Design and Fabrication of a Digital Solar-Powered DC Induction Cooker

Makinde Kayode[1], Lawal Olawale Kazeem[2], Amao Enock[3]

[1,2]*Department of Electrical Engineering, Federal Polytechnic Bida, Niger State, Nigeria*

[3]*Department of Physics, Federal Polytechnic Bida, Niger State, Nigeria*

Abstract: **The design and fabrication of a digital solar-powered DC induction cooker come with numerous advantages, including high efficiency, almost two times the existing technologies. Its portable compared to the existing technology, its efficiency comes with low power consumption i.e. all power that is generated is transferred, at least 80 % of the power generated and above all it is aimed at designing a stand-alone DC induction cooker. It encompasses the use of a heating element powered by a DC source from energy trapped from the sun, with the aid of PV cells, battery, charge controller, and relays using AT MEGA 328P microcontroller for switching and control purposes. The design enables the selection of time for either warming or cooking. The heat for cooking and warming is produced by the Nichrome wire (element) according to the time set. The temperature at 100°c was obtained at 45 minutes. The system's efficiency can be improved in the Nichrome wire (element) and a corresponding increase in the backup storage and the PV modules. The total energy generated from the solar system was 5760W at 24VDC with average sunshine hours in Bida as 8hours and the battery used is 2 pieces of a 12V-100AH which was connected in series to produce 24VDC. The design done for the induction cooker was rated at 400W. This means that the induction cooker can run for a minimum of 6 hours without any means of charging. It was observed the solar can sufficiently charge the battery two times in one day if it is been discharged.**

***Keywords*: DC, Solar, Induction, Microcontroller, Digital display**

I. INTRODUCTION

In early times, energy is completely harnessed from fossil fuels (coal, oil, and natural gas). As humans become more civilized, their industries also grow, which in turn increased energy demand. The rapid increment in population also contributed to the increment in energy demand. This caused an increment in the utilization of fossil fuels. Eventually, this started to degrade the environmental quality (Omer, 2008). The use of conventional energy has led to global warming, which is caused by the increase in the concentration of greenhouse gases in the atmosphere due to the burning of fossil fuels, causing the increment in the earth's mean temperature. This in turn causes climate change, which is responsible for different hazards such as floods and drought. The burning of fossil fuels also causes acid rain, which can harm forests, freshwater, and soil (Delaimy, 2020). The fluctuation and increment of fossil fuel prices are also other problems that affected countries, whose economy depends on nonrenewable energy. In Ethiopian rural areas, firewood is the main source of energy for cooking, but in cities, electricity, kerosene, and charcoal are the main sources for cooking. In Ethiopia, over 80% of the population utilizes biomass as a primary source of energy. According to (Amoah, 2020), the main reason for the consumption of biomass in sub-Saharan countries is for cooking purposes. In most developing countries, there is a shortage of firewood due to the high consumption of energy and cooking on an inefficient stove in a poorly ventilated space. Cooking food requires firewood gathering and frequent attention to make sure the food cooks evenly. Moreover, when women and children collect firewood for cooking and other purposes, they may face sexual harassment such as rape, unwanted pregnancy, psychological problem, and sexually transmitted diseases. Utilizing charcoal in poorly ventilated spaces can cause a serious respiratory problems due to the emission of carbon monoxide and other gases. Kerosene is expensive; therefore, it is not usually utilized in rural areas. To solve the above problem, in addition to energy conservation, researchers started to study more about alternative energy resources such as solar energy, which is commonly called renewable energy. These energy sources are clean and environmentally friendly. Green energy (renewable energy) plays an important role to have affordable, accessible, and reliable energy for all (Hulio, 2021). Renewable energy diversifies the energy source and reduces the utilization of fossil fuels. Therefore, solar energy is a preferable energy source for developing countries.

