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Energy-Efficient Self-Excited Brushless DC Motor for Refrigeration Systems

***Abstract**. The most common air cooling, ventilation, and refrigerating systems are traditional mechanical compression air-conditioning systems. By replacing the AC motor with a DC one and adding a solar panel, the system's efficiency can be improved, lowering energy usage and the cost of electricity bills. The dc air conditioner employed a 48 V DC compressor and two 430 W solar panels linked in parallel by a charge controller. Temperature was coded to track and manage the DC compressor's switching states. From this standpoint, we will start this paper through which we seek to raise the efficiency of air-conditioning system and reduce its consumption of electrical energy. This work aids in the development of a solar-powered DC air cooling system with dependable monitoring and communication. The novelty of the proposed work consists in the replacement the AC motor with a DC one and adding a solar panel, the system's efficiency can be improved, lowering energy usage and the cost of electricity bills. The dc air conditioner employed a 48 V DC compressor and two 430 W solar panels linked in parallel by a charge controller. The solution of the problem was carried out by the development of a solar-powered DC air cooling system with dependable monitoring and communication using Matlab software. The efficiency of the system's operation is improved and increased by using the monitoring and control of the refrigerator. The refrigerator's power was turned off when an open, bare, or over laden unit was discovered. It is possible to directly power low power devices used in homes, offices, hospitals, etc. utilizing DC sources. Reviewing the simulation results for cooling requirements and PV with batteries revealed that most of them were unrealistic due to a dearth of pertinent data and ensuing assumptions about crucial elements.*

Streszczenie.** Najbardziej powszechnymi systemami chłodzenia powietrza, wentylacji i chłodzenia są tradycyjne mechaniczne systemy klimatyzacji sprężonej. Zastępując silnik prądu przemiennego silnikiem prądu stałego i dodając panel słoneczny, można poprawić wydajność systemu, obniżając zużycie energii i koszty rachunków za prąd. Klimatyzator prądu stałego wykorzystywał sprężarkę 48 V prądu stałego i dwa panele słoneczne o mocy 430 W połączone równolegle za pomocą kontrolera ładowania. Temperatura została zakodowana w celu śledzenia i zarządzania stanami przełączania sprężarki prądu stałego. Z tego punktu widzenia rozpoczniemy niniejszy artykuł, poprzez który będziemy dążyć do podniesienia sprawności układu klimatyzacji i zmniejszenia zużycia przez nią energii elektrycznej. Ta praca pomaga w opracowaniu systemu chłodzenia powietrza DC zasilanego energią słoneczną z niezawodnym monitorowaniem i komunikacją. Nowość proponowanej pracy polega na wymianie silnika prądu przemiennego na silnik prądu stałego oraz dodaniu panelu słonecznego, dzięki czemu można poprawić wydajność systemu, obniżyć zużycie energii i koszty rachunków za prąd. Klimatyzator prądu stałego wykorzystywał sprężarkę 48 V prądu stałego i dwa panele słoneczne o mocy 430 W połączone równolegle za pomocą kontrolera ładowania. Rozwiązanie problemu polegało na opracowaniu systemu chłodzenia powietrza DC zasilanego energią słoneczną z niezawodnym monitorowaniem i komunikacją za pomocą oprogramowania Matlab. Efektywność pracy systemu poprawia się i zwiększa poprzez zastosowanie monitoringu i sterowania lodówką. Zasilanie lodówki zostało wyłączone po wykryciu otwartej, pustej lub przeładowanej jednostki. Możliwe jest bezpośrednie zasilanie urządzeń małej mocy stosowanych w domach, biurach, szpitalach itp. z wykorzystaniem źródeł prądu stałego. Przegląd wyników symulacji wymagań dotyczących chłodzenia i PV z akumulatorami wykazał, że większość z nich była nierealistyczna ze względu na brak odpowiednich danych i wynikających z nich założeń dotyczących kluczowych elementów.* (Energooszczędny samowzbudny bezszczotkowy silnik prądu stałego do systemów chłodniczych***)

Keywords: BLDC compressor, Photovoltaic systems; MPPT control, Energy consumption.
Słowa kluczowe: silnik bezszczotkowy, system chłodniczy

Introduction

There is a global movement to improve the efficiency of all electrical equipment, cut energy use, and switch to renewable energy sources, especially those that provide DC energy, such solar energy [1-2]. Over the past 25 years, there have been considerable advancements in the performance and efficiency of residential and commercial A/C systems, which have resulted in lower running costs [3–4].

