IMPACT: International Journal of Research in Applied,
Natural and Social Sciences (IMPACT: IJRANSS)
ISSN(P): 2347-4580; ISSN(E): 2321-8851
Vol. 4, Issue 12, Dec 2016, 87-94

FEASIBILITY EVALUATION OF SOLAR REFRIGERATION SYSTEM: A CASE STUDY

S. R. KALBANDE, SNEHA DESHMUKH & V. P. KHAMBALKAR

Department of Unconventional Energy Sources and Electrical Engineering, Dr. PDKV, Akola, Maharashtra, India

ABSTRACT

A brief description of the photovoltaic operated vapour compression refrigeration system and procedure for designing of photovoltaic systems are presented. To minimize environmental impacts associated with refrigeration system operation, it is reasonable to evaluate the prospects of a clean source of energy. The components of solar refrigeration system included DC vapour compression refrigerator, solar panel, solar charge controller and Lead acid battery. The appropriate sizing and configuration of these components was necessary for getting efficient performance of the refrigerator. Solar photovoltaic power for refrigerators has great potential for vaccine preservation in remote areas. The paper summarizes performance evaluation of system in terms of photovoltaic conversion efficiency and e xergy efficiency. The required conditions for the storage of vaccine in term of the temperature and the other related parameters have been studied in the investigation. The investigation reported that average photovoltaic conversion efficiency and exergy efficiency of refrigerator found nearer to 12.05% and 14.20% on full load condition in winter. It has been observed that refrigerator with full load condition has no impact on performance of solar powered refrigerator in terms of energy and exergy efficiency.

KEYWORDS: Solar Energy, Clean Power, PV, Vapour Compression Refrigerator, Energy Requirement, Efficiencies

INTRODUCTION

The energy consumption and electricity generation is mostly dependent on fossil fuel and in the process of electricity generation by means of these fuels a number of poisonous by products releases which affect the natural eco- system. Therefore, this valuable resource needs to be conserved by utilization of renewable energy especially solar energy which needs to be explored and also has gain more attention. Solar energy is virtually an inexhaustible natural source produces little or no greenhouse gases. It is known as a clean and environmental friendly energy source. Photovoltaic (PV) is a technology that converts sunlight directly into electricity. With the global demand to reduce carbon dioxide emissions, PV technology is gaining popularity as a mainstream form of electricity generation (Kaplnis and Papanastasious, 2006). A Photovoltaic-powered refrigerator is a cooling appliance that is operated completely with energy harnessed from the sun that has been converted to electricity through photovoltaic (PV). It can store food, medications, and other products that require less temperature (Chattopadhyay *et al*, 2013).

MATERIAL AND METHODS

The components of solar refrigeration system included DC vapour compression refrigerator, solar panel, solar charge controller and lead acid battery. The appropriate sizing and configuration of these components was necessary for getting efficient performance of the refrigerator. Average power consumption needs to be determined by considering the energy consumption of refrigerator and the total operating time.

SIZING OF PHOTOVOLTAIC STAND-ALONE SYSTEM

The photovoltaic system was designed to operate the DC vapour compression refrigerator. The size of a photovoltaic system was depended on the power capacity of the compressor, duty hours and the solar insolation (Bhuiyan and Asgar, 2003). The size of photovoltaic system was calculated by using following equations,

$$P_{out} = \frac{W_c \times D_H}{I \times F \times \eta_{bx} \eta_{inv} \times \eta_c}$$

Where,

W_c = Compressor power (Watt)

D_H = Duty hours (h)

I = average daily solar insulation (kWh/m^2)

F = array mismatch factor

η_b = Battery efficiency

η_{inv} = Inverter efficiency

η_c = Compressor efficiency

The size of the battery bank was decided using following formula.

$$\text{Capacity of Battery Bank} = \frac{\text{total load (W)} \times \text{working hour}}{\text{battery efficiency} \times \text{voltage}}$$

VAPOUR COMPRESSOR REFRIGERATION SYSTEM

Refrigeration included the process of reducing and maintaining the temperature of a body below the general temperature of its surroundings. In a refrigerator, heat was virtually pumped from a lower temperature to a higher temperature. According to Second Law of Thermodynamics, this process could only be performed with the aid of some external work (Charters et al, 2003). Power is regularly required to drive a refrigerator which consisted of following components:

Evaporation Unit

An evaporator consisted of coils of pipe in which the liquid-vapour refrigerant flow at low pressure and temperature was evaporated and charged into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbed its latent heat of vaporization from the medium (air, water or brine) which was to be cooled. The refrigerant temperature must be below that of the surrounding medium so that heat flows to the refrigerant (Kaushik, 1989).

