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Performance Analysis of Battery Endurance in a Bldc Motor-Based Mini Electric Vehicle: a Case Study at the Electrical Engineering Laboratory, Universitas Pembangunan Panca Budi

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ABSTRACT

The development of electric vehicle technology continues to experience rapid progress, especially in terms of energy efficiency and power storage systems. One of the main components in an electric vehicle is the battery, which plays a crucial role in determining the vehicle's range, performance, and energy efficiency. This study aims to analyze the battery life of a BLDC (Brushless DC) motor used in a mini electric car prototype. Testing was conducted at the Electrical Engineering Laboratory of Panca Budi Development University with various load scenarios and operating times to evaluate battery life performance. The research method was carried out through an experimental approach by directly measuring voltage, current, temperature, and operating duration using a digital measuring instrument and periodically recording the data. The test results showed that the battery has optimal performance within a certain current range, but experienced a decrease in capacity as the load and operating temperature increased. From the test results, it was concluded that battery life is greatly influenced by operational conditions and charging system management. This study provides an initial overview for the development of a battery management system (BMS) and energy efficiency design in a laboratory-scale mini electric vehicle. Development recommendations are directed at temperature control and load power regulation so that the battery can be used more optimally and sustainably.

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INTRODUCTION

Human activities are currently experiencing significant developments, one of which is the development in the field of transportation. This is marked by the increasing demand for vehicles, which are used to support daily activities. In Indonesia, almost all existing vehicles still use petroleum as their primary fuel. A survey by the University of California shows that the use of fossil fuels such as premium, pertamax, and diesel has reached 3 million cubic meters per year, with a percentage increase of almost 20%. According to the opinion of a professor at the Surabaya Institute of Technology (ITS), Mukhtasor, it is estimated that by 2041, petroleum fuels will disappear from circulation if the use of this fuel remains high

(Kisworo, 2012: 3). Therefore, to limit the use of fossil fuels or oil, the Minister of National Energy implemented a policy outlined in Presidential Regulation No. 5 of 2006, with one of the main policies being energy conservation. By 2025, energy consumption from petroleum is targeted to decrease to less than 20% (Kompas Daily, 2013).

The rapid development of science and technology has given rise to the idea of creating alternative vehicles to replace fuel-powered vehicles, namely renewable, environmentally friendly vehicles. The discourse on environmentally friendly vehicles can be applied to vehicles that are used as a power source. Electrical energy is one of the alternative energy sources, which can be used as a substitute for fuel oil. Electrical energy itself is familiar in people's daily lives, because nowadays it has become one of the basic needs in society besides the needs of clothing and food. The flexibility of electrical energy in converting energy into other forms of energy (mechanical, heat, light) and its easy distribution makes it a primary energy choice. The need for electrical energy is increasing, in line with the increase in population welfare. The use of electrical energy, especially for household purposes, is also increasingly diverse, as a result of the offer of various household appliances that utilize electrical energy such as irons, refrigerators, water pumps and so on. The use of electric cars is considered to be more effective, because in addition to not causing pollution, their construction is also simpler, their sound is smooth, durable, and have high energy efficiency compared to fuel-powered vehicles. The overall efficiency of electric cars is 48%, while fuel-powered cars only achieve an efficiency of around 25%. Therefore, moving a vehicle with the same weight requires only 3 kilowatts of energy, which is much lower (Indoenergi, 2012). With this background, the concept of creating an electric car with a capacity of two passengers was born.

An electric car certainly requires several supporting components, one of which is an electric motor. In this case, the electric motor is the main component, which functions as the driving force in an electric car. There are several types of electric motors, so the advantages offered by each electric car that is driven also vary. Therefore, the selection of an electric motor applied as a driving system must be adjusted to the needs of the electric car itself. From various types of electric motors, based on observations that have been made, the Direct Current electric motor is used as the driving system in electric cars. The use of a DC motor (direction) as the driving system of the electric car, because it has advantages such as easily being able to be driven in two directions of rotation. This can be done, by changing the positive (+) and negative (-) polarities of the DC source voltage. In addition, DC motors also have a high rpm rotation chain, and the DC motor speed can be easily controlled to be adjusted to the required needs. Therefore, it is also necessary to analyze and study further, about the DC motor selected for use as the driving system in an electric car with a capacity of two passengers.

