Electric Scooter with Efficient Power Monitoring and Extended Distance

by

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17914

Dissertation submitted in partial fulfilment of
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical and Electronic Engineering Programme
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in partial fulfilment of the requirement for the
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Approved by,

____

(Khairul Nisak Md Hasan)

UNIVERSITI TEKNOLOGI PETRONAS
SERI ISKANDAR, PERAK
January 2017

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHAMMAD AZZAM BIN AZHAR

ABSTRACT

Electric scooter is one of the popular options of vehicle nowadays, it is either comes in as Hybrid Electric Vehicle (HEV) or Battery Electric Vehicle (BEV). The distance for the electric scooter could travelled does not reach users' expectation compared to normal petrol powered scooter is one of the reasons why people choose to have normal petrol powered electric scooter instead of electric scooter. Electric scooters are always equipped with an indicator or known as Battery Monitoring System (BMS) for the user to check on the battery conditions which is not really accurate as the battery behaviour is a complex electrochemical component. BMS functions as a component to determine the battery level, speed as well as the distance range. The methods for monitoring of the battery state of charge (SoC), capacity, and remaining distance are explained in this paper. Research on Lithium-ion battery as well as the BMS are studied and reviewed to verify the performance and accuracy of the system. Type and performance of DC-DC Boost converter are also reviewed in this paper which helped to extend the range distance of the electric scooter could travel. Implementation of the battery monitoring system also conducted as well as simulation of the Boost Converter corresponds to the expected objectives as stated in this paper.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

Type of rechargeable battery and battery monitoring system (BMS) of Electric Vehicle (EV) or Electric scooter to be specific, will be explained in this chapter. The type of battery is the main concern as it is the crucial component to run the motor of the electric scooter. There are a few parameters considered in choosing the battery such as capacity, size, weight as well as the cost. The monitoring system is another essential component for the electric scooter as a safety precaution for the rider. This chapter is also included with the background study as well as the objectives of the research.

1.1 Research Background

Normal petrol powered vehicles gave many benefits to the user since it was invented. However, the excessive CO_2 emission from the vehicle and insufficient source of fossil fuel calling the world to come up with solution of Electric vehicle. Electric vehicle or scooter is a vehicle supplied with electricity instead of petrol, it is powered with rechargeable battery to drive one motor or more. Electric scooter was not a popular option in recent years due to the distance travelled was only around 30 to 40 km for speed of less than 50 km/h. Charging station for electrical vehicle was barely seen on the road and took hours to charge the vehicle instead of refuelling petrol would take only a few minutes. It is globally known as one of the transportation medium that is environmental friendly as it is emitting zero carbon dioxide compare to other normal vehicles. Hazardous gases will not emit by the electric scooter since the mechanism that causes it to move is only battery. It is also not consuming to sound pollution. Most of the electric scooters nowadays powered by Lithium-ion batteries, Nickel-Metal Hydride batteries powered in earlier model.

1.2 Problem Statement

The first problem identified is current electric scooter mostly operated with lead-acid battery or Nickel/Cd to supply the DC motor but limited to distance at usually up to 30 to 40 km for one journey after a full charge due to its lower battery capacity with heavier weight.

Another problem faced by the rider is there is no indication on the level of battery left throughout the journey. The monitoring system shows the state of battery based on the voltage measured which can be misleading and is not accurate. Knowing the state of battery left, user can estimate on how far the scooter able to go.

1.3 Objectives

The objectives in this project are:

1. To analyse the type of dry cell that is suitable to run an electric scooter for a distance of more than 60km with lighter weight as well as smaller in size.
2. To create a monitoring system for the rider to know the battery voltage level left, speed and range distance of the scooter could travel when riding the electric scooter.

1.4 Scope of Study

These are the scopes of study in this project which includes:

1. Dry cell capacity and ability to rotate the motor so that the electric scooter could travel more than 60km. The size and weight of the battery will be taken into consideration.
2. Coding or programming to create a monitoring system to monitor the battery voltage level, range of distance could travel and speed of the electric scooter.
3. Hands on skills to fabricate a prototype for testing purpose.

CHAPTER 2

LITERATURE REVIEW

This chapter will discuss on the past research regarding electric or battery powered scooter, performance of Lithium-ion battery as well as the comparisons with other rechargeable dry cells. The monitoring system of the battery voltage level and conditions are also discussed in this chapter.

2.1 Electric scooter

In 2011, Bertoluzzo and Buja discovered that Lithium-cobalt battery is believed to be the best lithium-ion battery for its high electrical potential and excellent energy feature with peak current of 300A and used them as a drive train for electric scooter [1]. Later on 2013, National University of Singapore (NUS) have developed and tested a battery-powered electric motorcycle. The Honda CBR400 was installed with lithium polymer battery pack that supplied to a DC motor as a propulsion system. The motorcycle engine and some components were dissembled and installed with battery pack as well as motor as a drive train [2]. The specifications of the battery and motor as well as the results from a few research are tabulated in Table 2.1 below [1, 2].

Table 2.1: Comparison of past research on electric scooter

Author	Battery specifications	Motor specifications	Speed	Distance travelled
Weigl et al., 2013	LiPo battery, 72V	72V	100 kmh	64km per charge
Bertoluzzo et al., 2011	Type: Lithium-cobalt battery Voltage: 13 cells of 3.7V Capacity: 100 Ah Current discharge: 50 A	Rated voltage: 48 V Torque: 45 Nm Power: 2.8 kW Speed: 594 rpm	45 kmh	150 km

2.2 Lithium-ion battery

Lithium-ion battery cell is one of the popular rechargeable battery supplying power for electric devices and Hybrid Electrical Vehicle (HEV). Malaysia market leading electric scooter, Eclimo ES-11 occupied their unit with capacity of 3078Wh Lithium-ion battery with battery weight of 50kg [3]. HEV has passed through three phase of battery development from Lead-acid to NiMH and recent technology of Lithium-ion battery. There is various type of dry cell in this world, many of them are rechargeable. Among rechargeable battery, Li-ion gets more attraction compared to Nickel rechargeable battery due to its uncommon characteristics such as high cell voltage, higher energy capacity as well as small self-discharge quantity [4].

Table 2.2: HEV rechargeable battery comparison [5]

Description	Lead Acid (Pb)	Nickel-Cadmium (NiCd)	Nickel-Metal Hydride (NiMH)	Lithium-ion (Li-ion)
Energy density (Wh/kg)	30-50	45-80	60-120	110-160
Nominal voltage	2V	1.25V	1.25V	3.6V
Maintenance	90 – 180 days	30 – 60 days	60 – 90 days	Not necessary
Self-discharge/month	5%	20%	30%	10%
Charging time	8-16 h	1 h typical	2-4 h	2-4 h

Recent HEV battery, Lithium-ion battery indicates the best performance out of the other phase of HEV battery. Table 2.1 shows the comparison of rechargeable battery for HEV [5]. According to Li and Zhang (2009), referring to the table above indicates that Lithium-ion battery could produce less than 50kg of battery as current design, taking the lowest range of energy density of 110Wh/kg would produce a slightly higher battery capacity of 3300Wh with lighter weight at only around 30kg.

There are differences between Lithium battery and Lithium-ion, some lithium batteries are not rechargeable but Li-ion batteries are rechargeable. There are variety brands of Lithium battery in the market, but they were not sold in standard size such as AA, C or D, the reason behind it is because to avoid Lithium-ion battery being charge to the not designated charger. They are only sold in 18650 (18mm x 65mm) size at higher voltage of 3.7 V, it is possible to get a lower voltage but would cost more money. Table 3.1 shows the list of Lithium-ion battery in the market with details.

