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Portable Photovoltaic System for Charging and Micro-Scale Heating

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***Abstract*— Emboldened by the continually increasing demand for sustainable and portable energy resources, the development of solar-based systems in a compact fashion for use in off-grid systems has also evolved. This paper addresses the design and experimentations carried out on a solar-powered heating and charging station, which is further connected with a 10Wp solar PV panel, a 12V/24V solar charge controller, a 12V Lithium-Ion battery, and a nichrome wire heating element. In the proposed system, solar radiations are initially converted to electrical energy, which then goes through regulation and further energy storage for later use. This stored energy can further be used for charging small electronic devices, such as mobile phones, and producing heat through Joule heating. This heating device can further be used for heating small amount of water, through a properly controlled process. Some experimental results have demonstrated that the working of the proposed system largely depends on the solar radiation intensity and the connected loads. Although it provides a lower power conversion, this design provides an efficient use of solar energy in a compact, portable manner, which can be used in an educational setup or in a disaster management scenario.**

***Keywords*— Portable solar system, Photovoltaic energy, Solar heating and charging, Renewable energy, Nichrome wire, Lithium-ion battery.**

I. INTRODUCTION

Modern energy access remains a critical challenge for approximately 80 million refugees, as camp infrastructure often cannot support basic needs like lighting, communication, and cooking [1]. Traditional cooking methods using firewood or charcoal are not only time-consuming and tedious but also contribute to deforestation and present severe health and safety risks to women and children [1]. While fixed microgrids provide robust power, they require permanent infrastructure, and standard solar home systems are typically limited to low-power devices [1]. To bridge this gap, research has focused on developing portable photovoltaic power stations that offer microgrid-level power with the flexibility of personal systems, capable of meeting a family's full range of energy needs in humanitarian or rural off-grid contexts [1], [5]. Recent technological advancements have further enhanced these portable systems by incorporating smart features and improved efficiency. For example, some designs now utilize Internet of Things (IoT) technology to allow users to remotely monitor and control parameters like voltage, current, and AC load in real-time [4].

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Other innovations include single-axis solar tracking systems that can increase generated power by over 60% compared to fixed panels by following the sun's path throughout the day [5]. Additionally, multipurpose units are being developed for specific needs, such as portable cooling and heating devices that use Peltier modules to replace bulky, environmentally unfriendly compressors and refrigerants [3]. These integrated systems provide sustainable, environment-friendly power solutions for diverse applications, including disaster relief, camping, and emergency home backup [2], [4].

II. Literature Review

Kanagamalliga et al. [6] provides a research work based on solar energy offers a sustainable way to charge phones, cutting dependence on conventional power. MPPT and smart regulators improve efficiency under changing sunlight. Portable solar chargers with proper battery management are vital for off grid and emergency use.

Rajasekaran et al. [7] provides research on adoption of the thermoelectric cooling method which gives an effective way of conserving medicines, particularly in cases where the use of electricity is a constraint. Based on the knowledge of the Peltier effect, the improvement of solar batteries, as well as batteries, these units are effective in their use for cooling purposes. Some challenges exist in the use of the current devices, which are not portable, thus the development of new ones that are smaller in size compared to the previous designs.

Viveka et al. [8] studied that solar power banks are environmental-friendly options rather than traditional normal charging devices. This includes solar cells, batteries, and converter systems that allow reliable energy supply with the function of wireless charging. To meet growing demand, their size is reduced in order to cover wireless and AC charging functions of portable devices.

Seddegh et al. [9] studied latent heat storage in solar water heating to improve efficiency and temperature stability. Phase change materials were highlighted for maintaining consistent heat during variable solar input. Key challenges include cost, durability, and effective heat transfer. Rekstad et al. [10] analyzed passive houses with different heating systems. Results showed solar heating reduced energy use more effectively than air–water heat pumps. The study underscores how heating choices influence efficiency in low-energy homes.

Kok et al. [11] developed a portable solar wireless charger featuring an STM32 microcontroller and a 6500 mAh battery. The system utilizes a P&O MPPT algorithm alongside a three-stage charging process to maximize energy extraction while protecting battery health. Their results confirm that integrating magnetic induction allows for efficient, cable-free charging suitable for mobile devices in remote areas.

Patil et al. [12] made a grid interactive photovoltaic system designed with a PIC16F877A microcontroller aims to ensure even power supply between a solar panel and a lead acid battery. A buck converter is used to ensure that charging takes place at an unchanged voltage, thereby offering an uninterruptable power supply to the load despite variation in solar insolation levels. This approach brings to focus the importance of grid backup throughout this concept. Nurwidiana et al. [13] design an off-grid rooftop solar system for independent electric vehicle charging in Indonesian households. The study determines that a 4-kW system, supported by 36 battery units and a 4000-watt inverter, successfully meets daily mobility energy demands. Their results highlight the feasibility of decentralized solar energy to provide clean, reliable vehicle charging while significantly reducing carbon emissions.