Literature Review

Electric Cars

An electric car is a car driven by an AC or DC electric motor. The type of electric motor used is a Brushless Direct Current electric motor or abbreviated as BLDC. This electric car uses electrical energy stored in rechargeable batteries or other energy storage devices. The electric motor provides instant torque, as well as creating strong and smooth acceleration. The first practical electric car was produced in the 1880s. Electric cars have several potential advantages compared to other conventional cars, the most important of which is that electric cars do not produce emissions like general vehicles that run on oil. In addition, electric cars also reduce greenhouse gas emissions because they do not require fossil fuels as their main driving force (binusuniversity, 2018). Below is Figure 2.1 of an electric car with a capacity of two passengers which is the work of Electrical Engineering students at the Panca Budi Development University, Medan.

Figure 1 . UNPAB Electric Car
Source: author 2022

Main Components of Electric Cars

Generally, the components of an electric car are the same as those of an electric car in general, except that the components of an electric car used by the work of UNPAB students are only DC electric motors, controllers, and batteries. However, the components of this electric car are considered much simpler than those of a regular car. This is because according to some people, electric car components only contain a few large batteries. In fact, there are other things besides batteries in the components of this electric car. The components of an electric car are batteries, induction motors, inverters (DC-DC converters), on-board chargers, and controllers. All of these electric car components have their respective functions and are quite important in the movement of the car. The main components of an electric car are divided into 4 types. All of these main components of an electric car have important functions, which is why they are called main components. Then there are the main components of an electric car that are usually found in an electric car. The following is an explanation of each important component in this electric car:

1. **Traction Battery Pack/Traction Battery**

The first main component of an electric car is *Traction Battery Pack* or commonly called Traction Battery. Traction batteries are made in a strong and sturdy form and their function is as a direct current or DC (Direct-Current) electrical energy storage system. Increasingly developed, now there are many types of traction batteries. However, the main components of this electric car are generally made of Lithium-ion Battery. And this type of Lithium-ion battery is the type of traction battery that is most widely used in electric cars today. The reason is, this type of battery is considered to have the best durability. More clearly about how it works, the main component of an electric car flows DC electricity to the inverter to rotate or move the traction motor when there is a signal from the controller.

2. **Controller**

The third main component of an electric car is*Controller*. There is a reason why the controller is the main component of an electric car. This is because the main function of the controller is to regulate the energy in the battery pack, as well as the inverter to then be distributed to the traction motor. More clearly, the controller works when there is input from the car's pedal which of course the pedal is controlled entirely by the driver. Then through this controller, the voltage and frequency entering the electric motor will be regulated to determine the speed of the car. So in other words, the controller as the main component of this electric car manages the flow of electricity generated by the traction battery, controlling the traction speed and output torque.

3. **Induction Motor**

As mentioned previously, the traction motor is also a key component of an electric car. The traction motor is an electric dynamo that plays a crucial role in the electric car's circuitry. The traction motor itself functions to provide rotational power to the transmission and wheels. Therefore, the traction motor is what, in other words, makes an electric car move. The traction motor and controller are interconnected, because when the controller supplies power from the traction battery, the traction motor for the electric car will work to rotate the transmission and wheels. Some hybrid cars use a type of generator-motor that functions as a driver and regeneration. The BLDC (brushless DC traction motor) traction motor is the most dominant application. Meanwhile, for electric cars of the BEV type, this component usually replaces the function of the internal combustion engine (ICE). Some electric car manufacturers use permanent magnet motors, and several other manufacturers apply three-phase induction types.

4. **Charger**

Another important component of an electric car is the charger. The charger is a supporting or complementary component for electric cars. As the name suggests, the charger's primary function is to recharge the electric car's battery pack. The BLDC motor of this supporting electric car works by utilizing the PLN AC electricity which is then converted into DC electricity to be stored in the battery pack. Like gadgets, chargers on electric cars are also divided into two types. On-board charger: This type of electric car charger is directly located and installed inside the car. Off-board charger: This type of electric car charger is located outside the car body. Thus, if an electric car is equipped with an on-board charger, the electric car can directly receive PLN AC current. Meanwhile, electric cars with off-board chargers cannot. This type of car must use direct current in the charging port.

