Design and Retrofitting of A 200 Litres Solar Powered Freezer

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Abstract - The design and retrofitting of a 200 litres solar powered freezer is a refrigeration system that runs on the solar energy. It was embarked upon as a result of the epileptic power supply to the rural areas in the country and the absence of a grid supply to some locations where needed. The solar refrigerator comprises of the following components, the D.C compressor (Danfoss BD72K), charge controller (30A, 12/24V), solar battery (12V, 200AH), solar panel (12V, 450watt) and a 200litres freezer. The power is not supplied either from the national grid nor the generator system, but from the solar panel. The solar panels convert the solar energy into electrical energy and store it in the battery. During the day, the solar refrigerator get its power supply directly from the solar panel, but when the solar irradiance drops, the freezer compressor obtain it source from the stored energy (battery). The battery is recharged when excess amount of power is produced by the solar panels. The output supply of the batteries and the solar panel is DC with voltage of about 12-14VDC. A microcontroller was used to display the inner temperature of the freezer and also to protect the compressor by switching it off when the door is opened for a particular period of time. A charge controller was connected to the battery and the solar panel to regulate the voltage from the solar panel for the charging of the battery. The system is capable of running for 26hours without the presence of sunlight when the battery is fully charged; it also has a high storage capacity of 200 litres and longer operation time as compared to previous solar refrigerators.

Indexed Terms: D.C compressor, solar panels, microcontroller, solar battery

I. INTRODUCTION

Refrigerators used in daily life are one of the indispensable tools. Uninterrupted power should be supplied to refrigerators in order to maintain cooling service. Photovoltaic (PV) systems provide an independent, reliable electrical power source at the point of use, making it particularly suited to remote locations. For this reason, nowadays, the use of PV solar energy in refrigeration has been increasing in rural regions (Mehmet, 2011).
Photovoltaic (PV) powered refrigerator or freezer has a cooling capacity lower than typical alternative current (ac) unit because of its smaller compressor. Using the energy efficiently in solar or other renewable energy powered systems is more crucial than others since the limited sources and high costs for the storage capacity (Ekren, 2011). 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 nearest future.

Conversion from sunlight to electricity is completed using PV semiconductor materials, in most cases, pure crystalline silicon is used. They are called PV because of the ability of these semiconductor materials to convert the energy contained in photons of light into electrical energy (Masters, 2013). In developed countries, the deployed PV systems are based on grid-connected topologies since the grid is very stable. For developing countries, this is not the case, where the grid is intermittent or some of the population have no connection to the grid. This is the reason renewable off-grid solutions are sought after (Qaiser, 2014). The main reasons behind the search for alternative energy solutions are increasing power requirements and demands, the high cost of fossil fuels and the environmental impact of their use in generating electricity. It is for these reasons that the development of sustainable and affordable energy resources that are not harmful to the environment remains imperative.

II. METHODOLOGY

In designing a retrofitted micro-controller-based freezer, there are many guides involved in the design. This guide provides the information to correctly select the compressor, batteries, solar array, wiring, the blower (cooling fan), limiting resistors and many others. The method adopted in this study is purely experimental. The device was designed using mathematical analysis and was converted into experiment by following the design results obtained in procuring the needed materials for the design.

A. Procedures Applied in this Paper

There are many procedures used in this project work and these are:

1. Freezer volume (chosen, which was 200ltrs)
2. Load requirement
- Compressor size
- Size of cooling fan (chosen)
- Size of indicator lamps
3. Sizing the main control switch
4. Determination of backup size
5. Determination of PV size
6. Selection of charge controller
7. Determination of the limiting resistor

In this paper, the following procedures were taken:

1. Selection of freezer volume: In this paper, a specified volume was chosen, which was 200 liters

2. Load requirement: The total load including the compressor, the fan and the lamps will be calculated.

Compressor size, Size of cooling fan and size of indicating lamp

The compressor size was selected from Danfoss compressor data sheet (compressors.danfoss.com). From the data sheet, the compressor suitable for the 200litres volume is BD72K which has the total consumption of about 80W (table 1).

