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Review Article

Performance Study of a DC Refrigerator Powered by Different Solar PV Modular Sets: Paper II

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Abstract

This study exhibits the performance of a DC domestic use refrigerator. Sixty Watts rated power unit was used. Two PV sources of solar electricity power of 100 W_p and 70 W_p modules. A battery of 12 V and 21 A_h, was connected to the cycle.

The experiments were carried out using five different conditions for the power connection: The battery was used in different conditions as follows: standalone full charged; either initially full charge or completely discharged and connected with either one of the module generator.

Five experiments with different combinations in the connection conditions of the battery and the modules. The on/off sequence effect on the performance of: T_e; T_c and, T_L were mainly monitored.

In this study, it was required to study the lowest solar power supply condition that may be unsuitable to sustain continuous operation. This helps generators designers and conserves energy.

Acceptable performance was reached in four experiments. The fifth experiment was with initially completely discharged battery with the 70 W. module, gave continuous cyclic on/off which is an un-acceptable performance.

T_e - evaporation temperature, T_c - condensation temperature, T_L is the Load temperature, T_{amb} - ambient. V - Volts; A_h - Ampere hour and W - Watts.

Keywords: Solar Energy; Refrigeration; DC Refrigerators

Introduction

One of the most important solar energy applications is the refrigeration field. This application helps in remote areas far from grids. Refrigerators in such areas are used to preserve foods and vaccine. Jordan has a suitable weather conditions to use solar energy. Jordan solar radiation is considered high enough to be utilized in electricity generation. (Table 1) shows the solar parameters levels in Jordan.

Table (1): Solar Specification of Amman, (Ayesh, 2013)

Title	Values	
Location	30N	
Shining Period	10-12 Hours/Day Year Around	
Sunny Days	320 Day/Year in Mountains	344 day/year in desert
Design Values	5.5 kW/m^2. Day in Summer	3.5 Kw/m^2. Day in Winter

Lately literature showed that

[1] Studied and tested direct drive photovoltaic refrigerator by using ice storage in New Mexico. The refrigerator used thermal storage and was connected direct to the photovoltaic panel; this was accomplished by integrating a water-glycol mixture as a phase change material into a well-insulated refrigerator cabinet and by using microprocessor based control system to connect the P.V panel directly to a variable - speed D.C compressor.

The refrigerator performed well and needed minimum four hours daily of solar insulation and consumes approximately 55W_s. In a hot day the refrigerator operated on a small PV module 80 W_P. A 60 W_p was incapable to operate the unit. [2] studied experimentally the performance of a one ton split unit air conditioner. With a solar generator as an electrical power source.

In this study, an air conditioning unit of one ton of refrigeration was used. The generation system consisted of an array of: seven PV modules; an inverter and two batteries were used to operate the conditioning unit. The results showed that there was no deference in the performance of the air conditioning unit when using the same refrigerant and changing the source of power from mains to solar power. Same results were obtained by: [3-5]. This study aimed to reduce the power generated to the limit that production can't succeed to sustain acceptable operation. The following conditions of powers supply were tested:

(a) Using a charged battery only.

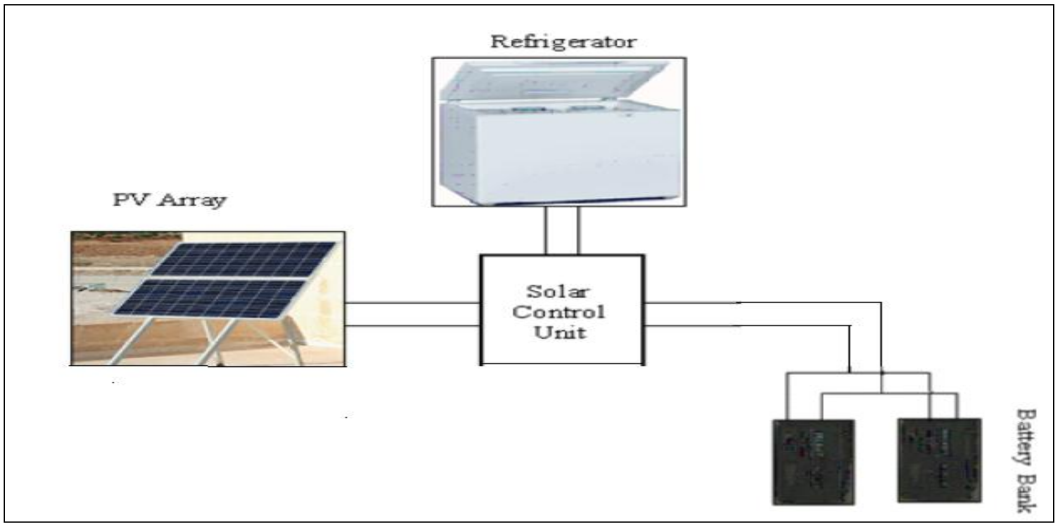
(b) Using 100 W_P photo voltaic panel in the following two cases: charged battery and discharged battery.

(c) Using 70 W_P photovoltaic panel also in two cases: charged battery and discharged battery. The last test of completely discharged battery with 70 W_p module was the un acceptable with continuous cyclic on/off operation.