Solar energy has the potential to become the primary energy source in all of Africa. This is mainly due to the high solar intensity reaching the earth's surface. Also, these countries get solar energy for a longer period throughout the year. We can use solar energy for different purposes such as generating electricity, boiling water, and cooking food. A lot of research work has been carried out on this work, some of which are;

(Khan, 2020) worked on the development of a solar PV-based inverter-less grid integrated cooking solution. They proposed a system that incorporates a control circuit that connects grid electricity to the solar PV. Via a DC link and provides a DC output eliminating the requirements of grid-tied inverters. In the proposed system, preference for power delivery is always given to the solar PV and the grid effectively operates as the backup for the system when solar PV output fluctuates due to varying weather and climatic conditions. The disadvantage of this system lack of a reliable backup system, as the grid supply was proposed as the backup.

(Akinwole, 2019) designed and implemented an electric cooker control system as a means of preventing domestic fire incidents. The paper established the fact that the system will prevent ubiquitous fire incidents associated with electric stoves and other heating devices. It describes the appliances of simple electronics circuitries in designing the low-cost cooker control device. It is believed that the unit will prevent fire incidences associated with an electric cooker, The paper recommends the incorporation of an embedded system with Liquid Crystal Display in future design improvement. The setback is that it does not have backup power.

(Adebayo, 2017) designed and constructed a DC Operated Electric Cooker using service main as a source, the work relates to an inverter circuit driving device of a cooker, and more particularly to an inverter circuit of a cooker which is capable of varying the width of a drive pulse to an inverter with a variation in an input voltage to vary a switching frequency of the inverter, thereby stabilizing heating power generated by a switching operation of the inverter and preventing an internal device of the inverter from being damaged due to the variation in the input voltage, The inverter circuit is applied to the cooker to heat an object (cooking vessel) to be cooked by controlling a power switching device therein. The power switching device performs a switching operation in response to a control signal to apply a drive voltage to the induction coil for the inner pan to heat the inner pan. The inverter circuit comprises a power source for supplying a commercial alternating current (AC) voltage and a rectifier for rectifying the AC voltage supplied by the power source. The type of construction is dependent on the source from the service main, therefore cannot always be used whenever needed. There should be provision for an alternating source for the construction.

(Omotoyosi, 2015) worked on standalone parabolic Dish solar cooker for Africa condition. The study presented in this report considered a prototype solar cooking system that is relatively cheap and that can be modified to meet these challenges faced in African communities. A parabolic solar cooker, which uses a parabolic dish as a concentrator, was designed and developed. The concentrator used was a television satellite dish of 2mm diameter, in which the reflecting area was covered with reflective aluminum strips. The dish concentrates radiation from the sun onto a conical cavity receiver placed at its focal point. The system uses heat transfer fluid as its working fluid and a cuboid-shaped storage tank insulated with ceramic wool to enhance the sensible heat storage technique used. While a cooking head in the form of a flat spiral copper tube put onto the storage tank was used as the cooking section. The solar cooker was tested under winter conditions in South Africa, and each cooking test was done according to international standard procedures for testing solar cooker performance. Utilization efficiency of 47% was achieved, the energy efficiency was 0.05%, and the average characteristic boiling time was around 13.32min/kg. The solar cooker can be used indoors, thus eliminating the need for its user to stay in the sun. But the problem with this project work is that there is no reliable backup system in case of fluctuation of heat transfer as it working fluid. But here a reliable backup system is provided.

II. AIM AND OBJECTIVES

This work aims to design and build a solar-powered induction cooker top using a DC power source and control the power output by varying operating frequencies. The basic objectives of this research are as follows:-

- ✓ To design a microcontroller-based DC induction cooker with a digital display
- ✓ To reduce theuse of conventional energy consumption.
- ✓ To design a standalone DC induction cooker

A. *Advantages of solar induction cooking device*

- It's a standalone system;
- Reduce electricity bills;
- Easy to install;
- Simple and reliable;
- Safety;
- Low maintenance;
- No fuel cost and spills;
- The system can be made to be mobile;
- High radiation index;
- Sustainable development.

