STUDY ON ULTRA CAPACITOR

AHMAD MUSTAQIM BIN JOHAR

PSM Report II

Projek Sarjana Muda

Supervisor:DR. SAFARUDIN GAZALI HERAWAN

Second Examinor: DR. FADHLI BIN SYAHRIAL

Faculty of Mechanical Engineering

Universiti Teknikal Malaysia Melaka

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STUDENT'S DECLARATION

I admit that this report entitled "Study on Ultra Capacitor for Electric Motor" is my own work except it is cited from other reference source.

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ABSTRACT

Energy storage device is device which have a capable of saving and storing energy in term of electricity. The energy storage device is a very crucial device which have many particular usage because it can be used in variety of application and purpose. In this modern era, usually the energy storage device that being used is a battery. But usual battery have some weakness which it only be used once. For rechargeable battery, it may consume a lot of time to charge it up. So, it is not recommended to be used for emergency or time limited case. With the presence of new technology, there is another energy storage device is created which is the ultra capacitor. In this research, the ultra capacitor is studied to see how fast ultra capacitor can be charge and discharging for electric motor.

ABSTRAK

Peranti penyimpanan tenaga adalah alat yang mempunyai kemampuan untuk menyimpan tenaga dalam bentuk elektrik. Peranti penyimpanan tenaga adalah alat yang sangat penting dan mempunyai banyak kegunaan tertentu kerana ia boleh digunakan dalam pelbagai aplikasi dan tujuan. Dalam era moden ini, biasanya peranti penyimpanan tenaga yang biasa digunakan adalah bateri. Tetapi bateri biasa mempunyai beberapa kelemahan iaitu ia hanya boleh digunakan sekali. Untuk bateri boleh dicas semula, ia pula memakan banyak masa untuk mengecas semula sehingga penuh. Jadi, ia tidak digalakkan untuk digunakan untuk kecemasan atau dalam kes masa yang terhad. Dengan adanya teknologi baru pada masa kini, terdapat satu lagi peranti penyimpanan tenaga yang telah tercipta dicipta iaitu ultra kapasitor. Dalam kajian ini, ultra kapasitor dikaji untuk melihat berapa pantas kadar ultra kapasitor boleh dicas dan menyahcas untuk motor elektrik.

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LIST OF ABBREVIATIONS

EDLC	Electrochemical Double Layer Capacitor
PC	Pseudocapacitor
DC	Direct current
AC	Alternate current

LIST OF SYMBOL

V	Voltage flow
C	Capacitance
Q	Charges flow
U	Energy output
P	Power output
R	Resistance
Vs^{-s}	Rate of voltage flow per second

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Energy storage device is a device which could store energy in term of electricity. This device is important as it is widely used in variety of application. Device used for electric storage today is battery or capacitor. But this conventional device may has weakness which is take some time to charge it. Therefore, we need another energy storage device to replace the function of battery which is ultra capacitors.

Ultra capacitor is used to store electrical energy (electrostatically) rather than chemical state as in batteries. No chemical actions involved which mean it can be used for a long cycle. Ultra capacitors or similarly known as supercapacitors or electrochemical double layer capacitors (EDLCs) are electrochemical capacitors that have higher energy density when compared to common capacitors.

Capacitor are made with a dielectric placed between opposed electrodes to accumulate charges in the dielectric material. The energy is stored by removal of charge carriers which are electrons from one metal plate to another. This charge separation create potential between two plates. Many materials can be inserted between the plates to allow higher voltage to be stored which lead to higher energy densities for any certain size. For example, aluminum electrolytic capacitor use an aluminum oxide as the dielectric.

For ultra capacitor, it does not have any dielectric but rather utilize the phenomena typically referred to the electric double layer as shown in Figure 1.1. In electric double layer, the effective thickness of dielectric is thin because the porous nature of carbon the surface area is high which translate to high capacitance. When, two different phases contact together, positive and negative charges are set in array at boundary. This array is known as Electric Double Layer (Josie Garthwaite, 2011).

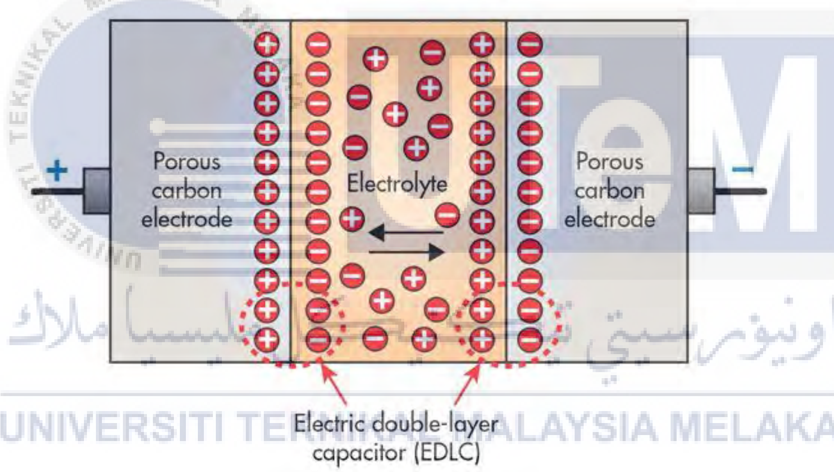

Figure 1.1: Part of ultra capacitor.

Nowadays, ultra capacitors are being developed for transportation which they used a large capacitor to store energy instead of the rechargeable battery banks inside the hybrid vehicles. Other than mobile application, ultra capacitors also may be used in photovoltaic system for renewable energy.

1.2 PROBLEM STATEMENT

Energy storage device is essential is important for nowadays application and purpose. Instead of using battery or conventional capacitor, ultra capacitor is the best choice for energy storage device as it has more advantage. Some of the benefit for using this device instead of battery and capacitor are; it is small (can be carried anywhere easily), cheap and economic and can be used for many cycle (rechargeable). Although there are battery that are rechargeable, but the rate of charging and discharging is slower compare to ultra capacitor. Therefore, ultra capacitor is be chosen to be the new energy storage device due to its endurance and quality rather than battery. But the problem is, how much fast that ultra capacitor could save time for charging compare to the battery. Figure 1.2 shows same ultra capacitor with difference specification from single manufacturer.

Figure 1.2: Ultra capacitor

1.3 OBJECTIVE

The objective of this project are as follows:

1. To study the ultra capacitor.
    - Know the application that used in ultra capacitors.
    - Learn the basic connection on ultra capacitor for charging.

2. To investigate on how (method) to charge the ultra capacitor fast.
    - Ideal voltage input for charging.
    - Time taken for charging the ultra capacitor.

