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Experimental study of 12V and 24V photovoltaic DC refrigerator at different operating conditions

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ABSTRACT

Energy efficient approach of providing refrigeration needs is of one of the challenge facing most developing countries. The objective of this work is to study the effect of ambient temperature on the performance of 12 V and 24 V photovoltaic DC refrigerator with/without loading operated at 25 °C and 35 °C . Experiments were carried out at different thermostat setting of the refrigerator. The daily compressor run time and energy consumption of the refrigerator were calculated at various operating conditions. The monthly and annual consumptions of the refrigerator were also carried out. The minimum and maximum increase in compressor run time per day for every degree increased (in average from 25 to 35 °C) in ambient temperature is investigated and f°und to be 0.216 h/°C and 0.912 h/°C for 12 V system. While for 24 V these values rises to 0.317 h/°C and 1.079 h/°C, for different thermostat settings. Also the increase in energy consumption per day for every increased in loading for 12 V and 24 V operation were recorded as 76.9 Wh/L and 91.7 Wh/L respectively. The comparison results showed that 12 V operations of DC refrigerator can be much more efficient than 24 V operations especially at higher ambient temperature with an average of energy saving of 81.28 kWh/year.

1. Introduction

In the past few years, renewable energy has greatly spread out in the global energy market. In 2016, the amount of investments in renewable energy counted as more than double the amount spent on non-renewable energy sources like cool and gas fire plants [1]. Globally, 8.1 million workers were employed in the renewable energy sector with 2.8 million of them working in the solar modules production [2]. By the year 2020, the International Energy Agency, estimated that 5% of the global power production will be from solar energy [3]. In most developing countries, especially in remote and rural areas that are facing shortage of electricity, the main reason for using renewable energy is to access to electricity [4]. Renewable energy resources, like PV, wind or hybrid systems, are used to generate an electrical power by using various technologies in association with storage system to be used during the period of emergency or when these resources are not use. Among the various stand-alone appliances, photovoltaic powered refrigeration systems have drawn the attention of many researchers as a result of steadily increasing in overall energy consumption of the system [5–8]. Electric power generated by photovoltaic panels is used to drive direct current (DC) refrigerator based on vapor compression cycle in association with battery, charge controller [9–12] and inverter [13,14]. Solar refrigeration is divided into two types; namely they are solar photovoltaic refrigeration and solar thermal refrigeration [15,16]. Du [17] and Pan [18] have conducted some studies in order to enhance the overall efficiency of the refrigerator, increase the system stability and reliability as well as optimizing the refrigeration equipment structure. Solar PV refrigeration is grouped into two categories; thermoelectric refrigeration and vapor compression refrigeration. The thermoelectric refrigeration system uses electrons rather than refrigerant as a heat carrier. This type of refrigeration is characterized light weight, reliable, noiseless, rugged, and low cost [19]. As early as 2003, a research on thermoelectric refrigeration carried by Dai et al. [20] showed that the system able to get a COP of 0.3 and the refrigerator temperature inside the cabinet was in the range of 5–10 °C. Due to the various limitations of the thermoelectric refrigerator, the research concluded that this type of refrigeration is suitable for cold storage only but not for freezing. So, photovoltaic vapor compression refrigeration has attracted many researchers' interests [21]. Nowadays, as the results of the development in technology, the efficiency of the PV module increases and the cost of power generated from the photovoltaic power station decreases. Moreover, the advantage of solar photovoltaic refrigeration is the stability in operation and high efficiency in compare with solar thermal refrigeration. Therefore, this fact make research on solar photovoltaic

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refrigeration employed vapor compression cycle is essential; all over the world [21]. Aktacir [22] achieved a temperature of −10.6 °C inside the cabinet of the photovoltaic refrigerator driven by PV energy. In our daily activities, refrigerator has become one of the essential appliances. Moreover, in food industry, more than 45% of foods rely on the refrigerators to maintain freshness, and consequently, refrigerators power consumption in food industry accounts for a high proportion of electricity Therefore, in development consideration in many industries energy consumption of refrigerators has become an important issue Chuang et al. [23]. Therefore, energy saving related technology in refrigerators has been widely investigated [24,25]. In this study, increase in energy saving is achieved by improving some of the major components of the refrigerator. Ghadiri and Rasti [26] by optimization of some components of the refrigerator, achieved 23.6% reduction in energy consumption.

Some research studies including Gin et al. [27] have applied phase change materials (PCM) to the refrigerator. PCM absorbs heat to suppress the temperature rise. Compressor is account to be the most energy consuming part in the PV refrigeration system. DC compressors were used in the solar photovoltaic refrigerator to reduce the losses of conversion of DC to AC. The operation of the compressors by the PV panels is followed by the use of a controller, which provides startup, maximum power tracking and power management of system [28]. Many solar PV refrigeration researchers worked on the conversion of conventional refrigerator incorporating AC compressors to DC PV refrigerator that uses DC compressors. Kaplanis and Papanastasiou [10] and Modi et al. [8], converted conventional refrigerators with different sizes to DC PV refrigerators. Over the past five years, solar PV refrigeration is being the best choice and more acceptable for household refrigeration as the result of drastically reduction in the price of the solar PV systems [29,30].

