STUDIES OF A SOLAR POWERED REFRIGERATOR WITH THERMAL STORAGE SYSTEM

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ABSTRACT

The declination in the availability of fossil fuels due to increase in population growth hence also increase in consumption of energy in any form so use of fossil fuels will further deteriorate the environment. One of the growing industry is refrigeration and air conditioning due to the change in life style and also essential for the increase shell life of fruits, vegetables and to store certain medicines and vaccines. World Health Organization (WHO) is focusing to use the solar operated refrigerator to store the vaccines at the desired temperature for their effective use in the rural areas of Africa and South Asia. The use of solar operated refrigerators can be more effective if supported by coolness storage.

In this project, efforts have been made to run a refrigerator with solar Photovoltaic power and to store the coolness to maintain the temperature during off sun shine hours.

This experiment describes an autonomous power source supply for the house hold 165L refrigerator and which is powered by the 300 watt photovoltaic cell. Requirement of storage of perishable food item was been fulfilled where electricity is not available or also be a good setup to save our fossil fuels. Problem arises at the night time there is a no sunlight so production of electricity through solar panel is not possible. But problem is being solved by storing coolness during day time using ice gel packs. Ice packs capable of maintaining temperature below 15°C.

Food transportation and storage at low temperature is always being crucial matter through Worldwide which is being solved by this Phase Change Material (i.e. ice gel packs).

Keywords: Solar Photovoltaic Cell, Inverter ,Battery, Refrigerator, PCM.

1. INTRODUCTION

The demand of the energy increasing as the population and economy is growing. The use of fossil fuels will further deteriorate the environment. One of the growing industry is refrigeration and air conditioning due to the change in life style and also essential for the increase shell life of fruits, vegetables and to store certain medicines and vaccines. World Health Organisation (WHO) is focusing to use the solar operated refrigerator to store the vaccines at the desired temperature for their effective use in the rural areas of Africa and South Asia.

Most common vaccines require a storage temperature range of 0-8°C to retain their potency (WHO,1988). It is essential that refrigeration units used for storing the vaccines be powered by a dependable power source. Autonomy from conventional mains electric power supply is desirable though its use is not precluded if available and required.[1]. Solar refrigeration is a promising photovoltaic (PV) application, especially in countries with a high level of solar insolation. It is usually used in the pharmaceutical, medical and food industries but their main application is the transportable vaccine cold chain in hospitals and remote areas.[2]

Recently, energy conservation and reduction of global warming effect become one of the most important subjects in the worldwide. Since the proportion of the refrigeration systems’ energy consumption in overall energy consumption is steadily increasing, these systems are under research. Many vehicles used in transportation of goods or recreation such as trucks, caravans, boats, cars, etc. are often equipped with small cooling appliances. Compressor of these kind of applications might be designed to operate low voltage direct current, such as, 12-24 volts. The electrical energy produced by renewable energy systems like photovoltaic panels is in the form of the DC electrical energy[3]. In parallel to that discussions were held at various times (starting in 1998-99) between UNEP, WHO, Greenpeace and GTZ with the objective to promote environmentally sound refrigerators.[4]. Along with photovoltaic systems, solar thermal energy has been used over the last few decades to meet the refrigeration needs for both domestic and industrial purposes[5].

The main reasons for the increasing energy demand for summer air- conditioning and Refrigeration are the increased thermal loads, increased living standards and comfort demands in conjunction with architectural characteristics and trends[6].

The use of solar operated refrigerators can be more effective if supported by coolness storage.

Food transport and storage at low temperatures has always been an important matter worldwide and is becoming even more important due to dietary needs and population growth. The issue of improving food storage
applies to food transportation in refrigerated vans and food storage in domestic refrigerators and freezers[8]

In this project, efforts have been made to run a refrigerator with solar Photovoltaic power and to store the coolness to maintain the temperature during off sun shine hours. For off sunshine hours we use phase change material (PCM) to provide coolness. PCMs are commonly known as the Latent heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or “Phase”. The use of Phase Change Material (PCM) in a latent heat storage system is an effective way of storing thermal energy and has the advantages of high energy storage density and the isothermal nature of the storage process [9].

2. OBJECTIVE
As we know our fossil fuels resources (i.e coal, petroleum etc) is vanishing day by day. So we are moving towards renewable sources. Sun energy is one of the solution of renewable sources and it is available in abundance, can use it for generating electricity.