B. *Disadvantages of existing cooking technologies*

- Dependent on non-renewable resources;
- The cost of electricity bills and gas increases with resource demands;
- A large amount of CO_2 emission;
- An electric stove is slower to cool down;
- The electric stove may not work during storms (due to power outages);
- Gas is dangerous due to the possibility of gas leaking;
- Gas gives off humid heat rather than dry required for effective roasting.

C. *Disadvantages of solar induction cooking device*

- Distributed nature of solar energy (can be partly overcome by concentration);
- Absence of energy storage.

, the second is an inherent (can be overcome in PV systems by the use of conventional storage batteries

III. MATERIALS AND METHOD

A. *Materials*

An induction cooker transfers electrical energy by induction from a coil of wire into a metal vessel. The coil is mounted under the cooking surface, and at a high frequency (e.g. 24 kHz) an alternating current is passed through it. The current in the coil creates a dynamic magnetic field.

In this paper, solar energy is used as a source of power for the induction stove. The block diagram and the flow chart of the proposed work are shown in Figures 1 and 2 respectively.

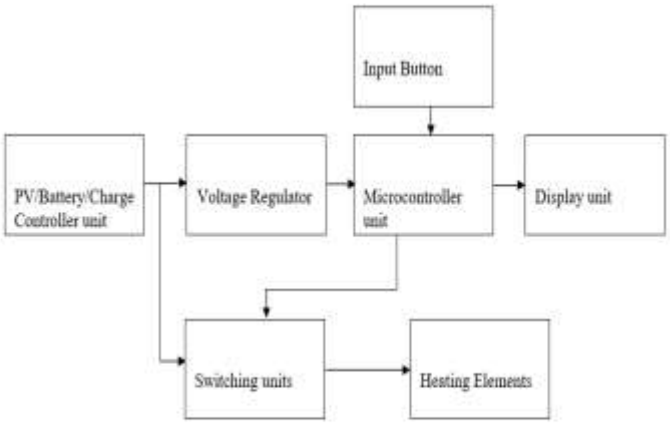


Figure 1: Block diagram of adigital solar-powered DC induction cooker

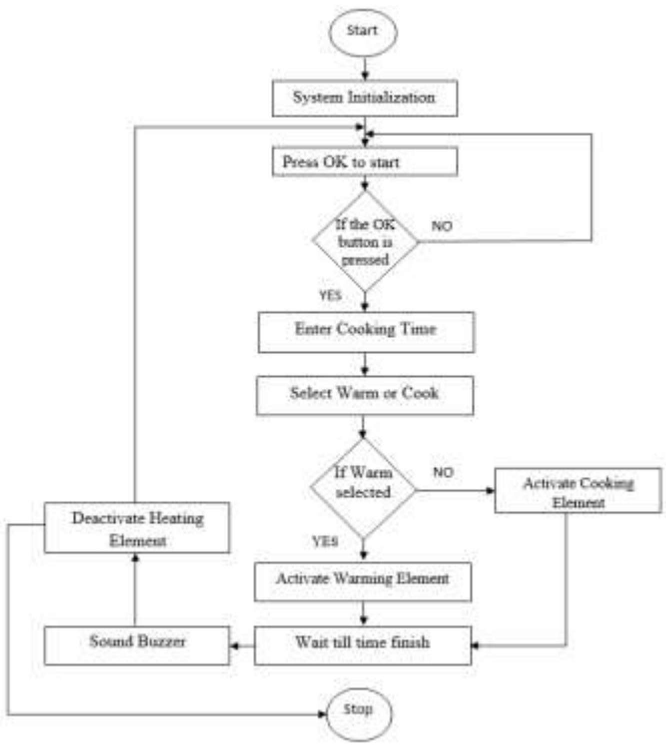


Figure 2: Flow Chart of the Sequence of operation of the Solar Powered DC Induction Cooker

