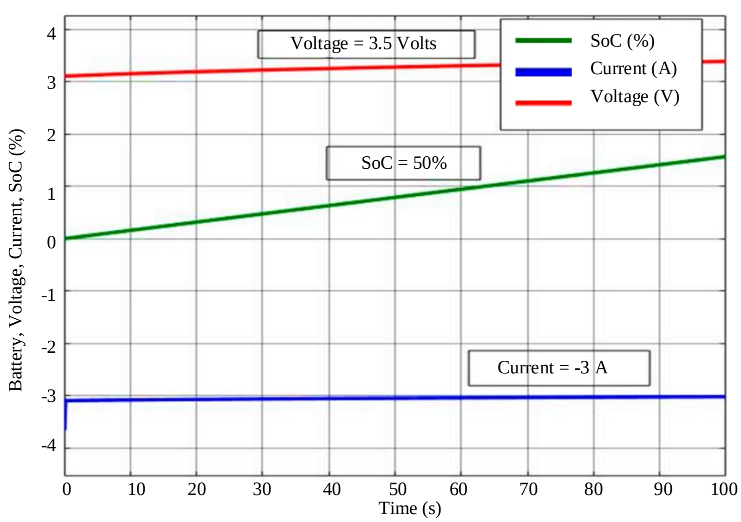


(b)

Fig. 4 Simulation results of SEH system for 10 seconds under PWM and P&O MPPT control. Current while charging, Battery SoC (BSoC) and voltage with PWM control BSoC while charging, voltage and current with P&O MPPT management

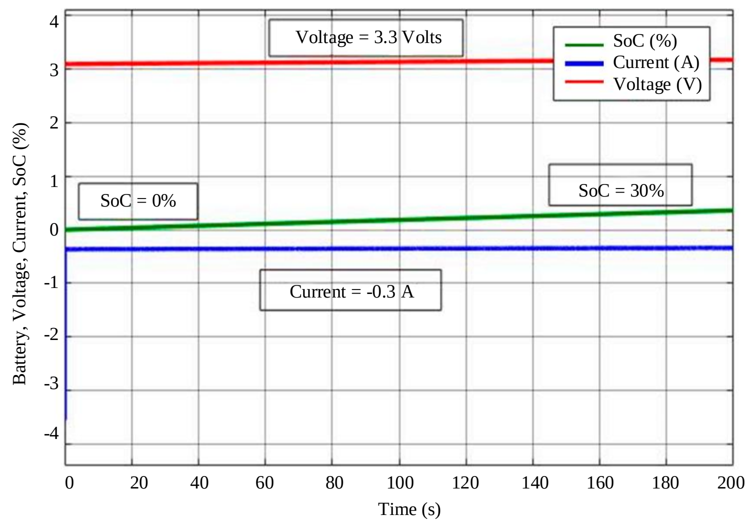


(a)

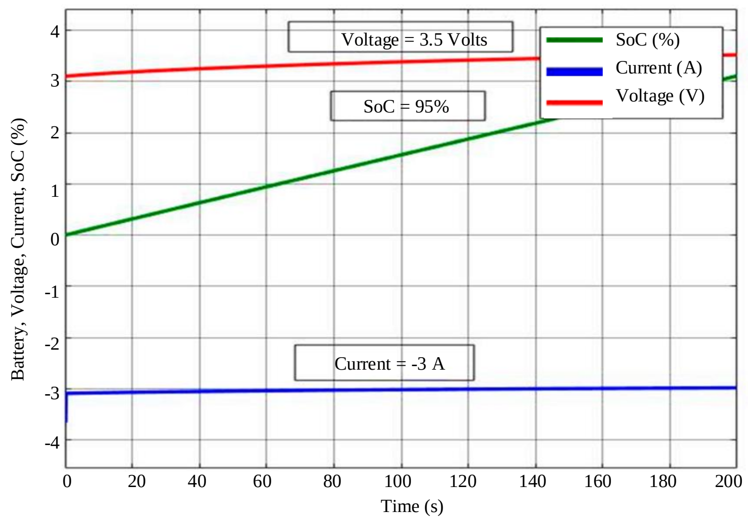


(b)

Fig. 5 Results of a 100-second simulation of a solar SEH system with PWM and P&O MPPT control BSoC, voltage and current (a) during charging with PWM control. Current BSoC and voltage, and (b) during charging with P&O MPPT control



(a)



(b)

Fig. 6 Simulation results of a 2000s solar SEH system controlled by PWM and P&O MPPT. BV, current and SoC (a) while feeding by PWM control, BV, current and SoC, and (b) while feeding by P&O MPPT control

4. Conclusion

An optimal photovoltaic harvester machine was examined on network elements employing MPPT was built and simulated using MATLAB/SIMULINK. The MPPT-based harvesting mechanism starts charging at rapid speeds. As the battery charges, the SoC and terminal voltage begin to rise. The sum of the performance of the MPPT and the Boost converter yields the efficiency of the energy harvesting circuit (η_sys). This study uses SEH-WSN node modelling, simulation, optimization, and a hardware experiment. To use a MATLAB simulation, PWM and MPPT are two types of solar energy harvesting system controls that have been researched and evaluated. The MPPT-controlled buck converter's efficiency is demonstrated to exceed its PWM-controlled alternatives. Voltage graphs for the battery SoC and terminals have been shown. By combining the effectiveness of the Step-Down converter, PWM, and MPPT, the total energy harvester circuit effectiveness (η_sys) is determined. Measurements on the SoC and node voltages of the battery have already been provided. When the PWM efficiency, buck converter performance, and MPPT performance are added, the entire energy harvesting system effectiveness η_sys is calculated. According to simulation results, the MATLAB/SIMULINK model's Produced good quality Solar Energy Harvesting effectiveness (96.06 percent) was higher than PWM-controlled system performance (87.76 percent). A SEH-WSN component's actual technology development used a PWM-controlled buck converter to detect ambient temperature wirelessly.

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