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Development Of An Innovative Solar Powered Portable And Modular Stove

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Abstract *- The project aims to integrate solar energy with contemporary cooking systems to alleviate the burden of high transportation costs for Liquefied Petroleum Gas (LPG) cylinders in the eastern and north-eastern regions of India. This burden is exacerbated by specific socio-economic and geographical factors, making transportation costs sometimes exceed the price of the LPG cylinder itself in certain areas of our country. We aim to create a modular multipurpose cooking appliance that operates on a battery, which is charged through solar photovoltaic cells. The primary motivator for our project is the significant increase in solar energy production achieved in a relatively short period. Our system features three compartments for different purposes, depending on the type and amount of food to be cooked. Resistance coils built into the body of the cooker heat the stove, delivering 200 Watts of power. Furthermore, we have cooked food on the designed stove and analysed the data obtained. The satisfactory results regarding the cooking duration for different types of food have led us to conclude its effectiveness for households in distant rural areas of the country.*
Keywords – LPG, Solar energy, Photovoltaic cells

INTRODUCTION

India has rapidly become a leader in renewable energy and is actively expanding its solar power production [1]. We are endowed with abundant sunlight year-round due to its favourable geographical positioning in the Northern hemisphere [2]. Despite being located in this hemisphere, India's unique climatic conditions create a semi-tropical environment throughout the subcontinent, ensuring a consistent supply of sunlight. Leveraging these geographical advantages, we propose a novel approach to cooking through the creation of a modular, insulated solar electric device that operates on photovoltaic energy. We seek to harness renewable energy sources effectively while addressing the cooking needs of households accustomed to LPG gas stoves. This paper delineates our strategy to design a solar electric stove that is user-friendly, compact, portable, and cost-effective, catering to the diverse requirements of Indian consumers. By incorporating renewable energy technologies into daily cooking methods, we aim to create a sustainable and eco-friendly approach to food preparation in India.

LITERATURE SURVEY

Solar-based cooking has enormous potential to address the demand for clean cooking by decreasing energy usage and enhancing both environmental quality and public health. The cookers that allow for the direct application of solar energy for cooking purposes are called solar cookers. Arunachala & Kundapur (2020) have shown different types of cookers [3]. The cookers are commonly classified as tube, panel, box, and parabolic cookers. Some particular designs are difficult to classify in these categories. Box solar cookers are among the most widespread and used devices. They usually consist of a thermally insulated box having a transparent element on the top and reflective panels to direct sunlight into the cooking chamber (Tiwari & Yadav, 1986) [4]. A. Lamkaddem, N. EL Moussaoui et al. highlight about the stoves powered by stored batteries. Here, the emphasis is made that the stoves can work irrespective of the weather conditions when the energy is supplied from the power reserves stored in the battery [5]. S. Siddiqua; S. Firuz et al. also emphasise more on both on grid and the energy stored in batteries through photovoltaic cells [6].
India is set to become a major power in the 21st century. Many individuals have emerged from poverty, turning them into stakeholders in the country's growth. It is the fifth largest economy [7] and will steadily increase its share the world's economy. An economy can thrive by advancing its secondary sector, which includes manufacturing and industry. Investing in this area boosts productivity, creates jobs, and drives