Condenser Unit

The heat which was absorbed by the evaporation unit and heat added during the compression process librated to the cooling medium through the cooling condenser and the vapour then returns to the liquid state. The rate of heat transfer depended upon area of the condenser, material quality, temperature difference and condition of the surface.

Compressor Unit

A compressor is the heart of the refrigeration system. Its purpose is to maintain the desired evaporator pressure corresponding to the requirement of the low temperature. Reciprocating type vertical compressor is suitable for smaller unit. Piston is the main moving part in the compressor which is driven by both the connecting shaft and crankshaft and both these shafts are driven by an electric motor. Electrical motor proves to be a good prime mover and can be operated easily.

Refrigerant

It is a substance which acts as cooling agent which absorbed heat from another body. ideal refrigerant should have normal boiling point in the range of -40°C to 0°C, non-toxic, non-flammable, and stable. The additional primary requirement included zero Ozone depletion potential (ODP) and zero global warming potential (GWP). The Hydrofluorocarbon (HFC) refrigerants used in this refrigerator fulfill all these requirements.

Capillary Tubes

A capillary tube is a long, narrow having constant diameter. The word capillary is a misnomer since surface tension is not important in refrigeration application of capillary tubes.

Insulating Material

It is used to prevent the flow of heat from outside warm space to the cold refrigerating space. The thermal conductivity of the insulating material is low. Spray polyurethane or polyurethane foam (PUF) insulation is flexible in terms of the surfaces they can be applied on.

Performance of Refrigerator

The performance of refrigerator was evaluated at full load test in terms of photovoltaic efficiency and exergy efficiency (Bolaji et al, 2011)

RESULT AND DISCUSSIONS

EXPERIMENTAL SYSTEM

A SPV refrigeration system consisted of DC vapour compression refrigerator of 25 litre capacity. Considering the power requirement of its continuous operation, two 80 W SPV panels were used to convert solar energy into electrical energy. The panels were arranged in parallel. The purpose of this arrangement was to have sufficient potential difference across the 12 V battery for properly charging of battery. The panels were kept on fixed masonry structure at 35° (tilt angle) from horizontal, facing south direction. A battery was used so that it could give high starting current required to start the motor of compressor. It consisted of one 12 V – 150 Ah sealed lead batteries connected in parallel. Panel were connected to the battery via charge controller which avoided the battery from deep discharge. Battery supplied DC current to refrigerator as it operated on DC current. In the whole system connections 10 ampere rating wire was used. A multimeter was connected in between the refrigerator and battery for measuring current and voltage (Eltawil and Samual, 2007).

Photovoltaic Operated Refrigeration Cycle

Photovoltaic (PV) panels convert solar radiation to direct current (DC) electricity using semi conducting materials. Solar photovoltaic panels produced DC electrical power that could be used to operate DC refrigerator (Best and Ortega, 1999). The major considerations in designing a PV-refrigeration cycle involved appropriately matching the electrical characteristics of the motor driving the compressor with the available current and voltage being produced by the PV array. The rate of electrical power capable of being generated by a PV system is typically provided by manufacturers of PV modules for standard rating conditions, i.e., incident solar radiation of 1,000 W/m^2 and a module temperature of 25°C. Unfortunately, PV modules operated over a wide range of conditions that are rarely as favorable as the rating condition (Fatehmulla *et al*, 2011).

SPV Panels

A solar panel is a photovoltaic module which is built up by a combination of solar cells. The material of the solar cell for the solar panel used in this research project was silicon. A solar panel converts the solar radiation into direct current electricity. They were mounted on terrace installations used a simple frame holding modules at a fixed tilt angle towards the sun. When solar energy hits the top layer of silicon produced DC current.

Battery

Lead acid batteries were selected to function as energy storage in the stand alone photovoltaic DC refrigeration system. Batteries stored direct current electrical energy in the chemical form for later use. In a PV DC refrigeration system, the battery was used to supply power continuously. Sealed lead acid batteries were most efficient and available in the small size. The sizing of battery should be sufficient to supply power during night and cloudy weather condition.

Solar Charge Controller

A solar charge controller was connected to the electrical connection of solar powered refrigerator system. It was connected between the solar array and the battery bank. A solar charge controller’s primary function is to protect the battery bank from overcharging and control discharging and permanent damage of the battery.

System Wiring

Power wiring in conduit was installed from the solar array to the controller. Control wiring in conduit was installed from the battery to the compressor and sized properly to minimize losses.

FULL LOAD TESTING OF REFRIGERATOR

The relationship between different parameters by graphical analysis and data obtained during full load applied to the refrigerator in November month were tabulated in table 1.

The performance of refrigerator during full load was observed and following section describes the performance of system during winter season (Eltawil and Samual, 2007).

