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DESIGN AND EXPERIMENTAL STUDY OF AIR CONDITIONING SYSTEM USING BRUSHLESS DIRECT CURRENT (BLDC) COMPRESSOR IN NATIONAL ELECTRIC CAR

Nasruddin[1*], Hotdian Sinambela[1]

[1] *Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok, Depok 16424, Indonesia*

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ABSTRACT

Electric car is one technology that is designed to reduce the risk of pollution that causes global warming but an air conditioning system is required to create thermal comfort for its users. Therefore national electric car (MOLINA) made by the University of Indonesia will use BLDC compressor for the air conditioning system. Cooling load calculation is required to design the air conditioning system. This research will calculate the cooling load of MOLINA UI and also select the compressor that will be used in the air conditioning system. Then, the air conditioning system that has been designed and built will be tested for its performance. In the performance test, temperature and flow velocity of MOLINA air conditioning duct will be measured. Then proceed with simulation of temperature distribution and air flow in MOLINA cabin. Moreover, the energy consumption of MOLINA air conditioning systems that is using a BLDC compressor will also be measured. Based on this research it is known that the value of the cooling load on MOLINA UI is 2894.12 Watt (9875.15 BTU/h), average energy consumption of air conditioning systems MOLINA UI without inverter is ranged about 540 to 857.3 Watts and efficiency of inverter is ranged about 84.7% to 89.4%.

Keywords: Air conditioner system; BLDC compressor; National electric car

1. INTRODUCTION

The car is one of the most common vehicle used by Indonesians. Commonly, cars use gasoline and biodiesel as their fuel. In a car engine, a combustion reaction will occur and it will produce gases, such as CO, CO_2, and others (Avallone & Baumeister III, 1996). These gases constitute some of the causes of the pollution that leads to global warming. This is the reason that more research on electric cars is required.

Air Conditioner is a complementary elements in vehicle that can create a thermally comfortable state by producing cold air (Kavanaugh, 2005). Besides, it is very useful in countries such as Indonesia, which has a tropical climate (Wong & Chow, 2001). An AC in a vehicle is needed to provide a level of thermal comfort for its users. The main AC components are compressor, condenser, expansion valve, and evaporator. The compressor is a component that requires the most energy to run the AC system to produce cold air. The compressor works to raise the pressure of the refrigerant, which serves as a working fluid to dispose heat from the system (Incropera & De Witt, 2007).

* Corresponding author's email: nasruddin@eng.ui.ac.id, Tel. +62-21-7270032, Fax. +62-21-7270033
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In cars that use combustion engines, compressors utilize the motor by using the belt coupling system. This coupling system causes a massive loss of energy due to friction, slip, and other factors. This coupling system is also used in some electric cars on the market. In cars, a compressor coupled with an electric motor uses energy from the battery.

The AC system of the national electric car (MOLINA) designed by Universitas Indonesia (UI) uses a different system than that existing on the market, which using brushless direct current (BLDC) compressor. This type of compressor can perform at a variable speed based on the load to be disposed in the car using cabin a module. Therefore, by using this type of compressor, it is expected that the energy consumption of an AC system can be reduced and become more efficient.

2. EXPERIMENTAL SETUP

The methods used in this research are a literature study, a simulation, and an experiment. This research can be divided into two sections: design and testing. The design stage will involve a calculation of the total load of heat that must be removed from the MOLINA cabin and will be designed the mounting of the AC components in the car through a simulation.

The testing phase will involve measuring the temperature and velocity of the AC ducts in the car cabin. Then, this phase will proceed to the simulation stage, which will involve a measure of the energy consumption of the AC system that uses a BLDC compressor (Sorenson, 1980).

The measuring instruments in this research that are used to measure velocity and temperature that blower will be produced, which is an anemometer type Lutron AM-4204, and to measure the energy consumption of the AC system, a Power Quality Analyzer (PQA) PW3198 will be used. The source of energy that drives the AC system will be GS type 190H52 batteries and a SOUER HDA-2000C type inverter will be used to change the direct current (dc) of the battery into an alternating current (ac).