2.1 FIRST OBJECTIVE
Provide Storage System (Refrigerator) in Rural Area where electricity is not available: In rural region there is problem with electricity. And without electricity there were facing many problem like storage of product. They are unable to store vegetable, they unable to store medicines which have to store below 8°C or 20°C etc. Solution of the rural people for storing of items is being solved only by the refrigeration if running through solar PV panel.

2.2 SECOND OBJECTIVE
Provide Back Up Storage System at Night Time: Now problem arises at the night time there is no sunlight so production of electricity through solar panel is not possible. But problem is being solved by storing coolness during day time using icepacks.

Therefore, second objective of the project is to maintain the temperature below 15°C during night time or off sun hours.

3. SYSTEM DESCRIPTION

![Diagram of Solar Refrigeration System]

Fig 3.1: Diagram of Solar Refrigeration System

These experiments conducted at Jaipur (latitude 26.9˚N, longitude 75.8˚E). We had chosen 300 watt photovoltaic cell. There are four panels two of 100 watt each and 2 of 50 watt each. These panels are kept on the stand and stand is inclined at a 27˚ at jaipur and it is facing to the south direction. Facing to south direction so that solar panel will maximum intensity and 26˚ C is the optimum inclination so that photovoltaic cell will get maximum intensity. All the four panel is connected in the parallel. We connect panel in parallel because we can get increased current through output and one more advantage of connecting parallel is, we get less effective load resistance

Output of the solar panel is connected with the inverter. Inverter is getting input in the form of Direct Current (DC) for which it produced intended power which is required by the system the system is (refrigerator). We use microtek inverter of 1kVA. Inverter output waveform is in the form of sine wave. Inverter frequency output of a inverter is same as standard power frequency i.e 50 or 60 Hz. And the voltage is providing to the household (here we had taken household appliances as a refrigerator ) such as 220 V. As the change in the load of the inverter there is a change in output voltage of the inverter. Battery is taken as load and it is connected with the inverter. We had taken battery Amaron Raja group of Amaron Go battery. Battery is of 12 volt and 36 ah. All the runtime of the inverter is dependent on the battery power and how much current is being drawn from the inverter at a given interval time. As the amount of the appliances increase in the inverter the runtime of the inverter will decrease. Runtime of an inverter have to maintain we have to add the additional batteries so that runtime will increase. Now we connect refrigerator with the inverter. We had taken 165 litre refrigerator of the brand Videocon. In this refrigerator there is compressor whose capacity is 0.2 TR. Refrigerant used in this refrigerator A1- R134a. R134 is of hydro fluorocarbon whose chemical formula is 1,1,1,2- tetrafluoroethane CH₂FCF₃ Refrigerant is of group A which means it is low toxicity which is below 400ppm. Refrigerator is of group 1 which means it is very very low flammability it is being tested on 21˚C and at 101 K Pa it does not show any flammability. Refrigerator maintain temperature at the vegetable zone is around the 6˚C to 10˚C and it maintain temperature at freezer at the -4˚C to -10˚C.

Two T type thermocouples have been used to measure the temperature of the freezer and vegetable section respectively. One glass thermometer was used for the room temperature measurement. The voltage and current were measured using multimeter. Solar the radiation was measured using a pyranometer.

Limitation: Standard double door freeze has been procured for the local market. It has limitation of refrigerating capacity, being design on 24 hours operating cycle as per the load.

3.1 SOLAR PANEL DETAILS

Photovoltaic Cell is used to convert direct sunlight fall on the cell into the DC current. We had taken 4 panels 2 panels are of 100 watt and 2 panels of 50 watt each.
And all the panels are put on the stand and this stand is inclined at the 26 degree and these panels are facing towards south direction cause we know in south direction where solar intensity is higher. These panels are connected in parallel mode. These panels are able to produce 17V to 19V and 12amp to 14 amp. All the four panel is connected in the parallel. We connect panel in parallel because we can get increased current through output and one more advantage of connecting parallel is, we get less effective load resistance.

