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

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Declaration

It is hereby declared that,

1. The thesis submitted is my/our own original work while completing degree at BRAC University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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Abstract

The 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 functional to solar. Solar energy is renewable energy. Renewable energy is currently the biggest R&D at this moment. The amount of non-renewable energy is decreasing day by day and increasing global warming simultaneously. Bangladesh is at no different point. We have very limited non-renewable energy and it's decreasing day by day. Only 6% of the country's total population has access to natural gas, primarily in urban areas. Keeping in mind the potential of solar energy, our goal is to design an electric stove that will use solar energy. The main source of power is solar in addition to 48V batteries as back up and the main grid as emergency backup. This system is run by two burners which are controlled by a heat controller. The batteries are charged by photovoltaic solar panels when the batteries are not being used. Heat controllers are also used to vary the temperatures. As it is called an improved version, this stove is structured over verification of a double burner stove named "Performance and Testing of the Improved Solar Electric Cooking System". In this improved version we have worked to bring out some significant changes involving size, material, cost, cooking time and design. Here we have presented a comprehensive study over performance-based and test analysis between both stoves comparing theoretically, experimentally, and development works. To justify our result, impedance has been matched to get the maximum output power. Cooking time data and input power vs output power data has been analyzed to obtain optimum results. To compare the effectiveness as compared to natural gas, this thesis has several analyzed data that were taken under different electrical components or materials. Finally, we have come up with the best and effective solution for the urban areas of the country which will help to reduce the usage of non-renewable gas and electricity too.

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List of acronyms

W (Watt)

V (Voltage)

Amp (Ampere)

AWG (American Wire Gauge)

PWM (Pulse Width Modulation)

MPPT (Maximum Power Point Tracker)

SOC (State of charge)

HVD (High voltage differential)

LVD (Low voltage disconnection)

AGM (Absorbent Glass Mat)

MMCFD (Million Cubic Feet per Day)

TWH (Terawatt-Hour)

KWH (Kilowatt-Hour)

Chapter 1:

Introduction

1.1 Project Outline

This solar stove is a new path for the cooking environment in Bangladesh. This solar stove is completely dependent on renewable energy. This energy harnesses the power of the sun and converts into electricity through PV panels. This system will reduce the consumption of natural resources. This solar stove also consumes electricity as a backup system. Since our country is having a scarcity of electricity so we kept electricity as a backup option while solar PV panels as the main option. Since we are using batteries to store the charge, so it has many beneficiaries. This is a green energy system with no emission of harmful gases. This designed electric stove is much better and improved compared to the previous version “Performance and Testing of Improved Solar Electric Cooking System”. 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 electric stove, gas stove. We have discussed the purposes of this project and the challenges we need to overcome. We have explained every component in detail.

1.2 Literature Review

The first paper is about the recent technologies applied to the solar cooking system [1]. The different cookers are being demonstrated on the ground of efficiency and performance. Based on these, three types of solar cookers are chosen. They are Panel cookers, Box cookers and concentrating cookers. These three types of cookers are selected to compare among their different purposes and their advance technology. The comparison will be based on analytic, comparative and configuration wise.

The analytic part is based on economic and social acceptance over these cookers to make it successful globally. In the final comparison, which is a comparative study, three selected cookers are compared and come up with a conclusion on which cooker is more efficient. To compare configuration wise, it is to be considered the different applications depending on different design, demography, and performance. These three solar cookers are being categorized into three different segments. Which are structural, storage of energy and the transferring of heat. Every technological study is considered over performance and cost. After analyzing it can be concluded that the concentrating cooker is more efficient over the box cooker and panel cooker based on performance. Mostly, the heat storage system determines efficiency. As for the economic aspect, the panel cooker is widely accepted as it is the most affordable than the other two. The Box cooker and concentrating cooker requires additional equipment such as heat storage, reflectors unit. These include additional costs. In the end, there are some drawbacks as there is a lack of social interest and acceptance. There are also pathways to solve the problems. Also, some suggestions are offered on future developments to be continued to bring more advance solar cookers.

An induction cooker is another model to be described. The simulation, design and practical study [2]. The proper structure will include the main power system, battery, charge controller, switch, inverter, solar. In this system solar panel is connected to a DC-DC converter. It shares the power between the battery charge controller and the switch. The main grid is connected using an AC-DC converter. It also shares power between the battery charge controller and auto-switch. A set of four 12-volts batteries are connected in series to get 48-volts. It is used to maintain load leveling. The battery is connected to the solar charge controller. In the solar charge controller, a heat controller is connected and the coils are connected which are used as a load. The current flow can be varied using a potentiometer which is connected to the heat controller too.

A solar steam cooking system was introduced in India for industrial cooking and its application was basically on boiling type cooking [3]. The system consists of Scheffler dish, storage tank, and reflector. As the light fell onto the Scheffler dish, it goes towards the reflector. The reflector then passes high temperatures to a storage tank. Inside the tank, there is water. When it receives high temperature, it converts water into steam. Through insulated piping, it then transfers the steam for cooking in the kitchen. The temperature reaches approximately 150 to 180 degrees Celsius [4]. Using this process, items can be cooked for up to 200 people. This method is cost-efficient but it has some drawbacks. This method does not apply to household appliances. This method was mainly focused on institutional kitchens. The cost varies demographically. This method also depends on climate to some extent. During warm, humid, dry weather, there is enough sunlight to transfer heat. But in cold weather and rainy days, there are not sufficient sun lights.

Furthermore, another insulated solar electric cooking system has been explained and the system is developed using an electric heater, insulator and solar panel [5]. A low wattage solar panel is connected with an electric heater directly which is a well isolated and insulated chamber. As for the insulated chamber, heat loss is minimized. Barbeque, boil & simmer cooking and thermal storage are three different types of insulated solar electric cooking are mentioned here. Water boiling, egg fry, rice, etc. has been tested with this system. This system can keep the food items hot after it is being cooked. Thus, it will minimize the use of fossil fuel which is usually used to keep the food warm. This project was implemented in two areas in Uganda. One is placed in northern Uganda and the other one is in Gulu. The users appreciated the project. Still, there are some limitations which are as follows. The project cannot be operated during the night when there is no sun. The power cannot be controlled to control the heat of the heater.

1.3 Motivation

Previously an electric cooker was designed named "Development of Double Burner Smart Electric Stove Powered by Photovoltaic Energy"[6] composed under the supervision of CARC. In this project, we developed an improved version of the earlier one. And to attempt this practically, we had our motivation from "Bondhu Chula" innovated by the "Bangladesh Council of Scientific and Industrial Research" (BCSIR) [7]. This stove was mostly targeted for rural people. People in rural areas mostly use earthen stoves. While cooking, this kind of stove usually emits smokes which is harmful to the breathing system. In order to solve the problem, they added an external pipe so that the smoke can go outside. Such a small change yet so powerful. This huge change motivated us to develop the system further. Over the years cooking system has evolved from time to time. People have worked on different methods and have done many experiments with solar cooking. Several types of cooking systems have been used. Such as boxed solar cooker, panel solar cooker, parabolic solar cooker, etc. But most of these methods have been proven inefficient over time to time. So, it is our other motives to make the system in such a way so it can be used for a longer period and make cooking time lesser.

1.4 Features of the solar cooker

The current version of the solar cooker includes a PV solar panel, charge controller, battery, backup power supply, heat controller and Slow Cooker and infrared cooker. In this system, the sunlight(photon) is converted to electricity and the power is shared between the battery and the load. This system can operate one load at a time. 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 the infrared cooker. 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 source 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 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 much faster. A slow cooker is used for cooking rice, beef, chicken, fish, vegetables, boiling, pulse. On the right side, we have an infrared cooker. Infrared cooker is used for making any fried items.

1.5 Project Challenges

Fulfilling the need of every person is quite impossible. Dhaka is overpopulated and Bangladesh is the most densely country. But to minimize the shortage of power, any type of power is being carried on. That is why using renewable energy is very important. Focusing on this issue, earlier another electric cooker was designed named "Performance and Testing of the Improved Solar Electric Cooking System" composed under the supervision of CARC [8]. They designed it successfully but their efficiency was very low. So, we found some scopes to improve the efficiency of the system. First of all, the difference between input power and output power was very high. Which means, the system had low efficiency. That means more time to cook and a loss of energy. So, we performed an impedance matching test. We finally came up with the highest possible efficiency. Second of all, we had to redesign the coil since we have changed the resistance. Third of all, initially we were using PWM controllers. These controllers were not able to withstand the power supplied through it. As a result, they kept on burning one after another. We tried using 10 amps, 15 amps, 20 amps, and 40amp PWM controllers. All of them failed. Finally, we swapped the PWM controller with a heat controller. The heat controller was able to supply and withstand the required power of the system. Finally, we had to change the batteries. Since previously used solar deep cycle battery was not able to give a long time back up. And we had to maintain the battery regularly. So, we swapped the batteries. We have used a set of sealed lead-acid batteries. This is a very good quality battery. This battery was able to give roughly 3-4 hours of back up at a stretch. The previously used batteries were able to provide a backup time of 1.5-2 hours. Our main goal is to design an improved version of the previous electric stove by providing more output power, by getting more efficiency, by making cooking time lesser than the previous group. We have used 16AWG coils. For increased back uptime, we have increased the ampere-hour of the battery. To overcome the short-circuit problem, an electric insulator has been used on top of the coil.

1.6 Advantages of PV Energy to the Economy and Environment

PV energy comes from solar energy. Solar energy will never run out. On the other hand, the cost of PV panels is decreasing day by day. Also, the efficiency of the panels is increasing. There is an estimation of different renewable energy sources. We can clearly state that solar energy is the highest among all of them. Solar energy is a renewable energy source. Converting solar energy into heat energy is pollution-free. The cooking methodology from the solar stove is also green.

In 2018 the generation of solar energy was almost 500 Tera-watt per hour globally. If we can harness more of solar energy and utilize it properly, then we will not have to worry about non-renewable energy sources. The following figure explains the amount of renewable energy generation in tera-watt per hour globally. The figure clearly explains the amount of solar energy generation is has increased drastically between 2010 to 2018.

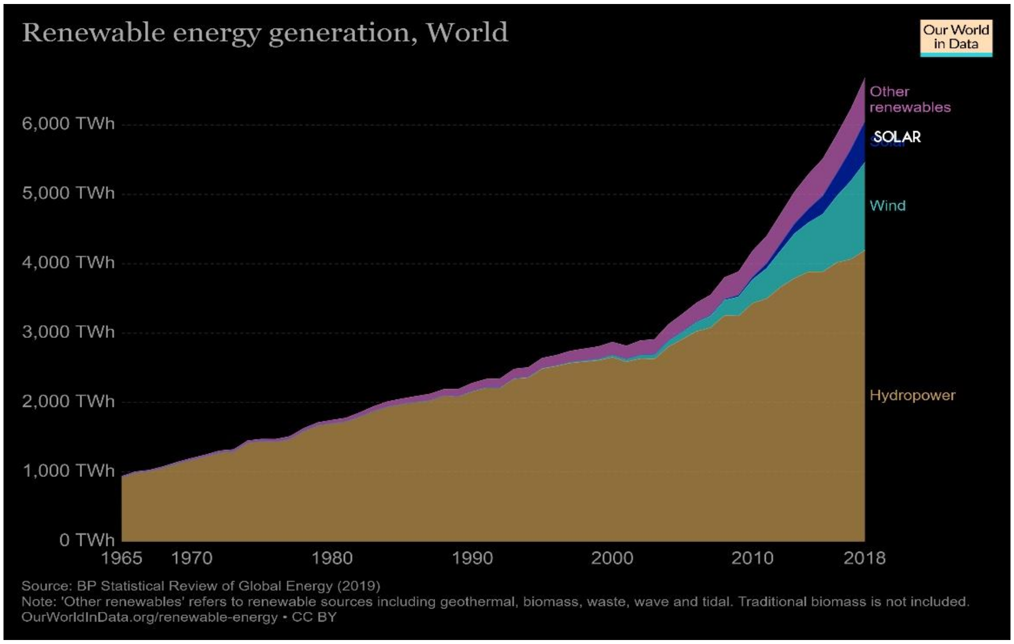


Fig (1): Renewable energy generation [9]

Extracting energy from non-renewable energies pollutes the environment. Pollution further occurs from its usage. These energy sources are limited. It is a very high time to start looking for renewable energy sources. There are a handful of numbers of renewable energy sources. Among all of them, solar energy has a vast contribution. Though solar energy is a cumulation of solar photovoltaic energy and solar thermal energy, here solar photovoltaic will be discussed mostly.

1.7 Clean technology & sustainability of the solar cooker

Why the solar stove is a green technology/clean-cooking technology:

1) It does not produce any smoke or toxic gas
2) No air pollution due to smoke
3) It does not require any fuel or wood
4) Saves fuel and woods as a result we do not need to cut down any trees
5) No chance of fire hazard as heat is generated without fire
6) No carbon emission
7) No CFC gas produced
8) No black carbon parts in the cooking utensils resulting in using less soap
9) Batteries used in the system are easily disposable

10) It uses sun as power source. So, it is sustainable in every way
11) The system is saving current from our national grid by taking current generated from solar panel

It is clear that the solar cooker is environment friendly and sustainable in every way. In this era of green technology, the solar cooker will be a great fit as it is designed to be a part of clean cooking technology.

1.8 Problems and Expenditures of Existing Electric Stove

Usually, regular stoves provide high wattage ratings. They differ between 1500W-3000W normally. From the wattage, we can approximate the cooking cost with such stoves. For a 2000W stove, assuming the cooking time for a family is 3 hours. Then the cost will be 2*3=6 KWH. For consumers, it is 6 electrical units. Each unit costs 6.02 taka [10] then the total cooking cost will be 36.12 taka. The monthly cooking cost will be 1083.6 taka. This is a typical calculation of a small family.

The regular electric stoves are high in wattage ratings. Normally they differ between 1500W-3000W. The lowest, one can find is 1000W. From that wattage rating, it can be approximated, how much the cooking cost could be with those stoves. For example, with a 2000W stove, if the total cooking time for a given family is 3 hours for a day, then cost for that day cooking will be. The cost will increase for a moderate or a big family. In many urban areas, in apartments especially, people do not have a gas connection. They use cylinder gas. Each cylinder cost approximately 2500 taka. One cylinder is certainly not enough for a big family. We can assume that it is expensive. On the other note, Bangladesh does not have enough production of electricity compared to the demand. The country has 800MW of shortage every day [11]. It is to be mentioned that electricity is available to all. Only 50% of the country's total population has access to electricity [12]. Rural areas are yet to be supplied with electricity. Especially the hill tract regions and tribal areas are yet to see electricity. Therefore, electricity is very important. Consuming electricity for cooking can be avoided. Electricity should rather be used more in research, service and industrial work. Gas storage is also not sufficient enough. Most of the gas reserved is used in the production of electricity. So, using gas for a longer period of cooking is not wise as there is a shortage of this energy. Even in Dhaka city, the capital of the country has a shortage of gas. Some very busy regions of the capital are deprived of gas for several hours of a day. Therefore, we should be using fewer fossil fuels. Keeping all these in mind, this thesis tried to find out a new way of cooking using solar energy.

1.9 Overview of the contents

Structure and system designing:

In this chapter, we will discuss the design of the system including the working principles of the system. We will also discuss the internal designing of the system comprising of the block diagram, wiring diagram, design, and working principles. Then we will discuss the designing of the solar PV system, its necessity, calculations, and efficiency. Then we will discuss the specifications of the slow cooker and newly introduced infrared cooker. Finally followed by the required battery for the system.

System Components:

In this chapter, we will discuss the components used in our system. We have changed the resistance of the coil by undergoing impedance matching. The analysis of the test will be discussed along with the efficiency test and limitations. We have changed the heat controller. The specifications of the controller will be discussed along with circuit diagram, wiring analysis, switching methods and finally the performance and the efficiency test. Then we will discuss the digital charge controller that we have swapped with previously used analog charge controller. The emergency power back up of the system which is used “AC-DC power supply” will be discussed. Finally, we will be talking about battery size and its back-up performance.

Data Analysis:

In this chapter, we will be discussing the data analysis we have performed throughout the thesis. Comprising of the objective of the analysis, detailed battery performance test results will be discussed. Further analysis will be justified for different resistance values, the efficiency of the system. Heat controller, cooking data, cooking time analysis will be undertaken in this chapter. Finally, we will be discussing about the customer and the merchandise survey.

Comparative Study:

In this chapter, we will discuss the justifications of the analysis by doing a comparative study. The comparisons will be made with the previous version "Performance and Testing of Improved Solar Electric Cooking System". We will be comparing the structure, coils, cooking data, heat controller performance, induction cooker, gas and LPG stove, and other solar cookers. Then we will be discussing the budget and the payback calculation. Finally, the cost comparison between conventional cookers.

Future Development:

In this chapter, the limitations that we have faced will be discussed. Based on the limitations found we will be discussing how to improve the system in detail. We will also discuss the future scopes of this solar cooking system. And a new technology known as the "Induction Cooking Method" will be discussed.

Using solar in cooking has been used in the last few decades. Each new cooker came up with new technologies, techniques from using panel to box cooker to evacuated tube cooker. This has motivated us to bring new methods and new creations. All of the methods had one thing in common. Which is, to use renewable energy sources. That is because we are dependent on electricity and natural gas. These energy sources are non-renewable. To substitute natural gas and electricity, we have planned to design our stove based on the solar system. Our motive is to make it cost-efficient, safe, efficient and avail with energy. In our society, people have not realized the importance of solar energy. So, this cooking technique is not much popular among everyone. It is yet to be recognized. This solar stove has been motivated by the previous version of a solar stove named "Performance and testing of Improved solar electric cooking system." Their work has inspired us to create a better version with improved efficiency and additional features following the challenges we have faced.

Chapter 2:

Structure & system designing

Bangladesh is a tropical country. In the country's context using solar energy as renewable energy is very suitable. Here, the country gets a suitable amount of sun hour every day. To design a solar cooking system, there are a lot of things to take into consideration. To design such a system, there are some major components to decide at first. These components have to be sized depending on the system. To finalize that, the system's energy losses, power consumption, applications, and usage have to be considered.

2.1 Design of the proposed system

The system consists of PV panel, one slow cooker, one infrared cooker, 2 pairs of 12Volts batteries making a total 48Volt, coils, heat controller, one control box consisting of solar charge controller, power supply, AC-DC converter.

Batteries are required to store charge. So that it can be used when there is no sun. A power supply is required for emergency backup. It is used when there is no sun and no battery backup available. The charge controller is used to maintain the integrity of the system and keep the system safe.

In this system, the PV panel and the batteries are considered as the primary power source, while the national grid is considered as an auxiliary power source. The system's main load consists of 5.4-Ω heater coils. This system provides approximately 500W. This amount of power is good enough for a family to cook. In this system, we are drawing 10A current and the battery is 48 volts. So, the output power is approximately 480W. In version-3 solar deep cycle battery has been used. In this commercial version, we have replaced the previous batteries with a sealed lead-acid battery. That is because the sealed lead acid battery provides better performance and better back up. In this system, we have used a digital solar charge controller. The ratings of different major components are discussed in the upcoming topics.

Fig (2.1): Outlook of the system

2.2 Working principle of the system

Four 12-volts batteries are connected in series to make it 48volts are connected to the solar charge controller. 48volts, 750W PV panels are connected to the solar charge controller. The main grid connection can be plugged in whenever required. A 15A DC MCB is connected between 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 connected with the heat controller. This two-way switch is the selection key between the slower cooker and the infrared cooker. 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. Again, the two-way switch is used to select which of the loads will be operated, either slow cooker or infrared cooker. The charge controller will share the power with the battery and load.

The circuit breaker will work only when excessive current flows. The current will flow from the solar PV panel and the remaining from the battery. Then it will heat the coils and provide the heat. Using this heat cooking can be done.