Experimental Set Up and Instrumentation

The experimental apparatus was built up so as to accommodate changes required in connecting any one of the modules output to the battery and the solar controller. The system is shown in (Figure 1) below

Figure (1): Schematic of the PV-refrigerator system



Technical Specifications

The DC refrigerator

(Table 2) shows the manufacturer specifications for the DC refrigerator used in this study. (Figure 3) shows the DC refrigeration box used, with some measuring equipment used.

Table (2): Specification of the refrigerator

Model	Description
Voltage	12 V
Max. Power input	60 W
Operating current	5A
Refrigerant	R134a
Minimum freezer temperature	-30° C
Country made in	China

Solar generator

(Table 3) shows the manufacturer specifications of the two PV modules used in this work.

Table (3): Specifications of P.V

	$70W_P$ Module	$100W_P$ Module
MODEL	OOXH1A0 249	ZN-100M
Nominal maximum power output	70 W_p	100 W_p
Open Circuit voltage	21.5 V	21.6 V
Short Circuit current	4.35 A	6.27 A
Nominal maximum output voltage	16.9 V	17.57 V
Nominal maximum output current	4.14 A	5.7 A
Maximum system power	750 W	1000 W

The Battery and the Charge Controller

(Table 4) shows both the battery and the charger controller manufacturer specifications.

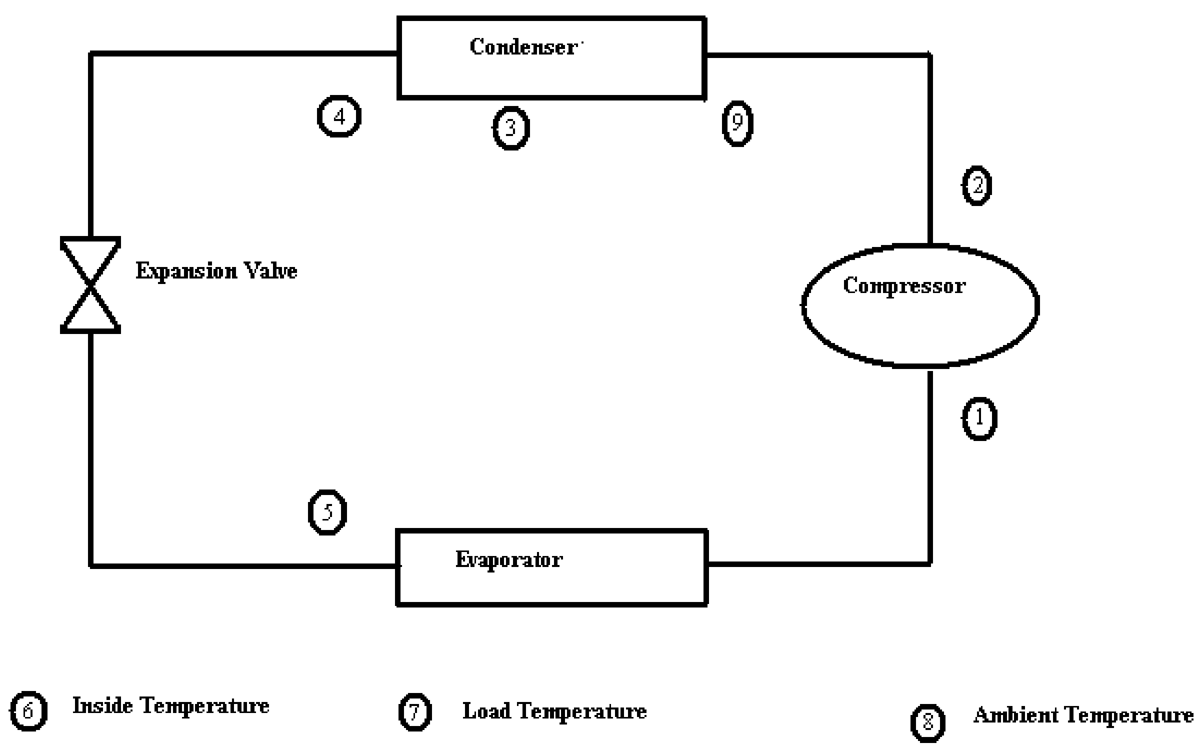
Table (4): Battery and Charge controller

Item	Specification
Batteries	Excellence, EB12-21 (12V21AH)
Charge controller	Tristar, (10-68V, DC, solar current 45A)

Measurement

Thermocouples (K-type) were used to measure the temperature of the nine locations shown in (Figure 2). These locations represent: Suction temperature, T_1; Discharge temperature, T_2; Condensation temperature, T_3; Outlet of the condenser temperature, T_4; Evaporation temperature, T_5; Freezer temperature, T_6; Load temperature, T_7; Ambient temperature, T_8 and Inlet of the condenser, T_9. Stop watch for monitoring the experimental results at a certain time intervals.

