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DESIGN AND FABRICATION OF A SOLAR-POWERED ELECTRIC STOVE FOR RURAL AND URBAN COMMUNITIES

CAPSTONE

B.Sc. Electrical & Electronic Engineering

Miquilina Selasie Anagbah

2019

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THESIS

CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfillment of the requirements for the award of Bachelor of Science degree in Electrical & Electronics Engineering.

Miquilina Selasie Anagbah

2019

DECLARATION

I hereby declare that this capstone is the result of my original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

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Candidate's Name:

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Date:

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I hereby declare that the preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University College.

Supervisor's Signature:

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Supervisor's Name:

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Date:

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Acknowledgments

First, I want to express gratitude to the Almighty God for a successful project. I also want to thank my supervisor, Dr. Robert Sowah for guiding me on this project as well as Dr. Nathan Amanquah, Dean of Engineering and Senior Lecturer of the Electronical and Electronics Engineering Department, Ashesi University for his steady direction and inputs on this capstone project. Further, I will like to thank Nicholas Tali, Senior Laboratory Manager, Ashesi University for his help on getting components for the design implementation and his guidance on practical techniques in electronics. A final thanks to the Department of Engineering of Ashesi University for subsidizing the cost of components and encouraging the completion of this task.

Abstract

More than 2.2 million Ghanaian families in rural areas depend on firewood and charcoal as fuel for cooking [1]. This high dependency is taking a toll on forest resources due to rampant deforestation. "Ghana's forest cover, which stood at 8.2 million hectares in 1900, has now been reduced to about 1.2 million hectares, with an estimated loss of 65,000 hectares of forest annually" [2]. More so, Ghana has been facing energy challenges with the birth of frequent load-shedding, termed "dumsor." This is even worse in rural areas because they do not yet have access to electricity. The problem of electricity accessibility could be solved in Ghana, benching on the testimonies of renewable energy and the technologies associated with it. Thus, the goal of this project is to design and fabricate a solar-powered electric stove. The motivation for this project is the inaccessibility of electricity, especially in rural communities and the shortcomings of Liquified Petroleum Gas (LPG), a possible alternative. Success on this project will be defined by a simple and affordable design which will store solar energy during the day and can be used both in the day and at night for cooking. This design will go a long way to improve the lives of individuals in the country whiles safeguarding our environment.

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Chapter1: Introduction

1.1 Introduction/Background

Firewood and charcoal are two important fuels for cooking in households and wayside eateries in Ghana. These two commodities are on the rise in the market because there is less of an alternative due to the standard of living and economic conditions of the country. The closest resort to using a more convenient and cleaner source of energy for cooking is Liquefied Petroleum Gas (LPG). This source of fuel is quite expensive, interim, and not readily available in some regions of the country. Hence the justification for firewood and charcoal usage. These forms of fuel have been long existing in the country and therefore form a significant component of the cooking culture in typical rural areas and some urban homes.

The rise in the population size of Ghana makes this exploitation more alarming. With the high dependency on wood fuels and the increase in demand for them, the effect is an increase in deforestation and hence a disruption in the country's ecosystem [3]. More so, the use of charcoal and firewood pose significant health risks to the users due to the exposure to smoke and heat.

With the evolution of technology in this modern era, a befitting solution to this problem will be the introduction of electric stoves to save the environment as well as individuals from the dangers of using wood fuels. Nonetheless, the current energy generation and the distribution state of the country makes this solution almost impossible. First, electricity usage is expensive due to the cost of production and distribution. Hence many households barely can afford electricity. Also, electricity distribution does not have nationwide coverage yet [1]. Thus many rural areas have no access to power. The idea of flooding the local market with electric stoves is, therefore, a nonworkable solution, likely to cause a population out-roar and instead make the lives of individuals more miserable.

1.2 Problem Definition

With these insights drawn, there is a need to define a problem perspective. Majority of the Ghanaian population depend on firewood and charcoal as fuel for cooking. This high dependency is taking a toll on forest resources due to rampant deforestation. Thus, households in Ghana, mainly rural areas, need access to an alternative clean source of energy for cooking to gradually curb the use of charcoal and firewood which will, in turn, reduce deforestation.

1.3 Objectives of the Project Work

1. To design a more efficient solar-powered electric stove with the least number of solar panels.
2. To improve the capacity of the storage battery while optimizing the size and weight of the system.
3. To introduce smart technology in the design while maintaining efficiency.

1.4 Expected Outcomes of the Project Work

Based on the project objectives, the expected outcome is a complete product that harnesses a renewable energy source, particularly solar energy (which is ubiquitous in Ghana), to provide off-grid electric power for cooking. The product must be user-friendly, affordable and easy to fit in the cooking culture of the country, especially for a population that holds cultural heritage in high esteem. Another significant expected outcome is an improvement in the battery capacity where a lesser number of batteries can be used to achieve the required functionality.

1.5 Justification/Motivation for Project Topic

The inspiration for this project was drawn from the seventh sustainable development goal – the provision of affordable and clean energy. Ghana has abundant untapped natural resources which can be used judiciously in various ways to better the lives of the people. The proposed solution combines the need to solve an energy problem with this sustainable development goal as foundational motivation. This will ensure that the cleanest but, yet affordable energy provision approach is incorporated. Consequently, the broad energy transformation picture is solar energy to electrical energy and then heat energy, for cooking purposes.

Another motivation for this project is the health hazards associated with the use of firewood and charcoal. Extended exposure to the smoke released from these wood fuels leads to respiratory diseases, eye irritations, etc. LPG does not necessarily make this situation any better. This is due to the hazards associated with gas cylinders. They may explode and cause fatal accidents. Gas leakages can pollute the air in the home and over time lead to various illnesses and most commonly, the outbreak of fire [4] [5].

1.6 Research Methodology Used

This primary research methodology considered is from a qualitative and quantitative perspective. The qualitative research technique for this project was mainly done through literature reviews and expert judgment from experts on the field to understand the in-depth design and ongoing research on this topic. Quantitative data was taken at the various stages of the component designs through software simulations, breadboard prototypes, and a final PCB board design.

1.7 Facilities/Materials Used

A significant part of this project was done in the mechanical and electrical engineering laboratories on the Ashesi University campus. Some materials that were used include a solar panel, storage batteries, power meter, microcontroller, and several circuit components such as capacitors, inductors, LEDs, LCDs, and ICs.

1.8 Scope of Work

The scope of this project entails two aspects: mechanical design and circuit design. This project works correctly on the section of conversion of solar energy into electricity, which would, in turn, be harnessed into the primary source of heat for cooking in the system. Currently, facts have it that solar panels and photovoltaic cells are inefficient in their output, as they produce a relatively low voltage[6]. For the cooking system constructed for the project, research into energy capturing and its governing principles was utilized to amplify the voltage to values enough for providing the power required to provide heat for cooking.

In addition to this, the project covered the use of different functionalities in different times of the day (referred to as ‘modes’ in this project) to suit the changing luminosity of the sun as the day goes on. This would allow the system to store energy during the daytime for use at night when there is no sunlight. The project also allowed for a metering system to help keep users updated on the state of the charging system from a Liquid Crystal Display.

1.9 Proposed Chapter Outline

In this publication, the subsequent chapters would contain information on the following aspects of the project;

- Chapter 2: Literature Review
- Chapter 3: Design
- Chapter 4: Methodology
- Chapter 5: Testing / Evaluation

  Financial Analysis
- Chapter 6: Future Work

Chapter 2: Literature Review

2.1 Design of Solar-Powered Conduction Cooking System

The invention of solar based cookers dates to 1767. This technology over the years has been improved upon gradually, and the current era of solar cookers is leaning towards smart technology [6] [4]. In 2016, researches were conducted in Independent University and BRAC University in Bangladesh to improve solar-based electric stoves. The studies were conducted in Bangladesh based on the motivation that in rural towns in Bangladesh, natural gas is scarce, LPG is expensive, and the cheapest sources of fuel for cooking (i.e., charcoal and firewood) were causing health issues while deforesting the land [7]. The authors proposed that even though access to electricity was not universal in rural areas, solar energy, which is ubiquitous, could be used to generate electricity and further converted to heat energy. This system directly worked as an electric stove yet obtained power from solar irradiation. Thus, the design was heavily dependent on solar panel installations with batteries for storage.