**Fig 3.3:** Block diagram of Panel connected in parallel

**Table 3.1:** Electrical specification of 100 watt PV module

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max system voltage</td>
<td>1000V</td>
</tr>
<tr>
<td>Max peak power</td>
<td>100 W</td>
</tr>
<tr>
<td>Maximum power point voltage</td>
<td>18.6 V</td>
</tr>
<tr>
<td>Maximum power point current</td>
<td>5.53 A</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>22.851 V</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>5.903 A</td>
</tr>
</tbody>
</table>

**Table 3.2:** Electrical specification of 50 watt PV module

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max system voltage</td>
<td>600 V</td>
</tr>
<tr>
<td>Maximum power</td>
<td>50 W</td>
</tr>
<tr>
<td>Voltage at maximum power point</td>
<td>17.6 V</td>
</tr>
<tr>
<td>Current at maximum point</td>
<td>2.00 A</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>21.6 V</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>3.00 A</td>
</tr>
</tbody>
</table>

**Table 3.3**: Technical features of the fridge

<table>
<thead>
<tr>
<th>Model</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>165 L</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>R134a</td>
</tr>
<tr>
<td>Compressor capacity</td>
<td></td>
</tr>
<tr>
<td>Motor Power</td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>0.165 cubic meter</td>
</tr>
<tr>
<td>Thickness of insulation</td>
<td>4 cm</td>
</tr>
<tr>
<td>Type of Insulation</td>
<td>PUFF</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>0.027 W/m °C</td>
</tr>
</tbody>
</table>

**Table 3.4**: The Technical Specification of the inverter

<table>
<thead>
<tr>
<th>Model</th>
<th>Solar Sinewave UPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS1130/SS1660</td>
<td></td>
</tr>
</tbody>
</table>

3.2 REFRIGERATOR

Refrigerator is an appliance which is used to cooling or thermal storing of the substances such as perishable food so that it will does not get spoiled and food does not get decayed. Refrigerator runs by the electrical power for that we supplied electrical power through inverter. For cooling purpose in the refrigerator R134a refrigerant is being used. This refrigerant having low toxicity and low flammability. We have taken 165 litre of fridge in which compressor is of 0.1TR. It maintain the freezer temperature is about -8°C to -10°C which is enough to freeze any food items. And it is capable of maintaining vegetable zone at 6°C to 10°C.

3.3 HYBRID INVERTER

We had taken new generation range of sine wave Hybrid solar Inverter which are based on digital signal controller (DSC) technology. Hybrid solar Inverter means which is capable of getting charge from solar panel and also with the mains (i.e electricity) . While inverter is charging in main mode its energy consumption is low.

Highly efficient transformer is build up which helps in fast charging of battery and it saves energy. As the Dual Charging Mode is best for the areas where the electric power is cut down for a long period like in rural area or remote area. Additional By Pass Switches is being inbuilt, which enables us to isolate a UPS from mains.

**Table 3.4**: The Technical Specification of the inverter

<table>
<thead>
<tr>
<th>Model</th>
<th>Solar Sinewave UPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>100V-300V (wide input voltage range)</td>
</tr>
<tr>
<td></td>
<td>180V-260V (normal input)</td>
</tr>
</tbody>
</table>
runtime in the inverter we have to connect battery as the runtime of the inverter is decreased to increased that is increased because as the load in the inverter increased Battery is connected so that the runtime of the inverter.

**Battery**

Battery is device which convert stored chemical energy into the electricity by consisting of two or more electrochemical .Battery is connected after the inverter . Battery is connected so that the runtime of the inverter is increased because as the load in the inverter increased the runtime of the inverter is decreased to increased that runtime in the inverter we have to connect battery as the load. We had taken Amara Group of battery of 135Ah.

**3.5 PHASE CHANGE MATERIALS**

The Latent heat storage materials are commonly known as PCMs. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or “Phase”. The use of Phase Change Material (PCM) in a latent heat storage system is an effective way of storing thermal energy and has the advantages of high energy storage density and the isothermal nature of the storage process

**3.6 TYPES OF PCM**

- **Water and Gel Packs** Ice and gel packs became the most popular for keeping the substances cool around the 0°C.
  
  **Advantage**
  
  - Good performance
  - Non Toxic
  - Low cost
  - Non flammable
  - Environmentally friendly.

- **Salt Hydrates**: Salt hydrates as PCM have been most researched material as latent heat storage. Salt hydrates is a most economical after water and gel packs.
  
