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PULL DOWN CHARACTERISTICS OF A BOTTLE COOLER WITH DC COMPRESSOR OPERATED UNDER SUNLIGHT AND ARTIFICIAL SOLAR SIMULATOR

Shaji Sidney, Kalidas Alias Vignesh. P and Mohan Lal D*
*Author for correspondence
Department of Mechanical Engineering,
Anna University,
Chennai, 600025,
India,
E-mail: mohanlal@annauniv.edu

ABSTRACT

This work envisages on the development of an indoor solar simulator setup for operating PV panels and PV powered refrigeration appliances with a DC compressor. The use of DC powered devices helps in the elimination of inverters which aid reduction of cost and power loses. The solar simulator focuses on providing a test facility for a bottle cooler with a DC compressor solely powered from a PV panel of 125W capacity. Halogen lamps are used in the simulator as they are inexpensive, readily available and their light intensity can be fully controlled by regulators. The lights in the solar simulator are arranged in a zig-zag pattern to obtain uniform illumination throughout the panel with minimum overlapping of light radiation. In order to perform various test conditions with respect to the light intensity, the distance between the simulator and the panel can be varied. The solar simulator is kept ON for a minimum of 30 minutes prior to the testing to obtain a steady state and uniform levels of irradiation. The compressor used in the bottle cooler is a DC powered Danfoss BD35K compressor which has an inbuilt control unit for smooth operation of the compressor during fluctuating solar irradiation and it works for a wide range of voltage of 10 to 45 V. The refrigerant used in the bottle cooler is iso-butane due to its low GWP and ODP values.

An experimental comparison in the pull down characteristics of the DC powered bottle cooler and I-V characteristics of the PV panel used was performed using sun light and artificial solar simulator. In both cases, the bottle cooler unit is kept in the same environmental condition except for the PV panel that is kept in both conditions separately. The I-V characteristic experimentation was performed by applying load through a rheostat. Based on the I-V characteristics, the panel efficiency was found to be 9.27% under sunlight and 6.93% under the solar simulator setup. It is to be noted that the panel temperature was higher at outdoor conditions compared to that at indoor testing as fan cooling was provided during the test under the simulator. The average light intensity on the panel was lower at outdoor compared to indoor testing conditions. The pull down temperature was obtained by placing RTDs at various locations in the cabin and the average value was taken. The pull down time for the bottle cooler under the sunlight was 32.78 minutes while it was 29.5 minutes when tested under the solar simulator. Although the panel efficiency and the pull down time with the solar simulator is lower than the values observed from the open sun light, due to its consistency the simulator can be used as a test facility for PV powered DC appliances.

INTRODUCTION

Carbon emission and energy crisis have caused the global community to focus on renewable energy sources. Solar PV is a promising sustainable technology that can even provide up to 100% of the world's energy eliminating all fossil fuels. In this context it is prudent to device appliances and gadgets which can work efficiently with solar PV.

The thermal performance characterization of a 100 W AC powered domestic refrigerator using a field of photovoltaic panels, a battery bank and an inverter was performed [1]. A refrigerator of 165 litre capacity was redesigned to be solar driven by adding battery bank, inverter and transformer, and four 35W solar photovoltaic panels. The maximum COP obtained was 2.102 and the COP was noted to go down while approaching noon [2]. While no performance degradation was reported in the earlier work [1]. A domestic refrigerator (165 litre) was converted to be a solar powered one using a 440 Wp solar panel and a BD35F DC compressor. At low compressor speeds the COP of the compressor was better [3]. McCarney et al. [4] reviewed the refrigeration systems for vaccine storage as per the requirements by WHO and the problems faced by WHO in vaccine storage related to poor system sizing, poor installation, battery failures and maintenance problems. An indoor simulation setup with 16 tungsten halogen lamps was made to power three 75 Wp solar panels, the system was used in a PV/T collector, i.e. hybrid solar PV and thermal solar collector and can be used to analyse both thermal and electrical performance [5]. A solar simulator with 30 halogen floodlights each of 400 W coupled to a solar tube and concentrator collectors was made to cover an area of 2.32m^2. Tungsten halogen lamps are widely used in the solar beam experiment for solar simulator applications because it provides a very stable and smooth spectral output [6].

