Analysis Performance of Full Direct Current (DC) Refrigerator Medium Temperature

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Keywords: DC Refrigerator, Performance, Medium Temperature, Cold Chain.

Abstract: The development of solar power systems in the tropics is very important as a good alternative energy of conventional fuels (fossil). In addition, the rapid development of batteries become a good new to improve the performance of solar energy storage. Thus, the refrigeration system with a direct current (DC) system is very well developed. This study aims to obtain the optimum performance of the medium temperature refrigerator DC system with solar energy sources using batteries directly without an inverter. With this method, it is expected that the system can be more efficient from energy loss of DC current to AC current conversion. This research is an experimental research which was conducted by built a test rig consisting of two main equipment, namely a DC current refrigerator system and a solar power system. The test was carried out in the Bali-Indonesia region according to the conditions of the intensity of sunlight and the refrigerator system was tested with a load of fresh vegetable products. The results of this study found that the DC refrigeration system was able to work well with COP of 3,6. From these results it can be concluded that this system is very feasible to be developed along with the development of electrical energy from solar power. This system is also very feasible to be developed to support the cold chain system in Indonesia to improve the quality of fresh vegetable and fruit distribution.

1 INTRODUCTION

Refrigeration system is very important to be developed in order to get health and fresh food preservation, especially fresh fruits and vegetables. However, investment cost of refrigeration systems in developing countries are still relatively expensive (Santosa, et al., 2020a). One of the best solution is develop a renewable energy system, especially solar energy to drive the refrigeration system. This is because of during the day refrigeration system need high energy consumption and at the same time the energy output from the sun also reaches its peak (Santosa, et al., 2021). As a tropical region, Indonesia is very suitable to develop and innovate solar energy systems. From various previous developments, it was found that a solar power system to drive the refrigeration system is very compatible with an integrated energy source system with conventional electrical energy sources. Innovations for the efficiency of the refrigerator system have also been developed, such as with a natural humidifier in combination with a solar energy source. As well as with the efficiency of heat transfer in the main components of the refrigeration and air conditioning system (Santosa, et al., 2020b, 2020c).

Conventional refrigerator systems which driven by solar power systems has been studied for Gupta et al., (2014), Bilgili, (2011) and Modi, (2009). The research was conducted by developing off grid (stand-alone) solar panels for conventional refrigerator systems. The solar power system was analysed according to the capacity of the refrigerator system and it was found that solar power is very suitable for the refrigerator system. The system was further redesigned with a battery and inverter system. From the test results, the average coefficient of performance of the refrigerator system is quite good, which is around 2.1. However, there are still economic constraints which still require relatively

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Santosa, I., Waisnawa, I., Sunu, P., Suarsana, I. and Wiguna, I.
Analysis Performance of Full Direct Current (DC) Refrigerator Medium Temperature.
DOI: 10.5220/0010939600003260
In *Proceedings of the 4th International Conference on Applied Science and Technology on Engineering Science (iCAST-ES 2021)*, pages 41-46
ISBN: 978-989-758-615-6; ISSN: 2975-8246

expensive investment costs, because the price of batteries is still relatively expensive. Furthermore, it is recommended to emphasize as a follow-up for urgent matters from the government, that the system cannot survive economically if it is not given appropriate incentives which are calculated around 15% of investment costs (Opoku et al., 2016).

One of the most important things to do is how to optimize the solar power system and the energy efficiency of the cooling system applied. One of the variables that has been studied is the comparison of system efficiency between 12 V and 24 V DC systems which are operated at temperatures of 25 ° C and 35° C. From the results of this study, it is found that the comparison of operating a DC 12 V refrigerator is much more efficient than the operation of a 24 V refrigerator. V (Daffallah, 2018). Another thing that has been studied is from an economic point of view, which compares the solar power supply system used for an AC refrigerator operating system with an inverter and a DC refrigerator without an inverter. The results showed that the DC refrigerator has the potential to reduce the overall system installation cost by 18% compared to the AC refrigerator. And it is also recommended that for an off grid solar power system it is more economical to use a DC refrigerator than an AC refrigerator (Saliliha and Birhane, 2019). Reducing energy consumption in the refrigerator system is also carried out with good control of the load from the system. refrigerator energy consumption is affected by room temperature, door opening and thermostat setting. Another thing is that it is necessary to reduce energy consumption by reducing the capacity of PV generators and batteries. This optimization reduces the cost of autonomous PV installations and helps generalize renewable energy in the domestic refrigeration sector (Ouali et al., 2016).

