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Design and Development of a Retrofit Electric Motorbike

Z. Zainol, S. F. Toha, N. A. Kamisan, W. M. S. W. Bukhari

Abstract— In the electric vehicle (EV), rechargeable battery serve as the energy source for all its system operation which include an electric motor for the propulsion system and also other auxiliary components. This contributes to a large number of batteries needed to support the EV's operation and in turn contributes to heavyweight, poor durability and high total cost of EV. Therefore, it becomes an important issue to be tackled in EV technology in order to enhance the battery energy capacity for long range operation. Based on the simulation, the Electric Motorbike (EM) required an average power of 2069 Watt to manoeuvre around 65.3km in range. The differences between a field test and the data from the simulation are 7%. The categories of target people that will use the EV are the people that live in the urban area.

Keywords: Durability; Electric Vehicle; Energy; Range;

1. INTRODUCTION

Automotive industries have kept evolving since the first steam engine car was invented. An electric vehicle (EV) has existed in the middle of the 19th century. However, the EV was less preferable compares to a fuel-based vehicle due to its performance. Recently in this 21st century, the technology in EV has increased with better electric motor design, high density of energy storage, easy access to electric energy, rapid development in renewable energy and awareness on green effect and CO2 emission on earth had increased a demand to change from internal combustion engine (ICE) to EV. Several countries including Denmark, Paris, India, China, United States of America, United Kingdom and much more will follow in banning fuel and gas engine in the near future (2030-2040) accordance with United Nation's resolution in Sustainable Development Goals. Nevertheless, Malaysia also is keeping her track in accordance to these changes by initiated the Fleet Test Vehicle (FTV) Programme, under the Ministry of Energy, Green Technology and Water (KeTTHA). The programme will focus on revitalising the green technology infrastructure and promoting the electric vehicle (EV) with projection to achieve 15% EV usage in Malaysia by the year 2020, (BERNAMA, 2012). Several EV charging stations are built to support the EV pilot programs.

A fully battery powered EV is completely depending on the battery capacity. Lighter and compact size battery pack, high storage capacity and high energy are some criteria for an ideal battery. Regardless of any topology of EVs, the prime objective is to satisfy the driver's power demand by managing the power flows and simultaneously satisfying other constraints such as state of charge (SOC), state of energy (SOE) of the energy storage, emission control and drivability, (S.F. Toha, et. Al, 2013 and S. F. Toha, 2013). The categories of target people that will use the EV are the people that live in the urban area. In result, it will help to lighten the burden of the people.

Motorcycles are high in demand among urban citizen as their mode of transportation because the vehicles came in a smaller size, convenience for short distance-travel and at the same time, enable a rider to avoid hassles such as traffic congestion and parking insufficiency. A scarcity of land and the nature of a vehicle that requires an efficient start and stop mechanism during travel have caused this preference to be more prevalent among the urban community. The usage of powers two-wheelers is highly favoured in Asian countries (Hardt, C., and Bogenberger, K., 2017) as compared to the European population as a means of individual transportation. Statistically, in Figure 1, it can be seen that motorcycles are dominating the chart in each state as the most registered mode of transport as compared to other types of transportation in Malaysia. It recorded that 12,094,790 motorcycles are being registers as reported by Road Transport Department, Malaysia. Rampant price fluctuation and decreasing non-renewable energy show sign of diminishing petroleum resources. Thus, the need of providing alternative source of power to the vehicles has been apparent in which can be solved through the use of pollution-free electric vehicles (Nandedkar, M. Wagh, N. and Rege, S., 2017).

