Performance Analysis of Vapour Compression and Vapour Absorption Refrigeration Units Working on Photovoltaic Power Supply

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Abstract: This study involves a performance analysis between solar photovoltaic (SPV) operated vapour compression and vapour absorption refrigeration systems. For the purpose of comparison, two refrigerators working on different refrigeration cycles (compression and absorption) have been selected. The temperature and energy consumption of both units were recorded by using various parameters. The results show that though the vapour absorption refrigerator takes more time to decrease the temperature of the cabinet in comparison to the vapour compression refrigerator yet it consumes less power. The vapour absorption system is especially useful in rural areas having no or less frequent power supply where we want to preserve drugs and food items because it can maintain a constant low temperature between 6-10°C if delivered on the same temperature . The initial capital cost of the absorption refrigeration system is also less than compression system.

Keywords: Photovoltaic Panel 1; Absorption refrigerator 2; Compression refrigerator 3; Battery 4; Inverter 5.

1. Introduction

Large number of population in developing countries like India live in the rural or remote locations where grid electricity is unavailable. So the storage of drugs and food is not possible because of low temperature requirements. [1]. In India, there are innumerable places where the functioning of well known technology vapour compression refrigeration does not work effieciently due to shortage of electric energy. In this scenario, it is reasonable to evaluate the prospects of a clean source of energy that will not only operate the refrigeration system but also minimize environmental hazard associated with the refrigeration system operation [2].

Kim and Ferreira [3] provided a broad overview of various technologies available for the use of solar energy for refrigeration purposes which includes the solar electric, thermo-mechanical, absorption and also some newly emerging technologies. Eltawil *et al.* [4] classified various available solar technologies into two groups: solar thermal and solar electric. Out of all, solar photovoltaic (SPV) is found to have a widespread application due to simplicity, compactness and also because of its high power to weight ratio. The SPV system also has no movable parts and an easy installation. Enibe [1] discussed the possibility of using SPV powered vapour compression system, continuous and intermittent liquid or solid absorption system and adsorption system, in the rural and remote areas.

Kattakayam *et al.* [5,6,7] described an autonomous power source for a domestic refrigeration unit which was powered by a field of photovoltaic panel back-up by a generator set.

It was observed that there is no degradation in the performance when a non-sinusoidal waveform AC source was used to run the refrigerator, although it may involve only a slight additional heating of the hermetic compressor.They also performed the thermal mapping and the cool-down, warm-up and steady state performance of a 100 W AC operated domestic refrigerator powered by a field of photovoltaic panels, a battery bank and an inverter.

the same principle storage for the purpose of storing the potatoes. In this study a cooled storage structure (1.0 m3) was used for curing purposes. The cost of storage of energy in the form of thermal energy is more than the conventional storage i.e battery. However, it is expected that the cost will reduce as the production increase in the future.

Kaplanis et al. [9] describes the design and development phases to convert a conventional refrigerator to a solar powered one. In this study, some modifications were introduced to reduce both the heat loss and the cooling load but it resulted in the decline of the useful volume capacity by 30%. Tests were also carried out to study the performance of the refrigerator components and especially the compressor's components along with the refrigerator as a whole.

A fabrication, experimentation and simulation stage of a 165 liter domestic electric refrigerator to a solar powered was presented [10]. Various performance tests were carried out to study the performance of the fabricated system. A 140Wp photovoltaic capacity and two 12V-135 Ah battery banks were used. It is the least possible configuration required for this converted system to work properly under normal condition. The coefficient of performance (COP) was observed maximum in the morning and it decreased with time. Economic simulation using RET Screen 4 was carried out for Jaipur city vapour absorption system has ammonia water refrigerant pair. Experimental setup has been developed and various observations and test were conducted. The observed parameters are- voltage, current of PV panels, battery voltage, temperatures of the refrigerator cabinet at different spaces. The following sections describe the system description and results.