B. Methods

a. Solar Battery

The battery is a device consisting of two or more electrochemical cells that convert stored chemical energy into electrical energy. The battery used for this work is a lead-acid type. Without the battery, the system will only power when the sun is shining. The power would be interrupted each time the cloud passes i.e. no power will be available. A 24VDC-100AH battery was used for this design. The solar battery span from the manufacturer was given as 5 years with a DOD of 80%

b. Solar Photovoltaic Panel (Solar Module)/DC unit

The solar panel is a photovoltaic cell that converts the energy from the sun directly into electricity and this is known as the photoelectric effect. This is used to charge the batteries during the day and stored the excesses for use at night if the need arises. The panel voltage is given as 24VDC. 4pcs of 180W 12VDC (with a span of 25 years as indicated by the manufacturer) panels are connected in a series-parallel arrangement for 2 pairs of 24VDC connected in parallel. Below are the theoretical calculations for the design of a solar panel system. Firstly battery capacity selected is 24VDC and 100 Amp Hours (AH). The conversion of AH into watts is required and the conversion can be seen below;

$P_{\text{available}} = AH x V_{\text{battery}}$
AH = Battery size
V_{battery} = Battery Voltage
$P_{\text{available}}$= available power in watts hour (WH)
$P_{\text{available}} = 100AH x 24V = 2400WH$

The equation above shows that 2400W of power can be supplied for 1 hour, and 1200 W in 2 hours etc. The energy intake is proportional to battery discharge. The amount of power in a battery (battery size) can always be adjusted, 24 V, 100 AH battery is used for research purposes only. Though the rule of thumb says a battery can give as much as 50 % of its capacity as there is a drop in voltage as power is dissipating. The amount of power the panel can give to the battery is calculated as 4 x 180W panels multiply by the average hours of the sun during the day. In Bida, we receive a huge amount of solar radiation of about 6.2KW/m^2 to 6.5KW/m ^{2} per day. The average amount of sun in Bida is 8 hours and the charging amount can be calculated as 720Wmultiplied by 8 hours to give 5760W. This means that the system can charge the battery to its full state (5760/2400) two times in one day.

c. Solar Charge Controller

The charge controller is an electronic voltage regulator that is used to limit the rate at which electric current is being drawn in and out of batteries. The charge controller turns off the charging when the battery reaches the optimum charging point and turns it back on when it goes below 100%. The charge controller has three pairs of terminals; a pair for the panel output, another pair for the battery and the final pair for DC loads only (DC cooker). The current of each panel was 7A and the panel arrangement was series parallel to produce a 24V/14A maximum current. Therefore a suitable charge controller for this work was chosen to be 24V/30A PWM. Therefore the controller is rated 24V, 30A.

d. Voltage Regulator

This is the electronic device that maintains the voltage of the power source within an acceptable limit. The voltage regulator is needed to keep the voltage within the prescribed range that can be tolerated by the electrical equipment using that voltage. A 78 series regulator was used in this work (7812 and 7805). This type of regulator can accommodate a maximum voltage of 36V and supply a stable out pout of 12V. Therefore, it's a 12V voltage regulator

e. Microcontroller

A microcontroller is a small computer on a single integrated circuit. In modern terminology, it is similar to but less sophisticated than a system in a chip (SoC); an SoC may include a microcontroller as one of its components. A microcontroller contains one or more CPU (processor cores) along with memory and programmable input/output peripherals, microcontrollers are designed for embedded applications, in contrast to the microprocessor used in personal computers or other general purpose applications consisting of the various discrete chip. Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems (https://en.m.wikipedia.org/wiki/microcontroller). The Microcontroller (figure 3) used in this work is the 28-pin ATmega328p and the characteristics and pictures are presented in table 3.1 and figure 3.3. The ATMega328p has 14 digital input/output pins (of which 6 can be used as Pulse-width modulation outputs), 6 analogue inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC -DC adapter or battery to get started.

Figure 3: Pin configuration of ATmega328P chip

f. Switching unit

Semiconductor devices are used as switching elements in this work. Insulated gated bipolar transistor (IGBT) was used in the induction cooking system. The IGBT (figure 4) ability to handle a high voltage of 600V at low conduction with a frequency between 10-65 kHz makes a better option.

