

The Comparison of Electric Motor Performance in Powering Electric Motorcycle

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Abstract. The increase use of vehicles with combustion engine has caused intensive exploration of fossil fuels and severe pollutions. The replacement of this engine with electric motor is expected to solve both problems. For optimal selection of the motor, assessment of its performance is necessary. This may be carried out by comparing the performance of the motors used for powering electric motorcycle. This paper presents the performance comparison of 2 motors powering a modified motorcycle. The engine of the motorcycle was successively replaced with BLDC motor and DC motor and their performances were measured. The motorcycle was loaded with 1 and 2 passengers with the total weight of 59 and 109 Kg, respectively. The motorcycle speed (km/h) was adjusted up to 30 km/h. The results of the test indicate that DC motor requires power of 557.74 Watt at the speed of 317.04 rpm and generates torque of 16.81 Nm with energy consumption of 41.55 km/kWh. For the BLDC motor, it requires power of 526.62 Watt at the speed of 316.78 rpm and generates torque of 15.88 Nm with energy consumption of 50.59 km/kWh. For the same distance, DC Motor enables generates higher torque than BLDC motor. However, BLDC motor may present lower energy consumption per kWh than DC motor.

1 Introduction

The mobility of people is one of the phenomena associated with economic growth and national development. It is a common challenge to increase people's mobility while decreasing congestion, traffic accidents, and air pollution. It was reported that urban vehicle transport is the primary source of air pollution, accounting for 75% to 85% of pollutant emission [1]. Therefore, efforts should be made to reduce greenhouse gas emissions while still allowing people to move. The goal of decarbonizing the air in the transportation sector may result in two innovations, including the electric vehicle and the car club. The last plan enables fewer car owners, which in turn result in less fossil fuel use. These initiatives are anticipated to promote emission control, sustainable development, economic growth, and energy security [2].

There is another problem regarding transportation activity, where this transportation sector employs internal combustion engine that takes much fossil fuel. This extensive use of fossil fuels has caused persistent reduction of fossil deposit. Together with other sectors that

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also take fossil fuels, the trend of fuel consumption will continue increasing, which causes fuel deposit to finish faster. According to studies on 2019 carried out by international oil companies together with independent energy organizations, a prediction was made warning that oil reserves will be depleted in about 50 years. A number of developed countries are currently setting up the strategy for fulfilling the energy demand for electricity, heat and transportation from renewable energy resources by 2050 [3].

The environmental effects of fossil fuel consumption are another great concern in the global level. Transportation sector seems to be the one responsible for both aforementioned problems. In one hand this sector takes much fuel causing fuel deposit reduction, and this also leads to pollution problem [4]. It comes to a dilemma, while transportation sector is required by people, yet it may lead to some drawbacks. Without a strategic intervention, the problem of fuel consumption and CO₂ emission may persist or even rapidly increase [5]. In this circumstance, looking for solutions on how transportation systems are operated utilizing resources other than fossil fuels while implying less environmental consequences would be the greatest alternative [6].

Electrical energy is expected to be the most feasible type of energy for different use, including transportation system. Some reasons behind this prediction are based on the characteristic of this energy. This energy is easy to generate using different type of resources, may be delivered efficiently across long distance and it is suitable for different applications [7]. The use of electrical energy for transportation system needs fundamental change of motorcycle. The prime mover of the motorcycle is replaced with electric motor and the energy is stored in a battery [8]. The development of motorcycle powered by electric motor is still in the beginning stage yet the real electric motorcycles are now used and commercially available [9]. However, some researches are still required to improve the product and how some identified drawbacks may be resolved.

Electric transportation system is well-researched topic. The topic on this idea is extensive including policy, simulation, hardware and software development, infrastructure modification, economic analysis, and future development. For development of electric motorcycle, the topic of research includes the use of motor and the related analyses, controller development, storage and charging strategy, construction of chassis and body.

Research on motor application for electric transportation system covers some topics. One of them is modification of prime-mover and its further innovation [10] that enables enhancement for extending the range of driving [11]. Regulating power supply for the motor leading to enhancing prime mover performance using new approach is another topic [12]. The control for electric motor is also receiving extensive attention ranging from simulation to real application. Control simulation that includes traction control using conventional control methods [13], controlling the magnetic field to enhance the performance and efficiency [14], and development of control system that enables driving the motor using novel approaches [15]. However, fewer publication is found in real implementation of the control strategy for a prototype system [16] as well for the real system [17].