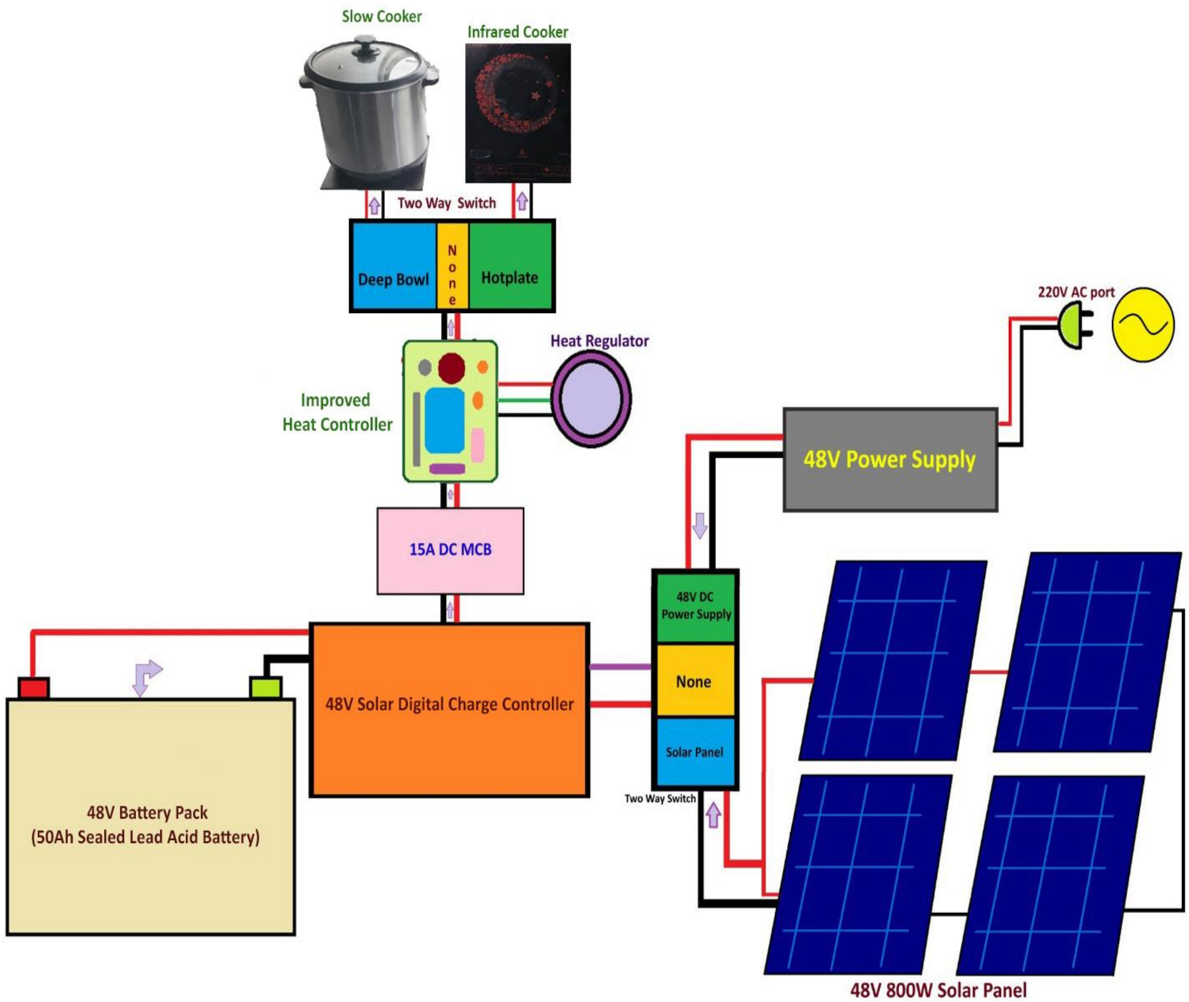


Fig (2.2): Block diagram of the system

2.3 Specification of the system

In the following table, the specification of the solar stove system has been provided. The net weight of the stove is 97KG. The mainframe is made of stainless steel and wood. The coils are of 5.4Ω. The main power source is solar. This is renewable energy and it is harmless to the environment. We have also used a 48V battery. The 4 batteries store charge from solar. There is a digital solar charge controller rated 48V and 50A. There is a heat controller connected to the load to control the output power.

Type	Specification
Net Weight	97 KG (Battery Weight: 52KG)
Housing	Wood and Stainless Steel (Top Surface)
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

Chart (2): Specification of the system

2.4 Designing a Solar PV system

2.4.1 Introduction: Renewable Energy in Bangladesh

We can see the unpleasant situation of energy distribution in our country. According to the Statistic of Bangladesh Bureau, in the year 2010, approximately 90% of people get the opportunity to have access to electricity while only 42% rural people to have the access to supplied electricity. Another survey tells that about 59% of people in Bangladesh have access to grid connection. This information is taken from a 2013 statistical point of view. The government is always working on this issue. They are installing more and more electrical capacity but it is not enough. Roughly 16 million people are household users out of 21 million people. About 50% of connections are for household working. This number can be increased if we can motivate people to start using renewable energy devices. Since the population is so high, it is difficult to create enough electricity. The largest consumers of this electricity are residential sectors, industries, and agriculture sectors. Bangladesh's electric power industry has low plant efficiency, high system loss, shortage of funding for maintenance, poor plan efficiency, blackout. It is very difficult to meet the demand for electricity for the past few decades [13]. In Bangladesh, the use of natural gas is quite vast. Natural gas is mainly used for industrial work, producing urea and other fertilizers, domestic chores and captive power generation. The domestic sector and household sector have the greatest number of customers and it consumes roughly 11% of the total production of natural has. The government's priority is to increase the supply of gas to fertilizer factories and industries.

Due to the scarcity of natural gas household gas connection is not the main priority of the government.

From July 2010 to 2013 the pipe gas connection was suspended in the domestic sector. But it was resumed later because of the repeated pleas from the affected stakeholders. It was done by diverting supplies from some fertilizer industries and power plants. The country is still facing a gap in the supply and demand of this natural gas in the household sector. The government plans to import more LPG to cope up with the shortage. The demand for the gas supplement is 3,300mmcfd. The amount of supply is 2,70 mmcfd in Bangladesh. Governments have tried to increase the supply but doing so the cost is being increased too. Pricing of natural gas has been tough for people living in a developing country like Bangladesh. The government has planned to introduce LPG as an energy supplement but it is very expensive. Also, it would make people dependable on the imported resource.

The environment is constantly changing. We, humans, are affecting the environment. People are too dependent on non-renewable energy. It is not beneficial. We use methane and black carbon which is the cause of global warming. Carbon and methane are mostly used in open cooking fires. Fossil fuels like coal are used to generate electricity and burning such fuels create a massive amount of Carbon-di-Oxide in the atmosphere which creates Global Warming. People are using an excessive amount of such methods. If the energy is clean, it will be better for the environment. Neither the government has not taken any initiative nor the industries taken any precautionary measures for the exploitation of such resources. It has now become a necessity to introduce some alternative energy sources. [14] [15].

2.4.2 Average sun time

Finding the average sun time is important because the presence of solar power helps the stove to operate, also it helps to recharge the battery. The sun time is not always the same throughout the year. In January and March, the average sun time is from 8 am to 4 pm. The highest sunshine is gained from 12 pm to 3 pm. From April to August the average sun time is from 6 am to 6 pm. The highest sunshine is gained from 11 pm to 4 pm. From September to December the average sun time is from 7 am to 5 am. The highest sunshine is gained between midday and 4 pm. If we operate the stove during the highest sunshine then the system will be the most effective.

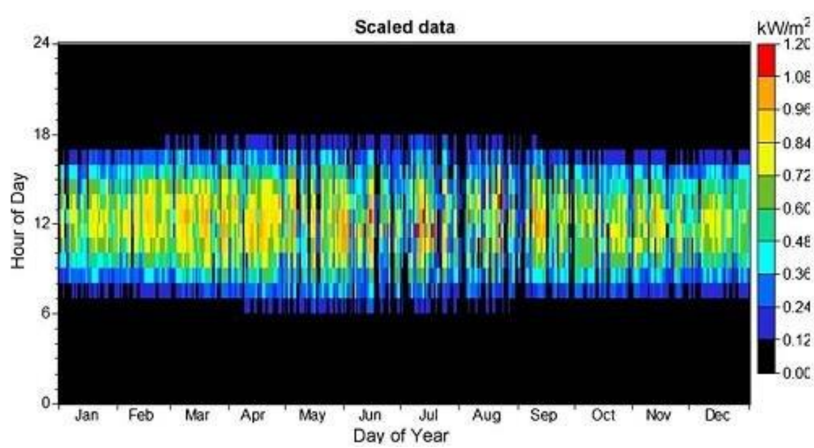


Fig (2.3): Monthly average sunshine hours in Bangladesh [16]

2.4.3 Panel Sizing

Usually, in a solar photovoltaic system, the sizing calculation has been done after the battery selection and charge controller selection. The load of the system is approximately 500W, current flow is 10A through the load, voltage is 48V. In the case of the battery, it is rated as 50AH by the manufacturer. The efficiency of the battery is approximately 80%. Per day power consumption is roughly 1728W. So, the total power consumption is (1728/0.8) = 2160W. The lowest average sunshine in this country is 2.6 hours. It is during the rainy season. The average operating hour of the stove is 3 hours daily. The average sunshine hour is 5.67 hours in Bangladesh. This duration is more than 2 times compared to the lowest average sunshine hour. To set up a standard specification of the stove, the daily average operating hour is taken as 3 hours. Therefore, the solar energy capacity of this system becomes (2160/3) = 720W. Considering other losses as negligible in the system, the considered value is 760W. Two 180W and two 200W monocrystalline PV modules have been connected in series to get 760W from the PV panel [17].

2.4.4 Types and efficiency of different solar panels

There are 3 generations of solar PV panels consisting of 7 different types.

1st generation: These are the traditional solar panels made of polysilicon and monocrystalline silicon.

Monocrystalline Solar Panel (Mono-SI): This is the purest one made of monocrystalline silicon. It has a uniform dark look and has rounded edges. The purity of the silicon causes its efficiency rates. The latest one has above 20% efficiency. It provides high output power, occupies less space, lasts longer. It is also expensive. It is being less affected by high temperatures.

Polycrystalline Solar Panel (Poly-SI): It has squares and the angles are not cut. It looks blue and speckled. This panel is made of melting raw silicon. It is cheaper and faster to process. Its efficiency is 15%. It is also lower in price. It has a short life span. This type of panel is affected by high temperature.

2nd generation: These are thin-film solar cells. These panels are mostly used for photovoltaic integrated into buildings, photovoltaic power stations or smaller solar systems.

Thin-Film Solar Cells (TFSC): This type of panel is easy to produce. It is also cheaper. Silicon, cadmium or copper is used on a substrate to manufacture this panel. TFSC panels are flexible. It is not much affected by high temperatures. It consumes a lot of space.

Amorphous Silicon Solar Cell (A-Si): It is mainly used in pocket calculators. It is a triple-layered technology. It is the best among thin-film variety. Here 'thin' means 1-micrometer length. It has a 7% efficiency. It is very cheap.

3rd generation: This generation's solar panels are still in the research and development phase. Some of this type generates electricity using materials which are organic. Others use inorganic materials. Biohybrid Solar Cell is one of the types which is 1000 times more efficient than 1st generation solar panels. Cadmium Telluride Solar Cell (CdTe) is another type of solar panel which is in the research phase. It is made up of Cadmium Telluride. It has a relatively low cost and short payback time. Among all solar technology, Cadmium Telluride requires the least amount of water to produce. It is expected to keep our carbon footprint low. However, Cadmium Telluride is toxic if inhaled or ingested. The last type of this generation is Concentrated PC Cell (CVP and HCVP). It has an efficiency rate of up to 41%. This is the highest among all the photovoltaic systems.

2.5 Specifications of both burners

2.5.1 Slow cooker

A slow cooker is a set up on the countertop electrical cooking system which is used to simmer at a lower temperature than all the other cooking methods. The main goal of the system is to reduce the cooking time. In this cooking methodology, we can capture as much heat as possible. In this version of the solar stove, we have designed a slow cooker using a 1000W, 1.5-liter rice cooker. It is a cooking pot in round shape and made of metal. To cover the edge of the pot we have used a lid made up of glass. This slow cooker is safe to use. The lid prevents the warm vapor from escaping. It works as an energy reservoir. The coil we used to heat the cooker is 16AWG coil. We have opened the bottom part of the cooker and placed the designed coil inside of it. This coil is 5.4 Ω. This coil connection goes through a two-way switch. A metal bar is used underneath the coil so that the coil is in a fixed position. Varieties of items can be cooked in this slow cooker. We have boiled water, cooked rice, beef, chicken and pulse.

Fig (2.4): Slow Cooker

2.5.2 Infrared cooker

Previously described slow cooker is not suitable for frying items. That is why we have designed another system for cooking frying items. It is called an infrared cooker. The 5.4-Ω coil has been fitted inside a frame. An infrared glass has been placed on top of the coil and the frame. The glass protects the coil from any dangers like short-circuit which can be caused by the usage of metallic pans. This infrared glass also protects the coil and circuitry from liquids used in for cooking. The glass helps to keep the heat centralized. There is a knob that is being used to control the heat of the system. We have fried eggs in this infrared cooker.

Fig (2.5): Infrared Cooker

2.6 Required battery for the system

In version-3 solar deep cycle battery had been used. We have changed the solar deep cycle battery with a sealed lead-acid battery. There are three main reasons for this. Mainly, solar deep cycle batteries are required maintenance. For a regular user battery maintenance is a problem. They reduce the hassle; sealed lead acid battery is a better replacement. A sealed lead-acid battery does not require any external maintenance. The other reason is solar deep cycle batteries are heavier and consumes more space than sealed lead-acid battery. The last reason is that sealed lead acid batteries provide better performance, stability and back up time.

Fig (2.6): Sealed Lead- Acid battery. (12V Each)

Chapter 3:

System Components

In this chapter, the components used for the project and the modification was made on top of previous version to improve the efficiency of the system will be discussed. The performance and efficiency of each component and how it helps to make the system a better one will be shown here too.

3.1 Hot Plate

Hot plate is the heating element of solar cooker. It converts electrical energy into heat through which the food can be cooked. 2 hot plates have been used in the system. One is in slow cooker and the other one is in the infrared cooker.

Fig (3.1): Picture of hot plate

Throughout the thesis time, it was searched how the system efficiency can be improved and one of the solutions was redesigning the hot plate. Details about the whole process is given below.

3.1.1 Coil measurement

Different thickness of coil wires has been tested. Among all of them, 16AWG gave the best result for cooking purpose. It can hold constantly desired 10A current without any disturbance. If any thinner wire (18/20 AWG) was taken, the coil heated up too much and cut up. On the other hand, if any thicker wire (14 AWG) we taken, the coil didn't get hot enough to cook food. On both cases, the desired result could not be achieved. So, for the best result, the decision was taken to go with 16 AWG wire for the system. The length of hot plate coil wire is 170cm.

3.1.2 Hot Plate re-designing

From the beginning of the thesis, it is found that previous version of the system was not efficient enough and it was taking a long time to cook foods. After doing a fair bit of research, it was found that the resistance of the load was not properly matched with system impedance. So, with the help of Impedance matching method, the problem was solved. It is found that for the 48V system, to get 500W, 5.4Ω is the best possible solution.

3.1.3 Hot Plate Comparison: Here is the comparison of hot plate data between commercial version and version 3.

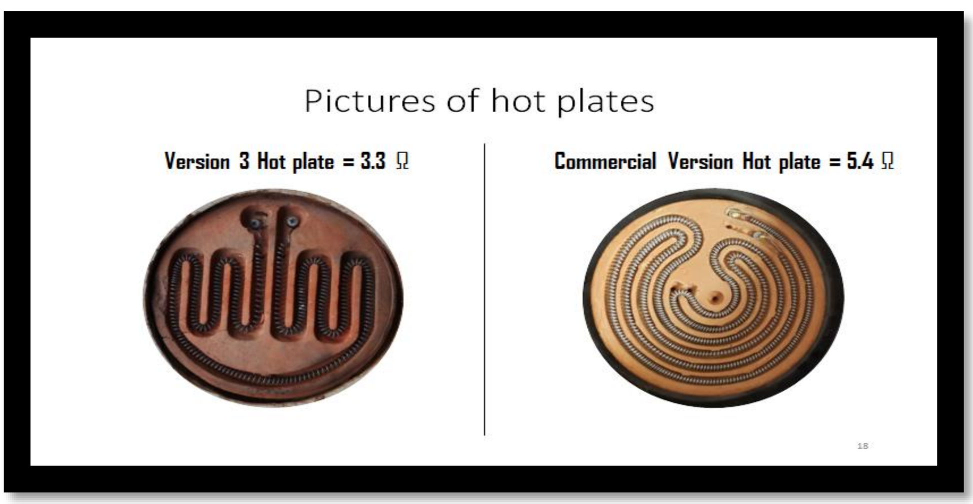


Fig (3.2): Picture of Hot plate of version 3 and the commercial version

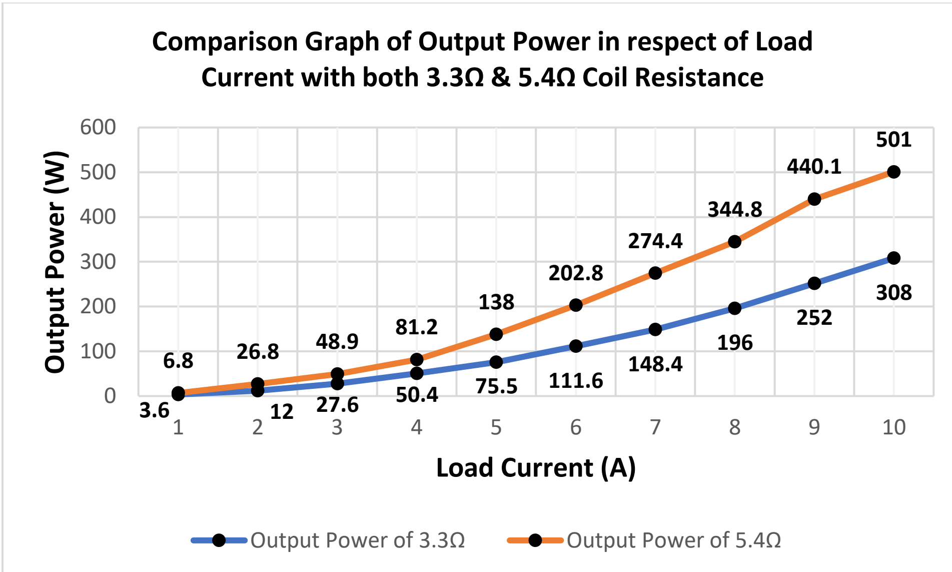


Fig (3.3): Comparison graph of the output power with 3.3Ω & 5.4Ω coil

Here it can be seen that, after the improvements done, the performance of electric cooker has improved significantly. From the graph, at 10A current the previous version's output power was only 308W whereas commercial version's output power is 500W. So, it is a big improvement over previous version and as a result, the cooking time has reduced significantly.

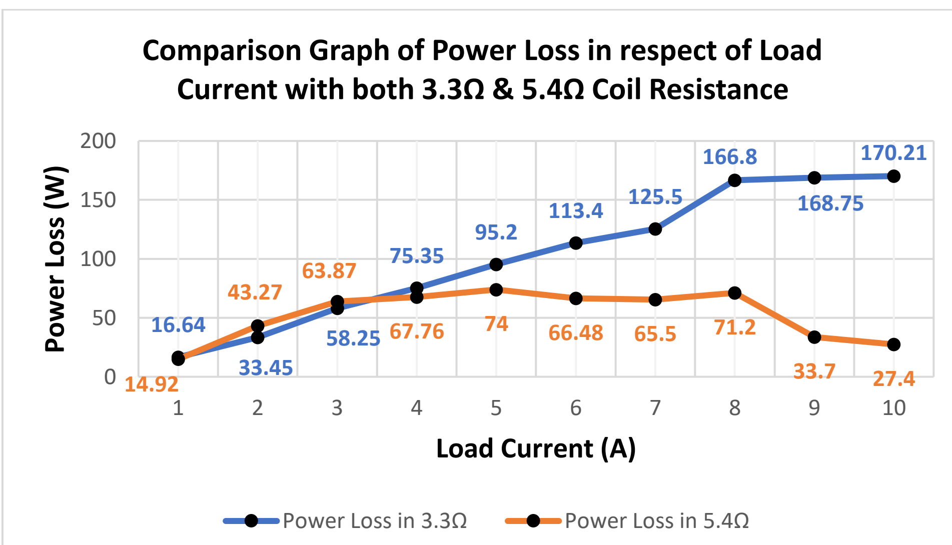


Fig (3.4): Comparison graph of power loss with 3.3Ω & 5.4Ω coil

In this graph, the comparison of power loss between commercial version and previous version's system has been shown. It can be seen that by applying Impedance matching method, it was possible to reduce the loss of the system quite a bit. Compared to previous version's 170W loss, it was reduced to only 27W.

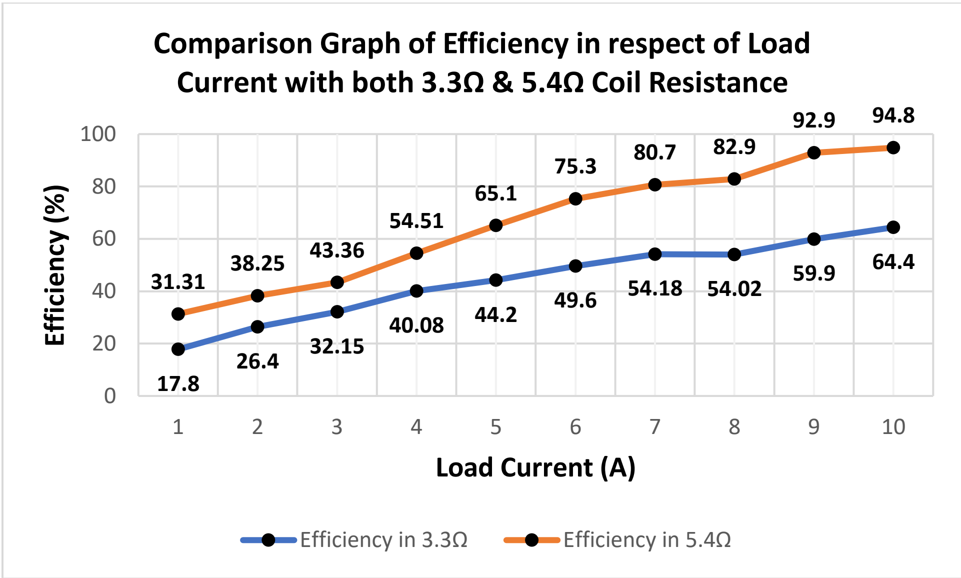


Fig (3.5): Comparison graph of the system efficiency with 3.3Ω & 5.4Ω coil

In the system efficiency graph, it can be seen that for the modified load, there is a big improvement in system efficiency. The commercial version was 95% efficient whereas version 3 was only 64.4% efficient. So, in conclusion it can be said that the commercial version electric cooker is much better and efficient in every way possible.