Table 2.3: Li-ion battery in the market of size 18650

Description	Voltage	Max discharging current	Capacity
Brand : Tangsfire Model : - Weight : 47g	3.7V	30A	2500mAh
Brand : Nitecore Model : IMR18650 Weight : 48g	3.6V	30A	2000mAh
Brand : Nitecore Model : NL1834 Weight : 45g	3.7V	30A	3400mAh
Brand : LG Model : HE4 Weight : 46g	3.6V	35A	2500mAh
Brand : LG Model : HG2 Weight : 46.6g	3.6V	20A	3000mAh

2.3 Boost Converter

To extend the travel distance range for the electric scooter, boost converter is proposed in this project. The input voltage will be taken from the battery pack which are connected in parallel so it will hold more capacity but with slightly lower voltage supply. Therefore, the purpose of boost converter is to increase the input voltage from the battery pack to produce higher output voltage to meet the voltage supply requirement of the motor. Table 2.4 below is a compilation of research papers proposed boost converter with different method. Nikhil et. al. proposed a buck-boost converter which consist of 48V 40Ah battery that connected parallel with supercapacitor of 16V 58F, the function of the buck-boost is to increase the voltage of the supercapacitor bank from 16V to 48V. It is a bidirectional buck-boost converter as it buck the power incoming from motor for regeneration [6-8]. Interleaved DC-DC Converter is a converter with numbers of boost modules which each module consist of IGBT that shared the battery current equally was reviewed in [6, 9], Omara and Sleptsov proposed two interleaved DC/DC buck-boost converter of two modules consist of IGBT switches on each of the module [6], however Sakka et. al. reviewed on interleaved 4-channel boost converter consisting of 4 identical modules that each of the module consist of IGBT, diode and inductor that connected in parallel [9].

Table 2.4: Research on different type of boost converter

No	Author	Research Title	Findings
1	Nikhil et al. (2013)	Design Approach for Electric Bikes Using Battery and Super Capacitor For Performance Improvement	• Battery pack connected parallel with supercapacitor via buck-boost converter. • Input voltage = 15V Output voltage = 48V
2	Remon et al. (2016)	PI Controlled Bi-Directional DC-DC Converter (BDDDC) and Highly Efficient Boost Converter for Electrical Vehicles	• Combination of IGBT and MOSFET connected in parallel. • Input voltage = 24V Output voltage = 222.7V
3	Omara et al. (2016)	Bidirectional Interleaved DC/DC Converter for Electric Vehicle Application	• Using PI current and voltage controller • Input Voltage = 144V Output Voltage = 400V
4	Sakka et al. (2011)	DC/DC Converters for Electric Vehicles	• Boost DC/DC Converter: consist two semiconductor switches (diode and switch) and one storing element (capacitor) • Interleaved 4-channel DC/DC Converter • Full-bridge DC/DC Converter

MOSFET and IGBT were known for its special characteristic which are fast switching and low ON state Voltage characteristic respectively. Combination of both MOSFET and IGBT have created a new technology of power conversion which known as "Mixed Parallel Operation". Both component complete each other process whereby MOSFET reduces the turn-off loss of IGBT while IGBT reduces the turn on loss of MOSFET. Figure 2.1 below is the circuit diagram of the proposed device. [7]

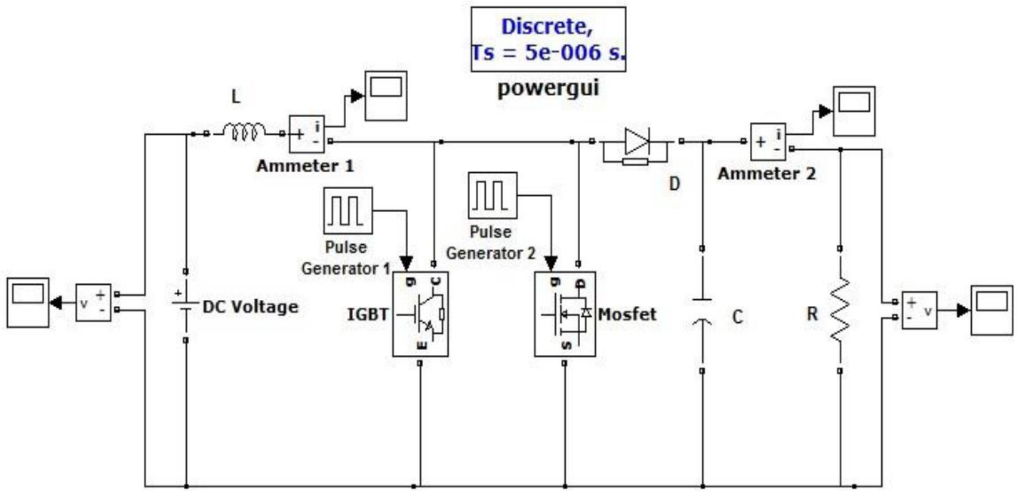

Figure 2.1: Circuit diagram of parallel IGBT-MOSFET switch boost converter [7]

This combination device has a higher efficiency compared to other conventional boost converter. The data comparison of efficiency as tabulated in the Table 2.4.

Table 2.5: Comparison between typical and parallel IGBT-MOSFET [6]

Boost Converter	Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Efficiency (%)
Conventional	48	139.6	333	11.1	55
	24	69.71	166.3	5.543	55
Remon. et. al.	48	113.5	450.7	9.014	74
	24	56.08	222.7	4.453	74

2.4 Monitoring system for Li-ion battery

Electric scooter users might face a difficulty to trace on how much power left in the battery for the electric scooter to travel for distance. Recent electric scooter does not equip with monitoring system which makes it quite hard for the user to estimate how long they can go. Monitoring system in this context is define as precise information provider of internal conditions of the battery, as in State of Charge (SOC) and State of Health (SOH). Where SOC indicates the battery charge left while SOH indicates the health condition of the battery which signify as loss of capacitance or power [10]. All this information could produce another information on the distance of the scooter could covered.

2.3.1 Model-related SoC estimation

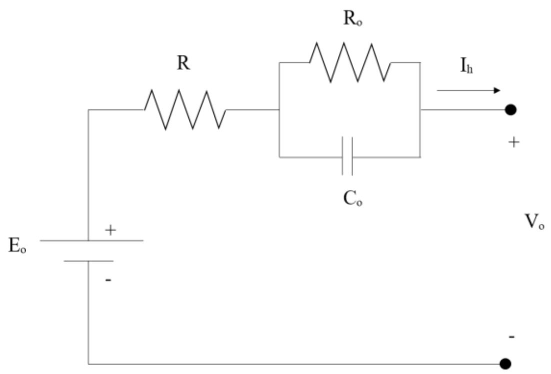

Figure 2.2: Thevenin basic model [8, 9]

Simplified electric circuit consists of capacitors, resistors and voltage source to run a test on battery discharge to check on the battery performance. Considering Thevenin model as shown in Figure 2.1, voltage source connected to a resistor series with RC network, from the load current change can predict the voltage transient response that can be applied in dynamic conditions. However, researchers found that due to the temperature and deterioration of battery, Thevenin basic model is not efficient. The internal resistance would not give out a sufficient information on the battery characteristics. This is because some of the parameters are expected to be constant during the test are actually vary on the run time depending on the state and history of the cells [11].

Similar approach reviewed in [12], SoC estimation is by using a simple model which comes with few equations that applied electrical measures. The SoC of the battery can be integrated through the relationship with the battery Open Circuit Voltage (OCV). The idea is to estimate the OCV of the battery through the model and calculate the estimated SoC from the relationship of OCV-SoC. By measuring the battery voltage, current and temperature, the estimated battery OCV can be obtained through electrical model for SoC estimation. This method might not give out accurate value as it is only performed well for new batteries, but working fine in estimating the SoC during charging and discharging for the battery performing well in producing the behaviour throughout the process.

