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Endurance Testing of the Electric Vehicle that Converted from the Internal Combustion Engine Vehicle

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Abstract

In Indonesia, to accelerate the use of electric vehicles (EVs), one of the programs to do is the conversion of internal combustion engine (ICE) vehicles to EVs. This paper presents an overview of the endurance test for ICE vehicles that converted to EVs as far as 10,000 km to see their performance. We used three types of motorcycles, two types of batteries, and two types of passenger load. To get a distance of 10,000 km, the tested vehicle travels about 200 km on 4 different routes every day, where each route has different characteristics of road conditions. After getting the 10,000 km testing, all the types of the electric motor are in good condition and have no minor obstacles. Technically, several improvements need to be done to succeed this program, i.e., wiring and socket that are applied in this program need the waterproof wiring and socket, the converter part needs to be taken care of to avoid rust, and the placement of electrical components that have air conditioning fins (especially inverters) needs to be ensured that they will be exposed to air when the motor is used.

Keywords

Electric vehicle (EV); Endurance; Conversion; Internal combustion engine (ICE)

1 Introduction

In 2018, the national energy demand of Indonesia was dominated by fuel consumption with the amount of 450 mBOE where the majority of which is used for the transportation sector consumes 391 mBOE [1]. The growth rate of motorized vehicles, particularly motorcycles, had the highest growth with an average growth of 8,8% per year from 2010 to 20182). This growth must be followed by a simultaneous supply of fuel oil, but in fact, on the contrary, the domestic oil production rate decreased by around -2,4% per year from 2008 to 2018 [2]. Other than a shortage of fuel supply, primarily for private two-wheeled vehicles, another impact of fuel usage is emissions, which are estimated to reach 375,5 grams of CO_2e/km [3].

In the beginning of 2022, PLN has been an oversupply of electricity because there has imbalanced between electricity supply and demand in Indonesia, where the supply has oversupplied the demand [4-5]. One of the reasons oversupply productions is due to the downturn in economic activity due to the Covid-19 pandemic [6]. Thus, one strategy can be used to reduce the need for oil for motorized vehicles [7], as well as to absorb the excess supply of electricity from PLN which is the adoption of electric vehicles with the good control, good load leveling, and frequency regulation in grid [8-10]. This strategy has also been supported by the Indonesian government through Presidential Regulation Number 550 of 2019 concerning the Acceleration of the Battery Electric Vehicle for Road Transportation. In addition, the use of electrical vehicle is also providing the environmentally friendly transportation to support the growth of tourism sector in Indonesia [11].

P3tek KEBTKE (Research and Development Center for Electricity, New, Renewable Energy, and Energy Conservation Technology) has been implementing the conversion of ICE motorcycles to EVs since 2021 to support the acceleration program. Furthermore, the

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safety and quality aspect of the converted vehicle must meet the requirement of a certification test. First, the stages of certification test is registering the converted vehicles to Ditjen Hubdat (land transportation regulator); Second, test of performance and safety will be conducted BPLJSKB (vehicle testing and certification center), which will be tested basic system requirement of vehicle and electrical safety requirement; Finally, test certificate of converted EV will be granted to the applicant.

To give an overview and information related to the level of endurance of the electric motor result from the conversion of the ICE to EV motor, it is necessary to conduct a endurance test. The purpose of this paper has presented the results of the endurance test carried out for the motorcycle from the conversion of ICE to EV with 10000 km. This endurance test would be based to the improvements of the ICE to an EV conversion program.

2 Methodology

2.1 Converted vehicles from ICE to EV

The conversion of an ICE motorcycle to an EV motorcycle requires several main and supporting components (converter kit), as shown in Table II. The conversion process starts by measuring the ICE motorcycle weight, checking the initial condition (tires condition, chains, frame, electricity/lights, etc.) before conversion, and testing the performance of the ICE motorcycle by using a dynamometer. Once the initial stages were completed, the engine and transmission of the ICE motorcycle were uninstalled and were continued by designing and manufacturing a mounting for the electric motor and battery compartment. The location of the battery compartment is on the motorcycle frame, while the size is adjusted to the dimensions of the battery. The electric motor is placed parallel to the wheel drive gear which is transmitted through a chain. The EV that was converted from an ICE motorcycle can be seen in Figure 1.