3.1.4 Limitations

Though the efficiency of solar slow cooker was maximized, still there are a few limitations to it. The system cannot go over 10A current with the redesigned hot plate. As a result, the system output cannot be over 500W. It is enough power for the slow cooker but restricted in fast cooking.

3.2 Heat controller

3.2.1 Specifications

One of the major components of the system is the heat controller. It transfers power coming from charge controller to the hot plate. The heat controller operates at 48V and can supply up to 20A current without any problem. It uses PWM technology to transfer power. The amount of current flow into out load can be controlled with the heat controller. Thus, the heat of our cooker with heat controller can be controlled. There is a potentiometer to control the current flow. It operates at a reference voltage of 0-5V. When the potentiometer is at the left most position, there is no current flow to the load. Turning it clockwise increases the current flow and at right most position, 10A current flows to the system. There is enough heat sink to dissipate excess heat generated at the heat controller.

Fig (3.6): Picture of the heat controller

3.2.2 Circuit diagram

Here is the circuit diagram of the heat controller. It consists of a microprocessor, some transistors, capacitors, resistors, relay and operational amplifiers.

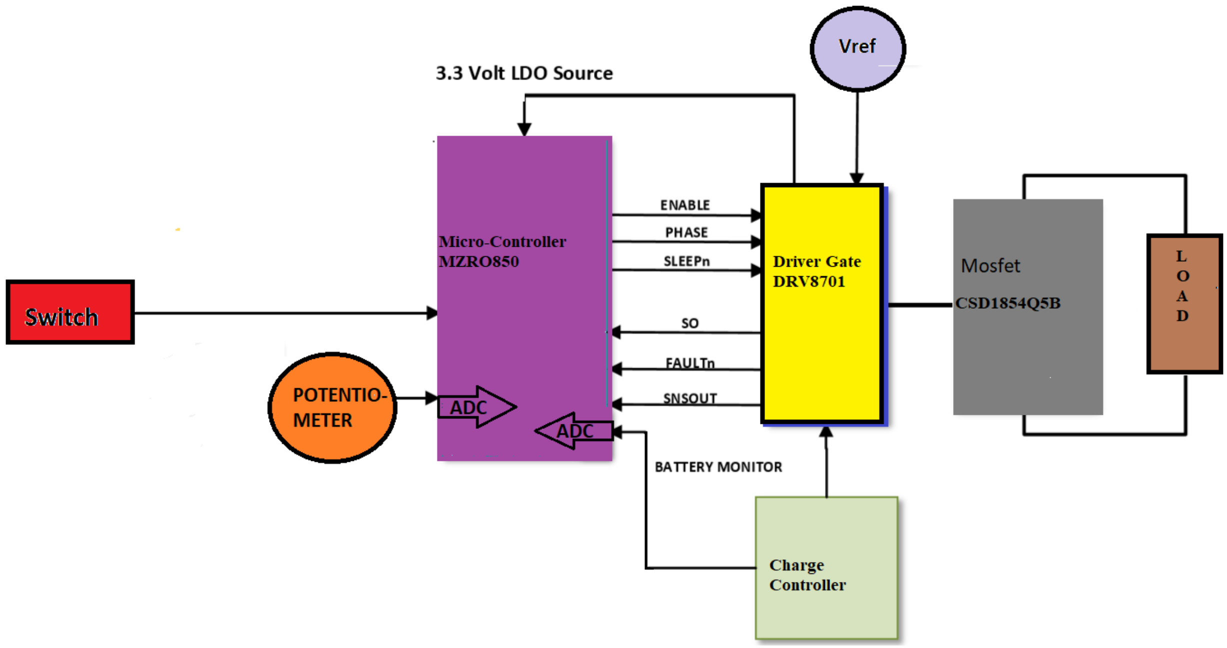


Fig (3.7): Internal block diagram of the heat controller

DRV8701 is a single H-bridge gate driver which has 4 external N-channel MOSFETs. It is used to drive a 48V bidirectional DC motor. This chip allows easier interface to controller circuits.

If the nSLEEP in is set low then the driver sets to sleep mode. Sleep mode shuts the internal circuitry to achieve low quiescent current draw.

The nFAULT pin indicates the fault conditions. Undervoltage lockout, overcurrent shutdown, charge pump faults, short-circuit protection and over temperature are the fault conditions.

The SNSOUT pin of the driver indicates when the device is in current chopping mode. When the driver is in a slow decay mode caused by internal PWM current chopping, the open-drain SNSOUT output is pulled low. If the current regulation is disabled, then the SNSOUT pin will be high.

The enable pin powers up the driver when required.

The microcontroller does the rest of the job. It takes input from the switch and the potentiometer. Then passes the signals as Pulse Width Modulation then sends them to the driver DRV8701. The driver then opens the mosfets, which then power ups the coils.

Using pulse width modulation to control a motor has an advantage. Which is, the power loss is small in switching transistor. That is because the transistor is either on or off. As a result, it has a reduced power dissipation. This gives linear control which results better speed stability. The amplitude of the motor's voltage also remains constant. So, the controller is always at full strength.

3.2.3 Wiring analysis

The heat controller consists of 4 sets of wire. 1st set of wire is coming from the battery and solar panel combination. It gives power for the system. 2nd set of wire is for potentiometer. Three wires are connected to potentiometer which are + ve, - ve and variable wire. 3rd set of wire is for ON/OFF switch. And the last set of wire is for the load which in our case is the hot plate.

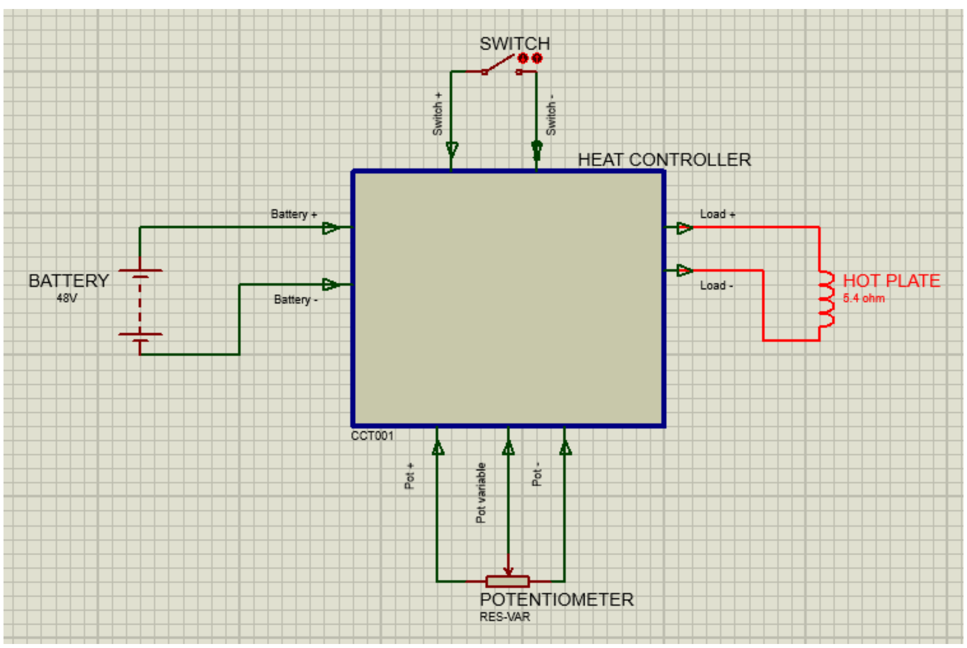


Fig (3.8): wiring diagram of the heat controller

3.2.4 Performance & efficiency test

The heat controller has been tested thoroughly to make sure that the system does not make any trouble due to overheating problem of the heat controller. While performing the tests, the system was running with constant 10A current. The test result is following:

Temperature Test of Heat Controller:

Time (Min)	**Temperature of heat controller body (°C)**	**Battery CC Voltage (V)**
1st	31	51.2
5	31	51.3
6	32	51.3
9	33	51.3
11	34	51.3
22	35	50.7
26	36	50.7
35	36	50.5
46	36	50.4
75	37	50

Chart (3.1): Temperature of the body of commercial version heat controller

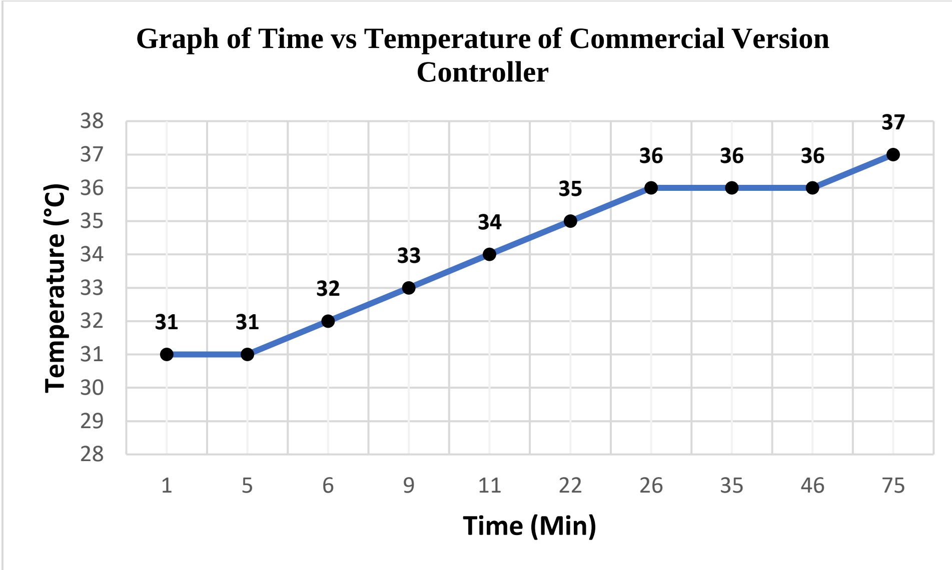


Fig (3.9): Time vs temperature of the heat controller graph

From the graph it is observed that after running the system for one and half hour, the heat controller's temperature increased only by 6 degree Celsius which is quite good for a system. So, the performance of the heat controller was satisfactory.

For efficiency test, the following set of data was taken to calculate the efficiency of the heat controller. From the chart we can see that the difference between input and output power of the heat controller is quite low. It is only 27.4W loss when the system is running at 10A giving the desired output of 500W. The efficiency is almost 95% which is very good for a system.

Efficiency chart for commercial version heat controller:

Battery voltage (CC) (V)	**Before Controller Current (A)**	**Input Power (W)**	**Load Voltage (V)**	**Load Current (A)**	**Output Power (W)**	**Power Lost (W)**	**Efficiency (%)**
54.3	0.4	21.72	6.8	1	6.8	14.92	31.31
53.9	1.3	70.07	13.4	2	26.8	43.27	38.25
53.7	2.1	112.77	16.3	3	48.9	63.87	43.36
53.2	2.8	148.96	20.3	4	81.2	67.76	54.51
53	4	212	27.6	5	138	74	65.1
52.8	5.1	269.28	33.8	6	202.8	66.48	75.3
52.3	6.5	339.95	39.2	7	274.4	65.5	80.7
52	8	416	43.1	8	344.8	71.2	82.9
51.5	9.2	473.8	48.9	9	440.1	33.7	92.9
51.3	10.3	528.4	50.1	10	501	27.4	94.8

Chart (3.2): Efficiency chart for commercial version heat controller

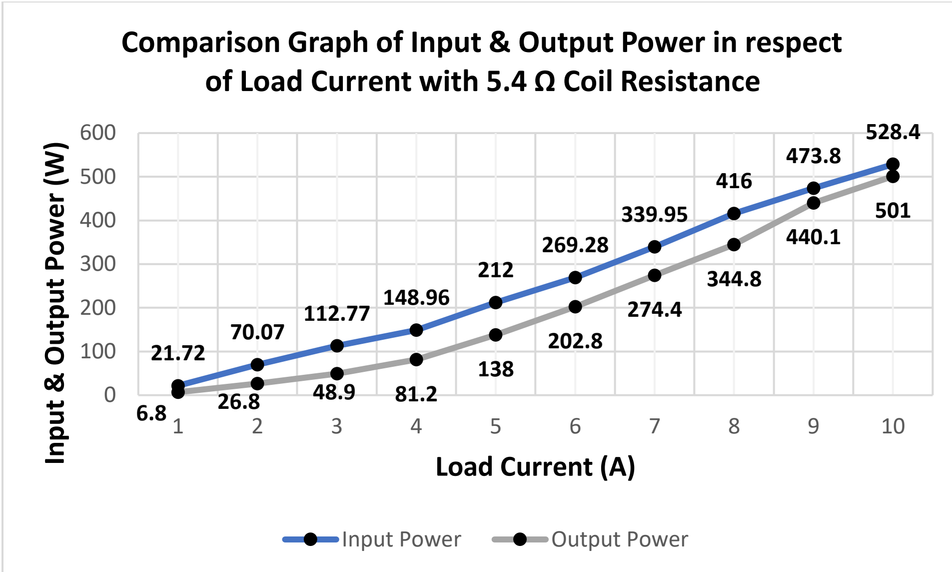


Fig (3.10): Input and output power of the heat controller

Result: For 5.4Ω load resistance, the efficiency increases gradually as the load current increases. The highest efficiency was achieved when the load current was 10A. The efficiency is 94.8%.

3.2.5 Switching methods

In the system, only a single heat controller was used to run both slow cooker and infrared cooker. A DPDT (Double Pole Double Throw) switch was used to easily switch between two cookers. When the switch is turned to the right side, the infrared cooker will be ON and the switch turned to the left side means the slow cooker will be ON.

Fig (3.11): A DPDT switch

3.3 Charge controller

Solar charge controller is used to combine the current from the solar panel and battery to supply to the load. When the cooker is on, the supply current is shared by the PV panel and the batteries. It comes to the cooker through the charge controllers. When the cooker is off, the battery is charged by the PV panel through the charge controller. For an off grid solar system like commercial one, solar charge controller is necessary for its protection. The charge controller protects the battery from overcharging. The system is a 48V system and intended to run the system at constant 10A current. There are two types of solar charge controller widely available in the market now. One is the PWM based charge controller and the other one is MPPT based charge controller. Both the charge controllers were tested for the system. After testing, we found that MPPT (Maximum Power Point Tracker) based charge controller is best for the system. The rating of the charge controller is 48V, 50A. There are few reasons why this charge controller was chosen. It has the following features:

1. It has an LCD display which can show battery SOC, LVD, HVD
2. The LVD and HVD can be manually controlled
3. It has a temperature probe which can sense environment temperature
4. In a case of over heat, it disconnects automatically
5. Safe and easy to use

Fig (3.12): Solar charge controller

Through this charge controller, the HVD and LVD of the battery can be controlled. Desired HVD was set to protect the battery from over charging and LVD to protect the battery from draining below rated voltage. The auto disconnect function in the charge controller helped not to worry about overcharging or any overheating issue. There are 6 ports in the charge controller, they are: + Panel, -Panel, +Battery, -Battery, +Load, -Load. The connection of the Solar PV panel and the AC-DC power supply is connected with the +Panel and – Panel port of charge controller through a DPDT switch. 48V of battery connection is coming to the + and – Battery ports of charge controller. The remaining ports: + and – load is connected to the battery wires of heat controller through a MCB (Miniature circuit breaker). The MCB protects the system from over current flow. When the load is ON, the green light turns on and when the batteries are charging, the red light on charge controller turns on.

3.4 AC-DC backup power supply

The system has a backup power supply in case of rainy days or there is less sun time. In these times, the system will run on backup power supply as well as the batteries will be charged. After the batteries have charged, power supply can be turned off as the batteries will give sufficient back up. In our country, the rating of national grid is 220V AC. So, we need an AC-DC converter to run the system with national grid. The power supply converts 220V AC current into 48V DC current for the system. A one-way power diode is added in the output side of power supply as protection. Input of the power supply is connected to wall socket and the output is connected to the DPPT switch through which we can select between solar panel and power supply.

Fig (3.13): Backup AC-DC power supply

3.5 Battery

3.5.1 Battery analysis

Battery is used for storing charge and use it when needed. Usually, when the system is ON, batteries provide most of the power for the system along with the solar panel. When the system is off, batteries are charged with solar panel. For the system, 4*12V batteries were used. The 4 batteries were connected in a series connection. Thus, desired 48V was acquired to run the system. Two types of batteries were tested for thesis project. One is the solar deep cycle battery and the other one is sealed lead acid battery. After analyzing testing data, decision was taken to use sealed lead acid battery for the project. Benefits of sealed lead acid battery are:

1. It is maintenance free.
2. The cost is low compared to Li-ion battery
3. It can hold high current flow.

Fig (3.14): Sealed lead acid batteries in series connection

In the system 50Ah sealed lead acid batteries are used. 50Ah is selected on the basis of panel power & average sunlight of our country. The analysis for the battery is shown below:

Panel = 800W

Average Sun time in Bangladesh = 3 hours

So, 760W * 3 Hours = 2280WH

System = 48V

So, 2280WH/48V = 47.5AH≈50AH

Therefore, 50Ah batteries are needed to charge the batteries full by 1 day with our 760W solar panel.

3.5.2 Analyzing battery discharging rate

Sealed lead acid battery was used for the system. From the spec sheet it is found that these batteries can be drained up to 50% S.O.C.

Desired Current for the system = 10A

So, 50AH/10A = 5Hours.

For 50% S.O.C,

Around 2.5 hours of backup time is expected from these batteries.

Here are some field test data for battery backup test.

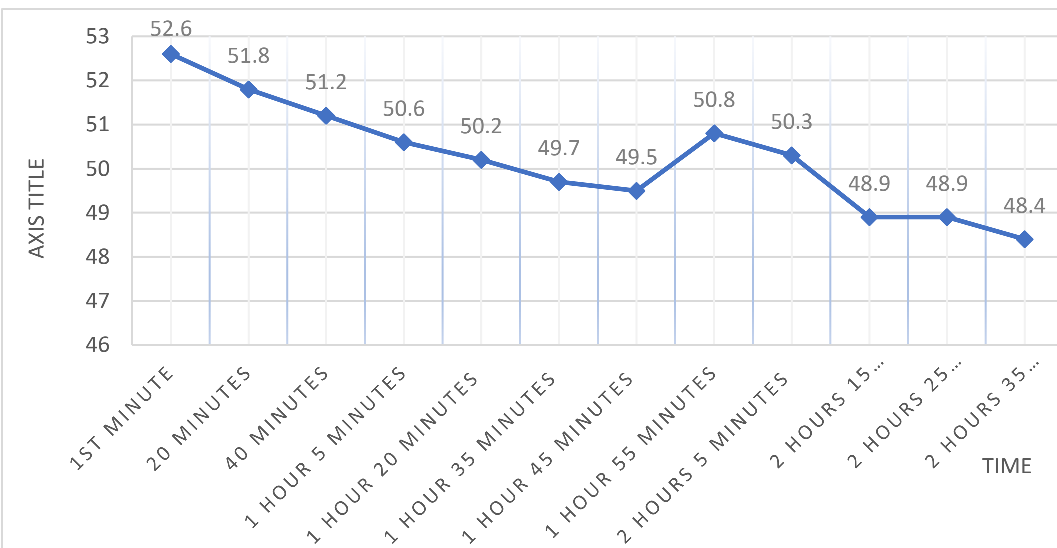


Fig (3.15): Battery discharge voltage at a constant 10A current

Here, the battery is discharging at a stable voltage. After 2hours and 35 minutes, battery reached at 48.4V which is 50% S.O.C according to spec sheet.