Reducing indirect CO2 emissions from electrical generation, which are responsible for the majority of an A/C system's climate impact, is another benefit of increasing A/C system efficiency (see Section 3). Manufacturers have innovated since the early 1990s to increase efficiency for both entry-level and high-end equipment [5-7].

The Kingdom of Saudi Arabia also aspires to improve energy efficiency and rationalize consumption to save its natural resources and enhance the economic and social wellbeing of its population. Furthermore, according to official statistics, air conditioners use close to half of the electricity generated in the Kingdom [8-10]. Due to their prolonged operation, the majority of air conditioners in household appliances require a significant amount of electrical energy, which raises the cost of the electricity bill.

Other variables, such as the location of the air conditioner, the size of the room, and meteorological variables, affect the effectiveness and energy consumption of the air conditioner [11–13]. Given that there are numerous varieties of air conditioners, such as split air conditioners, portable air conditioners, and windows air conditioners [14-16], there are several initiatives to increase the energy efficiency of air conditioners. Unfortunately, because new systems are expensive, customers often choose the more affordable ones that are already on the market, despite manufacturers' best efforts to increase efficiency and lower electricity use [17-18].

However, such behavior is not in line with the global goal of preserving our valuable finite resources in order to ensure the sustainability of our planet. To preserve our precious, finite resources, we thus attempt to go one step further in our project by aiming to improve the effectiveness of the air-conditioning systems and reduce their energy usage [19-20].

Proposed methodology

This sector presents the clear description about the proposed solar-powered DC air cooling system with dependable monitoring and communication. Since direct current compressors don't need extra parts like a power inverter that an alternate current compressor would, some studies have shown that these compressors have the ability to be employed in energy-efficient cooling system. Any issue with the refrigerant cycle's components interacting with the operational environment's quick changes can be resolved by using this device [21-22].

The goal of this work is to obtain the improved output power with reduced energy consumptions. For this purpose, it is essential to combine renewable energy sources, which is what this essay aims to underline.

The parts of the inverter were eliminated by employing a DC compressor that also operates solely on the required power from the batteries or the power converter from the sun. Due to the fact that this activity generates power for cooling, it is feasible. This research project is cost-effective and has benefits for the future.

Mathematical Model. Model of PV

A solar cell uses the photovoltaic effect to transform light energy into electrical energy. The solar cell's circuit diagram is displayed in Figure 1. This diode is connected in parallel to the source current for the constructed solar PV cell. DC power is produced using solar energy and the solar panel.

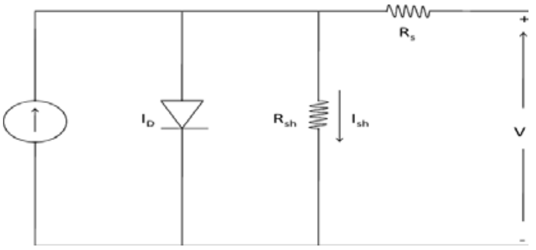

Fig. 1. Solar Cell

DC electricity is produced when a solar ray hits a solar panel, and this power linearly varies with solar irradiation. A semiconductor with a P-N junction in it generates this power. The voltage would rise if the solar cells were connected in series, while the output current would rise if they were connected in parallel.

