Design Analysis Of Kitchen-Waste-Heat Energy For The Production Of Telephones' Chargers As An Alternative Grid Technology

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***Abstract*—Cell-phones have become indispensable companions to both the urban, rural and nomadic group of Nigerian populace. These phones operate with batteries of different grades and ratings. The batteries' stored energy often got used up; and the available alternative power sources are not complementing. This research work is therefore aimed at designing and developing a locally-made off-grid electrical power charger for cell-phones. We achieve this using the principle of thermoelectricity; and the phenomenon is called the Seebeck effect. This gave rise to the technology used in converting heat energy directly into electricity. In this work, we are harvesting cooking waste heats as the raw material. This technology was invented since 1885 and many developed nations used it to improve their technology. Our team has investigated upon this technology with the aim of using it to improve our local technology. We came up with this design and development as is being presented in this work. Commercial production of the product will automatically avail cell phone users with affordable, reliable and efficient locally produced cell phone power chargers. In fact as one cooks with woods, charcoal or stove, the cell phone could be charged automatically with this product. They are therefore very useful in urban, rural and nomadic communities that have little or no presence of conventional electricity supplies.**

Keywords—Seebeck effect, nomadic, cell-phones & off-grid.

I. INTRODUCTION

In many rural areas of Africa and other developing countries of the world, people manage their lives without some basic necessities of such as electricity, water and sanitation. However, telephone services have become an unavoidable necessity. This is because Smart Phones are fast becomming indispensable companions to both the urban dweller, rural and nomadic group of the entire populace. The simplest of these Smart-Phones has important features like touch-lights, radio reciever, time piece, maillings facility apart from the normal making and answering voice calls. These phones are battery powered and thus needs constant power to function. To charge those Smart Phones, people use to walk for miles to some common charging centers which sometimes are unavailable in most rural communities. In most cases people are compelled to stay back for hours for the Smart Phones to charge; and some people even leave their phones overnight. It is very exciting and convenient to own Smart-Phones even in our rural settings because it is a two-way communication unlike others means where messages are relayed through people or write letters. "The upgrade technology system on Smart-Phones today makes life easier for everyone in rural areas but our major challenge is when it comes to charging them in the villages we have to find a power supply," says one irritated rural customer. (Susan P. Wyche, 2007).

People are crazy to charge their Smart-Phones in rural area whenever there is an opportunity. When there is a wedding or death in a community all the villagers know there will be a power supply, as fuel will be purchased for generator to provide power supply for lighting throughout the night. Long queues of people lined up waiting for their turn to charge their Smart-Phones. It takes 1 to 2 hours or more for Smart-Phones to be fully charged while others will be waiting for their turns.

Some people who are tired of searching for opportunities to charge their mobile phones just lost interest completely as it too much hassle as eventually they will find out their "SIM" cards are de activated as well.
Solutions do exist including car batteries; diesel generators, solar installations and entrepreneurial charging kiosks, but all have limits, mostly their lack of affordability by the poorest and most remote, inconvenience and required maintenance.

In other cases, hunters, hikers, mountain climbers, backpackers e.t.c in the bush always move with smart-phones with GPS and some other electronics gadgets. These gadgets are powered up by batteries to keep them running and so need electricity to charge up the batteries. Spare batteries and solar chargers are often being used to support or recharge the gadgets. However, the spare batteries often got used up and the sun rays are very weak or even unvailable for the solar chargers. The solar charger is not filling the gap either because the sun in some of the wilds are not reliable available and sometimes it is either rainning or there are other circumstances that make it impossible to charge with the solar panel. Other alternatives are either too expensive or impracticable in such rural and outdoor areas. Thus there is a great need of some locally available renewable energy sources to avail the situation. This necessitated this important research of harvesting and harnessing heat energy from heating sources and to provide the necessary electric power to ensure affordable and locally available means of powering Smart-Phones.

This research work therefore provided local technology for powering Smart-Phones. It is poised towards harvesting and converting waste cooking heat to provide the required electrical energy. It uses the principle of *thermoelectricity*. Thermoelectricity means the direct conversion of heat into electric energy. In this research project, we are harvesting and directly converting waste-cooking heat into electrical energy to power our cell-phones.

This physical phenomenon where materials develop an electric potential due to temperature difference is known as thermoelectric effect.