From the literature survey, it is evident that halogen lights can be used in indoor solar simulators as they are cost effective and are workable while testing solar based DC devices. Hence an attempt has been made to study the performance of a 70 litre bottle cooler operated with a DC compressor powered through a solar panel. The solar panel was exposed to natural sunlight as well as to a solar simulator system and the results are compared.

NOMENCLATURE

I_{sc}	[A]	Short circuit current
Voc	[V]	Open circuit voltage
I_m	[A]	Mean current
V_m	[V]	Mean voltage
PV		Photo-Voltaic
FF		Fill Factor
η		Efficiency
P_{in}	W/m^2	Intensity of light incident on the panel
COP		Coefficient of Performance
W		Watts
Wp		Watts-Peak
IV		Current-Voltage
GWP		Global Warming Potential
ODP		Ozone Depletion Potential
AEO		Adaptive Energy Optimisation

EXPERIMENTAL SETUP

The experimental setup consists of a PV module (poly crystalline silicon solar cells) of glass to tedlar type; rated at 125Wp with manufacturer's ratings of I_{sc}=8.061A and V_{oc}=21.280V. The PV panel dimensions are 0.675m wide and 1.49m long consisting of 36 solar cells connected in series and with a module area of 0.9983m^2. The output of the solar panel was connected to the DC compressor of the bottle cooler.

For a stable and standard operating condition with the avoidance in weather dependency and for repeatability while conducting experiments using solar panels, a solar simulator setup was constructed. The simulator consists of an array of halogen lamps fitted to a stand whose height can be adjusted in order to simulate different ambient solar light intensities. Halogen light sources are inexpensive, readily available and their intensity output can be fully controlled with a variable power supply. Halogen lamps also provide a smooth spectral output when compared to other light sources [5, 6]. Each halogen lamp is rated with a capacity of 150 W with a reflector-casing unit and totally 45 lamps are used. Initial experimentation was performed by arranging the lights in three rows but the spatial non-uniformity was huge. So, to overcome this, the lamps were arranged in a zig-zag pattern in five rows to ensure uniform illumination. The lamps were fitted to a light stand board of 2.44m length and 0.92m width to illuminate a the panel. The distance between each light was 0.20m along the length and 0.19m along the width. For precise adjustment of the intensity of the halogen lamps and to provide uniform light, intensity light dimmers were used. A portable Tenmars solar power meter was used to measure the light intensity in W/m^2.

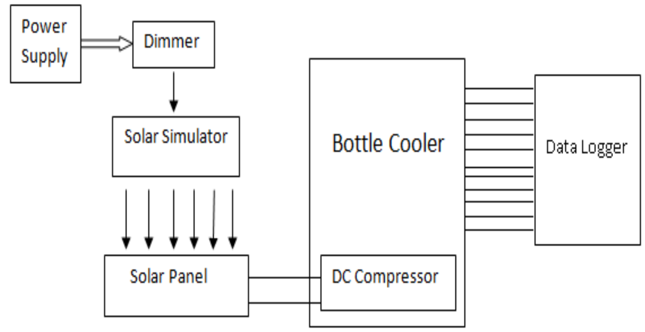

Figure 1 Indoor solar simulator schematic representation

The compressor used in the bottle cooler is a DC powered Danfoss BD35K compressor which has an integrated electronic control unit called the Adaptive Energy Optimization (AEO). This unit helps in the automatic variation in the speed of the compressor with respect to the load and also helps in smooth start-up of the compressor. The compressor operates in a wide range of voltage 10 – 45 V making it very suitable for solar applications [7]. The refrigerant used in the bottle cooler is iso-butane (R600a) which has an Ozone Depletion Potential (ODP) of zero and a low Global Warming Potential (GWP) of three. The charge of the refrigerant used in the bottle cooler is 42 grams. In the bottle cooler RTDs were fixed at the compressor suction and outlet, condenser outlet, capillary outlet, evaporator inlet and outlet. The cabin air temperature was measured at three locations. An Agilent make data logger (Model No: 34970A) was used to log the temperatures, the current and voltage to the compressor. The photograph of the indoor test setup is shown in figure 2.