economic growth, ultimately leading to improved living standards [8]. This step will demand a large amount of energy to be produced in the country. Most of the energy is being produced through fossil fuels. The energy production in the country is increasing every year [9]. Electricity is among the most efficient forms of energy. The peak electricity demand in India in 2015 was 180 GW [10], while in the year 2022-23, it rose to 417 GW, reflecting an average growth rate of 9.78%. [10], [11]. The demand in electricity will also increase steadily in the journey of growth and development of India in the coming years. There are also many other drivers for this growth, like the usage of clean energy resources and the promotion of Electrical vehicles [12]. Simultaneously, India aims to boost energy output by significantly enhancing the generation of green energy [13]. Based on the availability of land and solar radiation, the potential solar power in the country has been assessed to be around 220MW per square kilometre, with an estimated number of more than 280 sunshine-lit days available annually [14].
The Indian government has set a target of 60 GW to be installed through solar power by 2022 under the National Solar Mission (NSM) [15]. The target is planned to be achieved through various policy decisions and schemes such as the Scheme for the Development of Solar Parks and ultra-mega Solar Power Projects, the Central Public Sector Undertaking(CPSu) Scheme Phase-II (Government Producer Scheme), the Production Linked Incentive scheme for 'National Programme on High-Efficiency Solar PV Modules', etc. [16], [17], [18]. India has declared that by 2030, the energy derived from green energy resources will be 40% of its energy produced from renewable energy sources. The potential to produce energy from green resources is substantial. The Government is aggressively promoting green energy due to challenges posed by fluctuations in international oil prices, as India lacks domestic oil resources to meet its market demands [19]. Approximately 80 percent of households in India rely on solid biomass, such as firewood, crop residues, and cow dung, as their primary cooking fuel source. The reliance on traditional biomass for cooking with rudimentary stoves contributes to indoor air pollution, as incomplete combustion generates toxic by-products. This can lead to health issues such as chronic bronchitis, cataracts, and tuberculosis. [20]. Within the country's northeastern region, the population is sparse, as indicated by the population density data from the latest census released by the government in 2011. The population density of most states is more than 250, whereas it is less than 161 in just eight states [21]. The transportation cost of LPG cylinders in hilly and sparsely populated areas, especially in the country's eastern regions, is significantly high, amounting to approximately half the price of an LPG cylinder itself. [22].
Transporting LPG to sparsely populated areas does present a unique set of challenges. Maintaining a consistent supply chain and ensuring the safety of both personnel and the community is crucial. Training personnel in technical aspects and safe transportation practices is essential to prevent accidents and ensure smooth operations. Additionally, maintaining the quality of technical personnel can be challenging in remote areas where resources and infrastructure may be limited. Retaining customers in these areas can be challenging, particularly if they encounter financial obstacles that hinder their ability to refill their LPG cylinders consistently [23]. In these situations, customers may revert to traditional biomass-based cooking methods because of the accessibility of both the cooking equipment and fuel supply. [24]. The import of Liquefied Petroleum Gas (LPG) was 23.23 million metric tonnes in India [25]. In India, we depend on using fossil fuels, i.e., Liquefied Petroleum Gas (LPG) and Piped natural gas (PNG) for cooking, which are imported and stand highest among budget expenditures on imports [26]. The government is trying to reduce the dependency on the import of petroleum products by promoting the usage of renewable resources [27]. The Government of India and various states are encouraging people to utilize solar energy for cooking purposes through different schemes [28]. So, when such an ecosystem exists, individual households can also benefit and utilize solar energy for cooking.
Cooking with solar energy is not a novel idea; it has been explored and utilized in various forms for many years. This approach offers a sustainable alternative that leverages natural resources for culinary purposes. Renewable radiation has numerous potential home and industrial purposes. As the price of solar photovoltaic panels (PV) continues to drop yearly, more are being installed each year to produce power. The aim is to use the available energy from green energy resources and utilize them for the sustainable development of our country. The project attempts to integrate solar energy with modern-day cooking systems and efficiently utilize solar energy for cooking at cheaper amounts in such areas.
In light of these facts, we have developed a plan for a new cooking method that fully utilizes solar energy. We aim to design a modular, portable, insulated, and integrated electric stove powered by solar energy. Introducing insulation around the heating element in conventional stoves can minimize heat loss through convection, significantly improving cooking efficiency. This approach maintains higher temperatures within the cooking chamber, reducing energy consumption and ensuring consistent cooking results. Our project features a stove design consuming only 200W of power for 2.45 hours daily, ideal for a family of

five. The prototype utilizes a resistance coil powered by a battery charged through solar panels. Based on these considerations, we plan to develop a modular, portable, insulated electric stove fully powered by solar energy. Solar cooking isn't novel; it's a proven concept leveraging renewable radiation for diverse domestic and industrial applications. With the declining cost of solar PV panels, their widespread adoption is increasing annually. Our project aims to merge solar energy with contemporary cooking methods, enabling cost-effective cooking in various regions. As PV panel costs plummet due to mass production, harnessing green energy becomes feasible for every household. India imports roughly half of its cooking fuel, highlighting the urgency for renewable alternatives [25].
Our focus was on creating a solar stove for household use. Typically, it takes 83.34 Watts per hour to raise water from 25°C to 100°C in one hour, neglecting heat dissipation. However, conventional cooking methods often waste energy due to heat loss through convection. Introducing insulation can effectively mitigate this energy loss.

