Compressor Speed Variation toward Solar Display Cabinet Cooling System Performance

I. D. M. Cipta Santosa , I. G. N. Suta Waisnawa, I. G.A. B. Wirajati and P. W. Sunu

Mechanical Engineering Department, Politeknik Negeri Bali, Kampus Bukit Jimbaran Badung, Indonesia
idmcsantosa@pnb.ac.id

Abstract. The conversion of an alternating current (AC) motor-compressor of refrigeration system toward a direct current (DC) motor need to be good analysis to get better performance of the system. The compressor type changing can affect lower compressor work due to a changing refrigerant used and also power supply mechanism characteristics. However, this system will have better future because of the energy source that uses energy from photovoltaics which is one of the best renewable energies. The aimed of this study is to obtain the optimization coefficient of Performance (COP) of the DC refrigeration system by simulating compressor speed and airflow velocity for condenser cooling. The method used is an experimental method by making settings to adjust the compressor speed and condenser fan speed. As for the refrigeration system, temperature is measured at 4 (four) main points to analyze COP based on the concept of thermodynamics. The expected results are the COP characteristics resulting from the simulation of compressor speed variations. From the trend obtained, it can be analyzed to optimize the compressor speed and also the condenser airflow speed to get the most optimal performance from the refrigeration system for display cabinet allocation.

Keywords: Compressor Speed, Solar Display Cabinet, COP.

1 Introduction

Because of the need for good quality fish and meat for the needs of supermarkets and restaurants, it will increase the use of freezers or coolers for display cabinets. Along with this, energy use will also increase. Thus, efforts are needed to save energy by increasing the Coefficient of Performance (COP) of the system [1]. One way to save energy from using a display cabinet refrigeration system is to use new, renewable and sustainable energy sources [2]. With the efficient use of energy and energy that has low operational costs, this system will be able to compete well to be used to improve the quality of food products [3].

To get optimal performance from a direct current (DC) refrigerator system, designing a refrigerated display cabinet with a high-performance coefficient and low energy consumption has an important role to play in maximizing energy savings [4]. Compres-sors have a leading position in refrigeration systems using mechanical vapor compression in terms of energy consumption. Correct selection and adaptation of the

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compressor will increase the efficiency of the refrigeration system and reduce energy consumption to a large extent. Several studies have been carried out previously with the method of varying the compressor rotational speed. By providing variations in compressor rotation, the required electric current also varies, the refrigerant flow rate flowing in the system will also vary. With a modeling combined with standard test conditions, it shows that a system with a variation of compressor speed gets an efficiency of 15% compared to a conventional refrigeration system and a more stable temperature in the cooler room (compartment) [5]. Linear compressors can adjust the mass flow rate in response to system requirements to achieve capacity modulation. Numerical model of a variable speed system with variable displacement driven by a linear compressor to study the characteristics of the system, with an error of the model below 9%. From the overall characteristics, it is found that larger compressor strokes tend to have higher optimal refrigerant loads. It is particularly suitable for low-load vapor compression refrigeration systems using micro-duct heat exchangers and the development of control strategies for various applications [6].

In an environmentally friendly refrigerated display cabinet system with variable speed compressor technology designed to analyze the effect of fixed and variable speed compressor technology on the performance coefficient and total energy consumption. Widespread use of environmentally friendly cabinets, in systems with varying compressor speeds consumes 25.9% less energy [7]. The refrigeration compressor will experience power loss and cannot even be turned On or Off if the PV power plant suddenly fluctuates.