2.3.2 State of Charge

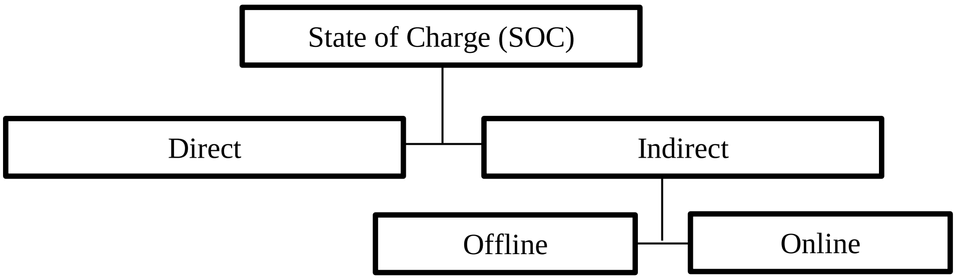

Figure 2.3: State of Charge methods [5]

Calculating and estimating the state of charge of Li-ion batteries is an alternative for users to measure the time usage. Thus, the users can estimate how long the battery could last [11, 13]. Figure 2.2 as interpreted by Rezvanizaniani et al. explains the State of Charge can be classified into two, which are direct and indirect. For indirect method, the online measurement referred as measurement of the battery during operation by observing the behaviour of the battery current, voltage and temperature. Some cases required to observe on the pressure. This method known as one of the most efficient procedure. However, this online method might lead to inaccurate outcomes due to the precision of the sensors involved [11]. The behaviour of the batteries can be test through the charge or discharge process of a battery [14]. The process of charge and discharge depends on the surrounding, where temperature will give significant difference towards the performance and lifespan of the battery.

Heat will produce when the internal resistance is large, thus will cause deterioration towards the battery [11, 15].

As mentioned by W. Waag et al, SoC can be find out by Ampere-hour counting. Accurate calculation from the battery capacity and current measured from the Lithium-ion battery can predict the changes of SoC. This method is efficient for Lithium-ion battery as no side reaction occurs during operation provided with known initial SoC of the battery. However, a long run of ampere-hour method could lead to an accumulative error due to frequent inaccuracy. Thus, this method is best integrated with another method such as Open Circuit Voltage (OCV)-based SoC estimation. Else Ampere-hour can collaborate with power analysis or SoC estimation based on resistance from the battery. [12]

2.3.3 Capacity estimation

Battery capacity is an indication of available battery content to be used at fully charged. Due to battery ageing, the capacity of battery might change over time. The voltage is increase and decrease during charging or discharging respectively. A lower capacity will show a slightly higher voltage change during charging or discharging process compared to the same type of battery with higher capacity. Therefore, the ampere-hour charging or discharging process are relevant with the voltage difference between charged and discharged of a battery.

This method can relate with battery OCV between before and after the charge and discharge process which the battery capacity is measured through the OCV-SoC relationship. Two SoC points required to measure to obtain a more accurate capacity estimation. However, on-board applications might find this method quite complicated to conduct due to the overvoltage takes some times to reduce after discharge.[12]

2.3.4 State of Health

Comparing the performance and condition of a brand-new battery with a used battery of a same kind is known as State of Health (SOH). There is no specific way to define the SOH of a battery unlike the SOC as it is commonly assumed and evaluate, however the outcome is not precise. Basically, the SOH is indicated by the changes occurred towards the capacity and internal resistance of the battery. There are a few symptoms that can be observe such as instant power loss, temperature rise, corrosions and etcetera. To estimate the usage of a Lithium-ion cells, parameters such as capacity, charge and discharge rate, internal resistance have to be observed. During operation of a cell, internal resistance might be high when the capacity is large [11].

CHAPTER 3

METHODOLOGY

To achieve the objectives stated, these are things needed to be taken into account as interpret in the figure 3.1 below.

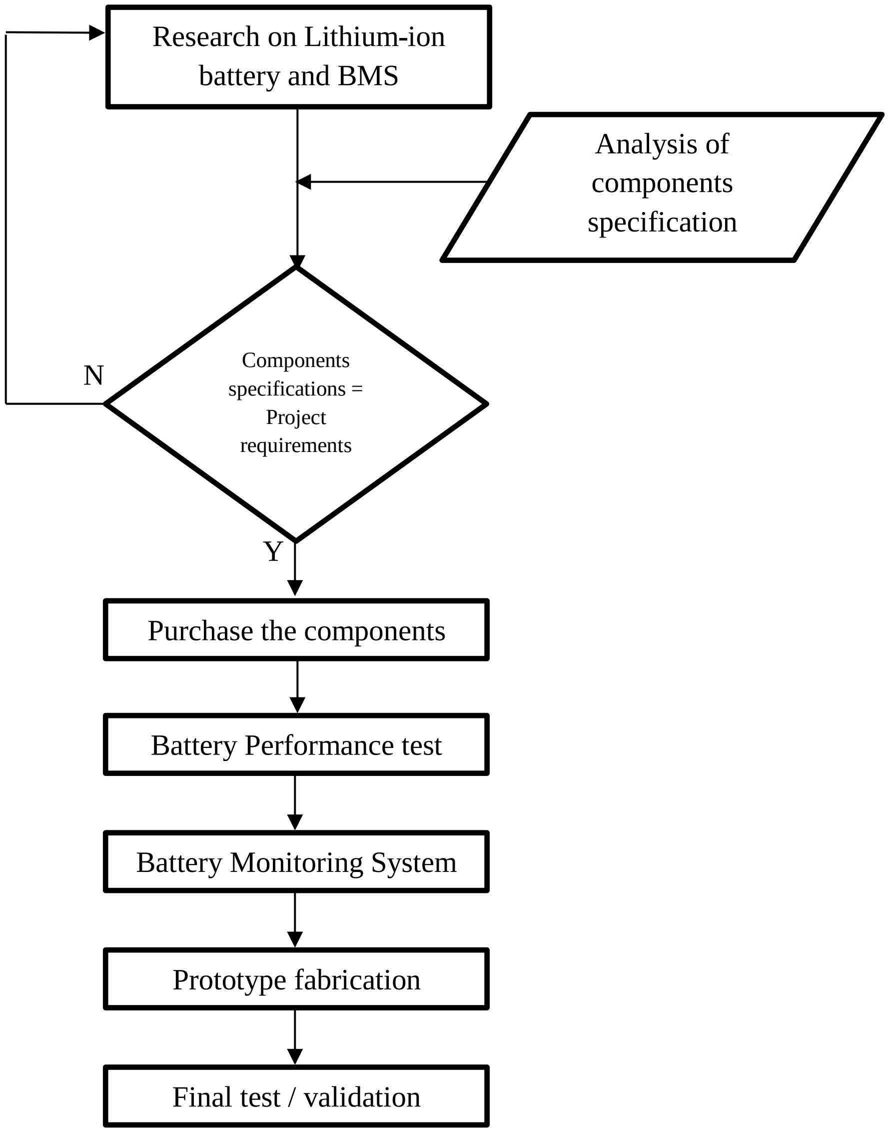

Figure 3.1: Flow of project

3.1 Gantt Chart FYP1 and FYP2

Table 3.1: Gantt Chart FYP1

	TASK	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP SEMESTER 1	Topic selection														
	Information gathering														
	Extended proposal														
	Data gathering														
	Proposal defence														
	Component testing														
	Interim report submission														

Table 3.2: Gantt Chart FYP2

	TASK	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP SEMESTER 2	Project fabrication	■	■	■	■	■	■	■	■	■	■	■	■		
	Progress report							■	■						
	Data analysis and troubleshoot								■	■	■	■	■	■	
	First draft submission													■	
	Oral presentation													■	
	Dissertation submission														■

3.2 Prototype fabrication

The prototype will be presented in a scaled down size version of a bicycle instead of an electric scooter due to time, manpower and budget constrain. The scaled down ratio of electric scooter and bicycle is 10:1 which applied on the battery pack and weight. However, the prototype is installed with real electric scooter motor that will be explain in this subchapter.

