Performance evaluation of solar photovoltaic panel driven refrigeration system

C S Rajoria*, Dharmendra Singh and Pankaj Kumar Gupta
Department of Mechanical Engineering, Govt. Engineering College Bikaner (Raj.), INDIA

*Corresponding author E-mail: shakes2001@gmail.com

Abstract. The solar photovoltaic (PV) panel driven refrigeration system employs solar PV panel and play a vital role when combined with storage batteries. The variation in performance of solar PV panel driven refrigeration system has been experimentally investigated in this paper. The change in battery voltage is analyzed with respect to panel size. Different series and parallel combinations have been applied on four solar PV panels of 35W each to get 24V. With the above combination a current in the range of 3-5 ampere has been obtained depending upon the solar intensity. A refrigerator of 110 W and 50 liters is used in the present investigation which requires 0.80 ampere AC at 230 V. The required current and voltage has been obtained from an inverter which draws about 7 ampere DC from the battery bank at 24V. The compressor of the refrigerator consumed 110W which required a PV panel size of 176 W approximately. It is important to note that the compressor consumes about 300W for first 50 milliseconds, 130 W for next five seconds and gradually comes to 110 W in 65 seconds. Thus panel size should be such that it may compensate for the initial load requirement.

1. Introduction

Solar energy carries a great potential in a wide variety of applications specifically in India, the majority of population lives in rural areas where power supply is irregular. In the current scenario more than 60% of the country’s power need is fulfilled by fossil fuel based power plants which is depleting very fast. Due to shortage of fossils fuels and environmental pollution concerns, renewable energy is emerging as a potentially viable source that will eliminate the crises of power and also the environmental pollution. There are various solar thermal applications and solar refrigeration is one of them in which the system uses solar heat to produce the refrigerating effect, in this system a collector is used. A solar collector provides heat to the heat engine or thermal compressor in a heat driven refrigeration machine.

With the recent trend of developing more sustainable processes, there has been a growing interest on thermal energy activated cooling machines. These systems represent an environmental friendly alternative to standard compression chiller as they can be driven by solar energy and biomass which are available in abundance in India. This can lead to significant reduction in GHG emissions [1, 2]. Solar PV panel driven refrigeration systems are simple, compact and have the low weight to power ratio [3]. Also it has no moving parts, less maintenance and has a long life. Since the sunshine hours are available in the daytime, therefore this system can used effectively in offices and buildings where work is carried out in day time. However, this system can be used during night hrs if battery bank storage is used. Thermal mechanical refrigeration, Absorption, Adsorption and Desiccant cooling are the example of solar thermal refrigeration system. However some draw backs are always associated with the SPV system like costly, Low efficiency, and low energy generation during s low sunshine hours/days and not worked during night [4].
To preserve the vaccine and food low temperature is required and temperature will be maintained near about 10\(^\circ\)C to avoid the generation of micro-organism [5]. Electrical energy is a main source of energy for producing low temperature. For vaccine and food preserve purpose here we have convert a 50L refrigerator to serve as the PV powered. Refrigerator is made by branded company one which finds wide spread application in the hotel rooms, dispensaries, offices, this unit require 50 Hz main supply with an voltage Range of 180-250V. The normal rated power consumption of such a unit ranges from 100-120 W.

2. Main components of the system

The following are the main component of the system.

(1) Solar PV Panels: CEL Sahibabad manufactures standard as well as customized panels. The present system employs 35 Wp solar PV panels to run the refrigerator, one panel gives up to 2.13 A (\(I_{max}\)) and 16.4 V. Different series and parallel arrangements have been made to get the required current as shown in Figure 1(a-c). The PV panels were arranged in a set of two panels in series connected in parallel with another set of two panels in series to supply the sufficient voltage to the system either directly or to battery bank. The present study incorporates four panels initially which was further extended to six and finally eight panels respectively.

![Diagram of PV panel arrangements](image)

(a) 4 solar PV panels  
(b) 6 solar PV panels  
(c) 8 solar PV panels

Figure 1: Different series and parallel arrangements of solar PV panels

(2) Charge Controller: A charge controller (CC) having six terminal forming 3 pairs each having a pair of negative-positive. One pair is connected to Solar PV panels, second to Battery and third to Load, but in the present case charge controller is not directly coupled with the load due to heavy current
required by refrigerator at the beginning. Initially the compressor required 20A D.C. and charge controller is unable to supply required current to the compressor. So compressor is attached to the battery bank. The battery bank worked as a buffer stock between panel and compressor.

3) **Storage Battery:** The PV panels are used to charge a battery bank of 2 x 12V x 135 Ah lead acid batteries connected in series to provide a nominal output of 24V. At fully charged condition, the battery bank was charged up to 27V and discharges at 23V at 50% State of charge (SOC). Battery terminal connected to the solar PV panels and Load. The Load is not directly connected with PV due to large current required by the compressor of the refrigerator.