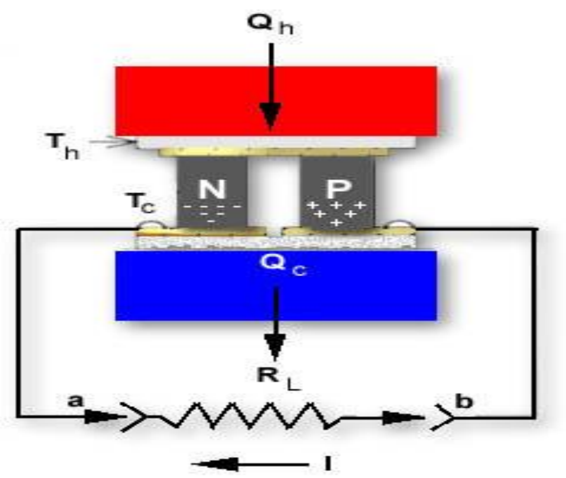

Figure 1: Single Thermoelectric Couple where Th > Tc.

Thermoelectric generator: two pieces of semiconducting materials with different (opposite) Seebeck coefficient can exploit a temperature gradient to deliver electrical power to an external load R_{Load}, indicated with R_L in the text.

The semiconductor materials are N and P type, and are so named because either they have more electrons than necessary to complete a perfect molecular lattice structure (N-type) or not enough electrons to complete a lattice structure (P-type). The extra electrons in the N-type material and the holes left in the P-type material are called "carriers" and they are the agents that move the heat energy from the cold to the hot junction. Heat absorbed at the cold junction is pumped to the hot junction at a rate proportional to carrier current passing through the circuit and the number of couples.

The thermoelectric effect is the direct conversion of temperature differences to electric voltage. All thermoelectric power generators have the same basic configuration, as shown in the figure 1. A heat source provides the high temperature, and the heat flows through a thermoelectric converter to a heat sink, which is maintained at a temperature below that of the source. The temperature differential across the converter produces direct current (DC) to a load (R_L) having a terminal voltage (V) and a terminal current (I).

There is no intermediate energy conversion process. For this reason, thermoelectric power generation is classified as direct power conversion. The amount of electrical power generated is given by I^2R_L, or VI. According to Joule's law, a conductor carrying a current generates heat at a rate proportional to the product of the resistance (R) of the conductor and the square of the current.

With no load (RL not connected), the open circuit voltage as measured between points a and b is:

$$\mathbf{V = S \times DT}$$

Where:

V is the output voltage from the couple (generator) in volts

S is the average Seebeck coefficient in volts/°K

DT is the temperature difference across the couple in °K (DT = Th-Tc). When a load is connected to the thermoelectric couple the output voltage (V) drops as a result of internal generator resistance. The current through the load is:

$$\mathbf{I = S \times DT / R_C + R_L}$$

Where:

I is the generator output current in amperes

Rc is the average internal resistance of the thermoelectric couple in ohms

RL is the load resistance in ohms

The total heat input to the couple (Qh) is:

$$Q_h = (S \times T_h \times I) - (0.5 \times I^2 \times R_c) + (K_c \times DT)$$

Where:

Qh is the heat input in watts

Kc is the thermal conductance of the couple in watts/°K

Th is the hot side of the couple in °K

The efficiency of the generator (Eg) is VI / Q_h.

We have thus far discussed an individual thermoelectric couple, but since a complete module consists of a number of couples, it is necessary to rewrite our equation for an actual module, as follows:

$$\mathbf{V_o = S_M \times DT = I \times (R_M + R_L)}$$

Where:

Vo is the generators output in volts

SM is the module's average Seebeck coefficient in volts/°K

RM is the module's average resistance in ohms

The power output (Po) from the module in watts is: $P_o = R_L$ x

It is possible, but unlikely, that the precise conditions will exist within a given generator application whereby one module will provide the exact output power desired. As a result, these thermoelectric generators contain a number of individual modules which may be electrically connected in either series, parallel, or series/parallel arrangement.

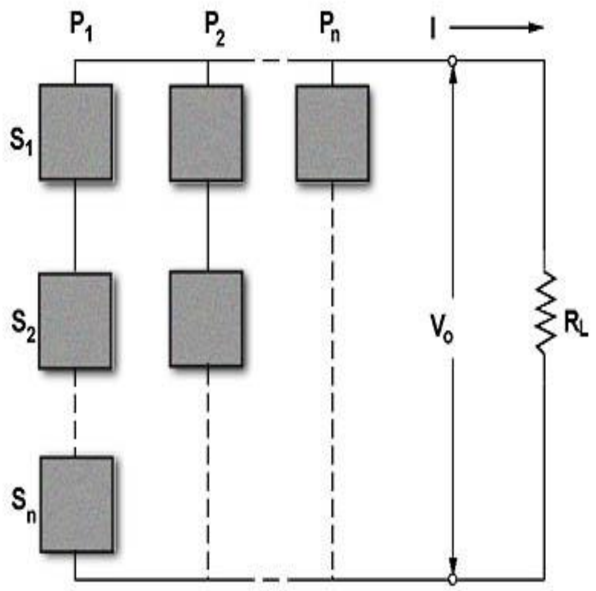

Figure2: Our Thermoelectric Generator with a Series-Parallel Arrangement of Modules

