International Journal of Scientific Research and Engineering Development-– Volume 9 Issue 5, Sep-Oct 2026
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Design and Implementation of an IoT Enabled Solar Powered DC Cooking System

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Abstract:

Reliance on wood, charcoal, fossil fuels and grid dependent electric cookers contributes to indoor air pollution, deforestation, and unreliable energy access, particularly in off grid and rural communities. This paper presents the design, implementation, and experimental evaluation of an Internet of Things (IoT)-enabled solar powered Direct Current (DC) cooking plate developed as a sustainable, remotely monitored alternative to conventional cooking systems. The prototype integrates a 420 W photovoltaic (PV) array, a solar charge controller, a 12 V/7 Ah auxiliary battery, a 12 V/200 W DC heating element, current, voltage and temperature sensing circuits, a power MOSFET switching stage, and an ESP32 microcontroller that provides local display through a liquid crystal display (LCD) and remote monitoring and control through a Wi-Fi based IoT interface. Design calculations were used to size the heating element, sensing circuits, switching device, battery, DC-DC converter, and photovoltaic array, and the resulting prototype was assembled and tested. Experimental results obtained over two independent monitoring periods show that the system continuously acquired and transmitted voltage, current, instantaneous power, and accumulated energy readings to the IoT platform, confirming correct operation of the sensing, switching, and communication subsystems. The results demonstrate the feasibility of combining solar energy harvesting with IoT based monitoring and control for low voltage DC cooking applications and indicate the need for extended field trials to characterize long term performance.

Keywords — **DC cooking plate; ESP32 microcontroller; Internet of Things (IoT); remote monitoring and control; renewable energy; Solar energy.**

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I. INTRODUCTION

The continued reliance on traditional cooking methods based on wood, charcoal, and fossil fuels carries severe environmental and health consequences. Combustion of these fuels releases large quantities of greenhouse gases, drives deforestation through demand for firewood, and exposes users, particularly women and children in poorly ventilated kitchens to indoor air pollution linked to respiratory disease, eye irritation, and circulatory problems [1]. Transitioning to cleaner cooking methods is therefore critical for both environmental sustainability and public health.

Solar energy offers a clean, abundant, and renewable alternative capable of reducing dependence on finite fuel resources. Solar cooking technologies exploit photovoltaic (PV) conversion or concentrated solar thermal energy to heat food, lowering the carbon footprint of cooking while extending access to underserved communities that lack conventional energy infrastructure [2], [3].

Electric hotplates are portable appliances that convert electrical energy into heat for cooking and conventionally operate on alternating current (AC) drawn from the utility grid [4]. In regions with unstable electricity supply, this dependence causes frequent interruptions, higher energy costs, and continued reliance on kerosene, charcoal, and firewood, with the associated pollution and health risks [5].

Direct Current (DC) hotplates powered by solar energy present an alternative that removes the dependence on grid electricity: such appliances can be operated directly from batteries charged by PV panels, offering reduced running costs, improved efficiency, portability, and suitability for off grid and rural use.

Integrating Internet of Things (IoT) technology into a solar powered DC hotplate adds a further layer of intelligence and automation. This paper presents such a system: an IoT enabled hotplate that can be monitored and controlled remotely from a smartphone, tablet, or computer, allowing the user to switch the appliance on or off, monitor temperature and battery status, and receive safety alerts from any location, thereby improving convenience, safety, and energy efficiency [6].

Conventional electric and gas cookers remain widely used despite their high energy consumption, reliance on non renewable resources, and contribution to air pollution and climate change; unreliable grid supply in many regions further compounds these problems. This work addresses these challenges through the design and implementation of an IoT enabled solar powered DC cooking plate that harvests solar energy for cooking while providing real time remote monitoring and control of the cooking process, optimizing energy use and improving user convenience.

The remainder of this paper is organized as follows. Section II reviews related literature. Section III presents the system design and implementation. Section IV discusses the experimental results, and Section V concludes the paper with recommendations for further work.