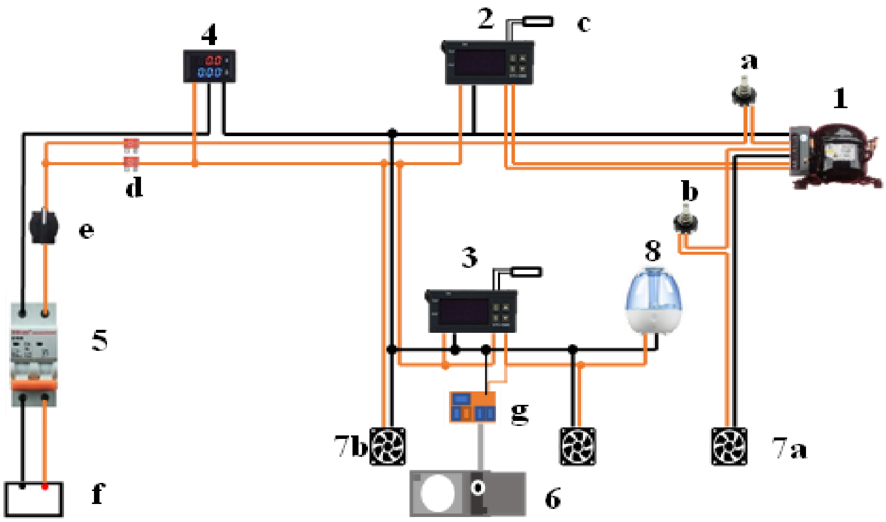
In the case of fluctuations in solar radiation to keep the system running continuously and stably, a proper system design is required to match the power consumption of the solar AC system to the proper PV capacity, adjusting the adaptive controller and compressor accordingly. The highest system COP reached 0.289 [8]. While research for a DC-based regeneration system so that the solar power system does not use an inverter can save energy significantly, namely the better performance on using DC over AC power source and the power consumption rate has a smooth pattern at the starting-on time until approach a rated power. The measured efficiency of the battery-load topology approaches 99% compared to that of the battery-inverter-load topology, which is approximately 78.5% [9].

Thus, the aim of this study is to obtain the performance of a solar DC refrigeration system with variations in compressor speed so as to obtain the COP characteristics of the compressor speed and also obtain optimum operation of the refrigeration system..

2 Methodology

2.1 Experimental Simulation of Compressor Speed Variation

The instrumentation system and the compressor speed variations are arranged in a way of working as shown in Fig. 1. This system is an electrical system with the way it works can be explained as follows. When the MCB (1) is turned on or in the ON state, the thermostat (2) will turn on, when the thermostat is turned on, the sensor (c) will detect the temperature in the refrigerator/compartment (6).



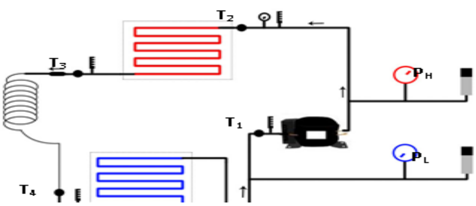
Legend:

1. compressor	a. speed controller
2. thermostat	b. speed fan controller
3. humidifier	c. sensor
4. multimeter	d. fuse
5. MCB	e. power switch
6. compartment	f. power supply
7. fan	g. terminal
8. humidifier	

Fig. 1. Schematic diagram of instrumentation and speed control.

If the sensor on the thermostat has not reached the set temperature, then the thermostat relay will change to normally close so that the compressor (1), evaporator fan (7a), condenser fan (7b) will turn on. And when the refrigerator room temperature has been reached as set, the thermostat relay will change to normally open so that it can cut off the current to the compressor, evaporator fan and condenser fan. The same system also applies to setting the hygrostat (3) to adjust the humidifier (8). Meanwhile, potentiators (a) and (b) are used to adjust the compressor speed and fan speed. and the compressor speed is calculated by approaching the ratio of the incoming electric current to the speed level set on the speed control.

Schematic installation of measuring instruments and instrumentation for measuring the refrigeration system using a data logger system which is recorded every 20 seconds with a schematic diagram shown in Fig. 2 below.



Legend:
1.T_1 = Temperature at point 1
2.T_2 = Temperature at point 2
3.T_3 = Temperature at point 3
4.T_4 = Temperature at point 4
4.P_H = High pressure
5.P_L = Low pressure

Fig. 2. Schematic diagram of refrigeration measurement.

2.2 Data Acquisition and Data Analysis

Before carrying out data collection for the DC refrigeration system with variations in compressor and fan speed, pay attention again to the machine to be tested whether it can run normally or not, and prepare the tools to be used, so that the data collection process runs well. Data collection was carried out by following the following test procedure:

- Prepare all measuring instruments that will be used for data collection.
- Installation of thermocouple measuring devices, multichannel thermometer displays with data loggers. With the test points are as follows:
  T_1 = Temperature at compressor inlet
  T_2 = Temperature at condenser inlet
  T_3 = Temperature at condenser outlet
  T_4 = Temperature at evaporator inlet
  T_5= Temperature at surrounding environment
- Check all equipment is functioning properly (normal)
- Ensuring that all measuring instruments are properly installed at predetermined points so that later will get accurate results.
- Turn on the system and turn on the data logger.