Research to perform optimization with the variable speed method has been investigated by (Su, et al, 2020; Xua, 2017). The method used is to model variations in the performance of the refrigeration system by determining the compressor speed variation. The analysis and simulation results show that the refrigeration cycle COP for is around 2.25 when the compressor is running at low speed, and the COP drops to the lowest value of 1.85 when the compressor is operating at the highest speed (Su, 2020). Furthermore, because the system directly uses the solar power system, the radiation intensity has a significant effect on system performance. With the increase in radiation intensity, this is certainly very beneficial for system operations in the tropics (Xua, et al, 2017).

Based on the above literature review, it can be summarized that solar energy sources are very eligible for the operation of the refrigeration system. However, the conventional refrigeration system (with AC current) is still constrained by the relatively expensive investment costs associated with the cost of batteries and inverters. While the innovations that have been made to overcome this and at the same time to improve the performance of the refrigeration system are by developing a system based on full direct current (DC), innovating for load and infiltration efficiency, and investigating compressor rotational speed. Thus, this research aims to obtain a DC refrigerator system that is directly supplied with energy from photovoltaic so that it can be more efficient in terms of operational costs and investment costs.

2 METHODOLOGY

This research is an experimental research, where the method is divided into two parts including the experimental rig and the measurement method as well as data analysis.

2.1 Experimental Rigs

In general, experimental rig is explained with a schematic diagram shown in Figure 1 as follow.

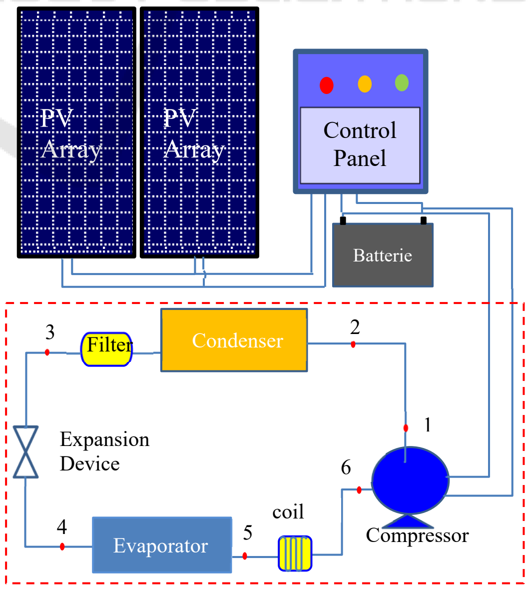
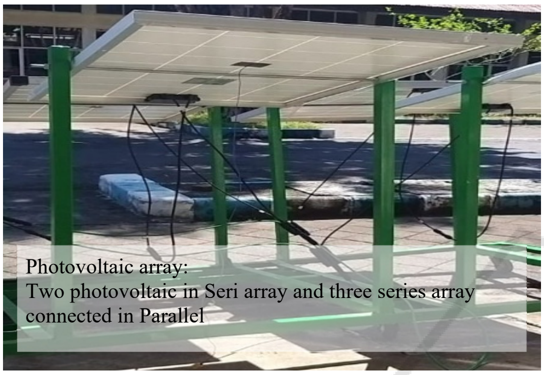


Figure 1: Diagram schematic of experimental rig.

This research is an experimental study with two main types of equipment, namely: a solar power generation system (Photovoltaic) and a medium temperature refrigeration system with direct current (DC).

Photovoltaic is assembled with an "off-grid" or stand-alone system equipped with an energy storage system with a battery. This system was chosen because to get a complete test to drive the direct current (DC) refrigeration system directly. DC refrigeration system is a medium temperature system with cooling capacity up to -5 ºC. The overall experimental rig system design is shown in Figure 2 as follow.



(a)

(b)

Figure 2: Test rig: (a) Photovoltaic array, (b) Full DC refrigeration system.

The photovoltaic circuit uses a series and parallel circuit system with a slope of 15º north. For the battery/ battery charging control system using a system with Solar Charge Control (SCC). This SCC controls the battery charge and can control the supply of DC current directly from the photovoltaic system.

While the refrigerator system is a system with a direct current (DC) system as a whole. The refrigerator prototype was built with an experimental rig to facilitate testing and improvement. For the design of the DC refrigeration system, the main components have been designed consisting of a DC compressor, condenser, evaporator, capillary tube, cooling room box which is made with a special frame to be tested continuously with the AC refrigerator system. The system is also equipped with a natural humidifier system with a monitored hygrostat system. This system is used for storage at medium temperature conditions with temperatures up to -5 ºC and 95% humidity. This humidifier system is operated on and off with a timer control and an automatic opening and closing mechanism for the duct.

2.2 Data Acquisition and Analysis

Data collections are shown in Figure 3 and Figure 4. In Figure 3 show the measurements state from point 1 to point 6 in the refrigeration system. While in Figure 4 show the positions of cabin room temperature (T7 and T11), and product temperature (T8, T9, T10). The instrumentation and measurement devices were already calibrated very well. Meanwhile, secondary data were obtained from other previously published journals and references.