NEGERI *State*	MOTOSIKAL *Motorcycle*	MOTOKAR *Motorcar*	BAS *Bus*	TEKSI *Taxi*	KERETA SEWA & PANDU SENDIRI *Hire & Drive Car*	KENDERAAN BARANG - BARANG *Goods Vehicle*	LAIN - LAIN *Others*	JUMLAH *Total*
PERLIS	78,263	23,868	176	126	79	1,998	2,281	**106,791**
KEDAH	895,435	320,739	2,956	2,331	1,384	40,025	30,947	**1,293,817**
PULAU PINANG	1,346,531	1,081,715	5,164	3,784	1,735	78,180	39,626	**2,556,735**
PERAK	1,308,482	736,210	4,699	3,665	878	76,011	60,190	**2,190,135**
SELANGOR	1,342,398	1,085,737	6,773	15,322	2,202	188,492	138,808	**2,779,732**
W.P. KUALA LUMPUR	1,770,360	3,720,213	19,002	55,371	46,331	268,007	238,654	**6,117,938**
NEGERI SEMBILAN	531,677	329,952	2,483	1,933	564	48,687	16,471	**931,767**
MELAKA	449,980	328,242	1,692	1,558	434	28,352	14,092	**824,350**
JOHOR	1,786,021	1,420,665	8,712	12,624	2,758	150,258	97,921	**3,478,959**
PAHANG	569,530	365,682	1,967	1,892	982	46,415	28,945	**1,015,413**
TERENGGANU	369,304	199,191	1,069	927	328	22,230	13,451	**606,500**
KELANTAN	524,619	291,052	2,020	1,522	587	29,885	16,657	**866,342**
SABAH	362,369	614,021	7,169	4,629	3,908	123,376	99,434	**1,214,906**
SARAWAK	754,778	747,282	3,117	2,436	1,700	94,912	100,888	**1,705,113**
PORTAL RAKAN NIAGA	5,043	607,127	0	29	15	1,159	81	**613,454**
MALAYSIA	**12,094,790**	**11,871,696**	**66,999**	**108,149**	**63,885**	**1,197,987**	**898,446**	**26,301,952**

Fig. 1: Total motor vehicles by type and state in Malaysia. Jabatan Pengangkutan Jalan (2015)

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Meanwhile, among the criteria for much preferable EV is low-power usages as it is more cost-effective and this has become the contributing factor in considering energy-efficient EV as the best alternative besides its known advantage of lower energy emission (Ruensumruay, S., Pattaraprakorn, W., Chutiprapat, V., and Bhasa-putra, P., 2016). In fact, development of low-powered EV at the moment has been focusing on electric motorcycle (EM) due to the pressure exerted from the energy crisis as well as worsening environmental impact caused by the usage of motorcycles in urban area (Mou, T. L., Kin, W. P., Hangyuan, L., and Zhengchao, X., 2013). In addition, it has been proven that the EV consumes less energy thus making it more economical. Furthermore, the use of EV is beneficial to reduce environmental pollution by reducing the greenhouse effect. The greenhouse effect occurs due to the reaction between carbon monoxide and nitrogen oxide that emitted from the vehicle using petrol and diesel. Motorcycles are the contributing factor towards 10% of air pollutant in Taiwan consisting of pollutants, HC and CO (Lu, C. H., Hwang, Y. R., and Shen, Y. T., 2012). The project will benefit both the user and the nation with a cheaper cost to operate an electric vehicle and creates a healthier environment accord-ance with Goal 7 of UN Sustainable Development Goal for affordable and clean energy.

As part of mitigation measure in environmental protection, the government aims to lessen the amount of emissions coming from greenhouse (GHG) and air pollutants (HC, CO, NOX, PM, and SOX) produced from vehicles (Wang, F. K., & Saito, M., 2016). In achieving that particular goal, the reduction of CO2 emission caused by transportation sector and high-penetration of renewable energy in the market can be leveraged through the mechanism of utilizing electricity-powered vehicles, (Baptista, P., Duarte, G., Goncalves, G., and Farias, T., 2013). The move wills positively impacted the urban area as the local emission of CO2 almost goes to zero and at the same time, the sound pollution can be reduced by using electricity-powered vehicle. It has been studied that lower noise pollution, zero emission of GHG and 75% reduction of CO2 emission can be achieved through EM which consequently act as an effective environmental mitigation measure in the urban area, (Ahn, Y., Jun, C., and Yeo, H., 2016).

2. PROBLEM STATEMENT AND ITS SIGNIFICANCE

The main challenges of an EV are the batteries capability to supply sufficient energy for a driving range, comparable to petrol fuelled vehicles. On top of that, a large total number of batteries in EV also contribute to heavyweight, long charging time, and poor durability. Range anxiety is the fear that a vehicle has insufficient range to reach its destination and would thus strand the vehicle's occupants. Range anxiety is one of the factors that influence Malaysian drivers' acceptance towards EVs. To tackle the issue of range anxiety power optimization in EVs is vital. The conventional cell balancing method detects the final voltage of each cell and consumes a long period of time to balance all cells since the cell balancing will only active at the end of the charging process. It is also less preferable to use because of the obvious impact on battery runtime due to the fact that 100% of the access energy from a higher energy cell is dissipated as heat. This wasting of energy effectively leads to overall lower system efficiency, counterproductive to the idea behind EVs.