Graph of battery discharging rate

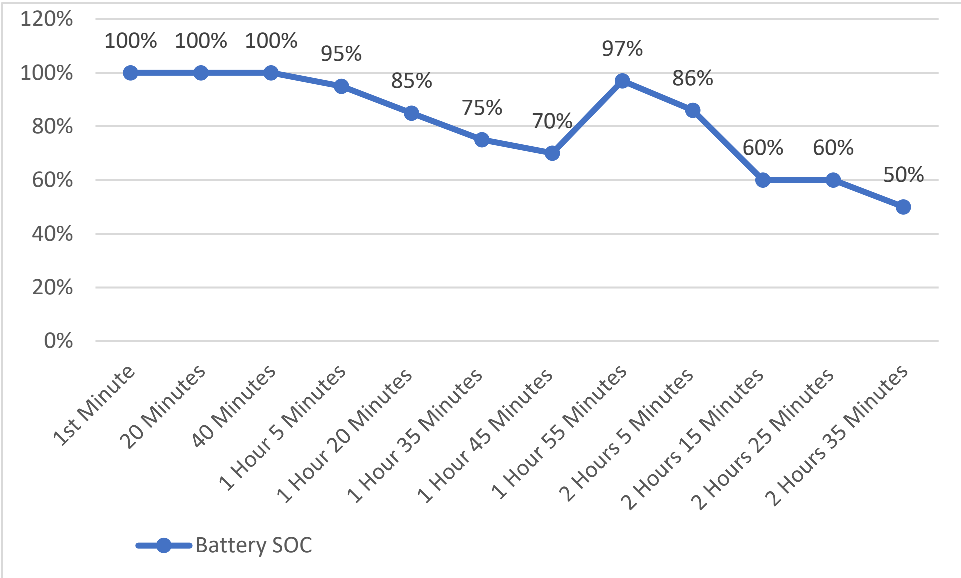


Fig (3.16): Battery S.O.C while doing back up test

From the graph, after 2 hours 35 minutes, battery SOC is at 50%. So, the estimated backup time was correct and the batteries performed as expected.

3.6 Display

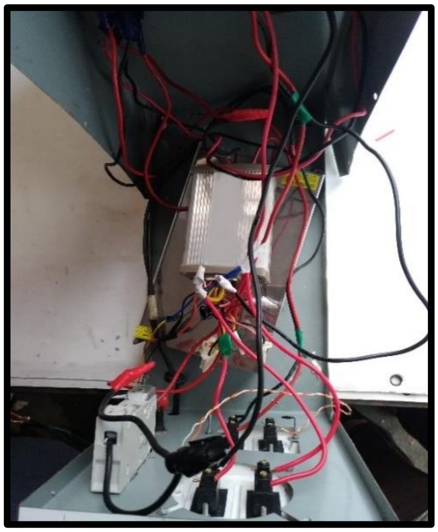
A power display has been added to the system as a part of improvement. It helps to see the amount of power delivered to coils which helps to produce heat for cooking. It shows load power as well as load voltage and current. As a result, power can be easily controlled by looking at the display without any special probe like clamp meter and volt meter.

Fig (3.17): Power display of the system

3.7 The control box

For ease of use, a control box has been introduced in the system. Solar charge controller, Heat controller, power supply all are fitted inside the control box. A set of wire is going in the cooker. The MCB is fitted inside the control box. Also, the switch to change between power supply and solar panel to charge the battery is fitted in the control box too. With the control box, there is no hassle in connecting wires. It is designed to just plug and play. Plug in the wires of cooker, battery and solar panel and it is good to cook. The potentiometer used to control the heat is fitted in the infrared cooker to reach easily.

(a)



(b)

(c)

Fig (3.18): Picture of the control box: (a) Front view (b) Inside view (c) Rear view

Chapter 4:

Data Analysis

4.1 Objective of the 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. Lots of different type analysis is done in basis of various parameters. Most of the components used in the previous system was modified to get better result in various terms. Battery backup test, impedance matching test, heat controller efficiency test &cooking time test are done in order to improve the efficiency of the system. A lot of graphical analysis is done in basis of different parameters.

4.2 Battery Performance

Battery performance test is designed to determine whether batteries are fit for the purpose for which it was intended before it is approved for use in the product. Batteries are used in this system for backup as there will be no sun at the night. From the SOC chart, the batteries were drained up to 50% SOC to maintain the quality of the batteries. The objective of this test is to see how much time this system runs without sunlight. The system constantly ran at 7.5A to 9A current. Later, the battery performance test will be presented graphically to see the overall backup of the system.

4.2.1 Battery backup test for 24V system

Battery backup test of new Sealed Lead Acid batteries with 24 Volt system using 24V 500W heat controller & 3.3Ω hot plate without using solar charge controller.

Runtime	Battery Voltage (V)	Load Voltage (V)	Load Current (A)	Output Power (W)
1st Minute	25.7	14.19	9	127.71
10 Minutes	25.7	17.67	11	194.37
20 Minutes	25.7	13.92	9	125.28
35 Minutes	25.7	14.5	9	130.5
55 Minutes	25.61	14.53	9.1	132.22
1 Hour 15 Minutes	24.93	14.3	9	128.7
1 Hour 45 Minutes	24.96	14.3	9	128.7
2 Hours 15 Minutes	24.91	14.3	9	128.7
2 Hours 45 Minutes	24.87	14.5	9	130.5
2 Hours 55 Minutes	24.75	14.3	9	128.7
3 Hours 10 Minutes	24.52	14.2	9	127.8
3 Hours 20 Minutes	24.25	14	9	126

Chart (4.1): Output power chart of 24V system

Result: The 50% SOC for 24V system is 24.2V. The system ran up to 24.25V for almost 3 hours 20 minutes. The battery performance for the 24V system was satisfactory as it gave much better performance than the solar deep cycle batteries. The current supplied to the system was pretty constant. But there were some power losses as there was some voltage difference between battery close circuit voltage & load voltage. The output power of the system was approximately 130W constantly.

4.2.2 Battery backup test for 48V system

Battery backup test of new Sealed Lead Acid batteries with 48 Volt system using 48V 1000W heat controller, 3.3Ω hot plate & 1K Pot without using solar charge controller.

Runtime	**Battery Voltage (V)**	**Load Voltage (V)**	**Current (A)**	**Output Power (W)**
1st Minute	50.9	30	10	300
15 Minutes	50.8	31.5	10	315
30 Minutes	50.9	30.64	10	306.4
45 Minutes	50.3	30.5	11	335.5
1 Hour	49.7	35.2	10	352
1 Hour 15 Minutes	49.6	31.97	10.5	335.7
1 Hour 32 Minutes	49.3	31.3	10.1	316.1
1 Hour 47 Minutes	49.1	31.0	10.1	313.1
1 Hour 57 Minutes	48.7	30.54	11.2	342
2 Hours 3 Minutes	48.6	30.2	10.3	311
2 Hours 8 Minutes	48.6	30.1	9.5	286
2 Hours 13 Minutes	48.6	30.2	9.5	287
2 Hours 18 Minutes	48.5	31.2	9.3	290.2
2 Hours 25 Minutes	48.8	31.4	10.1	317.1

2 Hours 30 Minutes	48.4	31.3	10.1	316.1

Chart (4.2): Output power chart of 48V system

Result: The 50% SOC for 48V system is 48.4V. We ran the system exactly up to 50% SOC for almost 2 hours 30 minutes. We also monitored the current whether it was constant or not. The result was satisfactory. The output power of the system was approximately 300W constantly. There were power losses in the system still the battery performance was better than the previous solar deep cycle batteries.

4.3 Impedance matching

In electronics, impedance matching is the practice of designing the input impedance of an electrical load or the output impedance of its corresponding signal source to maximize the power transfer or minimize signal reflection from the load.

Impedance matching was a very important test for the system. The system was losing too much power initially. After going through the impedance matching test, the optimum resistance for the hot plate is found. The result was fascinating. Now the system was performing better and dissipating much more heat, which is essential for the purpose of use.

To perform this impedance matching test for the system, different resistance of hot plate and the readings of output power have been taken. The test was performed on AWG 16-gauge coil in the system. 1.5Ω, 3.3 Ω, 4.5Ω, 4.8Ω, 4.9Ω, 5.2Ω, 5.3Ω, 5.4Ω, 5.5Ω, 5.8Ω & 6.1Ω resistances were used in the testing. The test operated in different ampere of load currents. The most suitable operating load current is 10A since the system was designed to produce 500W output power. Now, the calculated results for 10A current in the system will be discussed.

It is optimized that 5.4 Ω hot plate resistance best suits the system. Because, it gives the highest amount of efficiency.

4.4 Efficiency performance of the system

4.4.1 Input & Output power analysis

Resistance = 1.5Ω

Battery voltage (CC)	Before Controller Current	Input Power	Load Voltage	Load Current	Output Power	Power Loss	Efficiency
(V)	(A)	(W)	(V)	(A)	(W)	(W)	(%)
50.3	4.5	226.35	8.5	3	25.5	200.85	11.27
49.7	7.1	352.87	14.9	5	74.5	278.37	21.11
49.7	9.1	452.27	14.6	7.9	115.34	336.93	25.5
49.3	12.3	606.39	20.8	10	208	398.39	34.3
48.8	15.5	756.4	24.2	16.3	394.46	361.94	52.15

Chart (4.3): Data chart for 1.5Ω resistance

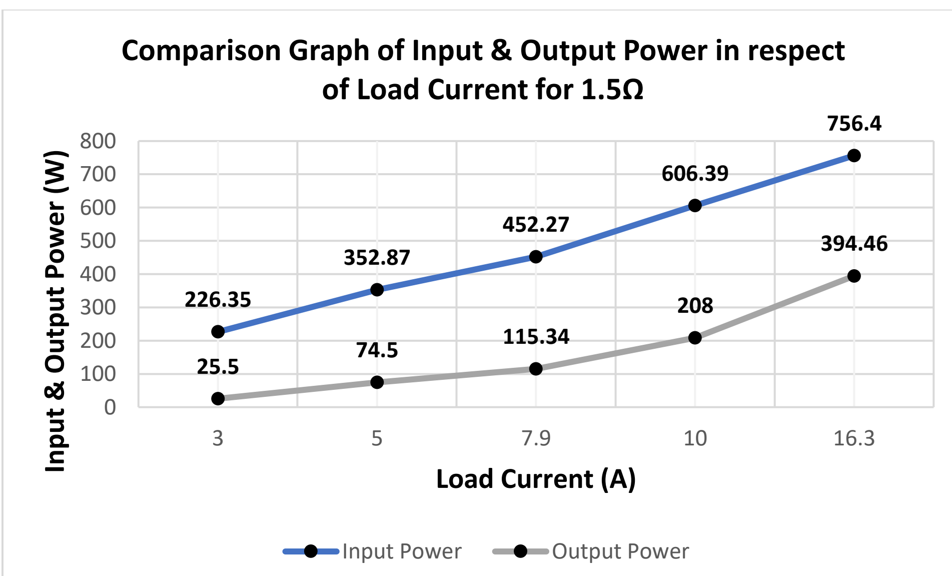


Fig (4.1): Comparison graph of Input & Output power for 1.5Ω resistance

Result: For 1.5 Ω resistance, when the load current was 3A the difference between input power and output power was 200.85W. When the load current was 5A the difference between input power and output power was 278.37W. When the load current was 7.9A the difference between input power and output power was 336.93W. When the load current was 10A the difference between input power and output power was 398.39W. When the load current was 16.3A the difference between input power and output power was 361.94W. The higher the difference between input power and output power, the higher is the loss and higher the efficiency. Since, our system runs on 10A current, we can see that, the efficiency is 34.3% and certainly not efficient enough.

Resistance = 3.3Ω

Battery Voltage (CC)	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(V)	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
50.6	0.4	20.24	3.61	1	3.6	16.64	17.8
50.5	0.9	45.45	6	2	12	33.45	26.4
50.5	1.7	85.85	9.2	3	27.6	58.25	32.15
50.3	2.5	125.75	12.6	4	50.4	75.35	40.08
50.2	3.4	170.7	15.1	5	75.5	95.2	44.2
50	4.5	225	18.6	6	111.6	113.4	49.6
49.8	5.5	273.9	21.2	7	148.4	125.5	54.18
49.7	7.3	362.8	24.5	8	196	166.8	54.02
49.5	8.5	420.75	28	9	252	168.75	59.9
49.3	9.7	478.21	30.8	10	308	170.21	64.4
49.3	10.3	507.79	34.3	11	377.3	130.5	74.3
49.2	11.9	585.5	38	12	456	129.5	77.9
49.1	12.8	628.5	40.7	13	529.1	99.4	84.18
48.8	13.9	678.3	43.3	14	606.2	72.1	89.4
48.6	15.1	733.86	47.1	15	706.5	27.36	96.27

Chart (4.4): Data chart for 3.3Ω resistance

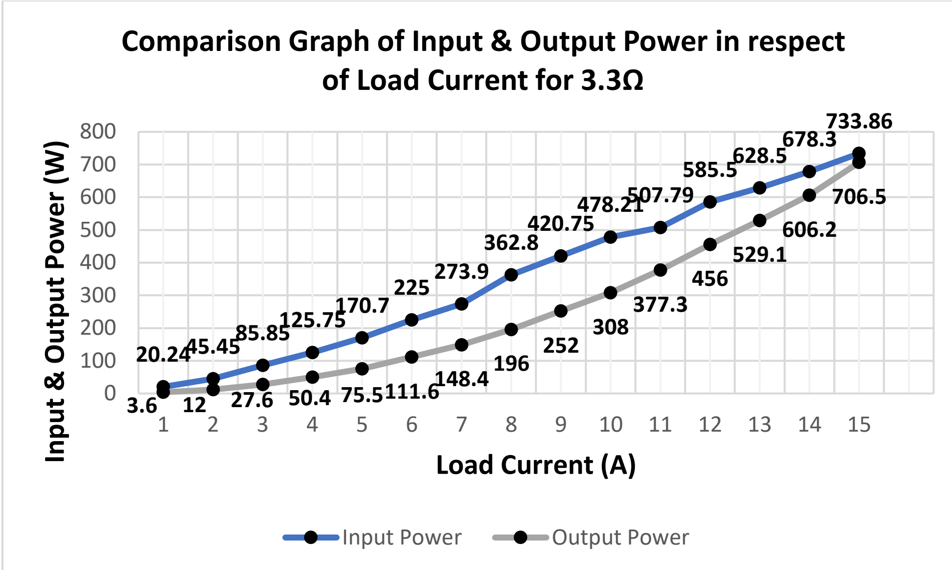


Fig (4.2): Comparison graph of Input & Output power for 3.3Ω resistance

Result: For 3.3Ω load resistance, gradually the efficiency increases as load current increases. The highest efficiency is being achieved when the load current is 15A. At 15A current the efficiency is 96.27%. But our system is ideal for 10A current. At 10A current the efficiency is 64.6%. Which is very poor. That is why it is decided to increase out resistance further, so that we can reach higher efficiency.

Resistance = 4.5Ω

Battery voltage (CC)	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(V)	(A)	(W)	(V)	(A)	(W)	(W)	(%)
52.5	2.1	110.25	11.3	3	33.9	76.35	30.75
52.1	3.9	203.19	19.1	5	95.5	107.69	47
51.6	5.8	299.3	27.3	7	191.1	108.2	63.85
51.1	9.6	491	40.4	10	404	87	82.28
50.5	13	656.5	49.7	12.5	621.25	35.25	94.63

Chart (4.5): Data chart for 4.5Ω resistance

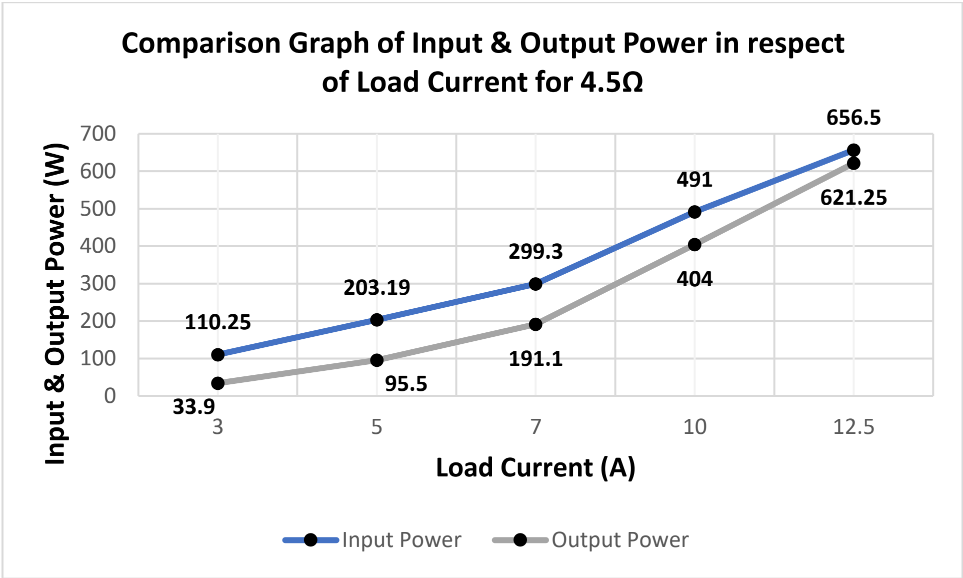


Fig (4.3): Comparison graph of Input & Output power for 4.5Ω resistance

Result: For 4.5 Ω resistance, when the load current was 3A the difference between input power and output power was 76.35W and the efficiency was 30.75%. When the load current was 5A the difference between input power and output power was 107.69W. And the efficiency was 47%. When the load current was 7A the difference between input power and output power was 108.2W. And the efficiency was 63.85%. When the load current was 10A the difference between input power and output power was 84W. And the efficiency was 82.28%. When the load current was 12.5A the difference between input power and output power was 35.25W. And the efficiency was 94.63%. The system is stable in 10A current and for that case, the efficiency is 82.28%.

Resistance = 4.8 Ω

Battery voltage (CC)	Before Controller Current	Input Power	Load Voltage	Load Current	Output Power	Power Loss	Efficiency
(V)	(A)	(W)	(V)	(A)	(W)	(W)	(%)
54	0.8	43.2	3.4	1	3.4	39.8	7.87
54	1.5	81	7.3	2	14.6	66.4	18.02
53.5	2.1	112.35	11.6	3	34.8	77.55	30.97
53.3	3.1	165.23	16.6	4	66.4	98.83	40.19
52.9	4.5	195.73	24.81	5	120.5	75.23	61.56
53.2	5.7	303.24	28.9	6	173.4	129.8	57.18
53	6.4	339.2	32.5	7	227.5	111.7	67.07
52.6	6.8	357.7	35.8	8	286.4	71.3	80.07
52.3	7.7	402.7	40.2	9	361.8	40.9	89.84
51.9	9.5	493.05	44	10	440	53.05	89.24
51.5	11	566.5	50.2	11	552.2	14.3	97.5

Chart (4.6): Data chart for 4.8Ω resistance

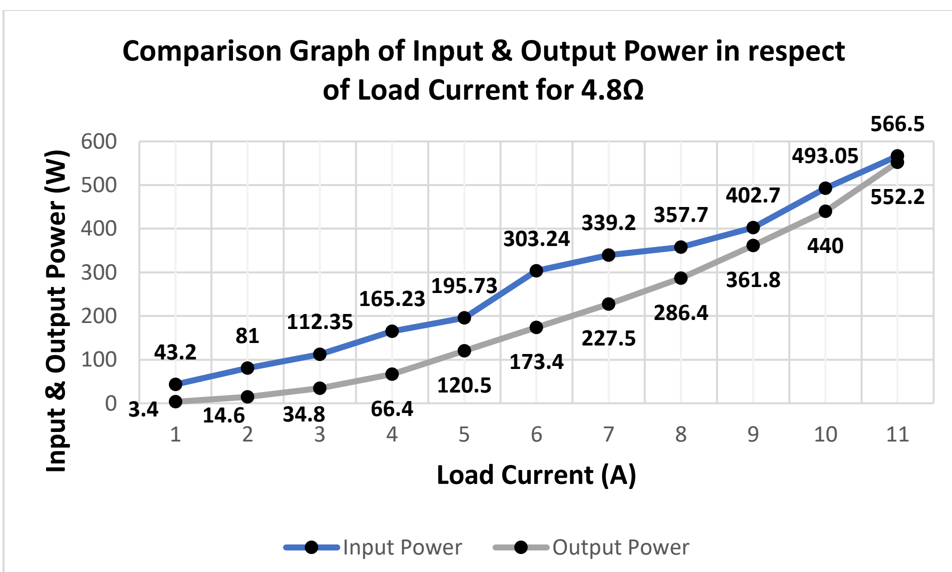


Fig (4.4): Comparison graph of Input & Output power for 4.8Ω resistance

Result: For 4.8Ω load resistance, the efficiency increases gradually as the load current increases. The highest efficiency we can get is when the load current is 11A. The efficiency is 97.5%. Our system is ideal for 10A current. When the load current is 10A, the efficiency 89.24%. 4.8Ω resistance provides better efficiency than 4.5Ω resistance.