2. System Description

For comparative study purpose two refrigerators that work on vapour compression and vapour absorption principle of refrigeration with almost similar volume capacity as easily available in the market were used. Vapour Compression systems have mainly four elements in the refrigeration system i.e. compressor, condenser, expansion valve or capillary tube, and evaporator. In the evaporator the refrigerant is vaporized and heat is absorbed from the material contents or the space being cooled. Vapour Compression Refrigerator (VCR) has a mechanical compressor driven by electric motor of 110 W.

In vapour absorption solar cooling system, mixture of refrigerant and absorbent is used to replace mechanical compression by thermo compression through generator-

Cherif et al. [8] analysed the dynamic behavior, performances and simulated responses of a photovoltaic (PV) refrigeration plant using latent storage. They also provided a new storage strategy which substitutes the battery storage with thermal, eutectic, latent or a hydraulic storage. Eltawil et al. [4] also used

(India). The system was not economically viable without initial financial incentives and larger panel size was also recommended for sustainable system and more battery for backup.

DC compressors were used in the solar photovoltaic refrigerator to reduce the losses of conversion of DC to AC, refrigerators designed especially for vaccine purposes, but they required a very high level of insulation [11,13]. Due to high cost of this type of compressor the availability and use of this refrigeration systems is very less in India. Michael K. Ewert et al. [12] presented the field test result of battery free solar refrigerator having 110 mm insulation to reduce the heat transfer. Field test performance and user acceptance have both been very good so far. In this refrigerator, phase change materials has good freezing properties uesd as thermal storage.

The solar cooling technology has the technical and financial barrier but it is expected to become competitive with the conventional system in the future when the production of solar panel will increase and prices of fossil fuels will shoot up.

In this paper, performance comparison of vapour compression refrigeration system (VCRS) and vapour absorption refrigeration system (VARS) operated by a solar PV array carried out with the help of transys simulation tool. Vapour compression system uses R-134a refrigerant and absorber assembly. Here, a small Vapour Absorption Refrigerator (VAR), has a generator in which an electric resistance of 65W is attached. In this system NH_3-H_20 work as the absorbent and refrigerant pair, the temperature of the generator is controlled by the thermostat. Other specifications of refrigerators are shown in table 1.

Table 1. Specification of vapour absorption and vapour compression refrigerator

S. No	**Parameter**	**Vapour Absorption Refrigerator**	**Vapour Compression Refrigerator**
1	Make	JVD	Videocon X-Lent
2	Capacity	41 Liters	50 Liters
3	Energy input	Electrical	Electrical
4	Power Usage	Electric Resistance 65W	Compressor–110 W

5	Refrigerant	NH_3-H_20	R-134a
6	Current requirement	0.34 Amp	0.7 Amp

Fig.1. Vapour Absorption Refrigerator

Fig.2. Vapour Compression Refrigerator

Figure 1 and 2 show the internal image of vapour absorption refrigerator (VAR) and vapour compression refrigerator (VCR) respectively. The VCR has a small ice cabin whereas the VAR system has only an evaporator plate and behind it, the cooling coil is attached. Only the evaporator cabin provides cooling throughout the cabin by thermo-syphon effect.

The details of other components in the experimental setup are as follows:

Photovoltaic Panels: Model 35 FR 36, 35 Wp are used to run the refrigerators, one panel gives up 2.13 A I_{max} and 16.4 V at peak power output 2.40 A short circuit current and 21.0 open circuit voltage. The dimension of one module is 1009 x 403 x 40 mm. The 8 SPV panel is arranged in combination of two series and four parallel panels to charge the battery bank (Figure 3-4).