Figure (2): Temperature measurements on refrigeration cycle



Experimental Procedure

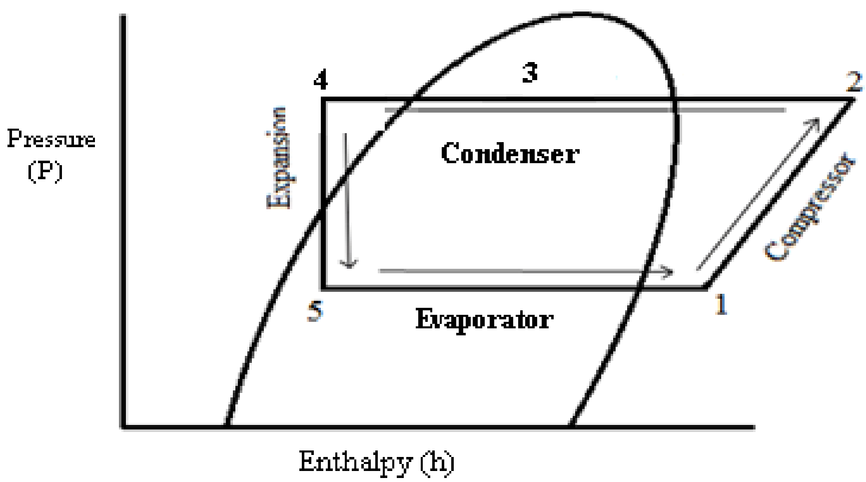
This research relied mainly on experimental data for temperatures at nine locations that were indicated (Figure 2). The power consumption, COP, Mass flow rate, Capacity, Pressure were the monitored or calculated performance parameters. The following procedure was followed:

First step was to operate the refrigerator empty, without load, once T_e reaches -20°C the load, which is a tin container of half a liter of water heated up to 80° C will be installed inside the refrigerator. All the temperature readings are to be recorded at a constant time intervals from beginning time on of the refrigerator.

Discussion

(Figure 3) Represents a typical the refrigerator thermodynamics cycle. This is the Pressure – Enthalpy relationship. The 100 W_p module generates 1.66 of the rated power, (66% extra) and the 70 W_p module generates 1.16 of the rated power, (16% extra). The performance parameters are dependent on T_e and T_c and was calculated using the usual known relations of vapor compression refrigeration cycles and (Figure 3) illustrations. Thirty curves (not included in this paper), which were used to study the performance of the refrigerator exhibited a satisfactory performance. These result showed conformity the literature works by: [1-7].

Figure (3): Pressure – Enthalpy diagram for a typical vapor compression cycle



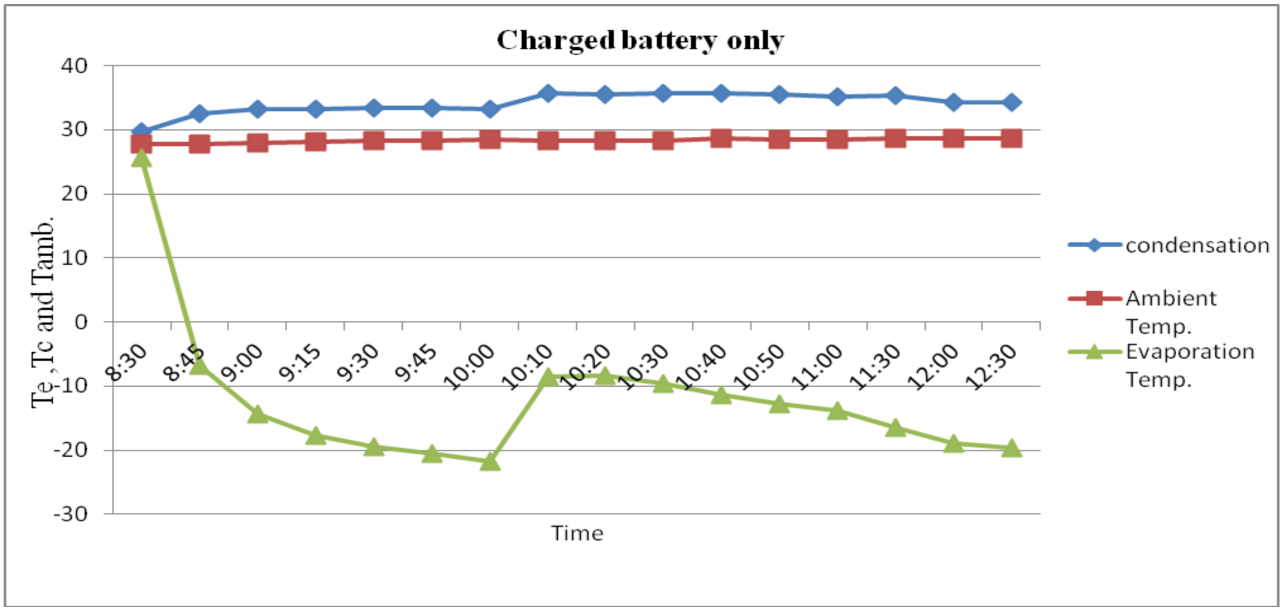
Time History Analysis

Time history for the experiments results were exhibited in (Figures 4-12). This was for the cases of: Fully charged battery standalone; 100 W_P module with initial full charged battery; 100 W_p module with initial complete discharged battery; 70 W_p module with initial full charged battery and 70 W_p module with complete discharged battery.