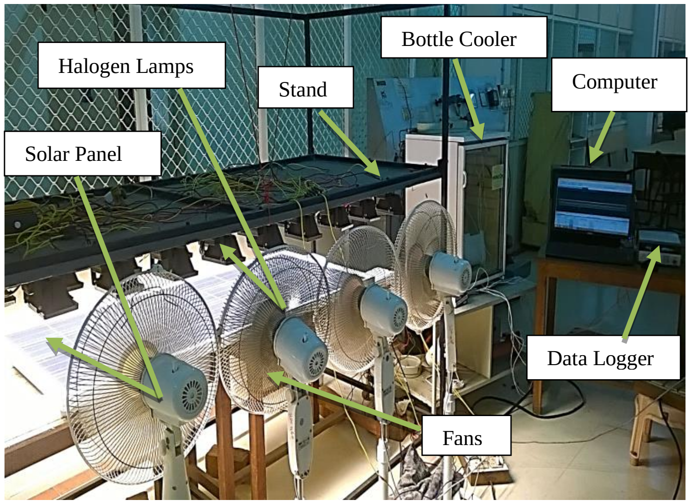

Figure 2 Indoor test setup unit

EXPERIMENTATION PROCEDURE

The first challenge was to obtain uniform illumination throughout the PV module. The distance between the PV panel and the light source was varied to different heights and it was at 30cm distance that the light intensity was found to match with the manufacturer's standard test conditions of 1000W/m^2. Light dimmers (electrical power regulators) were used to vary the intensity of the halogen lamps, as it is necessary to avoid higher intensity concentration on the middle portion of the PV panel; this was done for precise adjustments. All the 45 lights were let to glow for 30 minutes prior to the testing, so that all the tungsten halogen lamps were uniformly heated to provide a constant intensity, i.e. the steady state condition [6]. Four high speed fans were used to blow air across the PV panel to control the surface temperature of the PV panel to avoid overheating and to improve the PV panel efficiency. First the PV panel efficiency was checked by plotting the IV characteristics followed by the pull down performance test using the solar simulator followed by a similar test with the panel kept under the open sun. In both cases the bottle cooler unit was tested without any load and was kept inside the lab.

I-V CHARACTERISTICS

The I-V characteristic curve was plotted using the indoor solar simulator and followed by the open sunlight. In the indoor solar simulation, the panel was kept horizontally without any inclination so that the light falls perpendicular to the panel and the light intensity (P_{in}) was maintained at 1000W/m^2. Initially the V_{oc} was obtained without applying the load. The load used was a standard rheostat of 50 ohms and 5 A. The load was applied by gradually varying its resistance value; the corresponding current and voltage were observed using ammeter and voltmeter and the IV curve was plotted as in figure 3 from which the V_{oc}, I_{sc}, I_m and V_m were observed as 18.7V, 5.65A, 4.47A and 15.8V respectively . Using the values obtained the panel efficiency was calculated using the following expressions and was found out to be 6.93%.