The measurement of the flow velocity and temperature of the air coming out of the AC ducts will last for 11 min, because by that time, the temperature will already be fixed. For the measurement of power consumption, the measuring instruments that will be used are in the form of two pieces PQA. The PQA sensor will be placed on the cable that connects the inverter with the AC system modules, as well as on the cable that connects the battery to the inverter. In the measurement position between the inverter and the module, 1P3W settings will be used, and in the measurement between the battery and the inverter, direct current (dc) settings will be used. Before taking measurements in all phases, the sensor calibration must be done using a clam on the ac/dc 1000A. After the calibration process is complete, the measurement of the phase electricity consumption can be conducted by recording every second.

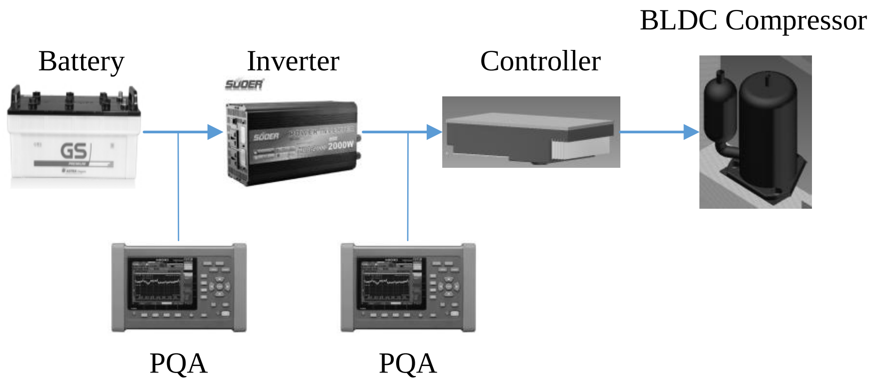


Figure 1 Setup of the experiment measuring the whole consumption energy and efficiency of the inverter

3. RESULTS AND DISCUSSION

3.1. Maximum Cooling Load of MOLINA Cabin

The cooling load must be calculated in the design stage to determine the specifications of the components that should be used. The calculation results show the maximum cooling load of the MOLINA cabin is equal to 2,894.12 watts. The total cooling load is obtained by calculating the metabolic load, the direct radiation load, the diffuse radiation load, the reflected radiation load, the ambient load, the exhaust load, the ventilation load, and the motor blower load (Vaghela & Kapadia, 2014; Zheng et al., 2011). Then, based on the cooling load, the compressor type GA092MA is selected with a maximum cooling load of 2,958 watts, and this compressor will be used in the cooling system of the MOLINA UI.

3.2. The Measurement and Simulation of the Flow and the Temperature Distribution of the MOLINA Cabin

The results of the measurement of the air flow rate and temperature on the AC duct in the MOLINA are 11.2 m/s and 7.1 m/s, respectively, with an exit temperature of about 18°C. The results of the flow velocity measurement show the highest speed variable that can be generated by the evaporator blower in the MOLINA UI.

Having obtained the velocity and temperature of the air flow, the next step is simulation of distribution temperature the MOLINA cabin with FLUENT, which aims to determine the flow pattern and temperature distribution in the cabin of the MOLINA UI. Regarding the MOLINA cabin, real parameters, such as the length and shape of the interior and the components contained in the cabin, have been cultivated in accordance with the actual situation.

When running the air flow rate and temperature distribution simulation, the author includes a parameter that corresponds with the design steps that have been conducted. A few of the parameters include: interval size meshing (20 mm), total meshing (1,922.090 cell), air viscous type (k-epsilon), air pressure when operating (1 atm), driver heat flux (0.017135 W/m^2), passenger heat flux (0.0110872 W/m^2), windshield heat flux (1134.61 W/m^2), side mirror heat flux (261.78 W/m^2), rear glass heat flux (261.78 W/m^2), upper body heat (34.2 w/m^2), side body heat flux (22.8 W/m^2), rear body heat flux (22.8 W/m^2), velocity of the inlet flow (5 m/s), angle speed of the inlet flow (45°), inlet temperature (18°C), and battery temperature (40°C). The boundary condition of the system can be seen in Figure 2.