The Case of Charged Standalone Battery

(Figure 4) represents a normal operation along four hours of the test. Between 10:00 and 10:20 an increase of 10 degrees in T_e encountered. This was caused by the installation of the load in the refrigerator. Minor increase in T_c was noticed. Two hours were required to reach the conditions of -20°C.

Figure (4): Evaporation temperature T_e, condensing temperature T_c and T_{amb} versus Time



Full Charged Battery With 100 W_p Module

The rate of the drop in temperatures was suitable for the experiment. The refrigerator was put on at 9:45 and reached lowest temperature of -20 at 11:00. Increase of 10 degrees in T_e, and minor increase in T_c are shown in (Figures 5, 6). The refrigerator recovered the T_e conditions in about two hours. Successful operation was prevailing.

Figure (5): Evaporation temperature, T_e , condensation temperature, T_c and T_{amb} versus time

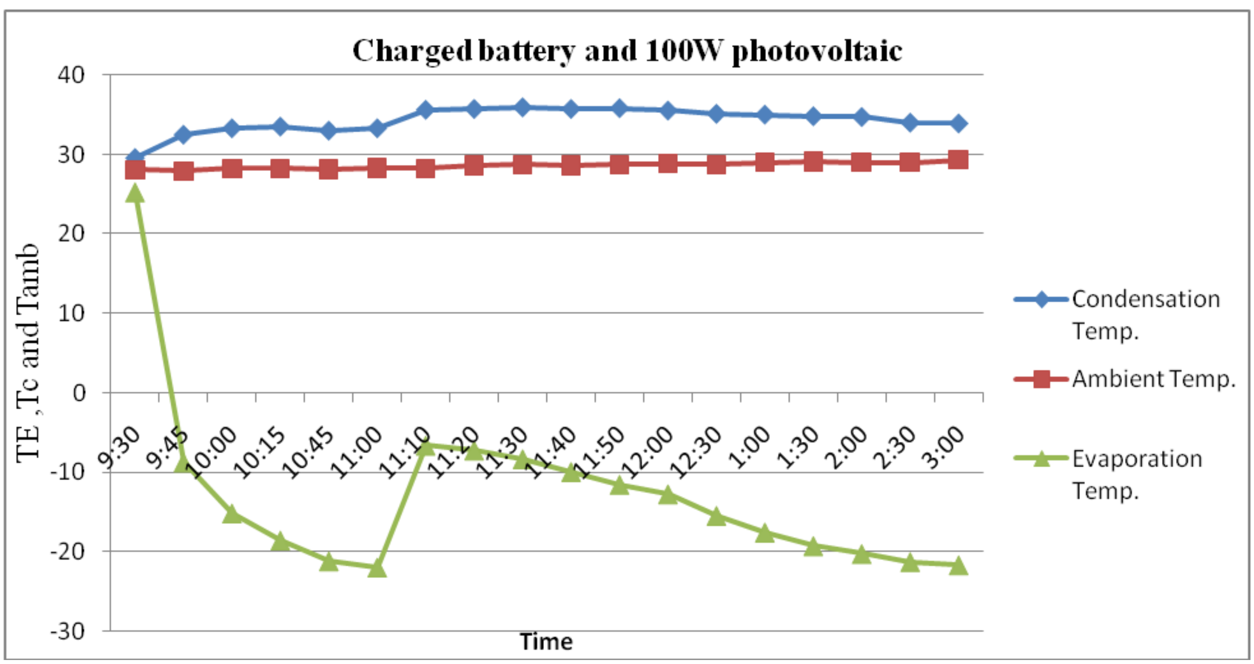
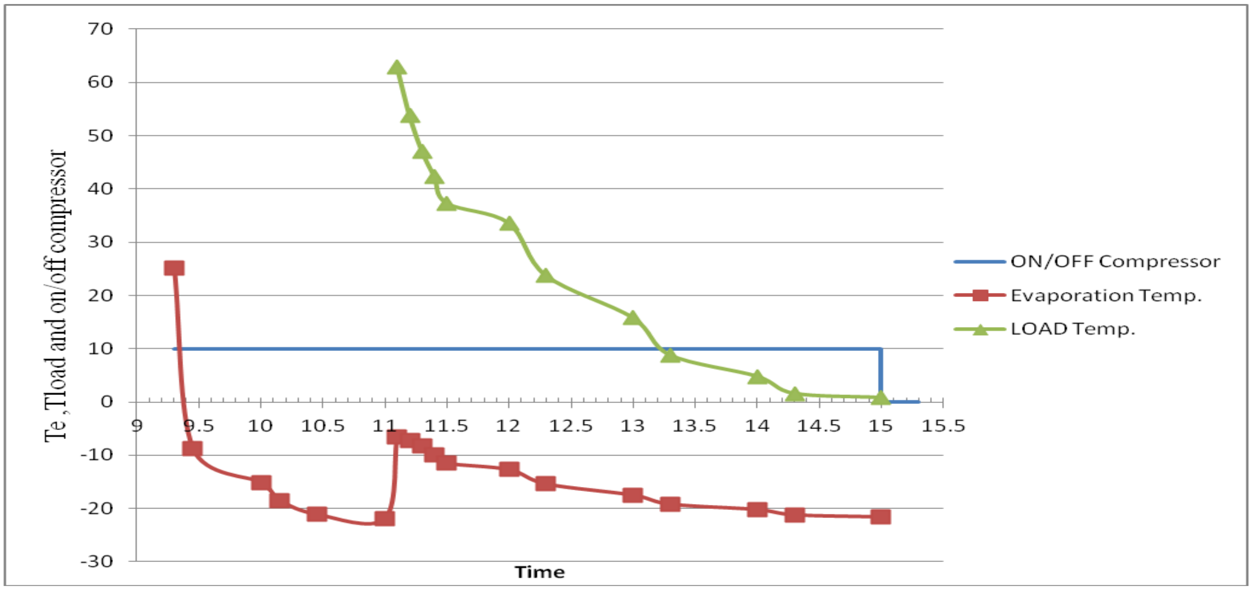