1.4 SCOPE OF PROJECT

The scope of this project are:

1. Only use the same type of ultra capacitor for every experiment that will be conduct. The difference could only be the type of connection which are parallel or in series.
2. Study on the application of electric motor and generator and how on getting a certain speed of motor with its output voltage.

CHAPTER 2

LITERATURE REVIEW

2.1 HOW ULTRA CAPACITOR WORKS

An ultra capacitor functionality are same as capacitor but have different form from an ordinary capacitor. It differs in two aspect which are its plate effectively have a much bigger area and the distance between the plates is smaller. The plates are made from metal that coated with a porous substance such as powdery or activated charcoal which effectively make the area bigger to store more charges.

Chris Woodford (2016) state that for ordinary capacitor, the plate separate by a relatively thick dielectric made from ceramic, plastic film or air. When capacitor is charged, positive charges is form at one plate and negative charges are on the other side of plate. This creating an electric field between them. While in ultra capacitor, there is no dielectrics when compare to ordinary capacitor. Instead, the positive and negative plate are soaked in electrolyte and separated by an insulator made from carbon, paper or plastic. When the plate are charged up, an opposite charge forms on either side of separator creating an electric double-layer.

The capacitance of ultra capacitor is higher as the area of plate increases and distance between plate decreases. When the electric double layer is form, the thickness is could be one molecule thick compared to dielectric or conventional capacitor. Therefore, supercapacitor will have more capacitance.

2.2 CHARGE AND DISCHARGE OF ULTRACAPACITOR

To store or add energy in ultra capacitor, it need to be charge just like the battery. But to charge ultra capacitor, we must have to deliver a large amount of current at a wider range of voltages. This is because ultra capacitors often start at zero volts and the voltage is proportional to the coulombs of charge (Yogesh Ramadass, 2013). In charging or discharging process, the ultra capacitor can be mounted in two ways which are in series or parallel circuit. In series circuit, it will increase the value of overall voltage but reduce its capacitance. On the other hand, for parallel circuit the voltage of ultra capacitor will be always the same as the ultra capacitor's voltage itself but the capacitance will increase much more than in the series circuit. Theoretically, the value of voltage and capacitance can be calculate by using formula as shown below:

- For series circuit:

  Voltage, $V_T = V_1 + V_2 + V_3 \ldots + V_n$

  Capacitance, $\dfrac{1}{C_T} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3} \ldots + \dfrac{1}{C_n}$

- For parallel series:

  Voltage, $V_T = V_1 = V_2 = V_3 = V_n$

  Capacitance, $C_T = C_1 + C_2 + C_3 \ldots + C_n$

As the energy storage mechanism of the ultra capacitor is not a chemical reaction, the charging and discharging process of ultra capacitor can occur at the same rate. Many ways are possible to charge the ultra capacitor. But since the ultra capacitor voltage is relatively limited compared to the application requirement, it is important to connect the ultra capacitors in series to achieve the voltage required. The charging method could be either through constant current or power charging through direct current (DC) source or alternate current (AC) methods.

2.3 ENERGY AND POWER OUTPUT OF ULTRACAPACITOR

Capacitance of ultra capacitor is the capability of the ultra capacitor to store electric charges. Usually, every product of ultra capacitor have stated its capacitance to the customer. But in theoretically, the capacitance can be calculated by using formula below:

$$C = \frac{Q}{V}$$

where C = Capacitance (F)

Q = Charges flow (C)

V = Voltage (V)

The energy stored in an ultra capacitor is expressed in term of the work done by the battery. The work to move a charge element from negative plate to positive plate is equal to voltage on ultra capacitor. The voltage represents energy per unit charge and it is proportional to the amount of charge on the ultra capacitor. To determine the energy output from the ultra capacitor, we begin with the basic formula of energy storage on capacitor:

$$\mathrm{dU} = \mathrm{V}dq$$

$$\mathrm{dU} = \frac{q}{\mathrm{C}}dq$$

$$U = \int_0^Q \frac{q}{\mathrm{C}}dq$$

$$U = \frac{1}{2}\frac{Q^2}{C}$$

Substitute the derive voltage equation from $\mathrm{C} = \frac{Q}{V}$ to become $Q = CV$ into above equation and we will get:

$$U = \frac{1}{2}\frac{C^2V^2}{C}$$

$$U = \frac{1}{2}CV^2$$

where U = Energy (J)

C = Capacitance (F)

V = Voltage (V)

Q = Charge (C)

Power in ultra capacitor describe the speed at which energy can be deliver from ultra capacitor to the load. According to Wen Hua et al (20016), the theoretical power value in ultra capacitor can be calculated by using equation below:

$$P_{max} = \frac{V^2}{4 \bullet R_T}$$

where P_{max} = Maximum power output

V = Voltage supply or delivered (V)

R_T = Total resistant also known as equivalent series resistant (Ω)

Theoretically, if the ultra capacitor have higher vaue of voltage and low equivalent series resistance, it will deliver more power to the load.

2.4 ADVANTAGES AND DISADVANTAGES OF ULTRA CAPACITOR

In application of ultra capacitor, there are many advantage and disadvantage of using ultra capacitor instead of other energy storage device such as battery. As we all known, battery and ultra capacitor are served to provide energy but the ultra capacitor have its own specialty and characteristic that can be serve more efficiently when using it.

One of the characteristic that ultra capacitor is selected to be used is because of it has higher specific power than any other energy storage device This is proven by Stefen Workstetter, 2015 as shown in Figure 2.1. It has the ability to charge and provide energy constantly. This unique characteristic had made the ultra capacitor used widely in high power and regenerative braking application. Besides, the ultra capacitor are extremely efficiently in storing energy even in under high load conditions which is up until 80% efficiency.