3.5.1 Motor propulsion system

The propulsion system used for this prototype is Brushed DC Electric Scooter motor. Originally, the installed sprocket at the shaft of the motor is 11 tooth sprocket for #35 rolling chain as seen in Figure 3.5, where the number 35 indicates the size of the chain that can fit to the sprocket. However, this sprocket size is not easily found on a bicycle as bicycle usually use a bigger chain.

Figure 3.2: 11 tooth sprocket for #35 rolling chain

Therefore, modifications have been conducted on the motor’s sprocket. The original sprocket was replaced with a custom-made sprocket which was fabricated to fit the shaft of the motor. The fabrication started with a solid cylinder shape metal that passed through lathing process with lathe machine to shape the metal to the required size. Precise work is important for lathing process to get the accurate dimension outcome. Parting or known as cutting process comes after the lathing process is done to separate the unused metal. Figure 3.6 shows the dimension and outcome from lathing and parting process, which was conducted with the same machine.

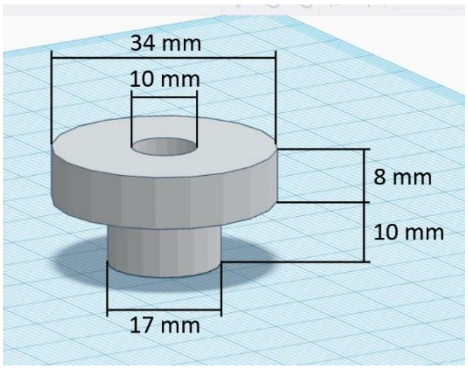

Figure 3.3: Dimension of solid metal

Figure 3.4: Lathing and parting process outcome

The metal is then fitted and welded to a 16 tooth freewheel sprocket which is easily obtained in the market. Precise welding also an important process that have been conducted to avoid unaligned sprocket. Figure 3.7 shows the outcome of the custom motor sprocket.

Figure 3.5: Custom-made sprocket installed on the motor

3.3 Analysis of battery specifications

The battery is tested with an electric scooter brushed direct-current motor (BDC) with voltage of 24VDC, rated current of 22A and power of 350W. The battery pack is designed slightly lower in voltage correspond to the specification of the motor. Initially, the battery pack is designed for a real size electric scooter. To operate at the established rated voltage, each battery pack constructed with 6 cells connected in series and parallel which produced maximum voltage of 12 V with capacity of 6 Ah for each unit. 5 units of battery packs are then connected in parallel which produce

12V with capacity of 30Ah. 2 sets of 5 units battery packs then connected in series that will produce 24V, 30Ah battery pack. This whole unit of battery require 60 units of cells and each cell weight 46.6g which makes the whole battery weight around 2.8kg excluding the battery housing. Figure 3.2 illustrates the battery configurations.

The scaled down size of battery pack will only require 1 unit of battery pack used in real scale of electric scooter which consist of 6 cells of LG HG2 Li-ion battery connected in series-parallel. The battery pack for this prototype will produce 12 V and 6 Ah of battery. Each cell weight 46.6g will make the total weight around 280g.

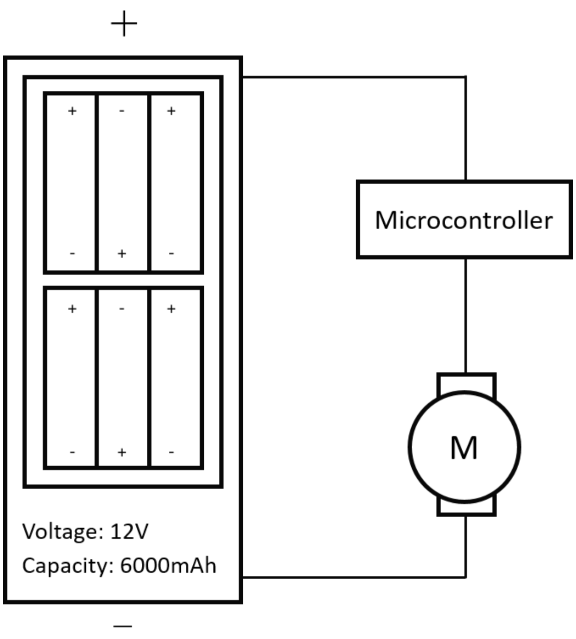

Figure 3.6: Prototype battery pack configuration

3.4 State of Charge (SoC)

The battery performance can be tested through the State of Charge (SoC) through charge and discharge process of a battery by directly measure the parameters of the battery during operation. Ampere-hour method can predict the change of SoC by measuring the capacity and current of the battery. This method is integrated with Open Circuit Voltage (OCV)-based SoC estimation method. Else, considering Equivalent Circuit Model (ECM) as illustrated in Figure 3.3 is another option to estimate the OCV of the battery through the model and calculate the estimated SoC from the relationship of OCV-SoC. The estimated OCV of the battery can be determined by measuring the voltage across the $V_{bat.}$

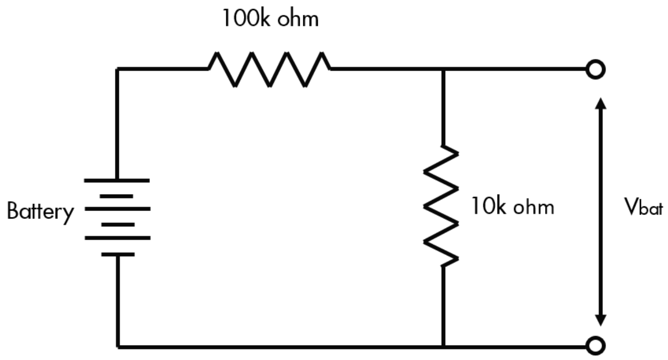

Figure 3.7: Sample of Equivalent Circuit Model (ECM)

3.5 Monitoring system

The Battery Monitoring System (BMS) circuit has been built to display voltage, speed and range distance for the scooter could go. The circuit setup as illustrate in Figure 3.6.

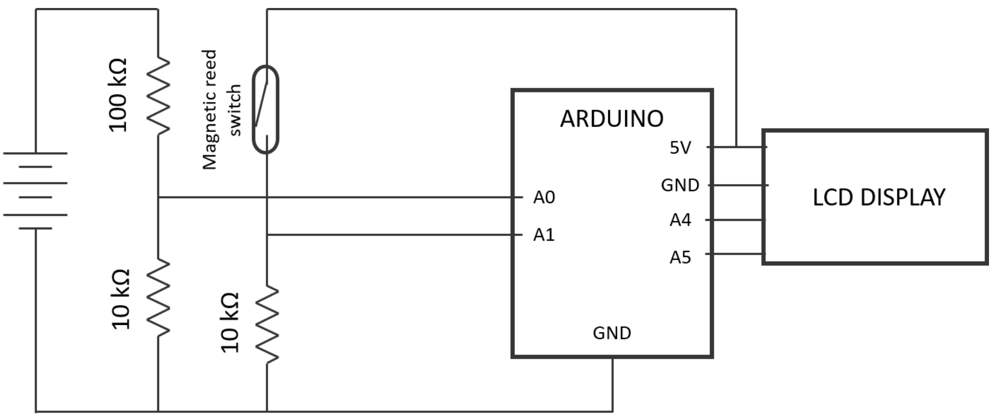

Figure 3.8: Schematic circuit diagram of integrated battery monitoring system

The battery pack will go through OCV-SoC estimation method to get the voltage and current of the battery by measuring through the circuit during operation which will transfer the information to the microcontroller. Figure 3.7 is image of a reed switch. Magnetic reed switch is a tiny component with dimension of 14mm (width) x 2mm (diameter) used to calculate the speed of the wheel. Reed switch acts like Normally Open (NO) switch when the reed switch is exposed to magnetic field, two piece of ferrous metal inside the component will attracted to each other which will close the connection. The connection will open back to the original position when it is not exposed to magnetic field. Reed switch will calculate the number of wheel turn and give input to Arduino as “reedCounter” in the coding as included in appendix.