2.2 Component Design

Both system designs from the two universities primarily consisted of solar panels and a heat controller(s). The first design from Independent University consisted of a group of solar panels, a controller and a conduction cooker. These were initially simulated in PSIM software to analyze and improve the design. A pair of five 95W solar panels connected in series were connected in parallel to generate an input voltage of 250 Vdc [7]. The controller was modeled like a buck converter using a combination of MOSFET, 3mH inductor, a 100uF capacitor, and a diode to regulate the power and output heat in the conduction cooker. A potentiometer was used to control the highest switching frequency of 20kHz. Values were taken for various duty cycles in PSIM and the maximum output power, voltage, and current was determined. This was represented in a graph of power versus duty cycle. The appropriate duty cycle for maximum power output was 70%. These results were necessary for fabricating the buck converter to regulate the desired power output. This same setup as simulated was implemented to prove the efficiency of the design for real-life cooking purposes. The solar panels were installed on a horizontal plane, each inclined at an angle of 15°. These were connected to the controller, and the controller was attached to the heating coils of the conduction cooker [7].

On the other hand, the design from BRAC university was made up of two 200W in parallel with two 180W solar panels for each burner, two AC burners, eight 12V batteries, charge controllers and heat controllers. The system was designed to be able to fit in the national grid, yet function when there is solar energy available. Each of the 200W and 180W was connected in series, and the pair, in turn, were joined in parallel. The maximum power to be generated by this configuration was 760 W for each burner. The purpose of the batteries was to store energy when the system was not in use and provide electricity for cooking later when needed. The individual burners were set up with a charge controller and heat controller each. The function of the heat regulator is to control the amount of heat supplied to the coils while cooking [6]. There was a switch connected to the regulator to turn the stove on and off.

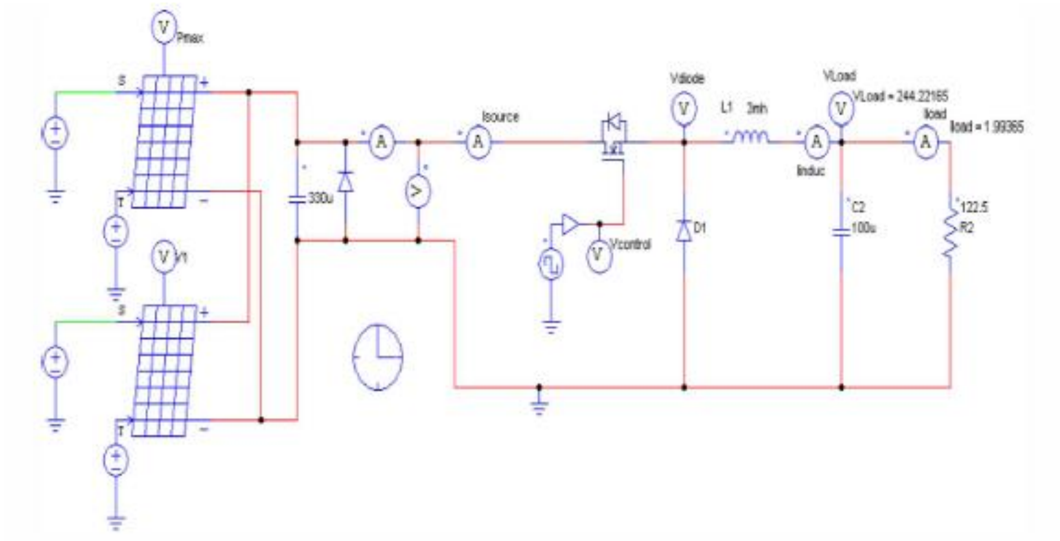


Figure 1 Schematic diagram of the solar-powered stove design

Source: Adapted from [7]

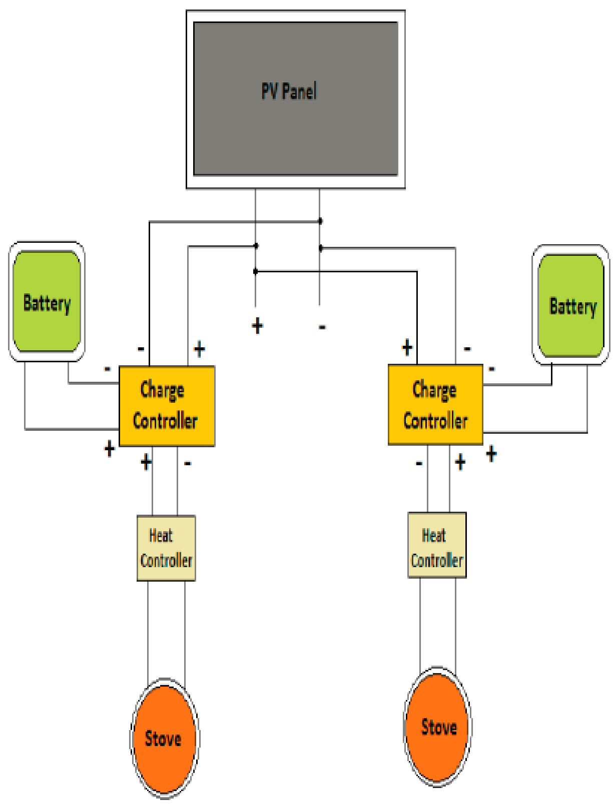


Figure 2 Block diagram of solar-powered stove design

Source: Adapted from [6]

2.3 Results Generated

When the switch was turned on, it supplied electricity to the coils, and the coils got heated up. In the first research, two actual cooking tests were conducted. First, the system was used to boil water and then used to cook a mixture of rice and vegetables. It took 25 minutes to boil the water and 1 hour to cook the rice. Some key factors surrounding these tests were the season and time during the day which the cooking was done. Both tests were done during the winter season. Hence the sun's irradiation was low.

On the other hand, stable power and high efficiency of 93% was recorded for the boiling process because it was done in the morning, whiles an unsteady power due to voltage fluctuations were recorded for cooking rice because it was done late in the afternoon. The efficiency, in this case, was 85%. An economic analysis of this design showed that the bulk cost of the cooking system involved the solar panels, which was 82% of the maximum price (60000 BDT). Also, a breakeven point of the system for a family of five members was estimated at two years [7].

Again, the second research produced successful results for the proof of concept. The batteries were charged by the PV panels when the system was off, and the heating coils were powered efficiently from the PV panels and the battery when the stove was turned on. In [6, Tab 1] shows a comparison between the cooking time of food items with the gas stove and the solar-powered electric stove. From the results, cooking with the stove was almost as efficient as the gas stove with little time elapses on the part of the designed stove. All the items were cooked for four persons. The total cost for the double burner solar stove was estimated at 132000 BDT. The authors interpolated that if a family uses the solar cooker in place of the gas cylinder, the total cost can be covered in less than three years (for moderate family) and approximately four years for small family [6].

Table 1 Comparison between the solar stove and LPG stove [6]

No of items	Name of the items	Duration in gas stove in minutes	Duration in experimental stove in minutes
1	Boiling water(500ml)	8	12
2	Rice(.5kg)	25	35
3	Noodles	14	17
4	Fish fillet	12	15
5	Chicken fry	16	22
6	Egg	4	4

2.4 Gaps and improvements

The other research by BRAC University was an innovation of the first one done by Independent University. The latter consisted of battery storage, a fewer number of solar panels and two burners; unlike the first one that had a single conduction coil with no batteries and a higher number of PV panels. On the contrary, the later was costlier with a cost difference of about 72000 BDT. This might mean a further improvement in the system will lead to a corresponding increase in the cost of the stove. This could in turn not meet the economic needs of the people and hence leave the problem at hand unsolved. Thus, a research objective in this project is to optimize the least number of resources for the project to reduce the cost of production.

Also, the batteries used in the second design were bulky and numerous. This made the whole design cumbersome and added to the cost as well. Secondary storage batteries over the years have been improved to be sizeable yet efficient in battery energy density and battery power density. This research experimentation furthermore seeks to use a more efficient approach to energy storage using sizable batteries while keeping the power quality and product coat at optimized levels.

Also, solar tracking could have been used to generate maximum power with a fewer number of solar panels, and an improved voltage amplification process could have been done to optimize the use of fewer panels. This will reduce the cost of the system and provide a shorter breakeven point.

Finally, there was no in-built metering system to help determine the power consumed about the number of hours used in cooking. Thus, a metering component will be included in the new design to help determine the amount of power stored at in the battery and the duration for which it can last if used at maximum capacity.

Chapter 3: Design

3.1 Review of Existing Designs

The existing technology for solar-powered electric stoves consists of PV cells, heat controllers, charge controllers, and large storage batteries. The most modern technology was designed as a two-burner stove with separate controllers and batteries [6]. Below is a block diagram of the design description.

