Solar Powered DC Refrigerator with a Monitoring and Control System

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***Abstract*-Food, medicine and vaccine in developing countries are often difficult to preserve due to epileptic power supply from the utility companies. In other to reduce the over dependence on the utility company and harness the abundant renewable energy resources. This paper presents the implementation of a solar power DC refrigerator with a microcontroller based temperature monitoring and control system. A DC compressor of 12V/59.8W Danfoss, 12V/100AH battery, a pair of 12V/130W solar panels connected in parallel through a 20A charge controller was used for the refrigerator. ATMEGA16 microcontroller interface with weight, temperature and momentary sensors was programmed in C language to monitor temperature and control the switching ON or OFF of the DC compressor. This project has demonstrated that the energy required for effective operation of DC refrigerator could be harnessed from renewable energy source at reduced cost, the flexibility of its application is vital in developing countries.**

I. INTRODUCTION

Solar energy applications in different fields is gaining rapid recognition, this is due to concern for the ever-increasing energy demand and the environmental sustainability. One of the important of this application is to power a refrigerator. it is difficult in developing countries to preserved perishable food, maintain blood bank and vaccine due to long-term and frequent power interruption. Locations far from electricity supply grid are worst hit [1].

Refrigeration is a method of lowering the temperature of substances below that of the surrounding in order to preserve or make them suitable for consumption in the future. When food items are stored in a refrigerator at temperatures below the freezing point, the growth of micro-organisms is greatly impaired. The total breakdown of the cell and fibers in the food items is thereby inhibited. Also, the rate of oxidation and fluid loss through evaporation is retarded [2]. Refrigerator with maintained temperature range help in maintaining vaccines potency and blood quality [3-4].

The focus of this paper is to demonstrate the opportunities of harnessing renewable energy source to power a refrigerator system effectively with minimum cost and high efficiency independent of location form electricity supply in developing country. The implementation of this was achieved by using a DC compressor that is either powered directly by battery and or the sun at regulated voltage by the charge controller hence eliminating the inverter component. The microprocessor based monitoring and control system incorporated enables the flexibility in the usage of the refrigerator with energy efficiency.

The rest of the paper is structured as follows: Section II presents the related work. Section III presents the methods and materials needed. The determination of material size were calculated and presented in Section IV. Section V covers the results and Section VI contains the conclusion and recommendations

II. RELATED WORKS

Some of the existing related solar powers DC refrigerator are briefly review to highlight the advantages with the one presented here.

Theoretical analyses and experimental investigation on the performance of Solar Photovoltaic driven thermoelectric cooler system for cold storage application is performed in [5]. A small storage box of 3 liter capacity was used for the examination. The experiment was setup and analyzed, and its performance in Delhi, India with the composite climate was observed. It was concluded that, the cooling power, energy efficiency was low for this system, but if a high figure thermoelectric materials with a good merit is found, then the systems is said to gain practical significance in near future. [2] Developed a Solar-Powered Mobile Refrigerator having an inverter to convert DC to AC to power the refrigerator and concluded that the installed PV system was able to power the conventional refrigerator successfully and therefore reduced both wastage and deterioration of perishable food items to the barest minimum. Although, the initial cost of production was said to be high because it was a just a unit, the operating costs of the system was cheap due to the low power consumption on the long run. It also shows that, solar power system is a realistic alternative energy source. [6] analyzed the performance evaluation of photovoltaic system designed for dc refrigerator, the no load and full load conditions of the performance of photovoltaic system were studied to assess its technical practicality. The study shows the necessity and value of energetic and exegetic techniques to evaluate solar photovoltaic (SPV) refrigerator performance. The development of a mobile Juicer with cooling system for

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retailing fresh fruit products is discussed in [7]. The project was conceived in order to upgrade the practice of selling sliced fruit products by providing a mobile system fitted with a hygienic closet and powered by the engine of a tri-cycle incorporated with devices that cool and extract juices for retail at different locations. It was recommended that further research is necessary to use solar panel for generating electricity to compliment the tricycle engine, other similar application of solar based system are discussed in [8-9].

This paper presents, the designed and implementation of a DC refrigerator that can be power directly from the sun or battery, a microcontroller based monitoring and control system incorporated with it is an additional advantage over similar existing once. A particular temperature range can be maintained to avoid energy waste and save cost.

III. Methods and Materials

The block diagram of the system is shown in fig. 1. The materials used in this work are; Solar panel, charge controller, 12 V battery, DC compressor, locally fabricated refrigerator, condenser, evaporator, cables, DC fan, microcontroller, LM35 temperature sensor, weight sensor, momentary sensor, relay, LCD and circuit board. The approach on the methodology was to determine the DC compressor rating in wattage that will refrigerate the volumetric capacity of the unit and total power demand of the refrigerator.

To coordinate the system, the microcontroller program was written in C using PROTEUS. The microcontroller automatically controls the system through the sensors at the input pins of the controller and delivers a command on the compressor. ATmega16 Atmel microcontroller brand was used for this work; it has higher frequency, large memory and high speed of processing than ATtiny. The block diagram is as shown in Fig. 2 and the flow chat of the program is shown in fig. 3.