Resistance = 4.9Ω

Battery voltage (CC)	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(V)	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
54.2	0.5	27.1	3.4	1	3.4	23.7	12.55
54	1	54	7	2	14.6	39.4	27.04
54	1.9	102.6	12.35	3	37.05	65.55	36.11
54.3	2.8	152.04	16.45	4	65.8	86.24	43.28
53.2	3.6	191.52	18.64	5	93.2	98.32	48.66
52.8	4.7	248.16	23.06	6	138.36	109.8	55.75
52.6	6.1	320.86	27.6	7	193.2	127.66	60.21
52.5	7.5	393.75	32.5	8	260	133.75	66.03
52.1	8.7	453.27	36.1	9	324.9	128.37	71.68
51.8	9.7	502.46	37.74	10	377.4	125.06	75.11
51.2	13.5	691.2	50.1	13	651.3	39.9	94.23

Chart (4.7): Data chart for 4.9Ω resistance

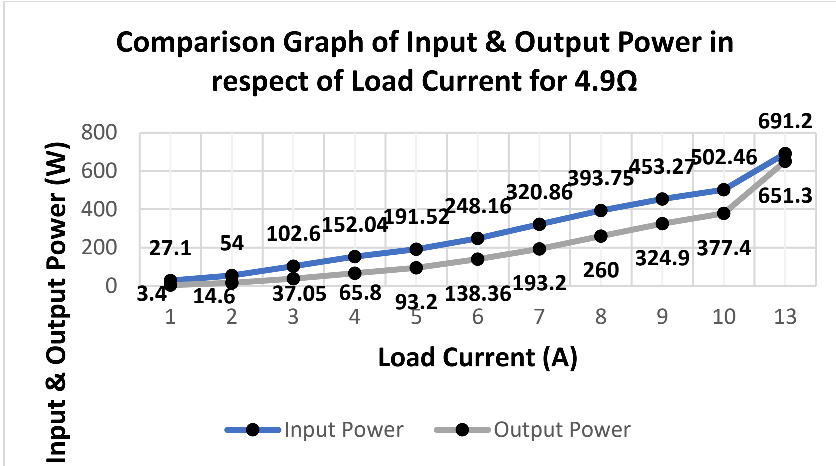


Fig (4.5): Comparison graph of Input & Output power for 4.9Ω resistance

Result: For 4.9Ω resistance, the efficiency increases gradually as the load current increases. The highest efficiency we can get is when the load current is 13A. The efficiency is 94.23%. Our system is ideal for 10A current. When the load current is 10A, the efficiency 75.11%. 4.8Ω resistance provides better efficiency than 4.9Ω resistance.

Resistance = 5.2Ω

Battery voltage (CC)	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(V)	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
54.3	0.6	32.58	5.35	1	5.35	27.23	16.42
54.2	1.3	70.46	10.2	2	20.4	50.06	28.95
54.1	2	108.2	13.3	3	39.9	68.3	36.88
53.8	3.2	172.16	19.8	4	79.2	92.96	46
53.5	4	214	23.55	5	117.75	96.25	55.02
53.0	5.2	275.6	30.1	6	180.6	95	65.53

52.4	6.4	335.36	34.62	7	242.3	93.02	72.25
52.1	7.3	380.33	37.44	8	299.52	80.81	78.75
51.8	8.3	429.94	41.5	9	373.5	56.44	86.87
51.4	10.2	524.28	48.3	10	483	41.28	92.13
51.2	10.9	558.08	50.3	10.5	528.15	29.93	94.64

Chart (4.8): Data chart for 5.2Ω resistance

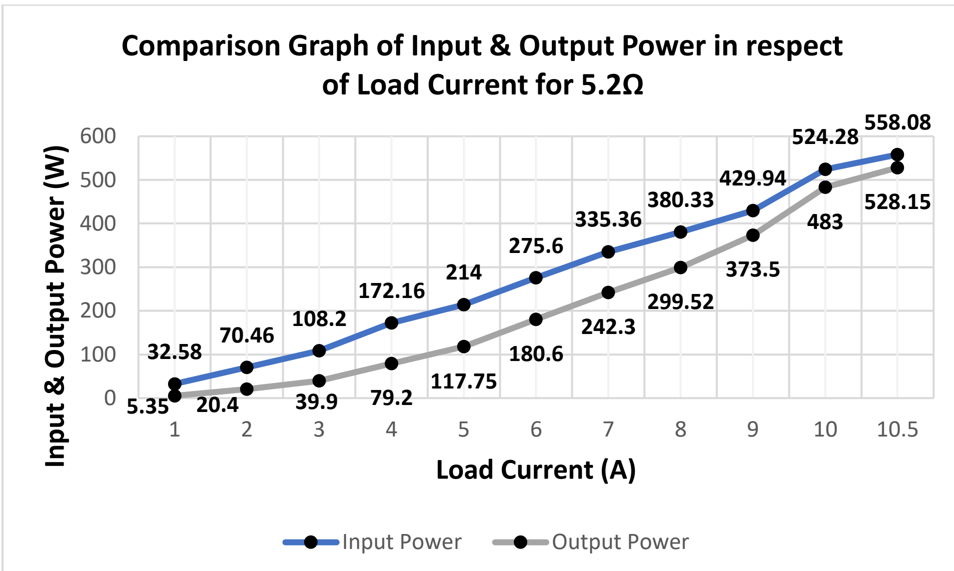


Fig (4.6): Comparison graph of Input & Output power for 5.2Ω resistance

Result: For 5.2Ω load resistance, the efficiency increases gradually as the load current increases. The highest efficiency we can get is when the load current is 10.5A. The efficiency is 94.64%. Our system is ideal for 10A current. When the load current is 10A, the efficiency 92.13%. 5.2Ω resistance provides better efficiency than 4.8Ω resistance.

Resistance = 5.3Ω

Battery voltage (CC)	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(V)	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
52.3	2.2	115.06	11.5	3	34.5	80.56	29.98
51.8	4.1	212.4	21.7	5	108.5	103.9	51.08
51.5	6.2	319	30.8	7	215.6	103.4	67.59
50.9	9.7	493.73	44.3	10	443	50	89.73
50.7	11.5	583	50	11.1	555	28	95.20

Chart (4.9): Data chart for 5.3Ω resistance

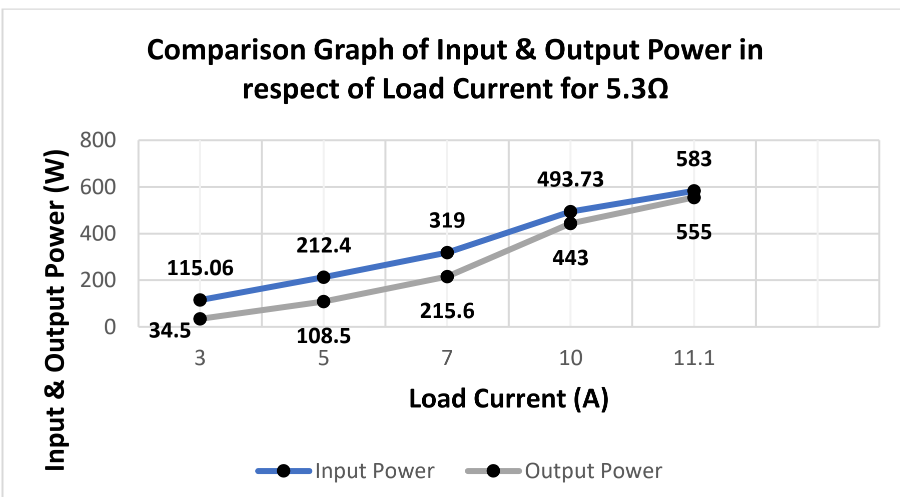


Fig (4.7): Comparison graph of Input & Output power for 5.3Ω resistance

Result: For 5.3Ω load resistance, the efficiency increases gradually as the load current increases. The highest efficiency we can get is when the load current is 11.1A. The efficiency is 95.20%. Our system is ideal for 10A current. When the load current is 10A, the efficiency 89.73%. 5.2Ω resistance provides better efficiency than 5.3Ω resistance.

Resistance = 5.4Ω

Battery voltage (CC)	Before Controller Current	Input Power	Load Voltage	Load Current	Output Power	Power Loss	Efficiency
(V)	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
54.3	0.4	21.72	6.8	1	6.8	14.92	31.31
53.9	1.3	70.07	13.4	2	26.8	43.27	38.25
53.7	2.1	112.77	16.3	3	48.9	63.87	43.36
53.2	2.8	148.96	20.3	4	81.2	67.76	54.51
53	4	212	27.6	5	138	74	65.1
52.8	5.1	269.28	33.8	6	202.8	66.48	75.3
52.3	6.5	339.95	39.2	7	274.4	65.5	80.7
52	8	416	43.1	8	344.8	71.2	82.9
51.5	9.2	473.8	48.9	9	440.1	33.7	92.9
51.3	10.3	528.4	50.1	10	501	27.4	94.8

Chart (4.10): Data chart for 5.4Ω resistance

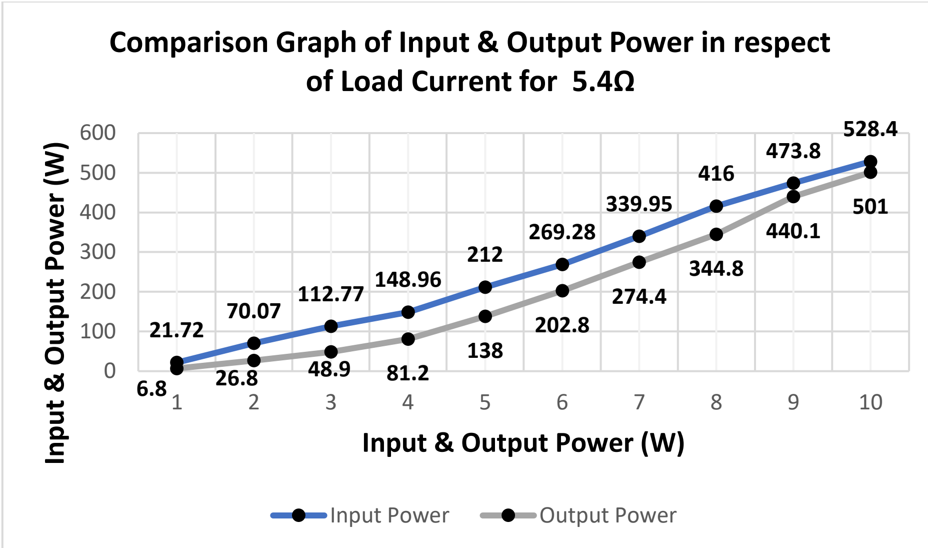


Fig (4.8): Comparison graph of Input & Output power for 5.4Ω resistance

Result: For 5.4Ω load resistance, the efficiency increases gradually as the load current increases. The highest efficiency we can get is when the load current is 10A. The efficiency is 94.8%. Our system is ideal for 10A current. When the load current is 10A, the efficiency 94.8%. 5.4Ω resistance provides better efficiency than 5.2Ω resistance.

Resistance = 5.5Ω

Battery voltage (CC)	Before Controller Current	Input Power	Load Voltage	Load Current	Output Power	Power Loss	Efficiency
(V)	(A)	(W)	(V)	(A)	(W)	(W)	(%)
54.4	0.8	43.52	2.66	1	2.66	40.86	6.11
54.2	.7	92.14	10	2	20	72.14	21.71
54.1	2.3	124.43	11.43	3	34.29	90.14	27.56
53.9	3.2	172.48	16.02	4	64.08	108.4	37.15
53.2	4.2	223.44	23	5	115	108.4	51.47

52.9	5.4	285.66	27.8	6	166.8	118.86	58.39
52.6	6.5	341.9	32.2	7	225.4	116.5	65.93
52.3	7.8	407.94	37.3	8	298.4	109.54	73.26
52.1	8.8	458.48	41.5	9	373.5	84.98	81.46
51.8	10	518	46.6	10	466	52	89.96
51.5	11	566.5	50.7	10.6	537.42	29.08	94.87

Chart (4.11): Data chart for 5.5Ω resistance

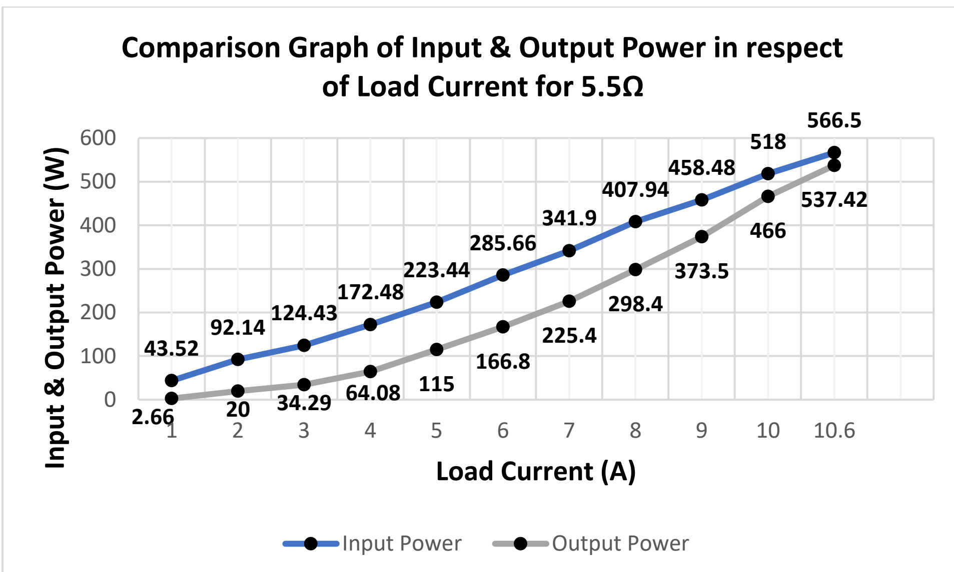


Fig (4.9): Comparison graph of Input & Output power for 5.5Ω resistance

Result: For 5.5Ω load resistance, the efficiency increases gradually as the load current increases. The highest efficiency we can get is when the load current is 10.6A. The efficiency is 94.87%. Our system is ideal for 10A current. When the load current is 10A, the efficiency 89.96%. 5.4Ω resistance provides better efficiency than 5.5Ω resistance.

Resistance = 5.8Ω

Battery voltage (CC)	Before Controller Current	Input Power	Load Voltage	Load Current	Output Power	Power Loss	Efficiency
(V)	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
52.1	2.8	146	16.6	3	49.8	96.2	34.11
51.6	5	258	28.1	5	140.5	117.5	54.46
51.3	6.9	354	38.4	7	268.8	85.2	75.93
51.1	8	408.8	42.1	8	336.8	72	82.39
51	8.4	428.4	45.3	8.5	385.05	42.9	89.88
50.8	9.9	502.92	50.2	9.3	466.86	36.06	92.83

Chart (4.12): Data chart for 5.8Ω resistance

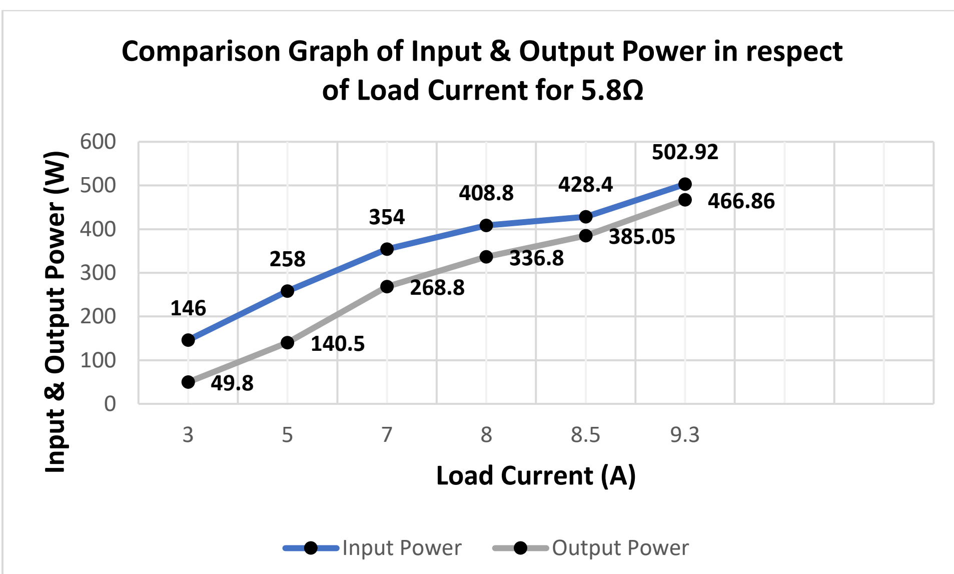


Fig (4.10): Comparison graph of Input & Output power for 5.8Ω resistance

Result: 5.8 Ω resistance was tested to observe the values of input power, output power, power loss and efficiency. The highest amount of power drawn was when the load current was 9.3A and that is 502.92W. The required output power for our system was 500W and 5.8Ω resistance provides that. But 5.8Ω resistance fails to draw 10A current in the system which is essential for the system. To conclude, 5.8Ω resistance cannot be used since it fails to provide the required current into the system.

Resistance = 6.1Ω

Battery voltage (CC)	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(V)	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
50.9	0.6	30.54	3.1	1	3.1	27.44	10.15
50.8	1.4	71.12	9.4	2	18.8	52.32	26.43
50.5	2.4	121.2	17.1	3	51.3	69.9	42.33
50.1	4.5	225.45	27.9	5	139.5	85.95	61.88
49.9	5.6	279.44	38.8	7	271.6	7.84	97.2
49.5	9.3	460.35	48.8	8.6	419.68	40.67	91.17

Chart (4.13): Data chart for 6.1Ω resistance

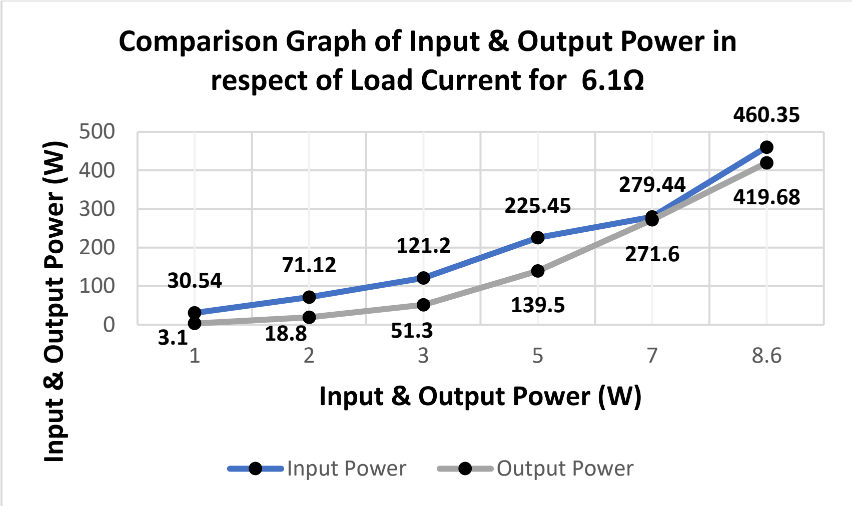


Fig (4.11): Comparison graph of Input & Output power for 6.1Ω resistance

Result: 6.1Ω resistance has tested to observe the values of input power, output power, power loss and efficiency. The highest amount of power drawn was when the load current was 8.6A and that is 460.35W. The required output power for our system was 500W and 6.1Ω resistance fails to provide that. Also, 6.1Ω resistance cannot draw 10A current from the system. To conclude, 6.1Ω resistance is not suitable for the system.

4.4.2 Battery voltage & load voltage comparison

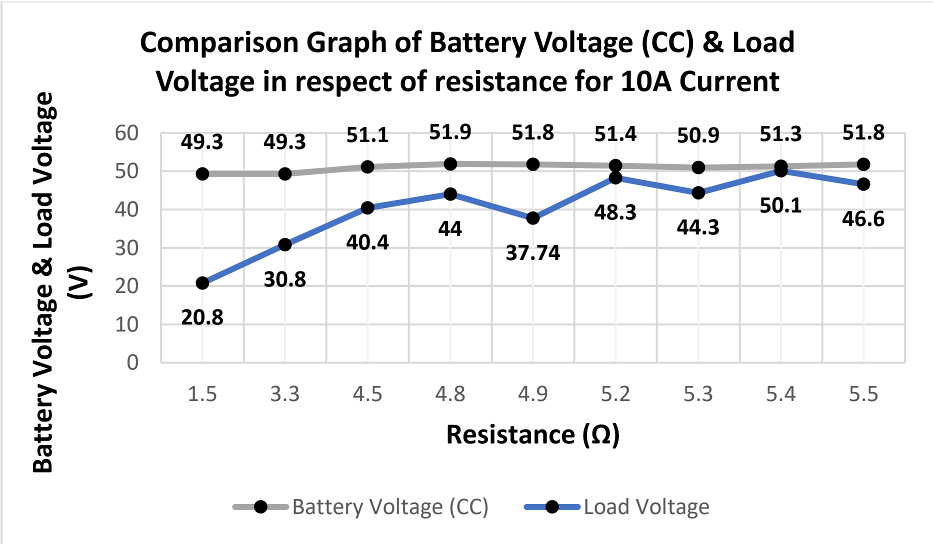


Fig (4.12): Comparison graph of Battery & Load Voltage for each resistance

Result: The aforementioned graph is the comparison between Closed Circuit battery voltage and Load voltage in respect of different resistances for 10A current. The lower the difference of closed-circuit voltage with Load voltage the lower is the power loss. From the graph, the lowest difference is for 5.4Ω resistance. For a 5.4Ω resistance the closed-circuit battery voltage is 51.3V and the load voltage is 50.1V. The difference is the lowest among other resistances. Based on the collected data and studying the graph, it is concluded that 5.4Ω resistance is the best fit for our system. Accordingly, 5.4Ω hot plate is designed and fitted it into the system.