Figure (6): Evaporation temperature, T_e, Load temperature, T and on/off Compressor versus time.



Complete Discharged Battery with 100 W_P PV Generators

Fifteen minutes were required to charge the battery. At 8:30, the refrigerator was put on until the end of test as shown in (Figures 7, 8).

At 11:00, T_e reached -20° C. The increase in T_e was about 20° while very minor increase encountered in T_c. Two waves of fluctuation were noticed between 11:20 and 12:00 for amplitude of 6° exhibited in (Figures 7, 8).

Figure (7): Evaporation temperature, T_e , condensation temperature, T_c and T_{amb} versus Time.

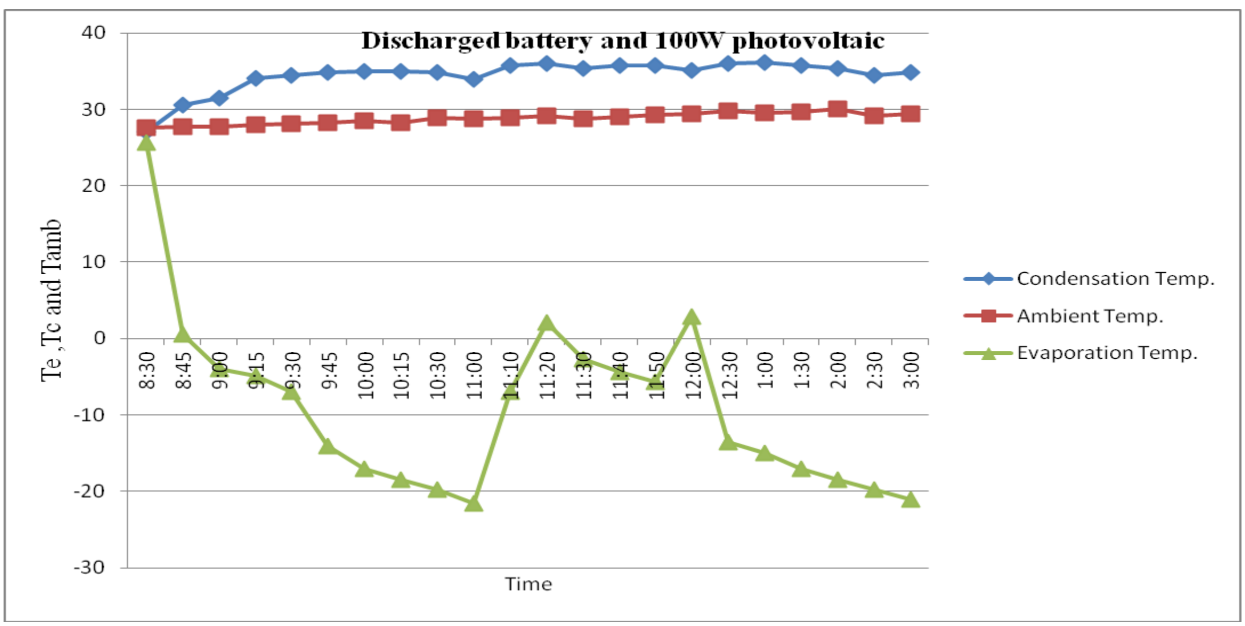
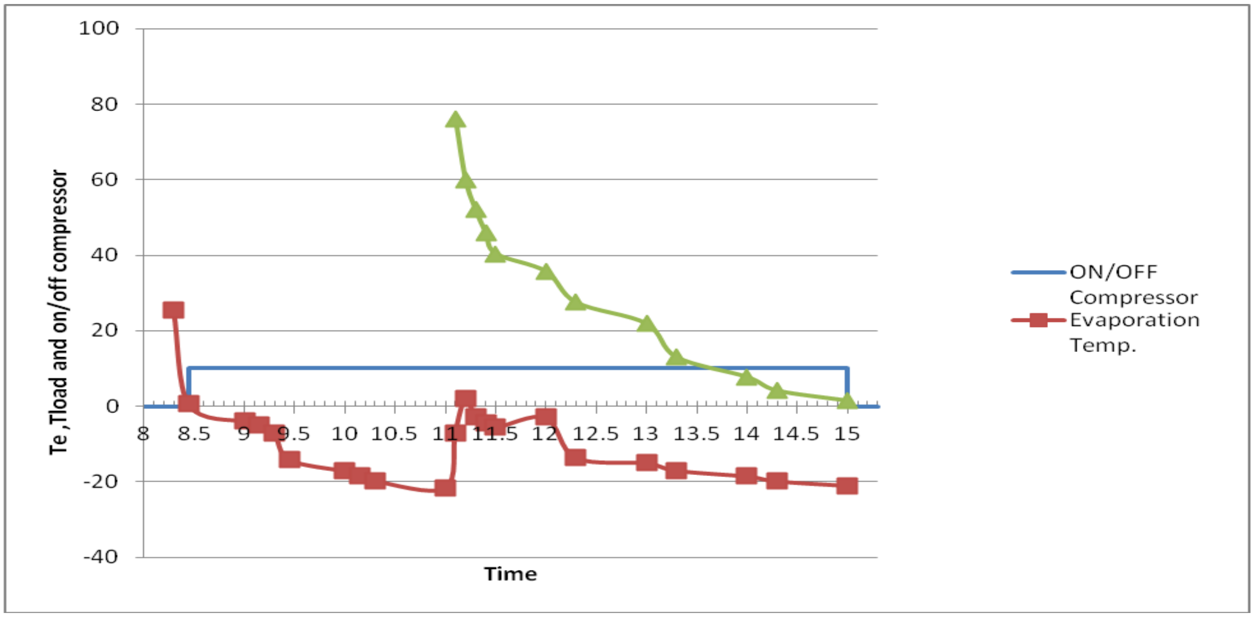


