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Improvement of Energy Efficiency and Effectiveness of Cooking in Solar Electric Slow Cooker for Tropical Countries

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***Abstract*— Cooking system has been evolving for a long time. From the parabolic system to solar cooking. Every method had its unique concepts. Attempts towards solar cooking have always been proven beneficent and successful. Solar cooking is a system where energy comes from the photovoltaic solar panel which is powered by sunlight. We have designed a system where solar energy will be stored in a pack of battery which can be used in the absence of the sun. Combination of PV panels and batteries will provide the required power during sun time. A full-time main grid back-up is also present in the system.**

***Keywords*— solar energy, PV panels, impedance matching, heat trapping, green energy**

I. Introduction

The solar stove is a new path for the cooking environment in Bangladesh. Our improved solar stove is completely a renewable energy-based design. The system harnesses power of the sun and converts it into electricity through PV panels. This system will reduce the consumption of natural resources. It also has the feature which allows it to use AC power as a backup of the solar energy. The plan was to develop a complete off grid cooking solution but AC power backup option is kept as well to make the system more uninterruptable and suitable for every situation. We are using batteries to store the charge and it is a green energy system with no emission of harmful gases. Our newly designed electric stove is much better and improved compared to the previous version "Performance and Testing of the Improved Solar Electric Cooking System" [1]. This version is referred as version-3. There have been some significant changes. For the experiment, we have performed field testing, analysis, impedance matching, efficiency improvement and payback calculation. We have also added some comparative studies regarding the performance of both the electric and gas stove. We have discussed the purposes of this project and the challenges we need to overcome.

People have been using solar power to cook for a very long time. The earliest evidence we got is in 1767 by a Swiss physicist named Horace de Saussure [2]. He invented the idea to cook food by concentrating sun light in a glass box. In 1905 Albert Einstein formulated the photon theory of light in which he described how light can liberate electrons on a metal surface. In 1954, based on photon theory, David Chapin, Calvin Fuller and Gerald Pearson of Bell Labs created the world's first photovoltaic cell that converted sunlight into electrical energy. In 2018 alone, the generation of solar energy was almost 500 terawatt per hour globally. But in Bangladesh there is a 500MW shortage of electricity on a daily basis and only 50% of the county's people have access to electricity [3]. Based on these concepts, CARC (Control & Application Research Centre) of BRAC University developed a single burner solar stove named "Development of Solar Electric Stove for Smart Use of Solar Photovoltaic Energy" in 2013 which used solar panel as power source and battery as backup [4]. As a successor of the project, a newly designed solar stove with two burners were introduced in 2016 named "Development of double burner smart electric stove powered by solar photovoltaic energy" [5]. In 2019 "version 3" were developed based on previous projects with short circuit protection named "Improvement of Environment Friendly Solar Electric Cooking System" [6]. Taking inspiration from previous versions and "Bondhu Chula", we have developed commercial version by modifying the whole system [7]. We have improved the design of the load coils to match with system's impedance to get maximum efficiency. An improved heat controller design and better heat trapping system is being used to get more power to load which resulted in producing more heat without any power loss. Also, single heat controller is being used to run both burners resulting in a cost-efficient system. These improvements gave us a stable and reliable system with high efficiency and reduced cooking time. By efficiency it is being implied, efficiency in terms of costing, in terms of energy consumption, in terms of energy conversion.

II. FEATURES OF THE SOLAR COOKER

The current version of the solar cookers includes a PV solar panels, charge controller, battery, backup power supply, heat controller and Slow Cooker and hot plate. In this system, the sunlight (photon) is converted to electricity and the power is shared between the battery and the load. One cooker can be turned on at a time with this system. A two-way switch is added in the system so that the user can choose which mode is to be used. Either the slow cooker or glass toped hot plate. The battery stores the charge so that the stove can be used when there is no sun. There is a DPDT switch that can be used to choose the power sources between AC power back up and PV panels as required. The coil emits very high temperatures. The temperature can be increased or decreased by controlling the flow of current. It can be adjusted by using the knob that is attached to the heat controller. The heat controller is basically a motor controller. Whereas, our predecessor group "Performance and Testing of the Improved Solar Electric Cooking System" used a PWM motor controller. The left side of the cooker is called the slow cooker. In a slow cooker, the heat-trapping method has been used. By trapping the heat, cooking can be done in an efficient way. Efficient in terms of converting to optimum energy conversion. A slow cooker is used for cooking rice, beef, chicken, fish, vegetables, boiling, and pulse. On the right side, we have an infrared glass top hot plate. Glass top hot plate is used for making any fried items.