3. DESIGN CONCEPT AND FEASIBILITY

The primary objective was to design an EM to travel a distance of 100 km on a single battery charge. The basic design concept used the frame of a fuel powered motorbike, the Honda CBR 250cc. The motor transmission, combustion engine system, fuel tank and exhaust system were removed from the motorbike and replaced with an electric motor and batteries. Figure 3 and figure 4 show the motorcycle (donor) before and after removing the fuel engine and unnecessariness part. Figure 5 shows the arrangement of batteries, BLDC motor and controller on the CBR250r's chassis. The motor mount was CNC milled from an aluminium plate. An aluminium profile was used to be battery pack racks. Since the motor and battery pack are heavy, an empty box is used represented them. It easier to relocate and modified the aluminium plate later on. The position of a driven motor is located nearest as possible to its original place. The reason is to reduce the vibration and maintaining the balancing on a motor as it located near to motorcycle's central point also. The battery pack is located at top of EV in order to protect them from debris on the road. The new non-propulsion wiring is made. The original wiring is removed since most of the connection to the mechanical part are no longer in used and to avoid any short circuit may occur with an open connection. The headlamp, tail lamp, signal lamp, horn, meter and brake lamp are maintained to their original position. Figure 6 shows a complete retrofit motorbike.

Fig. 3: After removing fuel tank, fuel engine

Fig. 4: Fuel engine mounted on the chassis

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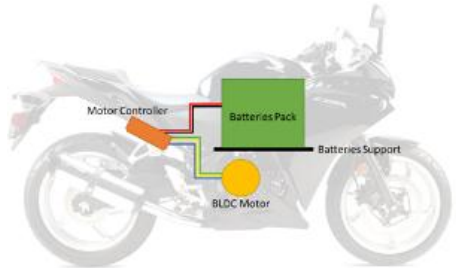

Fig. 5: Arrangement of Propulsion System.

Fig. 6: Complete retrofit motorbike.

3.1. BLDC Motor Selection

The motor parameter was determined using equations 1, 2, and 3 to find the suitable driven motor for the EM. Table 1 indicated the estimation parameter for EM.

Table 1: Estimation Value

No	Parameter	Value
1	Motor Weight, W_m	130 kg
2	Passenger Weight, W_p	70 kg
3	Wheel Size, T_w	17 in
4	Desired Speed, V_d	60 km/h
5	Rolling Pin friction, r_x	0.014
6	Drag Coefficient, C_d	0.6
7	Desired Range, R_d	100 km
8	Puekart Law, p	1.05
9	Voltage Motor, u	72 V

$$\omega_{EM} = 0.0025(v_d/r_w) \quad (1)$$
$$P_{EM} = (F_{EM} v_d r_x) + (0.5\rho A_s C_d v_d^3) \quad (2)$$
$$\tau_{EM} = 9.55(e_M P_{EM}/\omega_{EM}) \quad (3)$$

where, ω_{EM} is rotational speed in minutes (*rpm*), v_d is a desired velocity, r_w is a radius of wheel, P_{EM} is a power required for EM, r_x is a rolling friction coefficient, ρ is an air density coefficient, A_s is a frontal surface area, c_d is a drag coefficient, τ_{EM} is a torque of EM and e_M is a motor efficiency.

Table 2 shows the minimum specification of the driven motor for the EM's design.

Table 2: The EV parameter for 100km range.

No	Parameter	Value
1	RPM	737.17
2	Power, Watt	1835.90
3	Torque, Nm	20.21
4	Current, A	25.50
5	Batteries Capacity, Ah	55.80

Based on table 2, the EM was assumed to move on a flat surface with a constant speed of 60km/h. It needs about 55.80 Ah batteries capacity for a distance range of 100km.

3.2. Battery Pack Design

In the EM system, the BLDC motor is used with a capacity rated 5kWatt. An 18650 Lithium-ion cell is chosen to power up the EM. Table 3 is a specification for 18650 cells. The equation 4, 5 and 6 are used to determine battery's configuration.