Figure 1 The EV motor resulted from the ICE motor that converted

2.2 Endurance test parameter

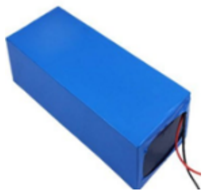
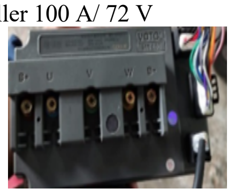
The endurance testing parameters were made up mostly of physical observations and reviews from riders who took part in the endurance test with the converted motorcycle. Several things observed in this test include vibration during the test, vehicle stability, suspension, and transmission. The test was also performed on rainy days, so whether the rider feels an electric shock or not is also considered a parameter that is included in the rider's log sheet. Each time the readers complete their route, the readers fill out a log sheet containing a review of the vehicle converted to an EV that they drive, as can be seen in Figure 2.

Aside from visual observation and review from the rider, other parameters included in this test can be seen in Table 3. As for the temperature measurement, the temperature that was measured during this test was the battery temperature, BLDC motor temperature [12], and controller temperature, which are the components where heat generation might occur. Real-time measurements were taken so that it could be monitored which of these parameters showed unusual characteristics during the test. Table 1 shows the type of motorcycle, driver load variation, variation of type the battery that used in the test, and the capacity of the BLDC motor.

Table 1 Variation of the endurance test

Test variation	Motorcycle 1	Motorcycle 2	Motorcycle 3	Motorcycle 4
The type of ICE **motor that converted to EV motor**	Honda Supra X 125	Honda Supra X 125	Yamaha Vega ZR	Honda Supra X 125
Load of driver	Single (without passenger) ± 60 kg	Double (with passenger) ± 120 kg	Single (without passenger) ± 60 kg	Double (with passenger) ± 120 kg
Type of Battery	LiFEPo	LiFEPo	Li-NMC	Li-NMC
BLDC motor capacity	2 kW	2 kW	2 kW	2 kW

Table 2 Converter Kit

Unit
Main Component
1. Battery 72 V/ 20 Ah 
2. BLDC Motor Mid Drive 2 Kw/72 V 
3. Controller 100 A/ 72 V 
4. Speed regulator 
5. MCB–DC 
Supporting Component
6. DC-DC Converter 72 V to 12 V 

Unit
7. BLDC motor mounting (to place BLDC motor into ICE motor frame) 
8. Modified wiring that adjusted from ICE wiring 
9. Battery Cover (as housing for the first component) 

Table 3 Experiment parameter

Number	Parameter
1	Travel distance (km)
2	Average speed (km/h)
3	Battery voltage (Volt)
4	Battery current (Ampere)
5	BLDC motor voltage (Volt)
6	BLDC motor current (Ampere)
7	Temperature (ºC)

2.3 Design and schematic of the monitoring device for the EV road test

A microcontroller was chosen to be the main controller of the monitoring device, in this experiment we used Arduino Mega 2560. The controller has the function to take data from the sensors, which could be seen from Table 4, and store it to the SD Card through the Data logger just like a Data Acquisition (DAQ) device. The data that is captured in a data logger is then downloaded and analyzed on a PC every day to see the abnormal phenomena that occur.

Table 4 Sensors

Number	Sensor		
	Parameter	***Model***	***Type***
1	Rpm	HW-201	digital
2	AC voltage	ZMPT101B	analogue
3	AC current	SCT-013-000	analogue
4	DC voltage	voltage divider resistor (10k ohm & 580 ohm)	analogue
5	DC current	ACS758	analogue
6	Temperature	DS18B20	digital