- After the system starts running, the data logger will record the results of the data on T1, T2, T3, T4, and T5.
- Tests were carried out, with load and without load, and the rotational speed of the compressor (step 1:1500 rpm, step 2: 2000 rpm, and step 3: 2500 rpm), condenser fan (step 1: 260 rpm, step 2: 520 rpm) were set by speed control.
- Pressure in high and low pressure line are measured by pressure gauge at compressor outlet and compressor inlet, respectively.
- After the no-load test is completed, the test will then be carried out with a 5-watt lamp load, with the same procedure repeating from the first step.

2.3 Coefficient of Performance (COP) Calculation

Equation (1) is The Refrigeration Effect (RE) is the heat received by the system from the environment through the evaporator per one mass of refrigerant rate. The refrigeration effect is an important parameter, because it is a useful and desirable effect of an engine cooling system.

$$RE = h_1 - h_4 \tag{1}$$

Where, RE is refrigeration effect (kJ/kg) and h is enthalpy (kJ/kg) . The amount of compression work (Wk) is equal to the difference between the enthalpy of refrigerant vapor leaving the compressor and the enthalpy of refrigerant vapor entering the compressor (Eq. 2).

$$Wk = h_2 - h_1 \tag{2}$$

Where Wk is compressor work (kJ/kg). Performance is a very important parameter in the cooling system, because the greater the price of performance (COP), the better the work of the cooling system (Eq. 3)

$$COP=RE/Wk \tag{3}$$

3 Results And Discussion

Based on the test results obtained, it has been analyzed into graphical forms of variations in temperature, pressure and compressor power input. Meanwhile, discussion or analysis is carried out based on COP characteristics obtained based on compressor speed and condenser fan speed. Results and Discussion are described as follows.

3.1 Data Acquisition Results

The results of data collection are shown in Figure 3 and Figure 4. These results represent one of the cases under test conditions with compressor speed step 3: 2500 rpm and condenser fan speed step 1: 260 rpm. The temperature setting condition in the compartment is 5°C, this is based on the working conditions of the display cabinet which ranges from 5°C to 10°C. As for the variation of compressor power, it is a variation of the consumption of the required DC voltage and current according to the operating conditions that are set.

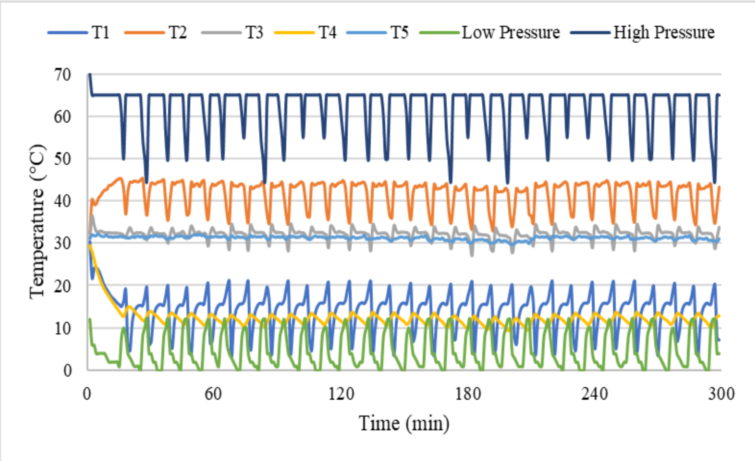


Fig. 3. Variation of temperatures and pressures with time (case: compressor speed step 3 and fan condenser step 1 with load)

From the characteristics shown in Fig. 3 it can be seen that the operational conditions of the system between the On and Off compressors are quite balanced because there is a load from the cooling system and also the condition of the compartment that uses glass for the needs of the display cabinet so that the heat transfer current from the environment to the compartment is quite high. This is an additional load from the cooler.

Fig. 4 shows the power consumption of the compressor shows that at the beginning of the operating system, it still requires high power because to achieve operating conditions at the desired setting. With the condition of the compressor speed of 2000 rpm with an average compressor input power of 60 watts when the refrigerator engine is running stably. This is due to the conditions at a moderate and constant speed so that the cooling rate is not too high. However, after the cooling conditions are reached, it will be stable for the On and Off conditions.