Fig.3: Solar panels

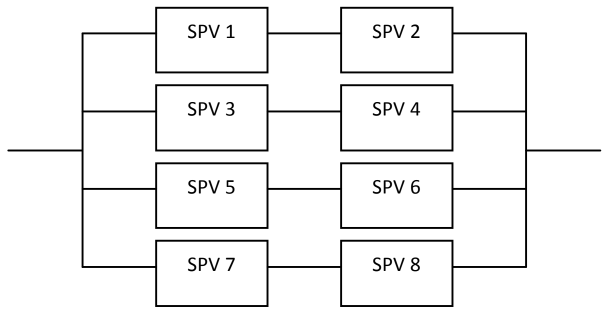

Fig.4. Arrangement of 8 Panels

Inverter: The figure 5 shows an inverter of capacity 1.5 kVA which converts the 24V DC supply by the battery bank to 220-240V A/C by the help of an inbuilt transformer.

Storage Battery: The PV panels charge a field of 2 x 12V x 135 Ah lead acid local made batteries connected in series to give a nominal output of 24V (Figure 6). The battery is charged up to 27V at fully charged condition and discharge at 23V at 50% State of charge (S.O.C). Battery terminal connected to the PV and Load.

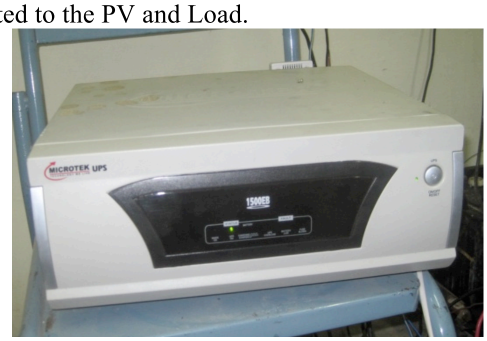

Fig. 5: Inverter (1.5 kVA)

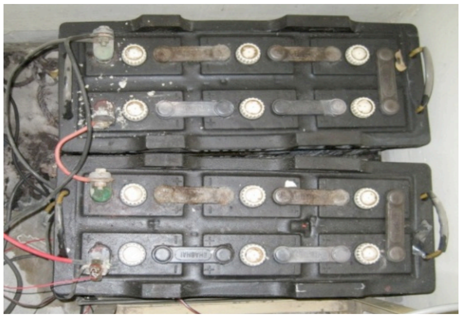

Fig. 6. Battery 12Vx135 Ah, 2Nos.

Charge Controller: Figure 7 shows a real image of a charge controller (CC) having four terminals, two pairs of negative and positive. One pair is connected with SPV and the other to battery bank. The refrigerators draw the power from the battery bank via. inverter. The battery bank works as a buffer stock between SPV panel and load.

CR-1000 data logger is used to record the various data over time in regular intervals that can be programmed by the user (Fig.8). The Data logger receives the data to be logged by connecting several sensors which include thermocouple, differential voltage sensor, current sensor. It uses a 12 V battery as a power source.

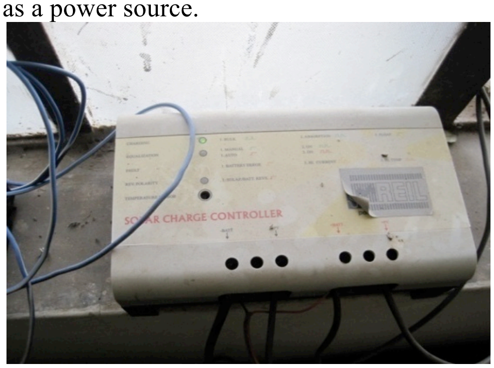

Fig.7. Solar charge controller

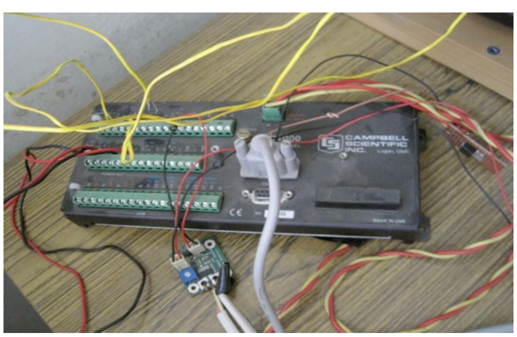

Fig. 8. Data logger

3. Performance Test

Experiments were carried out to analyze the performance of both the refrigerator by measuring the various parameters.