4.4.3 Efficiency test

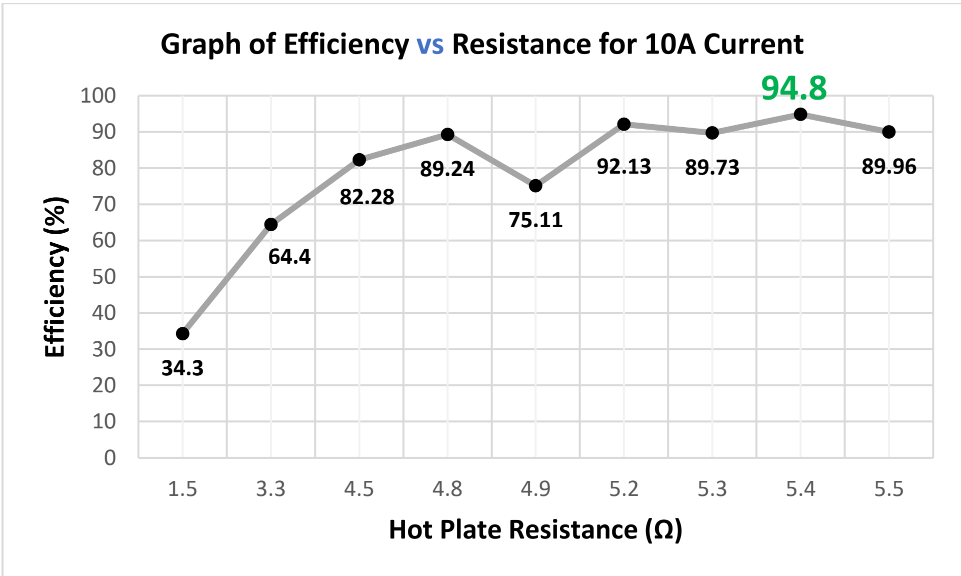


Fig (4.13): Efficiency graph for each resistance value

From the aforementioned graph it can be said that, 5.4 Ω resistance gave the highest efficiency. This was the result is found through impedance matching. In the graph the data points for 5.8Ω and 6.1 Ω has been skipped because the maximum is consecutively 9.3A and 8.6A. Since we are operating the system in 10A current.

1.5Ω resistance had 34.3% efficiency.

3.3Ω resistance had 64.4% efficiency.

4.5Ω resistance had 82.28% efficiency.

4.8Ω resistance had 89.24% efficiency.

4.9Ω resistance had 75.11% efficiency.

5.2Ω resistance had 92.13% efficiency.

5.3Ω resistance had 89.73% efficiency.

5.4Ω resistance had 94.8% efficiency.

5.5Ω resistance had 89.96% efficiency.

So, from the above data it is determined that 5.4 Ω resistance is the most efficient.

Result: After the impedance matching test, two hot plates of 5.4Ω resistance has been made. Then these are used into the system. Input power and output power for different ampere of currents for 5.4Ω resistance has been tested.

4.4.4 Power loss test

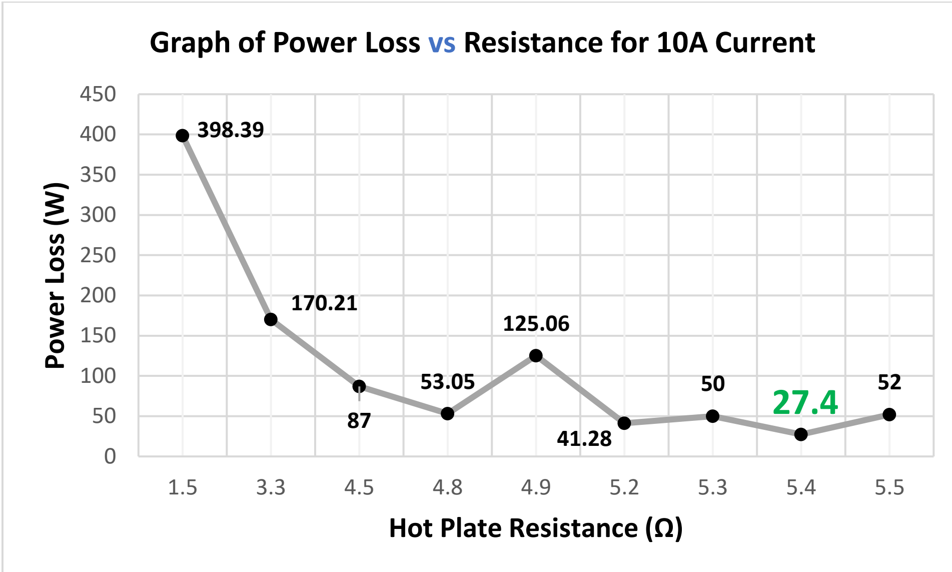


Fig (4.14): Power loss graph for each resistance value

Result: It is ideal to run the system at 10A current giving the output power approximately 500W So, the resistance value will be considered from where the minimum power loss for the system will be found. It is found that, at 10A current for 5.4Ω resistance the output power is 501W and input power is 528.4W. So, the power loss difference is only 27.4W. The hot plate for different resistance value is tested and from the graph, it is found that for 5.4Ω resistance, power loss is lowest. So, our desirable resistance value for the coil of the stove will be 5.4Ω.

4.5 Cooking data analysis

½ Liter water boiling test:

Time	**Temp**	**Battery voltage (CC)**	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(Min)	**(°C)**	**(V)**	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
1st	37	50.2	10	502	49.3	10	493	9	98.2
3	60	50.2	10	502	49.2	10	492	10	98
5	77	50.1	10	501	49.1	10	491	10	98
7	90	50.1	9.7	485.97	49	9.7	475.3	10.67	97.8
8	100	50.1	9.7	485.97	48.9	9.7	474.3	11.67	97.6

Chart (4.14): Data chart for ½ liter water boiling test

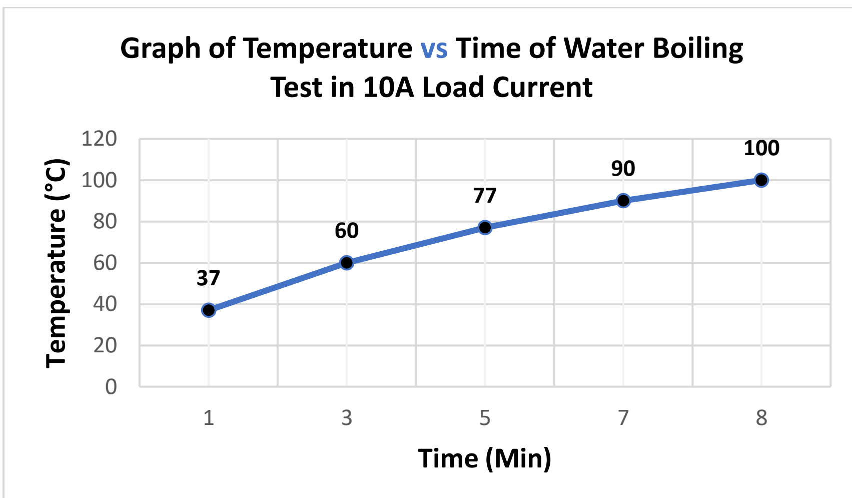


Fig (4.15): Graph of Temperature vs Time for water boiling test

Result: With 5.4Ω coil resistance, the efficiency was on average 98% for the water boiling test with Pre-Heating. With 500W output power the target was to boil ½ liter water with maximum efficiency to get a successful result. As the coil was Pre-heated so it took very less time to boil the water. In only 8 minutes the water got boiled which was a pretty good result for the system as in the previous design it took 11 minutes to boil the water with Pre-heating. The system was improved and so does the cooking time also got improved.

½ Kg Rice Cooking with 1 Lid:

Time	**Battery voltage (CC)**	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(Min)	**(V)**	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
1st	50.9	10	509	49.7	10	497	12	97.6
5	50.8	10.4	528.32	49.6	10.1	500.96	27.36	94.8
10	50.7	10.1	512.07	49.4	10	494	18.07	96.5
15	50.7	10.3	522.21	49.2	10.1	496.92	25.29	95.2
20	50.5	10.1	510.05	49.1	10.1	495.91	14.14	97.2
25	50.4	10	504	48.9	10	489	15	97
30	50.4	10	504	48.7	10	487	17	96.6
35	50.4	10	504	48.6	10	486	18	96.4

Chart (4.15): Data chart for ½ Kg rice cooking test with 1 lid

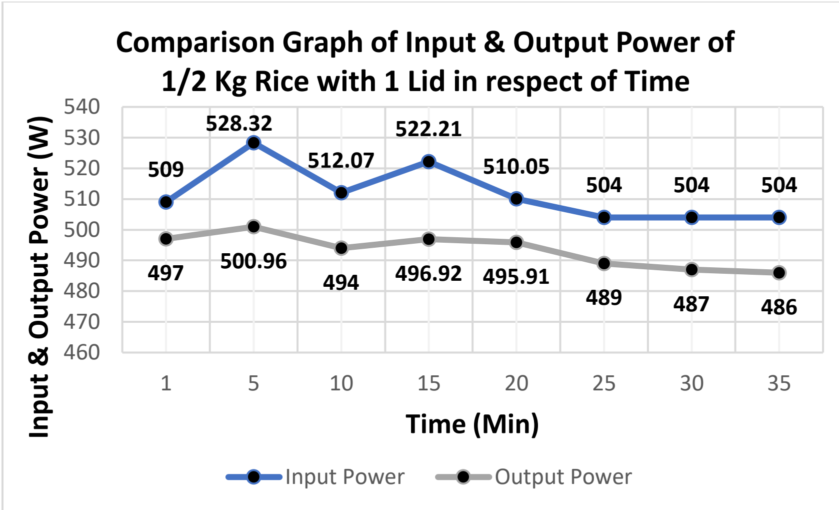


Fig (4.16): Graph of Input & Output Power vs Time for rice cooking with 1 lid

Result: The rice cooking test was done in the slow cooker. With 5.4Ω coil resistance and with 1 lid it took 35 minutes to cook ½ kg rice. The system constantly ran near 10A current to get 500W output power which helped our system to get an efficient result for cooking rice. From the graph, it can be seen that, the difference between input power and output power was very low so there was very fewer power losses. On average the efficiency was above 95% which was remarkable. In the previous design, it took 40 minutes to cook rice with 3.3Ω coil and 1 lid. In this design rice got cooked 5 minutes faster than the previous design. So, it can be said that by using the new designed 5.4 Ω coil the system became more efficient which helped to increase the efficiency of cooking. This test was done with only one lid and in slow cooker. If the test is done with 2 lids in the slow cooker, rice will be cooking even more faster and that will be the desire result for rice cooking purpose.

½ Kg Rice Cooking with 2 Lids:

Time	Battery voltage (CC)	Before Controller Current	Input Power	Load Voltage	Load Current	Output Power	Power Loss	Efficiency
(Min)	(V)	(A)	(W)	(V)	(A)	(W)	(W)	(%)
1st	52.6	9.8	515.48	49.4	9.8	484.12	31.36	93.9
10	51.7	10.3	532.51	48.9	10.1	493.9	38.61	92.7
20	52.4	10	524	49.7	10	497	27	94.8
26	51.8	10	518	49.8	10	498	20	96.1
29	52.1	9.5	494.95	48.1	9.2	442.52	52.43	89.4

Chart (4.16): Data chart for ½ Kg rice cooking test with 2 lids

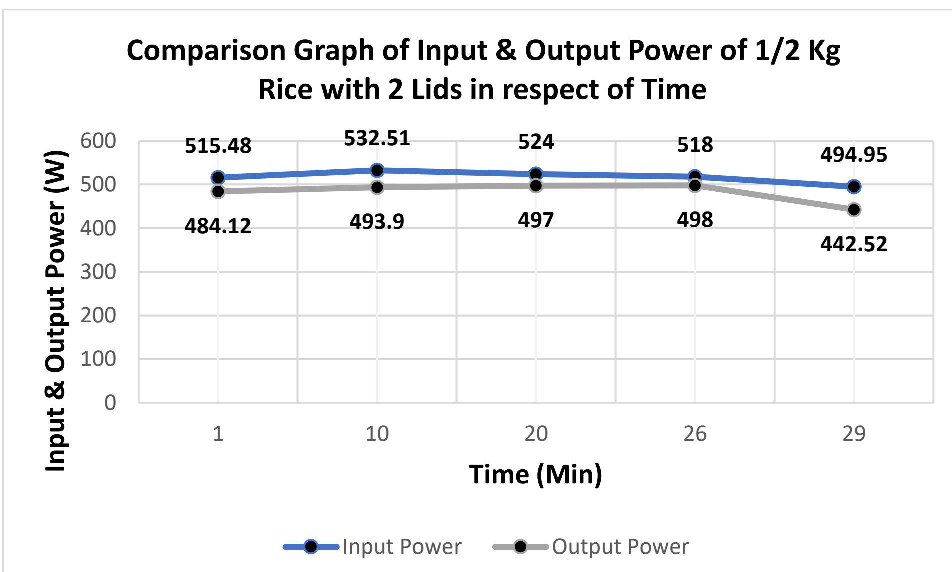


Fig (4.17): Graph of Input & Output Power vs Time for rice cooking with 2 lids

Result: The rice cooking test was done again with 5.4 Ω coil in the slow cooker. This time with 2 lids. It took 29 minutes to cook ½ kg rice. We could run the system with 500W & 10A current constantly. From the graph, it can be seen that the difference between input power and output power was low so there was very fewer power losses. On average the efficiency was above 92% which was great. In the previous design it took 35 minutes to cook rice with 2 lids in the slow cooker. In our design it is 6 minutes faster which is an enormous improvement. The target was to cook ½ kg of rice earlier than 30 minutes. By using 5.4 Ω coil, the desired result was found. As the efficiency of cooking time is a major concern for the system and as the newly designed 5.4Ω coil is much more efficient than the previously designed 3.3Ω coil, so this refinement was a great success compare to the previous design.

4.6 Cooking time analysis

Item	**Quantity**	**Time**
Rice	0.5 KG	28 Minutes
Rice	1 KG	47 Minutes
Rice	1.5 KG	1 Hour 5 Minutes
Water Boiling	0.5 LITER	8 Minutes
Water Boiling	1 LITER	15 Minutes
Water Boiling	1.5 LITER	25 Minutes
Water Boiling	2 LITRES	38 Minutes
Pulse	250 GM	23 Minutes
Beef	600 GM	55 Minutes
Chicken	1 KG	50 Minutes
Egg Fry	1 PC	6 Minutes

Chart (4.17): Data chart for different cooking time

Result: From the aforementioned chart, it can be seen that, the cooking time is now well improved and reduced. Compared to other designs of the solar stove this system gave the best cooking time which was a magnificent result. Later on, the cooking time comparison between previous design will be discussed. In this chart, it is very well understood that, all the data was very linear. Different amount of rice was cooked and water was boiled in order to see whether the data comes linear or not and the result was pretty linear. So, the system performed very stable with different quantities of items.

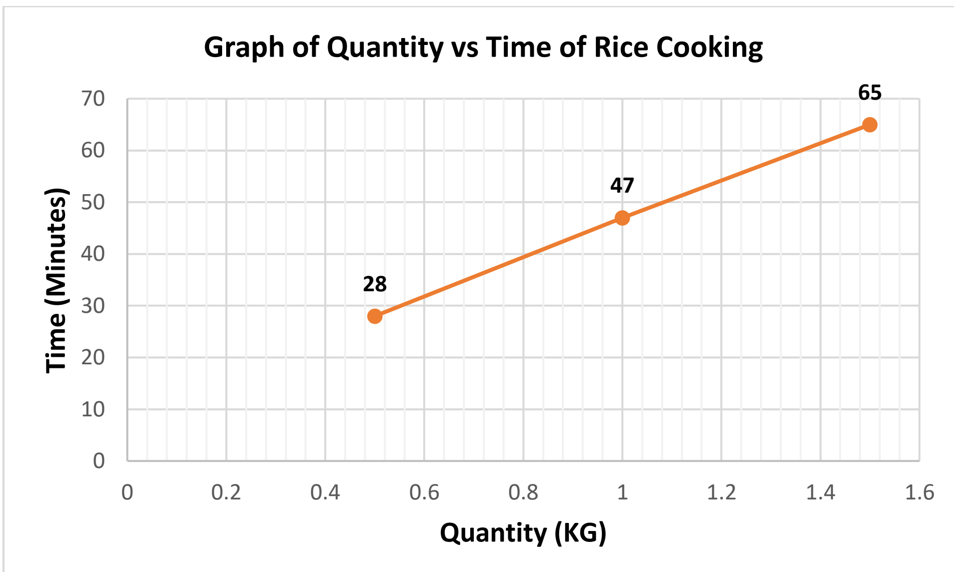


Fig (4.18): Graph of Quantity vs Time for different amount of rice cooking

Result: The graph shows the time is very linear. Three different amounts of rice were cooked to see whether the data becomes linear or not and the result was positive.

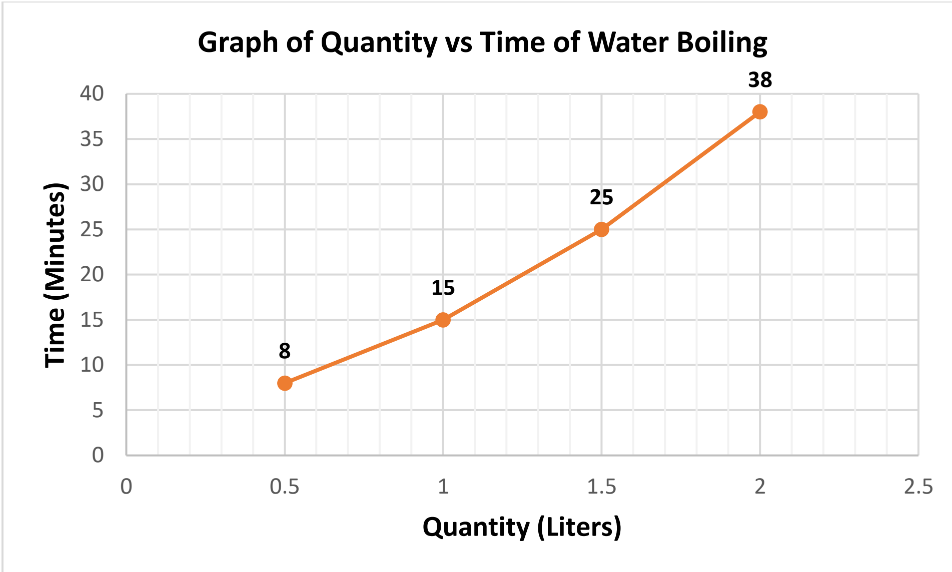


Fig (4.19): Graph of Quantity vs Time for different amount of water boil

Result: This graph also shows the time is almost linear for water boiling test. Four different amounts of water were tested to see whether the time of water boiling comes linear or not and the result was positive too.

Chapter 5:

Comparative study

5.1 Comparison with previous designs of the solar cooker

In version 3, Solar panel and the battery pack were connected through an analog charge controller. In the commercial version digital charge controller have been used for better and easy use. In version 3 there were 2 heat controllers each for individual cooker. In the commercial version, only one heat controller has been used for ease of use. It also helps to reduce the cost of the system. A switch has been added after the heat controller to be able to switch between the slow cooker and infrared cooker. For the battery pack, sealed lead acid battery has been used for low costing and ability to flow high current. Hot plates have been redesigned for better performance than the previous version.