Table 3: LG MJ1 18650 Cell

No	Parameter	Value
1	Nominal Voltage, V_b	3.6 V
2	Capacity, C_b	3.5 Ah
3	Weight	48g
4	Dimension	OD: 18mm, L: 65mm
5	Rated Continues Discharge Current	10 A
6	Rated Power/hour	12.6 Watth (3.6v x 3.5Ah)

$$C_n = T_L/(v_b c_b) \quad (4)$$
$$c_{ms} = v_{sys}/v_b \quad (5)$$
$$c_{mp} = c_n/c_{ms} \quad (6)$$

where, c_n is total cells required, T_L is a total load of the system, v_b is a cell nominal voltage, c_b is a cell capacity, c_{ms} is a series configuration for cell module, v_{sys} is an input voltage of the BLDC motor system and c_{mp} is a parallel configuration of cell module. The v_{sys} that available in the market are 48V, 72V, 96V and 120V. Thus, a battery configuration for EM is 20 series with 20 parallel (*20s20p*) and will give an output power to 5040 Watt. The battery specification is 72V with 70Ah capacity.

4. SYSTEM TESTING

The value in table 1 was computed in equation one till there for simulation EM's performance analysis. The analysis will study the effect of total weight, the differences of gear ratio and the drag coefficient toward its expected range distance. These values parameter was choose since it's easier to change and swap physically. The simulation also is done to obtain the optimise parameter of EM. The top speed of EM is set to 60km/h. Figure 7 shows the effect of passenger's weight toward range capability. The simulation is set for a passenger with weight 70kg as an average weight for people (Male) in Malaysia. With weight 70 kg, the EM can reach range up to 130km. Increasing the payload will reduce the range capacity since it needs more power to manoeuvre. Figure 8 shows the relation of changing gear ratio toward the range performance. The gear ratio is a ratio between front sprockets with rear sprocket. We maintain the 14 teeth of front sprocket since it an original sprocket for CBR 250R. The 42 teeth of rear sprocket also a standard part for CBR 250R given the gear ratio is 3. The range obtained with GR 3 is around 88km per charging. While GR 5 and GR 7 range performance is 53 km and 67 km. Increasing gear ratio will make the EM run faster and at the same time reducing the range performance. Figure 9 shows the effect

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Having a good air flow on the EM. The drag force, Cd is varying depending on the body fairing and passenger's body posture since it related to air resistance. As in result, Cd=0.6 will have a longer range compared to Cd=1.0 which give the value 152km and 101km respectively. A lower Cd can be achieved by lowering the passenger body toward the EM and having a good aerodynamic body fairing that can be installed on the EM. The aerodynamic body fairing will cut the air flow and reducing the EM air resistance. It also reduces the front sectional area, As by allowing air flow through the EM's body. The EM also has a field test and the data is recorded. Figure 10 and 11 show a result output of actual experiment of EM. The test has been done inside the International Islamic University Malaysia (IIUM). The IIUM was built on the hill, thus the road has an uphill and downhill road design that affecting the power consumption of EM during the test. The EM has a cruising mode and was set with 45km/h as a cruising's speed. The total distanced travel is 2.8km with average speed 36km/h and average elevation is 55km. The EM was installed a GPS sensor to record the position, elevation, and speed. The power consumption is recorded from a power log on the EM. The Filed test is done during a weekend where have a less vehicle on the road.

5. RESULTS

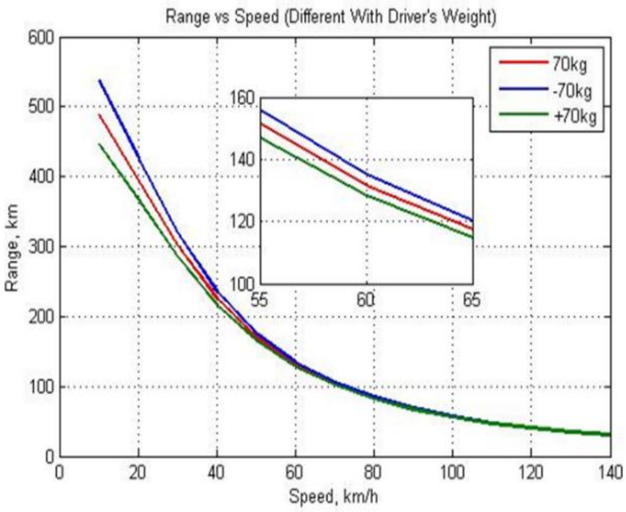

Fig. 7: Range vs Speed (Different Driver's Weight)