Figure 1 revealed that the insolation, S_{Ins} was low in the morning hours and raised up to 11.00 h and thereafter slightly increased upto 13:00 h. However, when the panel faced southward the sun rays were perpendicular to the array, resulting in increased insolation values, which peaked at 13.00 h. The maximum insolation 596.78W/m^{2}was recorded at 12.00 h and ambient temperature was about 29^{0}C during full load test.

Figure 2 Indicates the variation of power and solar radiation with respect to time as solar radiation increased the power also varying proportionally to the solar radiation. Initially solar radiation was less the power output was also low, it was recorded maximum 60.57 W at 12:30 and it varied from 5.71 – 60.57 W and recorded minimum 5.71 W at 17:00.

Table 1: Performance of spv Panel during Full Load Test

Time (h)	Panel Temp. (^{0}C)	Amb. Temp. (^{0}C)	Panel Voltage (V)	Panel current (A)	S.R. (W/m^2)	Power (W)	Photo-voltaic Efficiency (%)	Exergy Efficiency (%)
09:00	29.00	25.77	14.65	0.88	152.00	12.89	11.63	14.22
10:00	32.33	26.57	14.47	1.88	341.86	27.20	10.91	13.22
11:00	36.33	25.80	14.03	3.19	496.45	44.79	12.37	14.68
12:00	44.40	29.47	14.46	3.75	589.88	54.16	12.59	14.66
13:00	49.00	29.40	14.91	4.06	596.78	60.57	13.91	15.09
14:00	49.20	29.40	14.84	3.90	584.62	57.91	13.58	14.83
15:00	47.83	30.40	14.25	2.22	341.86	31.64	12.69	13.61
16:00	40.07	30.53	13.68	0.90	117.80	12.31	14.33	15.77
17:00	32.87	29.67	12.68	0.45	58.49	5.71	13.37	16.03

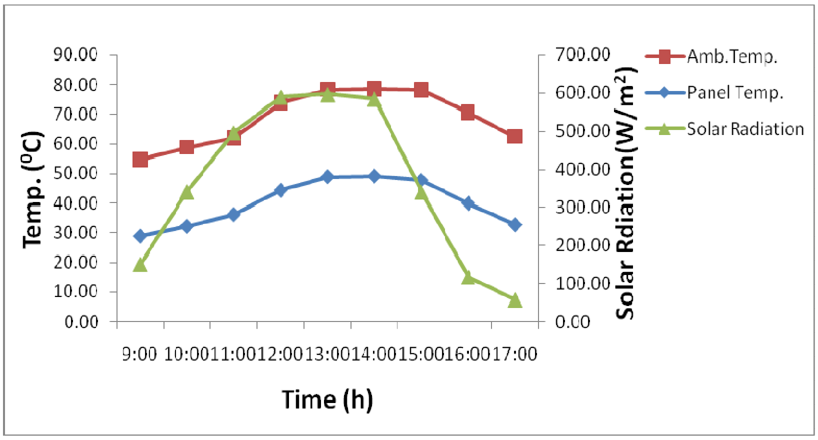

Figure 1: Variation in Temperature and Solar Radiation with Time (Nov 2015)

It revealed from figure. 3 that with the increase in solar radiation, power output also increased.

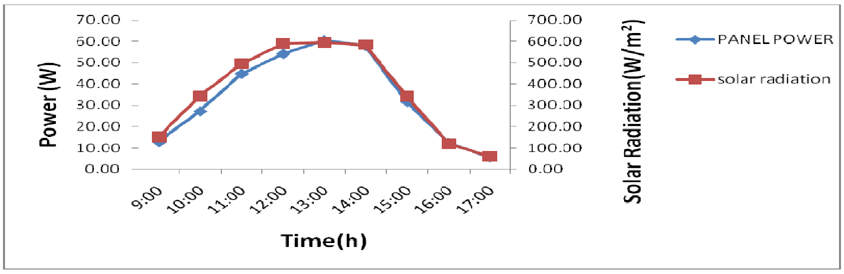

Figure 2: Variations in Power Output and Solar Radiation with Time (Nov 2015)

Figure 3 Indicates the exergy efficiency was found more 14.22% at 09:00 and then it increased with the increase in radiation upto 14.68 % at 11:00 hr. It started increasing upto maximum limit of 15.09 % at 15:00 hr and varied from 13.22 to 16.03% (Ahamed *et al*, 2011).

Photovoltaic efficiency is also varying similar to exergy efficiency. During the morning hours it was 11.63 % at 09:00 hr and then it started increasing and reached to its maximum limit 13.91% at 13:00 hr. it started to decrease upto 12.69% at 15:00 hr. In the morning and evening hours solar radiation intensity was minimum therefore the efficiency was found more during the afternoon hours it was found more therefore efficiency is less. The photovoltaic efficiency varied from 11.63 to 13.91% (Axaopoules and Theodoridis, 2009).

