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DESIGN AND CONSTRUCTION OF A SOLAR BASED INDUCTION COOKER

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Abstract

This work centers on the development of a solar based 2kW, 24V induction cooker that eliminates most of the problems associated with the conventional cooking methods in Nigeria. This work is unique because it was put together from locally sourced materials and it is solar based. The work was done by carrying out design of the various components and circuit that would aid the construction. Following the design, the required components were purchased and construction was done accordingly. Comparative test results showed that cooking by using the induction cooker has advantages over the conventional methods as cooking is faster, energy consumption is lower and this method of cooking is environmentally friendly.

Keywords: Induction Cooker, Solar, MOSFET, Battery, Microcontroller

1. INTRODUCTION

One of the basic challenges to most homes is the cost and scarcity of cooking fuels and gas. Those in the third world countries as Nigeria also depend on wood, coal and kerosene as source of fuel for cooking, lighting and heating. Consequently, these means of cooking have huge negative impact on man, cooking utensils and environment ranging from emission of gases, soot production and deforestation. A cleaner and alternative means of cooking is electricity, but due to its high cost and erratic power supply in Nigeria this method has not been embraced by majority.

On the other hand, the potentials of solar energy can be largely utilized as source of energy for cooking. However, this source of energy is not available twenty-four (24) hours so it is impossible to use it at night. Solar energy is a clean and reliable source of energy which can save the world from experiencing the shortfalls of non-renewable resources like coal, wood, etc [1]. With induction cooking a high efficient technique for cooking purpose, it can combine with solar system to provide a reliable future solution for cooking technology [2]. Although solar based cooking may have high initial cost, but over a long term it is cost effective solution. These days, induction heating is used in home appliances as it has high efficiency and its advanced power electronic composition. The heating process is used in industries for hardening, brazing and melting [3]. It is said to be highly efficient because 80% of the magnetic field that crated between the pan and the coil are all transferred to the coil [4]. The technique utilizes high frequency current supply that aids the induction of high frequency eddy current [5].

The high frequency current can be generated using two methods; namely soft switching and hard switching techniques. The later produces positive cycle as losses in the switching device and a high frequency in the LC circuit. While the former, soft switching technique, has the capability to reduce the switching losses and it can also be regarded as resonant technique [6, 7].

This research work is centered on the development and analysis of a 2KW solar-based induction cooker. The motivation to carry out this research is not just about another means of cooking but to have a readily available means of cooking that will be more effective, efficient and much safer than those already in use. This mode of cooking will reduce over dependence on natural gas, firewood, coal and kerosene and consequently, produce pollutants that impact human health and the environment negatively.

1.1 Electrical Induction Heating

In induction heating, an inverter configuration supplies a current of high frequency to an induction coil with the production of an alternating magnetic field. This magnetic field produces eddy currents when applied to a pan that is ferromagnetic in nature. The pan gets heat up through a magnetic hysteresis [3, 8].

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In the process of induction heating, a high frequency magnetic field is generated through a high frequency inverter with a frequency of several tens of kHz into a planar working coil placed below the pans/utensils. The pans act as the induction heating load of the high frequency inverter. The eddy currents which were induced electromagnetically are generated at the bottom of the pans in proportion to the high-frequency magnetic fluxes produced on the principle of electromagnetic induction [9].The pan/utensil heats up as illustrated in thefigure below;

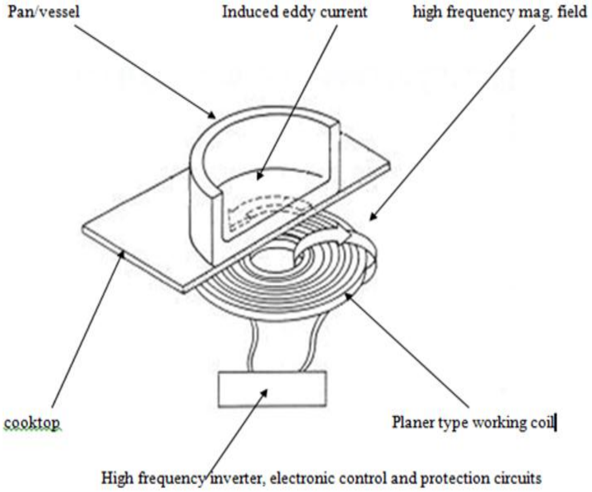

Figure 1: An illustration of a high frequency induction coil.