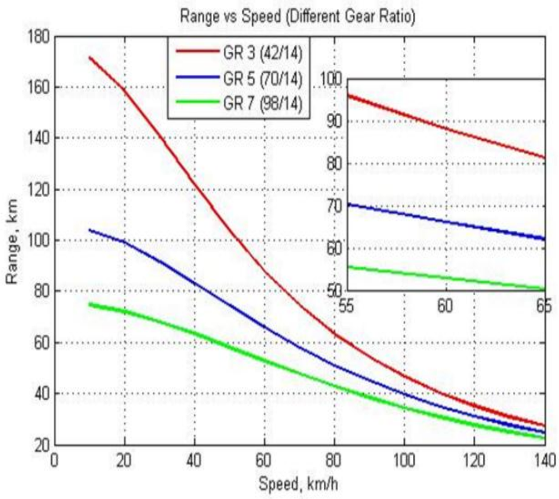

Fig. 8: Range vs Speed (Different Gear Ratio)

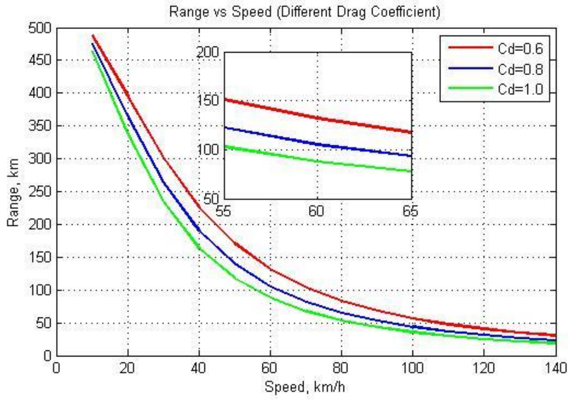

Fig. 9: Range vs. Speed (Different Drag Coefficient)

Fig. 10: IIUM's Track Test.

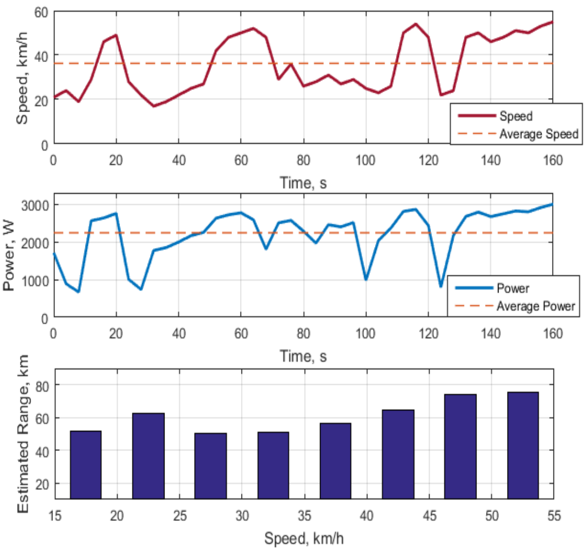

Fig. 11: Actual test on EM.

The speed and power are fluctuated due to the road's elevation. Thus, an average speed of 36.36 km/h is used to compute in the equation for finding the required power and estimated range n simulation. The average power consumption during the test is 2240 Watt with average range 60.7 km. We entered the value of driver's weight and average speed in the equation 1, 2, and 3 to obtain the value for simulation. All data are recorded in Table 4.

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Table 4: Comparison between simulation and actual data (Driver's Weight = 64kg)

1	2 Field Test	3 Simulation	4 Error
5 Average Speed, km/h	6 36.36	7 36.36	8 -
9 Average Power, Watt	10 2240	11 2069	12 7.63%
13 Estimated Range, km	14 60.7	15 65.3	16 7.04%

Based on the simulation, the EM required an average power, 2069 Watt to manoeuvre around 65.3km in range. The differences between a field test in campus and the data from the simulation are 7%. The difference is due to an assumption on rolling resistance coefficient, drag coefficient and frontal surface area coefficient of EM.

6. CONCLUSION

In this paper, we have discussed the importance and reason for retrofit of ICE motorcycle to EM. The study was focused on the selection of motor and calculation of energy storage based on desired speed and distance's range. The EM be able to move 100km with a cruise speed of 60km/h and 55.8Ah of energy storage. The construction of EM's battery pack is based on the total consumption energy. The EM has a battery pack with a configuration of 20 series and 20 parallel 18650's battery. The test on EM has been done to study the relation of driver's weight, gear ration and cruise speed with respect to distance range. The categories of target people that will use the EV are the people that live in the urban area.

In future research, the test will be conducted to study the effect of driving mode towards the battery storage. The selection mode will be city mode, racing mode and sports mode.

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