4) **Inverter:** An inverter-transformer assembly has been used to convert 24V DC supply from the battery bank to 220-240V AC. Inverter convert the DC into AC and transformer boost up to voltage. 1 KVA Inverter has been used to compensate for higher initial current requirement by the compressor.

5) **Refrigerator:** In the present investigation a 50L refrigerator has been used which works on normal voltage range and frequency. R-134a is used as the refrigerant. Pressure gauges have been used to measure pressures on the high and low pressure sides. Figure 2 shows the block diagram of the solar PV panel driven refrigerator.

![Figure 2: Block Diagram of Solar PV panel driven refrigerator](image)

3. Results and Discussion

Figure 3 shows the variation of voltage at charge controller (CC)-Battery terminal w.r.to time. It can be noticed that when we connect the system with four panels there is a slight drop in the voltage with the passage of time this shows that the power consumed by the refrigerator is more than the energy supplied by the panel so it may be concluded that four panel set (35W each) is insufficient to the run the refrigerator along with charging the battery for night operation. Further, when six and eight panels are used battery voltage has increased considerably. It can be inferred that minimum six panels are required for charging of battery which can run the compressor of the refrigerator. However in the case of six panels voltage rise is very low so eight panels are recommended for the smooth running of refrigerator in the day/night operation.
The variation of the direct current coming from the panel to the battery bank via charge controller has been shown in Figure 4. It has been observed that intensity of current directly depends on the panel size and a significant increase has been observed when the panel size is increased from 4 to 8 panels respectively. Also the solar intensity plays a vital role in deciding the intensity of current. The variation of solar radiation with respect to time is depicted in Figure 5.

Figure 4 shows the variation of current drawn by the compressor at different PV panel configurations, it is interesting to note that at four panel current drawn by the compressor is more than the current drawn by the compressor at six and eight panel set respectively this is due to the low battery voltage at four panel in comparison to the six and eight panel as shown in Figure 3.
Figure 6: Variation of Current Drawn by the Compressor w.r.t. time

Figure 7 shows the variation of compressor body temperature at four, six and eight panel configurations. It has been observed that with four panels the temperature of the compressor body is more in comparison to the six and eight panel due to low battery voltage operation at four panels.

The variation of DC ampere draw from the battery bank by the compressor via inverter during the one on-off cycle of the compressor has been depicted in Figure 8. The graph shows that in one cycle, the compressor remains at on position for about 80 s and 120 s in off position (No load and Thermostat at minimum position) it has been also observed from the graph that at the time of starting of the compressor draws about 19A Direct Current for 50 ms and rapidly comes down to 8A and further drops in the subsequent seconds. However when the compressor is off it has been observed that the inverter continuously draws a current of 3A approximately. So it can be concluded that the inverter used quite inefficient and further investigation is needed to see the effect various inverters on the performance of the system.

Fig 9 shows the wattage consumed by the compressor, at the time of the starting a very high power consumption of 258W is there and comes down to the 113W after 70-80s running.
In the simple calculation we take the compressor consumption of 110W on average and for that 110 x 24 =2640 Wh energy required if the compressor is running for 24 hours but actually the compressor is running 80/200 part of the time i.e. Compressor required (80/200) x 2640 =1056 Wh for one day/night operation (as per parameter recorded at no load and minimum thermostat position) for that if 6hrs sunny days is there it require 1056/6= 176 W panel size.

4. Conclusions
From the above investigation it has been observed that a panel size of 176W is sufficient to run the refrigerator for one day/night operation. But as we see in the case of four panels (35W each) which theoretically surpasses the required power is even not sufficient to maintain the battery voltage constant in the day time which is due to the losses associated with the various components. So we can conclude that panel size should be increased in such a way that it compensate for the following power consumption/losses.

1. High Power Consumption by the compressor at the time of starting.
2. Inverter losses.
3. Power consumption is more at the enhanced ambient temperature.
4. Power consumption by the lights in the cabinet of the refrigerator.
5. Thermal load on the refrigerator.

References
[1] T. Jaruwongwittaya, G. Chen, A review: Renewable energy with absorption chillers in Thailand, Renewable and Sustainable Energy Reviews. 14(5) (2010) 1437-44.
[2] H. Doukas, K.D. Patlitzianas, A.G. Kagiannas, J. Psarras, Renewable energy sources and rational use of energy development, Renewable Energy. 31(6) (2006) 755-70.
[3] Anish Modi, Anirban Chaudhuri, Bhavesh Vijay and Jyotirmay Mathur, Performance analysis of a solar photovoltaic operated domestic refrigerator, Applied Energy. 86(12) (2009) 2583-2591.
[4] A. Thomachan, Srinivasan K Kattakayam, Lead acid batteries in solar refrigeration systems, Renewable Energy. 29 (2004)1243–1250.
[5] D.S. Kim, C.A. Ferreira, Solar refrigeration options—a state of art review, Int. J. of Refrigeration. 31 (2008) 3-15.