2. MATERIALS AND METHOD The design and development of this system was carried out by the materials and method discussed below;

2.1 Materials

The research and development of the system was carried out by using the following materials;
i)Two (2)150W solar panels rated
ii) Two (2) deep cycle batteries of 12volts and 200Ah each.
iii) Eight (8) mica Capacitors of 10μF each.
iv) A 10-bit, 5-channel PIC16F876A Microcontroller.
v)7805 Voltage Regulator and 7812 regulator.
vi) Charge controller.
vii) 24/100V transformer.
viii) Battery cables and connector.
ix) Six (6) IRFP150N MOSFET.
x)Two (2) Diodes.
xi) Two (2) Variable resistors and ten (10) fixed resistors.
xii) Vero-board.
xiii) Two (2) IC sockets.
xiv)SG3524 PWM 15) Screws, bolt and nuts.

2.2 Design Method

This research was carried out by implementing the following methods:
i) Developing a block diagram of the induction cooker.
ii) Designing of the induction cooker drive circuit and induction coil.
iii) Implementing the designed circuit and conducting stage by stage testing.
iv) Carrying out of comparative testing and analysis of induction cooker.

2.2.1 Block Diagram of the functional Stages of the Induction Cooker

The basic block diagram of the implemented system is shown in figure 2, it shows the various functional blocks and how they are interconnected to give a complete and desired system performance.

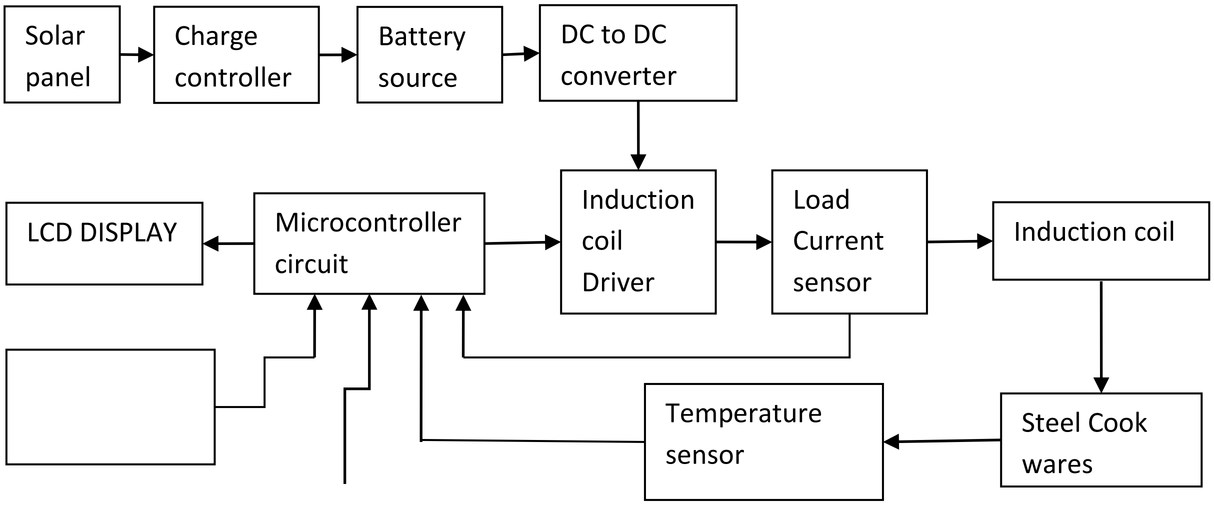

Figure 2: Functional Block diagram of the induction cooker.

The system design analysis is presented under the following sub-sections;

i) Power supply
ii) Microcontroller (high frequency pulse generator)
iii) H-bridge Pulse driver
iv) MOSFET driver
v) Heat induction tank and load current sensor
vi) DC to DC converter.

2.2.2 Design of Power Supply Circuit

The power supply for the control circuit is from the solar panel and it is to supply 12V and 5V to power the circuit. The circuit consists of an IC voltage regulator, 7812, 7805 and capacitors for noise filtration. The current limiting resistor R_L is to limit current to the voltage regulator.

$$R_L = \frac{V_{sol}-V_{reg}}{I_{reg}} \quad (1)$$

Where, Vsol = solar voltage = 19V,
Vreg = regulator minimum input voltage = 14V,
Ireg = regulator current = 1A.