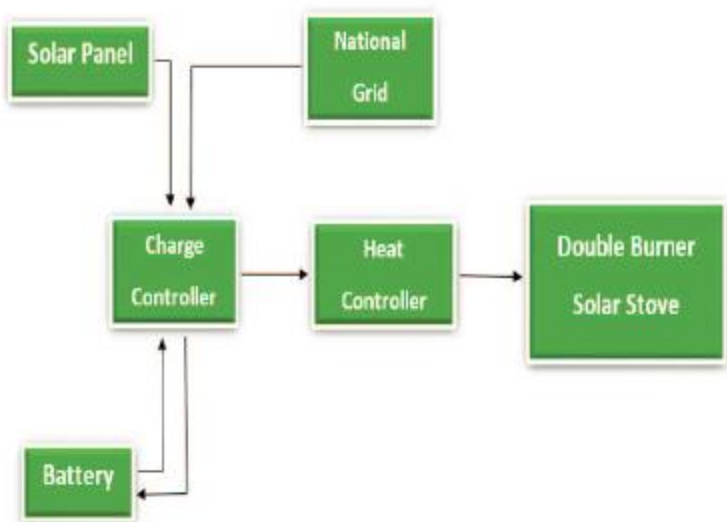


Figure 3 Block diagram of an existing design

Source: Adapted from [6]

The system above was designed to depend on solar energy and the possibility for dependence on electrical energy from the national grid was included as a future improvement of the system. Even though the model worked as expected, the cost of the entire system was very high. This emerged from the number of solar panels and batteries used in the design. Also, the two burners possessed individual batteries and charge controllers. As a result, the circuit design was bulky and not well optimized. The battery lacked a metering system to enable the user to determine the amount of power stored in the battery in real-time.

An alternative design would consider a more efficient but cheaper means of building a solar-powered electric stove. The power required for each burner would, however, remain like the design above, that is 500W. There would be a reduction in the battery size by inserting a boost converter to increase the voltage. In addition to the design, there would be an alternative to connect the stove to the national grid, such that the stove can use both AC and DC power sources. The total design initiative should account for innovation in the project to achieve the end goal while monitoring the cost of the stove. Also, the new design should have a display component for the user to read the battery power level and a corresponding duration of how long the system can function at maximum heat output.

3.2 Thesis Design Objective

1. To optimize electricity generated from solar panels for the required heat output for cooking.
2. To manage the cost of fabrication of the design at a capped price.
3. To introduce a power metering system for the user to determine the amount of power available in the battery and how long the system can function at maximum capacity.
4. To include an alternative connection of the stove to the national grid

3.3 Design Decisions

Alternative methods for each process were taken into consideration to achieve the thesis design objectives. The solar cooker consists of six main parts. These include:

1. PV Panels
2. Battery
3. Boost converter
4. Heat controller
5. Power meter

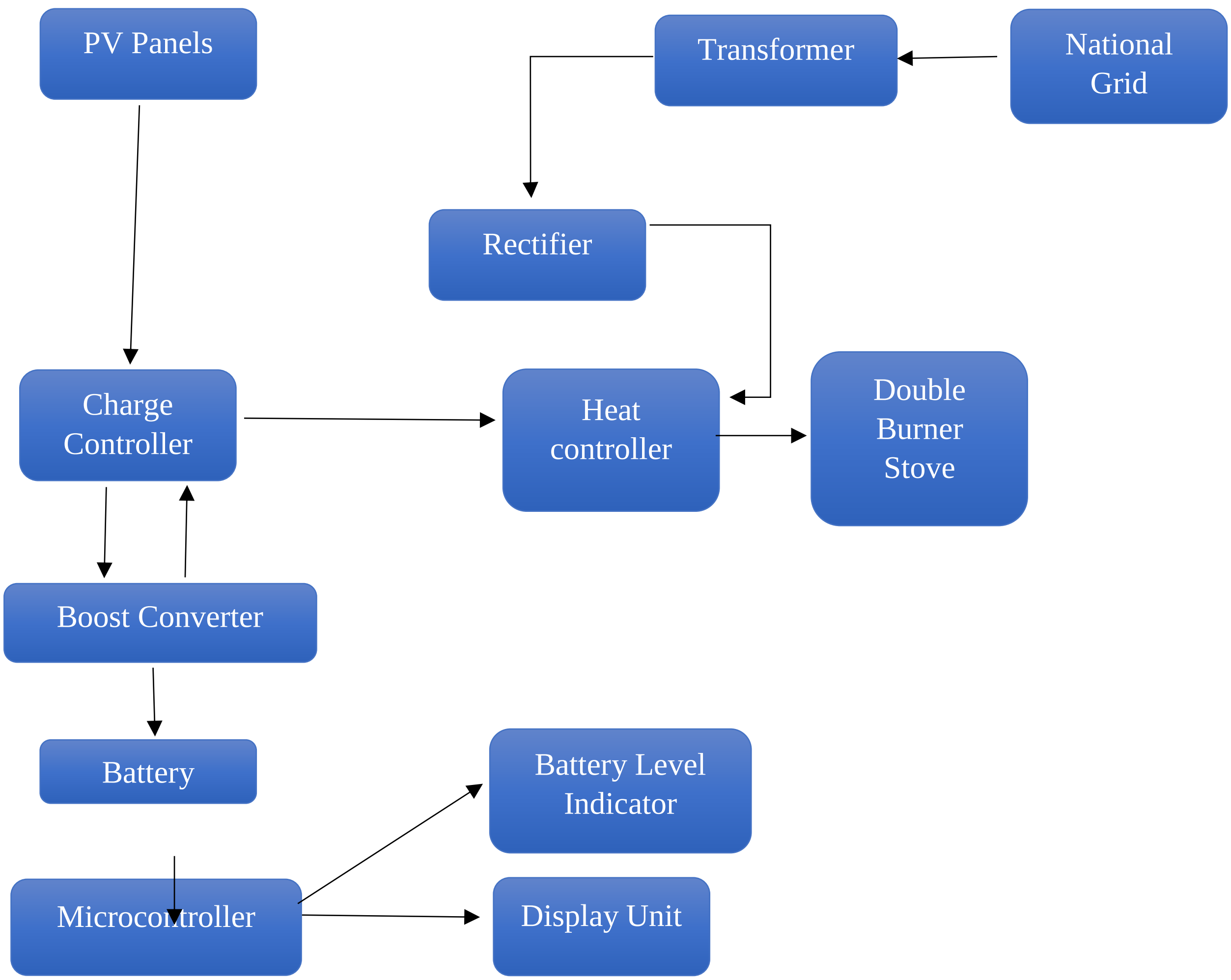


Figure 4 Block diagram of the new design

3.3.1 Heating Coils

The design for the heating coils was obtained from the existing research work by BRAC University [7]. The heating coils obtained were initially manufactured to use AC. However, this design allows the coils to use DC from the PV panels. The wattage of the coil was measured, and the new model designed to reduce the wattage of the coils while maintaining the efficient functioning of the heating system. Nonetheless, it was required in their research that the voltage of these coils was not too high as it would eventually increase the battery size and hence the cost of the battery. Thus, the alternative was to increase the current to obtain the targeted power of the coils; 500W. This was done by reducing the resistance of the coil through a parallel connection of separately cut coils of nichrome wire.

3.3.2 Boost Converter

The purpose of the boost converter was to step-up the voltage from the battery to meet the required voltage of the heating coils. Even though the current would be decreased from the source, this would not affect the current output for the coils which were newly designed with lower equivalent resistance. The benefit of the boost converter, in this case, reduced the battery voltage required whiles keeping the required voltage uncompromised. This, in turn, reduced the number of batteries needed to supply the required voltage for each burner. The boost converter was the main engineering contribution of the project. It consisted of capacitors, diodes, inductors and a MOSFET to act as a switch.

3.3.3 Charge Controller

The purpose of the charge controller was to act as a voltage regulator for the battery. The charge controller regulated the amount of current that flows into the battery to prevent cases of overcharging which would damage the battery in the long run. This would also affect the boost converter such that the voltage input would be within a required range to prevent destroying the components. The charge controller circuit was a simple voltage regulator included in the PCB layout.

3.3.4 Heat Controller

This component is one of the crucial parts of the product design. The purpose of the heat controller was to increase or decrease the amount of heat applied to the burner coils based on user preference. Each burner had a heat controller with a knob to control the amount of current supplied to the heaters. This design was perfect during simulation, yet unimplementable in practice. Hence a simple fan regulator was redesigned to suit the heat control functionality of the stove.