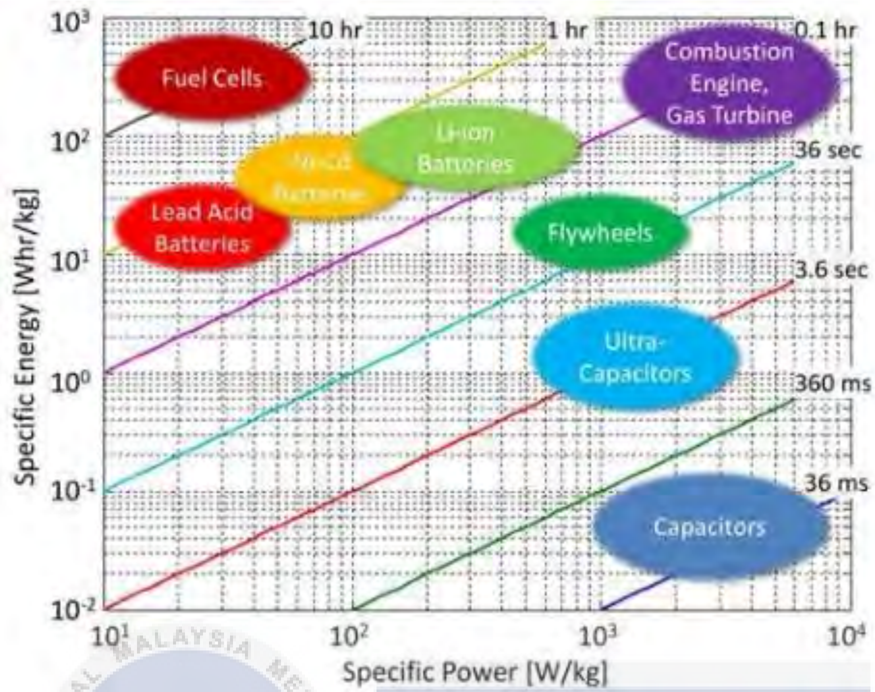

Figure 2.1: Graph comparison of specific power against specific energy among storage energy devices (Stefan Workstetter, 2015)

Besides, based on Marco et al, 2005 as shown in Figure 2.1, the ultra capacitor has long lifetime. It can withstand for about 10 to 20 years and about 1 million to 100 million charge and discharge cycles depends on how its usage and condition while for most battery, it can only be recharge up to 200 to 1000 times only (Marco et al, 2005). Even after undergo a lot of cycle, it have low rate of degradation in performance if it being used in operation condition. If there is increase in operating temperature or voltage, it may reduce the lifetime. But it is hardly to make the operating temperature of ultra capacitor to become higher or lower because ultra capacitor itself has wide operating temperature range which is starting from -40°C to 70°C.

Table 2.1: Ultra capacitor and battery comparison (Marco et al, 2005).

	Ultracapacitors	Batteries
Charging time	Fraction of a second to several minutes	Several hours
Self-discharging	Hours to days	Weeks to several months
Power density	> 1000 W/kg	<500 W/kg
Energy density	< 5 Wh/kg	10 – 100 Wh/kg
Charging /discharging efficiency	85% -98%	70% - 85%
Cycle life	10^6 - 10^8	200 – 1,000

Moreover, the ultra capacitor is more safe when in operation compared to battery. This is because, when there is extreme over-voltage conditions, the ultra capacitor shows no hazard risk. Compared to lithium and lead based high power battery, they have the risk of self ignition to explosion. This shown that the usage of ultra capacitor is safer in operation and can reduce the injury or damaging other component that located near the ultra capacitor.

On the other hand, the disadvantages of ultra capacitors is it had low amount of energy stored per unit weight (Wh/kg) compared to electrochemical batteries. So the ultra capacitor only can be used for low energy demand. If the product need to use large energy demand, there will be combination of ultra capacitor and battery.

Lastly, for choosing which energy storage device such as battery or ultra capacitor have their own interest based on what a product want or its certain functionality.

2.5 HOW TO INCREASE THE PERFORMANCE IN ULTRACAPACITOR APPLICATION

As shown in Figure 2.2, electrochemical ultra capacitor can be classified into two types which are electric double layer capacitor (EDLC) and pseudocapacitor (PC) according to ions accumulation mechanism and electron-transfer mechanism (G.A Snook, 2011). EDLC have shown good electrochemical stable and high energy storage capacity owning to their charging of electric double layer at electrode and electrolyte interface (Akhtar, 2015). EDLC performance is related to surface properties of electrode such as large surface to volume ratio, pore size and pore volume. All of that could can accelerate the generation of charges and provide better channel for fast ions movement in electrolyte. Activated carbon materials are common electrode material in EDLC as they have reasonably high surface area and more cheaper when compared to other carbon materials (Lozano Castello, 2003). Activated carbon materials generally exhibit disordered micropores which considerably suppress the accessibility of electrolyte and constrict the shape for charging, leading to gravimetric capacitance.

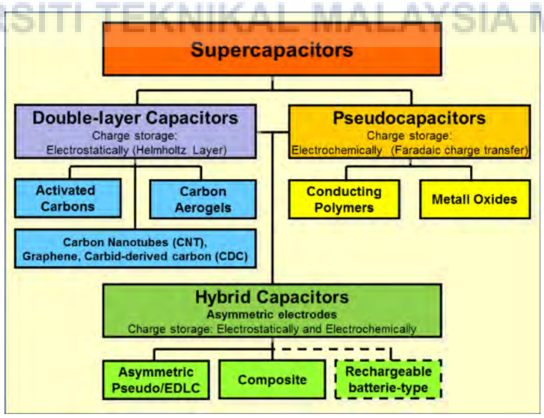

Figure 2.2: Type of ultra capacitor

An ultra capacitor model represents an important tool for evaluation and prediction using analytical methods or simulation before practical deployments as well as to overcome a major obstacle for ultra capacitor application. The charge loss due to self-discharge mechanism is namely as charge redistribution mechanism (Graydon, 2014). Vlasta Sedlakova et al (2015) has propose an equivalent-electrical circuit model of supercapacitor consisting of two ideal capacitors, two ideal resistor and one resister with time dependent resistance. The charge redistribution is given by drift and diffusion mechanism. The proportion between these two mechanisms probably depends on the type of electrolyte. To increase the rate charge distribution, it can be achieve by:

I. Use certain electrode material based for the ultra capacitor.
II. Develop an asymmetric ultra capacitor.
III. Low temperature solution process.

The selection of electrode materials play a crucial role in determining the electrical properties of an ultra capacitor. The metal compounds must get three characteristics when applying in ultra capacitor. First, it must have large conductivity. Second, there are more than two valences and the crystalline phase will not change with valence change. Third, the proton can intercalate into lattice of metal compounds especially for transition metal compound. Therefore, Yan Yan et al. (2016) introduces the application of vanadium based compound such as vanadium oxide, vanadium nitride, vanadium sulfide and their composite material in the ultra capacitor. This is due to vanadium based materials are known as one of the best active materials for high energy density electrochemical capacitor due to high specific capacitance, long cycle life and good electrochemical reversibility. But their poor electrical conductivity, poor cycling stability and low specific capacitance limits its application. To overcome this problem, prepare micro or nano structure materials, develop new type of control vanadium based composite material and develop an asymmetric ultra capacitor in the future (M. Yu et al, 2015).