Figure (8): Evaporation temperature T_e, Load temperature T and on/off Compressor versus time.



Full Charged Battery and 70 W_P PV Generators

From 8:30 at which the refrigerator was put on until to 9:00, the solar generated power was lower than the consumed power.

Depending on the battery charge, the refrigerator operated instantly. The refrigerator followed a continuous proper operation as shown in (Figures 9, 10). It took the system 3 hours to go back to the conditions of before load installation

Figure (9): Evaporation temperature, T_e, condensation temperature, T_c and T_{amb} versus time.

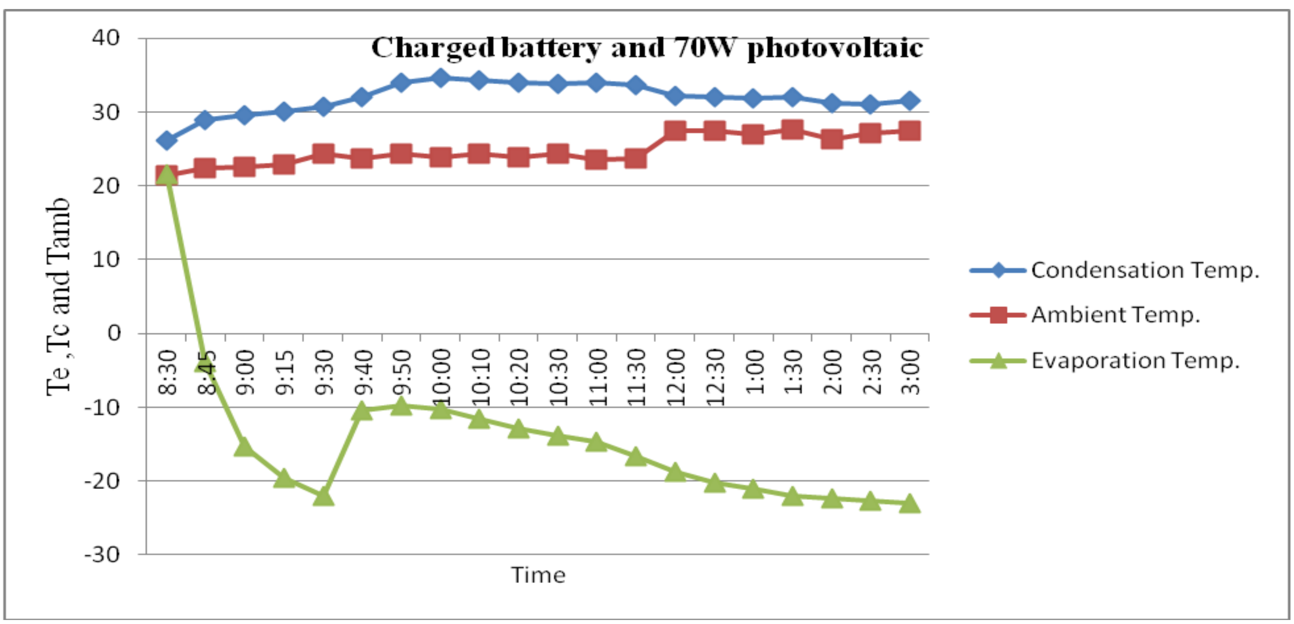
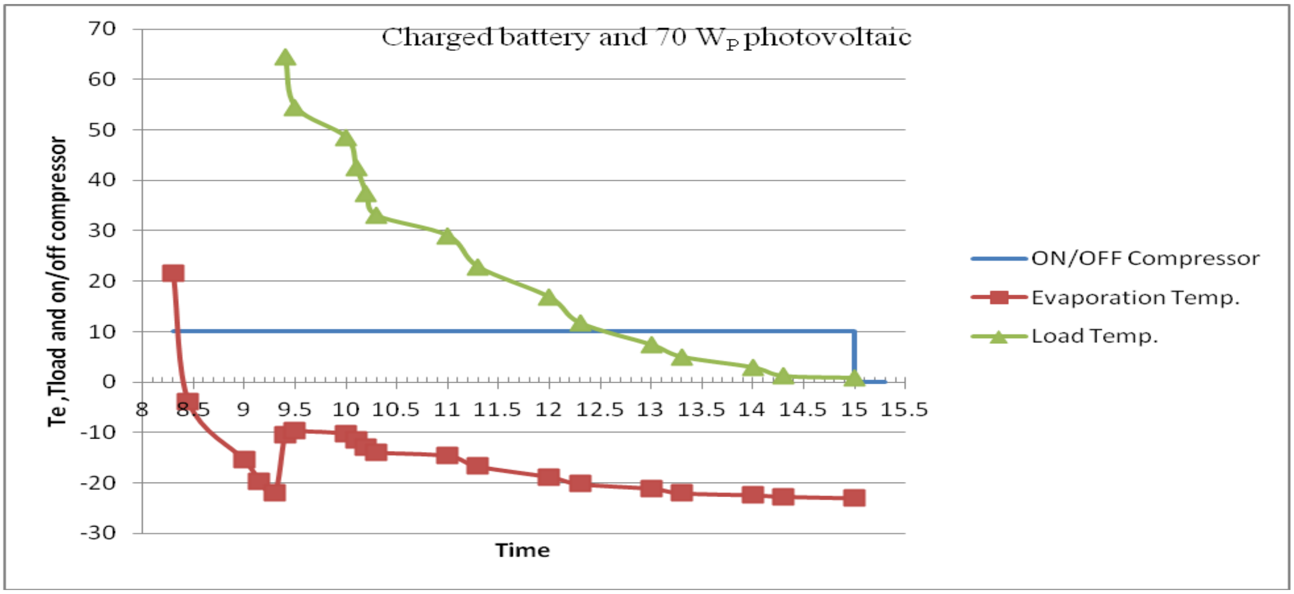