3.3.5 Power meter

The power meter is another critical addition to the electric stove design to measure the real-time power capacity in the battery. The purpose of this addition is to allow the user to determine the power available in the battery and provide information about how long the battery can power the coils at maximum current. The power meter was built digitally with a microcontroller, LCD screen, and resistors; initially set up by the microcontroller to display real-time values of the amount of power in the battery.

3.4 Design Iterations

The design decisions to design a solar system that can power two 500W DC heating coils were centered on choosing the specific LCD unit, calculating the peak wattage required, number of solar panels needed, battery capacity and charge controller specification.

For the peak watts required, it was estimated that the solar energy would be needed to power two AC heating coils each of 500W. The duration for the night mode function of the stove was estimated at 1 hour per day. Thus the total watts peak will be estimated as 2 x 500W x 1hr = 1000 Wh/day. The solar panel factor for Ghana is 5.22. From this information, the number of solar panels can be calculated. The size of the system can be obtained by dividing the peak watts by solar panel factor: 1000 Wh/5.22 = 191.57Wh. The number of panels required is approximately five panels of 200W.

There were two battery options available for the project: 12V 20Ah rechargeable battery and 12V 360W rechargeable battery. Even though these batteries were of the same voltage, the latter had a higher output which would suffice for the stove power requirement through a series connection. As a result, the 12V 360W battery was selected for the stove fabrication.

3.5 Design Justification

An alternative design would consider optimizing the maximum amount of solar energy from PV cells while reducing the number of solar panels used. This approach will include servomotors and algorithms for controlling the panel and directing it to positions to obtain maximum sunshine. Again, the alternative design would replace the sizeable two-battery system with an array of supercapacitors with enough capacity to supply power to the two burners with an almost equal or higher efficiency than the existing one.

The primary design challenge is thus to eliminate as much cost as possible by ensuring that the individual components of the stove are locally designed, engineered and built. This limitation informed the employed layout for this project including the various parts chosen for the circuit design. The design objectives are described in detail in the next chapter; as well as techniques and improvisions made to meet design above objectives.

Chapter 4: Implementation

4.1 Experimental Setup

The experimental setup for each component of the stove started with schematic diagrams, calculations for the missing parts and circuit simulations. The three main software used were Eagle (for PCB designs), Proteus and Ltspice for simulation. A detailed contextual model of the implementation is shown in figure 5. Each process taken to test the critical voltage sources of the stove is outlined in the proceeding subsections.

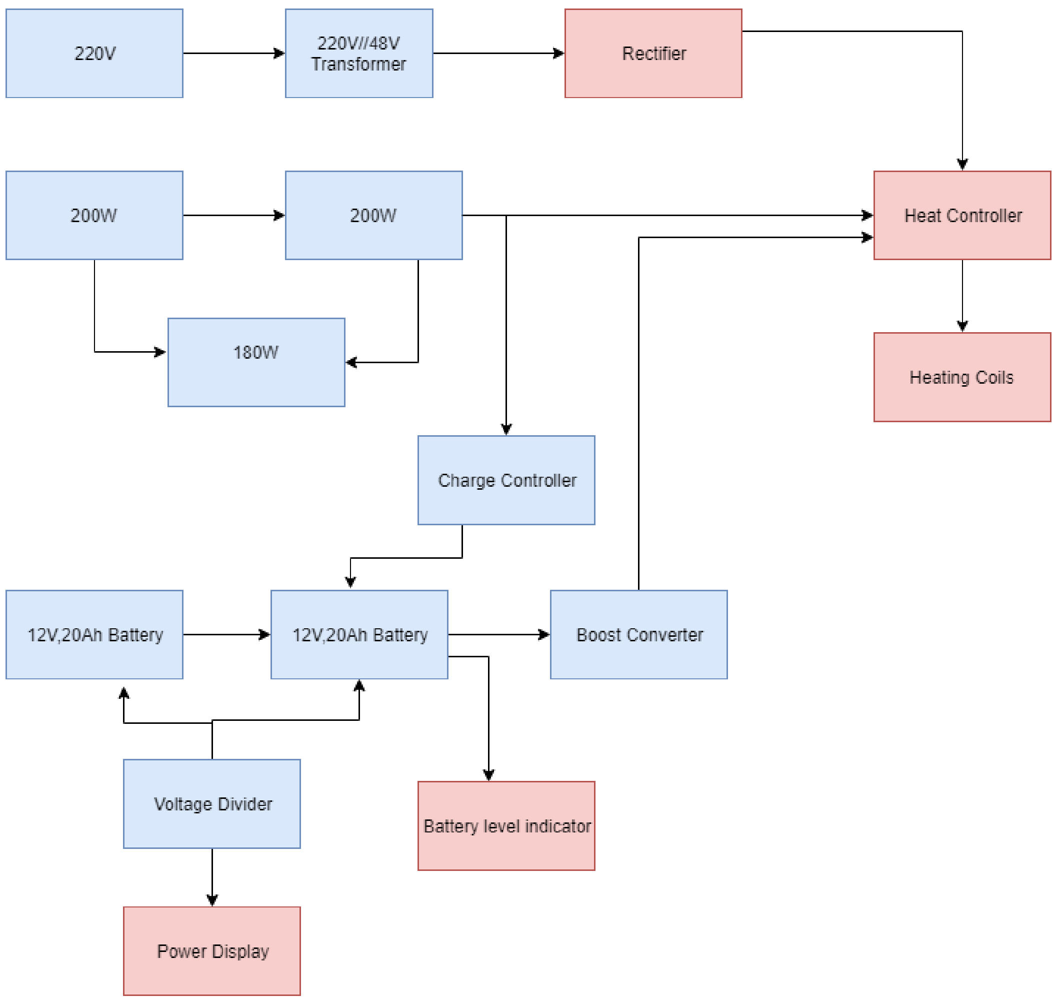


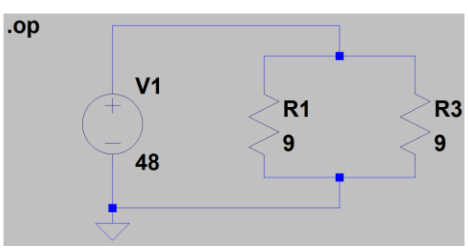
Figure 5 Detailed flow of contextual stove wiring design

The setup was done individually with the separate voltage sources tested progressively with the heating coils. The direct national grid voltage source was tested first with a 220/48 Vac transformer and a rectifier circuit to convert the AC to DC.

Unfortunately, the rated solar panels calculated for the project were physically unavailable for field testing; hence only a simulation for this voltage source was performed. As a result of this challenge, the batteries were charged externally and used for testing the boost converter as well as the other components, like the power meter.

4.1.1 Heating Coils

As described under the design section, the resistance of a single long AC heating element was measured, cut into small parts of equal resistance each, connected in parallel and the resultant resistance calculated. The total resistance of the coiled wire was approximately 36Ω. It was then cut into four short coiled wires each of resistance 9Ω. The two burners were therefore designed with a pair of 9Ω heating coils connected in parallel. The circuit simulation for heating coil design is in Fig 6 below.




```
        --- Operating Point ---

V(n001):        48              voltage
I(R3):          5.33333         device_current
I(R1):          5.33333         device_current
I(V1):          -10.6667        device_current
```

Figure 6 Heating coil simulated in LTspice

4.1.2 Solar Panels

For the required power of 500W, two 200W panels were connected in series and the duo combined in parallel to give a total of 580W. This arrangement was required to provide a voltage higher than 48V needed for the coils. The 200W PV panel has an operating voltage of 30V; giving a total of 60V through the series connection. The maximum driving current obtained from the series connection provides 6.9A. Therefore a parallel connection with the 180W PV panel yields a total flow of 6.2A + 6.9A = 13.1A. The specifications for each panel can be found in table 2 in the appendix. These were simulated in software.

4.1.3 Battery

Each burner required a battery size of 48V, however, to reduce the battery size and still obtain the needed voltage, two 12V 360W batteries were connected in series, and the resultant 24V was attached to a boost converter specially designed to increase the voltage to 48V while generating a current of 10.5A. The boost converter circuit was first developed in LTspice simulating software and then built on a breadboard to ensure proper functioning before printing on a PCB board.