Malinowski et al. [14] gives a review of solar photovoltaic systems and related power electronics from Malinowski et al. discusses research that addresses the growing shift towards renewable energy resources due to the greater cost-effectiveness of photovoltaic systems, especially with regard to domestic and industrial applications. However, a major challenge associated with this shift is related to storage and management of energy. Dlamini et al. [15] optimized off-grid PV plants by combining automatic solar tracking with an Efficient Power Regulating (EPR) system. Their research shows that integrating tracking with advanced battery management can increase energy efficiency by up to 50%. The study highlights the necessity of real-time power regulation for maintaining reliable autonomous energy systems. Wang et al. [16] presented a photovoltaic and battery-based energy system that provides reliable power storage and supply for standalone solar applications. Chakraborty et al. [17] developed a solar-powered energy harvesting system that efficiently utilizes available sunlight to operate low-power portable electronic devices.

III. Problem Statement

The growing use of low-voltage photovoltaic (PV) systems has increased the need for compact and efficient power electronic interfaces for 12V/24V applications. In remote and off-grid locations, access to reliable electricity remains a major challenge for communication and basic thermal requirements. Existing portable solar systems mainly focus on either electrical charging or heating applications individually, creating limitations in practical usage. Therefore, this research aims to develop a compact photovoltaic-based system capable of providing both electrical charging and localized heating using a single renewable energy source Existing solutions often face challenges related to size, efficiency, and power management. In addition, micro-scale heating loads require optimized power delivery to achieve effective localized heating. Therefore, there is a need to develop a miniaturized power electronic interface that improves energy conversion efficiency and enhances the performance of micro-scale heating systems.

Hence, the objective of this work is to design a compact power electronic interface for low-voltage PV systems and improve the efficiency of micro-scale heating loads used in localized heating applications.

- Efficiency Maximization: The project would be designed with the aim of achieving the highest efficiency in the conversion of sunlight to electricity by the solar panel while using the waste heat at the same time for increased efficiency beyond what would be experienced with the separate units.
- Sustainability: Creating an environment-supportive energy solution based on the sustainable energy principle of utilizing a non-polluting sustainable resource, such as the sun, instead of fossil fuels or non-rechargeable batteries.
- Off-Grid Charging: To empower a constant source of 5V electricity through USB to power small electronic gadgets like phone, tablets, and power banks, wherever regular power points are unavailable.
- Localized heating: This is useful for the production of useful thermal energy for simple heating applications such as heating a small amount of water or supplying a small amount of localized heat without depending on fuels from outside sources.

IV. Methodology/Experimental

Based on study of the literature review of the existing system on Solar application, A compact Portable Photovoltaic Charging with Microscale heating System has been proposed to address the limitation of portability, dual functionality and off-grid energy accessibility. The system consists of 10 W solar panel,12V lithium-ion battery, USB charging ports and a nichrome coil in a single setup. The solar energy stored into battery for continuous operations. The stored power is utilized for charging low-power electronic devices and generating localized heat which is regulated through the charge controller. The solar energy captured from the sunlight efficiently convert into electrical as well as thermal energy without any emission for the purpose of charging small devices and to heat a microscale water. The main purpose of this research is to develop an eco-friendly, User affordable and a portable system which can be easily handle by everyone and anywhere.

A. System Design

Fig.1 Solar panel

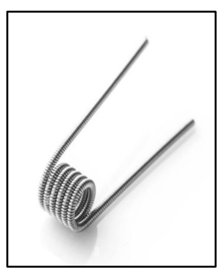

Fig.2 Nichrome coil

Fig.3 Rechargeable battery

Fig.4 USB cable

Fig.5 Charge controller

A Solar Panel of power 10W (Fig. 1) is employed as the major power source. The panel is responsible for harnessing solar power to produce electricity with an output voltage of 12V, ideal for charging a battery with a voltage of 12V through a charge controller (Fig. 5). The 12V battery (Fig.3) and solar charge controller ensures proper power control and protection against reverse flow, deeper discharge, and overcharge of the battery. The USB cable (Fig.4) ensures a constant output of 5V and is hence utilized for charging low-power gadgets. The nichrome wire coil (Fig.2) acts as a heating element and converts electrical energy into heat energy by utilizing the heating effect of resistive materials. The Lithium-ion battery works as a power source when there is less sunlight.