Another essential issue on electric transportation system is storage and the related topics. Research on this topic includes material development and modification that may achieve storage advantages [18, 19], charging control strategy [20] including the scheme of regenerative braking [21] that allows maintaining battery lifetime.

The performance of electric motor powering motorcycle is the crucial issue in developing the electric motorcycle. The type electric motor normally used in electric motorcycle is Brushless DC (BLDC) Motor. BLDC motor is extensively applied due to its cost efficiency and simple construction. The major advantages of BLDC motors are low maintenance, high efficiency, long life, low weight and compact construction [22]. However, the dependence of permanent magnet in its operation may leads to some drawbacks, mainly regarding the torsion capability of the motor [23]. On the other hand, DC motor may also be

used as prime mover for electric motorcycle. While it is not quite common, this possibility may still be overviewed.

In this paper some comparative studies were carried out to compare BLDC and DC motor for powering electric motorcycle. A motorcycle was modified by replacing the internal combustion engine with BLDC motor or DC Motor. The motorcycle is equipped with controller and instrumentation system. The motorcycle may run properly, and some tests and measurements were carried out. Some variables were taken into account in the tests and measurements including weight of passenger(s), speed, and distance to measure the different of power, torque and energy used.

2 System development

For development of motorcycle powered by electric motor, 2-type electric motor was alternately used, i.e. DC motor and BLDC motor. The modified motorcycle where the engine is replaced with electric motor is shown in **Fig. 1**. The specification of DC Motor and BLDC is given in **Table 1** and **Table 2**, respectively.



Fig. 1. The modified motorcycle powered by electric motor

Table 1. The parameter of DC Motor for electric motorcycle

Parameter	Specification
Model/ Motor Type	MY1020
Specification	1000W 36V/48V/60V
Unloaded Current (A)	$\leq 2.5/2.2/2.0$
Unloaded Speed (rpm)	3700
Rated Torque (Nm)	3.2
Rated Speed (rpm)	3000
Rated Current (A)	$\leq 35.6/26.7/21.5$
Efficiency	≥ 78

The measurement of motor performance was carried out by instrumentation system of the motorcycle supported by some sensors. This instrumentation system is in the form of data acquisition containing Arduino Mega in the backside of the mainboard as shown in **Fig. 2**. The mainboard employs voltage and current sensor where the pins are connected with the copper at the main board. Two DC buck step-downs in the mainboard are used to decrease the 54-V battery voltage to 12-Volt supplying the Arduino Uno and to 5-Volt supplying the sensors. A molex socket in the mainboard connects the magnet sensor attached in the frame that faces toward the wheel. A metal piece is attached on the wheel spoke at the point that is enabled to be detected by the sensor. The number of interactions between magnetic sensor and metal determines the rpm of wheel rotation. The instrumentation system mainboard is

placed in front side of the bicycle. This placement is aimed to facilitate the easy cabling of the mainboard with TFT.

Table 2. The parameter of BLDC Motor for electric motorcycle

Parameter	Specification
Model/Motor Type	BM1109
Specification	1000W 36V/48V
Unloaded Current (A)	$\leq 4.8/4.2$
Unloaded Speed (rpm)	3500
Rated Torque (Nm)	2.7
Rated Speed (rpm)	3100
Rated Current (A)	$\leq 28/21$
Efficiency	≥ 80