  Material comprises of MnH2O.
  
  Where M is an inorganic compound.
  
  Other subject of using salt hydrate is because of its characteristics of change in volume it can change its volume upto 10%. It is toxic in nature.

**Paraffins**: Paraffins are high molecular mass (HC) hydrocarbons with a waxy appearance in the room temperature.

Paraffins are categorised as even chained (n-Paraffin) and odd- chain (iso- paraffin). Because of stearic hindrances in the molecular packing of the iso- paraffin it can’t be make as a good PCM.

So we focused on the n-paraffin. Its melting point is directly depend on the number of carbon atoms. Paraffin is good PCM candidate for a particular application and for particular temperature ranges.

**Advantages**

- Good thermal storage capacity without super cooling.
- Chemical stability over many freezing and heating cycles.
- High heat of fusion
- Non-corrosive
- Compatible with all material.
- Non-reactive to most material of encapsulation.

**Vegetable based PCM**: Vegetable based PCM has been take over by paraffin product and salt hydrates. Researchers investigated around 300 different fat and vegetable oil based PCM temperature range from -90°C to 150°C. With latent heat range between 150 J/g to 220 J/g.

**Advantage:**

- Being renewable and more environmentally friendly
- Being compatible with wall timbers or analogous material that would soak up water from hydrates and bestow the salt hydrates inefficient as PCM chemicals.
- This PCM are capable of being microencapsulated , while salt hydrates are not.

The solar energy being a variable source of energy, if used in refrigeration applications, essentially require a thermal (coolness) storage system to provide temperature security for the products. However, the integration of thermal storage in refrigerators powered by solar are very limited.

Therefore, in this project efforts have been made to incorporate thermal (coolness) storage system in a solar Photovoltaic powered refrigerator.

**3.7 PERFORMANCE TEST**

This experiment is carried to analyse the performance of fabricated systems by checking out in various loading and unloading condition in the refrigerator.

**3.7.1 Experiments Performed**

1. Normal running of the refrigerator was observed under extreme conditions as the temperature inside the room reached around 36°C .This experiment was
performed with the solar Photovoltaic cells connected to the system and current drawn from the panels consumed by the load (battery/compressor). It is observed under no loading condition in freezer.

2. Refrigerator was running on loading condition and it observed under extreme conditions as the temperature inside the room reached around 37°C. This experiment was performed with the solar Photovoltaic cells connected to the system and current drawn from the panels consumed by the load (compressor/Battery). It is observed under loading condition. Under loading we had taken 2kg ice gel packs.

3. Compressor of the refrigerator is kept off. To study the effect of coolness storage, the refrigerator was loaded with 2kg of ice gel packs (frozen elsewhere).

3.8 EXPERIMENTAL CONDITIONS
The conditions maintained during the course of all the tests are specified below:
1. The refrigerator and other equipments were kept in a room. Except the Solar Photovoltaic cells.
2. The solar panels were kept at a place where there was no shade throughout the day, at an angle of 27° to the horizontal facing the south direction.
3. The Thermocouple position was set at the freezer and veg. zone to measure the temperature.
4. The panels were always kept dust free to take advantage of maximum possible solar insolation that can be gathered by the panels.
5. The door of the refrigerator was kept closed while the tests were being performed.
6. No external heating or cooling was provided during experimentation.

3.9 OBSERVATIONS AND ANALYSIS
The following profile of the various observed and calculated parameters give us an idea about the technical performance of the system.

3.9.1 No loading Condition
It can be seen that the freezer zone temperature becomes -5°C and below after 4 hours, it will go up to -6.8°C after 6 hours of running the temperature of the vegetable zone remains about 10°C.

3.9.2 Loading Condition
It can be seen that the freezer zone temperature unable to attained temperature that much attained by freezer under no load condition i.e. (-5°C ) it attained up to -2°C, it will goes up to -6.8°C .The temperature of the vegetable zone remains about 10°C.

3.9.3 Thermal Storage (Backup)
On 9th July 2015, To study the effect of coolness storage, the refrigerator was loaded with 2kg of ice gel packs.
(frozen elsewhere). The compressor of the refrigerator was kept off.