DESIGN OF THE PROPOSED SYSTEM

Our prototype comprises two central systems: a power supply unit outside and a cooking unit inside the kitchen. The power unit includes solar PV panels, a charge controller, and a battery for electricity supply. The cooking unit consists of three key components: a frying pan at the base, two stacked cylindrical containers made of food-grade stainless steel SS-304, and a perforated plate separating them. The cooking unit comprises four layers of materials. The innermost layer, in direct contact with the food, is made of food-grade steel. This layer is insulated by a second layer of flexible silicone heater, which is thermally conductive yet electrically non-conductive. This makes the stove safe for human handling. The third layer is insulation material, followed by an external layer of steel. All layers are securely welded and inspected for quality assurance.

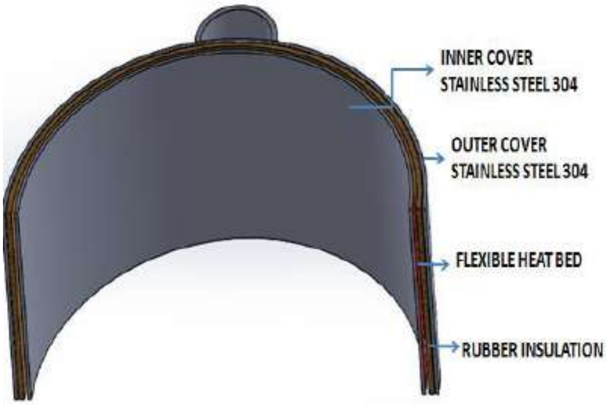

Fig 1: Section view of the cooking unit displaying four distinct layers

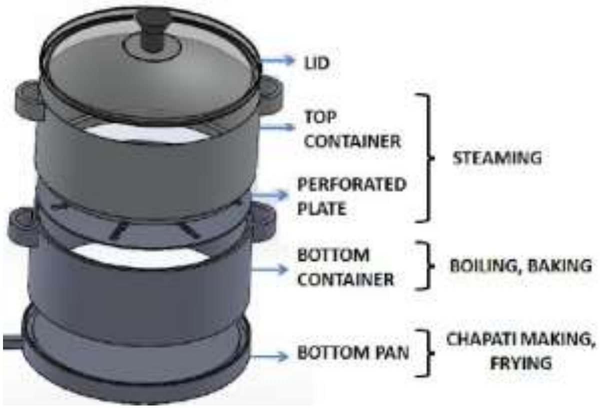

Fig 2: Exploded diagram of the cooking unit

The heat beds, which consume low power and heat up instantly, are affixed to the bottom and around the sides of the cooking container. When power is provided to the heat beds, the stainless steel plates heat up, heating the contents inside the cooking container. The heating element is rated at 200W at the bottom and 450W on the sides, but collectively, they are designed to supply only 200W. The insulation layer effectively minimizes heat transfer from the heating element to the external layer, concentrating heat within the internal layer where the food is contained. Heaters and insulation materials are readily available in local Indian markets, offering affordability and accessibility. The entire cooking unit is insulated to reduce heat loss.

Equipped with a thermostat and a backup grid connection, the cooking unit ensures continuous operation even during power outages. Our solar-powered Chulha prototype features a versatile cooking unit with heat beds, consuming only up to 200W to cook food daily for a family of five, equivalent to half a kilogram of rice.

A. Inbuilt Features:

We have integrated a digital display thermostat into the setup, connecting it to all the heat beds. This keeps food from burning or overcooking by enabling exact temperature tracking and pre-setting for different cooking procedures.

B. Charge Controller:

We implemented a PWM-based charge controller in our project to safeguard the battery against overcharging and over-discharging. This controller, with a capacity of 24V and 50 Amps, includes an indicator for monitoring battery status.

C. Adapter:

The charge controller links to the adapter, which in turn connects to the stove, ensuring it receives the necessary current to maintain the desired temperature. Additionally, an application has been created to control the stove's temperature via the adapter. This app interfaces with the adapter using Wi-Fi or Bluetooth, adjusting the current supplied to the stove as needed.

D. Batteries:

While India typically receives sufficient sunlight for solar power, auxiliary power sources may be required for stove operation during certain conditions.