III. SPECIFICATIONS OF THE SYSTEM

The solar cooker is designed to operate at 500W which is powered by a combination of 760W panel and 4 sealed Lead acid batteries. Specification of the system is given below.

Type	Specification
Net Weight	60 KG (Battery Weight: 52KG)
Housing	Stainless steel, plastic body, glass top
Cooking Elements	Resistance Elements
Power Source	Renewable Energy (Solar)
Voltage	48V
Power	500W
Battery	48V, 50Ah, 4pcs sealed lead acid
Solar Panel	760W Mono Crystalline (Manual Maximum Power Tracker)
Solar Charge Controller	48V,50A,1pcs
Control Type	DC Heat Controller

IV. WORKING PRINCIPLE OF THE SYSTEM

Four 12-volts batteries are connected in series to make 48volts that are connected to the solar charge controller. 48volts, 760W PV panels are connected to the solar charge controller. The AC power backup option can be plugged in whenever required. A two-way switch is there to select the power source as required. A 15A DC MCB is connected between the output of the solar charge controller and the heat controller. The potentiometer of the heat controller is used to vary the output power. Then a two- way switch is connected with the heat controller. This two-way switch is the selection key between the slow cooker and the glass top hot plate. The DC MCB (Miniature Circuit Breaker) protects the loads from flowing high current. If there is an overflow of current, the circuit breaker disconnects both the loads from the connection. The charge controller will share the power with the battery and load. Load current will be the combination of the currents supplied by PV panel and battery where Solar Charge Controller will prioritize the panel current and will ensure the maximum use of it. If the PV Panel current is not enough for the load, Charge controller will take the remaining current from the batteries and deliver rated 10A current to the load. Then it will heat the coils and provide the heat. Using this heat cooking can be done. 10A is considered as optimum flow of electricity because we want our system to be 480W.

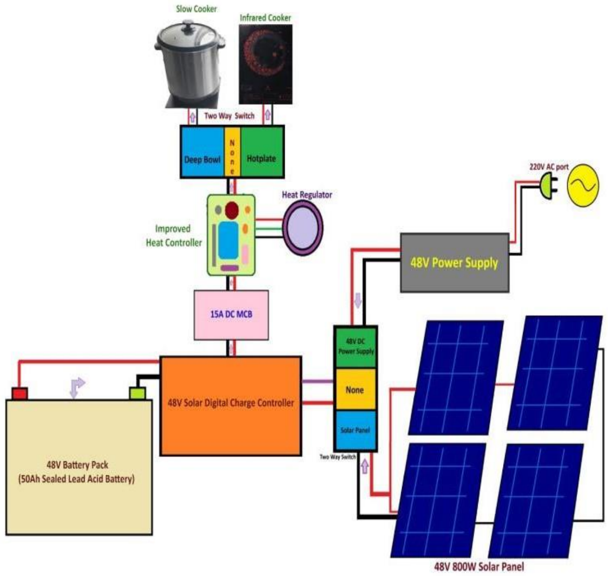
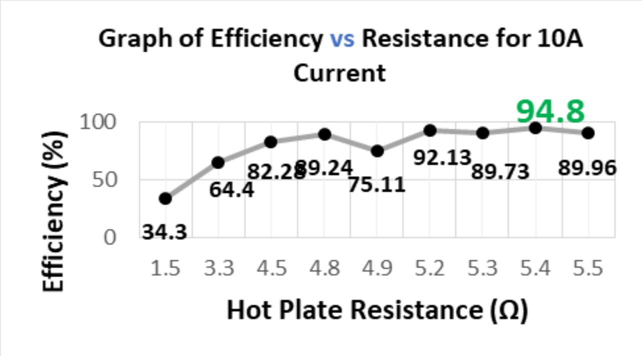