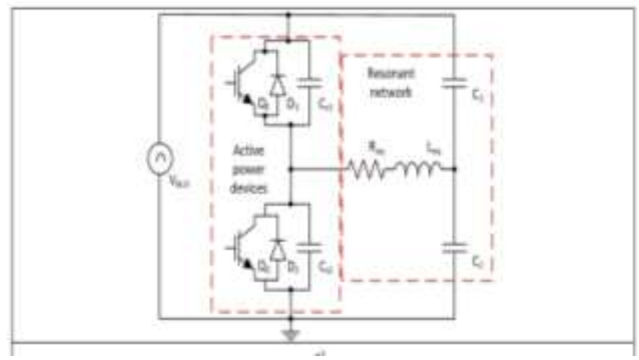


Figure 4: IGBT switching arrangement

g. Display unit

LED Display (light-emitting diode display) is a screen display technology that uses a panel of LEDs as the light source. Currently, a large number of electronic devices, both small and large, use LED displays as a screen and as an interaction medium between the user and the system. This part was used as means through which all the display operations are carried out.

h. Heating element

Induction Cooking is a type of electric cooking that uses magnetic coils to heat cookware. The beauty of the induction cooker is that the cooking surface itself remains cool while heat is generated within the cookware.

IV. OPERATION

An induction cooker looks much the same as any other ceramic cooktop, usually with distinct zones where you can place your pots and pans. The cooking surface is usually made from tough, heat-resistant glass-ceramic (1). Inside each cooking zone, there's a tightly wound coil of metal. When you turn on the power, DC flows through the coil and produces an invisible, high-frequency, alternating magnetic field all around it. Unless there's a pan in the cooking zone, no heat is produced: the cooking zone remains cold. You might be wondering why we need a high frequency (2). Place a pan in the cooking zone and the magnetic field produced by the coil (shown here with blue lines) penetrates the iron inside it (3).The magnetic field induces whirling electrical (eddy) currents inside the pan, turning into a heater (shown here in orange) (4).The heat from the pan flows directly into the food or water inside it (by conduction) (5).

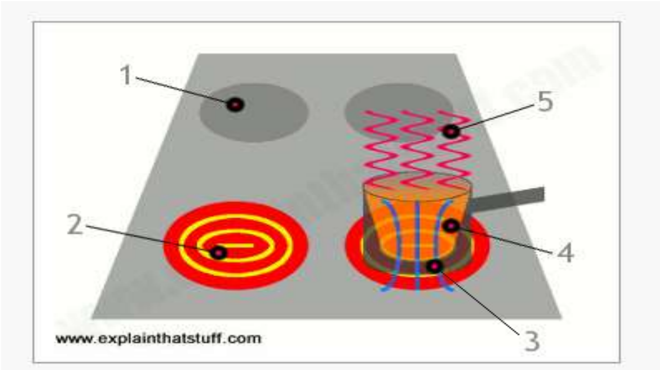
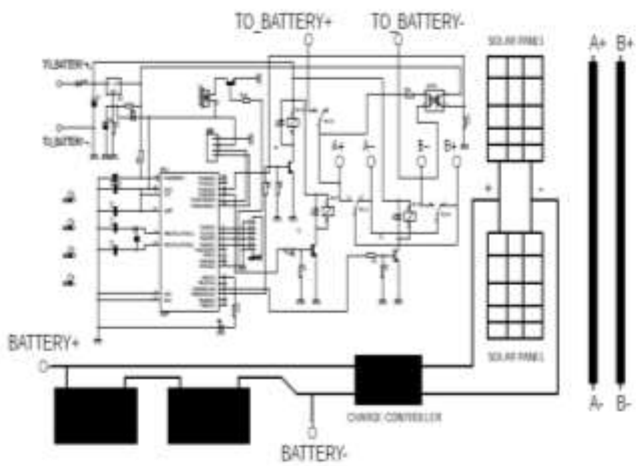


Figure 5: Induction cooktops (Chris W. 2021)

Figure 6: Schematic diagram of 24V Solar Powered DC induction Cooker

V. DESIGN



The design includes an induction coil which is supplied from a DC source. The panel was designed considering the batter size; a suitable charge controller was selected to charge the battery. The schematic diagram (figure 6) served as a guide for the design steps of the various units of the cooker. The diagram showing the connections of the entire circuit component and their values are shown in figure 6.

