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Design and Development of Adaptable Hot and Cold Water Dispenser with Inbuilt Inverter for Rural Communities in Nigeria

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ABSTRACT: *Accessible hot and cold water dispenser is not common in rural communities in Nigeria. Most water dispensers are expensive for low-income earners especially in rural communities in Nigeria. In this work, an attempt is made to design a low-cost adaptable water dispenser with an inbuilt inverter for rural communities. The water dispenser was designed and fabricated using available materials found locally. The technique of refrigeration system was employed which include the use of a Peltier module and spring heating element made of nichrome to generate the cooling and heating effect, respectively. The temperature-time range for the hot and cold chamber was evaluated and it was observed that temperature increases with time in the hot chamber and decreases with time in the cold chamber.*
Keywords*: Water Dispenser, Inbuilt inverter, Refrigeration system, Peltier module, Hot and cold chamber*

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I. INTRODUCTION

A water dispenser is one of the devices that make water accessible in public places or at home. Most water dispenser available includes a compressor for cooling and heating processes [1]. Research on water dispenser had been studied [2-13]. However, available work reviewed indicated that limited work has been done on the development of hot and cold dispenser machine locally in Nigeria for rural dwellers. Hence, in this work, an adaptable hot and cold water dispenser machine for rural communities in Nigeria was designed and fabricated.

II. MATERIALS AND METHODS

2.1 Source of Materials and Selection

All available raw materials were sourced from the Petroleum Training Institute Community and Effurun, in Delta State, Nigeria. The various materials used for the water dispenser were selected based on the following factors: Weight**,** Cost**,** Efficiency**,** Aesthetics, Durability, and Reliability**.** The various materials used are, fiberglass, plastic fittings (elbows and T-joints), mild steel pipe, bolts and nuts, screws, adhesives, pipes, plastic box, pipe fittings, plastic tap, transformer, Peltier device, heat sink components, spray paint, fan ,wires Mosfet, sandpaper, gum, battery, hinges, bolts and nuts, dispenser bottle, etc.

2.2 Components Design

Component design and analysis were computed for the inverter, Oscillator Unit, transformer; Components selection and specifications were done on op-amp, transistor, coil, conductors, etc.

2.2.1 Specification of the inverter

The design specification of the solar source inverter includes:
Inverter output voltage = 220V/240Vac
Operating frequency = 50Hz
Power rating =0.5kVA
Output waveform = modified sine wave
DC input = PV cell (solar panel)

DC storage =12Vdc
Low battery level =10.5Vdc
Over charge battery level =15Vdc
The design was done according to different circuit stages.

2.2.2 Selection of the Operational Amplifier (Op-amp)

The general purpose op-amp LM324 was used, with Output swing = + 12V and Supply voltage = 30V max

2.2.3 Selection of relay

The relay selected was T91-1C with Coil voltage = 12V and Coil resistance = 420ohm

Hence, Coil current = $\frac{coil\ voltage}{coil\ resistance} = \frac{12}{420}$ = 0.02857A (1)

2.2.4 Selection of the transistor

The transistor BE547 was used, with V_{BE} =0.7V, I_{cmax} = 100mA and Gain (β) = 150

But, $I_B = \frac{Ic}{\beta} = \frac{0.02857}{150} = I_B$ = 0.0001905A (2)

From the transistor input, $V_{out} - V_{BE} - I_B R_B = 0$

Where, V_{out} = 12V, V_{BE} = 0.7V

$R_B = \frac{V_{out}-V_{BE}}{I_B} = \frac{12-0.7}{0.0001905}$ = 59kΩ (3)

Battery nominal voltage = 12.2V. Thus a Zener diode of 12.2V was used.
Reverse voltage = 12V from battery. The diode IN5806 was used.
Charging current = 5.0A

$R = \frac{22V-12V}{5.0} = \frac{10}{5} = 2\Omega$ (4)

Power rating = P = I^2R = 50watts
For the Zener diode

Zener diode power rating = $\frac{1}{8}$ = 0.125 watts obtained from the data sheet.