3.1 Experiments Performed:

1. Behaviour of both the refrigerators was checked with photovoltaic power supply and conventional grid power supply.

2. Normal running test of the refrigerators was conducted under the hot atmospheric condition in the day time. This experiment was performed from the solar panels connected to the system and current were drawn from the panels consumed by the load (battery/compressor/electric resistance).

3. Pull down and steady state tests for ideal ambient condition were performed. This test was conducted to check the battery bank capacity.

4. The warm-up test was performed on both refrigerators. The refrigerators were switched off and allowed to reach near ambient condition conditions while the observations were taken.

3.2 Experimental conditions:

To draw a comparison between both the refrigerators, some basic conditions should nearly be the same such as the atmospheric temperature, solar radiation, starting battery voltage and thermostat cutoff point etc. To check the thermostat setting in the VAR, the thermostat is kept at the highest cooling point. The system is started on for a long time and temperature of bottom is recorded continuously and it is found that it goes down to 8 °C and remains constant. So the same lowest temperature recorded in the vapour absorption system is set in the digital thermostat of vapour compression system for similar purposes. The digital thermostat starts and stops the compressor according to the bottom temperature of the VCR at 8°C. The other conditions of experimentation are as follows:

1. The refrigerator and other equipments are kept in a room.
2. The solar panels are kept on roof of the room where there is no shade throughout the day at an angle of 30° to the horizontal facing south direction. The distance between panel and battery is minimized.
3. The thermostat position is set in such a way that when the temperature of bottom cabinet goes down below 8° C the compressor is automatically off.
4. No external load is kept inside the refrigerator during the experimentation. During the load condition only a water bottle is kept inside the cabinet.
5. The door of the refrigerator is kept closed while the tests are being performed.
6. No external heating or cooling was provided to the system during experimentation.

7. The panels are always kept dust free to take advantage of maximum possible solar insolation to generate electricity.

4. Observations and Analysis

For analyzing the performance of both the refrigerators, the temperature of the compartment was recorded along with the battery voltage and panel voltage, at different conditions with the help of a data logger. The final energy consumption in both the systems was calculated. The observations have been taken for both grid energy and SPV energy based vapour compression refrigerator and vapour absorption refrigerator respectively. In the vapour compression refrigerator, the temperature of the evaporator cabin tube had a very high fluctuation rate because thermostat cutoff is governed by the bottom cabinet temperature and due to thermal inertia the bottom temperature was up and down slowly and meanwhile the temperature of the evaporator tube became very high and very low. In the vapour absorption system the thermostat kept in the highest position at which maximum cooling was achieved, so no fluctuation was seen here in comparison to the vapour compression refrigeration system.

Figure 9 shows the variation of bottom cabinet temperature of the refrigerator which works on the vapour compression principle of refrigeration. It is clear from the graph that there is no effect on temperature either power is supplied by the grid or photovoltaic array; similarly figure 10 shows the same trend for refrigerator which works on vapour absorption principle. In the vapour absorption refrigerator it is noted that in the beginning for half an hour temperature increases after that temperature continuously decreases.