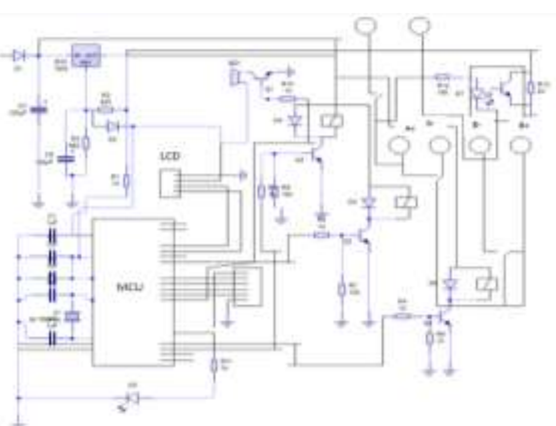


Figure 7: Circuit diagram of 24V Solar Powered DC induction Cooker

VI. TESTING, RESULT AND DISCUSSION

A. Testing

The pictorial view, assemblage and testing of the induction cooker are shown in Figures 8, 9 and 10 respectively.

Figure 8: Pictorial View of Solar Powered DC induction Cooker

Figure 9: Assemblage of 24V Solar Powered DC induction Cooker

Figure 10: Testing of 24V Solar Powered DC induction Cooker

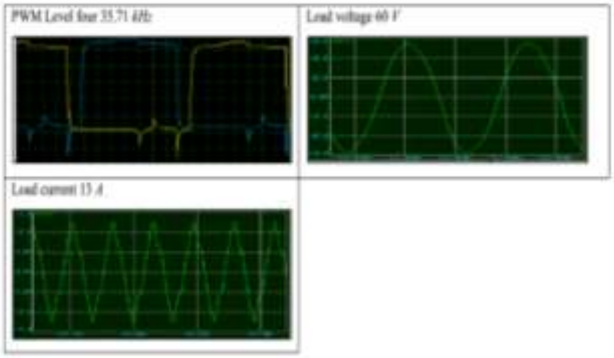


Figure 11: Power Level obtained from an oscilloscope

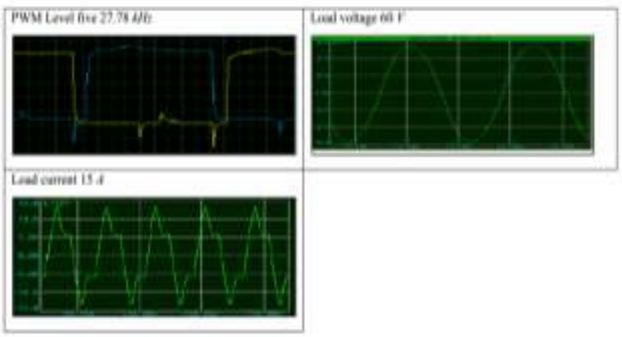


Figure 12: Power Level obtained from an oscilloscope

B. Result

The results obtained from the test carried out on the work are tabulated in tables1, 2 and3 below

Table 1: Results Obtained from Heating Element

S/N	Time (mins)	Initial Temp (ºC)	Final Temp (^{0}C)
1.	5	0	10
2.	10	10	20
3.	20	20	40
4.	40	40	60
5.	50	60	80

Table 2: Result Obtained for Charging of the Battery by the Day

S/N	Period of the Day (Time)	Battery Voltage achieved (V)
1.	8 am	2.00
2.	10 am	4.00
3.	12 noon	7.00
4.	2 pm	7.00
5.	4 pm	5.00