T.M. Masikwa et al. (2016) then proposed an article of high performance performance asymmetric supercapacitor based on molybdenum disulphide/graphene foam and activated carbon from expanded graphite. As stated before, assembling an asymmetric cell is importance to use electrode material which are more stable in different potential in same electrolyte to increase full cell voltage. But instead of using vanadium based, T.M. Masikwa replaced it with molybdenum disulphide based. For negative electrode; graphene, carbon nanotube or activated carbon is used due to high surface area, cheaper and good rate capacity (M. Jana et al, 2016). In this work, molybdenum disulphide and graphene foam were synthesized by hydrothermal process to improve the specific capacitance of composite. After successfully fabricate an symmetric ultra capacitor cell based on porous activated carbon derive from graphite material as negative electrode and molybdenum disulphide as positive electrode, the energy density obtained in this study is higher.

To prove the certainty of low temperature solution process ultra capacitor charge distribution, Phuong T.M. Bui et al. (2016) had make a study of this case. Among various manganese oxide (MnO_x), Mn_3O_4 has good deal in catalytic, electrochemical and electrochromic applications (H. Einaga, 2004; N.Sakai et al, 2005). Well-crystalline Mn_3O_4 nanoparticle were synthesized by high yield facile low temperature solution at 80’C for electro-active electrode material in ultra capacitor applications. Nam et al. had prepared manganese oxide film by using electrostatic spray deposition method and reported the specific capacitance of 330 Fg^{-1} (K.W. Nam et al, 2006). Chang and Tsai demonstrated the effect of heat treatment on anodically deposited manganese oxide film and evaluated the specific capacitance of 240 Fg^{-1} (J.K. Chang & W.T. Tsai, 2003). Phuong T.M. Bui et al. successfully synthesized highly dense Mn_3O_4 nanoparticles by facile low temperature solution process and apply as electrode material with activate carbon to fabricate high performance of electric double layer capacitor (EDLC). From cyclovoltametry results, Mn_3O_4 nanoparticles-activate carbon electrode confirm the excellent electrochemical performance when compare to bare activate carbon and bare Mn_3O_4.

For modeling of a capacitor with multi branch circuit, P.O. Logerais had perform study about it. He use multiple resistors and variable voltage capacitor. The basic circuit to model an utra capacitor consist of capacitor, resistor and a leakage. The determination of resistance and capacitance is obtained by charge and discharge tests at a constant nominal current. Two-branch model whose nonlinear capacitances vary with the voltage has been establish by Zubieta and Bonert (Zubieta & R. Bonert, 1998). Berrueta et al. had developed an equivalent circuit including three branches to model the double layer effect for which the capacitance is linearly related with the voltage, the charge penetration ant the ion/electron conduction lossed resulting from self-discharge (Berrueta et al, 014)]. The ultra capacitor multi branch model was implemented in Matlab Simulink environment using SimPowerSystems to represent the electrical electrical circuit (Camara, 2011). The capacitances vary with voltage, so P.O Logerais et al. developed another nested sub-block with a loop to calculate the non-linear capacitance. As the different internal phenomema are accounted for, the multi branch modeling of supercapacitors with temporal characterization will enable to simulate and optimize electrical energy storage in various applications such as hybrid system, wireless sensor and many more.

For some ultra capacitor application, it is usually used for energy storage for renewable energy or transportation such as energy harvesting in photovoltaic cell, electric vehicles and many more. According to Tinton Dwi Atmaja, the combination of battery and ultra capacitor could help the voltage change decrease slightly instead of significant dropped when battery is working alone.

Based on flexible mobility, charging station could be categorized into two different types which are fixed charging station (FCS) and mobile charging station (MCS). In this case study, the battery and ultra capacitor is used as energy storage system on mobile charging station for electric vehicles. This paper determined that Lithium–iron phosphate ($LiFePO_4$) is the most suitable battery and electric double-layer capacitor (EDLC) is the most appropriate ultra capacitor for MCS application. The combination of battery and ultra capacitor provide current and voltage respond which is fit to conduct fast or even ultrafast charging. Lithium–iron phosphate ($LiFePO_4$) was the most suitable battery for MCS application because this battery has superior thermal and chemical stability and, most importantly, this battery has higher discharge current than other batteries. But there are disadvantage of lithium battery which are require high production cost and need a protection circuit in order to maintain safe operation. In ultra capacitor consideration, the most appropriate ultra capacitor is electric double-layer capacitor (EDLC) because of having high power density.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the methodology that will be used in this project to obtain data needed in this project. The flow chart of the methodology is shown in Figure 3.1.

3.2 GENERAL METHODOLOGY

The action that need to be carried out to achieve the objectives in this project are listed below:

1. Literature review

   Any journal, articles, web or any material regarding this project will be review.

2. Experimental

   Experiment will be conducted to find out on how to charge and discharge the ultra capacitor with time. The best solution will be proposed at the end of the experiment.

3. Report writing

   A report writing for this project will be written at the end of this project.