P = IV

Hence, $I = \frac{10}{5} = \frac{0.125}{12.5}$ = 0.01042A (5)

But $R = \frac{P}{I^2} = \frac{0.125}{0.01042^2}$ = 1151.26Ω = 1.2kΩ

2.2.5 Design of the Oscillator Unit

The oscillator is required to generate a frequency of oscillation of 50Hz and this oscillation is determined by R_T and C_T. the oscillator is built around a single chip astable/multivibrator IC. The reason is to reduce connection and achieve compatibility. Based on these, the SG3524 IC was used, the frequency f, of operation, is given by;

$0.05 = \frac{1.18}{R_T C_T}$ (6)

Where f = 0.05 kHz

$R_T C_T = \frac{0.125}{12.5}$1.18/0.05 =23.6

Using a standard value of C_T = 1μF

$R_T = \frac{23.6}{1}$ = 23.6k Ω. Hence a variable resistor of 30kΩ was used.

The essence of the boofer amplifying unit is to isolate the oscillatory unit from the gate voltage of the MOSFET.
Output of the oscillator;
V= 12V, I= 20mA from the data sheet.

2.2.6 Design of the Switching Unit

The switching unit is also known as the driving unit. The drivers consist basically of transistors (field effect transistor) that supply the battery to the input of the step-up transformer alternative according to the frequency of the oscillator.

Primary current of transformer = I_1
Power factor of transformer pf = 0.8
Output power P_2 = 1kVA
Output voltage V_2 = 240V
Input voltage V_1 = 12V

$P_2 = V_2 I_2$

$I_2 = \frac{P_2}{V_2} = \frac{1000VA}{240V}$ = 4.17Amp (output current) (7)

For input current; we have that $\frac{I_2}{I_1} = \frac{V_1}{V_2}$ (8)

$I_1 = \frac{V_2 \times I_2}{V_1} = \frac{240 \times 4.17}{12} = 83.4$ Amp
Using a safety factor 1.5
$I_1 = 83.4 \times 1.5 = 125.1$Amp
Number of MOSFETs to be used = $\frac{current(primary\ current)}{current\ rating\ of\ MOSFET}$ (9)

Based on the primary voltage of 240, the MOSFET IRFP150 was used. Maximum current rating of IRFP150 is 30Amp. Using the Maximum Allowable Operating Current Rating (MAOC) of 10Amp. Thus, number of MOSFETs 125.1/10 = 12.5. Therefore, the needed numbers of MOSFETs are 12.6 MOSFTEs are used on each side of the center-tapped transformer.

2.2.7 Design of the transformer
The r.m.s value of emf is given as;
$E_{rms} = \frac{Vp}{\sqrt{2}} = \frac{2\pi f N Ø}{\sqrt{2}} = 4.44 f N Ø$ (10)
Determining the voltage per turn v
From equation (10), we have;

$V_1 = \frac{E_{rms}}{N} = \frac{4.44 f N Ø}{N} = 4.44 f\ Ø$ (11)
Rating in kVA could be expressed as;
$KVA = E_{r.m.s} \times I \times 10^{-3}$

Substituting $E_{r.m.s}$ in the equation we have;

$KVA = (4.44 f N Ø \times (I) \times (10^{-3}) = 4.44 f N Ø \times I \times 10^{-3}$ (12)
The ratio of magnetic loading to electrical loading, r could be expressed as;

$r = \frac{magnetic\ loading}{electrical\ loading} = \frac{Ø}{N1}$ (13)
but $N = \frac{Ø}{I \times r}$
$KVA = \frac{4.44 f \times Ø^2 2 \times I \times 10^{-3}}{I \times r}$ (14)

$Ø^2 = \frac{r}{(4.44 f) \times 10^{-3}} (kVA)$

Where, V_t = voltage per turns in volts; KVA = (E in volts) x (I in amps) x 10^{-3}; r = Ø/N i.e. magnetic loading / electrical loading; Ø = flux in weber; I = current in ampere; N = number of turns

2.2.7.1 Determining the number of turns
The voltage per turns V_t could be expressed as;
$V_t = C\sqrt{KVA}$ (15)
C = transformer core factor
Let, KVA = 1kVAand C =0.5
$V_t = 0.5\ x\ \sqrt{1} = 0.5$
For a 12V input:
$TURNS_{primary}\ (N_p) = \frac{12V}{0.5} = 24$turns (16)
Taking a design compensation winding of 10%
10% of 24turns = 2.4 turns.
Actual number of $TURNS_{primary}\ (N_p) = 24 + 2.4 = 26.4$ turns (17)
For output (secondary) 240V
$TURNS_{secondary}\ (N_s) = \frac{240}{0.5} = 480$turns (18)
Taking a design compensation winding of 10%
10% of 480 turns = 48 turns
Actual number, of $TURNS_{secondary}\ (N_s) = 480 + 48 = 528$ turns (19)
Turns ratio = $\frac{Np}{Ns} = \frac{26}{528} = \frac{1}{10}$
Turns ratio = 1:10
The efficiency of the transformer was computed as;

$$\text{Efficiency} = \frac{Power\ Output}{Power\ Input+losses} \quad (20)$$

Where the losses are from the iron and copper on the primary and secondary windings and
Output = KVA x Power factor
And Power Factor of 0.8 was used