The current (I) in amperes passing through the load resistance RL is:

$$I = NS \times S_M \times DT / NS \times R_M$$

The output voltage (V_o) from the generator in volts is:

The Output Power (P_O) from the generator in watts is:

$$P_o = V_o \times I = NT \times (S_M \times DT)^2 / 4 \times R_M$$

The total heat input (Qh) to the generator in watts is:

The efficiency (Eg) of the generator is:

$$E_g = P_o / Qh \times 100\%$$

Maximum efficiency occurs when the internal resistance of the generator (RGEN) equals the load resistance (RL). The generator resistance is:

$$R_{GEN} = NS \times R_M / NP$$

DESIGN PROCESS:

Our aim is to design a **6-12-volt, 1.5 ampere thermoelectric power generator**. The generator is needed to power smart phones and some other electronics devices. We following steps were used:

Step 1

1. The estimated maximum heat from the cooking process produces a 130°C temperature.
2. The idle temperature of the kitchen environment is 10°C.
3. Cold-side temperature of our generator is +30°C.

We obtain the values of $S_{M,}$ $R_{M,}$ and K_M for our calculations from thermoelectricity material data book.

Where

1. S_M is average Seebeck coefficient in volts/°K.
2. R_M is average resistance of the module in watts/°K.
3. K_M is thermal conductance of the module in watts/°K.

Step 2

We will reviewed the system parameters and make some preliminary calculations.

Given:

T_h = + 130°C = 403.2K;
T_c = + 30°C = 303.2K;
V_o = 12 volts;
I = 1.5 amperes

Therefore:

$T_{av} = (T_h+T_c)/2 = (403.2+303.2)/2 = 353.2$K;
$R_L = V_o/I = 12 / 1.5 = 8.0$ ohms.
$P_o = V_o \times I = 12 \times 1.5 = 18$ watts;
$DT = T_h - T_c = 403.2 - 303.2 = 100$K.

It is usually desirable to select a relatively "high power" thermoelectric module for generator applications in order to minimize the total system cost. For this reason we will choose a 127 couple, 6-ampere module to be used in our design.

From material data book our selected 127-couple, 6 ampere module, the following values are obtained at Tav = 353.2K:

S_M = 0.05544 volts/K (S_M is average Seebeck coefficient in volts/°K).
R_M = 3.0994 ohms (R_M is average resistance of the module in watts/°K).
K_M = 0.6632 watts/K (K_M is thermal conductance of the module in watts/°K).

The required power for the load has been calculated as 18 watts. It is now necessary to determine the minimum number of modules needed to meet this load requirement.

The maximum output power from one module is:

$P_{max} = (S_M \times DT)^2 / 4 \times R_M = (0.05544 \times 100)^2 / 4 \times 3.0994 = 2.479$ watts

The minimum number of modules needed is:

$NT_{min} = P_o / P_{max} = 18 / 2.479 = 7.3$ or 8 pieces.

Let us recall that the maximum generator efficiency occurs when **RGEN = RL**, so we selected the series/parallel module configuration that will best approximate this resistance balance. We however were careful of the following conditions:

1. A relatively low current (in the milli-ampere range) and moderate voltage is required.
2. That the maximum output voltage from the generator will be obtained from a straight series-connected group of modules only when the resistance of the load is significantly higher than the internal resistance of the generator.

We first examine the straight series-connected configuration. The resistance of a series string of eight modules is:

$$R_{GEN} = NS \times R_M / NP = 8 \times 3.0994 = 24.8 \text{ ohms}$$

But this value 24.8 ohm generator resistance is considerably higher than the 8.0 ohm load resistance, thereby indicating that a straight series module connection probably is not the best arrangement.
The next most logical connection configuration is two parallel strings of four modules, i.e., NS = 4 and NP = 2.
Generator resistance for this configuration is thus:
$R_{GEN} = NS \times R_M / NP = 4 \times 3.0994 /2 = 6.2$ ohms.
This value normally would be considered as being within the satisfactory range. In any event, this is the closest resistance match that can be obtained with the selected module type. The voltage for this arrangement (12.49 volts) is calculated as follows:

We can now see that Vo is quite close to the desired value and it is apparent that we have obtained the optimum series/parallel configuration. If "fine tuning" of Vo is required, it will be necessary to accomplish this either by some form of electronic voltage regulation or by externally altering the applied temperature differential (DT). In certain instances it will be found that the output voltage is significantly out of range despite trying all possible series/parallel combinations. In this event it may be necessary to use an alternate thermoelectric module having a different current rating and/or number of couples.