II. Literature Review

A. Overview of Enabling Technologies

The system draws on a number of established technologies, summarized in Table I, each of which contributes a specific sensing, control, or communication function to the overall design.

TABLE I Overview of Enabling Technologies

Component	Role in the Present System	Ref.
Internet of Things (IoT)	Enables real time remote monitoring, control and data driven optimization of the cooking plate via Wi-Fi	[7]
ESP32 microcontroller	Dual core processing, analogue/digital I/O, and integrated Wi-Fi/Bluetooth for sensing and communication	[8]
Photovoltaic (PV) panel	Direct conversion of solar irradiance into DC electrical power	[9]
Battery management system (BMS)	Protects the battery from overcharge, deep discharge and thermal stress while tracking state of charge/health	[10]
DC hotplate	Resistive heating element operated directly from low voltage DC without AC conversion losses	[11]
Current / voltage sensors	Non-invasive electrical parameter sensing for monitoring and protection	[12]
Relay / MOSFET switching	Electrically isolated switching of the heating load under microcontroller control	[13]
Liquid crystal display (LCD)	Local visual feedback of system parameters	[14]
Solar charge controller	Regulates PV to battery charging and protects against over/under voltage	[15]
Thermocouple temperature sensor	Wide range, self-powered temperature measurement of the cooking surface	[16]

B. Related Works

Rao et al. [17] investigated parabolic solar cookers for high temperature cooking, achieving temperatures of up to 200°C suitable for frying and baking; however, the system required precise solar alignment and was unsuitable for indoor or low light use, motivating designs — such as the present one — that combine IoT enabled adaptability with operation independent of continuous manual tracking.

Khan et al. [18] developed a portable solar cooker with an automated sun tracking mechanism based on light dependent resistors (LDRs) and a microcontroller, reporting a 25% efficiency improvement over fixed position cookers. The tracking mechanism, however, increased system cost and complexity while still depending on direct sunlight, suggesting the need for lower complexity, cost effective alternatives such as the IoT based approach adopted in this work.

Lakshminarayana et al. [19] designed and developed a solar electric hybrid heated bed smart electric stove supplied by approximately 300 W of solar power and a 12 V lead acid battery, with a control system to regulate heating. Testing under real cooking conditions produced satisfactory cooking time and energy consumption, demonstrating the feasibility of solar battery powered electric cooking, particularly for rural and off grid locations. The present study shares the use of PV energy, a 12 V battery, and heat regulation, but extends this work with ESP32-based IoT monitoring and control.

Atmane et al. [20] realized an autonomous solar powered heating plate using 600 W of PV capacity, dual DC/DC converters, twin thermal resistance heating elements, solar batteries, and a digital control unit that acquired meteorological, thermal, and electrical parameters both locally and remotely. Under an illumination of approximately 1115 W/m² and 22°C ambient temperature, the system delivered about 464 W of electrical power, reached a heating element temperature of approximately 700°C, boiled one litre of water to 90°C in 20 minutes, and heated 0.5 litres of oil to 270°C in 60 minutes. Unlike this high-power system, the present study is designed around a lower voltage 12 V DC architecture with an ESP32 microcontroller, dedicated voltage/current/temperature sensing, a relay/MOSFET switching stage, an LCD, and smartphone based IoT monitoring, extending prior work toward low voltage DC operation and remote observability.

III. SYSTEM DESIGN AND IMPLEMENTATION

A. System Architecture

The system consists of a PV array, a solar charge controller, a battery management system (BMS) with an auxiliary battery, a buck (DC-DC) converter, current, voltage and temperature sensing units, an ESP32 microcontroller, an LCD display, a Wi-Fi based IoT interface, a MOSFET switching stage, and a 200 W DC hotplate. Fig. 1 shows the overall system block diagram.

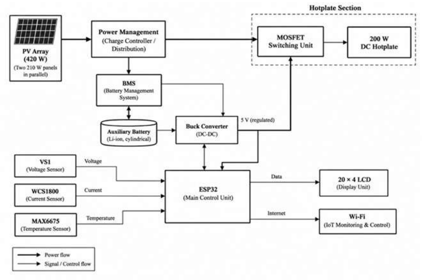

Fig. 1. Overall system block diagram.