4.1.4 Power Meter

Two major components that were also designed for the battery included the battery level indicator and the power display circuit. These two forms the power meter described under the design section. For the battery level indicator, an IC labeled LM3915 was connected on a PCB board to three LEDs to indicate when the battery is fully charged, half full and low on energy. The schematic diagram for this circuit is captured in figure 6 below. LM3915 is a monolithic integrated circuit that senses analog voltage levels and drives ten LEDs, LCDs or vacuum fluorescent displays, providing a logarithmic 3 dB/step analog display [8]. In this project, the bar graph display of the IC was used instead of the dot display which has a slower response than the former. Also, the power display circuit, which allows the user to read real-time power values from the system's battery was built with a voltage and current sensor, an ATMEGA8 microcontroller, and an I2C LCD. The schematic diagram for this is circuit is also shown in Fig 6. The ATMEGA8 is a microcontroller that can be configured with an Arduino device before fixing it on a PCB board. In this setup, the input signal to the microcontroller was obtained from the battery through a voltage and current sensor to the input pins of the board, that is pins A0 and GND. The output signals are retrieved from pins ADC5 and ADC4 at pins SCL and SDA respectively of the LCD (through the I2C module). An Arduino code was modified from [9] to configure the microcontroller, and formulae were derived to calculate the actual power of the battery. This feature is necessary during the night mode operation of the stove.

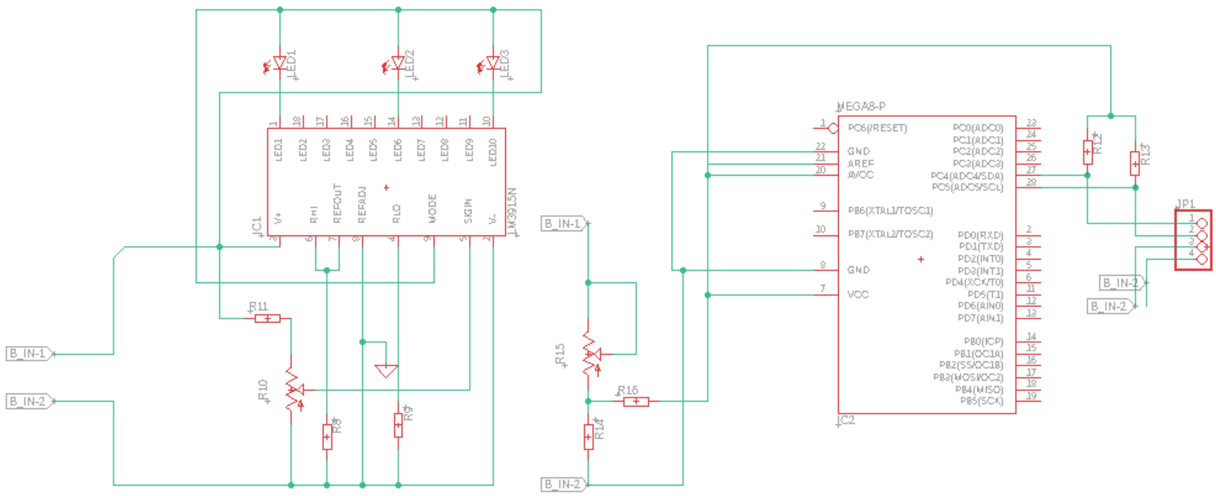


Figure 7 Schematic diagram of the battery level indicator and power display unit

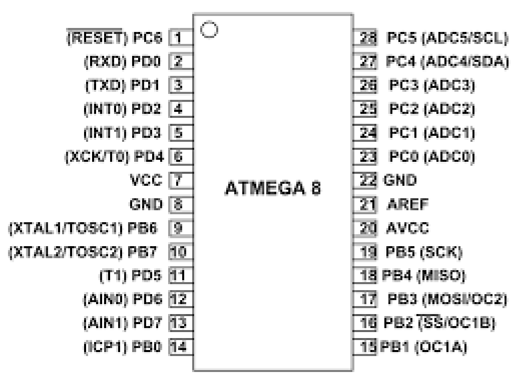


Figure 8 ATMEGA8 pinout

Source: Adapted from [10]

4.1.4 Boost Converter

The boost converter was one of the critical components of product design. It required several calculations to obtain the right sizing of the components used in the design. A typical boost converter consists merely of an inductor, a diode, a capacitor and a switch as shown in Fig 8. To obtain the inductor and capacitor size for the boost converter of input voltage 24V and output voltage of 48V, the following equations [11] and estimations were made:

$$V_{out} = \frac{V_{in}}{1-D} \text{ ----------(1)}$$

$$where\ Vout - output\ voltage$$

$$Vin - input\ voltage$$

$$D - Duty\ Cycle$$

From equation 1, the duty cycle was obtained at 75%. This value was further used to calculate the inductor and capacitor size.

$$L = \frac{(V_{out}-V_{in}+V_D)(1-D)}{\min(i_{load})f} \text{ --------(2)}$$

$$C = \frac{(i_{load})(D)}{(V_D)f} \text{ -----------(3)}$$

The values for the inductor and capacitor were 1.625mF and 0.346mF respectively. The frequency value was estimated from the literature [11]. However, in the simulation and final implementation, a design factor of 0.5 was added to each component size to obtain the desired outputs.

The switch in practice is replaced by a MOSFET which is fired at the gate by a pulse circuit. A monostable circuit was designed to function as a multivibrator for the MOSFET gate. This design was not valid because the frequency generated at the output could not be regulated easily due to the absence of specific capacitors. Thus, an NE555 IC was used instead of the traditional monostable circuit to generate the pulse signals. For this design, the voltage from the battery had to be stepped-down for the NE555. The maximum input voltage required for such IC is 18V which is lower than the 24V from the battery. Initially, a voltage divider was used to step-down the voltage from 24V to 9V. This design was not efficient because the output current from the voltage divider circuit was minimal. Hence it could not power the MOSFET. Finally, a voltage regulator – L7805C was used to decrease the input voltage to 9V with a high enough current for the timer IC. Once the timer circuit was done, an operational amplifier – UA741, was used in a non-inverting mode to amplify the output pulse voltage. The output of the pulse signal from the timer circuit was connected to the gate of the MOSFET (1RF540N) whose drain was connected to one end of the inductor and the source to ground. The circuit diagram and breadboard prototype of the boost converter is shown in Fig 9 and Fig 10.