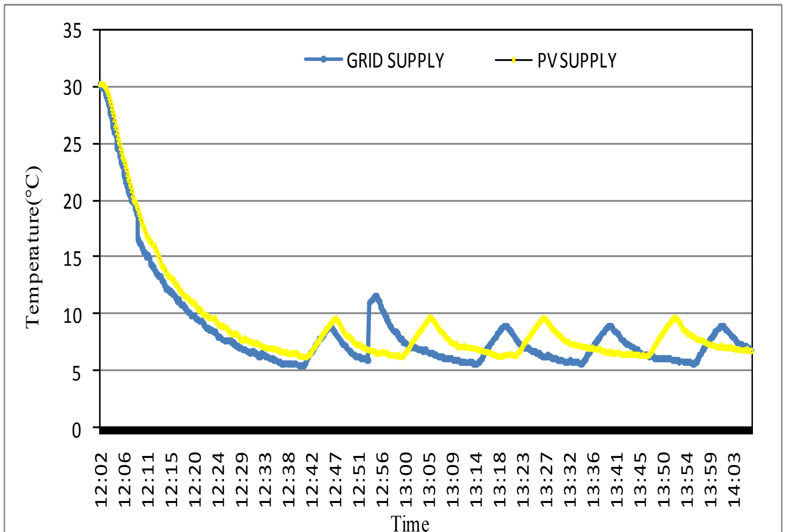

Fig :9 Variation of bottom cabinet temperature w.r.to time in VCRS

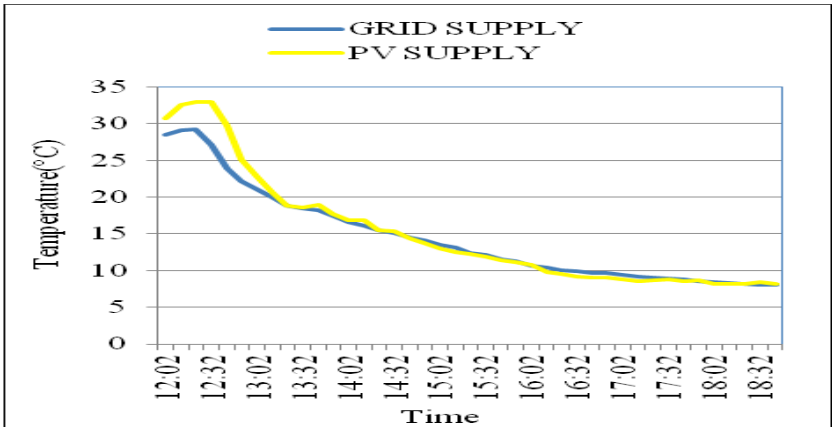

Fig. 10 : Variation of bottom cabinet temperature w.r. to time in VARS

4.1 Normal running test with power from both SPV and battery bank:

Figure 11 shows the variation of bottom cabinet temperature with respect to time having no internal load, the temperature of air was recorded at the bottom. The Plot shows that the rate of decreasing temperature in VCR is very fast in comparison to the VAR. In the VCR the fluctuation in temperature is seen due to thermostats cut off.

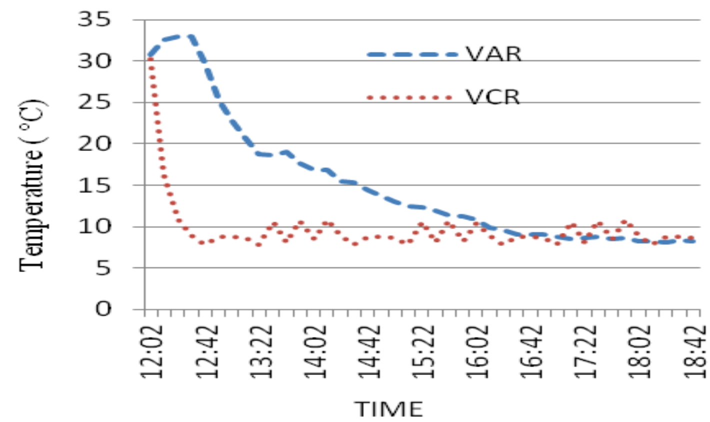

Fig.11 Variation of bottom cabinet temperature in VAR and VCR with time

Figure 12 shows the variation of battery voltage with respect to time at no load. The battery is attached by the solar panels. During the day time battery is continuously charged but simultaneously the refrigerator is also working so battery is also continuously discharged. From the graph it is clear that battery discharging is more rapid in the vapour compression system than the vapour absorption system. Initially in VCR there is rapid up and down in the battery voltage due to compressor off and on. In the daytime when the ambient temperature is increased ,the heat loss also increases resulting in less frequent cutoff of the compressor. Hence the plot is shown as straight. In the VAR the battery voltage drop is low due to lower power consumption.