2.4 Road test scheme

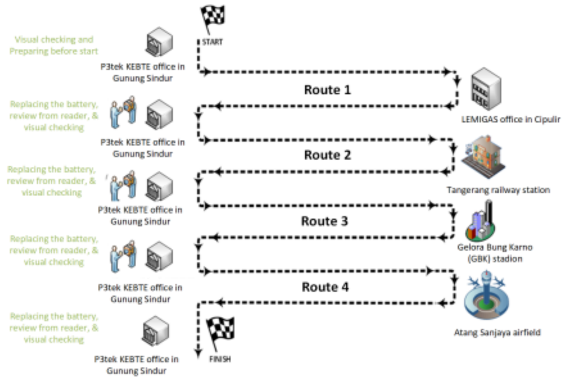


Figure 2 Route of the endurance test every day

The road test began on October 18, 2021, and ended on December 18, 2021, in which the road test will cover a distance of 200 km per day for each converted EV to complete 10,000 km in 2 months of testing, as can be seen on Figure2. On route 1, it will travel from P3Tek KEBTKE office, Gunung Sindur to Lemigas located at Cipulir Kebayoran Lama, this route describes a traffic jam in the morning, passing through several flyovers to test the power of the converted electric motorcycle. Route 2 starts from P3tek KEBTKE office, Gunung Sindur to Tangerang train station, this route is to test the strength of the converted motorbike in hot weather, dusty roads with a tendency to bad roads, and traffic jams. Route 1 and route 2 cover a total distance of 103 km.

Route 3 starts from P3tek KEBTKE office, Gunung Sindur to Gelora Bung Karno Stadium, this route describes the vehicle usage from developed residential areas towards the office center of Jakarta. While Route 4 starts from P3tek KEBTKE office, Gunung Sindur to Atang Sanjaya Air Base, this route shows a lot of inclines and traffic-free roads so that the maximum speed can be achieved. Route 3 and route 4 cover a total distance of 102 Km.

3 Results and Discussion

3.1 BLDC motor voltage and current

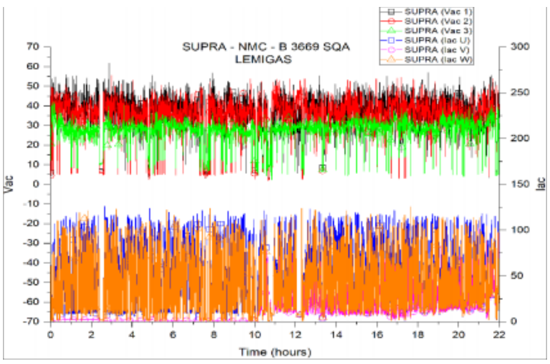


Figure 3 BLDC motor voltage and current of Supra Li-NMC during first route travel

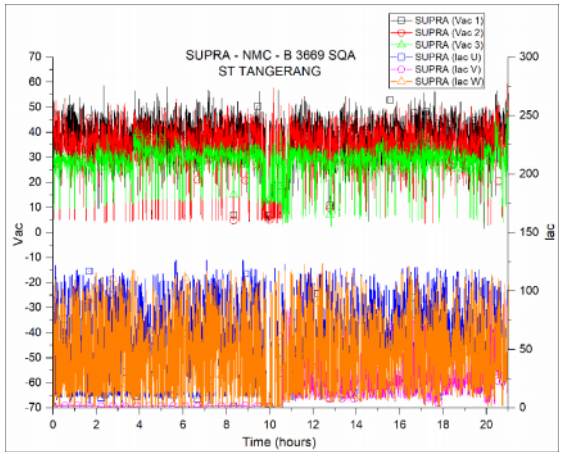


Figure 4 BLDC motor voltage and current of Supra Li-NMC during second route travel

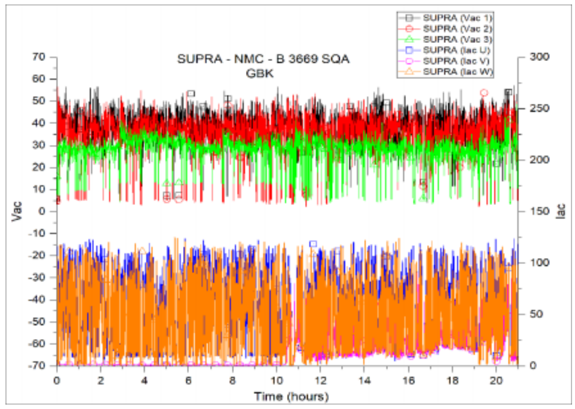


Figure 5 BLDC motor voltage and current of Supra Li-NMC during third route travel