The PV array converts solar irradiance into DC power that is regulated by the charge controller before being used to charge the battery and supply the load. The ESP32 acquires voltage, current, and temperature readings, displays them locally on the LCD, and transmits them to the IoT platform over Wi-Fi. When a user command is received (through the mobile/web interface) or a safety condition is detected, the ESP32 drives the MOSFET switching stage to connect or disconnect the heating element accordingly; the plate is automatically disconnected if the measured temperature exceeds a preset limit and reconnected once the temperature falls below the threshold, improving safety and prolonging component life.

B. Component Sizing and Design Equations

The cooking plate is a 12 V, 200 W DC resistive heating element. Its operating current and resistance are obtained from

$$I = \frac{P}{V} = \frac{200}{12} = 16.67\text{ A} \quad (1)$$

$$R = \frac{V^2}{P} = \frac{12^2}{200} = 0.72\ \Omega \quad (2)$$

A WCS1800 Hall effect current sensor (range ±35 A) was selected for non-invasive current measurement. Applying a 25% design margin to the operating current gives the design current:

$$I_{\text{design}} = I_{\text{load}} \times 1.25 = 16.67 \times 1.25 = 20.84\text{ A} \quad (3)$$

which lies within the ±35 A range of the sensor. Voltage measurement uses a resistive voltage divider (VS1) sensor, whose output is given by

$$V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{(R_1 + R_2)} \quad (4)$$

Temperature is measured with a Type K thermocouple interfaced through a MAX6675 module (range 0–1024°C, 0.25°C resolution) communicating with the ESP32 over SPI. The ESP32 microcontroller (3.3 V, 80 mA) has an estimated operating power of

$$P_{\text{ESP32}} = VI = 3.3 \times 0.08 = 0.264\text{ W} \quad (5)$$

and the LCD (5 V, 100 mA) requires

$$P_{\text{LCD}} = VI = 5 \times 0.1 = 0.5\text{ W} \quad (6)$$

A power MOSFET switches the heating current. Applying the same 25% design margin,

$$I_{\text{switch}} = I_{\text{load}} \times 1.25 = 16.67 \times 1.25 = 20.84\text{ A} \quad (7)$$

so a MOSFET rated at 30 A or higher was adopted. Summing the estimated power of the ESP32, temperature interface, LCD, current sensor, and switching/support circuitry gives the total auxiliary load,

$$P_{\text{aux}} = 0.264 + 0.100 + 0.500 + 0.100 + 0.500 + 0.500$$
$$= 1.964\text{ W} \quad (8)$$

to which a 30% design allowance is applied,

$$P_{\text{aux,design}} = P_{\text{aux}} \times 1.30 = 1.964 \times 1.30 = 2.553\text{ W} \quad (9)$$

giving a total system design load of

$$P_{\text{total}} = P_{\text{hotplate}} + P_{\text{aux,design}} = 200 + 2.553 = 202.55\text{ W} \quad (10)$$

For a 4-hour auxiliary operating period, the required auxiliary energy and corresponding battery capacity at 12 V are

$$E = P \times t = 10.212\text{ Wh} \quad (11)$$

$$C = \frac{E}{V} = 0.851\text{ Ah} \quad (12)$$

A 12 V, 7 Ah battery was adopted, providing considerably more capacity than the theoretical auxiliary requirement:

$$E_{\text{battery}} = V \times C = 12 \times 7 = 84\text{ Wh} \quad (13)$$

A buck converter steps the 12 V battery voltage down to the 5 V required by the sensing/display circuits, with an ideal duty cycle of

$$D = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{5}{12} = 41.7\% \quad (14)$$