$R_L = \frac{19-14}{1} = 5\Omega$

The closest value is 4.7Ω and this was used instead.

Capacitor C1 and C2 are optional but added to filter off circuit noise and the chosen values is 10μF each. Diode D1 is to prevent direct link for reverse current flow into the panel from the battery.

The IC voltage regulators used are 7805 and 7812.

2.2.3 Microcontroller and High Frequency Pulse Generator

The microcontroller circuit stage consists of the microcontroller that is programmed to generate the high frequency drive pulses of 32kHz to drive the induction coil. This choice of 32 kHz is the tolerance level of the MOSFETS point at which the operation of the MOSFETS became stable without persistent burning.

The microcontroller used in this work is the Microchip PIC16F876A. One of the most important features for its use in this research is that it has a 10-bit, 5-channel Analog-to-Digital Converter (ADC) with Programmable on-chip voltage reference (VREF) module and has enough ports (3) and pins (28). A 100,000 erase/write cycle Enhanced Flash program memory typical and selectable oscillator options. Pin 9 and pin 10 are for oscillator. The oscillator of choice because of its stability is the crystal oscillator and the chosen one is the 4.0 MHz because of its availability. Pin 1 is the master clear terminal and it is used here for startup delay to protect the program from timing problem at start caused by power up surge. Resistor R1 and Capacitance C1, determine the delay time.

For a startup time delay T_s = 330µs and C_s=C_1 = 100nF,
Thus;

$$R_1 = \frac{T_S}{0.7C_S} \tag{2}$$

R_1= 330 x 10^{-6} / 0.7 x 100 x 10^{-9}= 4.7 kΩ

A 16 MHz crystal was used for the internal oscillator and this will result in the instruction cycle value as;
Oscillator frequency F = 16,000,000Hz, Period T = 1/F = 1/16,000,000sInstruction cycle Ts = 1/(F / 4) = 0.25µs, The microcontroller also drives the LED indicator.
The limiting resistor value for the LED used can be determined thus,

$$R_7 = \frac{V_{cc}-V_f}{I_f} \tag{3}$$

Where, R_L = Limiting resistance, I_F = Forward conducting current, V_F = Forward voltage drop, V_{cc} = Comparator output.
For the LED, V_F = 2.2V, I_F = 8mA, V_{cc} = 5V (which is output pulse from microcontroller)

$$R_7 = \frac{5-1.8}{8x10^{-3}} = 400\Omega.$$

A value of 390Ω was used in the design as the closest standard.

C945 NPN (silicon) Specification

BV_{CEO} = 40V, BV_{CBO} = 70V, Ic(max) = 0.6A
Pd(watts) = 0.625W, Hfe = 100 typical, Vce (sat) = 0.2V

The microcontroller monitors the load current, drives pulses to the DC to DC converter stage and to the H-bridge network. R_{10} is for adjusting the load current converted voltage value fed to microcontroller internal ADC to convert to digital for further processing to aid in necessary decision making during system operation. R_{10} value was chosen to be a 10kΩ variable resistor for fine tuning purposes. The liquid crystal display is the output display unit of the system and it is connected to the microcontroller for displaying the temperature. The LCD is driven by the microcontroller using ASCII information of the ADC processed data.
The LCD used is the GM1602A model. It is a 16x2 character screen type and it is powered by +5V.

2.2.4 H-Bridge Driver Stage

The MOSFET used in the circuit are connected in half bridge drive mode so that a better AC can be easily generated with fewer harmonic. The half bridge driver used is the IR2110 low side and high side driver by International Rectifier.
The IR2110/IR2113 are high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels.
Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 500 or 600 volts.
Below are its specifications;
Voffset (IR2110) = 500V max, (IR2113) = 600V max, IO+/- =2A / 2A,
Vout = 10 - 20V, ton/off (typ.) = 120 & 94 ns, Delay Matching (IR2110) = 10 ns max, (IR2113) = 20ns max.