Table 1: Danfoss compressor datasheet

Model	BD36K	BD43K	BD52K	BD72K	BD92K	BD120K
Refrigerant	R600a	R600a	R600a	R600a	R600a	R600a
Displacement	2.5 cm³	3.6 cm³	4.3 cm³	5.2 cm³	6.6 cm³	9.1 cm³
Application	MBP/LBP	MBP/LBP	MBP/LBP	MBP/LBP	MBP/LBP	MBP/LBP
Voltage	DC12V~42V	DC12V~42V	DC12V~42V	DC12V~42V	DC12V~42V	DC24V~42V
Rotation RPM	2500~3500	2500~3500	2500~3500	2500~3500	2500~3500	2500~3500
Cooling Capacity	30~70W	40~90W	60~120W	80~180W	100~200W	120W~250W
Input Power	40W	55W	65W	80W	100W	120W
Current	3.3A (12V)	4.5A (12V)	5.5A (12V)	3.8A (24V)	4.2A (24V)	5A (24V)
Oil Charge	150 ml	180 ml	185 ml	185 ml	195 ml	250 ml
Cooling Type	Static cooling	Static cooling	Static cooling	Static cooling	Fan Cooling	Fan Cooling
N.W. (with control unit)	5 kg	5.5 kg	6 kg	6.5 kg	7.5 kg	8.5 kg

Now let us denote the compressor power as P_C. The fan power can equally be denoted as P_F, so that the total LED power will be denoted as P_{LED}. With this, we can say that the total power can be expressed as;

$$P_T = P_C + P_F + P_{LED} \quad (1)$$

3. Sizing of the main control switch

The switch is best chosen when equation 1 has been implemented.

4. Determination of backup size

The formula below was used to calculate the backup size

$$Battery\ size = \frac{(Load)}{(Battery\ voltage)} \times HRs \quad (2)$$

Where:

HRs = Time of Discharge

$Battery\ AH$ = Size of Battery

Load = Total load of the freezer

Battery voltage = Battery voltage

5. Determination of PV size

Stated in equation 3, formula used to calculate the charging current of the calculated battery size.

$$Charging\ current = \frac{Battery\ Ah}{Charging\ time} \quad (3)$$

6. Selection of charge controller

The size of the charge controller used in this project was calculated using the formula

$$C_c = \frac{W_p}{V_{bat}} \quad (4)$$

Where:

W_P= watt peak of the panel,

V_{bat}= battery voltage

7. Determination of the limiting resistor

The limiting resistor is the value of resistor that was used to limit the current across the indicating lamps, this can be expressed as;

$$R_{LED} = \frac{V_S - V_{LED}}{I_{LED}} \quad (5)$$

Where;

R_{LED} is the LED resistor, Vs is the supply voltage, V_{LED} is the LED voltage and I_{LED} is the LED current.

Circuit Diagram

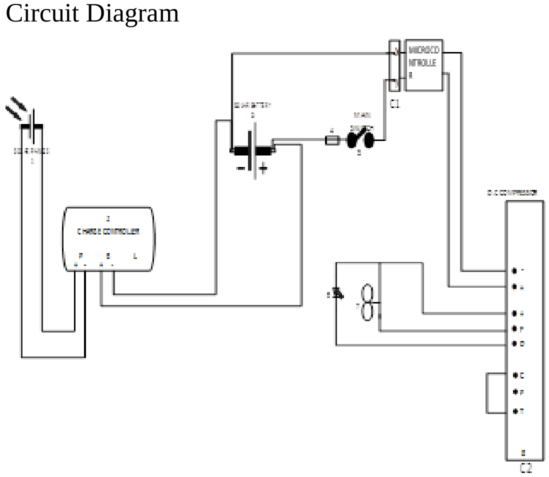

Figure 1: Schematic Diagram of the Design and Retrofitting of Microcontroller Based Solar Powered Fridge

Components Used

1. Solar Panel (12V/450W)
2. Solar charge controller(12V/30A)
3. Solar Battery(12V/200AH)
4. Fuse
5. Main switch
6. Light emitting diode (LED)
7. D.C fan 12V
8. Compressor (BD72K)

III. CONSTRUCTION

The construction of the solar powered freezer started by selecting domestic conventional A.C freezer of 200liters from the market and selection of a D.C compressor (BD72K) for the replacement of the A.C freezer compressor and charging of the compressor with required R600a refrigerant. The 12V/200AH solar battery was used to power the converted (retrofitted) freezer, the construction of each section was assembled to form a single unit. (figure 1)

A. The Refrigeration Section

The selected DC compressor was mounted and tightened properly using bolt and nut. The discharge low suction line (pipe) of the compressor is welded to the inlet of the condenser pipe coils mounted on the back of the freezer, dryer (filter) is then welded to the outlet of the condenser pipe coils and a capillary tube is welded to the dryer (filter). The capillary tube is also welded to the inlet of the evaporator pipe, coils and outlet of the evaporator pipe coils is welded back to the return low suction line of the D.C compressor, the compressor is then filled with R600a refrigerant through the charging pipe and closed.