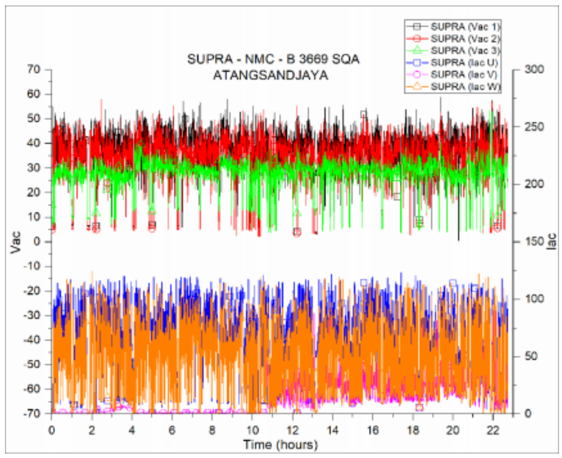


Figure 6 BLDC motor voltage and current of Supra Li-NMC during third route travel

Figure 3 to 6 shows the voltage and the current flowing from the controller to the BLDC motor of Supra Li-NMC with B 3669 SQW license plate number during the road test. The BLDC motor used in the converted EV is a 3-phase electric motor in which each phase of the motor is monitored to determine the voltage and current flowing. The synchronous phase between voltage and current at each pole of the motor makes a stable rotation for the BLDC motor so that the resulting rotation is stable as expected.

Figure 7 to 10 shows the voltage and current flowing from the controller through the BLDC motor during the road test of the third motorcycle that is an EV conversion from Supra X 125 with license plate number B 6784 SQV that uses LiFePo battery type with a capacity of 72V 18Ah.

The permanent magnet brushless DC electric motor (BDLC) used in the converted EV is a 3 phase electric motor in which each phase of the electric motor is monitored to determine the voltage and current flowing. Synchronous voltage and current at each pole of the motor make a stable rotation so that the resulting rotation is as expected.

The third type of motorcycle, namely the Jupiter MX with license plate number B 3686 SQB, has a LiFePo battery specification that has voltage and current characteristics so the resulting trend for the third motorcycle is similar to Figure 7 to 10.

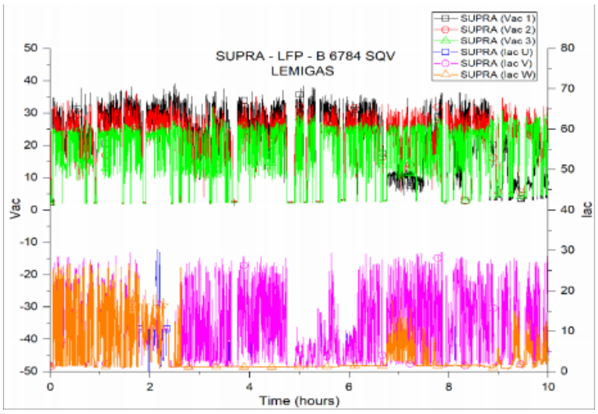


Figure 7 BLDC motor voltage and current of Supra LiFEPo during first route travel

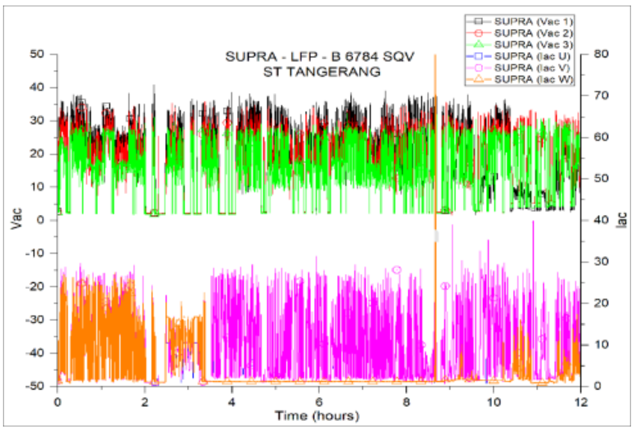


Figure 8 BLDC motor voltage and current of Supra LiFEPo during second route travel