IV. Determination of Sizes of Materials Used

Most of the materials used were selected based on the design calculation using relevant formulas. The refrigerator is designed for a capacity of 20 kg of any particular item intended to be refrigerate and the power requirement is determined as follows.

It is consider that, 1 ton of refrigerator have the ability to freeze 2000 lbm of water at 0 °C or 32 °F in the period of 24 hours. Alternatively, if the capacity is considered in term of rating in watts or kilowatts then, 1 Ton = 3.517 kW.

Using the data given above, the total power required to refrigerate 20 kg refrigerator capacity is determine to be 44.1 lbm. Which is equivalent to 77.5 W. Now 77.5 W of electricity is required to refrigerate 44.1 lbm (20 kg) of water in 24 hours. This designed refrigerator has a temperature monitoring and control system feature designed along with it. Fig 3 shows a flowchart developed to guide the operation of the system. ATMEGA16 microcontroller was used for the software implementation written in C.

In this work, the available DC compressor used is Danfoss 12 V/59.8 W capacity having 101N0210 electronic code unit with 2000 rpm and low power input of 17 W and maximum of 59.8 W. The power rating of the compressor + the power required by the Microcontroller + the power required by the weight sensor + the cooling fan power = total power required to operate the system which is: = 61.53 W

Therefore, 61.53 W is required to run the refrigerator system. From the calculated total load, the required battery capacity, solar panel, charges controllers were determined using the equations that follows. The values obtained are shown in table I. The daily average energy demand is given by (1)

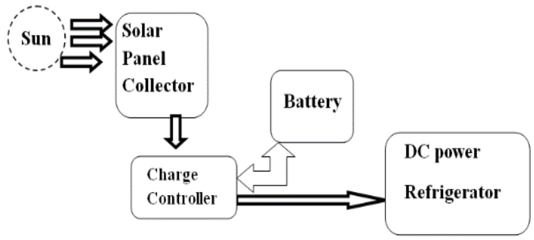

Fig. 1. A simple block diagram of the system

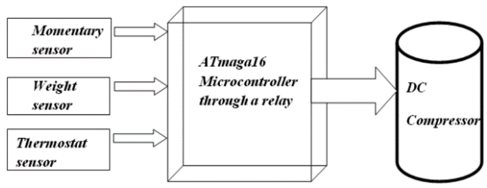

Fig.2. Block diagram of microcontroller design.

$$E_d = C_{eu} * hr \quad (1)$$

where C_{eu} is the hourly energy demand and hr is the number of hours.Estimated energy stored is:

$$E_{est} = E_d * D_{aut} \quad (2)$$

where D_{aut} is the number of days of autonomy (i.e the number of days the battery bank should supply without charging).

Safe energy stored is:

$$E_{safe} = E_{safe} / D_{dis} \quad (3)$$

where D_{dis} is the power discharged

Total capacity of battery bank is:

$$C_{tb} = E_{safe} / V_b \quad (4)$$

where V_b is the battery voltage and C_{tb} is the battery bank capacity. Table 2 gives the model specification of the solar panel used. The number of series modules is given by (5) and the number of parallel modules is given by (6)

$$N_{sm} = \frac{V_{dc}}{V_{pm}} \quad (5)$$

$$N_{pm} = \frac{V_{dc}}{V_{pm}} \quad (6)$$

The summary of the required PV array sizing is shown in table III. The required daily energy demand, E_{rd} is given by (7)

$$E_{rd} = E_d \quad (7)$$

average peak power is given by (8)

$$P_{avg\_peak} = E_{rd} / T_{sh} \tag{8}$$

the total DC current, I_{dc} is (9)

$$I_{dc} = P_{avg\_peak} / V_{dc} \tag{9}$$

the required charge controller rating given in Table 4 using (10) The required current, I_{rcc} is (10)

$$I_{rcc} = I_{sc} * N_{pm} * E_{safe} \tag{10}$$

and the number of charge controllers, N_{cc} is given by (11)