Step 3

It is now possible to complete our design analysis by determining power levels and efficiency. Since we have established Vo, output power (Po) can be simply calculated:

$$\mathbf{P_o = (V_o)^2 / RL = (12.49)^2 / 8.0.}$$

The total heat input (Qh) to the generator is:
The generator efficiency (Eg) is:

$$E_g = P_o / Q_h \times 100\% = 19.5 / 657.5 \times 100\% = 2.97\%$$

The heat transferred to the cold-side heat sink (Qc) is:

$$Q_c = Q_h - P_o = 657.7 - 19.5 = 638.2 \text{ watts}$$

The maximum allowable thermal resistance (Qs) of the cold-side heat sink is:

(Qs)= Trise / Q_c 30°C - 10°C / 638.2=0.031 °C/watt.

Table 1: Total number of modules @ different Cold side temperatures for specified Heat sources (Hot side Temp.).

Temp @ cold side Degrees C	Temp @ Hot side as 150'C	Temp @ Hot side as 125'C	Temp @ Hot side as 100'C	Temp @ Hot side as 75'C
0	2	3	5	8
15	3	5	7	12
30	4	6	9	28
45	5	8	18	50
60	7	12	35	260
75	10	23	85	367
90	18	48	450	445
105	34	210	467	445
120	84	323	485	477
135	400	400	500	500

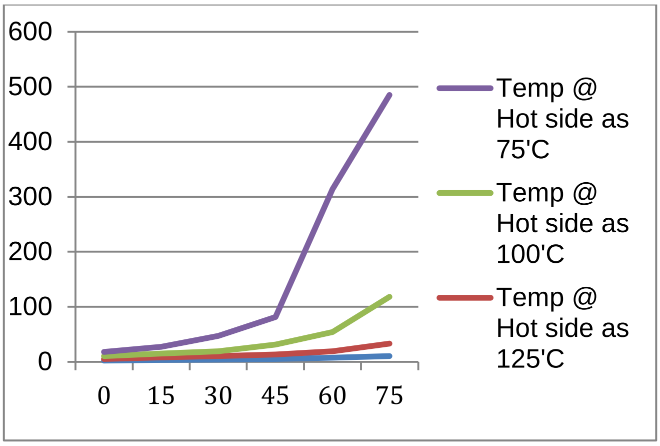

Figure 3: Graph showing number of modules @ different Cold side temperatures for specified Heat sources (Hot side Temp.).

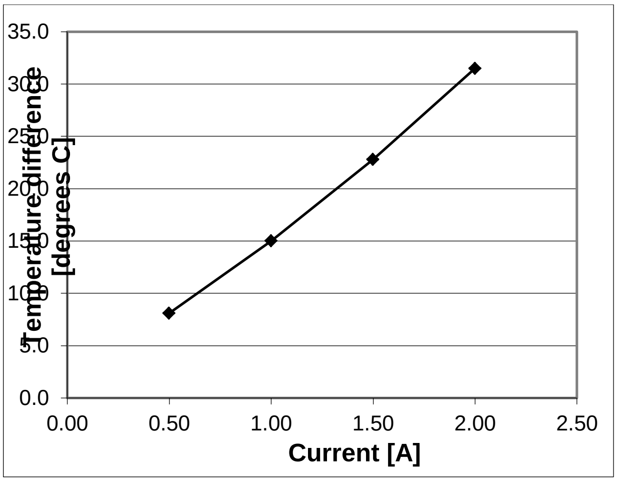

Figure 8: *The temperature and current relationship.*

Figure 8 shows the relation between the current through the Peltier element and the temperature difference between the sides of the element.

CONCULSION:

In thermoelectric generator design it is always desirable to maximize the applied temperature differential in order to minimize the total number of modules in the system. This situation can be clearly seen in Figure (3.4). Module requirements for a typical 12-volt, 1-ampere power generator are plotted at several fixed values of Th based on the use of 127-couple 6-ampere TE modules. From this graph, it is evident that a very large number of modules are needed when the cold side temperature (Tc) is high and the temperature differential, therefore, is small. Performance of the cold-side heat sink is of the utmost importance and its thermal resistance must be extremely low. In many cases, cold-side heat sink design will prove to be the most challenging engineering problem.

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