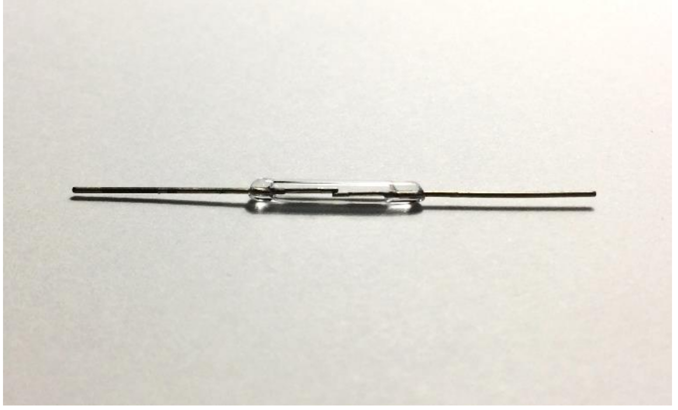

Figure 3.9: Reed switch

The speed obtained from LCD Screen (Arduino) will be recorded and compared with reading obtained from Tachometer as seen in Figure 9. Tachometer is an instrument to measure the rotation speed of a shaft of wheel, the instrument will measure in revolution per minute (RPM) unit. The wheel will be marked with white tape as a point of reference, Tachometer will then placed parallel to the reference point for it to trace the rotation.

Figure 3.10: Tachometer

Microcontroller acts as a data receiver, processor, and transmitter. There are many options for microcontroller, but Arduino is known for their user-friendly interface and easy to conduct compared with other microcontroller. The data will be calculated as explained in the algorithm or flow of the monitoring system below which are divided into phases:

Step 1: Turn on the Battery Monitoring System

Step 2: Microcontroller will read the battery voltage from the battery and take it as an input variable to the processor.

Step 3: Reed switch will count the number of turn from the wheel and send it to the processor as another variable to be processed as speed (km/h)

3.1 The first step is to get the speed (km/h) of the wheel by setting this formula,

$$RPM = \left(\frac{v, \frac{m}{h}}{60\ min}\right)/(\pi d) \quad (3.1)$$

d = diameter of wheel

v = speed variable from speed sensor.

For equation 3.1, speed is taken from the variable at the speed sensor at the wheel. Revolution per minute (RPM) is frequency of rotation, specifically the number of rotation in one minute.

Equation 4.2 explain how to get the distance of the scooter could travel for one minute, the circumference of the wheel is multiplied with RPM. Which will provide distance traveled for one minute.

$$wheel\ circumference \times RPM = distance\ for\ one\ minute \quad (3.2)$$

Step 4: Variable of battery voltage and speed obtained from Step 2 and 3 will be used in this step to obtain the distance estimation of the scooter could travel.

4.1 To get the distance for the scooter could travel, the formula is as follow:

$$Distance, d = \left(\frac{Battery\ pack\ size}{\frac{Wh}{m}} \right) \tag{3.3}$$

Battery pack size is obtained from equation below:

$$Battery\ pack\ size\ (kWh) = V_{pack} \times Rated\ battery\ capacity \tag{3.4}$$

V_{pack} = Voltage produced by battery pack

Watt-Hour per meter (Wh/m) is obtained from equation __ below:

$$Watt - Hour\ per\ meter = \left(V_{pack} \times \frac{I_{drawn}}{v} \right) \tag{3.5}$$

V_{pack} = Voltage produced by battery pack

I_{drawn} = Current drawn for specific speed

v = Speed of the wheel obtained from step 3

Step 5: Display those 3 variables on the LCD display.
Step 6: End

Arduino LCD display is an interface medium to display character that connected to Arduino. It comes in variety size of LCD display, but the most popular are 16x2 characters and 20x4 characters. 20x4 characters LCD display will fit 20 characters in line for 4 rows. Require a set of coding as attached in the appendix, loaded into an Arduino microcontroller to display the output. Figure 3.4 is a block diagram explains on the flow of the input passing through the process system before output is displayed at the LCD screen.

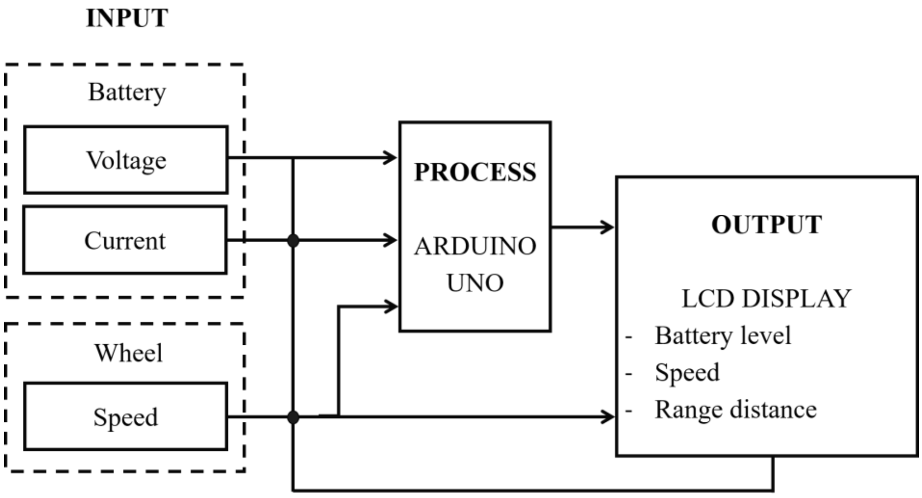

Figure 3.11: Block diagram of Battery Monitoring System (BMS)

3.6 Extended distance

Implementation of boost converter is proposed to extend the distance for the electric scooter could go. The idea of implementing boost converter is to increase lower input voltage of high capacity to have higher output voltage supplying to the motor. The block of electric vehicle with boost converter is as follows:

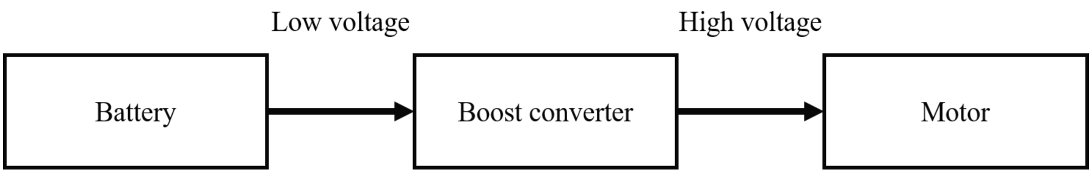

Figure 3.12: Block diagram of vehicle power converter

The parameters of the IGBT-MOSFET boost converter are as follow:

Table 3.3: IGBT-MOSFET Boost Converter parameters

Input voltage	12V
Output voltage	24V
Duty Cycle (MOSFET)	70%
Duty Cycle (IGBT)	50%
Fs	100kHz

Duty cycle, D is determined as follow:

$$D = 1 - \frac{V_{in(MIN)}}{V_{out}} \tag{3.1}$$

$V_{in(MIN)}$ = Minimum input voltage

The value of inductor, L is obtained by equation as follow:

$$L = \frac{V_{in(MIN)} \times D}{f_s \times \Delta I_L} \tag{3.2}$$

$V_{in(MIN)}$ = Minimum input voltage

D = Duty cycle from equation (3.1)

f_s = Minimum switching frequency of of the converter

ΔI_L = Inductor ripple current (5% of output current = 0.6A)

The value of capacitor, C is obtained by equation as follow:

$$C = \frac{I_{out(\max)} \times D}{f_s \times \Delta V_{out}} \tag{3.3}$$

$I_{out(max)}$ = Maximum output current

D = Duty cycle from equation (3.1)

f_s = Minimum switching frequency of of the converter

ΔV_{out} = Output voltage ripple

Based on the parameters obtained above as well as from Table 3.3, the converter model was built in MATLAB Simulink as seen in Figure 3.14.