2.2.8 Calculation of the Core Dimensions

Total core area = primary core area + secondary core area
But E = 4.44fØN
Ø = BA
Where, A = core area, B = maximum flux density = from 1 to 1.5wb/m^2 for iron core
E = 4.44 x f x B x A x N
N = N_p or N_s
For primary circuit E_p = 12V

$$A_p = \frac{Ep}{4.44xFxBxNp} = \frac{12}{4.44x50x1.5x26} = 0.001386m^2 = 13.86cm^2 \quad (21)$$

And for secondary, E_s = 240V

$$A_s = \frac{Es}{4.44xfxBxNs} = \frac{240}{4.44x50x1.5x528} = 0.001365m^2 = 13.65cm^2 \quad (22)$$

Total core area = primary core area + secondary core area
$A_{total\ core} = 13.86cm^2 + 13.65cm^2 = 27.51cm^2$

$$\text{Gross core area } A^i = total\ core = \frac{area}{stacking\ factor} \quad (23)$$

Using stacking factor of 0.9

$$A^i = \frac{27.51}{0.9} = 30.56cm^2$$

2.2.9 Heat Transferred Through the Coil

Heat transfer is the basis adopted for the achievement of both thermoelectric cooling of the Peltier device which serves the cold chamber and Heating of a coil which serves the hot side. Two cylinders of equal dimensions are provided containing water for the hot and cold chambers each. The heating coil is being lagged with porcelain beads in order to create a clearance between the heating coil and the circumference of the cylinder for the hot chamber so as to prevent short-circuiting of the circuit; while the Peltier device is in direct contact with the base of the cylinder for the cold chamber. The heat transferred to both chambers and Coefficient of Performance for the cold chamber is determined as follows:
Cylinders for both chambers of the following specifications were chosen as;
External diameter of both cylindrical chambers = 0.092m each
Internal diameter of both cylindrical chambers = 0.09m each
Height of cylindrical chambers = 0.1m
Transformer specifications adopted are:
i. Input = 220 – 240V AC, 50/60Hz
ii. Output = 12V DC, 5A (for cold chamber); 110V DC, 100W (for hot chamber)
The hot chamber is being powered by a heating coil made up of Nichrome which has the following properties:
Composition: 80% Nickel + 20% Chromium; Resistivity: (1.0 – 1.5) x $10^{-6}\Omega$m; Specific Heat Capacity: 450J.$Kg^{-1}K^{-1}$; Emissivity: (0.65 – 0.79); Thermal Conductivity: 11.3W. $m^{-1}K^{-1}$

To determine the quantity of heat transferred through the heating coil, the formula for thermal radiation was employed, thus

$$Q_{rad} = \varepsilon.\sigma.A_s (T_s^4 - T_{surr}^4) \quad (24)$$

Where σ = Stephan Boltzmann constant (5.67 x 10^{-8}W/m^2.K^4); where K = thermal conductivity of the material
ε = Emissivity of the material; 0.68 for Nichrome in this case, A_s= area covered by the material = $\pi(R^2 - r^2)$
R = 0.0520m; external radius of the spring when wound round the cylinder with Porcelain beads between them
r = 0.0475m; internal radius of the spring when wound round the cylinder with Porcelain beads between them;

$$A_s = \pi(0.0520^2 - 0.0475^2) = 4.4775 \times 10^{-4}m^2 \quad (25)$$

T_s = Temperature of the coil when heated (for 15 mins) = 80°C/353.15K
T_{surr} = Ambient temperature = 25°C/298.15K
Q_{rad}= 0.68 x 5.67 x 10^{-8} x 11.3^4 x 4.4775 x 10^{-4} x ($353.15^4 - 298.15^4$) = 2153.790W

For the cooling compartment, the following consideration was made:

Desired temperature of cold chamber = 10°C/283.15K
Temperature of water to be chilled; which is ambient temperature = 25°C/298.15K
Required time for attaining the desired cooling temperature = 7mins/420secs