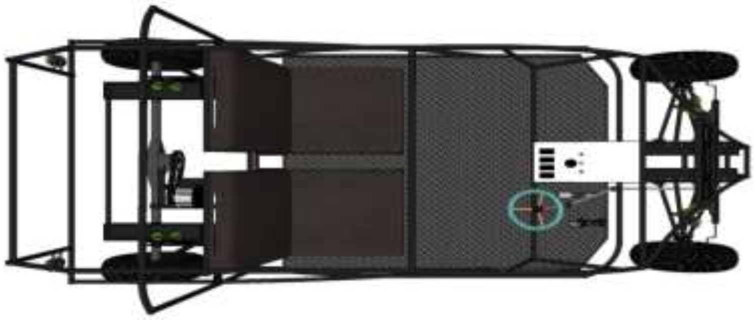

Figure 2. Contents of the UNPAB electric car components
Source: author 2022

BLDC Motor

According to Johan Wilberg (2016:11), a BLDC motor is a DC motor whose internal and external parts are swapped. In other words, the coil is on the outside and the magnet is on the inside. A BLDC motor is a DC motor whose winding and permanent magnet positions are swapped, namely the winding position is in the stator and the permanent magnet position is in the rotor. The rotor is the moving part and the stator is the stationary part. A BLDC motor can be driven using a three-phase semiconductor driver and the motor requires a rotor position sensor to start and make the correct sequential commutation to turn on the power source in the three-phase driver. For more details, see the figure below.

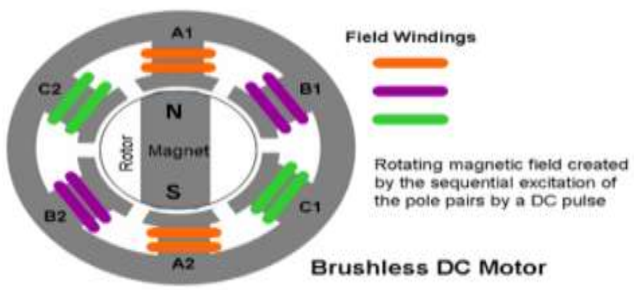

Figure 3. Brushless Direct Current Motor
Source: author 2022

From the image above shows that the position of the magnetic field is in the rotor part, namely the part that will move and the coil/winding is in the stator, namely the part that does not move. The winding consists of three different colors which explain that each color of the winding has a different phase, namely phase A phase, B and phase C or often also called phase U, phase V and phase W. Therefore, a three-phase driver/inverter is needed to generate the coil from each phase in the BLDC.

Abe Dharmawan (2009:5) states that in general, a BLDC motor consists of two parts, namely the rotor and the stator. The rotor is the moving part, made of permanent magnets, and the stator is the stationary part, made of three-phase coils. Although BLDC is a three-phase synchronous AC electric motor, this motor is still called a BLDC motor because in its implementation, the BLDC motor uses a DC source as the main energy source which is then converted into AC voltage using a three-phase inverter. The purpose of providing a three-phase AC voltage to the BLDC motor stator is to create a rotating magnetic field in the stator to attract the rotor magnet. Another opinion put forward by S. Rambabu (2007:8) states that a BLDC motor is defined as a permanently synchronized machine with rotor position feedback. BLDC motors are generally controlled using a three-phase semiconductor bridge circuit. The motor requires a rotor position sensor to start and make the correct sequential commutation to turn on the power source in the inverter section. Based on the rotor position, the power source commutates sequentially every 60 degrees. Based on the opinions of the experts above, it can be concluded that the BLDC motor is a type of synchronous motor. This means that the magnetic field generated by the stator and the rotor magnetic field rotate at the same frequency and speed. BLDC motors do not experience slip, unlike what happens in ordinary induction motors. A BLDC motor is an electromagnetic device that converts electrical energy into mechanical energy. Considering that a BLDC motor can be driven using a three-phase semiconductor driver and the motor requires a rotor position sensor to start and make the correct sequential commutation to turn on the power source in the three-phase driver, of course, a system is needed that is able to control the commutation according to the needs of the BLDC.

BLDC Motor Control

According to Johan Wilberg (2016:12), a normal DC motor is very easy to control the speed and direction. To control the speed, simply vary the input voltage. To change the direction, simply reverse the polarity. Speed is often controlled by pulse width modulation for DC motors and brushless motors. To operate a brushless motor, information from the rotor angular position sensor is essential. The BLDC motor control block diagram can be seen in