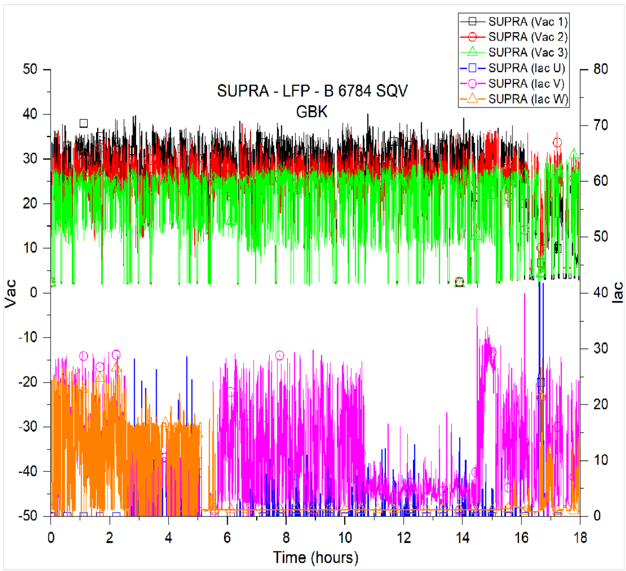


Figure 9 BLDC motor voltage and current of Supra LiFEPo during third route travel

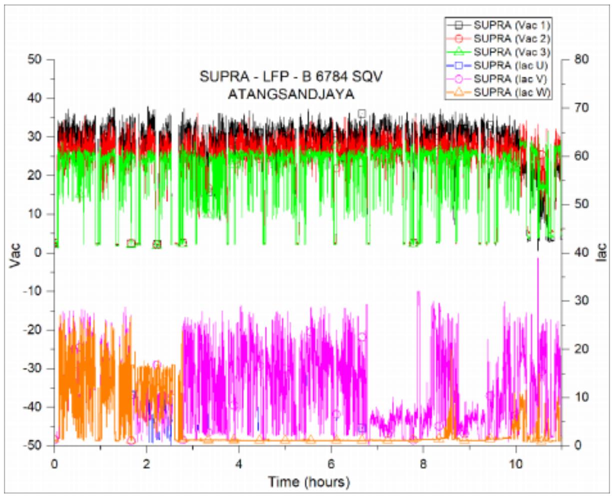


Figure 10 BLDC motor voltage and current of Supra LiFEPo during fifth route travel

3.2 Battery voltage and current

In Figure 11 to 14, the purple color shows the battery voltage has an up and downtrend according to the use of the test motorbike, where at the beginning the battery voltage reaches 85 VDC and the battery is again charged when the battery voltage reaches 68 VDC for around 2 hours of use or upon the completion of each route during the road test. At the time of testing, the B 3669 SQA motorcycle used Lithium nickel manganese cobalt oxides (Li-NMC) batteries with a capacity of 72 V 20 AH.