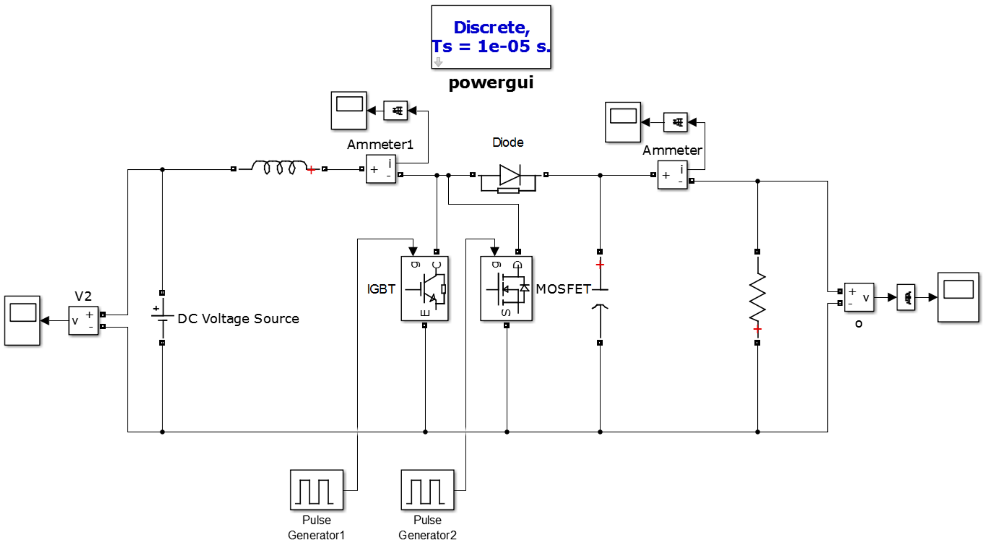

Figure 3.13: IGBT-MOSFET Boost Converter model

CHAPTER 4

RESULTS AND DISCUSSION

4.1 No load test

4.1.1 Motor connected to 12 VDC supply (Rated voltage)

The purpose of this test is to obtain the running time of the motor when it is not connected with load, by getting the current consume when it is supplied with 12 VDC and calculated with equation 4.1. The motor is directly connected to DC Power Generator and supplied with voltage of 12V. Theoretically, when the motor is tested with generator power supply running without load shows that the current consumes for the motor to run is 0.58 A.

$$Running\ time,\ t = \frac{Capacity\ (Ah)}{Current\ consumption\ (A)} \tag{4.1}$$

$$= \frac{6Ah}{0.6}$$

$$= 10\ hours$$

Therefore, the motor could run for about 10 hours if it is supplied with battery pack with voltage of 12 V and capacity of 6 Ah.

4.1.1 Motor connected to 6 Lithium-ion cells with total voltage of 12V

This test is conducted to test the running time of battery could last when it is connected with the motor. 6 units of 18650 Lithium-ion cells producing 12 V (full-charged) were connected in series-parallel and were directly connected to the motor, the voltage and nominal current were recorder throughout the test. It is found that the speed of the motor determined by the voltage supplied, the speed of the motor is gradually decreasing proportional to voltage supplied. The result from test found that the average time battery could supply the motor is for 9 hours 17 minutes before it is fully discharged. Results as tabulated in Table 4.1.

Table 4.1: No load test results

Run	Voltage	Operating current	Running time
1	12 V	0.6 A	9h 15m
2	12 V	0.6 A	9h 20m

4.2 Frictionless setup

The setup for this test was conducted in frictionless mode where the motor-driven wheel (rear wheel) was linked with chain to the gear attached at the motor. The wheel was hung above the surface away from the ground throughout the test. The main concern of having this setup is only to show the performance of Battery Monitoring System (BMS), since considering the friction with real run setup would require more time, manpower and cost for the system construction to ensure the prototype to be ready for use.

Figure 4.1: The construction of motor and chain

The setup of the prototype was arranged and constructed as seen in Figure 4.1. The results for this setup will show the performance of the Battery Monitoring System (BMS) which divided into subchapter of battery voltage and speed. To test the performance of BMS, the battery pack voltage values taken from the Arduino through LCD screen were verified with Digital Multi-meter (DMM) to check on the accuracy while the speed test were verified by comparing the speed values obtained from the Arduino through LCD screen were compared with values obtained from the Tachometer to check on the accuracy.

4.2.1 Battery voltage

The purpose of testing battery voltage is to check on the accuracy of the battery voltage produced by BMS. The setup for this test is battery pack was connected to the BMS and parallel to Digital Multi-meter (DMM). The accuracy of the voltage readings was verified where the readings of battery voltage displayed at the LCD from Arduino were compared with the readings of battery voltage obtained from the battery by directly measure with DMM. Table 4.2 below shows the values obtained from both source.

Table 4.2: Battery level test results

Test	Voltage Reading (V)		Error (V)
	Arduino	Digital Multimeter	
1	11.89	12.00	0.11
2	8.11	8.02	0.09
3	8.06	7.98	0.08
4	7.79	7.89	0.10

The battery voltage values were tested randomly at four point of different voltage as the battery discharged. The intention is to prove the reading accuracy. Table 4.2 above shows a slight error difference from both source. Therefore, the average error of battery pack voltage test conducted is 0.095V where the error value is still tolerable for it is not exceed 0.5V. Lower battery voltage produced from the BMS will give extra precaution to the rider on the battery pack level left.

4.2.2 Speed

The speed test was conducted to aim on the performance accuracy of the speed produced by BMS. The speed readings of the wheel obtained from the LCD Screen (Arduino) through reed switch as mentioned in the methodology were verified by comparing with readings obtained from tachometer. Tachometer was placed aligned opposite with reed switch to obtain exact values. The motor was supplied with fully-charged battery pack of 12V, the speed readings from both BMS (LCD Screen) and Tachometer were recorded at every 1V decrement until reached 4V as there is almost no rotation occurred at voltage level of 3V. Since the values produced by Tachometer are in RPM, therefore the RPM values obtained were calculated with formula below to get the values in the form of km/h. Complete test result of 12V until 4V is tabulated in Table 4.3.

$$Velocity, \left(\frac{km}{h}\right) = 2\pi r \times RPM \times \left(\frac{60}{1000}\right) \quad (4.2)$$

r = radius of wheel in meter = 0.34m

RPM = revolution per minute obtained from Tachometer.