2.2.5 Design of MOSFET Driver

The MOSFET stage conducts the necessary load current through the induction cooker. MOSFET**IRFP260N–*channel***was used in this design. Fixed resistors of 10KΩ were connected between the gate and source to aid fast switching by discharging any residual static charge at the gate. The IRFP260N data are as shown below;Drain to source breakdown voltage BV_{DSS} = 100V, Gate to source voltage (cut-off) = 4V. Gate to source breakdown voltage= ±20V, Drain current (continuous) = 41A, Drain to source resistance r_{DSS}= 0.055Ω,Power Dissipation, P_D= 230W
The load current was determined as;

$$\text{Power } P = VI \tag{4}$$

Where, P = 2000W and V = 12V, I = 83.3A (166.7/2) per half cycle,
Then 83.3/MOSFET rating rerated to 30A= approximately 3 MOSFETS on each arm of the half bridge or H-mode.

Capacitors C_5 and C_6 are connected to complete the conduction path for half bridge switching and their values are 1µF, 250V.

2.2.6 Induction Cooker Tank Circuit

The induction cooker inductor has to be a tank circuit for increased efficiency so that there will be good energy transfer. The tank circuit will enable the tank to self-oscillate at a higher frequency even when driven by the 100kHz pulses. The capacitor Cx and inductor Lx make up the tank circuit of the oscillator. The 100kHz pulses serves as power pumps to the drive the tank circuit, the tank circuit will then have parasitic oscillations that will rise up to 100kHz to aid in the efficiency.

The frequency of oscillation is given as;

$$F = \frac{1}{2\pi\sqrt{LC}} \qquad (5)$$

F = resonance frequency, Ls = inductance,Cs = tank capacitance

Parameters for the tank circuitis; F = 100kHz. C_1 = 1µF

Required inductance would be;

$$L = \frac{1}{(2\pi f)^2 C} \qquad (6)$$

$$L = \frac{1}{(2x3.142x100000)^2 1x10^{-6}} = 2.5\mu H$$

The capacitor C_5 and C_6 was made up of 5 units of 0.22µF capacitors as they will share the current. Using only one unit will cause it to heat up and burn off.

2.2.7 Load Current Sensor

This stage measures the current drawn from the power source to the induction coil during operation. The current transformer CT is the current sensor for monitoring the current drawn from the battery storage system during operation. The output is fed to a diode and capacitor to convert the voltage to DC with C_4 for filtering. R_{10} is for scaling the output of the current transformer. The op-amp voltage follower is for impedance matching so that voltage is coupled well from CT to microcontroller. The microcontroller converts the voltage to digital using its internal ADC and then uses this information for pulse width modulation and protection purposes. The current transformer is the AC load current transducer for monitoring the load current levels. The current transformer chosen ratio is 1:100.

This is due to the fact that we are dealing with low current. Thus;

$$\text{CT ratio} = \frac{Np}{Ns} = \frac{Is}{Ip} \qquad (7)$$

CT ratio = 1/100 = 0.01Ip

Where Np and Ns are number of turns for primary and secondary of *CT*. For Np =1 turn, Ns = 100 turns.

Secondary current Is = 0.01Ip = 0.01 x 100 = 1A

The output current must be converted to proportional voltage and this was done using a resistor connected to the output of the CTs.

For a maximum voltage of 10V the resistance would be;

$R_L = \frac{V_{out}}{I_s} = \frac{10}{1} = 10\Omega$

The voltage from the CT is ac and must be converted to dc. This was done using a half wave rectifier. A capacitor filter circuit is meant to filter off some level of AC ripples from the rectified DC.

2.2.8 DC to DC Converter Stage

This stage is the DC to DC converter stage, it steps up the battery voltage of 24V to 100V DC for more heating effect. Transformer T1 is a step up transformer, the MOSFETs M3 and M4 drives the battery voltage or load current through the primary of the transformer as driven by the microcontroller. Diodes D1 to D4 rectifies the output to DC while C8 filters the DC to remove ripples. The MOSFETs are the same used for MOSFET drivers IRFP260N. The step-up transformer is expected to step-up the battery voltage from 12V to 100V.

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

For N_p = 50 turns, V_p = 12V, V_s = 100V

Thus,

$N_s = N_pV_s / V_p$ = 50 x 100 / 12 = 417 turns.