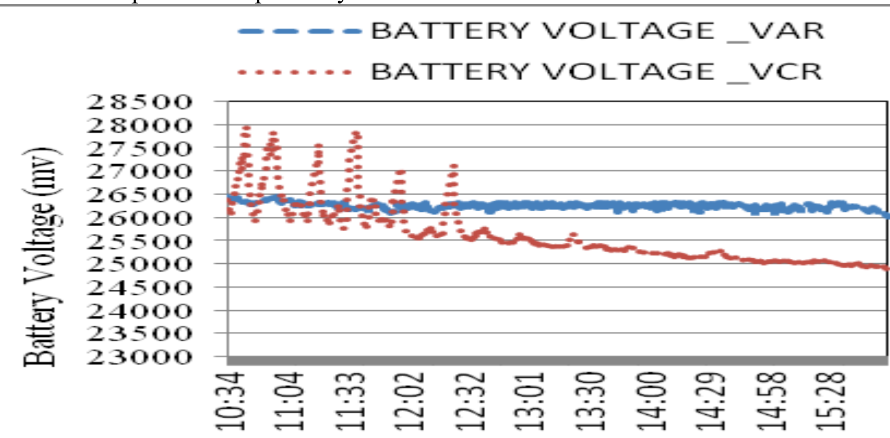

Fig. 12 : Variation of battery voltage with time (simultaneous charging)

4.2 Pull down test and normal running test with power from battery bank only:-

Pull down test was carried out on the better ambient condition in the night time when the power is consumed by the load (compressor/heater) is supplied by the battery bank only. Two bottles of water having one litre volume each is placed in the cabinet in the refrigerator for cooling purposes in both the refrigerators. Figure 13 shows that the water temperature drops in the four hours reading and it is clear that in the VCRS the temperature drop is more than the VARS. Similarly battery voltage drop in the VCRS is much more than the VARS as shown in the figure 14. The Vapour absorption refrigerator system has a low cooling rate (Figure 15).