B. Mathematical Models and Governing Equations Used in the System

The output power of a solar panel is calculated by multiplying its voltage and current, expressed in Equation (1)

$$P = V \times I, \quad (1)$$

where P=power, V=voltage, I=current.
To find the output current of the panel, you divide the rated power of the panel by its operating voltage using the formula (2)

$$I = P/V. \quad (2)$$

The energy storage capacity of a battery connected to the system is calculated with (3)

$$E = V \times Ah, \quad (3)$$

which gives the total energy in watt-hours. Here, V is the battery voltage and Ah stands for its ampere-hour capacity. When electrical energy passes through a nichrome wire used as a heating element, heat is produced due to electrical resistance. This heat energy is calculated using (4)

$$H = I^2Rt, \quad (4)$$

where I is the current, R is the resistance of the wire, and t is the time the current flows. The power dissipated in the heater is given by (5)

$$P = I^2R, \quad (5)$$

showing how much electrical power converts into heat at any moment.
To assess the thermal performance of the system, the heat needed to raise the temperature of water is calculated with (6)

$$Q = mc\Delta T, \quad (6)$$

where m is the mass of water in kilograms, c is the specific heat capacity of water (4186 J/kg·°C), and ΔT is the change in temperature. The heating efficiency of the system is determined by comparing the useful heat gained by the water to the electrical energy supplied, expressed as (7)

$$\eta = (Q\ \text{useful} / E\ \text{input}) \times 100, \quad (7)$$

where efficiency is a percentage.
Finally, the battery charging time can be estimated using (8)

$$t = Ah/I, \quad (8)$$

where t is the charging time in hours, Ah is the battery capacity, and I is the charging current. Together, these equations give a clear understanding of electrical power generation, energy storage, heat production, and efficiency in a solar-based heating system. This knowledge is important for practical applications.

V. Circuit Diagram

The system consists of a solar panel and solar charge controller with two USB ports that can be used to recharge low-power gadgets such as mobile phones. This is where the low-power gadgets such as the mobile phone will be connected for charging, hence the flexibility of the system. The 12V Lithium-ion battery is connected to the battery terminals of the charge controller. This can be the charge controller that manages the storage of the energy in the form of rechargeable batteries and prevents the batteries from being overcharged or deep-discharged in the case of the Lithium-ion battery. The nichrome coil functions as the heating element and is connected to the load terminals of the charge controller. Whenever there is power, the coil turns the electrical energy into heat energy.

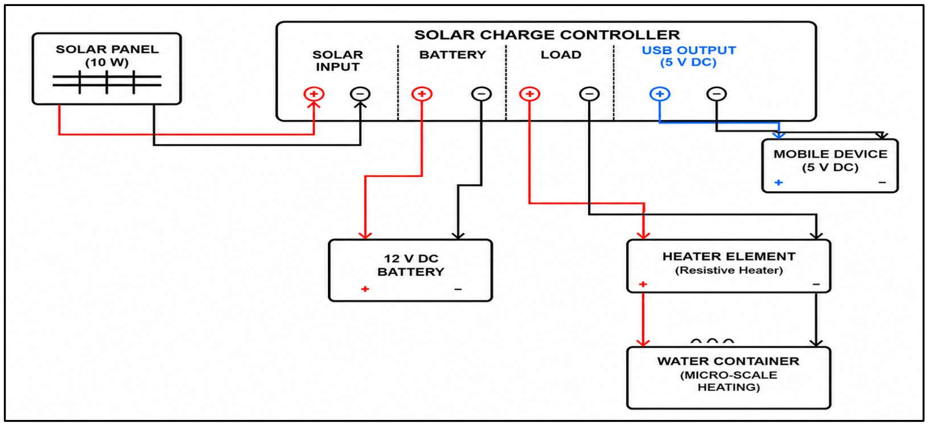

Fig.6 Block Diagram of system

VII. Comparison of Proposed System With Other Systems

The proposed system mainly focuses on portability and cost effectiveness. Most of the existing systems focuses only on either Charging application or heating application. while this system provides both photovoltaic charging and microscale heating in a single compact setup. This research follows a human-centric approach by combining both features to support people in areas where electricity access is limited or unavailable. The system becomes more energy-efficient, eco-friendly, and practical for real-life applications. The proposed research provides an innovative solution by giving dual output, this makes the system more energy-efficient, portable, eco-friendly, and suitable for rural and smart-energy applications, by providing better practical applications and higher system performance than existing models. This makes the proposed model more useful and adaptable compared to conventional existing systems.