Fig 5.3: Profile of temperature of ice pack in freezer and veg. zone, it is done on natural convection it is observed on 9th July 2015.
As it seen in the above table that freezer temperature is being achieved in order of 5°C and it also been observe that 10°C reduction in vegetable zone temperature.

4. RESULT AND DISCUSSIONS

4.1 ECONOMIC SIMULATION
The estimation cost of this project is about Rs. 36,149/-. We compare this project with Diesel Generator (D.G sets) capacity of 0.75KW. Which was usually used in the area where electricity is not available. In that area D.G sets were used to powered the refrigerator. We surveyed and analysed that average running and investment cost of the D.G sets is around Rs 30K. So Payback comes about one year.

Table 6.1: Cost of items used

<table>
<thead>
<tr>
<th>Items</th>
<th>Amount (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Panel</td>
<td>15000</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>7000</td>
</tr>
<tr>
<td>Inverter</td>
<td>6800</td>
</tr>
<tr>
<td>Battery</td>
<td>3399</td>
</tr>
<tr>
<td>Stand</td>
<td>2000</td>
</tr>
<tr>
<td>Cable</td>
<td>350</td>
</tr>
<tr>
<td>Meter</td>
<td>250</td>
</tr>
<tr>
<td>Icepack</td>
<td>350</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1000</td>
</tr>
<tr>
<td>Total</td>
<td>36149</td>
</tr>
</tbody>
</table>

4.2 HEAT LOSS THROUGH FRIDGE
Well known that fridge is in adiabatic system and we know that there is no heat loss through the adiabatic system but as in practical view there is a no system in the universe who does loose heat.
We can calculate heat loss by using formula:

\[
\frac{l}{U} = \frac{l}{h_i} + \frac{l}{k} + \frac{l}{h_o}
\]

\[
Q = U \times A_s \times \Delta T
\]

U= Overall heat transfer coefficient
hi= heat transfer of air inside fridge
ho= heat transfer of air outside fridge
l= thickness of insulation (i.e. PUF)
k= Thermal conductivity of PUF
Q= Heat lost

\[
\Delta T = \text{Temperature difference}
\]

\[
A_s = \text{Surface area of the fridge}
\]

Fig 6.1: Evaluation of the value of extraction heat loss.

Heat loss through the surface area of fridge is 2.232 m² at 3:00 P.M is around 44 W. At temperature difference of 40°C between refrigerator and room during the running hours of the compressor.

4.3 REQUIRED MASS OF COOLNESS STORAGE

\[
Q = U \times A_s \times \Delta T \times \text{time}
\]

\[
= 0.5 \times 2.23 \times 30 \times 18 \times 3600
\]

\[
= 2167 \text{ KJ}
\]

Required mass for 18 hours cooling = 6.5 Kg of ice gel packs

However, due to limitations of the compressor and solar, in the project the coolness storage material was used 2Kg only.

4.4 ENVIRONMENTAL BENEFITS
Electricity used in year by a conventional refrigerator = 1800 KWh

Assumption:
(i) 2.5 units per day
(ii) Operating Hours 15 hours/day no. of days in a year = 365

CO₂ generated due to use of electricity = 0.75 Kg/KWh
Total CO₂ generated in one year = 750 Kg

4.5 RECOMMENDATION
I. The size compressor and PV panel to be designed for a refrigerator working on solar energy only with coolness storage.
II. D.C compressor should also be tried.
III. Use of battery to be avoided by the use of DC compressor.

5. CONCLUSIONS
This experiment is conducted with PV array of 300 watt to check the performance of the refrigerator with load and no load conditions to study the coolness storage effect. Therefore, we found there is a loss of heat through the refrigerator also, we found heat loss around 44 watt at a time. Major benefit of this setup is its payback comes in just a year in comparison to Diesel Generator of 0.75 W, which was generally preferred in rural areas or remote areas. At the loading circumstances we were taken ice gel pack. Ice gel pack is once frozen it will get backup up-to 16-18 hours and it can maintain temperature about 10°C-15°C air inside the refrigerator and also it can maintain temperature around 3°C-8°C of the substances which was get contacted with the ice gel pack. For 18 hours of cooling ice gel packs require only 6.5 Kg, ice gel packs is cheap and easily available in the market. There is a need to optimize the size of SPV panels, battery and coolness storage material for 24 hours working of the system on solar PV.

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REFERENCES