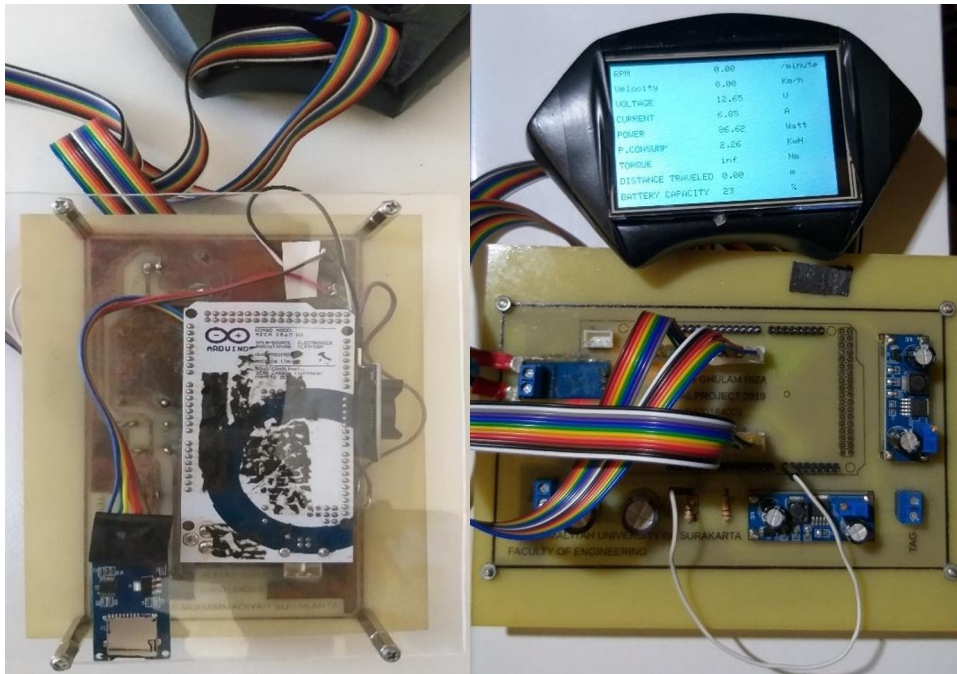


Fig. 2. Instrumentation mainboard from rear and front view

Once the instrumentation system has been completely developed, this may be attached to the motorcycle. Some checking and testing of the instrumentation system were conducted including verification of the presented data in TFT shield. The installation of instrumentation board at motorcycle and the display of TFT Shield are shown in **Fig. 3**. From the measurement results displayed in TFT shield, benchmarking with the measurements using standard measurement devices was done. This is to confirm if the deviation is acceptable. The measurement includes current, power, speed, torque, and energy for different distance and passenger weight.

3 Result and discussion

For the motorcycle driven by electric motor the test was carried out by varying the speed for the different passenger weight achieving different distance. The speed was adjusted to 7, 10, 20, and 30 km/h, while the passenger of the motorcycle was 1 person (59 kg) and 2 persons

(109 kg). The distance to travel was 1 km, 3 km, and 6.5 km (at public street). For the distance of 6.5 km, the passenger was only 1 person.

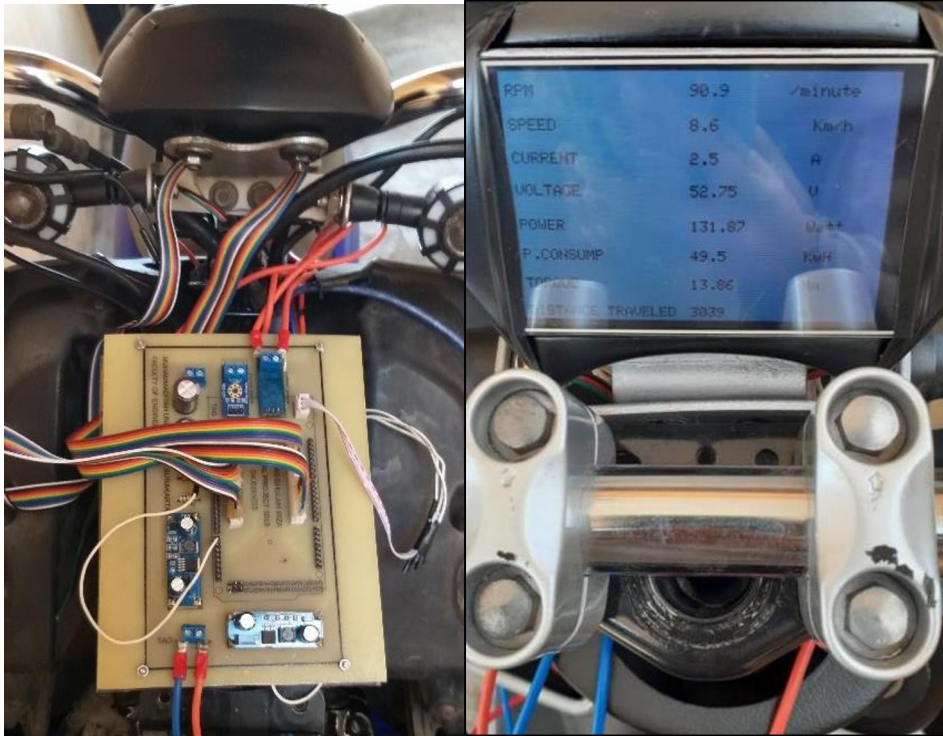


Fig. 3. The instrumentation system attached in motorcycle and the TFT display

For the test of motorcycle carrying 1 passenger and 2 passengers to travel for the distance of 1 km, the results of measurements of using DC motor and BLDC motor are respectively given by **Table 3** and **Table 4**.