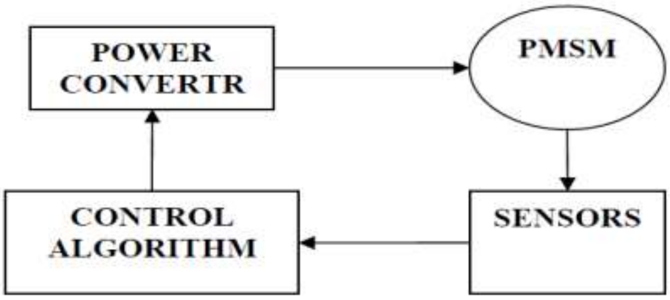

Figure 4. Block diagram of BLDC motor control
Source: S. Rambabu, Modeling And Control Of A Brushless DC Motor

The basic block diagram of a BLDC motor consists of four main components: a power converter, a Permanent Magnet Synchronous Motor (PMSM) sensor, and a control algorithm (S. Rambabu, 2007:9). The converter converts power from a source to a PMSM, which converts electrical energy into kinetic energy. One of the most interesting features of a BLDC motor is the rotor position sensor, which reads the rotor position and then uses it as a reference for commands.*timing commutation*on each semiconductor in the three-phase driver. The control algorithm functions as a controller for commutation changes that must be made so that the BLDC motor rotates. The control algorithm will receive the rotor position status relative to the stator sent by the sensor and provide an action in the form of output to the power converter. There are two methods in BLDC control, namely the conventional method or the six-step Pulse Width Modulation (PWM) method and the sinusoidal Pulse Width Modulation (PWM) method. The six-step PWM method is a method of providing PWM pulses in the form of trapezoidal waves, but this method is widely used in BLDC control. The second method is the sinusoidal PWM method, which is providing PWM pulses in the form of pure sinusoidal waves. However, this method is rarely used because of the complicated algorithm in generating sinusoidal PWM signals. The sinusoidal PWM generation process is done by comparing the sinusoidal signal with a triangular signal that has a higher frequency. To drive a BLDC motor, in addition to requiring a control system, an energy source in the form of DC voltage is also needed. DC voltage sources can be taken from a Power Supply, Generator, solar panels and batteries. In this study, researchers chose a battery as the DC voltage source.

PWM Six-Step Commutation Method

The six-step PWM method is a method of providing PWM pulses in the form of trapezoidal waves, but this method is widely used in BLDC control. In controlling BLDC motors with this method...*Pulse Width Modulation*(PWM) six step there are provisions that must be met in order to1963The system is running. These provisions can be seen in Table 2.1.

Table 2.1 BLDC Motor Control Provisions

Hall sensor A	Hall sensor B	Hall sensor C	Phase A	Phase B	Phase C
1	0	0	-VDCB	+VDCB	NC
1	0	1	NC	+VDCB	-VDCB
0	0	1	+VDCB	NC	-VDCB
0	1	1	+VDCB	-VDCB	NC
0	1	0	NC	-VDCB	+VDCB
1	1	0	-VDCB	NC	+VDCB

Source .Freescale, 3-Phase BLDC Driver Using Variable DC Link Six-Step Inverter

In Table 2.1 above, it can be seen that each phase required to drive the BLDC motor depends on the condition of the Hall sensor on the BLDC motor itself.

Hall Sensor

Hall sensors provide the information needed to synchronize motor excitation with rotor position to create a constant torque. These Hall sensors detect changes in the magnetic field. The rotor's magnets are used to trigger the Hall sensors. A signal conditioning circuit is integrated with a Hall switch that provides TTL voltage pulses with pointed tips. Three Hall sensors are placed 120 degrees apart and mounted on the stator wall. The Hall sensors' digital signals are used to read the rotor position. A block diagram of the Hall sensors is shown below.

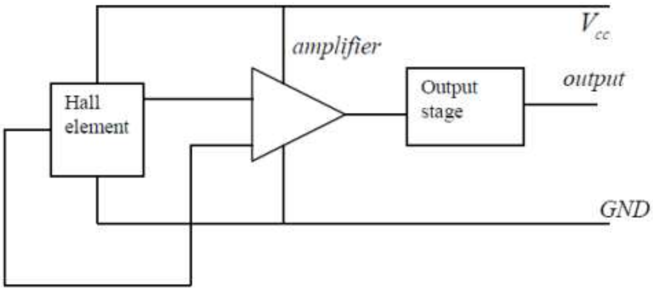

Figure 5. Hall Sensor Diagram
Source: Rambabu, Modeling And Control Of A Brushless DC Motor

RESEARCH METHODS

This research is an experimental study with a quantitative approach, aiming to analyze the performance and battery life of a BLDC (Brushless DC) motor used in a mini electric car. Testing was conducted directly in a laboratory environment using measurements.1964able1964structured electrical engineering. This research was conducted at the Electrical Engineering Laboratory, Panca Budi Development University.