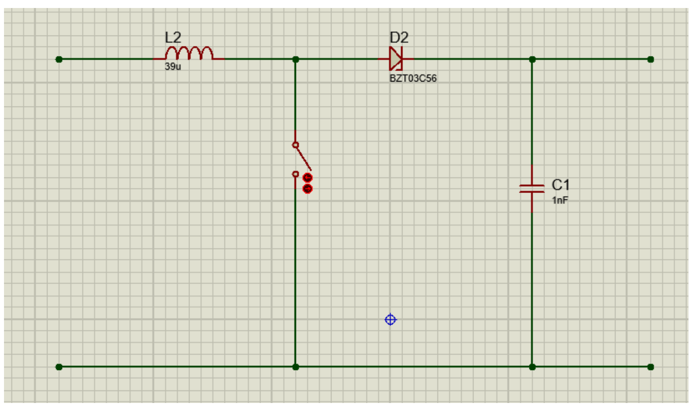


Figure 9 Schematic diagram of a generic boost converter

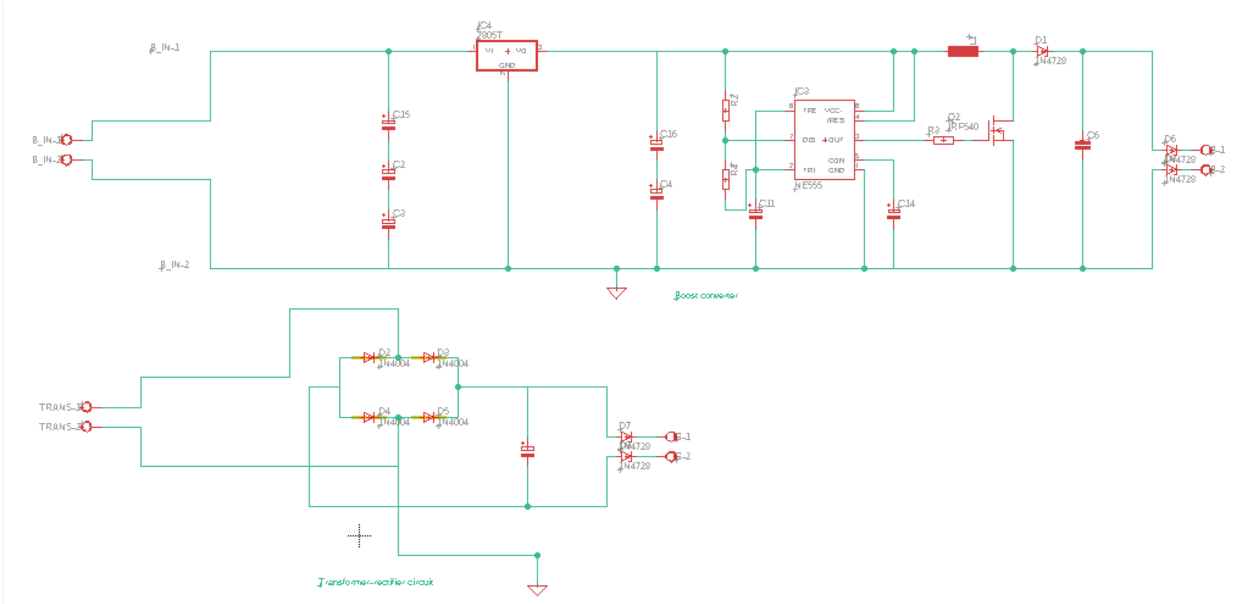


Figure 10 Schematic diagram of the boost converter

4.1.5 AC Power

This alternative power source was incorporated into the design so that the stove can be connected directly to the national grid. Because the entire model is solely dependent on dc power, a full-wave rectification circuit was designed to convert AC power to DC power before it is sent to the heat controller. The transformer used to step down the grid voltage from 220v to 48V was huge and bulky to fit on the printed PCB board. The circuit schematic for the rectifier is shown in Fig 11.

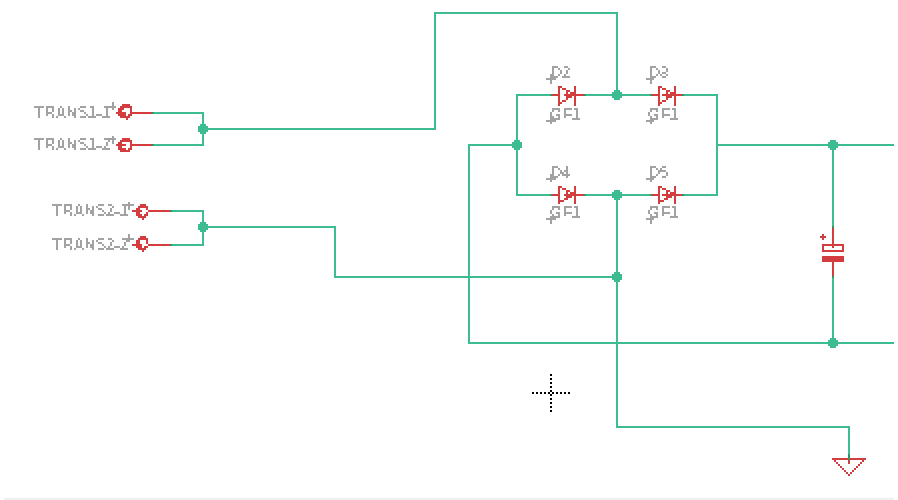


Figure 11 Schematic connection of AC power supply to the coils

4.2 Breadboard implementation

During the building process, the first aspect of the stove circuitry to be tested on a breadboard was the boost converter circuit for the battery. This was to verify the correct functioning of the calculated values from the simulation as well as incorporate a design factor to ensure efficient functionality. After a successful simulation of the boost converter on Proteus, it took several trials on the breadboard to implement the simulated design. The final working breadboard model of the boost converter is shown in Fig 11. The next circuit simulation that was tested was the battery level indicator and the power meter. These were tested using a power supply unit, LM3915 IC, LEDs, and resistors. This circuit worked as expected. A picture of this breadboard model is shown in Fig 12.

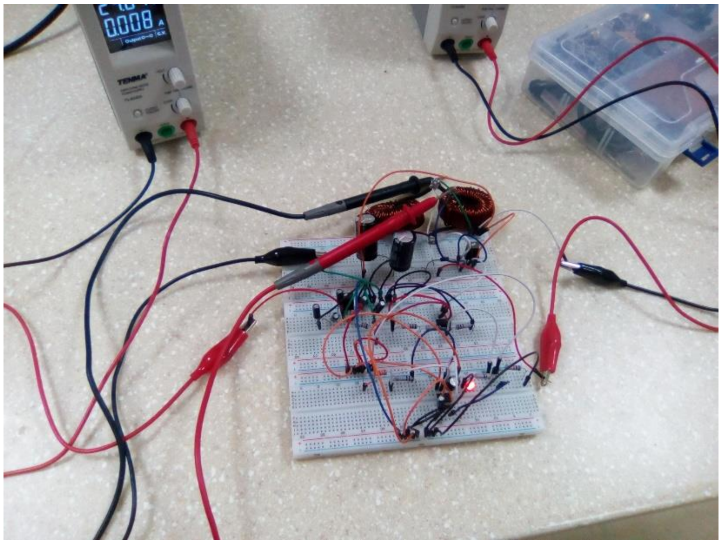


Figure 12 Breadboard setup of the boost converter

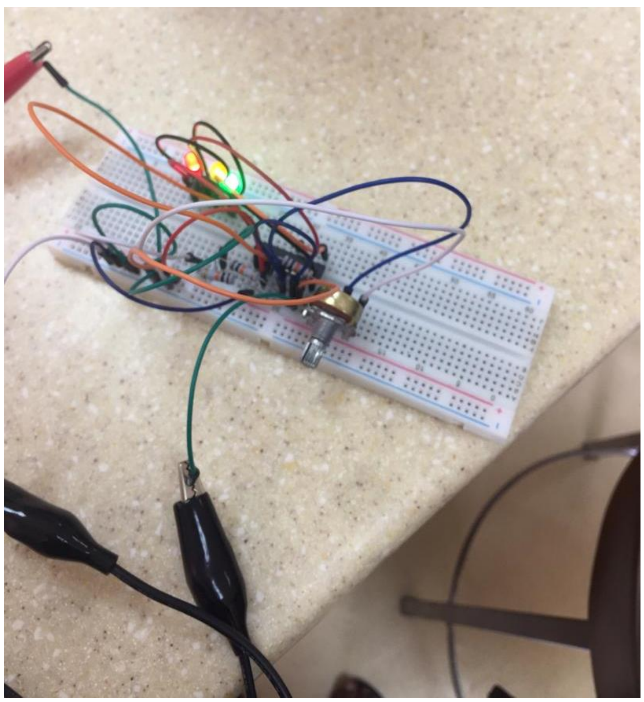


Figure 13 Breadboard setup of battery level indicator

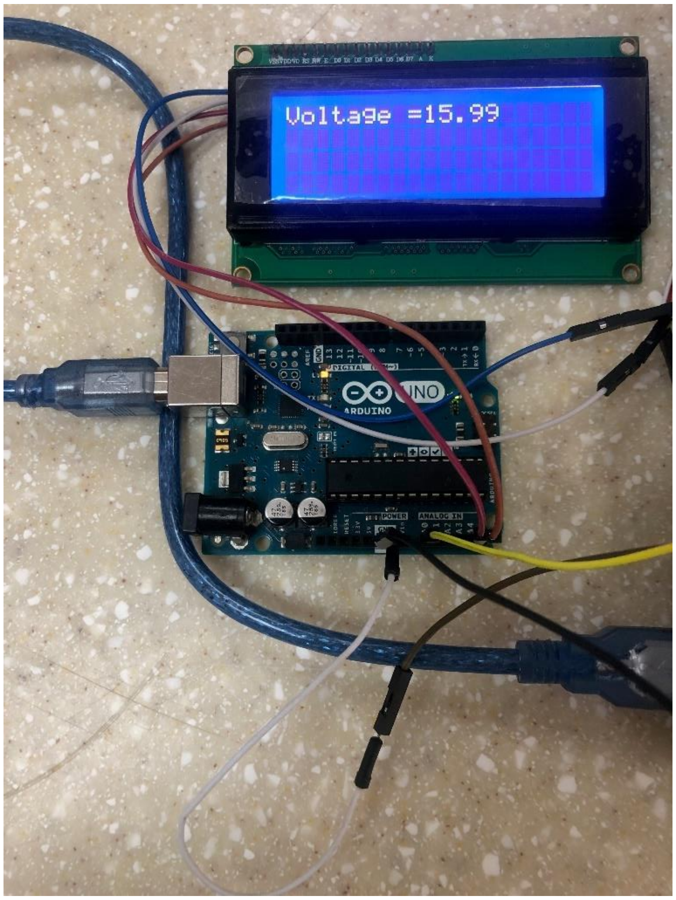


Figure 14 Breadboard setup of LCD for battery voltage

4.3 PCB Layout

After successfully simulating the various circuit designs in Proteus and testing the boost converter, battery level indicator, and power meter on a breadboard, the schematic diagrams were merged and exported to a PCB environment. They were neatly arranged and finally made ready to be printed on a board, using a milling machine. This phase of the project required a series of arrangements of the PCB board to obtain the best routing connection of the components. The circuit components were then soldered on the printed board. The final circuit board is shown in Fig 15. This board is the central control unit for the various power sources of the stove and the power metering of the battery.