Table 3. The test results for motorcycle driven by DC motor travelling for 1 km

Load: 1 person			Load: 2 persons		
Speed (rpm)	Energy use (km/kWh)	Torque (Nm)	Speed (rpm)	Energy use (km/kWh)	Torque (Nm)
72	33.59	23.9	30.23	25.82	74
105	29.14	24.80	22.47	32.8	102
210	26.75	23.7	24	26.8	207
302	24.69	17.40	21.9	19.55	303

It may be observed from the tables that BLDC motor uses less energy than DC motor. The speed and load were varied, and the measured energy consumptions confirm this conclusion. The energy use is indicated by the unit of km/kWh describing the distance that may be achieved for the energy of 1 kWh. In other word, motorcycle driven by BLDC motor may achieve longer distance for the energy of 1 kWh than that powered by DC motor. However, DC motor provides higher torque than BLDC motor. It may also be seen that for the load of 2 passengers, the required energy is higher than for the load of 1 passenger. As expected, the torque necessary for 2 persons is higher than that for 1 person. Another fact

from the measurement is the higher speed (rpm) implies less torque and higher energy consumption.

Table 4. The test results for motorcycle driven by BLDC motor travelling for 1 km

Load: 1 person			Load: 2 persons		
Speed (rpm)	Energy use (km/kWh)	Torque (Nm)	Speed (rpm)	Energy use (km/kWh)	Torque (Nm)
75	39.46	15.56	33.59	23.53	70
108	34.66	16.17	29.14	27.5	100
214	32.03	14.27	26.43	24.28	207
312	29.32	13.24	25.1	17.51	305

The measurements of the motorcycle travelling for 3 km with 1 passenger and 2 passengers, alternately powered by DC motor and BLDC motor are respectively given by **Table 5** and **Table 6**. The same trends with those given for the case of 1 km travelling may be observed. Furthermore, in comparison with the travelling distance of 1 km (**Table 3** and **Table 4**), the longer distance to travel suggests less energy use per-km. There is also a consistency with the previous results where the higher speed causes less energy and less torque. It may again be repeated while BLDC requires less energy for travelling the same distance, but DC motor enables providing higher torque.

Table 5. The test results for motorcycle driven by DC motor travelling for 3 km

Load: 1 person			Load: 2 persons		
Speed (rpm)	Energy use (km/kWh)	Torque (Nm)	Speed (rpm)	Energy use (km/kWh)	Torque (Nm)
74	59.86	19.19	73	50.25	22
104	53.66	21.19	101	48.15	28.77
212	45.78	19.74	211	42.7	23
317	41.55	16.81	315	39.68	18.8

Table 6. The test results for motorcycle driven by BLDC motor travelling for 3 km

Load: 1 person			Load: 2 persons		
Speed (rpm)	Energy use (km/kWh)	Torque (Nm)	Speed (rpm)	Energy use (km/kWh)	Torque (Nm)
73	63.69	18.5	59.4	21.6	71
106	59.88	19.86	51.46	23.25	103
210	49.67	18.92	43	21.7	213
316	45.92	15.92	40.9	17.37	319

For further comparing the performance of DC dan BLDC motor, the speed was gradually adjusted to 7, 10, 20, and 30 km/h. The distance to travel was 3 km and the number of passenger was 1 person. Some measurements were carried out including motor rpm, drawn current, used energy, and generated torque. The results are given in **Table 7**. These are also displayed in **Fig. 4** showing the relation between the speed with respect to current, torque and energy. It may be observed from the table and figures that in general DC motor may provide higher torque but requires higher current. The figures also indicate that both of motors require higher current to get higher speed. As a result, for higher speed the required energy also higher. In other word, for the same energy the distance that may be achieved is shorter if the motorcycle is driven faster. More specifically, DC motor needs higher current than BLDC motor for all speeds. Consequently, the energy needed by DC motor is more than

that required by BLDC motor. However, considering Fig. 4 (b), DC motor enables providing higher torque than BLDC motor for all speeds.