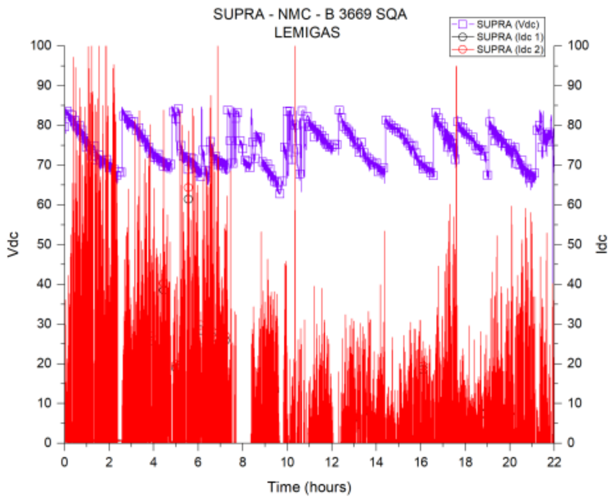


Figure 11 Supra Li-NMC battery voltage and current during first route travel

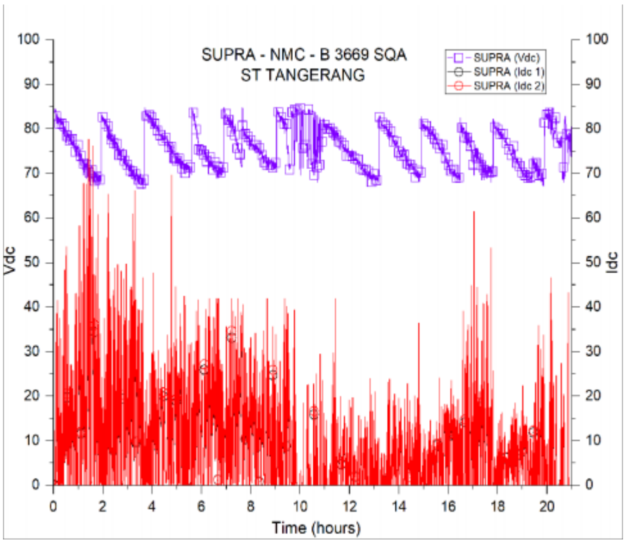


Figure 12 Supra Li-NMC battery voltage and current during second route travel

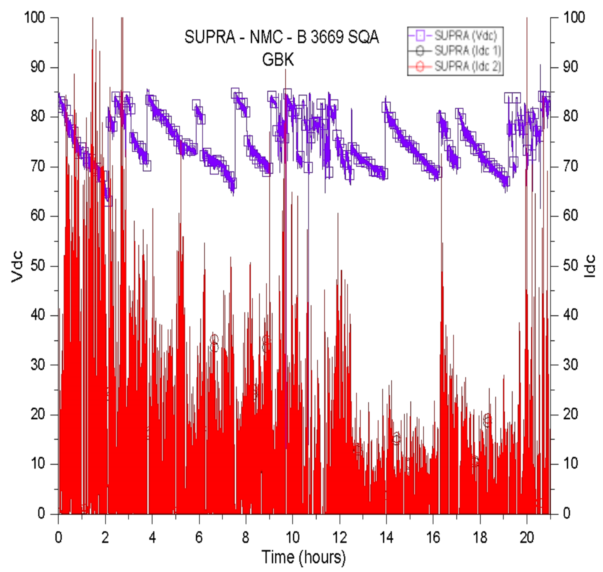


Figure 13 Supra Li-NMC battery voltage and current during third route travel

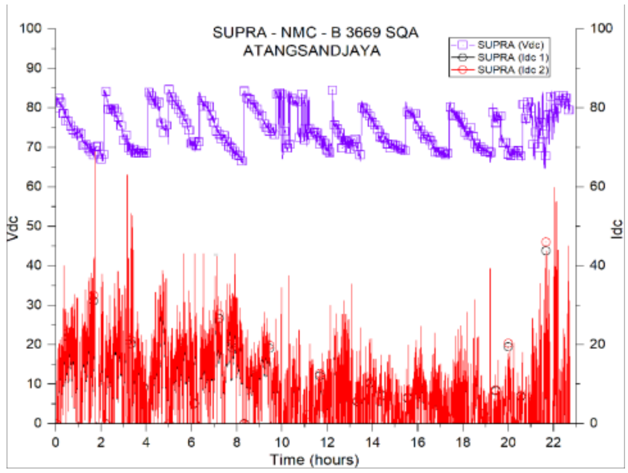


Figure 14 Supra Li-NMC battery voltage and current during fifth route travel

In Figure 15 to 18, the purple color shows the battery voltage has an up and downtrend according to the use of the test motorbike, where at the beginning the battery voltage reaches 78 VDC and the battery is again charged when the battery voltage reaches 68 VDC for about 2 hours of use or upon the completion of each route during the road test.