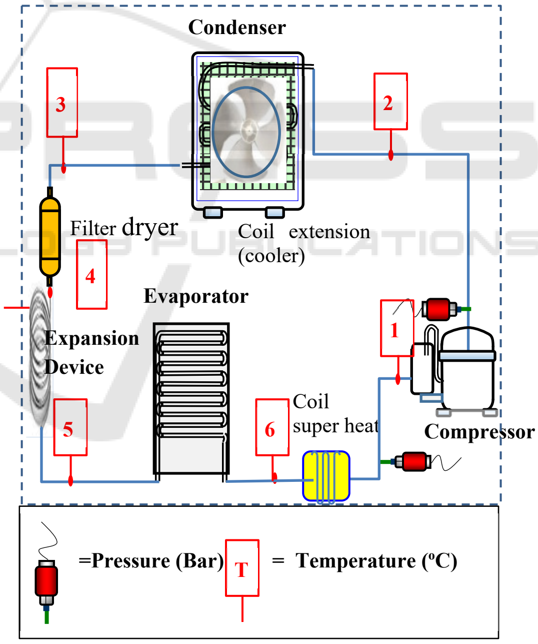


Figure 3: Temperature and pressure measurement on refrigeration system.

The data analysis method is carried out with statistics that can be shown by pictures, graphs or tables. The results of the analysis will be used as a reference for planning the optimization and efficiency of the use of solar power for the electricity consumption needs of the refrigerator system. Data analysis will use the help of several computer programs, namely: cool pack, PVSys, and spread sheet.

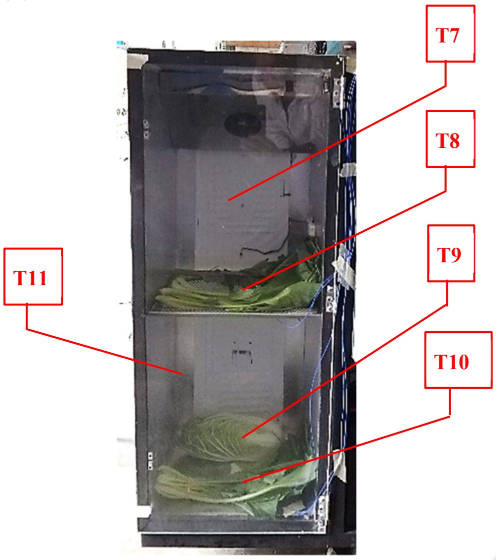


Figure 4: Temperature measurement positions on cabin and products.

The temperature is measured using a type K thermocouple, a pressure transducer with a voltage signal. Environmental conditions are measured using a special logger which includes air temperature, humidity and dew point. The thermocouple has an accuracy of +/- 0.5K, humidity +/- 0.5%, and pressure (voltage output) 0.08%. The pressure sensors use pressure transducers that are connected to a data logger. Voltage, electric current and solar intensity are measured separately with a digital system.

Data collection is carried out with loggers and by using high-precision instrumentation and measuring instruments. The research was carried out at the Refrigeration Lab, Bali State Polytechnic because some very necessary facilities are available in this Lab. The refrigerator testing procedure is carried out using a cooling load and without a cooling load.

Data is logged every 2 seconds and stored on the laptop. All experimental data is imported into spread sheets for easier calculation and analysis using simple statistical methods. Data is tabulated in tables as well as in graphs. The coefficient of performance (COP) of the system was calculated using the @Coolpack computer program and analysed. The effect of operating natural humidity is also observed in detail.

3 RESULTS AND DISCUSSIONS

Based on the testing procedure on the refrigeration cycle system, setting the test temperature is done at a temperature of 0°C. The results of the data logger are shown in the following tables and graphs Data is obtained from a complete data logger and data on the performance of the refrigeration system is taken during the most stable test as shown in Figure 5 and Figure 6 as follows.

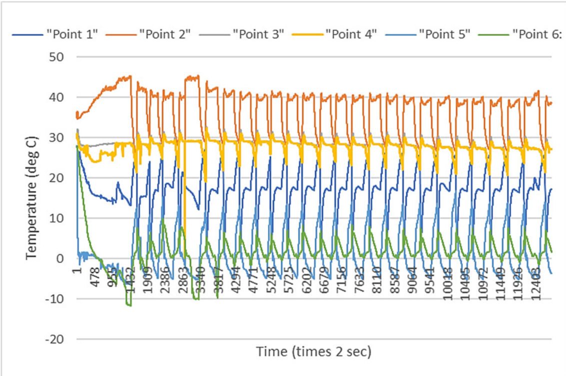


Figure 5: Temperature characteristic of refrigeration cycle.