$$N_{cc} = I_{rcc} * I_{sc} \tag{11}$$

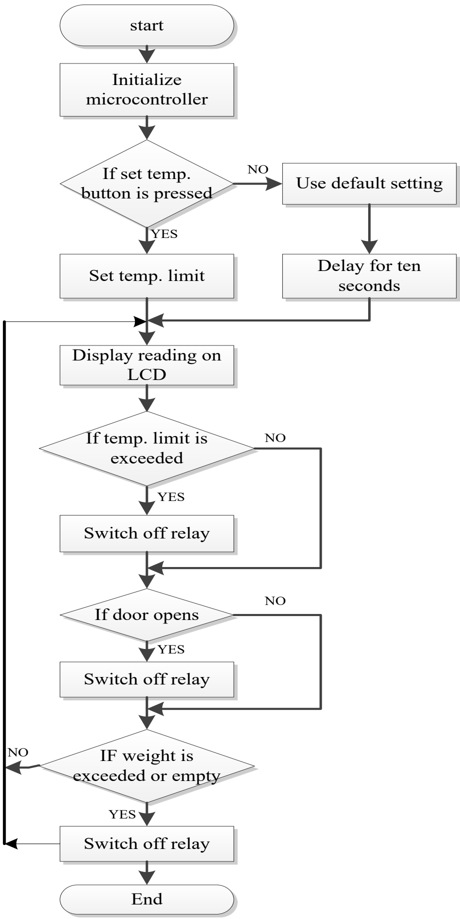

Fig. 3. Flow chart of the program

TABLE I
SUMMARY OF THE REQUIRED BATTERY CAPACITY SIZING

Parameter being determined	Computed parameter value
E_d	1476.72Wh/day
E_{est}	1476.72Wh
E_{safe}	1968.96W
C_{tb}	164.08A

TABLE II
MODEL SPECIFICATION OF RUBITEC SOLAR TYPE HU130/12V

Parameter	Value
Typical power	(5%) 130 W
Current at typical power (maximum power current) V_{pm}	7.23 A
Voltage at typical power (maximum power voltage) I_{pm}	18 V
Open circuit voltage (V_{oc})	21.5 V
Short circuit current (I_{sc})	7.74 A
Irradiance (E)	1000 W/m^2
Module Temperature (T_c)	25 ºC

TABLE III
SUMMARY OF THE REQUIRED PV ARRAY SIZING

Parameter being determined	Computed value
E_{rd}	1476.72Wh/day
P_{avg_peak}	164.08W
I_{dc}	13.67A
N_{sm}	1
N_{pm}	2

TABLE IV
SUMMARY OF THE REQUIRED CHARGE CONTROLLER RATING

Parameter being determined	Computed value
I_{rcc}	19.35A
N_{cc}	1

Fig. 4. Snapshot of the experimental setup.

The following cables links in the refrigerator system were appropriately selected: The DC cable from the PV array to the battery bank through the charge controller, I_cab, the DC cable from the battery bank to the compressor through the temperature sensor, I_cbc, the DC cable from the battery to the cooling fan, I_cbf

TABLE V
POWER CONSUMPTION, CURRENT AND VOLTAGE DROP

Time	Battery Voltage (V)	Compressor and fan current (A)	Compressor and fan voltage (V)	Power consumption (W)	Temperature (ºC)
7:00 PM	12.89	5.68	12	68.16	25.0
9:00 PM	12.53	3.61	12	43.32	23.0
11:00 PM	12.27	3.38	12	40.56	19.0
1:00 AM	12.01	3.17	12	38.04	16.0
3:00 AM	11.75	2.98	12	35.76	14.0
5:00 AM	11.49	2.75	12	33.00	12.0
7:00 AM	11.23	2.69	12	32.28	10.0
9:00AM	12.78	2.67	12	32.04	10.0
11:00AM	13.45	2.66	12	31.92	10.0
1:00PM	14.10	2.64	12	31.68	10.5
3:00PM	14.00	2.61	12	31.32	10.8
5:00PM	13.23	2.59	12	31.08	10.6
6:30PM	12.90	2.57	12	30.84	10.2

The cable rating of the above links were selected according to the Code of Practice for the Electricity (Wiring) Regulations 2015 Edition and Institute of Electrical and Electronic Engineering Regulations (IEEE).

V. RESULTS

Fig. 4 shows the pictorial view of the refrigerator with solar panel, charge controller and a battery. The power demands to run the refrigerator depends on it initial temperature and the preset value of the temperature that is desired to be maintained. Table 5 shows the results on testing the refrigerator on a typical day, at about 7:00pm the voltage of the battery after charging was measured to be12.89V, on switching ON the refrigerator the starting current was measured by multi-meter to be 5.68 A and the power consumed was 68.16 W. This was when the initial refrigeration temperature was about 25 ºC and the preset temperature is 10 ºC as programmed into the Microprocessor, as the time progresses through the night the battery voltage drops since the sun was no longer there to charger. It is also noticed that, as the temperature drops the power consumption also drops averagely whereas the preset temperature is fairly maintained. As the sun rises the next day the battery begins to charge. The result shows that, once the preset temperature is reached the power consumption remained fairly constant, also when the battery is fully charged can maintained the system for the night period.

VI. CONCLUSION

This paper has demonstrated the applicability of using renewable energy from solar to power DC refrigerator thereby reducing cost. The power consumption is relatively low (at average of 45W) where the lost are minimized. The monitoring and control unit of the refrigerator add to the efficient utilization of the system as the power supply to the refrigerator is disengaged whenever the unit sensors detects overloading, empty unit or when left open. The result of this work indicates that appliances use in homes, place of work, hospital et cetera can be powered directly using DC means with low power requirement. Therefore, it is recommended that DC power refrigerators should be promoted in rural settings and clinical institutions like hospitals, also the refrigerator casing is not as air tight as that of an ideal system therefore cooling effect is lost faster, in view of this; a new approach is advised on the refrigerator casing.

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