(1) $$I = N_p I_{ph} - N_p I_{rs} [e^{(\frac{q}{kTA}\frac{V}{ns})-1}]$$

Where V is the solar panel's voltage, and The P-N junction's ideality factor, A, has a range of 1 to 5. A PV module is made up of several PV cells, and when these modules are connected to one another in series or parallel, they create an array.

Model of Boost Converter

The series inductance (Lse), input capacitor (Cpv), and DC link capacitor (Cdc) of a DC-DC converter need to be evaluated. The switch and converter are constantly run in continuous conduction mode to lessen stress on the components. As a result, the continuous conduction mode is assumed for the converter design process. When creating the requirements for the boost converter, it is necessary to calculate the total computing current for the lowest input voltage.

Thus, the duty cycles necessary to provide the entire computational current is:

(2) $$D = 1 - \frac{V_{mp}\eta}{V_{dc}}$$

where V_{dc} is the input voltage, and η is the converter's efficiency, and is the DC output voltage. The series inductor Lse design can then be stated as follows when 10% is taken into account as the maximum permitted ripple in the rated DC current:

(3) $$L_{se} = \frac{D(1-D)^2}{2 f_{sw}} R$$

Where fsw is the switching frequency and D is the duty cycle. Similarly, when designing the output DC capacitor, the output resistor and inverter's working frequency, which is determined by

(4) $$C_{dc} = \frac{D}{2 f_{sw} R}$$

Model OF BLDC Motor

The modeling of the machine can be applied to the creation of the BLDC motor. It has a variety of distinctive dynamic characteristics since its rotor is fastened to the shaft with a permanent magnet. This is true since the magnet is what causes the flux linkage from the rotor.

This causes the magnetic flux connection to get saturated in this sort of motor.

The BLDC motor's one construction, like that of any other conventional three-phase motor, is powered by a source of three voltages (as illustrated in Figure-2).

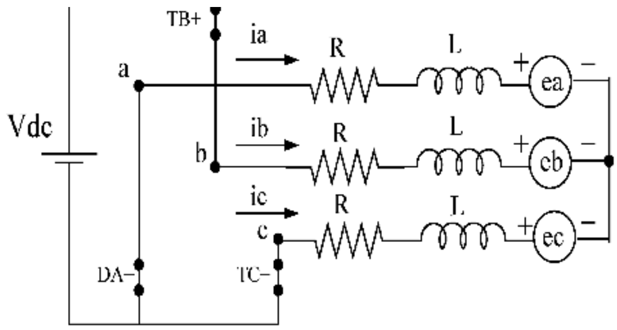

Fig. 2. BLDC motor

It is not necessary for the source to be sinusoidal. The maximum voltage limit of the motor, which is frequently a square wave, must not be exceeded by the peak voltage for whatever wave shape to be employed.

The BLDC motor's armature winding procedure is shown in the illustration below in a manner similar to this:

(5) $$uv_a = Rui_a + L\frac{dui_a}{dt} + e_a$$)

(6) $$uv_b = Rui_b + L\frac{dui_b}{dt} + e_b$$

(7) $$uv_c = Rui_c + L\frac{dui_c}{dt} + e_c$$

Alternatively, as follows in compact matrix form.

(8($$\begin{bmatrix} uv_a \\ uv_b \\ uv_c \end{bmatrix} = \begin{bmatrix} R+pL & 0 & 0 \\ 0 & R+pL & 0 \\ 0 & 0 & R+pL \end{bmatrix} \begin{bmatrix} ui_a \\ ui_b \\ ui_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

$$L = L_s - MH$$

Back emf declaration must be changed as described in

(9) $$e_a(t) = K_E * \varphi(\theta) * \omega(t)$$

(10) $$e_b(t) = K_E * \varphi(\theta - \frac{2\pi}{3}) * \omega(t)$$

(11) $$e_c(t) = K_E * \varphi(\theta + \frac{2\pi}{3}) * \omega(t)$$

Because we used a tiny letter in the preceding equation, the letter KE is either a capital letter or a lowercase letter when the back emf constant (KE) is taken into consideration together with the mechanical speed of the rotor.