VIII. Results and Discussions

Fig.7 shows the relationship between the heating of the coil with respect to time. It can be observed that the temperature of heating element increases with higher sunlight availability. The graph validates the effectiveness of the proposed system.Fig.8 represents the portability of the system. The prototype demonstrates the practical implementation of the proposed design for outdoor and rural applications. Fig.9 shows the initial connections of the proposed system where solar panel and battery is connected to a charge controller.Fig.10 represents the demonstration of mobile charging through the proposed system which also shows the reading of voltage output on charge controller and USB port of charge controller provide a stable DC output suitable for charging.

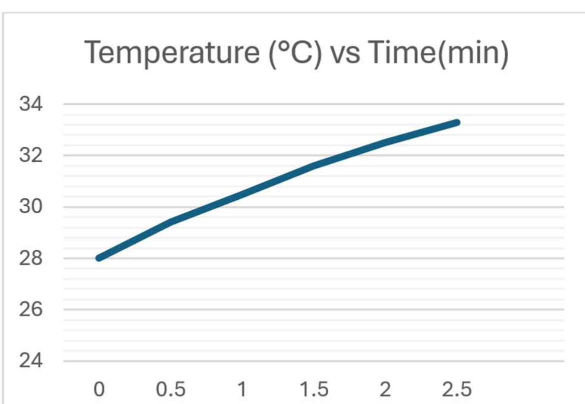

Fig.7 Thermal performance

Fig.8 Overall Setup

The solar charging and heating system also functioned properly in the project. The 10W solar panel was an effective means of providing the needed power to charge the 12V lithium-ion battery, owing to the solar charge controller. The solar charge controller was an extremely effective device in charging the battery, ensuring the supply of volts and currents of safe ranges to the battery.
The electricity stored in the battery powered the nichrome heating element. The Nichrome heating element provided a source of constant heat due to the resistive heating process. In addition to that, there were two ports on the charge controller. These ports provided a constant source of 5V DC voltage in the circuit. The device assisted in the charging of gadgets like phones.
From the above result, it can be seen that the system has the capability to integrate solar power generation, energy storage, heating, and USB charging. The capacity to enable all these processes at once can be regarded as effective in performing the duties of a renewable energy system.

Fig.9 Initial connections

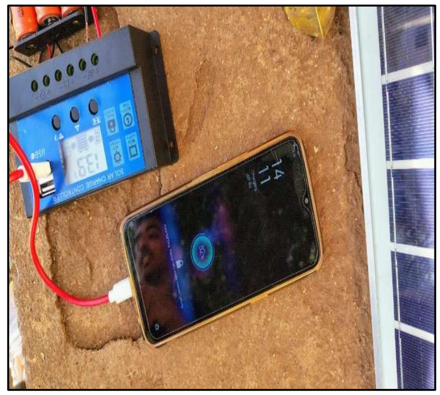

Fig.10 Mobile Charging

IX. CONCLUSION

The importance of this project is that it provides an explanation of how a solar charging system and a heating system can be designed and integrated. The solar system employed in this design is a renewable source of energy and generates electricity using a solar panel with a rating of 10W. The electricity is regulated by a solar charge controller and is further stored in a battery with a rating of 12V and which is made up of lithium-ion. The battery is able to supply electricity to a nichrome heating element, which is connected to the load terminal of the charge controller, and also supply regulated voltages of 5V that can be used to charge any device.
From the experimental results, it is confirmed that the system is reliable and functioning well, and managing the battery is also safe and effectively transferring the electrical energy into thermal energy. The proposed system acts as an eco-friendly and economically viable option for small-scale and off-grid use. This project aims to emphasize working with solar energy to fulfil different applications and adds in developing systems related to renewable energy resources.

FUTURE SCOPE AND FINDINGS

The experimental evaluation of the proposed Portable photovoltaic system confirmed that integrating solar power generation, battery-based energy storage, resistive heating, and USB charging within a single compact unit is practically achievable at a small scale. To improve the performance of the system we can use MPPT (Maximum Power Point Tracking) into the charge controller that would improve energy extraction across varying irradiance and temperature conditions beyond what conventional PWM-based controllers can achieve. Also, we can add IoT monitoring feature that can be help to understand the real time data, means current charging state, panel voltage, heating element temperature, and USB current. A solar tracking setup, either single-axis or dual-axis, can also be implemented to maximize solar exposure throughout the day and increase overall energy generation. In addition, integrating a thermoelectric module would make it possible to support both heating and cooling functions using the same system, increasing its versatility. By using the panel with high power and high battery capacity can lead to a great result overall. And also, adding phase change material (PCM) as a thermal storage medium will help retain heat energy for longer durations, even after sunlight is no longer available, thereby enhancing overall energy utilization and system effectiveness.

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