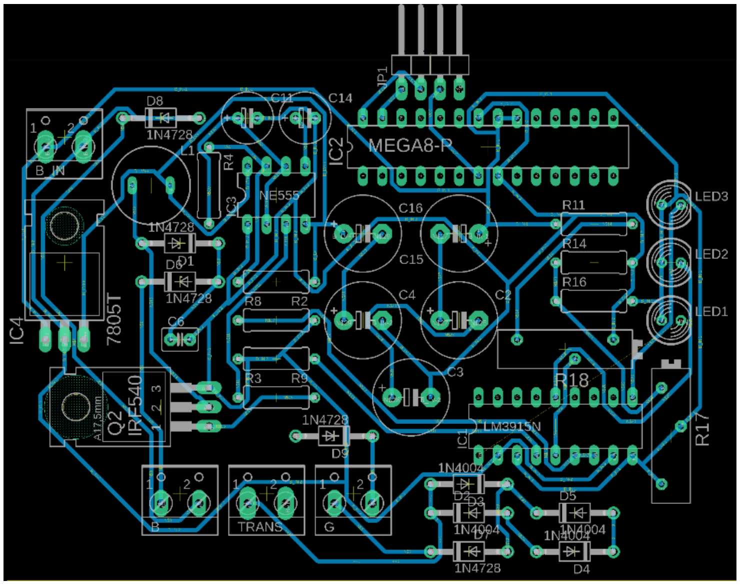


Figure 15 PCB layout of stove controller

Chapter 5: Results

5.1 Circuit Simulation

As mentioned earlier, the boost converter circuit was first simulated in LTspice and the result obtained was a graph of voltage and current against time. This graph is captured in figure 13, where the steady-state voltage at the end of the boost activity was 48.3V from a 24V DC source, and the current was 11.4A. The design was afterward built and tested on a breadboard. The LED battery level indicator and power display circuit were successfully simulated in Proteus.

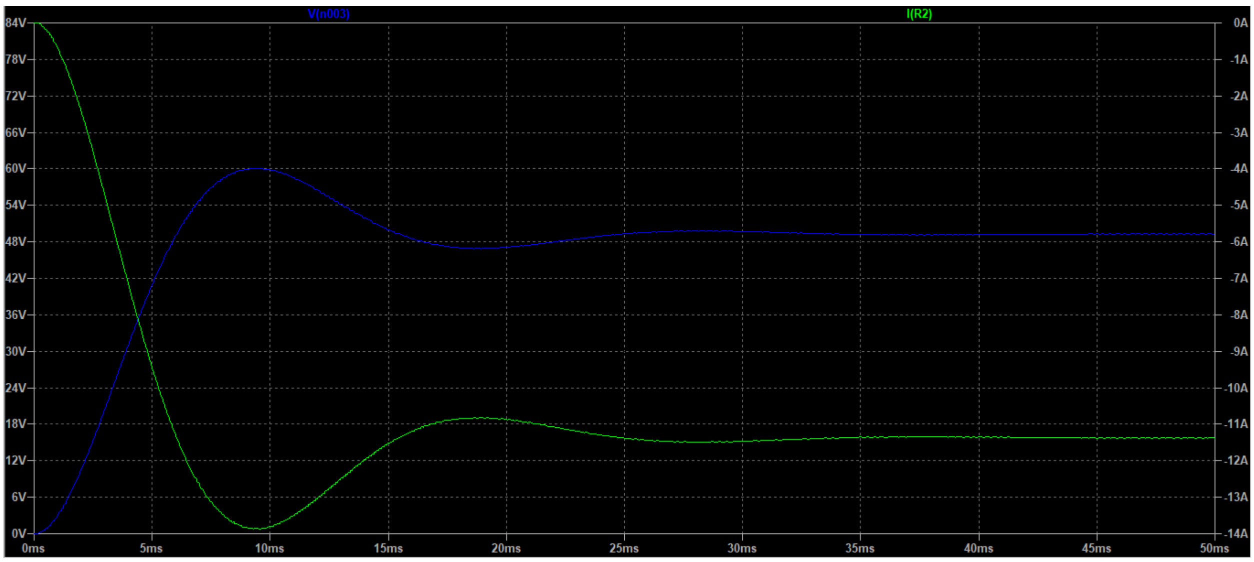


Figure 16 Boost converter output in LTspice

5.2 PCB Layout

Following that the PCB layout was successfully designed, it was printed, and the components soldered unto the board. The soldering was done carefully not to destroy the board. The board was tested afterward, and each compartment was working as expected. The next step was to combine the various voltage sources; in this case, the batteries and the grid into a complete setup for testing.

5.3 Field Test results

According to the project schedule, the complete stove design was to be tested first with the solar panels for three days to obtain useful data representation on the solar irradiance for different days. Since the panels were not available in school, the grid power supply was tested alongside the batteries. The batteries were charged separately with external power supply before used for the testing. Recommended dishes and their duration for cooking using only the battery source was determined for the users as a guide to using the product efficiently. Two everyday meals that are usually consumed at night in Ghana were selected for the test – noodles, and rice. The stove was also used to boil 1000ml of water to determine its optimum boiling time. Data of these findings are shown in tables 2. Again, there was analysis to analyze the rate of heating of a single coil of nichrome wire. This analysis was necessary to validate the efficiency of the stove. Qualitatively, the heat in the coils increased with an increase in current from the power supply. A graph was generated for three tests on the rate of heating and the margin of error calculated after merging the three data sets. A picture of the heating rate of the coil is shown in Fig 17.

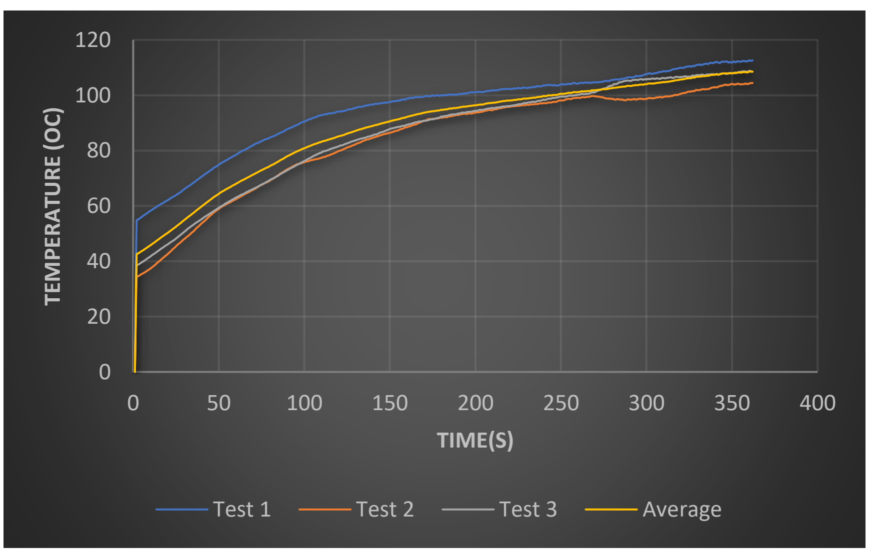


Figure 17 Graph of the heating rate of a single coil

Table 2 Comparison of cooking durations in relation to different voltage sources

Dish	Duration using batteries (minutes)	Duration using grid (minutes)	Duration with conventional electric stove (minutes)
Family pack noodles	18	12	10
3 cups of rice	50	45	40
1 liter of water	15	12	10

From table two, the stove functioned comparatively as efficient as the conventional electric stove with not more than 10 minutes interval between the various cooking times. This proved the efficiency of the product.

5.4 Economic Analysis

A financial analysis was conducted on the product and compared to the current household expenses on firewood and charcoal, to test the feasibility of commercializing this product. The full cost of the stove can be calculated after the enter circuit design is completed as well as the body of the stove is finished. Meanwhile, the table below shows a current estimate of the components used so far in the design.