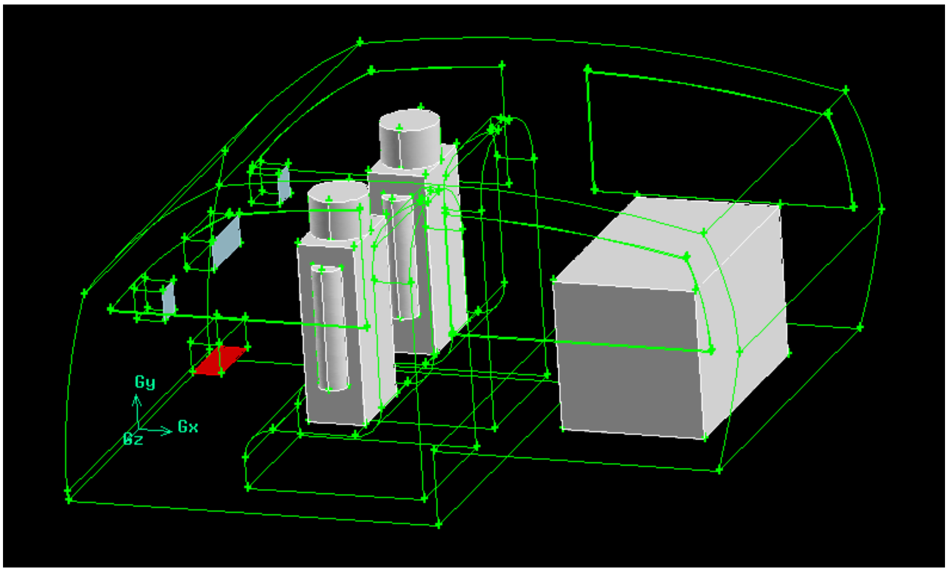
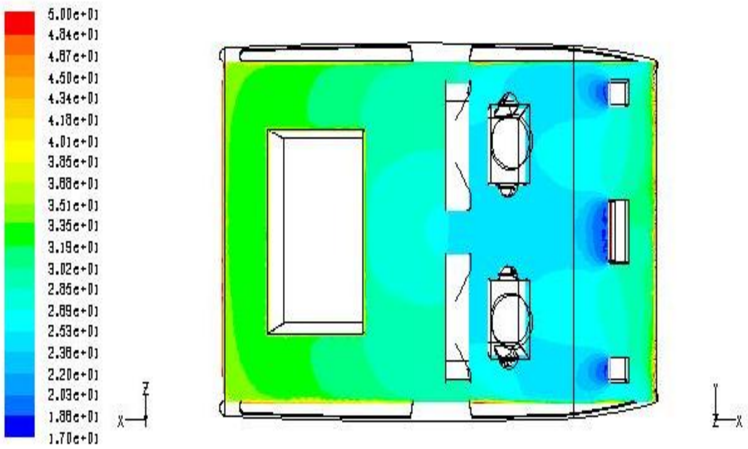


Figure 2 Boundary condition of the MOLINA cabin

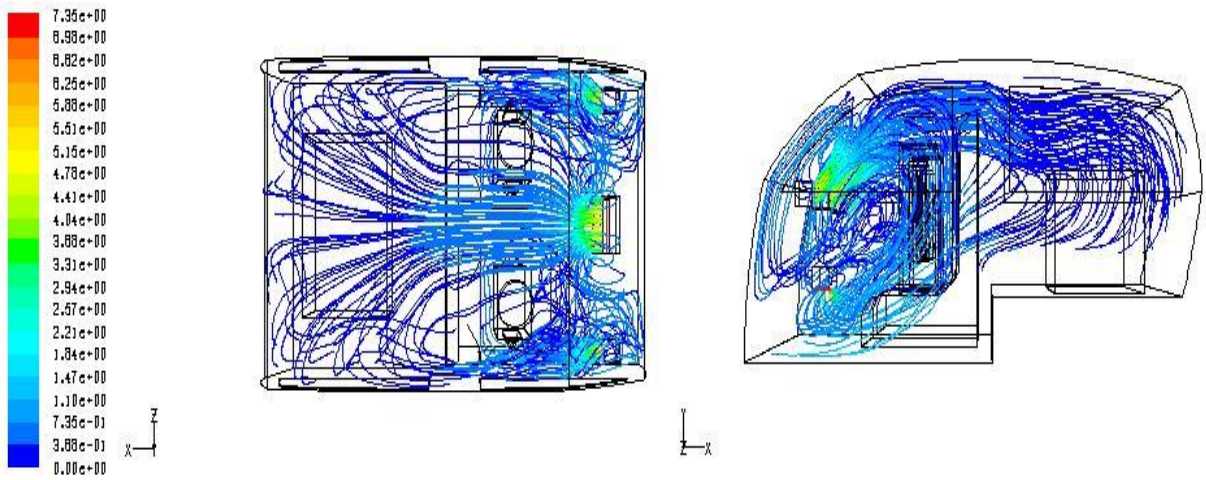
Then, the result of the simulation can be seen in the Figure 3.