B. Electrical /Wiring Section

Three (150 watt) solar PV panel is connected in parallel to bring an output of 450watt and mounted where it can trap the solar energy from the sun, 4mm stranded cable is used to connect the solar PV panel to the charge controller, battery and then to the micro controller. The electrical section is connected to the compressor electronic control unit and from the electronic control unit the compressor is powered for freezer operation. (Figure 2)

C. Pictorial Representation

Figure 2: Wiring Configuration

Figure 3: No Load Test

Figure 4: Freezer in Operation

Figure 5: DC Compressor

D. Load test

The no load test involes the process of loading the freezer (30,50 and 80 liters of water was used) The pictorial representation is shown below.

Table 2: Day 1: Hourly Voltage Drop at 30litres Load Without PV (Seven Hours, for 100AH Battery only)

Hour of Operation	Voltage Readings(V)	Current(A)
09:45am	12.5	9
10:45am	12.26	9
11:45am	12.14	9
12:45pm	12.04	9
01:45pm	11.91	9
02:45pm	11.74	9
03:45pm	11.54	9
04:45pm	10.53	9

Table 3: At Day 2: Hourly Voltage Drop at 40litres Load With PV (Ten Hours, for 200AH Battery and 300W Panel)

Hour Of Operation	Voltage Readings(V)	Current(A)
08:00am	12.5	9
09:00am	12.7	9
10:00am	12.9	9
11:00am	13.0	9
12:00pm	13.1	9
01:00pm	13.2	9
02:00pm	12.7	9
03:00pm	12.8	9
04:00pm	13.1	9

05:00pm	12.4	9
06:00pm	12.3	9

Table 4: At Day 2: Hourly Voltage Drop At 50 Litres Load Without PV (Eight Hours, For 200AH Battery and 300W Panel)

Hour of operation	Voltage Readings(V)	Current(A)
06:00pm	12.3	5
07:00pm	12.2	5
08:00pm	12.1	5
09:00pm	12.1	5
10:00pm	12.0	5
11:00pm	11.9	5
12:00am	11.8	5
01:00am	11.8	5
02:00am	11.8	5

Table 5: At Day 3: Hourly Voltage Drop At 80 Litres Load With Pv (Twenty-Four Hours, For 200AH Battery and 450Watt Panel)

Hour of operation	Voltage Readings(V)	Current(A)
09:10AM	25.0	5
10:10AM	25.0	5
11:10AM	25.4	5
12:10AM	25.6	5
01:10PM	25.8	5
02:10PM	25.9	5
03:10PM	25.9	5
04:10PM	25.7	5
05:10PM	25.5	5
06:10PM	25.3	5
07:10PM	25.2	5
08:10PM	25.1	5
09:10PM	24.9	5
10:10PM	24.7	5
11:10PM	24.5	5
12:10AM	24.3	5
01:10AM	24.1	5
02:10AM	23.9	5
03:10AM	23.7	5
04:10AM	23.5	5
05:10AM	23.3	5
06:10AM	23.1	5
07:10AM	23.1	5
08:10AM	23.3	5
09:10AM	23.5	5

IV. DISCUSSION OF RESULTS

At the first day of test using 100AH battery only without panel, the running current tested was 9A with 3A as starting current and 5A at half full load. The voltage reading and duration of time is also display in table 2 and 3 with load of 30 and 40 liters respectively

At day 2 of the test, using 200AH batteries with the solar panel (4 X 150W) connected to the battery gave readings of 13.3V on the battery when the load was applied and running current of the device as 5A with 50 and 80 liters of load as shown in table 4 and 5 respectively

At day3 A series connection was made using 300W solar panel and 200AH battery. Here the total voltage tested was 24.6V with a starting current of 6.5A and a running current of 5A, with readings of 24hour operation shown in table 5

Note: When the system voltage drops to 10.5V the system automatically shut down. The system gets iced within a time frame of 18 hours when connected in parallel (12V) and 9 hours when connected in series (24V), therefore making the design aim achievable

V. CONCLUSION

A solar – powered refrigeration system was designed, retrofitted and evaluated. The installed PV system was able to run the DC refrigerator effectively and hence reduced both wastage and deterioration of perishable food items to its minimum. Although, the initial cost of production seemed high because it was a single unit, but the operating costs of this system was reduced due to its operating lower power consumption on the long run. It also showed that solar system is a viable alternative energy source. Such system can suitably be used in many rural regions where electricity is unreliable or non-existent.

It was observed that the maintenance and running cost of the A.C freezer is about 30% higher than the D.C freezer.

RECOMMENDATION

During this work, some challenges were noted, and recommendations were made for future work. These recommendations are as follow:

1. For future design of the work, tracking system should be provided for the solar panel.

2. This paper is recommended for exhibition in small and large scales to attract investor's interest.

3. Demonstration of the PV drive system with the specific application of refrigeration appliances should be attempted.

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