Comparison between version 3 and commercial version:

Version 3	**Commercial version**
3.3 Ω coil	5.4 Ω coil
2 heat controllers	1 heat controller
2 potentiometers	1 potentiometer
Analog charge controller	Digital charge controller
40AH Solar deep cycle battery	50AH sealed acid battery

Chart (5.1): Overall Comparison between version 3 and commercial version

Comparison of block diagram of version 3 and commercial version:

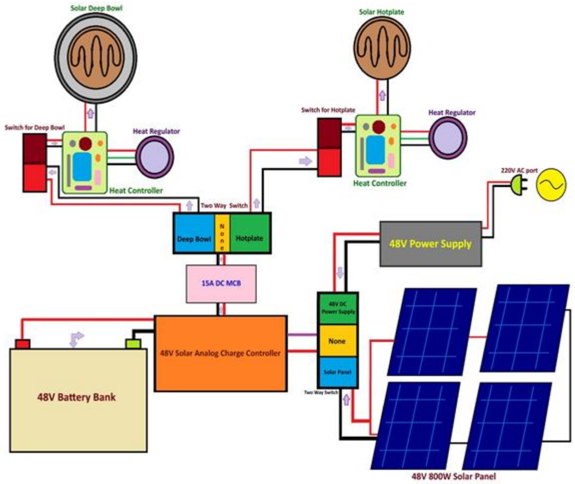
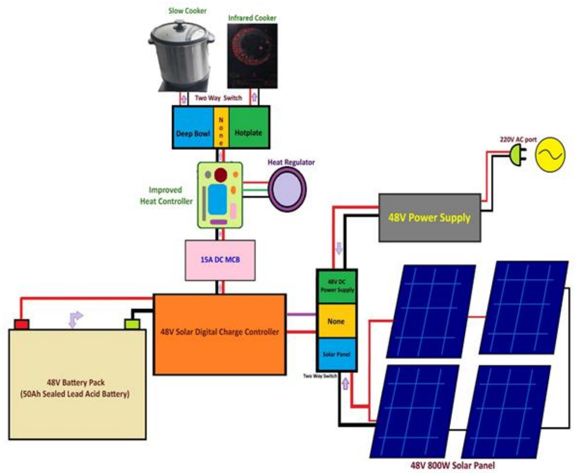
Version 3	Commercial version
	

Fig (5.1): Version 3 and the commercial version block diagram

5.2 Comparison of the structure

In version 3, the whole system was fitted in a wooden box. It was custom made. In the commercial version, the whole structure has been re-designed. Instead of a whole box, it has been broken down in some small components to deliver it easily. Instead of direct hot plate, an infrared cooker has been used to avoid any short circuit problem. A control box is designed dedicated for charge controller, heat controller and the power supply for ease of use. Battery box will be provided so that the batteries can be moved easily. From the 2 pictures provided below, it can be seen how the structure have been changed to make the product commercial.

Fig (5.2): Version 3

Fig (5.3): Commercial version

5.3 Comparison of different batteries

There are several types of battery which can be used in this version. LiFePO4, Lithium NMC, Solar tabular, solar deep cycle, AGM, GEL, Lead Acid, Lithium Ion, Sealed Lead Acid Batteries are studied and after considering pros and cons it was decided that Sealed Lead Acid Battery is the most suitable battery for the system. In the previous version, solar deep cycle battery was used. After 3 months of use, it couldn't hold charge as desired. As a result, alternative batteries were considered and the sealed acid battery gave the best result. Sealed lead acid battery can supply high current flow without any disruption. It has advantages like low cost, low weight and maintenance free.

Comparison between version 3 and commercial battery:

Version 3 (Solar deep cycle)	**Commercial version (Sealed lead acid)**
High cost	Low cost
Heavy weight	Low weight
Can't hold high current flow	Can hold high current flow
Frequent maintenance required	No maintenance required

Chart (5.2): Battery comparison between version 3 and commercial version

Version 3	Commercial version
	

Fig (5.4): Pictures of batteries of version 3 and the commercial version

5.4 Comparison of 3.3Ω & 5.4Ω coils

In version 3, 3.3 Ω coil was used in the hot plate. In the commercial version, as a part of efficiency improvement, the coils were redesigned. After testing, 5.4 Ω coils gave the best result. In this section, the comparison between 3.3 Ω and 5.4 Ω coil will be shown. Here are some testing data from field test for both 3.3 Ω and 5.4 Ω coil.

Resistance = 3.3 Ω

Battery Voltage (CC)	Before Controller Current	Input Power	Load Voltage	Load Current	Output Power	Power Loss	Efficiency
(V)	(A)	(W)	(V)	(A)	(W)	(W)	(%)
50.6	0.4	20.24	3.61	1	3.6	16.64	17.8
50.5	0.9	45.45	6	2	12	33.45	26.4
50.5	1.7	85.85	9.2	3	27.6	58.25	32.15

50.3	2.5	125.75	12.6	4	50.4	75.35	40.08
50.2	3.4	170.7	15.1	5	75.5	95.2	44.2
50	4.5	225	18.6	6	111.6	113.4	49.6
49.8	5.5	273.9	21.2	7	148.4	125.5	54.18
49.7	7.3	362.8	24.5	8	196	166.8	54.02
49.5	8.5	420.75	28	9	252	168.75	59.9
49.3	9.7	478.21	30.8	10	308	170.21	64.4
49.3	10.3	507.79	34.3	11	377.3	130.5	74.3
49.2	11.9	585.5	38	12	456	129.5	77.9
49.1	12.8	628.5	40.7	13	529.1	99.4	84.18
48.8	13.9	678.3	43.3	14	606.2	72.1	89.4
48.6	15.1	733.86	47.1	15	706.5	27.36	96.27

Chart (5.3): 3.3Ω coil data chart

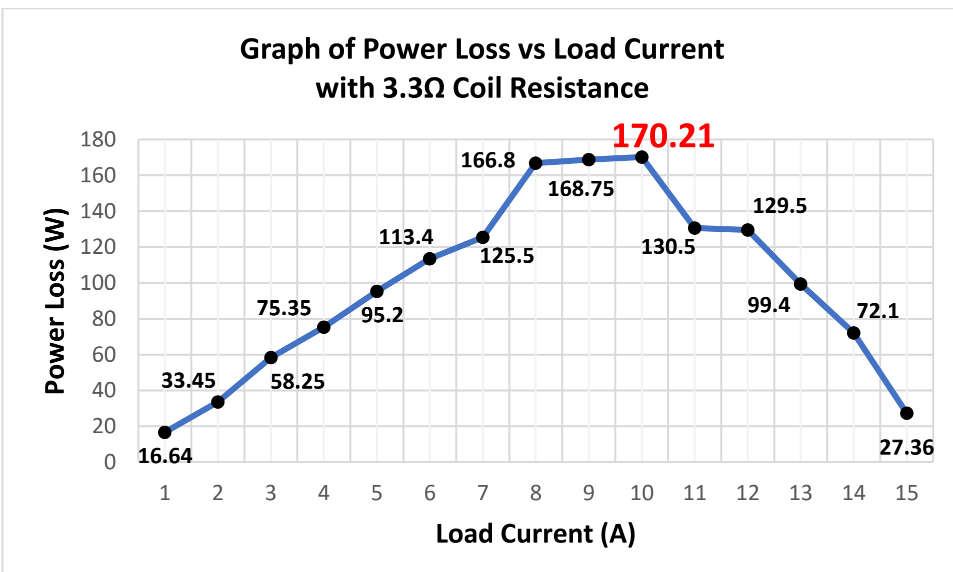


Fig (5.5): Graph of power loss with 3.3 Ω coil at different load current

Result: From this graph, it is seen that for 3.3 Ω coil at 10 Amp current the power loss is maximum.

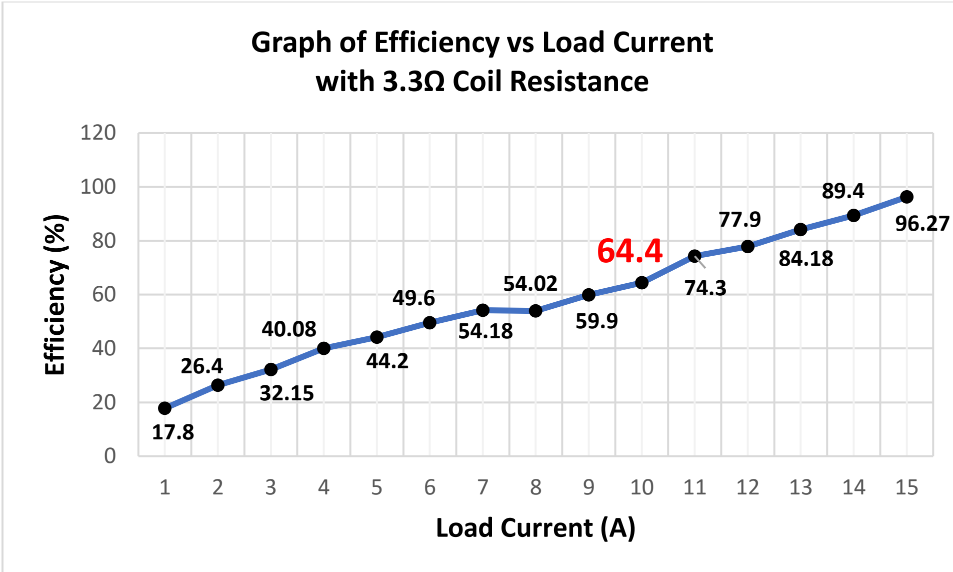


Fig (5.6): Efficiency graph at different load current

Result: From efficiency graph, for 3.3 Ω coil, at 10A current, the system is only 64.4% efficient which is not good.

Resistance=5.4Ω

Battery voltage (CC)	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(V)	(A)	(W)	(V)	(A)	(W)	(W)	(%)
54.3	0.4	21.72	6.8	1	6.8	14.92	31.31
53.9	1.3	70.07	13.4	2	26.8	43.27	38.25
53.7	2.1	112.77	16.3	3	48.9	63.87	43.36
53.2	2.8	148.96	20.3	4	81.2	67.76	54.51
53	4	212	27.6	5	138	74	65.1
52.8	5.1	269.28	33.8	6	202.8	66.48	75.3
52.3	6.5	339.95	39.2	7	274.4	65.5	80.7
52	8	416	43.1	8	344.8	71.2	82.9
51.5	9.2	473.8	48.9	9	440.1	33.7	92.9
51.3	10.3	528.4	50.1	10	501	27.4	94.8

Chart (5.4): 5.4Ω coil data chart

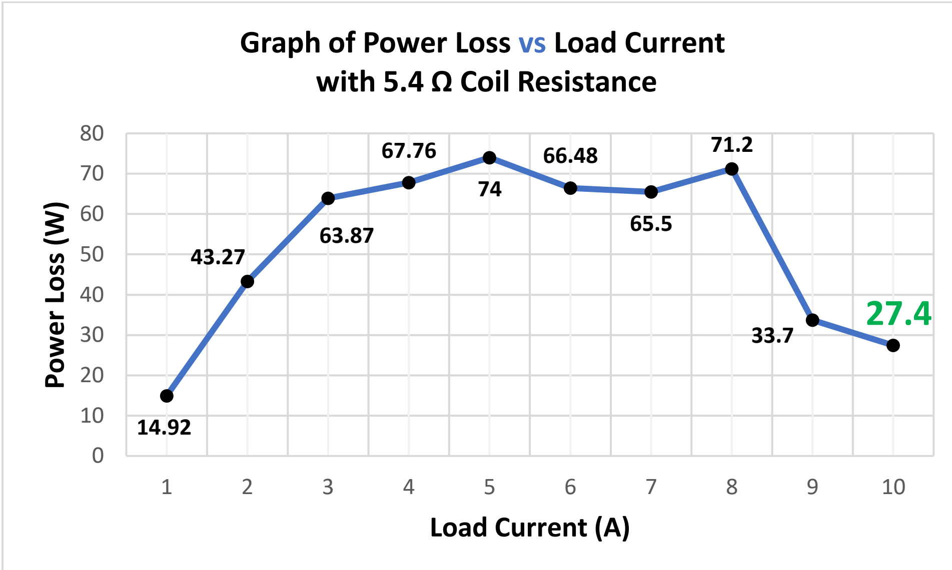


Fig (5.7): Power loss graph of 5.4 Ω coil

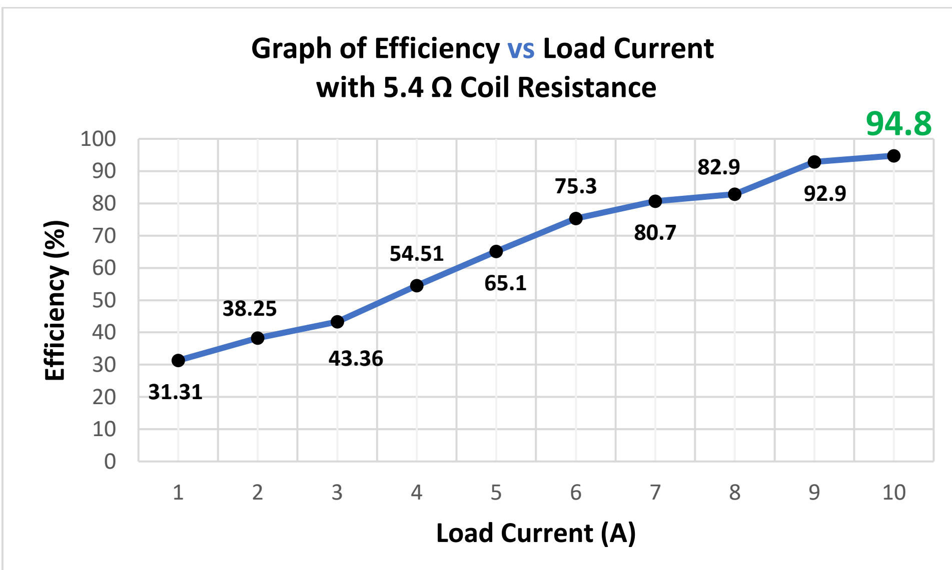


Fig (5.8): Efficiency graph of 5.4 Ω coil

From the power loss graph, it can be seen that for 5.4Ω coil, at 10A current, only 27W power is lost and from the efficiency graph, the commercial version coils are 94.8% efficient.

To compare these data side by side, here are some graphical representation of power loss and efficiency for both 3.3Ω and 5.4Ω coil.

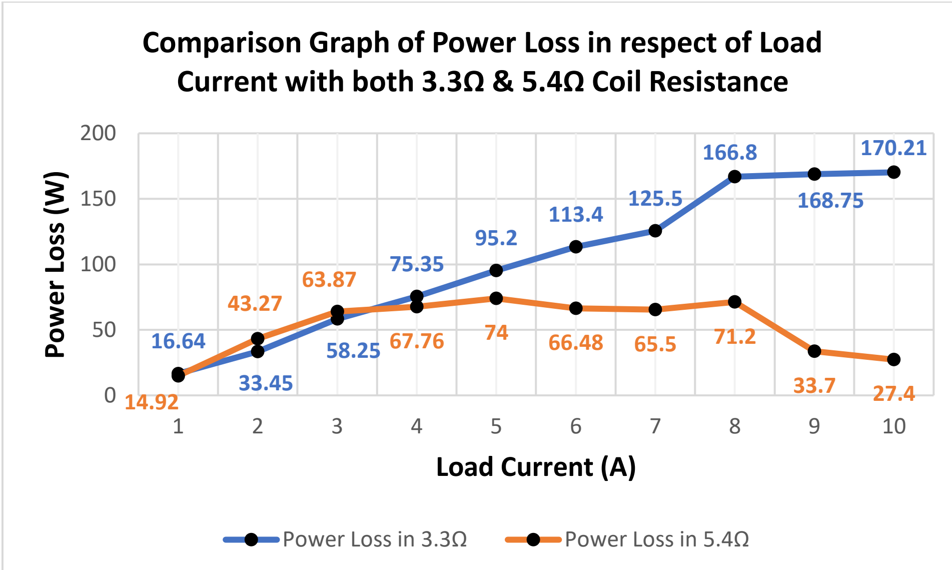


Fig (5.9): Power loss comparison of 3.3Ω and 5.4Ω coils

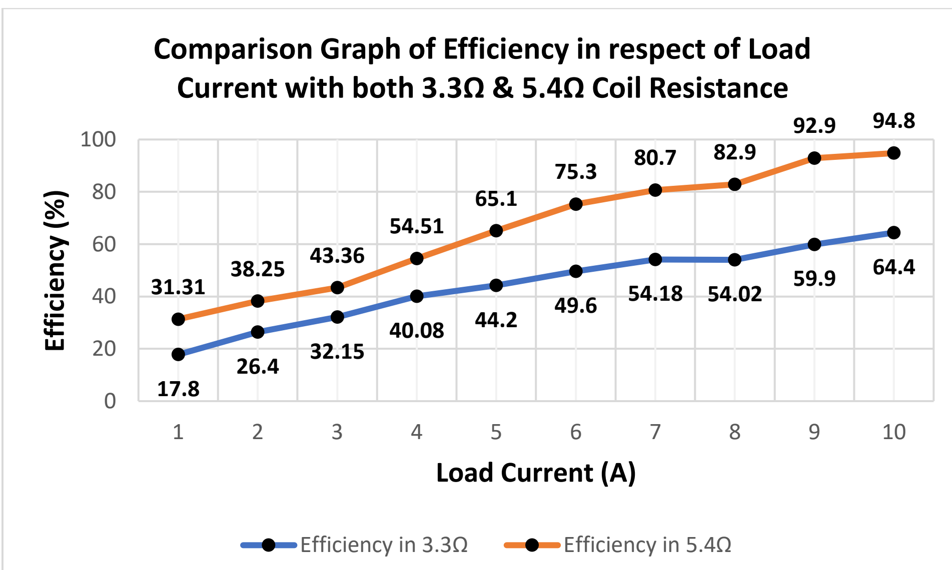


Fig (5.10): Efficiency comparison of 3.3Ω and 5.4Ω coils

Result: From these graphs, it is clear that the power loss curve and efficiency curve for 3.3Ω and 5.4Ω coils are quite different. It is clearly visible that the improved commercial version is better performing among two versions and gives the best efficiency possible.

5.5 Cooking data comparison with the previous version

Various items have been cooked to test the efficiency and improvement of the commercial version of solar cooker. In order to see the improvement, commercial version's cooking time data will be compared with the version 3 cooking time data. The testing data is given below:

ITEM	**QUANTITY**	**VERSION 3**	**COMMERCIAL VERSION**	**% of cooking time reduced**	**Gas Stove**
WATER BOILING	0.5 LITER	12 Minutes	8 Minutes	33	5 Minutes
RICE	0.5 KG	35 Minutes	28 Minutes	20	26 Minutes
EGG FRY	1 PC	10 Minutes	6 Minutes	40	4 Minutes
PULSE	250 GM	30 Minutes	23 Minutes	23	20 Minutes
BEEF	600 GM	1 Hour 10 Minutes	55 Minutes	21	50 Minutes
CHICKEN	1 KG	1 Hour 5 Minutes	45 Minutes	30	40 Minutes

Chart (5.5): Cooking time comparison chart

Here it can be seen that cooking time has improved significantly compared to previous version's cooking time. The main reason behind it is the efficiency improvement through impedance matching method. Efficiency improvement resulted in more heat produced in the heating coil which gives us reduced cooking time. By doing so, average cooking time reduced down to **28%** of previous cooking time which is a significant improvement over previous version.

5.6 Heat controller comparison with the previous version

In order to compare the previous version controller with commercial version's heat controller, 2 sets of data were taken with same resistance coil. One with the version 3 controller and one with commercial version's heat controller. The test results are following:

Resistance= 5.4 Ω (Test with Version-3 controller)

Battery Voltage (CC)	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(V)	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
54.4	0.4	21.76	5.18	1	5.18	16.58	23.8
54.2	1.7	92.14	12.43	2	24.86	67.28	27
53.5	2.8	149.8	18.3	3	54.9	94.9	36.6
53	3.5	185.5	22.9	4	91.6	93.9	49.4
52.4	4.2	220.08	26.8	5	134	86.08	60.9
52	5.3	275.6	31.25	6	187.5	88.1	68
51.6	6.5	335.4	36.6	7	256.2	79.2	76.4
51.1	8.3	424.13	42.9	8	343.2	80.93	80.9
50.8	9.2	467.36	47	9	423	44.36	90.5

Chart (5.6): Version 3 heat controller test with 5.4Ω coil

Resistance=5.4 Ω (Test with Commercial Version Heat Controller)

Battery voltage (CC)	**Before Controller Current**	**Input Power**	**Load Voltage**	**Load Current**	**Output Power**	**Power Loss**	**Efficiency**
(V)	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
54.3	0.4	21.72	6.8	1	6.8	14.92	31.31
53.9	1.3	70.07	13.4	2	26.8	43.27	38.25
53.7	2.1	112.77	16.3	3	48.9	63.87	43.36
53.2	2.8	148.96	20.3	4	81.2	67.76	54.51
53	4	212	27.6	5	138	74	65.1
52.8	5.1	269.28	33.8	6	202.8	66.48	75.3
52.3	6.5	339.95	39.2	7	274.4	65.5	80.7
52	8	416	43.1	8	344.8	71.2	82.9
51.5	9.2	473.8	48.9	9	440.1	33.7	92.9
51.3	10.3	528.4	50.1	10	501	27.4	94.8

Chart (5.7): Commercial version heat controller test with 5.4Ω coil

From the charts we can see that, with the version 3 controller, the output current was not going above 9A which resulted in limiting output power to 423W. On the other hand, commercial version's heat controller gave constant 10A output current and got desired 500W as output.

Now, some graphical representation of power loss and efficiency for both controllers are shown below.