The permanent magnet affects the torques produced as a result of the trapezoidal flux coupling.

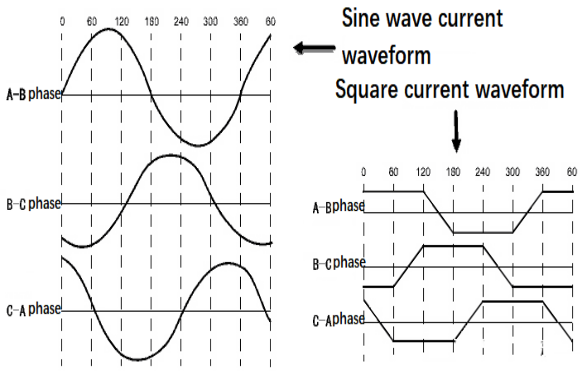

Fig. 3. Back emf and phase currents of a BLDC motor.

Simulation of the DC air conditioning systems

There is two type of DC air conditioner (OFF and ON grid system). In the OFF system, electricity is produced by solar panels only without any interference from the grid, and the surplus energy is saved in a battery to be used at the time of shortage. Part of the energy is transferred from the solar panels to the inverter and turns into alternating (AC) voltage and is used at home, and the other part is transferred to the battery and stored for use when needed.

In the ON system, electricity is produced by solar panels and from the grid. Energy is transferred from the solar panels to the inverter and turns into alternating (AC) voltage and is used at home as Off-grid (figure 4).

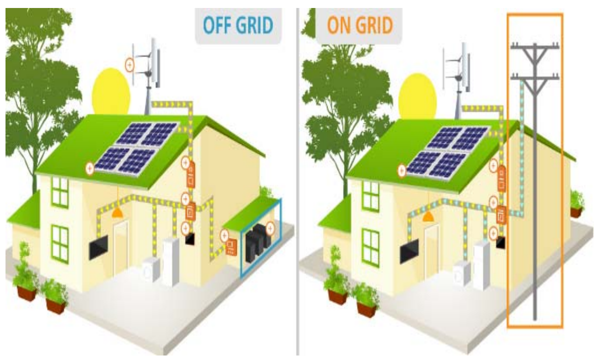

Fig. 4: On-grid & Off-grid systems

Although integrations and differentiations are easier to do analytically, analytical models play a significant role in facilitating machine analysis.

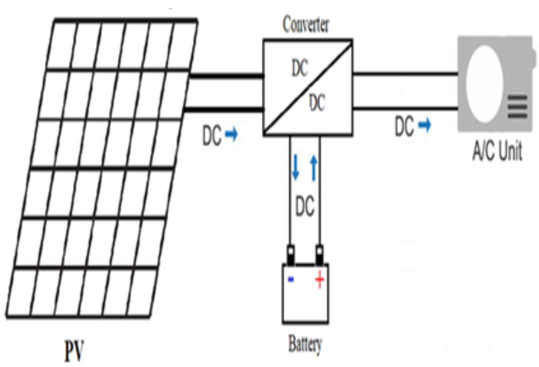

Fig. 5. Representation Model of the off grid system

In the first calculations of machine torque, where a trade-off between model accuracy and computation time may be made, they can be of significant assistance. Efficiency in these calculations is necessary for the better selection of machine drive.

This is the simulation model for the overall system, along with the parameters used for the global optimization enhancement.