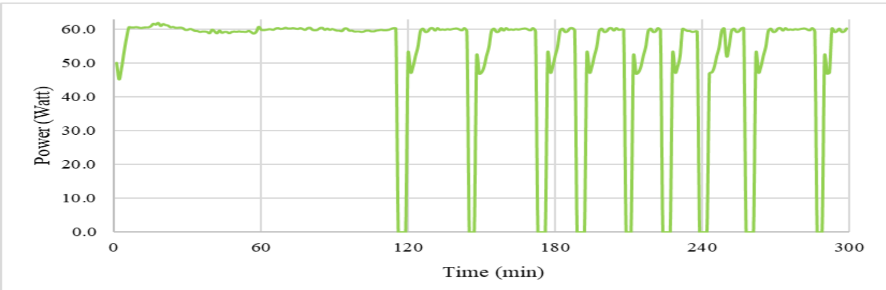


Fig. 4. Variation of compressor power consumption with time (case: compressor speed step 2 and fan condenser step 1 with load)

3.2 Analysis Coefficient of Performance (CoP)

From Fig. 5 is shown that the compressor rotational speed of 1500 rpm gets COP 5.98 which is lower than the compressor rotational speed of 2000 rpm which gets COP 5.81 and 2500 rpm gets COP 5.66, this shows that the higher the compressor speed the lower the COP that can be obtained by the refrigerator.

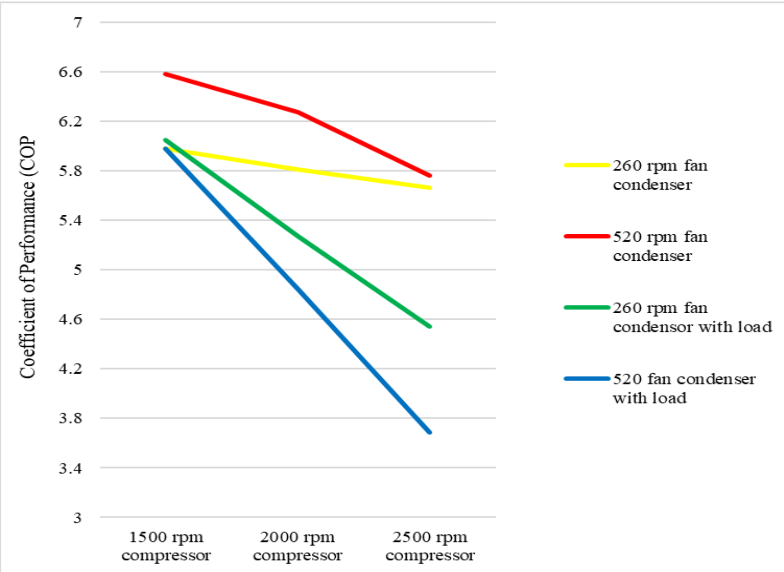


Fig. 5. Variation of compressor speed toward COP

The COP produced by a compressor speed of 1500 rpm with a condenser fan speed of 520 rpm is better than a condenser fan speed of 260 rpm, the same as a compressor speed of 2000 rpm with a fan speed of 260 rpm gets a COP of 5.81, and at a condenser fan speed of 520 rpm it gets a result of 6.27. the performance of the refrigerator engine decreases at a condenser fan speed of 520 rpm, so if this refrigerator engine is set at a compressor speed of 1500 rpm and 2000 rpm it is better to use a condenser fan speed of 260 rpm. At a compressor speed of 2500 rpm with a speed of 260 rpm, a COP of

5.66 is obtained, whereas if you use a rotational speed of 520 rpm, a compressor speed of 2500 rpm obtains a COP of 5.76, so it is better than a condenser fan speed of 520 rpm.

In testing with a compressor speed load of 1500 rpm with a condenser fan speed of 260 rpm, a COP of 6.05 was obtained and at a condenser fan speed of 520 rpm, a result of 5.98 was better than the previous fan speed. With a compressor speed of 2000 rpm and a condenser fan speed of 260 rpm you get a COP of 5.27, and at a speed of 520 rpm you get a COP of 4.84 which is better than a fan speed of 260 rpm, at a speed of 2500 rpm on the compressor and 260 rpm on the condenser fan you get a COP of 4.54, at a speed of 520 rpm get COP 3.69, it gets better when the condenser fan speed is 520 rpm.

Fig. 6 shows that the influence of the condenser fan speed affects the COP obtained by this refrigerator engine. In figure 4.26 with variations in the rotational speed of the compressor and condenser fan, different results are obtained, for example, a compressor rotational speed of 1500 rpm with a condenser fan speed of 260 rpm gets a better COP than a condenser fan speed of 520 rpm and it can be concluded that the compressor rotational speed of 1500 rpm actually it is better to use a condenser fan speed of 260 rpm when the refrigerator engine is without load.