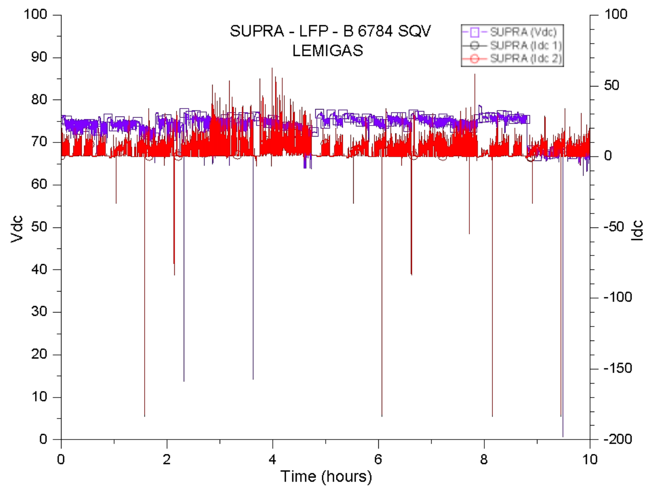


Figure 15 Supra LiFePo battery voltage and current during first route travel

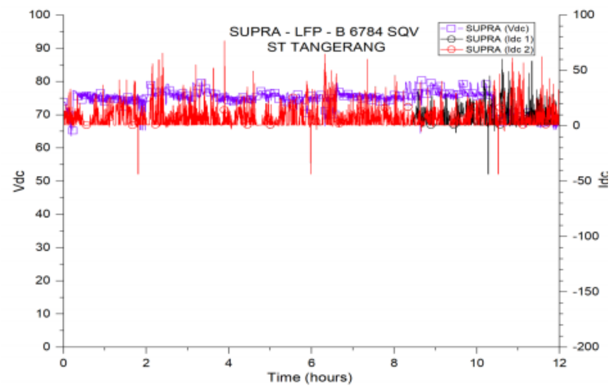


Figure 16 Supra LiFePo battery voltage and current during second route travel

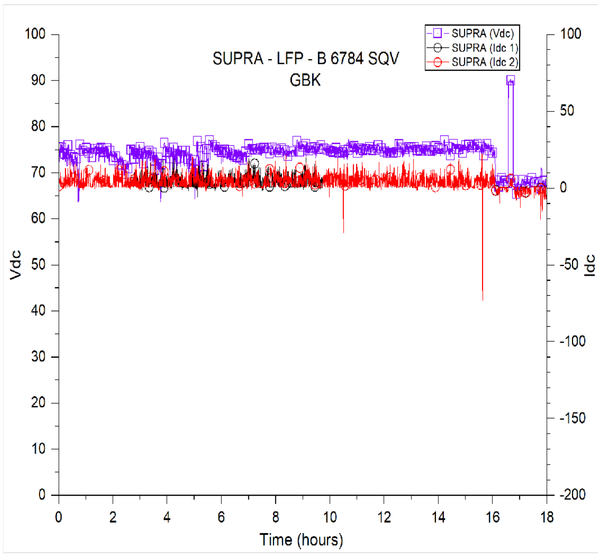


Figure 17 Supra LiFePo battery voltage and current during third route travel

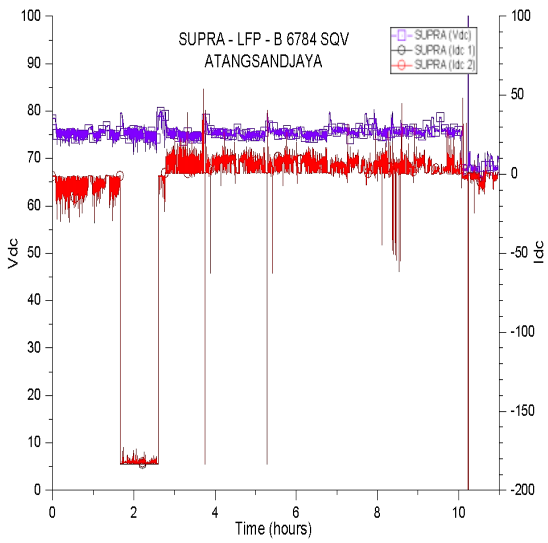


Figure 18 Supra LiFePo battery voltage and current during fifth route travel

3.3 Temperature of the main component of EV motor

Temperature monitoring for the main components of the converted vehicle is focused on battery temperature, BLDC motor temperature and controller temperature, as can be seen in Figure 19. Throughout the endurance test, the temperature trend on the controller tends to be higher than the battery and BLDC motor temperature. This phenomenon can be analyzed because the placement of the controller is on a former fuel tank holder on an ICE motorcycle that has not been conditioned to provide optimal air circulation for cooling the fins on the controller, see Figure 20. This causes the fins on the controller to be unable to get air exposure for optimal cooling.