(a) (b)

Figure 3 The MOLINA cabin temperature distribution contour: (a) top view; (b) side view

Based on the result of the simulation, it is discovered that the temperature around the MOLINA user in the maximum heat load ranges between 24°C and 26°C. The highest heat distribution will occur in the glass section, which has a temperature of about 48°C. Besides the glass section, the battery section also has a high temperature distribution due to the battery itself being around 40°C for its optimal working state. The result of the form of flow that occurs in the MOLINA cabin can be seen in Figure 4.



(a) (b)

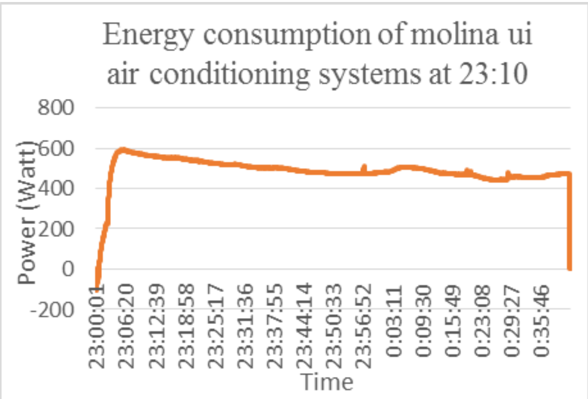
Figure 4 The Molina's cabin pathline flow: (a) top view; (b) side view

Based on the result of the simulation, it is discovered that the air flow rate around the MOLINA user is between 0.2 and 0.7 m/s. At this rate, the user should be expected to feel comfortable. The lowest air flow rate is found in the rear section of the car, which is around the car batteries. This occurs because the air flow output of the blower itself is not too high so as to cause the air to not fully reach the rear part. Besides, it is also known that by forming the flow at an elevated angle as great as 45°, the flow form will be diffused. In addition, besides that, by forming that angle, the temperature distribution diffusion will be more even because the cold air will drop down slowly to the lower part of the car. This is because the density of cold air is greater than that of normal temperature air, which tends to make the cold air move to a lower position.

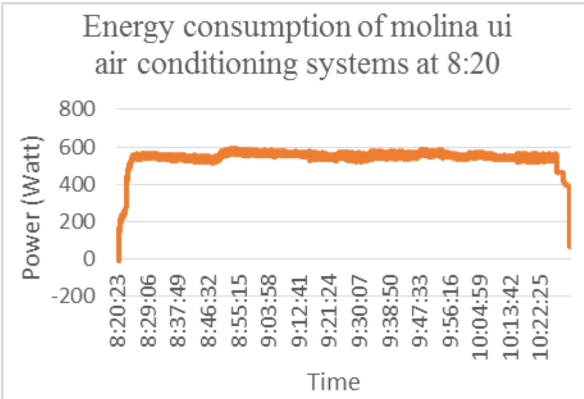
3.3. Measurement of the MOLINA AC System's Electricity Consumption

An electricity consumption measurement is intended to determine the total power needed to run the MOLINA AC system and to discover the efficiency value of the inverter that is being used. The energy consumption measurement from the MOLINA AC system is carried out at different times and also with different intensities of sunlight. The purpose of measuring under different circumstances is to determine the maximum consumption of the MOLINA AC system, to determine the energy range of consumption, and to determine whether the velocity control applied on the compressor can work well.