The under-mentioned figure shows the block diagram of the entire setup

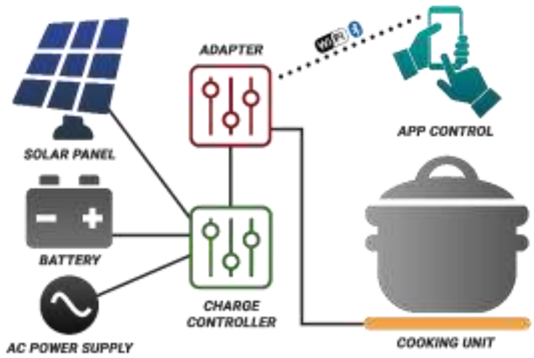

Fig 3: Schematic diagram of the solar-powered cooking system

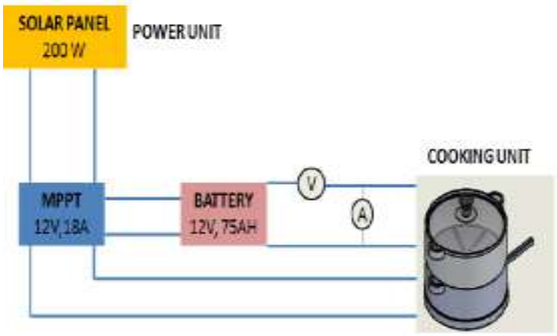

Fig 4: Schematic representation of the power unit with the cooking unit.

TABLE 1: BILL OF MATERIAL AND COST(INR) BREAK UP FOR SOLAR STOVE

Component	Type	Specifications	No	Cost
Power Unit:				
Solar PV Panels	Poly-crystalline	200 Watt	1	7200
Battery Backup	Lead Acid	12 V, 75A	1	3700
Charge controller	MPPT	12 V, 18A	1	1500
Cooking Unit:				
Heat beds	Material: Flexible silicon/ mica	Max. Temp: 200°C Voltage: 12/24 V Power:200 W	2	2000
Thermostats and switches	Digital	Voltage: 12V Temperature: -40°C to 120°C	1	1300

Material	SS 304, rubber Insulation	-	-	1700
Fabrication and Miscellaneous	-	-	-	2500
Total Cost				19900

Excess solar power is directed to recharge the battery during daylight hours when the cooking unit isn't in use. If demand arises, energy is drawn directly from the solar panels or shared between the battery and panels. At night, the battery exclusively powers the cooking unit, recharging during low or no-demand periods in the daytime. Should insufficient power be available from the panel and battery, an added feature allows for drawing excess power needed from local power distribution services. The preparation duration of various dishes, the heat levels, and the time taken for each are also documented.

Seasonal climate variations also influence power sharing. During the rainy season, lower insolation may limit direct solar energy use for cooking. Consequently, stored energy in the battery becomes vital for night-time use. We have considered that family size is around five and the average amount spent on the energy source needed for domestic cooking for a year. In India, 99.5% of households have LPG gas connections, and the average consumption is seven cylinders per year [29]. The following table shows the amount spent on setting up the solar stove and the cost needed. The following table highlights the Price variation for the LPG cylinders from the month of August 2021 to the month of August 2023

TABLE 2: PRICE(INR) VARIATION OF LPG CYLINDERS FROM AUGUST 2021 TO AUGUST 2023

Month and Year	**Average price per cylinder**
August 2023	929.00
March 2023	1129.00
October 2022	1079.00
May 2022	1029.00
August 2021	875.50

TABLE 3: YEARLY COST (INR) OF GAS CYLINDERS CONSUMPTION BY HOUSEHOLDS

Size of the family	Consumption of cylinders	Cost per cylinder	Overall annual cost
Three to Five	7	1008.5	7059.5
Five to Eight	9	1008.5	9076.5

Considering the average of the above LPG prices, the amount will be Rs. 1008/-. The initial investment for the solar stove system, including component purchases totalling Rs. 19,900/-, will be recouped within an average of two years, factoring in potential inflation.

POWER ANALYSIS

In our case, we have calculated the detailed module wise energy calculations. First, we begin with determining the power demand required for cooking food.

Estimated demand:

Total watts per hour (DC) X System Voltage = 200 W (1)

Total estimated time for cooking = 2.45 hrs. /day (2)

Watt hours per day (Total Watt x hours) = 200 x 2.45 = 490 Wh/day (3)

Generated electricity:

Power demand on daily basis= 490 Wh/day

Daily power requirements (corrected for battery losses through static average loss) = 499.80 Wh/day (4)

System voltage (DC) = 12 V, Amp-hours per day (Watts / Voltage) = 499.80 / 12V = 41.65 Ah/day (5)

<u>Battery bank calculation:</u>

No of hours needed for backup power = 24 hours (6)

Now from the above equation Amp hour storage (Raw capacity needed = 41.65 Ah/day (7)

Depth of discharge (assuming 50%) = 0.5 (8)

Required current backup (To prevent excess discharge) = 83.3 Ah (9)

Battery amps rating (20 hours) = 75 Ah (10)

No of batteries needed = 1 No (11)

<u>Required PV solar panels:</u>

Average Sunlight hours per day = 6 (13)

Worst weather multiplier (avg.) = 1.55 (14)

Total sun hours per day (assuming average sun) = Average daily sunny hours / worst weather multiplier = 3.871 hours.