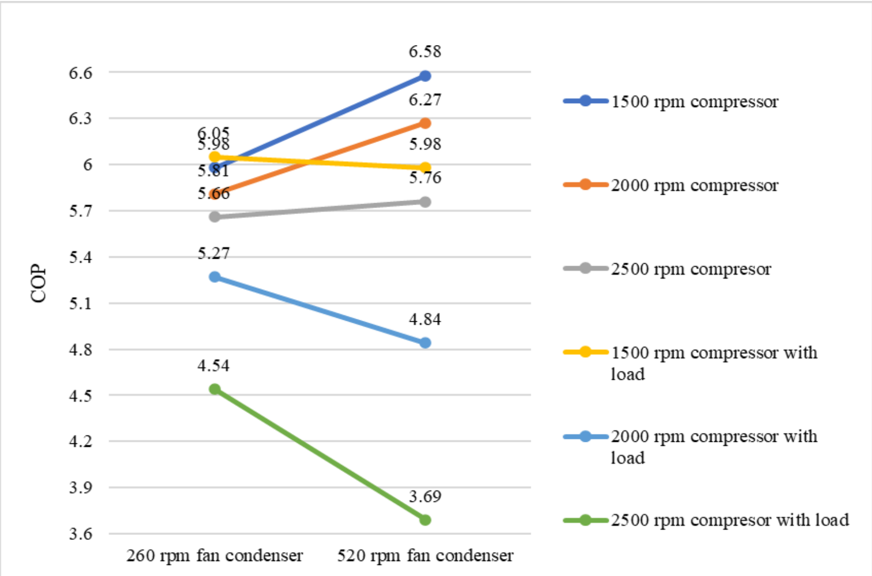


Fig. 6. Variation of fan condenser speed toward COP

At compressor speeds of 2000 rpm and 2500 rpm also get a better COP when using a condenser fan rotational speed of 260 rpm compared to a condenser fan rotational speed of 520 rpm, so a condenser fan speed of 520 rpm on this refrigerator engine at no load will make the COP higher from a speed of 260 rpm. Meanwhile, when the refrigerator engine is loaded with 5 watts of light, at a compressor speed of 1500 rpm with a condenser fan rotational speed of 260 rpm it gets a COP of 6.05 and at a condenser fan speed it gets 5.98 COP which means it is better to use a condenser fan speed of 520 rpm at a compressor speed of 1500 rpm , at compressor speeds of 2000 rpm and 2500 rpm also got a better COP when using a condenser fan speed of 520 rpm.

So, the refrigerator is more optimal to work at a condenser fan speed of 520 rpm when the refrigerator engine is under load, and this refrigerator engine is more optimal at a fan speed of 260 rpm when without load.

A decrease in COP due to an increase in compressor speed was also obtained with the same phenomenon that was studied by several previous researchers. Increasing the compressor speed can decrease the heating surface temperature but also decrease the coefficient of performance (COP). The highest COP at optimal conditions according to the system developed for both refrigeration and heat pumps. Vapor compression cooling system with a small capacity for certain cooling needs is obtained optimal speed at 3000 rpm [10, 11, 12]. But there is also research that gets compressor speed optimization when the average compressor speed decreases from 2910 to 2650 rpm, the average system performance coefficient increases by 7.5%. In addition, the compressor speed acceleration mode allows to stabilize the evaporation temperature, and the compressor speed deceleration mode allows to stabilize the compressor power [13,14]. Other experiments were carried out on variable speed operation and four different compressor constant speed operating modes. Temperature, pressure and power input measurements are obtained every 30 seconds. The researchers' experimental data were previously analyzed in terms of energy efficiency and exergy. The comparison shows that the variable speed operation of a direct current compressor can be much more efficient than the constant speed operation of a direct current compressor, especially at higher speeds [15].

4 Conclusions

Based on the results of the experimental tests and analysis that has been carried out above and referring to previous studies, it can be concluded as follows:

- From the performance test results of variations in compressor speed in DC refrigeration systems, the higher the compressor rotation speed, the lower the COP obtained.
- The effect of the condenser fan speed on the performance of the DC refrigeration system is that when the engine is running without load, using a condenser fan speed of 260 rpm will result in a lower COP than a fan speed of 520 rpm. Whereas when the engine is running using a 5 Watt light load with a condenser fan speed of 260 rpm, the COP results are higher than the fan speed of 520 rpm.
- To achieve optimization of energy saving, it is recommended that the speed of the DC compressor for vapor compression refrigeration applications is a variable speed because it can be adjusted according to the cooling load, when the cooling load is still high, the compressor speed is high to achieve a higher cooling rate, but when the cooling load is low then the compression speed is also low to get a higher COP. Meanwhile, a fast condenser fan speed can increase the heat transfer coefficient of the condenser.

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