ɳ$= (Voc \times Isc \times F.F)/Pin$

Where [8], $F.F = (Im \times Vm)/(Isc \times Voc)$

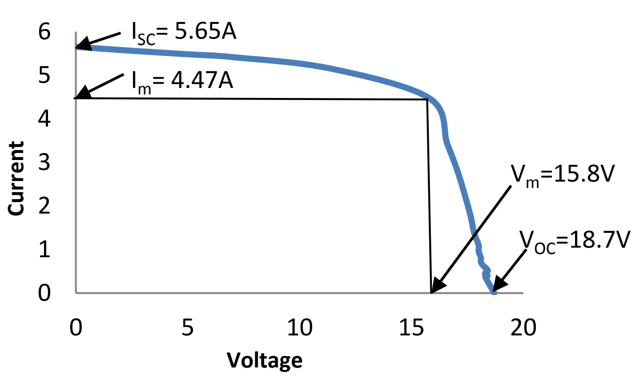

Figure 3 IV curve using the indoor solar simulator

The above experiment was repeated with the panel kept under the sunlight during the month of February in Chennai, India (late winter conditions) at around 10.05AM and the sun light intensity was 955W/m^2. The panel was placed in the open sun with an inclination of 30º facing south; using the same load the IV characteristics of the panel were plotted as in figure 4 in a similar procedure to that of the indoor simulator and the corresponding V_{oc}, I_{sc}, I_m and V_m were observed as 19.2V, 7.30A, 6.39A and 14.2V respectively. From the obtained values the efficiency was calculated to be 9.27% for a solar light intensity of 955W/m^2.

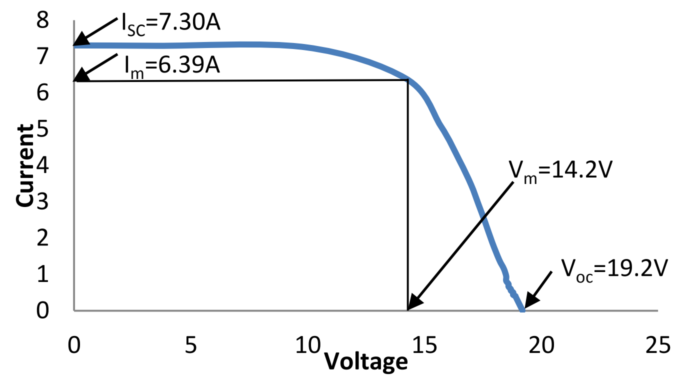

Figure 3 IV curve in the open sun

PULL DOWN CHARACTERISTICS

The power generated from the panel using the indoor simulator was fed directly to the DC compressor of the bottle cooler. The starting power used by the compressor was 66.4 W (5.13A and 12.93V) and the running power was between 50 and 65W as depicted in figure 4. Initially, during starting more current is required to overcome the inertia and static friction. The current rises but the corresponding voltage drops drastically resulting in inability of the compressor to start inspite of the presence of high power. However, the AEO unit in the compressor could manage the power demand and start the compressor with a power delay as in the figure 4.

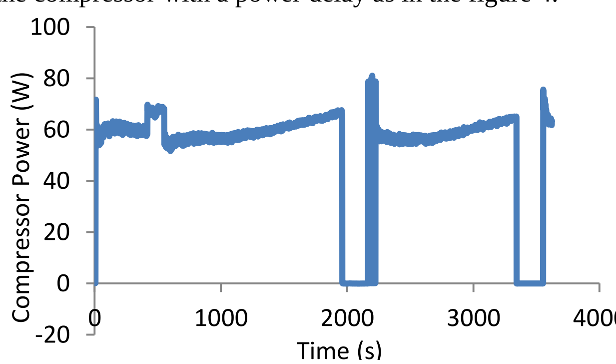

Figure 4 Power consumed by the bottle cooler using the indoor simulator

The cabin temperature of the bottle cooler was observed at three different locations and the average temperature was taken to be the cabin temperature. The cut off took place at a temperature of -1.143˚C and the pull down time taken to reach that temperature was 32.78 minutes with respect to the room temperature as in figure 5. After the cut off, after 4.63 minutes the cabin temperature reached 5.9˚C and the cut in took place. The next cut off took place at -1.18˚C with a corresponding ON time of 18.35 minutes. The cycle was repeated as shown in figure 5.