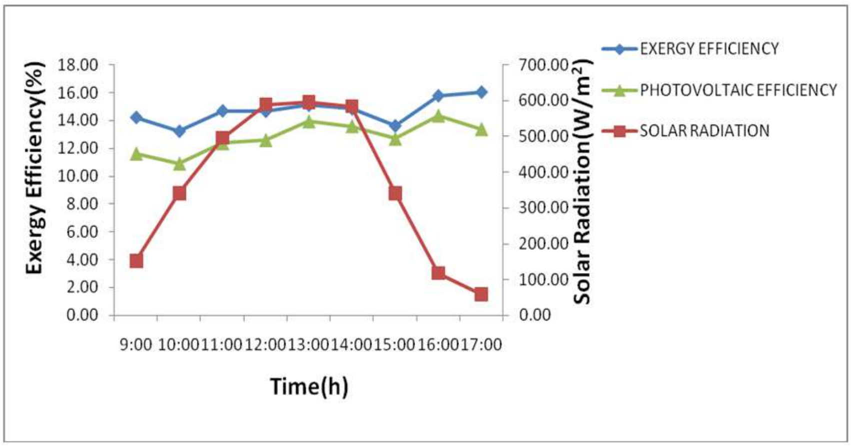

Figure 3: Variations in Exergy Efficiency, Photovoltaic Efficiency and Solar Radiation with Time (Nov 2015)

CONCLUSIONS

Solar radiation tends to be high in climates that have great need for cooling therefore a solar powered refrigerator system was developed. In most urban areas, it is difficult to use refrigerator due to long-term power cutoff; goods stored in refrigerator such as meat, dairy products, medicine and vaccines are mostly spoilt. Moreover, residential areas away from electricity grid in rural areas facing similar problems. Owing to these persistence problems and the solar insolation potentials, Photovoltaic-powered DC refrigerator system was developed. In present work, a photovoltaic system for DC refrigerator was designed and developed in meeting the needs of most rural areas which have no access to national grid or with unstable and erratic supplies of electricity. The solar photovoltaic operated DC vapour compression refrigeration system under test was able to maintain the temperature as specified by the WHO for the vaccine preservation (2-8°C). The average photovoltaic conversion efficiency and exergy efficiency of refrigerator found nearer to about 12.05% and 14.20% on full load condition in November 2015.

REFERENCES

1. Ahamed, J.U., Saidur, R. and Masjuki, H.H., (2011). ‘A review on exergy analysis of vapor compression refrigeration system’. Renewable and Sustainable Energy Reviews 15 (2011) 1593–1600.

2. Axaopoulos PJ, Theodoridis MP (2009). Design and experimental performance of a PV Ice- maker without battery. Solar Energy, 83:1360-1369.

3. B.O. Bolaji, M.A. Akintunde, and T.O. Falade (2011). Comparative Analysis of Performance of Three Ozone-Friends HFC Refrigerants in a Vapour Compression Refrigerator. Journal of Sustainable Energy & Environment 2 61-64.

4. Best, R. and Ortega, N. (1999). ‘Solar Refrigeration and Cooling’. Renewable Energy. 16. 685-690.
5. Bhuiyan, M.H.H., Asgar M.A. 2003. Sizing of a standalone photovoltaic power system at Dhaka. Renewable Energy. 28. P.929-938
6. Charters, W.W.S. and Oo, Y.L. 2003**.**Solar vaccine storage units for remote areas. International Journal of Refrigeration. Vol. 10 301-30.
7. Chattopadhyay, H., Manoj Kumar Rawat and Subhasis Neogi, 2013. A review on developments of thermoelectric refrigeration and air conditioning systems. International Journal of Emerging Technology and Advanced Engineering Vol. 3.
8. Eltawil and D.V.K. Samuel 2007. Vapour compression cooling system powered by solar PV array for potato storage. Agricultural Engineering International: The CIGR E Journal. Manuscript EE 06003. Vol. IX.
9. Eltawil M.A. and D.V.K. Samuel. 2007. Performance and economic evaluation of solar photovoltaic powered cooling system for potato storage. Agricultural Engineering International: the CIGR E Journal. Manuscript EE 07 008. Vol. IX.
10. Fatehmulla A., Al-sharmmani and Al-Bassam, 2011. Design of energy efficient low power PV refrigerator. http://ipac.kacst. edu.sa/eDoc/2011/193687_1.pdf.
11. Kaplanis S, Papanastasiou N (2006). The study and performance of a modified conventional refrigerator to serve as a PV powered one. J Renew Energy 31:771–80.
12. Kaushik, S. C (1989). ‘Solar Referigeration and Space Conditioning.’ Divyajypti Prakashan, Jodhpur.