Table 3 Cost of components for stove fabrication

Component	Number	Unit Price	Total cost
200W PV Panel	4	GH₵340	GH₵1360
180W PV Panel	2	GH₵280	GH₵560

12V 360W Battery	4	GH₵40	GH₵160
220V/48VStep-down transformer	1	GH₵250	GH₵250
Charge controller	2	GH₵40	GH₵80
PCB board & components	2	GH₵200	GH₵200
Nichrome wire	1	GH₵100	GH₵100
Casing	1	GH₵70	GH₵70
			Total = GH₵2780

Production cost = cost of circuitry + cost of casing = GH₵2780

From primary research, an average household in the rural area consisting of six individuals spends a minimum of GH₵5.00 on charcoal every day. In a year, the estimated total expenditure will be

$$\frac{365\ days}{year} * \frac{\text{GH₵5.00}}{\text{day}} = \frac{\text{GH₵1825.00}}{\text{year}}$$

For the total cost of the product, the payback calculation will be;

$$\frac{GH₵2780}{GH₵1825\ per\ year} = 1.523\ years$$

From this estimation, an average household in a typical Ghanaian rural area can cover the cost of the product in approximately two years.

Two cases were generated to include and exclude the solar panels, which form the bulk of the cost.

Case1(cost involving solar panels):

The total cost of the stove and solar panels is $GH₵1420 + GH₵1360 = GH₵2780$. A family that purchases the product together with the solar panel installation can pay back the price in two years with a daily payment of GH₵5.00.

Case2 (cost without solar panels):

The total cost of the stove $GH₵1420$. A family that purchases the product without can cover the entire cost in less than ten months with a daily payment of GH₵5.00.

Chapter 6: Conclusion

6.1 Discussion

The design of the stove was successful as well as the implementation. However, the implementation required more caution and the addition of a design factor for effective functioning. There were a series of trials, failures and redesigning to arrive at a useful product. The success of this project is a significant leap into the future of sustainable renewable energy development. Such contribution to the world of technology will ensure that clean energy is made accessible to all, for primary life activities such as cooking.

This stove depends on two primary sources of energy with batteries for storage. It provides a cleaner source of energy for cooking which eliminates the health risks associated with inhaling smoke from charcoal and firewood. Also, the environment is safeguarded from problems such as deforestation, and the release of wood ash into the air. From the economic analysis of the stove, it is worth noting that the bulk of the product cost is from the PV panels and the battery. However, the actual price of the stove is comparably low. Thus, with partnership from a solar panel manufacturing company, various avenues can be explored to make the panel installation affordable and applicable for other uses such as light bulbs, television sets, and different electrical gadgets. An aspect of solar power generation that has not yet gained grounds in Ghana is the use of solar roofing sheets. Solar roofing sheets could be used in place of the standard roofing sheets used in the construction industry to provide electrical energy for applications such as the solar-powered electric stove.

6.2 Limitations

A significant limitation to this project was the unavailability of some of the crucial circuit components on the local market. This introduced a lot of lag time in completing the fabrication of the stove. Some of the parts had to be imported; thus, the cost of fabricating the stove increased.

Also, the rated solar panels for testing the stove were not readily available in school. Therefore, no test was done for the solar connections of the stove. The battery was charged externally by a DC source.

Another issue was with software licensing and usage. The Proteus software was initially not usable because of licensing issues. Also, the Eagle software only allowed PCB layout designs and not simulations. This made simulations a bit problematic in the beginning.

6.3 Future Work

Future improvement in the design is an alternative battery storage system with better power and energy densities. This will improve the charging and discharging rate as well as the power that capacity of the stove when it is solely dependent on batteries. A control panel could also be incorporated into the circuit design to control the powering of the stove automatically. This control panel would include more functionality such as control buttons for specific food items, just like the microwave. Finally, this product could be improved with inbuilt maintenance circuits that can alert the user when there is a fault. It would also have safety and protective devices to safeguard the user against accidents.

Appendix

Table 4 PV panel specifications [12]

PV Panel Specifications	Monocrystalline 200W PV Panel	Monocrystalline 180W PV Panel
Maximum Power at STC (Pmax)	200W	180W
Maximum Operating Voltage (Vmp)	30.3V	30.3V
Maximum Operating Current (Imp)	6.93A	6.27A
Open Circuit Voltage (Voc)	37.7V	37.7V
Short Circuit Current (Isc)	7.74A	7.01A

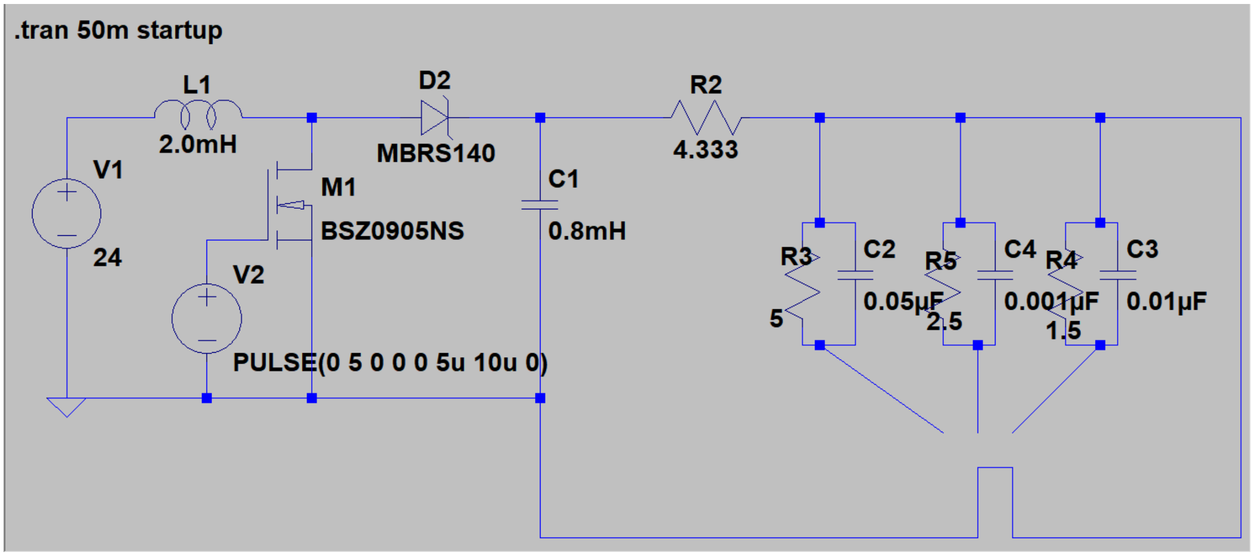


Figure 18 Boost converter simulation in LTspice

```
void setup()
{
  lcd.init();                        // initialize the lcd
  lcd.init();
  // Print a message to the LCD.
  lcd.backlight();
//Serial.begin(9600);
lcd.begin(16,2);
lcd.print(" Measure > 25V  ");
delay(2000);

}


void loop()
{

value = analogRead(voltageSensor);
  vOUT = (value * 5.0) / 1024.0;
  vIN = vOUT / (R2/(R1+R2));
  //Serial.print("Voltage = ");
  //Serial.println(vIN);
  lcd.setCursor(0,0);
  lcd.print("Voltage =         ");
  lcd.setCursor(9,0);
  lcd.print(vIN);
  delay(500);
```

Figure 19 Arduino code for LCD

Source: Adapted from [9]

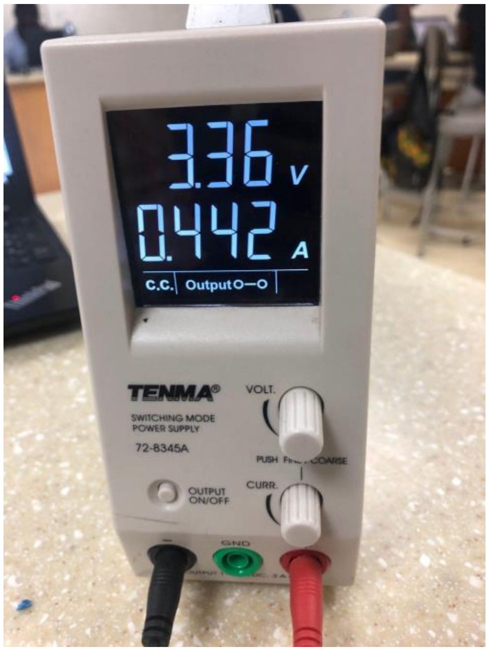


Figure 20 Voltage drop across resistance wire during temperature test

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