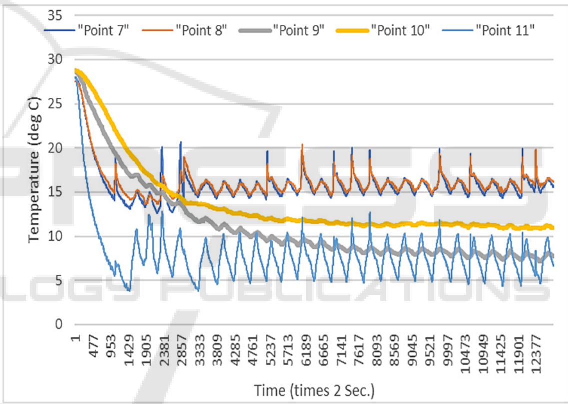


Figure 6: Variation temperature of cabin and products.

In Figure 5 can be seen that the compressor works very optimally according to the "on and off" control setting condition. Furthermore, the average operation temperature on each point or stage is shown in Table 1. In addition, in Figure 6 is shown the temperature condition in cabin and product (fresh vegetable). It can be seen that the temperature different between near evaporator position and near door position is slightly high at around 3°C, an also temperature different between upside and downside cabin at around 6°C. This problem can be solved with better insulation on the cabin.

In term of the theoretical Coefficient of Performance (COP) calculation is based on the average temperature and pressure conditions when operating (on) excluding when the compressor is off in each state with the type and specification of refrigerant using refrigerant-R600a. The conditions for each state (temperature and pressure), sub-cooled and super heat conditions for calculating the average theoretical COP are shown in Table 1.

Table 1: Average State condition during operation (compressor on).

Point	Average value	Point	Average value
T_1	7,4 ºC	P_h,T_{sat}	5,2 Bar, 40ºC
T_2	45 ºC	P_l , T_{sat}	1 Bar, -12ºC
T_3	33,0 ºC	RH %	95%
T_4	31,0 ºC	T_{sh}	19 K
T_5	-5,0 ºC	T_{sb}	7 K
T_6	-0,2 ºC		

From the data and calculations in Table 1, it can be seen that the condition of the degree of superheat (T_{sh}) is very good and it is very convincing that the evaporator capacity and compressor performance are very good and the condition of the refrigerant entering the compressor is really in a superheated vapor condition. In terms of the degree of sub-cooled, it is slightly higher (general standard 3K-2K) this is because the installed condenser capacity is slightly larger than the required capacity, considering the availability in the market for fin and tube type condensers. Meanwhile, the COP of the refrigeration system as a whole is 3.63. This COP for the medium temperature refrigeration system is quite good and can be improved again by improving the insulation in the cabin. Calculation of COP with @Coolpack is shown in the following figure.

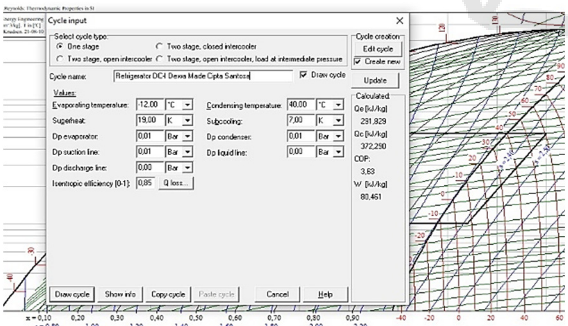


Figure 7: The COP analysis using computer program @coolpack.

4 CONCLUSIONS

Based on the above result and discussion, it can be concluded that the refrigerator system with total direct current (DC) has a good performance which indicated by the COP is 3.63. This COP can be considerable very good if compare with the conventional refrigerator system (alternating current-AC). However, to improve the optimisation of the system, it needs to be done with better insulation on cabin this is indicated by the temperature different between up and down part in cabin is slightly high at around 5ºC. And because of still development, this refrigerator DC has only been developed for household capacity.

Finally, it can be recommended that the refrigeration DC system has the advantage of being more efficient because it does not use an inverter which has significant electrical power losses in the solar power system circuit. This system will be very suitable for use in areas in agricultural centres with limited access to electricity networks as well as in hotels with integrated solar energy sources. However, this system still uses a battery so there is an additional investment for the battery. However, with future battery technology that is more sophisticated and mass production and battery life will be longer, this expensive investment cost analytically can become cheaper.

ACKNOWLEDGEMENTS

This research was supported by the Directorate of *Sumber Daya*, DIKTI, Ministry of Education, Culture and Research Technology, Indonesian Government, Grant No: 180/E4.1/AK.04.PT/2021 and 29/PL8/PG/2021 for the in cash contribution. The authors wish to acknowledge the contributions of The Mechanical Engineering Department -Bali State Polytechnic for the in-kind contributions. Also, Centre for Research and Community Service (P3M-PNB) for all administrative support.

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