Output Secondary Voltage = 100V rms.
Peak Voltage V_p= 100 x √2
V_p= 141.4V
Peak output voltage from bridge Rectifier
$V_{P.R} = V_p - 2V_d$,
$V_{P.R}$= 141.4 – 2(0.7) = 140V
where V_d = P-N junction drop

IN5400 diode Rectifier

A 1N5404 power rectifier diodes was used in the design and has the following specifications;
Forward DC Current = 3A @ 100°C, I surge (max) = 100A, Reverse voltage V_{RRM} = 600V.

$$\text{Ripple Voltage} = \frac{I_o}{2FC} \tag{8}$$

Where Io = regulator output current
Vr = Ripple voltage.
For I_O = 200mA, Vr =10V
C = 200 x 10^{-3} / 2 x 50 x 10 = 200 µF
This is a capacitor with at least 220uf and working voltage of 140V is needed. The one chosen for the design is 160V, 220 µF.

2.2.9 Construction of Dedicated Pot for Induction Cooker

The flow of Eddy current from a time varying magnetic field will only happen through a ferromagnetic material, for this reason; a dedicated pot had to be fabricated. The higher the proportion of magnetic material in a steel or an iron alloy material, the higher the flow of Eddy current which in turn produces higher level of heating effect.

During the course of this research, various types of materials and normal domestic pots were experimented on. The material that produced better response was used in the fabrication of the pot. The material in forging this pot is from the home DVD or VCD player casing.

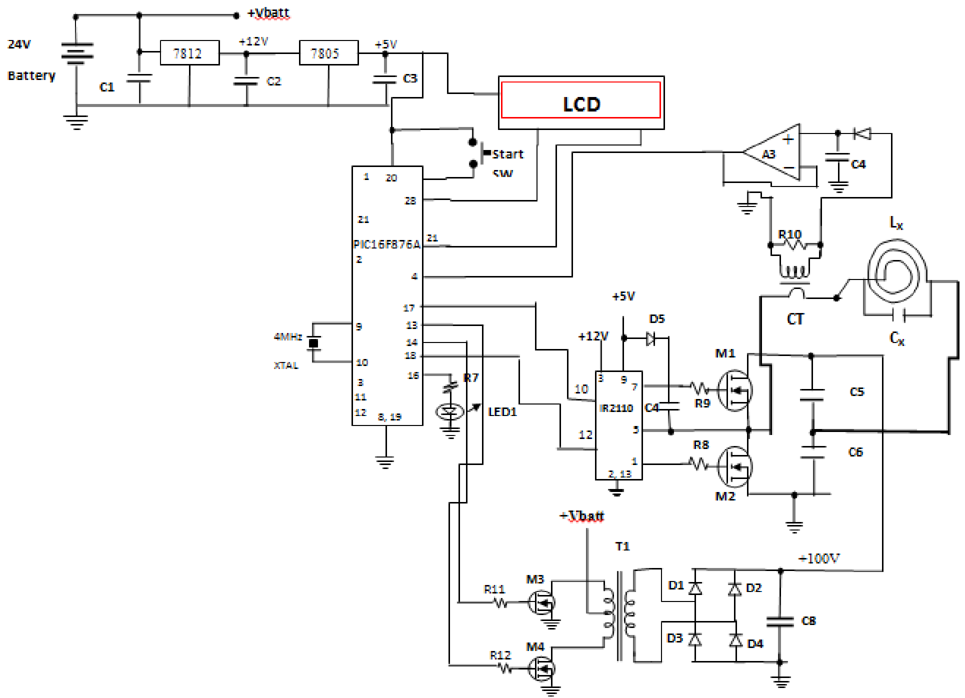

Figure 3: Complete circuit diagram of the induction cooker.

2.3 Operational Principle of the 24V, 2KW Induction Cooker

The cascade of two regulators (7812 and 7805) represent the power supply stage. This stage supplies the regulated dc of +12V and +5V to power the control circuit. Capacitors C1 to C3 are filter capacitors for filtering circuit noise and for regulation.

PIC16F876A is the microcontroller which is the heart of the control stage. Its function is generation of the high frequency pulses to the driver stage to drive the induction coil, monitor the load current to detect overload conditions and monitor temperature and effect power-adjust and temperature-adjust features. It starts operation when the start switch is made. The crystal oscillator (4MHz) connected between pins 9 and 10 is for its internal clock control. LED1 is for indication that power is on and system is active. The microcontroller was used based on enough number of pins and ports and its internal analog to digital converter (ADC) for processing load current and temperature sensor output.