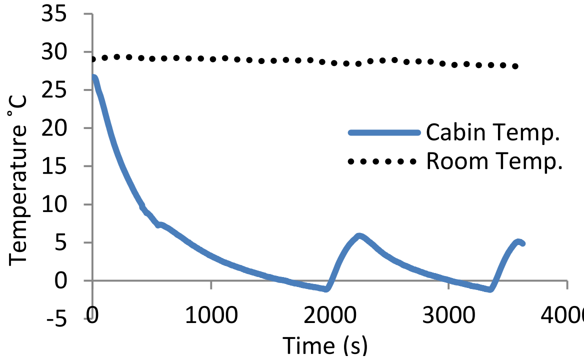

Figure 5 Pull down characteristics using the indoor simulator

Similarly the pull down test was repeated in the open sunlight from around 11:15AM to 12:30PM and the average sunlight intensity was 960W/m^2. The starting power used by the compressor was 83.49W (4.66A and 17.913V), the running power was between 49W and 83W. This wide range of power was due to the continuous variation in the solar intensity. The sunlight intensity went up very high from around 11:30 AM to 12:15PM (1005 to 1045W/m^2) and the corresponding power produced by the panel was high. At that time, AEO system in the compressor increased the speed of the compressor and more power was used by the compressor as shown in figure 6.

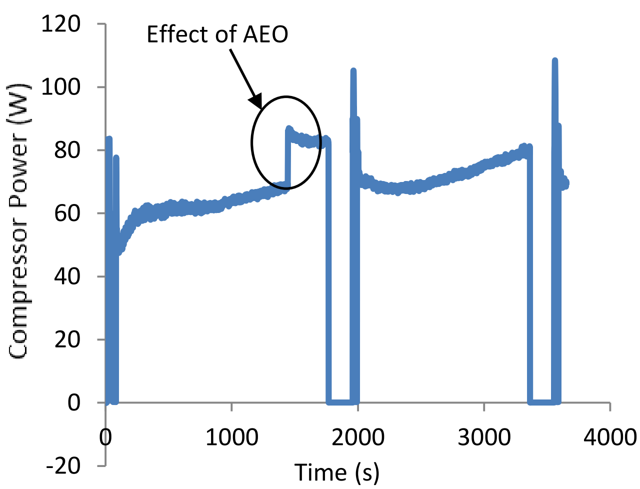

Figure 6 Power consumption by the bottle cooler in the outdoor test

The figure 7 depicts the pull down characteristics of the bottle cooler where the bottle cooler was kept, when the panel was kept under the open sun. The cut off took place at -0.5567˚C and the corresponding time required to reach the cut off temperature was 29.5 minutes. The cut in took place after 4.37 minutes and at 5.767˚C cabin temperature, and the next cut off took place at -0.637˚C, after 22.2 minutes.

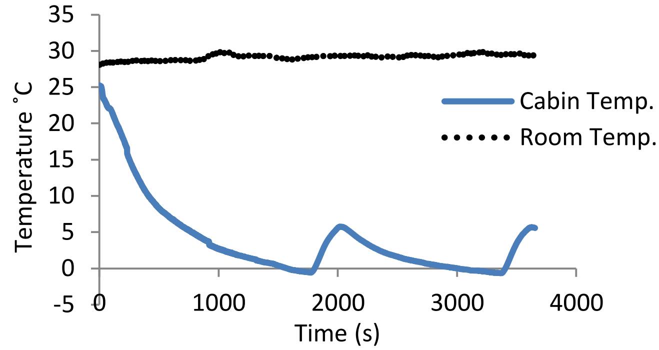

Figure 7 Pull down characteristics in the outdoor test

CONCLUSION

It is observed that the panel's efficiency was superior in the open sun when compared to the indoor testing and also the pull down time in the open sun was better than that of the indoor system. However, when it comes to testing the performance of DC devices in the open sun, consistency cannot be obtained due to lack of repeatability. This is due to the continuously varying solar intensity. Repeatability is possible in indoor simulators due to the continuous and smooth spectral output generated by the halogen lights used in the simulator. Thus the development of such solar light simulators would be an invaluable tool which shall enable researchers and industries to carry out and repeat experimental tests under various conditions without the exposure to the unpredictable variation of the outdoor weather fluctuations.

The performance comparisons are:

1) The pull down time for the system was 32.78 minutes while tested in the indoor simulator and 29.5 minutes while tested under the sun.
2) The ON cycle was 18.35 minutes while tested in the indoor simulator and was 22.2 minutes while tested under the sun.

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