Figure (10): Evaporation temperature, T_e, Load temperature, T and on/off Compressor versus time.



Complete Discharged Battery and 70 W$_P$ PV Generators

Generated solar power was higher than demand except before 9:00 am and after 14:40 pm. This long gave delay time of about one and half an hour to reach loading conditions. Several cycles of fluctuations of T_e caused by several on/off of low charge for the battery. (Figure 11) shows the time – values and the relation between: The evaporation temperature, T_e; the condensation temperature, T_c and the ambient temperature, T_{amb}. It is clear that T_e kept fluctuating before the load installation and after. Moreover, to the end of the experiment the refrigerator could not reach back to pre - load conditions. (Figure 12) presents the cut-in and cut- off at the daylong experiments. Several times the refrigerator experienced loss of power and was shut down, after a while solar power charged the battery enough to switch on.

The system was put on at 8:30 and it was noted that the refrigerator turned on and several on/off fluctuation occurred as shown in (Figure 12). Time of 3 hours was required for the refrigerator to reach the proper conditions for installation of the load, this was at 12:30. This is a long time and it was considered unacceptable operation. The installation of the load caused increase in the evaporation temperature, and fluctuation was noticed after that.

In this case of discharged battery and low solar generated supply, (70 W) lead to have: long delay in time to reach lowest T_e conditions; kept T_e and T_c fluctuating and did not reach normal low conditions after loading. All this concluded to consider this case as rejected and unsuitable power supply to operate the refrigerator.

Figure (11): Evaporation temperature, T_e, condensation temperature, T_c and T_{amb} versus time.