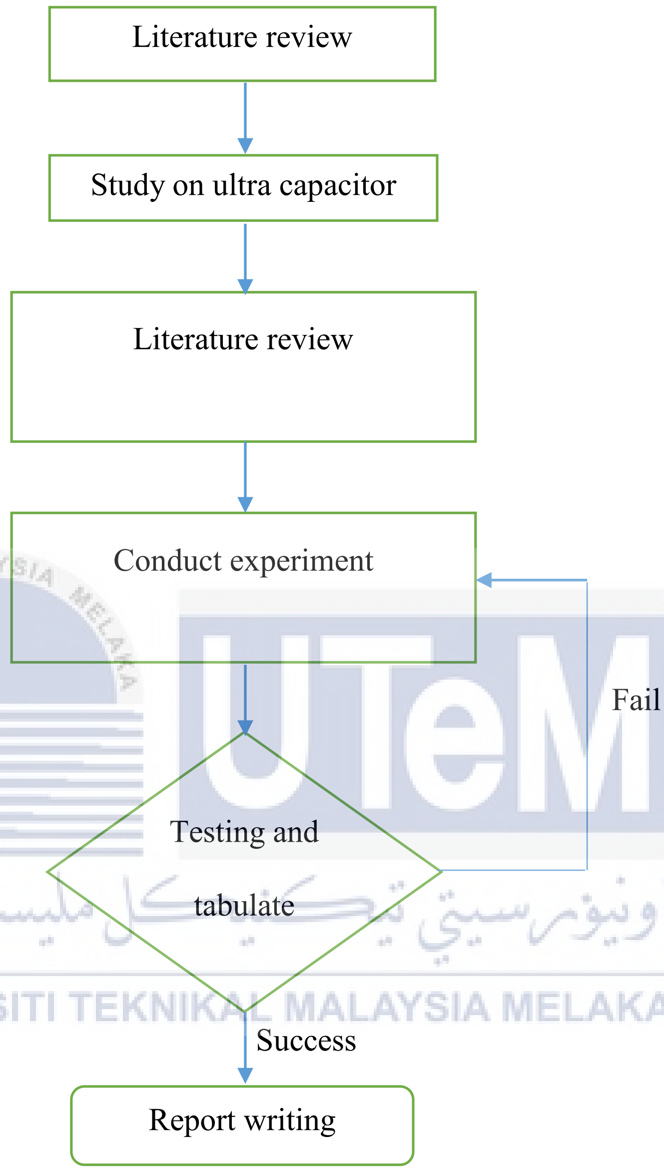

Figure 3.1: Flowchart of the methodology

3.3 EXPERIMENTAL APPARATUS AND SETUP

3.3.1 Ultra capacitor

In this project, ultra capacitor is the main device which will be investigate and to study on. The most important of the study is to investigate how fast ultra capacitor can be charge up and how long it can stand to power up electric device. Nowadays, there are many variation of ultra capacitor product. Even if having same voltage and capacitance, result of experiment may be vary depends on the ultra capacitor used. So, for every experiment we will use Maxwell BCAP1200P70 ultra capacitor brands. Table 3.1 shows the specifications of the ultra capacitor used:

Table 3.1: Specification of ultra capacitor (reference: Maxwell.com)

Rated Voltage	2.70V
Minimum Capacitance	1200F
Maximum Capacitance	1440F
Energy Stored	1.22Wh
Leakage Current at 25°C	2.7mA

Figure 3.2: Ultra capacitor used in experiment.

3.3.2 Generator

At the early stage, motor generator from mower generator is used for charging process. This motor use petrol fuel to be power up. But due to lack of power, the electricity produce by the generator could not charge the ultra capacitor. Figure 3.3 shows the motor generator used in the charging process experiment.

Figure 3.3: Generator and motor used in experiment.

3.3.3 Car Battery

At the beginning stage of charging experiment, the generator and motor used are not capable to handle the ultra capacitor. Therefore, for the charging process we used car battery instead of the generator. This is because the motor did not have enough power to rotate the conveyer belt fast enough so that the generator generate electric for the ultra capacitor. For every charging experiment we used Yuasa NS70T battery brands. Table3.2 shows the specifications of the car battery used in charging experiment.

Table 3.2: Specification of car battery (reference: yuasabattery.com)

Voltage	12.5
Plate Cell	11
Volume of Acid (litres)	5
Charging Current (A)	4.0

Figure 3.4: Car battery used for charging experiment.

3.3.4 Electric Unicycle

For discharging process, the electric unicycle is used as the electric motor that will be power up by ultra capacitor. This electric unicycle not come in single part as shown in Figure 3.5. It contain other part such as throttle grip to control speed, controller box which control every instruction made by throttle grip, and the electric unicycle itself. This unicycle need at least 24V of power supply to power it up.

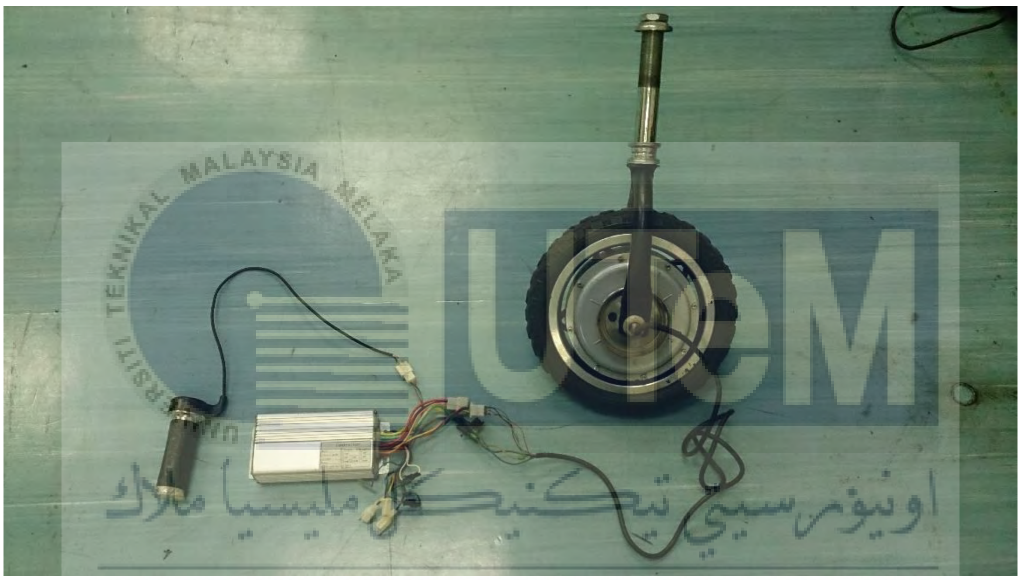

Figure 3.5: Electric unicycle and its part.

3.3.5 Setup Experiment

In this project, there will be two type of experiment which are charging and discharging of ultra capacitor. For each of experiment, there will be 2 cases which are the installation of ultra capacitor are in series or parallel. Both result will be observe and compared.

For charging experiment, the ultra capacitor will be installed to each other in series. Then, the ultra capacitor banks will be connected with the power supply which for this project it is the car battery. The initial voltage of ultra capacitor and car battery is recorded before starting the experiment. Then, after charged up the ultra capacitor, the time for charging process and final voltage of both ultra capacitor and battery is recorded. After that, calculate the charging rate for the ultra capacitor. The experiment is repeated by using the same step, but the configuration of ultra capacitor is change to parallel.

For discharging process, the ultra capacitor bank is used to power up the electric unicycle. The ultra capacitor bank must at least accumulate 24V to run the electric unicycle. The initial voltage of ultra capacitor is recorded. Then, by using ultra capacitor as power supply, determine the time that it can stand. Record the final voltage of ultra capacitor bank and calculate the discharging rate of the experiment. The experiment is repeated but the connection of ultra capacitor is change to parallel circuit. Table 3.3 and 3.4 show the expected tabulated table for charging and discharging experiment respectively.

Table 3.3: Expected table for charging ultra capacitor.

Time (seconds)	Voltage (V)
0	
2	
4	

Table 3.4: Expected table for discharging ultra capacitor.

Time (minute)	Voltage (V)
0	
2	
4	

CHAPTER 4

RESULT AND DISCUSSION

4.1 EXPERIMENTAL SET UP

Figure 4.1 shows the electric motor generator. The generator is power up by the mower machine to move the conveyer belt. When the conveyer belt is running, there will be power supply for the ultra capacitor. Initially, the generator is planned to be used for charging process.

