Power consumption analysis on large-sized electric bus

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Abstract. The increase of greenhouse gasses effect is one of the causes of climate change. The use of vehicles with fossil fuels is one of the contributors to pollution and global warming. Another reason why dependence on it should be reduced is the lack of Indonesia's petroleum reserves compared to other OPEC countries. Researchers are trying to anticipate this by developing electric vehicles capable of operating without pollution. Implementation of electric vehicles has begun with the electric train, tram, electric bus, and others. Vehicles with rails get electricity supplies from the grid along the tracks, but the type of freely moving vehicle without a rail requires another way to get electricity supplies. Electric vehicles with power storage (battery) have an advantage in the roaming area if supported by proper recharging techniques. In electric vehicles, the battery is recharged by the direct charging process or swapped with other one (swapping). If the vehicle has high mobility, such as public transport (bus) then the shortest charging time may be very important.

1. Introduction

Global warming, air pollution, and reduced fossil fuel sources are global issues that need to be sought immediately. USA became the largest contributor of carbon dioxide in the world by 28%. The biggest source of pollution caused the greenhouse effect is CO₂ exhaust from conventional motor vehicles with fossil fuels. Not using vehicle based on hydrocarbon fuel (HC) is one way to reduce CO₂[1].

Another thing that is not less important is the decline in oil reserves Indonesia, whereas as a member of OPEC Indonesia’s oil reserves are among the smallest [2].

There is no 100% perfect solution, this is because the vehicle needs of each person or area will be different. Technical studies cannot be separated with socio-cultural studies. The results of a comprehensive study stated that the development of electric vehicles in the form of buses is the most strategic in Indonesia. The bus was developed to be a comfortable public vehicle so that the use of buses and private vehicles with fossil fuels is significantly reduced, especially in urban areas.

2. Research planning

The objective of this research is to design prototype of electric bus and to test its performance to fit the needs of load, route, and bus driving character. Thus, the most appropriate propulsion system, battery type and charging mode can be determined. The speed of the vehicle when testing is set maximum 40 kph. This speed can be a profile for electric buses with frequent stop and shorter shelter distance.

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Frontal cross-sectional area (apprx.) 8,16 m$^2$, aerodynamic resistance ($C_d$) 0,5328 [3], and rolling resistance 0,002. In addition, there is the assumption of the fluid type mass, and the elevation angle.

Bus is tested without passenger load and without operating cabin air conditioner (AC). Thus the devices that must be functioned are the main motor, compressed air motor, and power steering motor. This is a minimal condition for running a bus. The distance traveled about 4.4 km. This route has short distance between stops and short stop time.

3. **Theory**

The needs of the main electric motor (bus drive) is calculated by the traction power analysis of the vehicle. The traction force required to drive the vehicle is influenced by several resistances that act while the vehicle is moving as illustrated by the following equation [4] (figure 1).

$$F = m a + R_a + R_{rl} + R_g$$  \hspace{1cm} (3.1)

![Figure 1. Forces for traction calculation.](image1)

![Figure 2. Main motor integration system.](image2)

The value of vehicle traction with a certain speed is obtained by the formula [5]:

$$P_o = \left( m \cdot a + \frac{1}{2} \rho \cdot C_d \cdot A_f \cdot v^2 + f_{rl} \cdot m \cdot g + m \cdot g \sin \alpha \right) \cdot v$$  \hspace{1cm} (3.2)

The main voltage of the battery is supplied to the controller then to the motor. The bus uses a multi-motor system in which each mechanism is driven by one motor.

The BLDC 200 KW 380V is used as prime mover. Maximum torque that can be achieved around 700 Nm. Motor works on a voltage between 230 ~ 400 VDC. The motor rotation is then coupled and forwarded to the gear box. How fast is the motor rotates depending on the number of resistance from an acceleration pedal. This resistance value is still analog, then translated by CAN board into digital signal, processed and given priority to send. The signal value is forwarded to the BLDC Controller with the CANbus protocol (figure 2).

Power steering using hydraulic system (figure 3). The hydraulic pump is rotated by a 3 phase 380 VAC induction motor with a capacity of 7.5 KW. In the design of power steering that has been installed, although already using an electric motor as a driver but has not been controlled by sensors. The electric motor keeps rotating even when the bus is idle. Motor Power Steering is enabled with a button on the bus dashboard. This button (switch type) provides an enable or a disable signal to the motor inverter.

Compressed Air is filled into the reservoir with reciprocating pump (figure 4). The pump is rotated by an electric motor with a power capacity specification of 4.4 KW 380 VAC 3 phase. For power steering currents limited to a maximum of 22 Ampere, while air compressor limited to a maximum of 10 A.
The value can be calculated with guidance of specification data of each motor. The main values to be input to the inverter are the working voltage of the motor, the maximum current, the working frequency of the motor, the inverter activation method, the rotation direction, the acceleration and the ramp up & ramp down time. Address parameters can be seen in the inverter book manual [6].

The motor for compressed air operates under pressure sensor trigger. The motor works when the minimum pressure is reached and will stop when the maximum pressure is reached (intermittent rotating). While the power steering rotates continuously (non-stop).