The energy consumption measurement in the MOLINA AC system is taken from when the MOLINA system starts working until the system stops working, which is caused by a drop in the potential difference of the battery that is being used, and the measurement will take place every second. The result of the measurement that was taken by the author can be viewed in Figure 5.



(a)



(b)

Figure 5 MOLINA energy consumption chart: (a) at night; and (b) in the morning

Based on the result of measuring the energy consumption above, it can be discovered that the MOLINA UI AC system when using a BLDC compressor and velocity control runs smoothly. In every energy consumption measurement, it is discovered that the diversity of energy consumption depends on the level of the imposition of heat that occurs in the cabin. The system without an inverter consumes a small amount of energy ranging between 490.32 W and 542.12 W. The imposition of heat is also small at night time and in the morning when the sunlight's intensity is still very low.

A different situation is shown when measuring the energy consumption of the system without an inverter on the next figure, which occurs in daylight and in the afternoon when the sunlight's intensity is at a peak, causing a much higher energy consumption ranging from 837.63 W to 855.7 W.

In the next measurement, the measuring instrument will be a two-piece PQA, where the instrument will be connected in before and after the inverter position. The measurement is taken to determine the whole system's consumption and to determine the efficiency value of the inverter. The result of this measurement can be viewed in Figures 6, 7, and 8.

Based on the data of the measurement above, it is discovered that the MOLINA AC system that uses BLDC compressors receives a considerably high amount of energy loss caused by the inverter that is used. The value of the inverter's efficiency ranges beteween 84.7% and 89.4%, where the efficiency value of a common electronic component ranges between 92% and 98%. With this data, it can be concluded that the type of inverter used in the current research is still less efficient and a replacement is still needed, so an AC system must be created that has a higher efficiency value.