Figure 4.1: Motor generator used in experiment.

But at the early test, the motor that currently used cannot move the conveyer belt that attach to the generator when the ultra capacitor is apply into the circuit even the ultra capacitor is in small number. It is due to the ultra capacitor need higher ampere value. As the mower machine has lower ampere value, the motor that used cannot supply enough power and it will automatically shut off.

The charging process cannot be done as the generator are not supplying the direct current to the ultra capacitor.

Figure 4.2: Conventional battery used in experiment.

Therefore, the experiment is come up into new solution which is the motor generator is be replaced by using other device. For the new experiment, a vehicle (car) conventional battery is used for charging process of ultra capacitor as shown in Figure 4.2. In the experiment, we connect the battery (act as DC supply) directly to the ultra capacitor to act as load for charging process as shown in Figure 4.3.

Figure 4.3: Set up for charging experiment.

4.2 CHARGING PROCESS FOR SINGLE ULTRA CAPACITOR

In experiment of charging a single ultra capacitor process, the setup is as shown in Figure 4.4. For charging a single ultra capacitor, the voltage that ultra capacitor can store is 2.7V. Therefore, if the reading of voltmeter has reach higher than 2.7V, the charging experiment will be stop and let the ultra capacitor to stable condition. In most of experiment, the ultra capacitor reach higher than 2.7V in less than 4 second. Even the voltage of ultra capacitor is getting higher than 2.7V after few second of charging process (sometime it would reach more than 4V), the fluctuation of voltage will reduce gradually until it reach about 2.7V when it is uncharged condition.

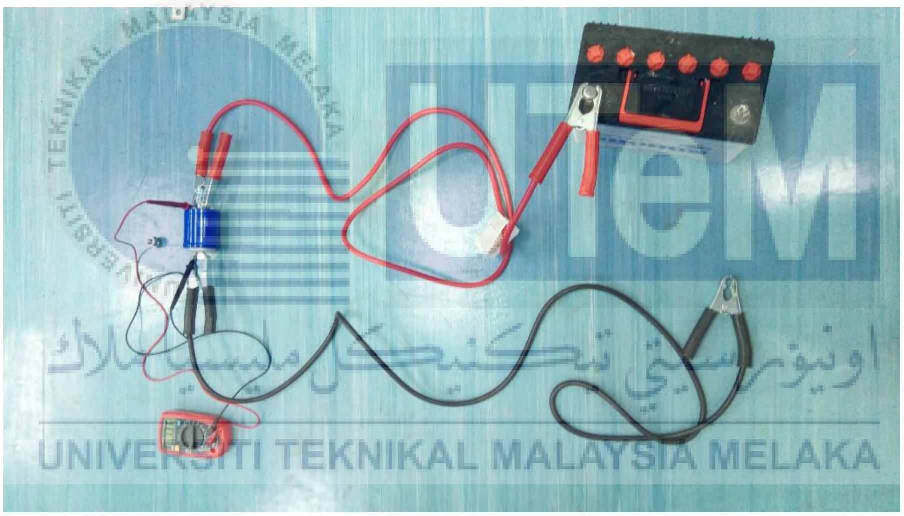

Figure 4.4: Set up experiment for charging process of single ultra capacitor.

The result of charging a single ultra capacitor experiment is as shown in Table 4.1, 4.2 and 4.3 respectively. Then, the graph of charging charging process is plotted to see the trend of charging process as shown in Figure 4.5.

Table 4.1: First attempt charging process for single ultra capacitor.

Time (s)	Voltage (V)
0	1.96
2	2.58
4	3.14

Table 4.2: Second attempt charging process for single ultra capacitor.

Time (s)	Voltage (V)
0	1.36
2	2.26
4	3.10

Table 4.3: Third attempt charging process for single ultra capacitor.

Time (s)	Voltage (V)
0	1.97
2	2.72
4	3.24

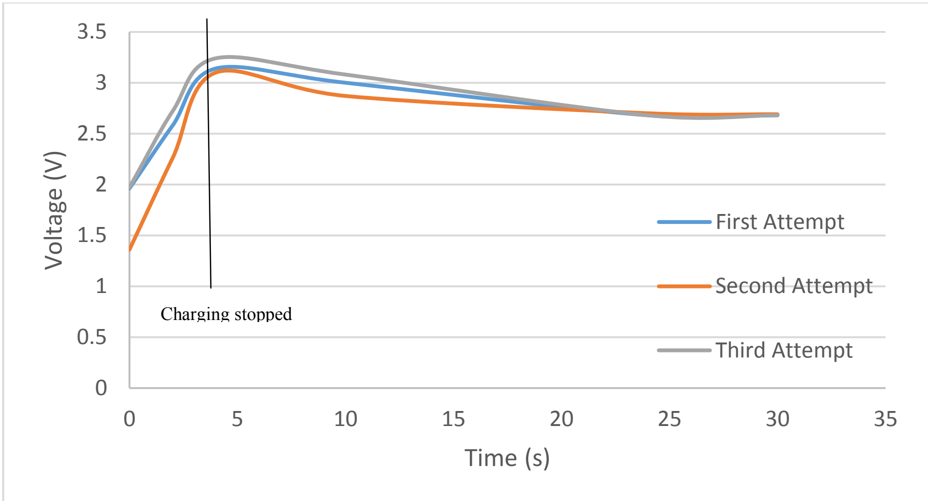

Figure 4.5: Graph of time against voltmeter reading for charging process in single ultra capacitor.

Charging rate:

First attempt: $\frac{3.14 - 1.96}{4} = 0.295V\mathrm{s}^{-1}$

Second attempt: $\frac{3.10 - 1.36}{4} = 0.435V\mathrm{s}^{-1}$

Third attempt: $\frac{3.24-1.97}{4} = 0.318\mathrm{Vs}^{-1}$

Average charging rate: $\frac{0.295+0.435+0.318}{3} = 0.349\mathrm{Vs}^{-1}$

4.3 CHARGING PROCESS FOR SERIES

In experiment of charging a series of ultra capacitor process, the setup is as shown in Figure 4.4. For charging ultra capacitor in series, it is been set to charge it for 4 ultra capacitor at once. As stated before, for each ultra capacitor, it can be accumulated about 2,7V. Therefore, for 4 ultra capacitor in series, it can be charge up until 10.8V theoretically.