Table 4.3: Speed test result

Test	Voltage (V)	Tachometer (rpm)	Speed (km/h)		Error (%)
			BMS	Tachometer	
1	12.00	589.0	74	81.15	8.81
2	11.00	547.0	71	76.53	7.23
3	10.00	509.9	65	73.06	11.03
4	9.01	478.5	60	65.74	8.73
5	8.00	438.7	51	58.43	12.72
6	7.05	401.9	47	52.35	10.23
7	6.00	362.5	40	45.57	12.23
8	5.00	316.9	35	39.61	11.64
9	4.00	272.0	31	34.87	11.09

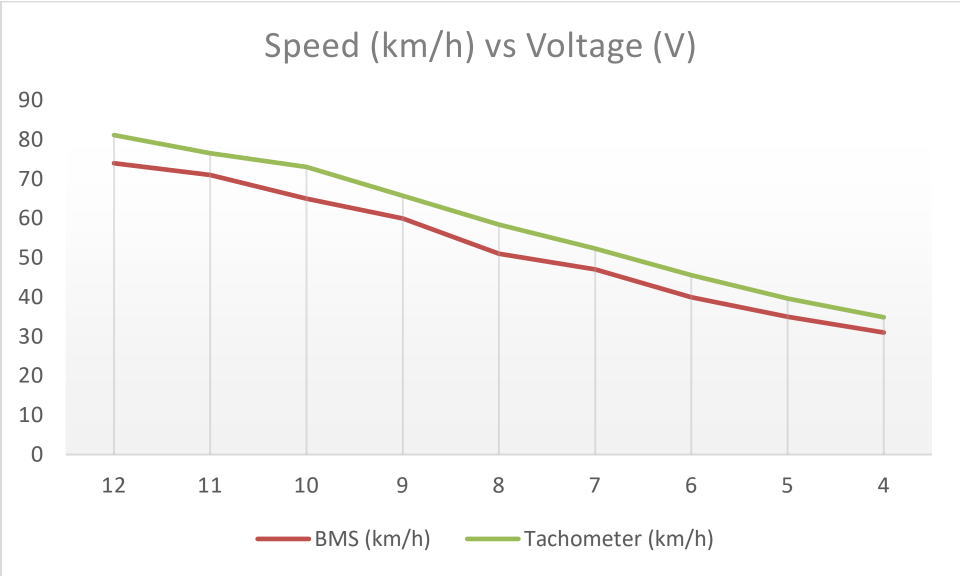

Figure 4.2: Speed vs voltage graph

The graph of speed vs voltage obtained from frictionless test as shown in Figure 4.2, the graph for Arduino which was obtained from the BMS shows a linearly decrease respective to graph obtained from the Tachometer. This graph shows shift-error as the errors are in the same range of below 15%.

4.3 IGBT-MOSFET Boost Converter

The purpose of this Boost Converter model is basically to stimulate a power converter with purpose to increase a low input voltage of 12V to obtain higher output voltage of 24V which corresponds with the motor requirement.

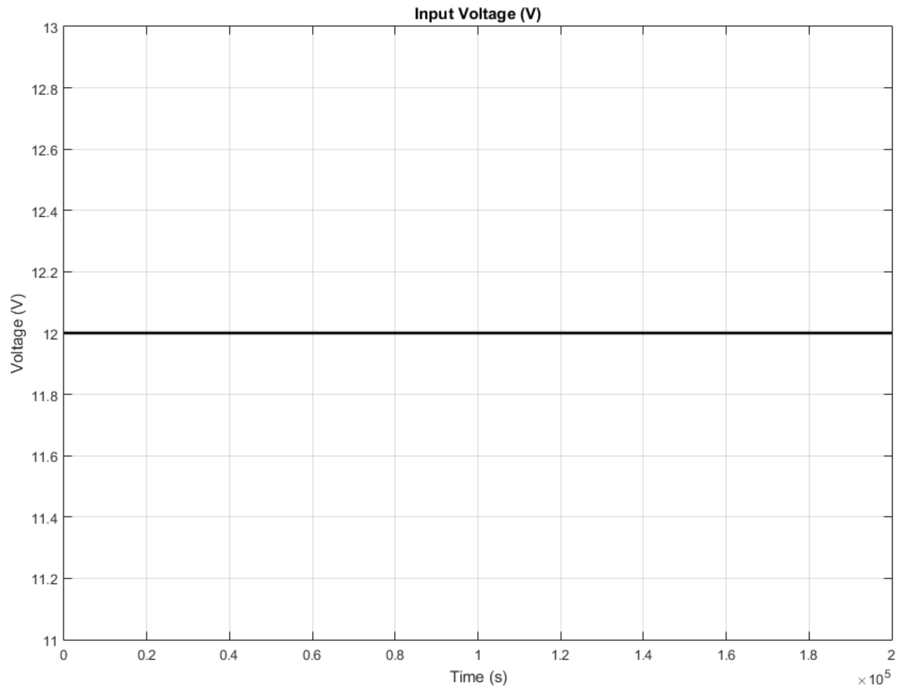

Figure 4.3: Input voltage graph

Figure 4.3 shows the constant input voltage supply waveform to IGBT-MOSFET Boost Converter where the constant voltage is 12 VDC, but the input voltage in the real application would vary due to state of charge (SOC) of the battery pack.

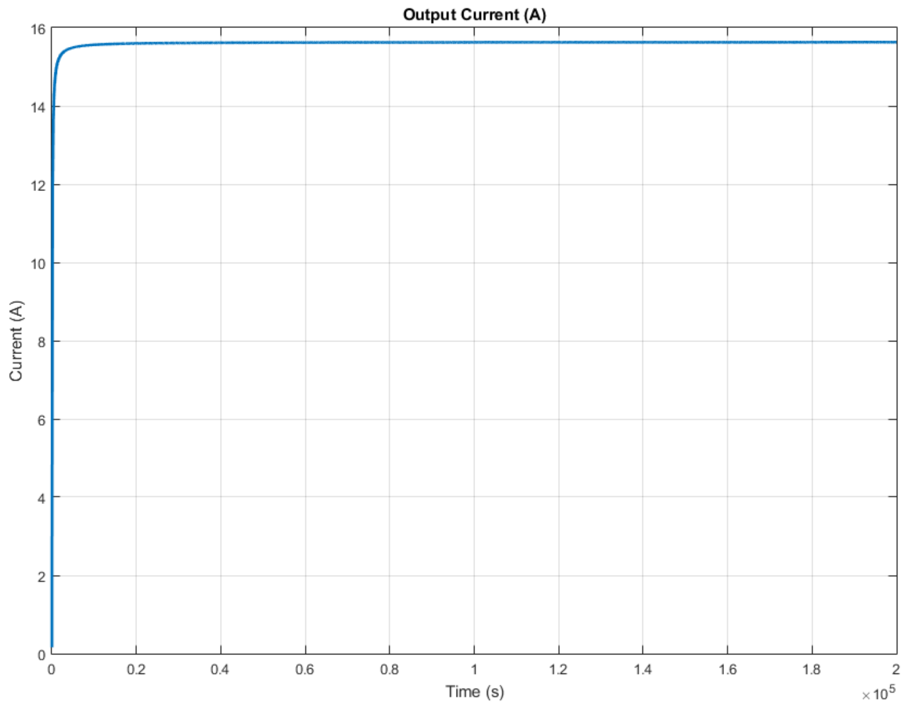

Figure 4.4: Output current graph

Figure 4.4 shows the output current waveform of IGBT-MOSFET Boost Converter where the peak current is 15.6 A for 55 A input current. The curve shown is in 3s where the curve get in stable condition in less than 1s.