Fig-1: Block diagram of the system

V. DATA ANALYSIS

The objective of various experiments and analysis is to prove that; this system is suitable for cooking in a very effective way with high efficiency. Battery backup test, impedance matching test, heat controller efficiency test and cooking time test are done in order to improve the efficiency of the system compared to the previous version. Varying the hot plate resistance from 1.5Ω to 5.5Ω, several data was recorded for 10A current in order to find the best efficiency result.

The purpose of the test was to find out the efficiency of energy conversion from electric energy to heat energy. Efficiency is power output by power input. Our input power



is drawn from the charge controller and the output power was measure on the load.

Fig-2: Graph of Efficiency vs Resistance for 10A Current

From the aforementioned graph it can be said that, coil with 5.4ohm resistance gave the highest efficiency.

VI. COMPARATIVE STUDY

n the version 3 system, 3.3Ω hot plate resistance was used where in this commercial version, 5.4Ω is used. Showing the comparison of efficiency from 1A to 10A currents for both of the resistance.

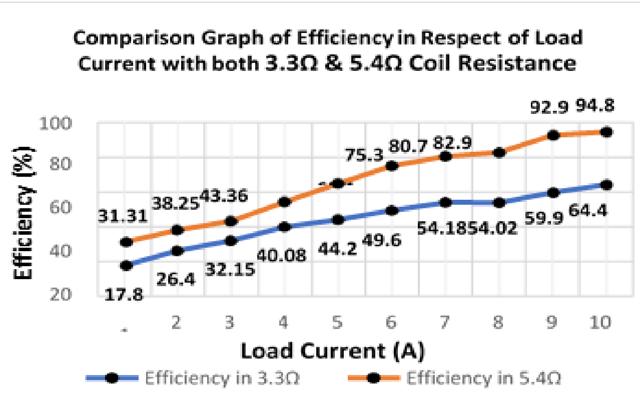


Fig-3: Comparison Graph of Efficiency in respect of Load Current with both 3.3Ω & 5.4Ω Coil Resistance

It is clearly shown in the graph that, 5.4Ω resistance is much more efficient than the 3.3Ω resistance which means the current version will produce more power than the previous version resulting in more heat produces in this version and the cooking time will be less than previous version. Also, we have improved the heat controller design which ensured a more stable system. Comparison between the previous heat controller performance and our new heat controller performance is given below:

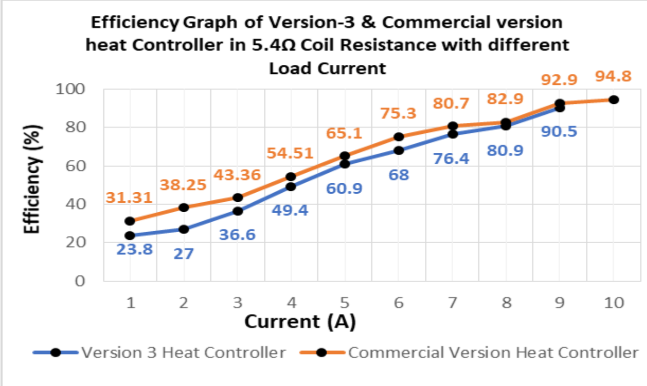


Fig-4: Efficiency Graph of Version-3 & Commercial version heat Controller in 5.4Ω Coil Resistance with different Load Current

Combining both improved heat controller and impedance matching resistance of load, we were able to achieve a far efficient system which required less cooking time. Various items have been cooked to test the efficiency and improvement of the commercial version of solar cooker. The testing data is given below:

Table-1: Comparison of required cooking time

Item	Quantity	Version 3	Commercial Version	% of cooking time reduced	Gas Stove
Water Boiling	0.5 L	12 Min	8 Min	33%	5 Min
Rice	0.5 Kg	35 Min	28 Min	20%	25 Min
Egg fry	1 Pc	10 Min	6 Min	40%	4 Min
Pulse	250 Gm	30 Min	23 Min	23%	20 Min
Beef	600 Gm	1 Hour 10 Min	55 Min	21%	50 Min
Chicken	1 Kg	1 Hour 5 Min	45 Min	30%	40 Min

Here it can be seen that cooking time has improved significantly compared to the previous version's cooking time. The main reason behind it is the efficiency improvement through impedance matching method. Efficiency improvement resulted more heat production in the heating coil which gives us reduced cooking time. By doing so, required cooking time dropped around 28% than previous version.

VII. BUDGET ANALYSIS

In the commercial version, modification was made in every component. New set of batteries, hot plates, charge controller, heat controller and infrared cooker were bought and modified to use in the system. Budget of the commercial version of electric slow cooker is given below:

Table-2: Budget of the project

Components	**Quantity**	**Cost per unit item**	**Net cost (BDT)**	**Net Cost (USD)**
PV Panel	760W	42	32000	375
Batteries	4	4250	17000	200
Charge controller	1	3000	3000	35
Heat controller	1	1500	1500	17
Hot plates	2	350	700	8
Infrared cooker	1	3000	3000	35
AC-DC power supply	1	2600	2600	30
Slow cooker	1	2500	2500	29
Miscellaneous Cost			2700	31
Total			**= 65000**	**=760$**

VIII. RUNNING COST CALCULATION

Here is a chart for yearly gas cost of different types of family. The comparisons are done by analyzing the number of cylinders used from small to moderate to big family; their per month cost and total cost per year.

Table-3: Running cost calculation

Family size (Persons)	Cylinder consumption (per month)	Total monthly cost (BDT)	Total yearly cost BDT	Gas line cost (per month)	Gas line cost (Yearly)
Small (2-4)	1	1700	20400	900	10800
Moderate (5-7)	1.5	2550	30600	900	10800

IX. PAYBACK CALCULATION

In the commercial version, modification was made in every component. New set of batteries, hot plates, charge controller, heat controller and infrared cooker

Table-4: Payback calculation

Type of calculation	**Type of family**	**Payback time (in years)**
With solar panels expenditure	Small (3-4)	65000/20400=**3.18** years
	Moderate (5-7)	65000/30600=**2.12**years
Without solar panels expenditure	Small (3-4)	33000/20400=**1.61** years
	Moderate (5-7)	33000/30600=**1.07** years

Now a days, it is mandatory to have solar panel in a house as per govt. rule. So, without solar panel cost, the time reduced to 13 months which is very good. After the payback, families can cook for free in their household with the solar cooker. Since this solar electric solar cooker is under testing condition it is hard to predict the depreciation of the system components, also the lifetime of the system yet.

X. FUTURE CHALLENGES

Costing is a huge matter of concern in any project. In our solar stove, we got feedback about it's costing to be high. As it is now in testing phase, the cost will surely come down in future. In future versions, costing of solar stove needs to be minimized in order to make it more affordable to general people. In the solar stove, we have tried to trap the heat as much as possible to make the system efficient. We feel like there is more room for improvement in this area. Better heat trapping system will further reduce the cooking time ensuring a much more efficient way of cooking.

XI. CONCLUSION

The main motive of the project was to build a stable system with improved efficiency and reduce the cooking time. Also, build dependable backup system as it is difficult to meet demand with the shortage of electricity [8]. After experimenting, analyzing and working for one year, the project is a success. We made the stove more user friendly and were able to reduce the power loss resulting in a much more efficient system than previous version. Improved heat controller and redesigned load resistance helped us to achieve our goal. This project is based on real-life problems. Such a system can be helpful in our life because it uses renewable energy sources and doesn't produce any harmful gases which helps us to build a green sustainable world.

XII. REFERENCES

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