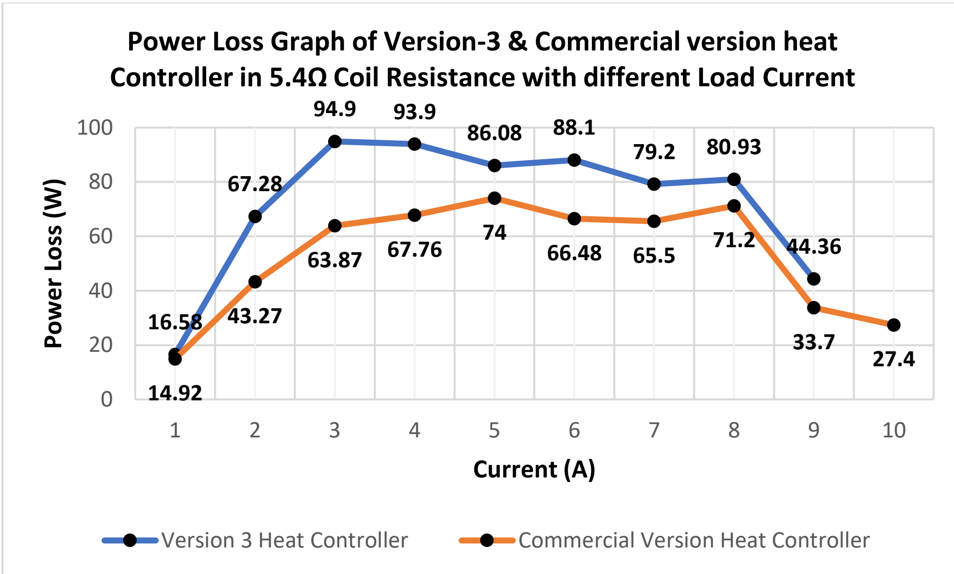


Fig (5.11): Power loss graph of both controllers

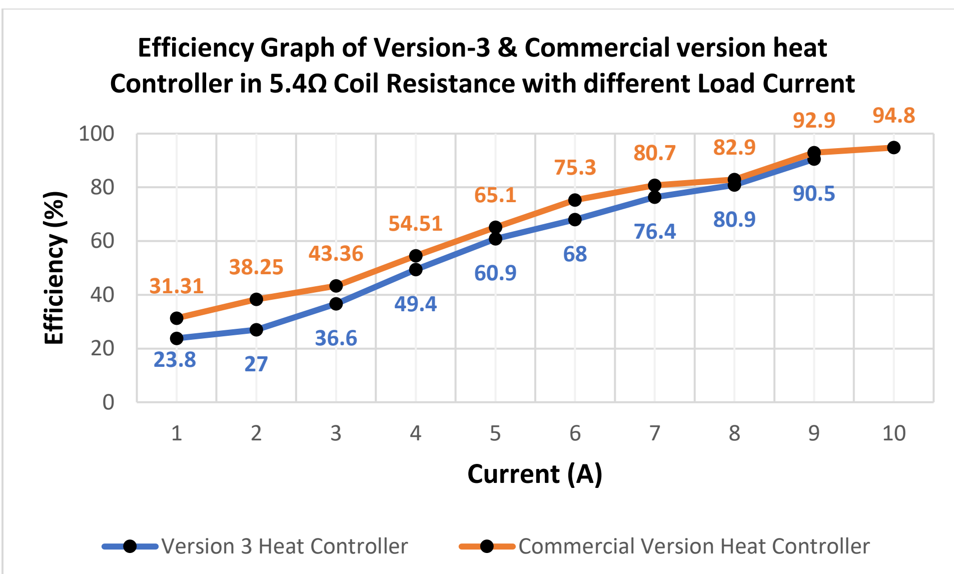


Fig (5.12): Efficiency graph of both controllers

Here it is visible that the power loss of the version 3 controller is 44.36W and power loss of commercial version's heat controller is 27.4W. From efficiency graph, the efficiency of the version

3 controller is 90.5% and commercial version heat controller's efficiency is 94.8%. So, it is safe to say that the commercial version heat controller is much better than version 3 controller.

5.7 Budget comparison

5.7.1 Budget analysis

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

Budget of the commercial version

Components	**Quantity**	**Cost per unit item**	**Net cost**
PV Panel	760W	42	32000
Batteries	4	4250	17000
Charge controller	1	3000	3000
Heat controller	1	1500	1500
Hot plates	2	350	700
Infrared cooker	1	3000	3000
AC-DC power supply	1	2600	2600
Slow cooker	1	2500	2500
Miscellaneous Cost			2700
Total			**= 65000**

Chart (5.8): Costing of the commercial version chart

5.7.2 Comparison with the previous version

Budget of version 3 of the solar cooker is given below:

Budget of version 3

Components	Quantity	Cost per unit item	Net cost
PV Panel	760W	42	32000
Batteries	4	2500	10000
Charge controller	1	5000	5000
Heat controller	2	650	1300
Hot plates	2	250	500
Stove body	1	4000	4000
AC-DC power supply	1	2600	2600
Slow cooker	1	2500	2500
Miscellaneous Cost			2200
Total			**= 60100**

Chart (5.9): Costing of version 3 chart

Here it is seen that; the budget of previous version is BDT 60100. A better-quality set of battery was needed for the commercial version for a stable system and long use. So commercial version's budget is a bit more due to extra cost of the batteries. But in the commercial version, using 1 heat controller instead of 2, some cost was minimized in the budget.

5.7.3 Cost comparison between the conventional cooker

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.

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

Chart (5.10): Costing of gas consumed chart

From the chart it can be seen that, without the cost of a stove, a moderate family's per month gas cost is 2500 tk. But in solar cooker, after installation, there is no monthly cost.

5.7.4 Payback calculation

In this section we will see how much time it is needed to payback the installation cost the solar cooker. Payback calculation chart is given below:

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

Chart (5.11): Payback calculation chart

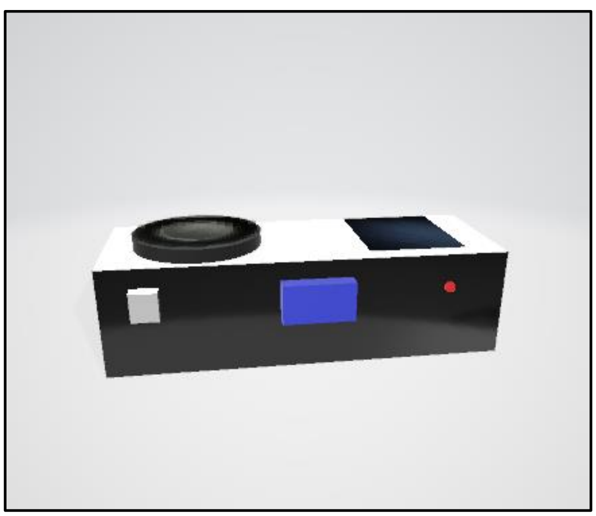
For a moderate family, payback time of installation cost with the solar panel is around 25 months. Now a days, it is mandatory to have solar panel in a house as per govt. rule. So, without solar panel cost, the time reduced to 13 months which is very good. After the payback, families can cook for free in their household with the solar cooker.

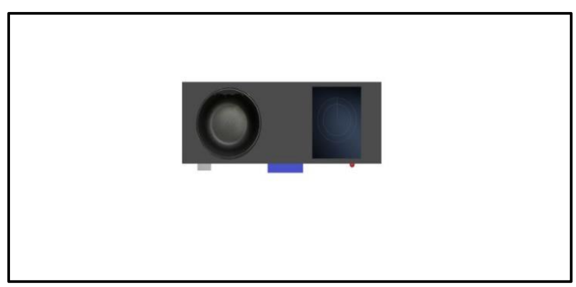
Chapter 6:

Future development

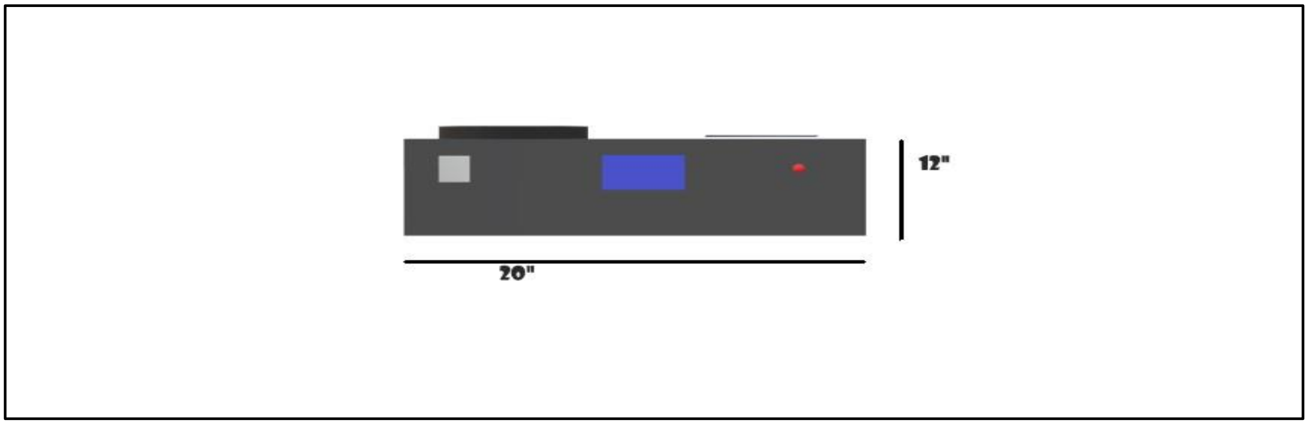
6.1 The controller box system structure

For the sake of the simplicity, the structure should be made as much simple as possible. Structure should be a solid frame. Inside the frame there should 2 compartments. Inside of one of the compartments, the batteries will be put alongside of the controller box. In another compartment, cooking utensils will be put. On top of the frame, on the left side will be the slow cooker. And on the right side, will be the infrared cooker. There will be a switch in the middle of the front panel. There will be a knob on the front panel. The knob will be used to control the temperature. There will be a display panel on the top of the benchtop. The display will be used to show the output power. The frame should be made of steel and other part should be made of wood. This way, it will be the cost efficient as well as less heavy.





(a) (b)



(c)

Fig (6.1): Future stove model (a) Overall view (b) Top view (c) Front view

6.2 Without battery system

For costing issue, there can be a good solution to reduce the costing not to use the batteries in this system. For that, it is needed to use the system directly connecting with solar panels. The without battery system is much cheaper than the with battery system. There is a lot of advantages and also disadvantages between these two systems.

6.2.1 Comparison of with battery & without battery system

With Battery	**Without Battery**
Can use the stove when there is no sunlight available and also at night.	Cannot use the stove when there is no sunlight available and also at night.
Costlier to install	Less costly to install
It provides the system with electricity during load shedding	It does not provide the system with electricity during load shedding
More heavyweight system	Less heavyweight system
More components to maintain	Less components to maintain

Chart (6.1): Comparison of with battery & without battery system

6.3 Pre-heating time improvement

½ Liter Boiling Water without Pre-Heating:

Time	Temp	Battery voltage (CC)	Before Controller Current	Input Power	Load Voltage	Load Current	Output Power	Power Loss	Efficiency
(Min)	(°C)	(V)	(A)	(W)	(V)	(A)	(W)	(W)	(%)
1st	29	53.1	10	531	51.4	10	514	17	96.8
2	36	52.4	10	524	48.5	10	485	39	92.6
4	45	52.3	10.5	549.15	50.7	10.3	522.21	26.94	95.1
6	54	52.2	10.5	548.1	50.7	10.3	522.21	25.89	95.3
8	62	52.1	10.6	552.26	50.6	10.3	521.18	31.08	94.4
10	72	52.1	10.6	552.26	50.6	10.3	521.18	31.08	94.4
12	82	52	10.5	546	50.5	10.3	520.15	25.85	95.3
14	90	52	10.6	551.2	50.5	10.3	520.15	31.05	94.4
16	100	51.9	10.4	539.76	50.5	10.3	520.15	19.61	96.4

Chart (6.2): Data chart for ½ liter water boiling test without pre-heating

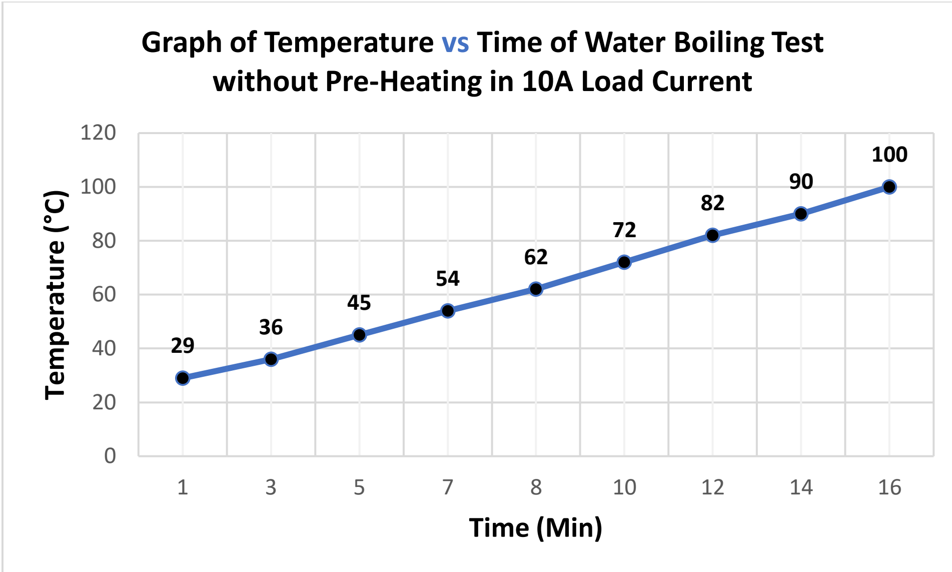


Fig (6.2): Graph of Temperature vs Time for water boiling test without pre-heating

Result: With 5.4Ω coil resistance, the system ran at 10A to 10.3A current constantly so that the system can get constant 500W output power. Firstly, the water boiling test was done without Pre-Heating. From the data, it is found that, the system was very much efficient. On average the efficiency was 95%. As the efficiency was good and there was less power loss so the actual data for the water boiling test was taken. Data in every 2 minutes was taken. It took 16 minutes to boil the water whereas in the previous design it took 20 minutes without Pre-Heating. So, 4 minutes less than the previous design to boil the water. In this design, the target was to improve the efficiency of the system. As the efficiency got improved, the data taken for every cooking test became beneficial for the system.

½ Liter Boiling Water with Pre-Heating:

Time	Temp	Battery voltage (CC)	Before Controller Current	Input Power	Load Voltage	Load Current	Output Power	Power Loss	Efficiency
(Min)	**(°C)**	**(V)**	**(A)**	**(W)**	**(V)**	**(A)**	**(W)**	**(W)**	**(%)**
1st	37	50.2	10	502	49.3	10	493	9	98.2
3	60	50.2	10	502	49.2	10	492	10	98
5	77	50.1	10	501	49.1	10	491	10	98
7	90	50.1	9.7	485.97	49	9.7	475.3	10.67	97.8
8	100	50.1	9.7	485.97	48.9	9.7	474.3	11.67	97.6

Chart (6.3): Data chart for ½ liter water boiling test with pre-heating

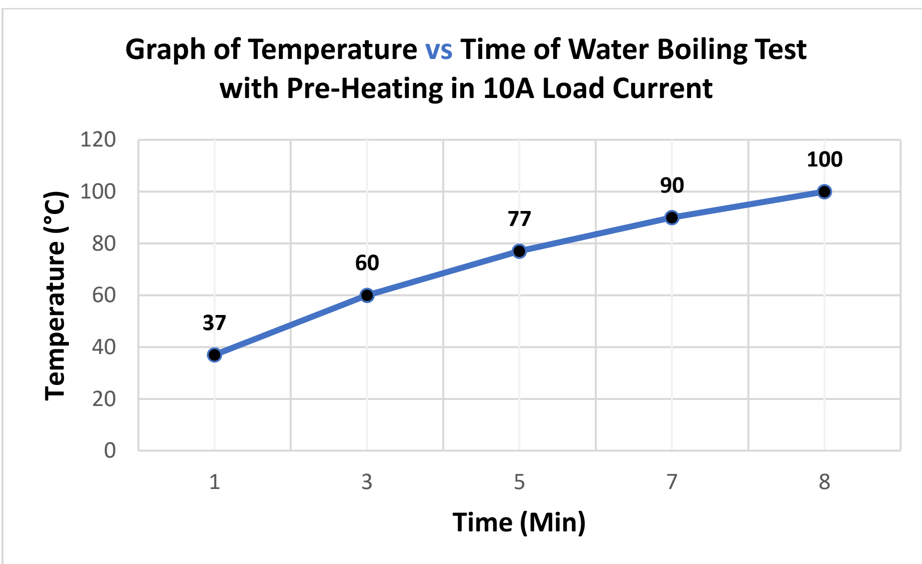


Fig (6.3): Graph of Temperature vs Time for water boiling test with pre-heating

Result: With 5.4Ω coil resistance, the efficiency was on average 98% for the water boiling test with Pre-Heating. With 500W output power the target was to boil ½ liter water with maximum efficiency to get a successful result. As the coil was Pre-heated so it took very less time to boil the water. In only 8 minutes the water got boiled which was a pretty good result for the system as in the previous design it took 11 minutes to boil the water with Pre-heating. The system was improved and so does the cooking time also got improved.

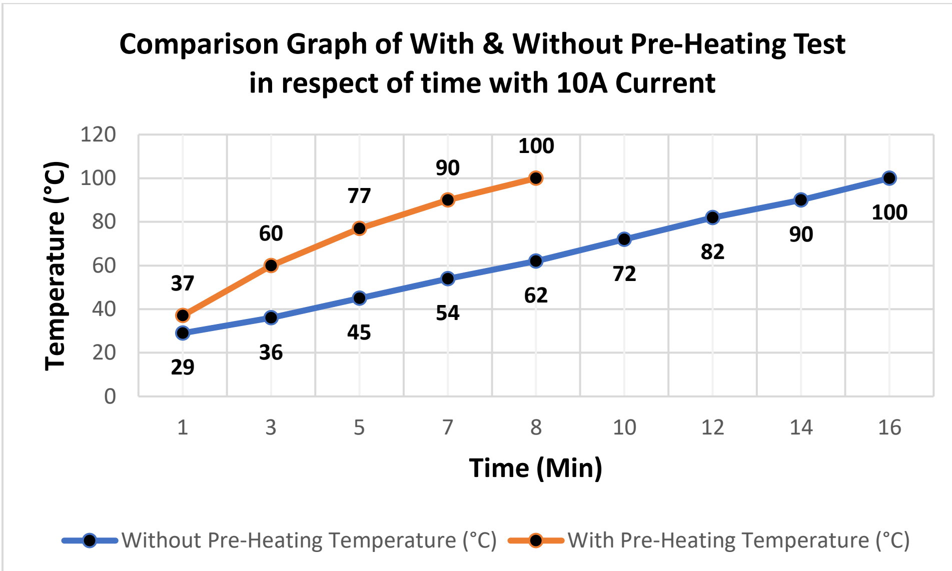


Fig (6.4): Comparison graph of Temperature vs Time for water boiling test with & without pre-heating

Result: Both of the tests were done in the slow cooker & the system ran at near 10A current on both of the occasion. It is found that, for this system the desirable current is 10A to get 500W output power. Efficiency was above 95% and the output power was near 500W on both of the test. From the above graph, it can be compared the time difference of water boiling temperature. When the coil is pre heated it takes half of the time when the coil is not pre heated. Both of the test was much beneficial than the previous design. As this test is done with 5.4 Ω coil and in the previous design the cooking tests were done with 3.3 Ω coil. For 3.3 Ω coil it takes longer time than the 5.4 Ω coil. So, the current design is much more efficient than the previous design. In order to make the system more efficient the pre-heating time has to be improved more. For the future improvement this step can be taken as one of the major tasks to be done in future.

6.4 Future Development Budget

Components	**Quantity**	**Cost per unit item**	**Net cost**
PV Panel	760W	42	32000
Batteries	4	13000	52000
Charge controller	1	3000	3000
Heat controller	1	1500	1500
Hot plates	2	350	700
Infrared cooker	1	3000	3000
AC-DC power supply	1	2600	2600
Slow cooker	1	2500	2500
Miscellaneous Cost			2700
Total			**= 100000**

Chart (6.4): Future development budget

6.5 Conclusion

After experimenting, analyzing and working for one year, the project is a success. The main motive of the project was to stabilizing the system, improve efficiency with a dependable backup system and to reduce the cooking time. Also, to make the system more user-friendly. A new cooking method of infrared cooking has been introduced. The other burner was a slow cooker. These cooking methods made a significant improvement in the system. The new heat controller was a huge success. It constantly flowed 10A current for a long period of time. Finding the impedance matching was another breakthrough. Previous versions had a lot of power loss due to this. The resistance of the coil has been changed and hot plate was redesigned. The efficiency improved for this was outstanding. There is also a national grid back up for emergency situations. To lower the consumption and to be efficient, only one of the two burners will be active at a time. Using the infrared glass to protect the system of getting short-circuit was helpful. It can be concluded that this version of the solar stove is better than other solar stoves that had been made previously. Such increased efficiency of this version makes us think about future enhancement and development.

This project is based on real-life problems. Such a system can be helpful in our life. Not only because it saves money but also it uses renewable energy sources. It is also a green product.

The thesis is great evidence to believe in the usage of this product in real life. This could be the solution to the problems of tomorrow.

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