Volume of cylinder = $\pi(R^2 - r^2)h$ (26)
D = external diameter of cylindrical chamber = 0.092m
d = internal diameter of cylindrical chamber = 0.09m
R = 0.046m; r = 0.045m
h = height of cylindrical chamber; 0.1m
Volume of cylinder = π x $(0.046^2 – 0.045^2)$ x 0.1 = 2.859 x $10^{-5}m^3$
Mass of cylinder = density x volume; ρ x v (27)
Where ρ = density of steel; 7850kg/m^3
m = 7850 x 2.859 x 10^{-5} = 0.224kg

Volume of water to be cooled = π x r^2 x h = π x 0.045^2 x 0.1 = 6.362 x $10^{-4}m^3$
Mass of water to be cooled = ρ x v (28)
Where ρ = density of water; 1000kg/m^3
m = 1000 x 6.362 x 10^{-4} = 0.6362kg
Q = m x C_p x ΔT (29)
Where m = mass in kg
C_p= specific heat capacity in J/Kg.K; (510.7896 for steel and 4186 for water)
ΔT = change in temperature
Q = $(m \times C_p \times \Delta T)_{steel}$+ $(m \times C_p \times \Delta T)_{water}$ = 1.7163 + 39.9470 = 41.7W

Coefficient of Performance of a heat pump = $\frac{Heat\ Output}{Energy\ Input}$ (30)

Heat output for the period of 7mins = 41.7 x 7 x 60 = 17498.6W (31)
Where, I = 5A, V = 12V, t = 7mins

Electrical Energy input = IVt= 5 x 12 x 7 x 60 = 25200W (32)
C.O.P. = $\frac{17498.586}{25200}$ = 0.7

III. RESULT AND DISCUSSION

The analyses obtained were factored into the development of the cold and hot water dispenser machine. The following components were constructed and assembled; construction of inverter, construction of the oscillator unit, construction of the switching unit, transformer construction, core windings, soldering of the component parts, installation, mounting on the casing, and transformer test. Figure 1 is the plot of temperature versus time of the hot chamber. From the plot, it was observed that temperature increases with time in the hot chamber. Equally too, figure 2, shows the plot of temperature versus time for the cold chamber. It was observed that temperature decreases with time in the cold chamber. An average of power loss of 26.7 watts for iron core and 23.2 watts copper using the open-circuit and closed-circuit test for iron and copper were recorded. An efficiency of 97% was obtained in the transformer unit. Figures 3 and 4 are the plot of power loss for iron vs. voltage and copper vs. voltage, respectively, in the transformer unit of the dispenser. It was observed that power loss in iron and copper increases with increase in voltage.