The current transformer CT is the current sensor for monitoring the current drawn from the battery storage system during operation. The output is fed to a diode and capacitor to convert the voltage to DC with C4 for filtering. R10 is for scaling the output of the current transformer. The op-amp voltage follower is for impedance matching so that voltage is coupled well from CT to microcontroller. The microcontroller converts the voltage to digital using its internal ADC and then uses this information for pulse width modulation and protection purposes.

The induction coil driver circuit function is to drive the load current from the power source (battery and power) through the induction coil as controlled by the microcontroller it consists of MOSFET transistors and driver IC IR2110.

IR2110 is the H-bridge driver IC and its function is to take the output from the microcontroller and boost it to drive the MOSFETs M1 and M2 connected with capacitors C5 and C6 to form a half bridge driver circuit. The high frequency pulse drives the battery power from the dc to dc converter stage output of 100V to the induction coil.

The induction coil is the output transducer that converts the electrical energy to heat in conjunction with the magnetic hysteresis and eddy current losses of the ferromagnetic material. It is driven by a high frequency voltage from a high frequency generating circuit and driver. For efficiency the induction coil Lx is connected to capacitor Cx in parallel to form a LC tank circuit to achieve parallel resonance so that efficiency can be achieved as LC tank circuit consumes lesser current/power at resonance.

The DC to DC converter stage comprises of transformer T_1, MOSFETs M3 and M4 and full wave rectifiers D1 to D4. The function of this stage is to boost the battery voltage of 24V to 100V dc for more heating effect. Transformer T1 is a step up transformer, the MOSFETs M3 and M4 drives the battery voltage or load current through the primary of the transformer as driven by the microcontroller. Diodes D1 to D4 rectifies the output to DC while C8 filters the DC to remove ripples.

The liquid crystal display (LCD) is for displaying the temperature, the standby mode and shows the name "INDUCTION COOKER".

3. RESULTS AND ANALYSIS

3.1 Comparative Testing and Analysis

Testing of the circuit was done to ascertain the workability of the principle of induction cooking as well as its potential of being a more adaptable means of cooking. The induction cooker was tested to determine how long it takes for it to boil water for the sole purpose of comparing its effectiveness (in terms of duration for boiling water, efficiency and energy cost) with the commonly used gas cooker in most homes.

3.1.1 Testing for the Duration of Boiling Water

i) Using Induction Cooker

Table1: Induction cooker test Result

Battery voltage(V)	Temperature (^oC)	Time elapse (Mins)	Eddy current(A)
24.20	60	2	30
23.90	70	4	28
22.90	86	6	26
21.50	92	8	25
20.25	96	11	24

This test is necessary to ascertain if the cooker can generate heat for cooking operation and how long it takes to boil water. Going forward, the following parameters are worthy of note.

(i) Initial battery voltage = 24.20V
(ii) Initial current drawn by the induction coil(no load) = 1.2A
(iii) Initial thermometer level = 32 ^oC
(iv) Final battery voltage after five readings = 20.25V
(v) Output voltage to induction coil = 80.0V

(vi) Quantity of water used in each case of testing = 1.2 L

ii) Using Cooking Gas

The outcome of boiling water with LPG gas is as shown in Table 2;

Table 2:Cooking Gas Test Result

Definition of state	**Cylinder weight, W(kg)**	**Water temperature(ºC)**	**Time (min)**
Before boiling	6.8	32.0	0.0
After boiling	6.6	100.0	13.0

3.2 Computation of Power and Efficiency

For Induction Cooker

Power output from battery (no dedicated pot on the coil) = V x I

V = 24.2x1.2 = 29.04W

Power output from battery (with dedicated pot on the coil) = V_{mean} x I_{mean}

Mean current (I_{mean}) = (30+28+26+25+24)/5 = 26.6A

Mean voltage ($V_{mean)}$= (24.20+23.90+22.90+21.50+20.25)/5 = 22.55V

Power output from battery (with dedicated pot on the coil) = 22.55 x26.6 =599.83W

Efficiency

Rate of power increase due to induction = 599.83/29.04 = 20.66 Efficiency = (20.66/29.04) x 100 = 71.13%

Energy CostPower output from battery in KWh = 599.83 x (11/60) = 0.11KWhEnergy cost drawn from battery by cooker = 0.11 x cost of 1KWh at BEDC rate= 0.11 x 31.26 =₦ 3.44k

For Cooking Gas

This test was carried out for comparison with the outcome of the induction cooker in terms of energy cost and efficiency based on the time it takes to heat up 1.2litres of water.