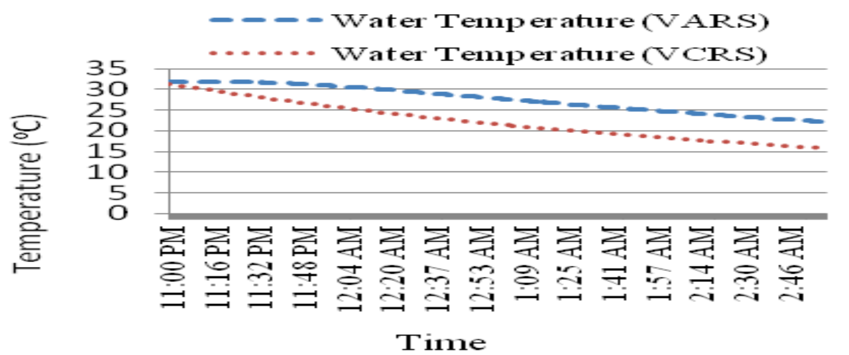

Fig. 13 : Variation of water temperature at two litre water bottle

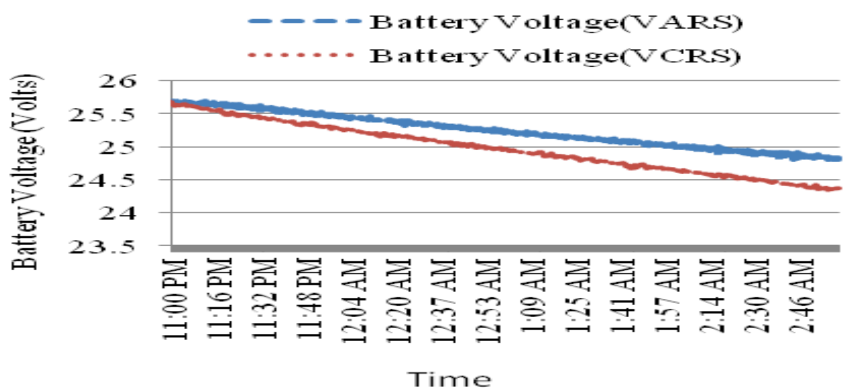

Fig. 14 : Variation of battery voltage with time at two litre water bottle

4.3 Warm- up test

In the figure 15 the temperature of the cabinet at bottom position for both the refrigerator is observed to stabilize a common value near the ambient temperature. Warm up test shows that in the VCRS the temperature inside the cabinet reach equivalent to the atmospheric condition in two hours whereas in the VARS it requires 3 hours. So VARS has better insulation in comparison to the VCRS. Figure 16 shows the stabilization time for both the refrigerators and it is clear that the vapour compression system requires very less time to stabilize temperature in comparison to the vapor absorption system. It is also seen that as the load increases, the stabilization time also increases in both the cases due to more heat which is removed from the load (for loading purpose a water bottle at normal temperature is placed inside the cabin)