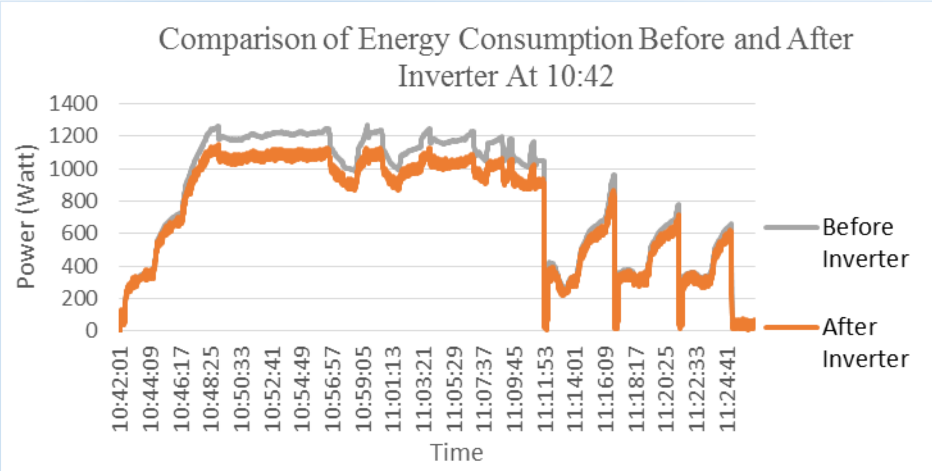


Figure 6 Whole energy consumption chart of the MOLINA AC system at 10:42

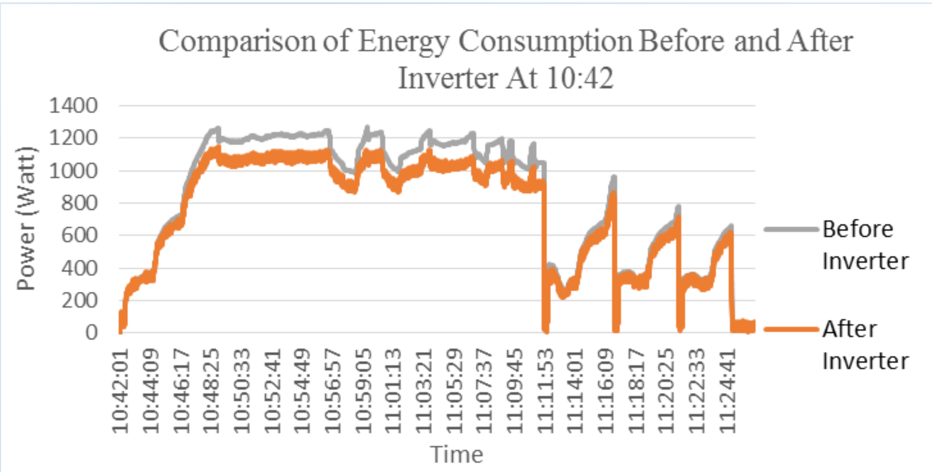


Figure 7 Graph energy consumption of the overall MOLINA AC system at 12:10

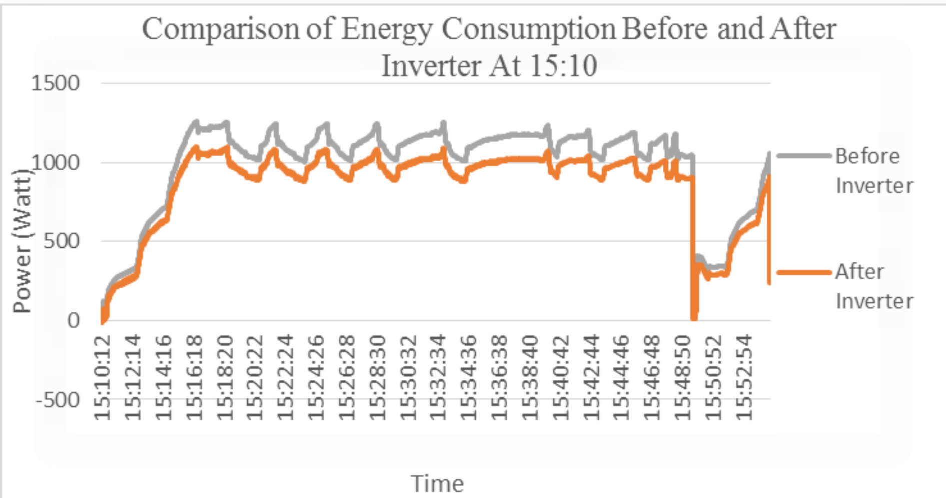


Figure 8 Whole energy consumption chart of the MOLINA AC system at 15:10

The value of the whole energy consumption of the AC system, including the inverter inside, ranges around 981.68 W, whereas in the MOLINA UI AC system, the value of energy consumption itself depends on the amount of the load contained in the MOLINA cabin.

From data in this research, some peaks will be found that occur because the maximum temperature of the system had been reached, so the work of the compressor will decrease and vice versa. Based on the data above, it can also be discovered that the type of battery being used is still inadequate to run the MOLINA AC system because of a rapid decline in the potential difference of the battery, even though its power has not yet been exhausted. This is shown in the system, which can be run again after the system has been stopped previously, even though the system has been running after stopping for a short period.

4. CONCLUSION

The amount of heat loading in the MOLINA cabin is 2,894.12 W. Therefore, the author used the LG GA092MA compressor. Then, the MOLINA AC system is worked using a new compressor that generates an output temperature from the AC duct ranging between 17°C and 19°C, and the highest compressor work and flow speeds ranged between 7.1 m/s and 11.2 m/s. Then, based on the simulation, it is known that the temperature around the MOLINA user ranged between 24°C and 26°C with a maximum heat load.

The energy consumption of the MOLINA AC system needs a maximum energy of 1.154 W at a standstill state and during daylight. During the morning and at night-time with the condition of a lesser amount of heat intensity, the AC system needs a power of 500–700 W for it to run, whereas the average consumption of the AC system with a BLDC compressor when neglecting the inverter ranges between 490.32 W and 855.7 W.

Based on the data results, the inverter that is used requires an average amount of power per hour around 981.68 W to run the AC system with the BLDC compressor. The value of work efficiency from the inverter in the MOLINA AC system ranges between 84.7% and 89.4%. Overall, this research has proven that by using the BLDC compressor in the MOLINA AC system, it can run smoothly, even though further research is still required.

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