Preliminaries:

Amount of gas used up = 6.8- 6.6 = 0.2kg

Energy (in KWh) used in boiling water = 2.8 KWh

** 1 kg of gas = 50.4MJ, Therefore 0.2kg of gas = 10.08MJ

** KWh of electricity = 3.6MJ, Therefore 10.08MJ of gas = 2.8KWh

Efficiency

$$\text{Efficiency of LPG} = \frac{\text{Weight of cylinder after boiling x time}}{\text{Weight of cylinder before boiling}} \text{ x } 100 \qquad (9)$$

$$\frac{(6.6\,x\left(\frac{13}{60}\right))}{6.8} \text{x } 100 = 21.03\%$$

Energy Cost

$$\text{Cost of gas for boiling 1.2L of water} = \frac{\text{cost of 1kg of gas}}{5} = \frac{350}{5} = ₦70.00$$

The results obtained from the table and computations shows that, the induction cooker is more efficient and cost effective than the cooking gas and it equally shows that the objectives for which this exercise was undertaken has been met largely.

3.3 Bill of Engineering Measurement and Evaluation

Below is the table for bill of engineering measurement and evaluation. It gives the relative cost per unit of components and the total cost of the work based on current market value in the year 2018.

Table 3:Bill of Engineering Measurement and Evaluation

S/No	**Items**	**Unit Price**	**Quantity**	**Amount(₦)**
1	Resistors	5	20	100
2	Mica Capacitors	10	8	80
3	7812	40	1	40
4	Variable resistor	20	2	40
5	Diode	10	2	20
6	Veroboard	150	1	150
7	Wire and cables	2000	lots	2000
8	Casing	1200	1	1200

9	IC socket	20	2	40
10	4.7Ω, 3W	20	1	20
11	Screws, bolt and nuts	700	lots	700
12	SG3524 PWM	100	1	100
13	Masking tape	200	1	100
14	IRFP150N MOSFET	400	6	2400
15	Battery cables and connector	1300	lots	1300
16	Transportation cost	4500	lots	4500
17	100W solar panel	42000	2	84000
18	200Ah,12V Battery	110000	2	220000
19	Charge controller	37000	1	37000
20	Microcontroller (PIC16F876A)	1500	1	1500
21	24/100V transformer	1200	1	1200
22	Miscellaneous	22570		22570
	TOTAL			**379160**

3.4 Payback Time

For one to buy into the induction means of cooking, economic metrics must be involved. Calculating the payback time will show an approximate point at which the cost of acquiring an induction cooker offsets the cost of acquiring and running a gas cooking arrangement.

In setting up a gas cooking arrangement for say a middle class family of six people, the following could apply.

Table 4: Cost of running a gas cooking arrangement

Item	**Unit**	**Amount per unit**	**Total (₦)**
12.5kg cylinders	2	12,000	24,000
Table top burner	1	12,000	12,000
table top burner after 2years	1	12,000	12,000
Other accessories		3000	3000
		Subtotal	**51,000**

Recurrent cost of running a cooking gas setup for say three years

(i) 25kg of gas in a month @350/kg and for 36 months = 315,000.00
(ii) Fare to buy gas @ 400/month for 36 months = 14,400.00

Subtotal of recurrent cost = ₦ 329,400.00

Total cost of using cooking gas for three years = 51,000.00 + 329,400.00 = ₦ 380,400.00

Therefore, the payback period for an induction cooker is three years given that the cost of setting up and running a gas cooker almost equal to that of induction cooker at three years.

4. CONCLUSION

The induction cooker design and construction as embarked upon in this work was successful as it was able to heat up water placed inside the pot. And the energy used in heating was much lower than that of cooking gas. The outcome is a proof of the concept that any steel material placed within the reach of alternating magnetic field can be heated up. The circuit basically consists of a high frequency pulse generator, driver and the inductor coil/tank circuit. The device main power was from the battery and supported by the solar panel.

The principles of operation have been highlighted and discussed. The circuit worked satisfactorily as shown by the test results though with some limitations.

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APPENDIX

Appendix A: Testing and adjustment of frequencies with dedicated pot

Appendix B: Testing with a regular cooking pot for heating effects