2. System description

In this study a photovoltaic DC refrigerator is experimentally investigated. The refrigerator is powered by 12 V and 24 V DC voltage from photovoltaic panels. Firstly one panel is used for the 12 V operations and secondly two panels connected in series are used for the 24 V operations. Specifications of the solar panel are shown in Table 1.

The IV and power curves for single and double panels are shown in Figs. 1 and 2 shown below respectively.

Two batteries each of 12 V, 150 Ah gel battery suitable for solar applications are used. For 12 V operations one battery is used whereas, for the 24 V operation two batteries connected in series is used. Battery charge controller is used to control the charging of the battery from the photovoltaic panels. The refrigerator uses DC compressor. The specification of the DC refrigerator is shown in Table 2 below.

The complete experimental set-up for the study is shown in Fig. 3. Details of the experimental performance of this DC refrigerator and other performance characteristics have been published in the work of Daffallah el al [6].

The refrigerator is located at Madinah in Kingdom of Saudi Arabia (KSA) In Medina, the summers are long, sweltering, and arid; the winters are short, comfortable, dry, and windy; and it is mostly clear year round. Over the course of the year, the temperature typically varies from 12.2 °C to 43.3 °C and is rarely below 8.3 °C or above

Table 1
Solar Panel specifications.

Panel specifications	
Maximum power (W)	150
Maximum voltage (V)	18.05
Maximum current (A)	8.31
Open-circuit voltage (V)	22.28
Short-circuit current (A)	9.35
Cell technology	Mono-Si

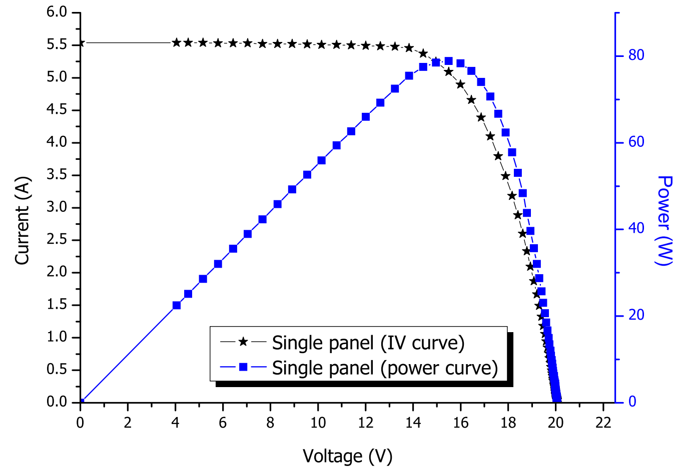

Fig. 1. IV and power curves for single panel.

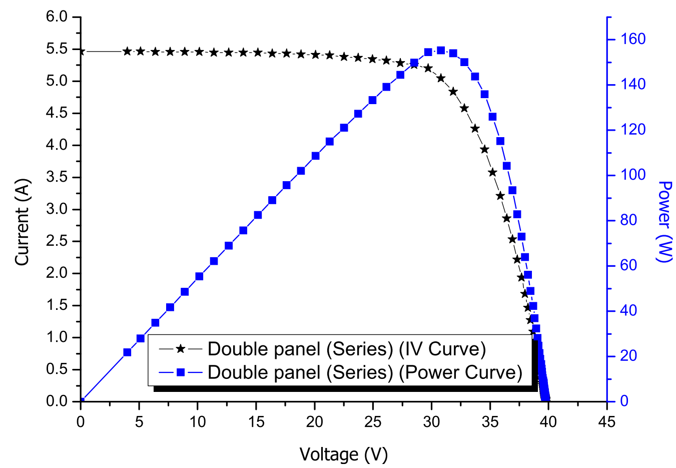

Fig. 2. IV and power curves for double panels.

Table 2
DC refrigerator specifications.

Refrigerator parameters	
Total capacity (L)	158
Capacity of freezer (L)	58
Capacity of refrigerator (L)	100
Rated voltage	12 V/24 V DC
Total input power (W)	75
refrigerant	R134a

45.5 °C. The refrigerator is allowed to run continuously for 24 h under different thermostat settings (from position 1 to position 4). The thermostat, which is fixed inside the refrigerator, is the controlling device that adjusts the temperature inside the refrigerator [6]. First the refrigerator is run with 12 V using one photovoltaic panel and one battery. And then two panels and two batteries connected in series were used to power the refrigerator under 24 V operations. In the two modes of operation (12 V and 24 V), first the refrigerator is run without load and then it is occupied with 10 L of water inside the refrigerator and freezer compartments. Also the systems were tested under different ambient temperatures (25 °C and 35 °C). In the experimental studies current and voltage from the photovoltaic panels were measured every 1 min and log into Agilent 34970 A data logger with accuracies as follows: 0.004% dcV accuracy, 0.06% acV accuracy and 0.01% resistance accuracy. To calculate the power consumption of the refrigerator, the current and voltage of the DC compressor is also measured. Since the