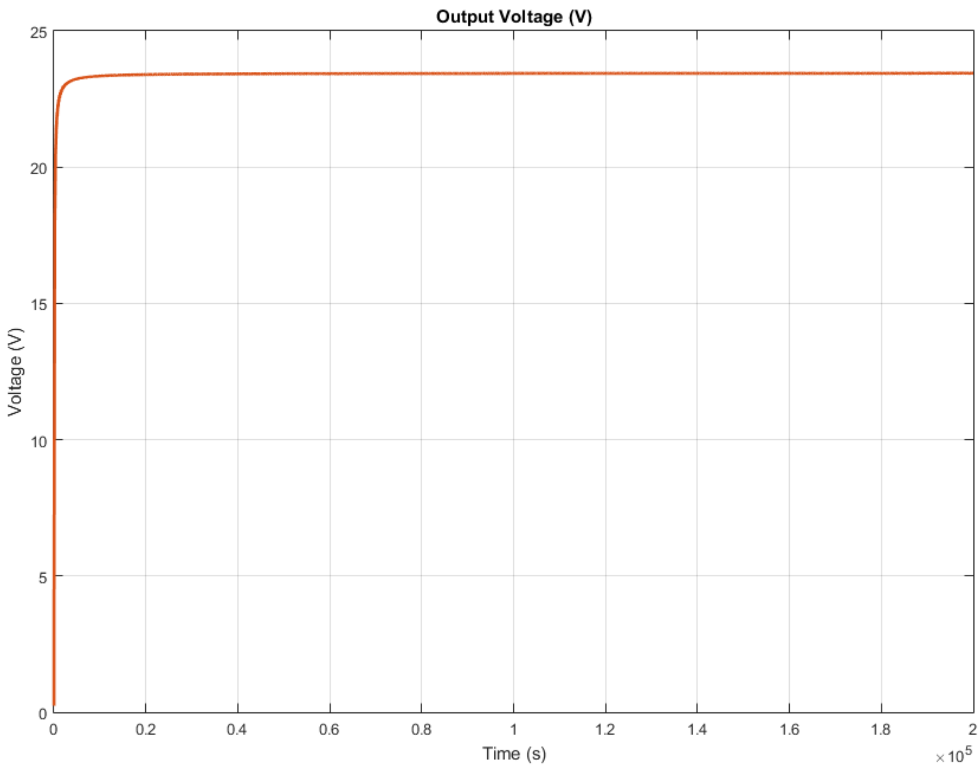

Figure 4.5: Output voltage graph

Figure 4.5 shows the output voltage waveform of IGBT-MOSFET Boost Converter where the peak voltage is 23.5 VDC for 12VDC input voltage. The curve shown is in 3s where the curve get in stable condition in less than 1s. However, the power efficiency of this model did not meet the expectation of high efficiency as stated in the reviewed model in chapter 2 with the same configuration. This model only reach 55% efficient.

Table 4.4: Results from IGBT-MOSFET Boost Converter

Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Efficiency (%)
12	55	23.5	15.6	55

$$Efficiency\ (\%) = \frac{P_{out}}{P_{in}} \times 100 \tag{4.3}$$

$$= \frac{(15.6)(23.5)}{(12)(55)} \times 100$$

$$= 55\%$$

From the outcome of the model as stated in Table 4.4, the model is able to give output of 23.5V which correspond to the rated voltage of the motor. Therefore, this model able to extend the range distance as it could supply voltage longer according to the capacity of the battery holds before the converter. The connection configuration of the battery pack before the converter is important to have a higher capacity of battery pack.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The reason of people choosing normal petrol-powered vehicle over electric vehicle is mainly because of the performance of the battery for long distance travel, no efficient monitoring system on the battery, as well as lack of charging station which then took hours for the vehicle re-charge. As a solution to the performance of the battery, Lithium-ion battery is the best option for Battery Electric Vehicle (BEV) such as electric scooter for its unique characteristic of higher energy densities, low self-discharge, and higher capacity. Some parameters have been considered in choosing the type of Lithium-ion battery including the capacity, voltage, current, weight and size. As a portable application of electric scooter, the weight and size of lithium-ion battery is the main consideration so that the scooter can equipped with a larger battery capacity with smaller and lighter battery pack.

Considering a DC-DC Boost converter is a good alternative to solve the problem of range distance for electric scooter to travel, however this is only proven through a simulation. Real application of the model might vary from the results gained due to unpredictable battery pack behaviour might affect the performance of the boost converter.

As for the battery monitoring system, the method proposed at methodology is yet the best alternatives to obtain the battery pack voltage level and speed in order to obtain the remaining distance of the scooter could travel. After all, the efficiency and accuracy of the monitoring system is depending on the ambiance that will affect the performance of the battery.

Eventually, this system would cost lesser compared to system in the market because of the components selection involved in this project is not expensive and minimum space required for the components since this system involving tiny components such as reed switch, resistor, capacitor, diode and Arduino UNO microcontroller.

5.2 Recommendation

For further research, the speed of the motor is expected to be varied by the user with implementation of Electronic Speed Control (ESC) before the power supplied to the motor as higher voltage will produce higher motor torque. The battery pack should be equipped with thermal monitor as well as temperature conditioner to keep the battery at suitable temperature to avoid overheating that can cause deterioration towards the battery health and lifespan. Considering to implement other model of boost converter as a comparison with the model implemented in this project, this is because the components of the inductor and capacitor might vary according to the design of the converter which would produce a better performance.

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APPENDICES

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#define reed A1
LiquidCrystal_I2C lcd(0x27, 2, 1, 0, 4, 5, 6, 7, 3, POSITIVE);
//VOLTMETER
int analoginput = 0;
float vout = 0.0;
float vin = 0.0;
float R1 = 100000.0;
float R2 = 10000.0;
int value = 0;

//SPEEDOMETER
int reedVal;
long timer;
int kmh;
float radius = 13.5; //define tire radius (inch)
float circumference;

int maxReedCounter = 100;
int reedCounter;

void setup (){
    pinMode(analoginput, INPUT);
    lcd.begin(20,4);

  //LCD DISPLAY
    for(int i = 0; i< 3; i++)
  {
    lcd.backlight();
    delay(150);
    lcd.noBacklight();
    delay(150);
  }
  lcd.backlight();

  lcd.setCursor(2,0);
  lcd.print("ELECTRIC SCOOTER");
  //SPEEDOMETER
  reedCounter = maxReedCounter;
  circumference = 2*3.14*radius;
    }
    else{
      if (reedCounter > 0){//don't let reedCounter go negative
        reedCounter -= 1;//decrement reedCounter
      }
    }
  }
  else{//if reed switch is open
    if (reedCounter > 0){//don't let reedCounter go negative
      reedCounter -= 1;//decrement reedCounter
    }
  }
  if (timer > 2000){
    kmh = 0;//if no new pulses from reed switch- tire is still, set mph to 0
  }
  else{
    timer += 1;//increment timer
  }
}
void loop(){
     //VOLTMETER
  //read the value at analog input
  value = analogRead(analoginput);
  vout = (value*5.0)/1024.0;
  vin = vout/(R2/(R1+R2));
pinMode(reed, INPUT);
    // TIMER SETUP- the timer interrupt allows precise timed measurements of the reed switch
  //for more info about configuration of arduino timers see http://arduino.cc/playground/Code/Timer1
  cli();//stop interrupts
  //set timer1 interrupt at 1kHz
  TCCR1A = 0;// set entire TCCR1A register to 0
  TCCR1B = 0;// same for TCCR1B
  TCNT1  = 0;
```

```
// set timer count for 1khz increments
  OCR1A   =   1999;//   =   (1/1000)   /
((1/(16*10^6))*8) - 1
  // turn on CTC mode
  TCCR1B |= (1 << WGM12);
  // Set CS11 bit for 8 prescaler
  TCCR1B |= (1 << CS11);
  // enable timer compare interrupt
  TIMSK1 |= (1 << OCIE1A);

  sei();//allow interrupts
  //END TIMER SETUP

  Serial.begin(9600);
}
ISR(TIMER1_COMPA_vect)  {//Interrupt  at
freq of 1kHz to measure reed switch
  reedVal = digitalRead(reed);//get val
of A0
  if  (reedVal){//if  reed  switch  is
closed
     if  (reedCounter  ==  0){//min  time
between pulses has passed
      kmh                              =
(56.8*1.609*float(circumference))/float
(timer);//calculate miles per hour
      timer = 0;//reset timer
      reedCounter                      =
maxReedCounter;//reset reedCounter
  if (vin<0.09){
    vin=0.0;     //statement   to   quash
undesired reading
  }
  lcd.setCursor(0,1);
  lcd.print("VOLTAGE : ");
  lcd.print(vin);
  lcd.setCursor(16,1);
  lcd.print("V");
  lcd.setCursor(0,2);
  lcd.print("SPEED   : ");
  lcd.print(kmh);
  lcd.setCursor(16,2);
  lcd.print("km/h");
  lcd.setCursor(0,3);
  lcd.print("RANGE   :  ");
  lcd.setCursor(16,3);
  lcd.print("km");
    delay(500);
}
```