Table 7. The comparison of DC and BLDC motor carrying 1 passenger travelling for 3 km

Speed (km/h)	Speed (rpm)		Current (A)		Energy use (km/kWh)		Torque (N.m)	
	DC	BLDC	DC	BLDC	DC	BLDC	DC	BLDC
7	74	73	2.98	2.68	59.86	63.69	19.19	18.5
10	104	106	4.63	4.25	53.66	59.88	21.19	19.86
20	212	210	8.85	8.24	45.78	49.67	19.74	18.92
30	317	316	11.35	10.48	41.55	45.92	16.81	15.92

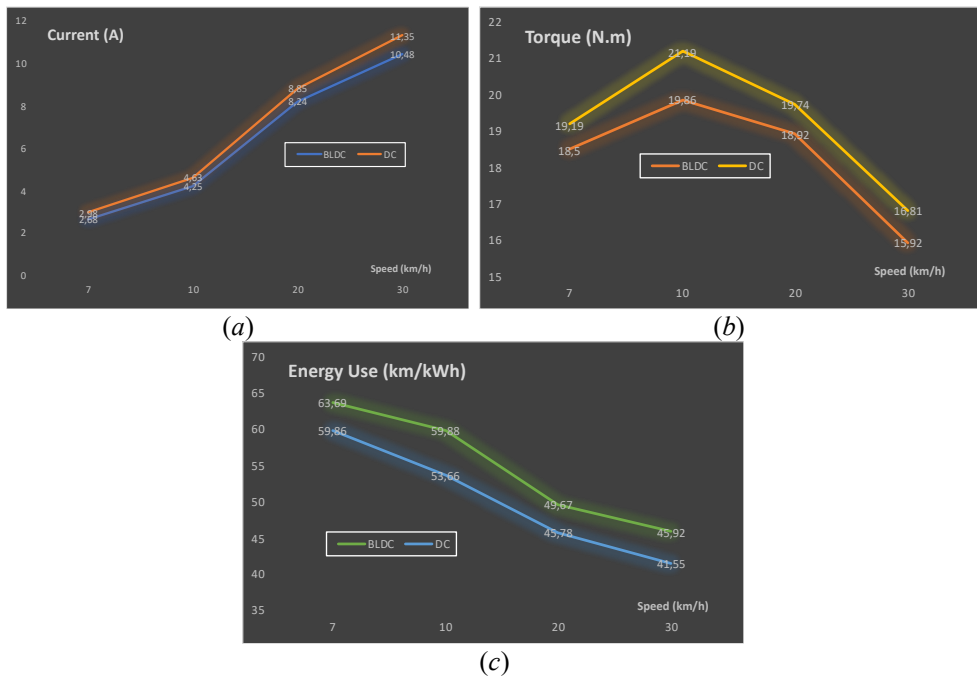


Fig. 4. The relation of (a) current, (b) torque and (c) energy for DC and BLDC motor carrying 1 passenger

The measurements were further carried out for the same distance and speeds but with 2 passengers. The results of measurements are given in Table 8. The results are also displayed in Fig. 5.

Table 8. The comparison of DC and BLDC motor carrying 2 passengers travelling for 3 km

Speed (km/h)	Speed (rpm)		Current (A)		Energy use (km/kWh)		Torque (N.m)	
	DC	BLDC	DC	BLDC	DC	BLDC	DC	BLDC
7	73	71	3.5	3.13	50.25	59.4	22	21.6
10	101	103	6.22	4.94	48.15	51.46	28.77	23.25
20	211	213	10.4	9.8	42.7	43	23	21.7
30	315	319	12.75	11.8	39.68	40.9	18.8	17.37

As expected, the current taken by the motorcycle carrying 2 passenger is higher than that taken by motorcycle carrying 1 passenger. It may be further highlighted that for all adjusted speeds, higher current is drawn by DC motor than BLDC motor. A notable different may be seen from Fig. 5 (b) where DC motor enables providing better torque at the low speed. This

implies that the torque of DC motor is sufficiently available and, when it is necessary, it can be used to fulfil the needed torque due to the higher load. The torque slows down when the speed increases but it is still higher than that of BLDC motor. In term of energy, this higher torque requires higher energy as shown in Fig. 5 (c). It may be observed from the figure that higher energy is needed at the beginning and it slows down when the speed increases. When the speed is high, the energy consumption by both DC and BLDC motor is expected to only be slightly different.