4. Result and discussion

The bus is tested at 334 Volt (BLDC) / 339 Volt (PQA) battery voltage position. The result of the test of the electric bus that runs for about 4.4 km obtained the data of 108 volts, voltage drop based on data from BLDC Controller logger, and 109 volts based on Power Quality Analyzer (PQA) data. Running duration is 908 seconds or 15 minutes and 8 seconds (figure 5).

Recording results of both devices show similar results. At a 230 volts, voltage drop is almost no more. During the driving, power steering is continuously active while the compressed water is actively start and stop in accordance with the reservoir volume condition.

Power steering and compressed air loads make the impact of linear voltage drops tend to be linear. This shows that the load of the two devices is relatively constant throughout the test (figure 6).
Ripple or spike on the chart is a condition in which the steering wheel is rotated left and right actively as if it were a winding path. Voltage drops with "interference" because the battery load changes. Moments later the system was tested with the condition as if it were a straight path, figured on the graph that the relative voltage drop is subtle.

![Figure 7. Comp. Air Current Profile VS Time.](image1)

![Figure 8. P/SCurrent Profile VS Time.](image2)

During the test, the motor compressor is only 2 times off. The rest of the motor continues to rotate. The load during the active motor is relatively constant, except when the reservoir is almost full the graph indicates a slight increase in current. Another phenomenon is the existence of spike when the motor is active (figure 7 - A).

The minimum pressure on the pressure switch is set to 6 bar. At this pressure the motor will be active. The motor will stop filling the reservoir when the pressure reaches 8.5 bar. The test results do not show any lack of air supply due to the frequency of braking, clutching, or leakage.

Power steering (P/S) motor currents show almost uniform fluctuations in almost equal ranges (figure 8). Spike in range B is a test condition with a sharp twisty road. Range C when road conditions are relatively straight with no sharp turns or just a lane move. The spike occurs because of more load when sharp turn. The rest of the current consumption is relatively stable.

![Figure 9. Bus Eff. VS Motor Eff. Map.](image3)

![Figure 10. Bus Torque VS Motor Eff. Map.](image4)

When turning the steering wheel for parking maneuvers (figure 8 - range D), bus speeds are often almost zero, so the front wheel load proportion is still relatively large. In this condition the required torque from hydraulic power steering pump jumps high, in other words the electric current of the
pump motor must be larger. With improper driving techniques the motor will often over load and die. The calculation or redesign of the driving force is necessary.

The BLDC motor character attached to the UI electric bus has the best power efficiency (95%) in the range of about 3800 to 4800 RPM. At that rotation the power output is about 80 to 130 kW.

In the UI electric bus test, the required power is recorded on the logger. If the power value along the way is spread on the Power Efficiency Map [7], it can be seen that the efficiency value is in the range of 70% to 87.5%. Only a small percentage is in the 90% area (figure 9). This is in accordance with the conditions at the time of the test in which the internal bus route UI only requires low speed with engine speed around 1500 RPM.

In terms of torque, the BLDC motor character attached to the UI electric bus has the best efficiency (95%) in the range of about 3800 to 4800 RPM. At that rotation the torque is about 150 to 320 Nm.

If the value of torque along the way spread on the Torque Efficiency Map can be seen that the efficiency value is in the range of 70% to 87.5%. The required torque is spread below 300 Nm (figure 10). The UI bus test route and the relative load when test does not require large torque and the bus does not require high rotation due to the character of DC motor which has sufficient torque at low rotation.

![Figure 11. Power from BLDC Logger.](image1)

![Figure 12. Mech. Power vs Elec. Power.](image2)

The power during testing indicates irregular fluctuations (figure 11). Among the test time ranges are 4 to 5 times with the highest spikes. In the last minute the fluctuations were not too sharp. This completes other test data that indicates an almost ending battery voltage. If this data is combined with road condition data then it will get a more sharp conclusion.

Mechanical Power is theoretically power calculation while Electrical Power is the actual power taken from the BLDC motor data. In Mechanical Power chart shown that when the bus requires thrust or uphill then the value will go positive, while when the road decreased power also decreased even to the negative (figure 12). While on the Electric Power chart shown that the motor provides power in accordance with the needs with value from zero to the positive direction, whereas if the road decreases the power of the bus motor cannot be changed as regenerative power. That’s why the lowest value on the Electric Power chart is zero.

If observed, the output power of the calculation result (theoretical) in general has a higher average than the actual power (input) logged by the motor. Whereas in theory the output power should be smaller than the input power. This phenomenon will be investigated and analyzed further. The hypothesis is that the theoretical formula does not consider that in actual conditions the bus is only need power impulsively. Power is delivered until the desired speed is reached. After the acceleration pedal is stepped on and released, there is actually some power that causes the bus to stay up for a certain time.
5. Conclusion
1. The voltage drop is quite significant if the battery voltage is not in the maximum position
2. In pressurized air filling, an increase in current occurs when the charge is almost full due to an increase in pressure as a load
3. Power steering loads are relatively constant and small compared to main motor loads
4. Power efficiency is in the range of 65% to 80%
5. Torque efficiency is in the range of 75% to 82.5%
6. Further analysis is required to compare theoretical test results

6. References
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