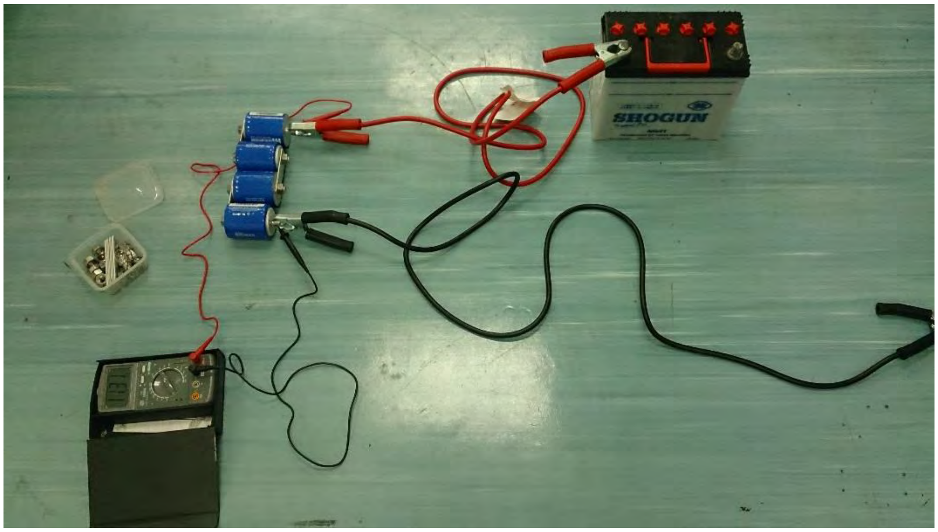

Figure 4.6: Set up experiment for charging process of series.

In charging process, it also same as charging single ultra capacitor. The voltage of ultra capacitor keep rise when charging even it is already exceed the overall voltage limit which is 10.8V. In this experiment, it is charged up until it reach 11.55V for first attempt, 11.49V for second attempt and 11.02V for third attempt as shown in Table 4.4, 4.5 and 4.6 respectively. Then, the series of ultra capacitor is let to be uncharged for few minutes until it reach the stable condition.

Table 4.4: Charging process of 4 ultra capacitor in series for first attempt.

Time (s)	Voltage (V)
0	9.10
2	9.64
4	10.07
6	10.51

8	10.82
10	11.09
12	11.32
14	11.38
16	11.48
18	11.55

Table 4.5: Charging process of 4 ultra capacitor in series for second attempt.

Time (s)	Voltage (V)
0	5.4
2	6.58
4	7.85
6	8.81
8	9.69
10	10.22
12	10.54
14	10.84
16	11.08
18	11.31
20	11.49

Table 4.6: Charging process of 4 ultra capacitor in series for third attempt.

Time (s)	Voltage (V)
0	5.3
2	6.51
4	7.56
6	8.33
8	8.98
10	9.61
12	10.01
14	10.20
16	10.52
18	10.69
20	10.83
22	11.02

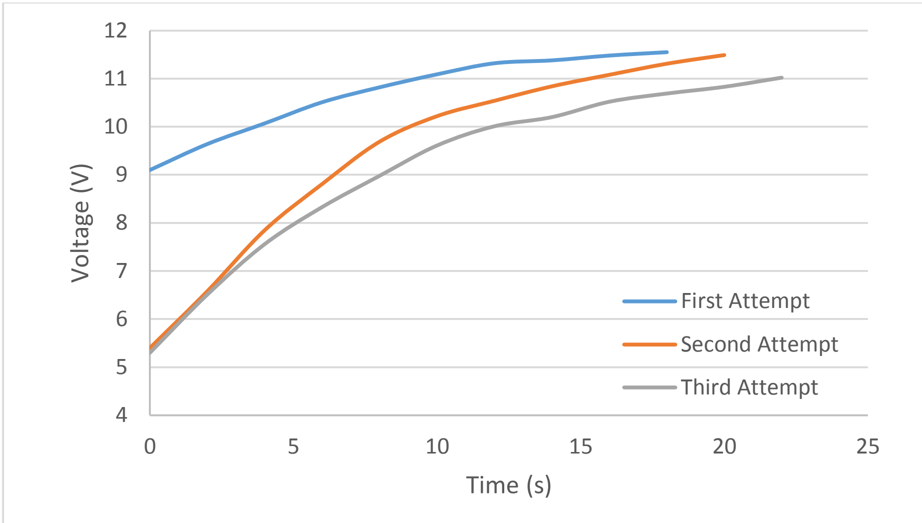

Figure 4.7: Graph of time against voltmeter reading of charging process for 4 ultra capacitor in series.

From Figure 4.7 above, it is the summary of the charging process for the first, second and third attempt for series of 4 ultra capacitor. The voltage of ultra capacitor is rise quickly after a few second of charging. Then, after passing through the limit of voltage for whole circuit which in this experiment is 10.8V, the charging process become slower. As shown in graph, as the voltage reaching 11V, the charging process is gradually slow.

After the series of ultra capacitor been charged up, it is let for rest for few minutes to let it reach stable voltage reading. For each minute, the reading will be observe, recorded and plotted in graph as shown in Figure 4.8. If the ultra capacitor is fully charged, the overall voltage should be 10.8V or even higher. On the other hand, some attempts of experiments shows that even after charging the ultra capacitor higher than the limit, the overall voltage still can decrease lower than the limit after be let a few while. This can be proved by the third attempt of experiment. The series of ultracapacitor which can accommodate 10.8V is charged up to 11.02V, but after let it to rest it is gradually reduce to 9.92V.

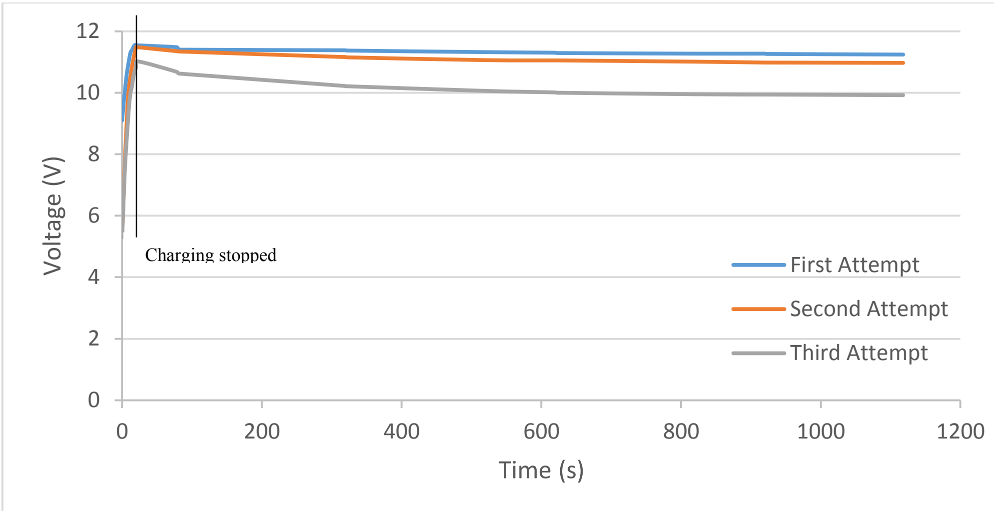

Figure 4.8: Graph of time against voltmeter reading of overall process for 4 ultra capacitor in series.