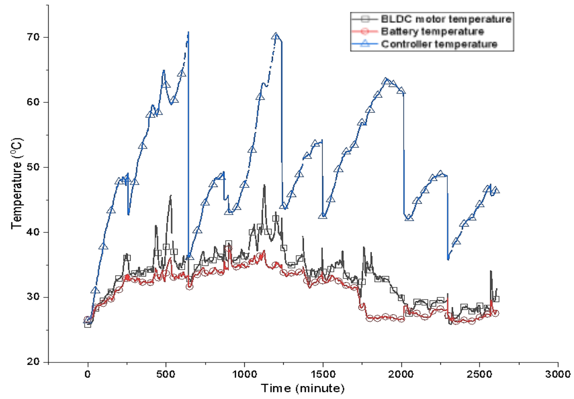


Figure 19 Temperature monitoring results during the endurance test

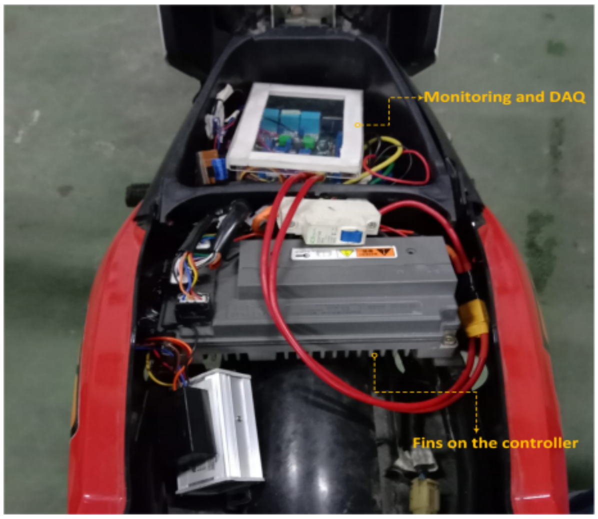


Figure 20 Controller that placed on the former fuel tank holder

3.4 Fuel and emission reduction projection from the use of converted EV motorcycle

The results of the fuel consumption test for ICE motorcycles that have been conducted by P3tek KEBTKE show that gasoline in Table 5 has an emission of 0.12 kg CO_2/h.

Table 5 Emission Test of ICE Motorcycle

Number	Variable	Value
1	Vehicle type	Motorcycle
2	Fuel type	Gasoline
3	Distance (km)	2.2
4	Average speed (km/h)	23.26
5	Travel time (h)	0.19
6	Fuel test consumption (km/l)	43.20
7	Fuel consumption/h (l/h)	0.5
8	Fuel consumption (l)	0.10
9	Calor value (Tj/l)	3.30 x10-06
10	Emission factor (kgTj)	69300
11	CO2 emission (kg CO2/h)	0.12

Data from BPS (central statistics agency) indicate that in 2019, the circulation of motorcycles in Indonesia has reached 113 million units. From the calculations in Table 5, the conversion of motorcycles as much as 10% of the total number in 2019, will reduce emissions by 2.5 million tons of CO2 per year assuming 5 hours of use per day.

Based on the performance test results, the use of electricity as fuel has a better economic value than using fuel oil. Table 6 shows the comparison of operational costs before and after the conversion of the motorcycle. Where on the assumption of usage per month is equal to 1000 km distance, the motorcycles that use fuel with 90 octane number cost Rp.237,245 while after being converted to electric it only costs about Rp.25,896. The economic value of the operation the EV motorcycle is 9 times lower than using fuel, this shows a pretty good prospect for ICE motorcycle's conversion to EV motorcycles.

Table 6 Comparison between ice and EV motorcycle cost

Number	Variable	Source	
		Fuel Oil	**Electric**
1	Cylinder/Power	110 cc	2 kW
2	Capacity	3.7 l	72V/20 Ah
3	Travel distance	43 km per l	56.7 km per kWh
4	Energy usage per 1000 km	23.3 l	17.6 kWh
5	Cost per month	Rp.237,245	Rp.25,896

From the calculation in Table 6 and BPS data, the conversion of motorcycles for about 10% of total motorcycles in 2019, will reduce the fuel consumption by 1.66 million barrels of fuel per month assuming the usage of vehicles is 1000 km per month.

4 Conclusion

Based on visual observations and reviews of the driver who conducted the test, the converted EV motorcycle has successfully passed the 10,000 km endurance test without any significant issues. Several improvements still remain to be made, including the wiring and sockets applied to this program require waterproof wiring and sockets with the same quality copper as the original built-in socket of the ICE motorcycle, converter parts (mounting, battery frame) need to be kept from rusting, the battery frame needs to be conditioned to protect the battery from splashes of water and shocks, and the placement of electrical components that have fins (particularly controller) needs to be confirmed to get exposed to air when the vehicle is used considering from the measurement results during the endurance test that the temperature of the controller was recorded to be the higher than the temperature of the battery and the BLDC motor.

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