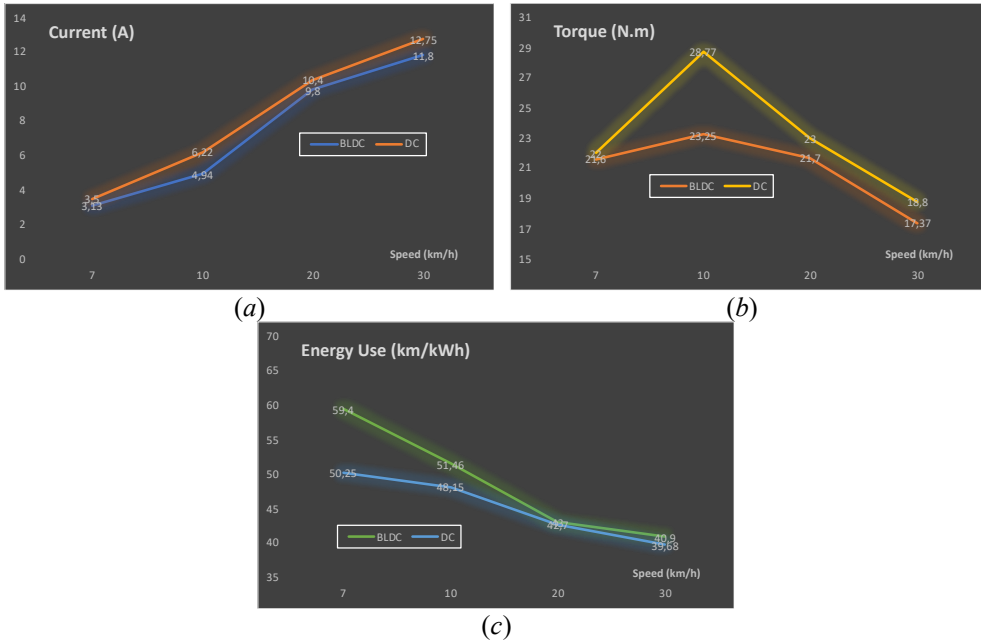


Fig. 5. The relation of (a) current, (b) torque and (c) energy for DC and BLDC motor carrying 2 passengers

The performance of the motors is further compared for travelling longer distance, which was 6.5 km. The motorcycle was driven by 1 passenger on the public street. The measurements were carried out and the results are given in Table 9. Please be noted that since the test was carried out on the public street then the speed might not be adjusted to be the same for both motors. However, the average of motor rpm, energy use, and torque were recorded. It may be observed from the tables that the average of rpm is about the same for both motors while BLDC motor may generate higher rpm. As expected for the longer distance, DC motor may provide better torque with slightly higher energy use. It falls to the decision if the need is for better torque, then DC motor will be the choice. However, if the reason is energy consumption, then BLDC motor may satisfy the requirement.

Table 9. The comparison of DC and BLDC motor carrying 1 passenger travelling for 6.5 km

Type of Motor	Speed (rpm)	Distance (km)	Energy use (km/kWh)	Torque (Nm)
BLDC Motor	222	6.5	68.4	13.2
DC Motor	219	6.5	63.47	14.18

4 Conclusions

The electrically driven motorcycle was developed by replacing the existing internal combustion engine with electric motor. For the purpose of performance comparison, the

motorcycle was interchangeably driven by DC and BLDC motor. A number of tests were carried out to compare the performance of the motors. An instrumentation system was developed to enable the measurements. This employs Arduino Mega as processor and supported some sensors to enable measurements that are displayed in TFT screen. The verification of the measurements displayed in the TFT screen confirm that the accuracy of the given results is acceptable. The tests were carried out by driving the motorcycle carrying the load for 1 and 2 passengers, with the adjusted speed increase, travelling for 1 km, 3 km and 6.5 km. From the tests, BLDC motor uses less energy that implies drawing smaller current than DC motor. However, DC motor enables provides higher torque for any speed level. For the bigger load, DC motor may give significantly higher torque to fulfil the need of torque. For the longer range of running, a fair energy consumption is expected to happen for both motors. The decision of choosing the motor falls on the consideration if the need is for better torque, then DC motor will be the choice. However, if the reason is energy consumption, then BLDC motor may satisfy the requirement.

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