Applying a 25% design margin to the total system load gives the minimum required PV capacity,

$$P_{\text{PV,min}} = P_{\text{total}} \times 1.25 = 202.55 \times 1.25 = 253.19\text{ W} \quad (15)$$

for which a single 420 W panel was adopted. Using a mean daily solar radiation of 5.21 kWh/m²/day (representative of the deployment location), the daily energy yield of the panel is

$$E_{\text{PV}} = P_{\text{PV}} \times \text{PSH} = 420 \times 5.21 = 2.19\text{ kWh/day} \quad (16)$$

The corresponding PV charging current and design current for the charge controller are

$$I_{PV} = \frac{P_{PV}}{V} = 35 \text{ A} \quad (17)$$

$$I_{CC} = I_{PV} \times 1.25 = 43.75 \text{ A} \quad (18)$$

for which a 60 A charge controller was adopted, providing adequate margin above the calculated design current. Table II summarizes the resulting design ratings of the major components.

TABLE II COMPONENT RATINGS AND DESIGN SUMMARY

Component	Design Rating
DC cooking plate	12 V, 200 W
Cooking plate operating current	16.67 A
Heating element resistance	0.72 Ω
Current sensor	WCS1800, ±35 A
Voltage sensor	Resistive divider (VS1)
Temperature sensor / interface	Type K thermocouple / MAX6675
Microcontroller	ESP32, 3.3 V
Display	5 V LCD
Switching device	Power MOSFET, ≥ 30 A
Battery	12 V, 7 Ah
DC–DC converter	12 V to 5 V buck converter
Solar panel	Single 420 W panel
Charge controller	60 A
Design auxiliary load	2.55 W
Total design load	202.55 W
Adopted PV capacity	420 W

C. Hardware and Software Implementation

The 12 V DC cooking plate and its MOSFET switching circuit were assembled first, followed by the WCS1800 current sensor (placed in the heating element current path), the voltage divider circuit (connected across the system bus), and the Type K thermocouple/MAX6675 interface (positioned at the cooking surface and connected to the ESP32 via SPI). The LCD was interfaced to the ESP32 for local display, while the 12 V battery, charge controller, and PV array were connected to supply the system, with a buck converter providing the regulated 5 V rail. Fig. 2 shows the system circuit diagram.

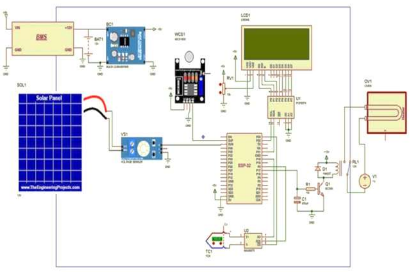

Fig. 2. System circuit diagram.

The ESP32 firmware initializes the peripherals and Wi-Fi connection, then cyclically reads the voltage, current, and temperature sensors, updates the LCD, transmits the measurements to the IoT platform, and generates the switching command for the MOSFET. Protective logic disables the plate, displays an alert, and sends a notification to the IoT platform if the battery voltage falls below a set threshold or the plate temperature exceeds a set limit. Fig. 3 shows the software flowchart.

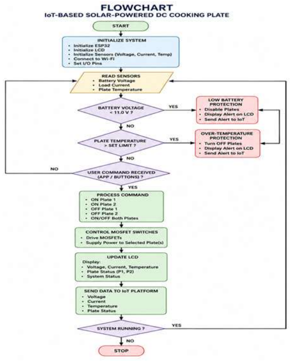

Fig. 3. Software flowchart of the IoT based solar powered DC cooking plate.

The IoT interface receives system voltage, heating element current, plate temperature, and heating status from the ESP32 over Wi-Fi, allowing the operating condition of the plate to be observed remotely and complementing the local LCD readout. Fig. 4 shows the constructed prototype.

Fig. 4. Constructed prototype of the IoT based solar powered DC cooking plate.

IV. RESULTS AND DISCUSSION

The developed system was subjected to experimental testing to evaluate its electrical monitoring and control performance. Voltage, current, instantaneous power, and accumulated energy were logged through the IoT interface over two separate test periods, summarized in Table III.