As mentioned above, we had selected the panel of the power rating of 200W and the peak amperage was 12.5V. So, the Current obtained by the panel is 16Amps according to the equation. By (5), we need 41.65 amp-hours per day. The quantity of amps can be generated within 3 to 4 hours of sunlight and can be saved in the battery. Therefore, the single photovoltaic panel selected was adequate to meet our requirements.

PERFORMANCE DETAILS

The set up consists of 200 W solar panel, a battery backup of 900 W (12V, 75 Ah) and a 200 W load. During an average of around 6 hours of sunshine per day, assuming the photovoltaic panel delivers 70% of its nominal power, which is 140W, and the remaining 60W comes from a fully charged battery rated at 900W with only 50% discharge considered, the estimated cooking duration at full load is 7.5 hours. And at part loads i.e. for 100 W, the available power from the solar panel is more than sufficient hence there will be increase in offered cooking duration. During non-sunshine hours, considering the discharge of the by battery to be 50%, the cooking hours offered is 2.25 hours. The total capacity at full load considering both day and night will be 1950 Wh.

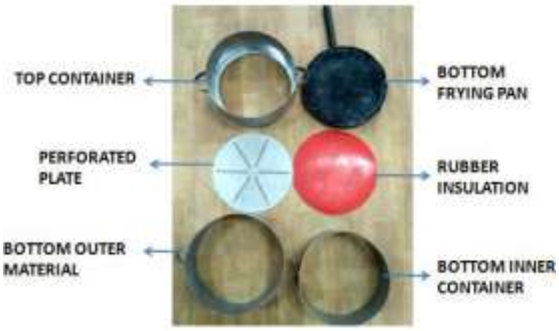

Fig 5: Disassembled parts of the Cooking unit prototype.

Fig 6: Heat beds developed in the lab

The graph below shows the temperature curve for boiling 1L of water. The heat bed load was supposed to be 200W theoretically, and when measured during the experiment, it was found to be 186 W and fluctuated up to 198 W.

Fig 7: Bottom pan assembly with heat bed and rubber insulation

Fig 8: Complete assembly showing the bottom pan, bottom container, perforated plate, top container

Fig 9: Testing of the prototype with a battery, temperature display and thermostat in the lab

TABLE 4: TIME TAKEN FOR TESTING

Sno	Cooking application	Quantity	Approx. time (mins)
1	Boiling (Water)	1 litre	46
2	Streaming (Potatoes)	4 Nos.	60
3	Baking (Chapati)	1	10
4	Boiling (Rice)	250gms	62

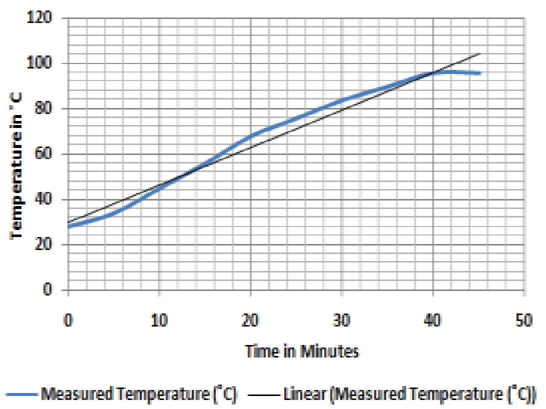

Fig 10: Temperature measurements over time for boiling water

INTELLECTUAL PROPERTY STATUS

By this project, BMS College of Engineering and M/S Solar Green Club were honoured by a patent granted by the Patent office, Government of India by the title "Heating Element for a Cooking Apparatus using a DC Power Source".

CONCLUSION

This project has the potential to usher in a new era for cooking in an environmentally friendly manner. It focuses on reducing dependency on LPG gas and addressing electricity shortages in our country while maximizing the use of solar energy. The integrated insulated resistor coil stove, equipped with a heat controller, is designed for user-friendliness. The coils generate optimal heat, and the controller allows for heat adjustment as needed. Backup batteries store excess solar energy. Various field tests have been conducted to determine the cooking times for different types of food, as this is a crucial aspect of the project. Additionally, the initiative aims to enhance opportunities for Micro, Small, and Medium Enterprises in India within this sector. Our goal is to provide a high-quality, easy-to-use product that effectively utilizes renewable energy.

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