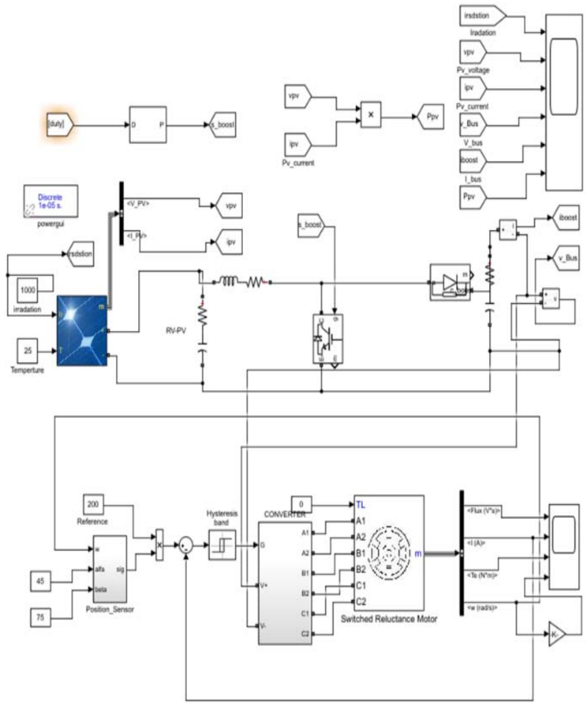

Fig. 6. System Simulation circuit

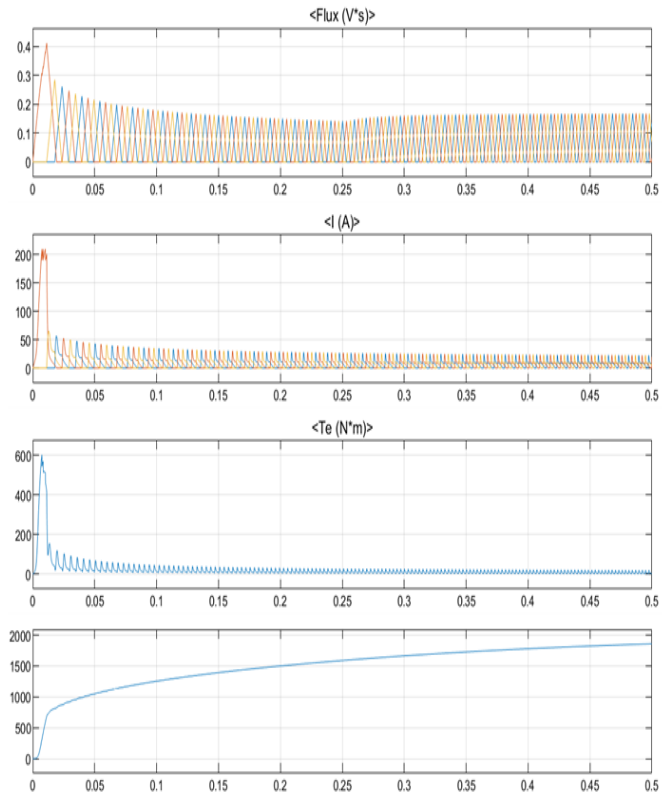

Fig. 7. Performance of switched reluctance BLDC motor

This simulation demonstrates how to calculate the switching reluctance motor's efficiency. The model reproduces a whole AC cycle with the corresponding ideal

DC voltage and AC RMS current for a specific degree of solar irradiation. The ideal values based on the model solar characteristics are shown in Figure 6.

Figure 7 illustrates how using a BLDC motor with a trapezoidal drive results in greater efficiency. It shows that the designed drive system is very suitable for use with the air conditioner fan motor system.

The air conditioner fan motor system uses a BLDC motor in sine wave form with sinusoidal drive. The motor's DC connection, however, has a high voltage that demands a lot of power. Moreover, the vector power used by the sinusoidal drive is challenging to implement and results in a costly motor.

Conclusion

The purpose of this paper is to model and execute simulations of a solar PV powered DC air conditioner in order to fulfill the cooling demand in KSA. The efficiency of the system's operation is improved and increased by using the monitoring and control of the refrigerator. The refrigerator's power was turned off when an open, bare, or over laden unit was discovered. It is possible to directly power low power devices used in homes, offices, hospitals, etc. utilizing DC sources. Reviewing the simulation results for cooling requirements and PV with batteries revealed that most of them were unrealistic due to a dearth of pertinent data and ensuing assumptions about crucial elements.

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