TABLE III EXPERIMENTAL TEST PERIODS

Test	Start Time	End Time	Duration
Test 1	12:40:52 PM	12:41:26 PM	34 s
Test 2	12:44:39 PM	12:45:18 PM	39 s

Fig. 5 plots the voltage, current, instantaneous power, and accumulated energy recorded during the two tests. In Test 1, voltage declined steadily from 10.60 V to 9.40 V while current rose from 1.76 A to 2.21 A; in Test 2, voltage remained comparatively stable (5.25–5.32 V) while current varied between 2.00 A and 2.20 A. The difference between the two ranges indicates that the tests captured different monitored electrical conditions, while the smooth, low noise trends within each test confirm that the voltage- and current sensing circuits reliably tracked and reported their respective quantities through the IoT interface.

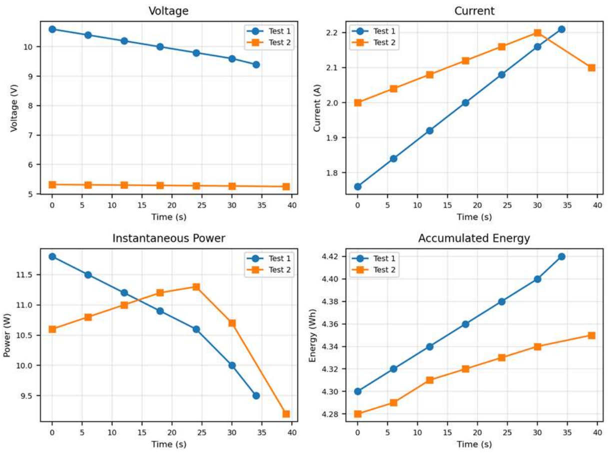

Fig. 5. Voltage, current, instantaneous power, and accumulated energy recorded during the two experimental test periods.

Instantaneous power varied between 9.5 W and 11.8 W in Test 1 and between 9.2 W and 11.3 W in Test 2, consistent with the corresponding voltage and current trends; these values reflect the specific electrical conditions captured during the short test windows and should not be interpreted as the rated 200 W load of the cooking plate. Accumulated energy increased monotonically throughout both tests (4.30–4.42 Wh in Test 1 and 4.28–4.35 Wh in Test 2), confirming that the monitoring subsystem correctly integrated power over time. Taken together, the results verify the functional operation of the sensing, switching, display, and IoT communication subsystems, although the short (34–39 s) duration of the recorded tests limits their use for characterizing daily solar yield, battery autonomy, or long duration cooking performance.

V. Conclusion and Recommendations

An IoT based solar powered DC cooking system was designed, implemented, and experimentally evaluated. The prototype combines a 420 W PV array, a 60 A solar charge controller, a 12 V/7 Ah auxiliary battery, a 12 V/200 W DC cooking plate, voltage, current, and temperature sensing, a MOSFET switching/protection stage, an ESP32 microcontroller, an LCD, and a Wi-Fi based IoT interface. Component sizing was established from first principles electrical calculations, and the resulting design was implemented and tested.

The experimental results confirmed that the system could acquire voltage and current measurements and derive corresponding power and accumulated energy values, communicating them through the IoT interface, while temperature monitoring and switching control supported safe, regulated operation of the cooking plate. The system therefore met its principal design objectives and demonstrated the feasibility of an IoT enabled, solar powered DC cooking approach. However, the short duration of the recorded tests (34 and 39 seconds) means the results mainly validate immediate sensing and control functionality rather than long term solar yield, battery autonomy, or cooking performance.

Based on these findings, the following are recommended for future work: (i) conduct long duration testing under varying weather and operating conditions to obtain representative daily yield and battery autonomy data; (ii) enhance the IoT platform with historical data logging, trend visualization, and automated alerts for abnormal voltage, current, or temperature readings; (iii) further optimize temperature based automatic control to reduce unnecessary energy consumption; (iv) incorporate additional safety features such as over/under voltage protection and automatic shutdown under abnormal conditions; and (v) evaluate the system with real cooking loads under varying conditions to quantify heating time and practical energy consumption.

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