The main objects in this research are:

1. Lithium-ion type batteries of a certain capacity (e.g. 12V/20Ah),
2. BLDC motors are used as the main drive in laboratory-scale mini electric cars,
3. Motor control circuit and1964able1964power monitoring.

Data collection is done through:

1. Direct observation during the test,
2. Recording of electrical parameter data such as voltage, current, temperature, and operating time,
3. Use of digital measuring instruments such as multimeters, data loggers,1964able1964digital meters, and DC wattmeters.

Test implementation steps include:

1. System Preparation
   Mini electric car assembly with battery and BLDC motor. Installation of sensors and measuring instruments for data recording.
2. Full Battery Charge
   Charge the battery until it reaches maximum capacity (fully charged).
3. Operation Testing
   Run the mini electric car with standard load continuously until the battery power runs out. Data recording every 1 minute or according to certain intervals: voltage, current, temperature, time, and distance traveled (if available).
4. Test Repetition
   Testing was carried out several times with varying loads (light, medium, and heavy loads) to compare battery life results under different conditions.
5. Data Processing and Analysis

The test results data are processed in the form of graphs and1965able. The analysis was carried out to determine the pattern of voltage, current, temperature, and battery endurance time against the BLDC motor workload.

Figure 6. System Flowchart

RESULTS

Data Testing Results

In this study, the battery used to test its performance is a Li-Ion battery pack with specifications of 72 Volt 20 Ah. Testing was carried out in three environmental conditions, namely heat, rain and night with a light load on the conversion vehicle. Testing was carried out three times each in each weather condition with a distance variation of 10 km and until the battery capacity reached 5% remaining.

The data collection process begins with preparing the tools and materials used during the test, then the test is carried out by driving an electric mini car starting from Building M of Panca Budi Development University to around 10 hectares of Unpab land with a maximum distance of around 30-40 km. In this data collection process, distances ranging from 10, 20, 30 km are used and until the battery is 5% remaining. To get a distance of 30 km, the electric motor will stop at every 10 km for the data collection process and this will continue to repeat until the distance of 30 km is reached. This testing process is carried out three times in environmental conditions namely hot, rainy, and night. This repetition up to three times is done to ensure the consistency of the measurement results and reduce the possibility of experimental errors.

The data collection in this study aims to analyze the performance of a 72 Volt 20 Ah assembled battery pack in an electric mini car under various conditions. Data was collected through a series of tests involving key parameters, namely distance traveled, travel time, initial-final battery voltage, initial-final battery capacity, State of Charge (SOC) percentage, battery working current, vehicle speed, and temperature (battery, MOS (BMS), and environment). Furthermore, the average of each parameter will be calculated to provide a general overview of battery performance in each test. The image below is documentation during the electric mini car testing process in progress.

Figure 7. Mini Electric Car Battery

The results of the researcher's trial will be carried out when the mini electric car is almost finished where the components have been installed from the drive system, brake light controller, etc. that have been installed. The purpose of this car trial is to see the power of the car, the speed of the car and to conduct inspections on all components of the electric vehicle, so that after it is finished, revisions can be made to this car and bring in experienced practitioners in their fields. After the trial is carried out, if there are any shortcomings found, they will be immediately revised or repaired again to obtain a final product that is roadworthy.

Table 1. Battery performance testing during the day

Testing	Distance Travel (Km)	Voltage Beginning-End Battery (Volt) V1	V2	Capacity Beginning-End Battery (Ah) P1	P2	Temperature (°C) Baterry T1	T2	MOS T1	T2
	10	82.9	79.3	16.7	13.7	32	35	36	38
1	20	79.3	73.1	13.7	9.3	35	39	38	42
	30	73.1	68.3	9.3	5.7	39	42	42	45

	42.03*	68.3	62.2	5.7	0.8	42	48	45	48
	10	82.8	78.4	15.1	11.5	32	39	38	42
2	20	78.4	71.4	11.5	7.8	39	42	42	45
	30	71.4	69.2	7.8	3.6	42	45	45	48
	37.28*	69.2	66.4	3.6	0.9	45	48	48	50
	10	82.2	77.5	13.5	9.7	33	39	33	42
3	20	77.5	71.2	9.7	5.7	39	44	42	48
	30	71.2	66.5	5.7	0.6	44	53	48	55