Table 3: Result at Full Battery Voltage

S/N	Battery Voltage	Cooking period (Time)
1.	25.6V	50mins
2.	24.9V	1hr.30mins
3.	24.5V	2hrs
4.	24.0V	3hrs
5.	23.05V	6 hrs

C. Discussion

The implication of the result obtained is as follows:

- The set time has nothing to do with the hotness of the plate i.e. it does not increase or reduce the voltage across the plate (table 1).
- The set time of cooking may vary according to the battery voltage supply source i.e. depending on whether the battery is fully charged or not (table 3).
- The system will shut down when the battery runs out of power.
- Any fluctuation from the power source (battery) trips the system and has to be set to run again.
- The digital dc electric cooker required a little literacy for operation hence; it may be hard to be operated by an illiterate.
- The rate or value of voltage to the heating element determined the time taken for the food to be cooked, hence the user must be able to estimate the time it would take for his/her food to be done bearing in mind the rate of heating of the element is directly proportional to the power supply.
- The higher the resistance the higher the output power and vice versa (figure 11 and 12)

VII. CONCLUSION

The induction cookers in the market use mains power to operate and that limits the flexibility in terms of power sources. The working principle of this work is similar to what is in the market as mentioned earlier, but with more of advancement features like using a DC power source, taking solar as a means of charging the battery (storage) and also making it a complete portable standalone product makes the difference. The benefits of this device include the economics of which the energy is free from the sun, environmental looks at zero released of toxic gases in the atmosphere and health in terms of decreasing the amount of fossil fuels usage. The cookers in the market are completely dependent on electricity generated by a utility company. The introduction of solar energy comes intending to fill the big gap existing in the use of electricity that is 100 % dependent on non-renewable resources. Although the unit is very expensive, it cost a total sum of **₦326,870**, but over five years of usage it is worth it when compared to gas or the amount to be paid on utility bills for that period of five years.

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APPENDICES

Appendix A: Maintenance Prescription Manual

	Common faults	Causes	Remedies
1.	Solar panel low output Source from the solar panel.	The solar panel may not receive much sun rays and dirt may have accumulated on the surface of the panels.	Reposition the panels in the right direction for them to receive more intensive rays from the sun and clean the surface regularly.
2.	Partial contact between terminals of panels.	This might be because of rusting which has taken place between the plate and lead coming out from the panel.	Disconnect and apply grease or oil to rusted parts and reconnect again.
3.	Battery not producing expected output	Ageing may have occurred in the battery due to constant use and overcharging	Replace aged batteries with new ones according to the design specifications and ratings and ensure to stop overcharging the battery.
4.	Battery not charging or takes longer time to charge	the terminals of the batteries are not well connected	Check the intensity of the solar panel if it is giving accurate voltage for charging.
5.	Charge controller Not charging the battery	Maybe the terminal connecting to the charge controller is not well connected to the source or is connected wrongly.	Reconnect the charge controller terminal correctly and accurately to produce output
6.	Elements When it's not heating	When the Nichrome wire is disconnected	Check and reconnect the wire
7.	Buzzer When there is no alarm	The buzzer has burnt	Replace buzzer
8.	LED When it's not indicating	The LED is burnt	Replace LED

Appendix B:

Bill of Engineering Measurement and Evaluation

S/N	Description of Components	Part Number	Quantity	Unit Price ₦	Total Price ₦
1	Capacitors	MKP270	4	10	40
2.	IGBTs	160N60UFD	2	500	1000
3.	Variable resistor	2k	2	10	20
4.	Decoupling caps	100nF	2	5	10
5.	Microcontroller	Atmega 328	1	3000	3000
6.	LCD	20 x 2	1	1000	1000
7.	Heat sinks		1	300	300
8.	Coil	99.5 uH	1	1500	1500
9.	Batteries	12V- 100AH	2	70,000	140000
10.	PSU complete	400 W 24V DC	1	15,000	15,000
11.	Solar panels	SS 180W 12VDC	4	40,000	160,000
12.	Charge Controller	24V-30A	1	15,000	15,000
13.	Cable	4mm^2		5,000	5,000
Total		**326,870**			