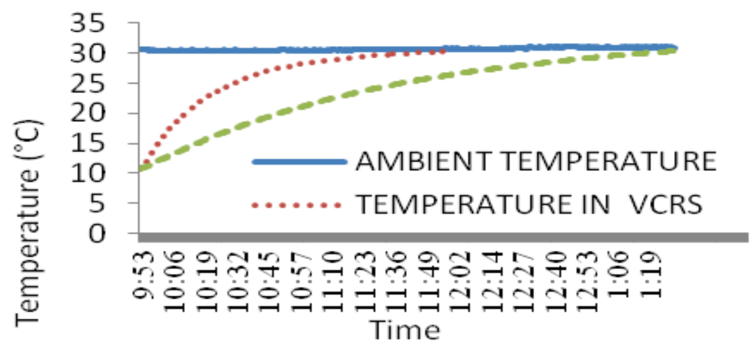

Fig.15 Warm up characteristics of VCRS and VARS at no load

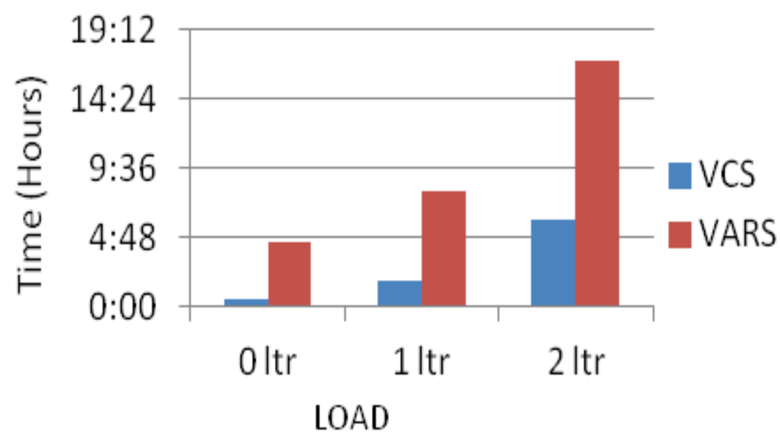

Fig. 16 Stabilization time on different load

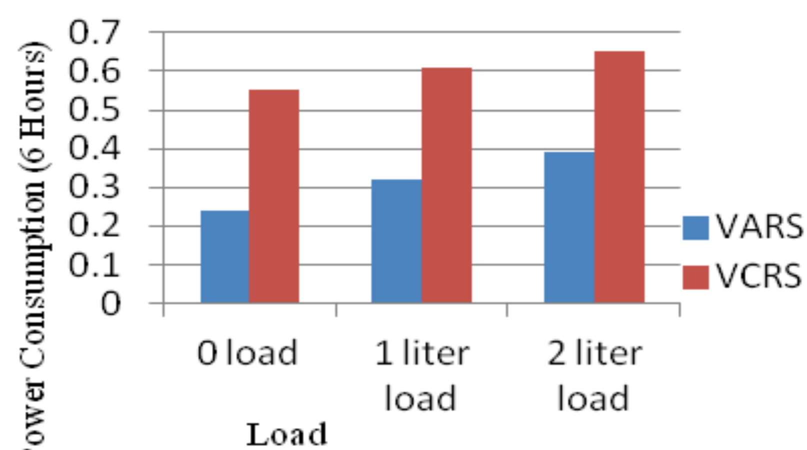

Fig.17: Power consumption at differnt loads for 6 hours

Figure 17 shows the power consumption recorded for 6 hrs working of the refrigerators in either case. From the graph it is clear that the vapour compression system requires very high power consumption in comparison to the vapor absorption system. It is also seen that as the load increases the power consumption also increases in both the cases due to more heat which is removed from the load.

5. Economics

Due to high power consumption in the vapour compression system its cost is much more than the vapour absorption system. Table 2 shows the economical comparison of the two refrigeration system based on photovoltaic power supply.

Table 2. Economical Comparison of VCS and VAS

	Vapour compression System		Vapour Absorption System	
	Size /capacity	Cost* (Rs.)	Size /capacity	Cost* (Rs.)
Refrigerator	50 litre	6500/-	41 litre	8000/-
Total power consumption in a day actual recorded	2500 Whrs		1500 Whrs	
Solar panel Size assuming 6 hrs sunny days	425 W	42500/-	250 W	25000/-
Battery size One day backup	12 V 210 Ah 2 Nos.	30000/-	12V 125 AH 2 Nos.	24000/-
Inverter	1 kVA	7000/-	0.6 kVA	5000/-
Total cost		86000/-		62000/-
Subsidy 30% provided by Govt.		25800/-		18600/-
Net Initial Investment		60200/-		43400/-

* approximate Costs in Indian markets

6. Result & Discussion

1. The temperature profile inside the refrigerator is same irrespective of mode of supply either from grid or solar. However in both the supplies minimum 190V AC is required to run the compressor. In case of PV if battery is not charged to deliver starting current then inverter does not allow the compressor to start where as in the case of grid supply this problem does not arise.

2. The vapour absorption refrigerator may start at comparatively lower battery voltage due to requirement of constant current. In the beginning VARS require approximately 04 A direct current from 24 V batteries, whereas in the case of VCRS it is as high as up to 18 A for instant and after that it decreases to 8 A in normal running.

3. In the VARS the battery discharged at a very slow rate on the other hand in the VCS battery discharged at a high rate due to more running current as well as high starting currents.

4. The VCS has nearly 1:2 on off cycle so number of starting required is more hence more times the high value of current from battery is required consequently battery discharged quickly.

5. Due to high starting current in the VCS it required battery more than 50% charged and larger inverter capacity to handle the large amount of current. Where as in the case of VARS small capacity inverter may be used.

6. VARS required much more time to stabilize at load condition in comparison to VCS. So VARS is not recommended for the high cooling however it can maintain the desired temperature within 10 C.

7. Conclusions

It is technically feasible to operate both refrigerators VCRS and VARS as photovoltaic refrigerators. Under normal operating conditions both refrigerators working on photovoltaic power supply, behave similar to working on grid electricity. Performance test shows that vapour compression refrigerator system has a very high cooling rate and more power consumption in comparison to vapour absorption refrigeration system. The VAR system has low capital cost than VCR system.

The VARS can be used for preserving the drugs and medicine in the remote areas where no more cooling is required only temperature is to be maintained and that too at much lower cost than the VCS. In this case if it is possible to transport the drugs and medicine by refrigerated vehicle maintained at the desired temperature at the desired place than VARS has the viable solution to preserve these at low cost than the VCS

It may be recommended that if a high cooling rate is required frequently one should select vapour compression refrigeration system and if only the temperature is to be maintained in the cabinet then the vapour absorption system is capable with less capital investment than compression system. The Vapour absorption system also performs noise free operation with less maintenance cost.

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