Note: * = SOC has reached 5% (battery energy is depleted)

Table 2. Battery performance testing at night

Testing	Distance Travel (Km)	Voltage Beginning-End Battery (Volt)		Capacity Beginning-End Battery (Ah)		Temperature (°C) Batterry		MOS	
		V1	V2	P1	P2	T1	T2	T1	T2
	10	82.6	78.6	12.2	9.1	30	33	36	39
1	20	78.6	74.3	9.1	6.2	33	33	39	41
	30	74.3	71.6	6.2	2.9	33	36	41	42
	35.91*	71.6	70.4	2.9	0.9	36	36	42	42
	10	82.9	79.8	11.5	8.5	33	35	38	39
2	20	79.8	75.6	8.5	5.2	35	36	39	42
	30	75.6	72.8	5.2	2.3	36	36	42	44
	34.41*	72.8	68.8	2.3	0.9	36	36	44	42
	10	82.8	78.3	10.7	8.2	32	33	36	39
3	20	78.3	74.9	8.2	4.7	33	36	39	42
	30	74.9	71.3	4.7	1.4	36	36	42	44
	31.53*	71.3	71.2	1.4	0.9	36	36	44	42

Note * = SOC has reached 5% (battery energy is depleted)

Table 3. Battery performance testing in rainy weather

	Distance Travel (Km)	Voltage Beginning-End Battery (Volt)		Capacity Beginning-End Battery (Ah)		Temperature (°C) Battery		MOS	
		V1	V2	P1	P2	T1	T2	T1	T2
	10	82.9	78.9	9.6	6.8	25	29	27	35
1	20	78.9	76.6	6.8	3.7	29	32	35	38
	29*	76.6	73.5	3.7	0.9	32	33	38	39
	10	82.8	78.2	8.9	6.1	27	29	27	35
2	20	78.2	75.8	6.1	3.2	29	30	35	38
	29*	75.8	73.9	3.2	0.9	30	32	38	39

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	10	82.7	79.5	8	5.2	25	29	27	35
3	20	79.5	76.1	5.2	2.1	29	30	35	36
	24*	76.1	74.3	2.1	0.8	30	30	36	38

Data Processing Results

Based on the data obtained from the test, the following average data results were obtained:

Average Battery Voltage Consumption

Battery voltage consumption can be calculated from the average voltage test results in table 4.4 below and the following is a sample calculation.

ΔVKB= V1 – V2

ΔVKB = 82.6v – 78.4v

ΔVKB = 4.23v

Where:

ΔVKB : Battery Voltage Consumption (Volts)

V1 : Average initial voltage (Volt)

V2 : Average final voltage (Volt)

When an electric car is operating, the battery voltage will gradually decrease as it discharges. The greater the power consumption, the greater the battery voltage. This voltage also depends on the vehicle's load, speed, and road conditions, whether uphill or downhill. The following table shows average battery voltage consumption during tests during the day, night, and in the rain.

Table 4. Battery Voltage Consumption

	Mileage	Voltage Average Battery (Volt)		Consumption Voltage
Testing	(km)	V1	V2	Battery (ΔVKB)
	10	82.6	78.4	4.23
Afternoon	20	78.4	71.9	6.50
	30	71.9	68	3.90
	39.66*	68.75	64.3	4.45

Test results show that battery performance and durability are significantly affected by load conditions. The heavier the load, the higher the current required, and the more rapidly the battery experiences voltage degradation and temperature increases. This demonstrates that power management and battery cooling systems are critical factors in designing mini electric vehicles.

CONCLUSION

Based on the results of testing and analysis that have been carried out on the battery life of the BLDC motor of a mini electric car, the following conclusions were obtained: Battery life is greatly influenced by workloadreceived by the BLDC motor. Under light loads, the battery can last up to 62 minutes, while under heavy loads it only lasts 35 minutes. The greater the load, the higher the current and operating temperature of the battery. which results in a faster voltage drop and has the potential to accelerate battery cell degradation. The maximum temperature recorded at heavy load reached 48°C., which is above the ideal operating temperature limit for batteries. This demonstrates the importance of a cooling system or temperature management to maintain battery efficiency and lifespan. Power management and load design are very importantin mini electric car systems to maintain energy efficiency and overall vehicle performance. Battery Management System (BMS) developmentIt is recommended to be able to monitor current, voltage and temperature in real-time, and provide protection against extreme conditions that can damage the battery.

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