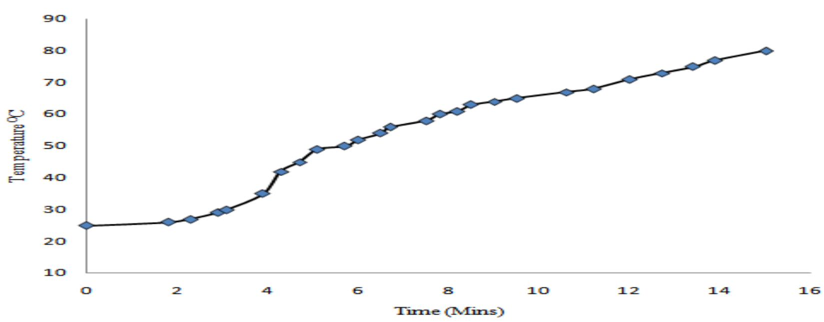

Figure1 : Graph of Temperature of the Hot Chamber

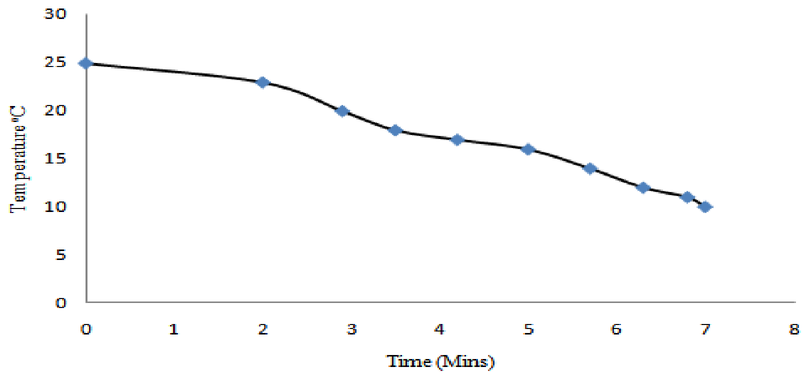

Figure 2: Graph of Tempreture of the Cold Chamber

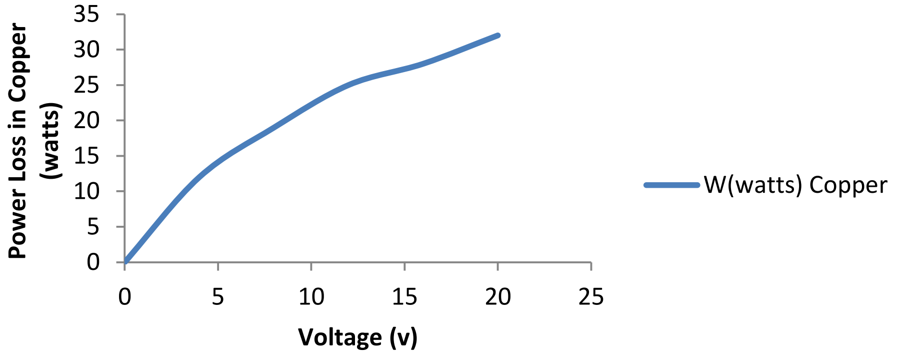

Figure 3: Plot of Power Loss in Copper vs. Voltage

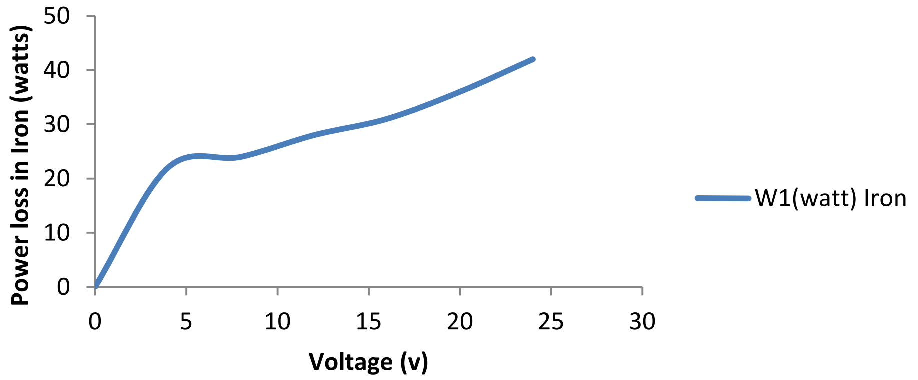

Figure 4: Plot of Power Loss in Iron vs. Voltage

3.1. CAD Drawing and Product Developed

Figure 5 shows the CAD drawing in millimeters for the water dispenser machine while figure 6 is the pictorial view of the developed hot and cold water dispenser.

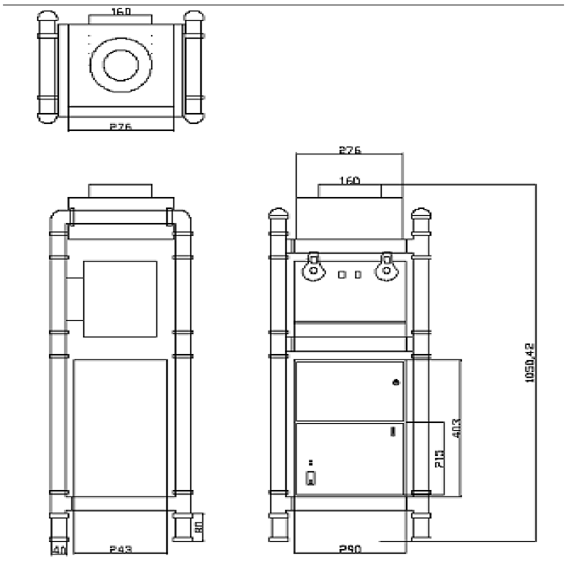

Figure 5: Orthographic Drawing Hot and Cold Water Dispenser with Inbuilt inverter

Figure 6: Pictorial view of fabricated Hot and Cold Water Dispenser with Inbuilt inverter

IV. CONCLUSION

In this study, water dispenser with an inbuilt inverter was designed and fabricated. The device works without a compressor, condenser or evaporator. The Peltier module cools the water in the cooling chamber, and the Nichrome serves as the heating element in the hot chamber unit. The research work employed the principle of thermoelectric for refrigeration using a Peltier device. It is expected that this device if mass-produce would in no small measure contribute to the availability of potable water in our rural communities in Nigeria.

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