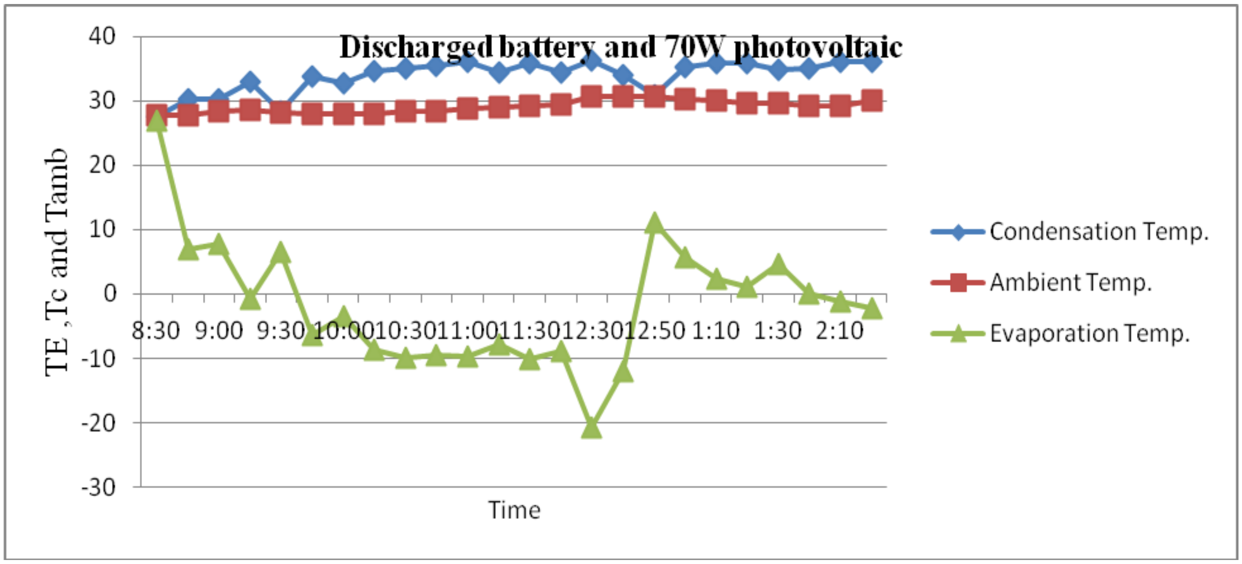
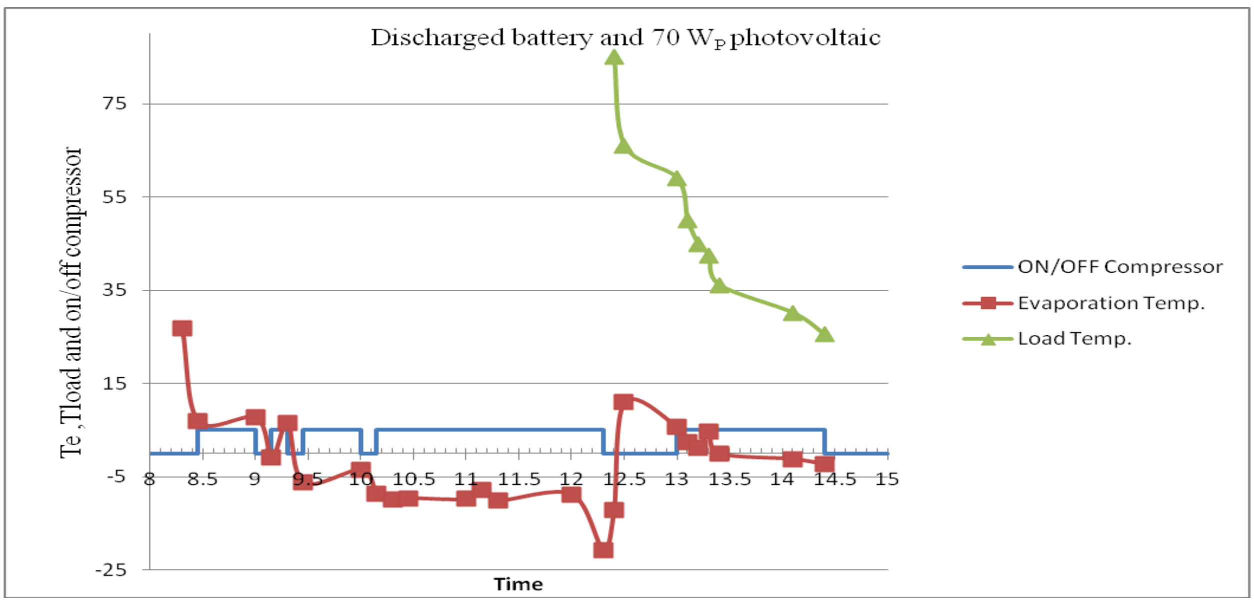


Figure (12): Evaporation temperature, T_e, load temperature, t and on/off compressor versus time.



Conclusion

This work experimented five ways to power a 60 W rated domestic refrigerated by a photovoltaic generators. This arrangement used a storage battery. Three levels of generated power were tested as follows: No generation power, battery alone; generation of extra 16% to the rated power and generation of extra 66% to the rated power.

The battery used was: Standalone; initially discharged or initially full charged. Four ways powered the refrigerator satisfactorily. The aim of this study was to reach a case of the lowest solar power supply conditions that may be un suitable to sustain continuous operation. This case was not reported by literature before. This helps generators designers; conserves energy and reduce costs of equipment used.

The fifth connection method, which was of initially discharged battery and of extra generated power, only equals 16% to the rated power, failed to satisfy continuous operation of the refrigerator.

The failure was due to the following noticed bavour:

1. Long time was required to reach the lowest operating temperature of -20°C for T_e.

2. Fluctuation cyclic operation for both T_c and T_e.

3. Refrigerator was unable to reach again to pre- load conditions.

Using a battery and keeping it initially charged reduces the required power generated. This will be used for generators designers and will conserve energy consumption. Also this will reduce the energy costs.

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