Charging rate:

First attempt: $\frac{11.55-9.10}{18} = 0.136Vs^{-1}$

Second attempt: $\frac{11.49-5.4}{20} = 0.305Vs^{-1}$

Third attempt: $\frac{11.02-5.3}{22} = 0.260Vs^{-1}$

Average charging rate: $\frac{0.136+0.305+0.260}{3} = 0.234Vs^{-1}$

4.4 CHARGING PROCESS FOR PARALLEL

In experiment of charging a parallel of ultra capacitor process, the setup is as shown in Figure 4.9. For charging ultra capacitor in parallel, the experiment is set to be charge up same as series part experiment which is 10.8V. But in this case, each experiment is using 8 ultra capacitor which are 2 ultra capacitor is installed parallel and link it 4 times to reach 10.8V.

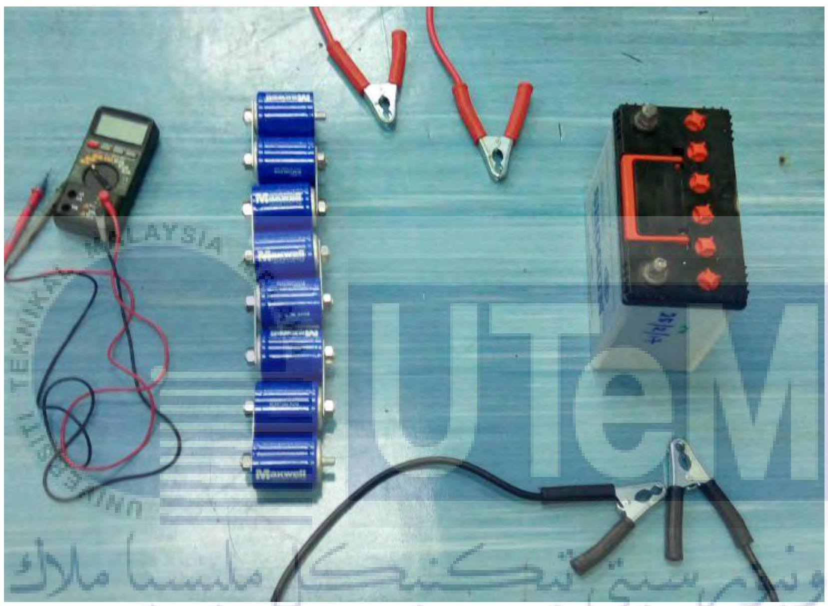

Figure 4.9: Set up experiment for charging process of parallel.

This overall voltage of 10.8V can be determine theoretically. Unfortunately, devices such as multimeter and voltmeter cannot read the overall voltage of ultra capacitor installed in parallel. Therefore, the initial and final reading of voltage is taken one by one for each ultra capacitor for this case study. The order of ultra capacitor I as shown in Figure 4.10 below. Then, after experiment is conducted, the result is recorded as shown in Table 4.7.

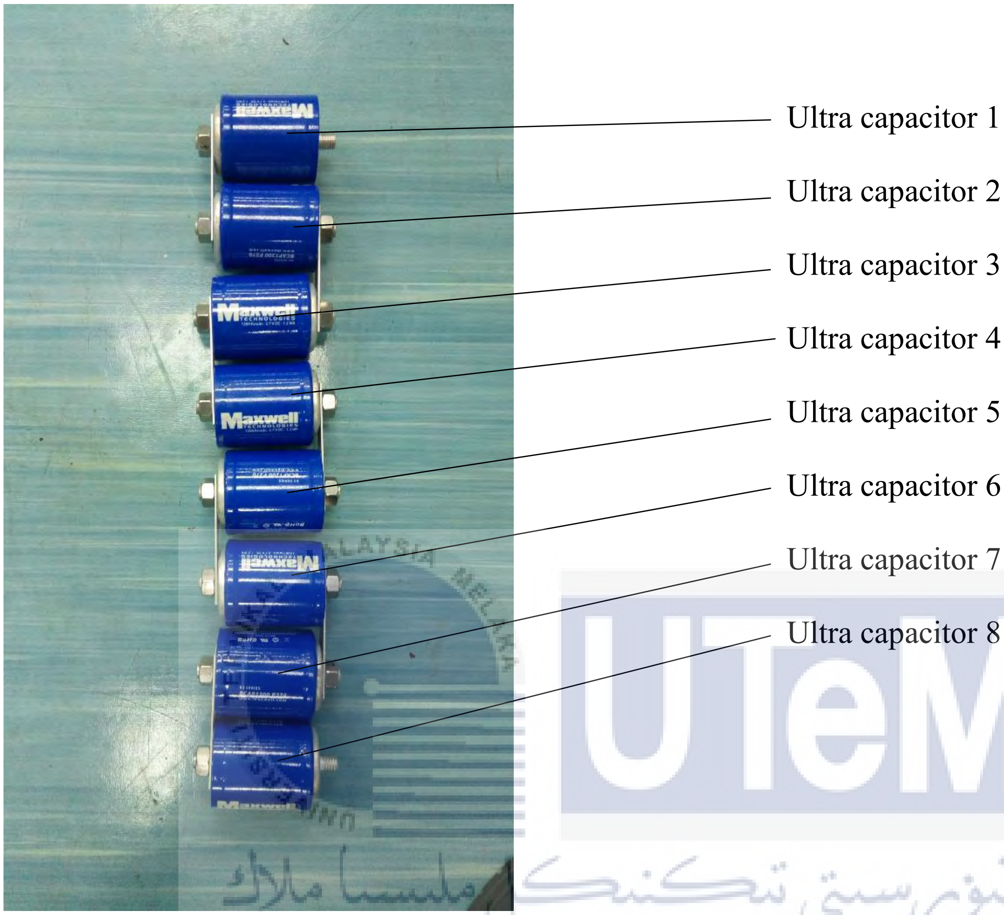

Figure 4.10: Shows the configuration of ultra capacitor in parallel.

Table 4.7: Charging process of ultra capacitor in parallel.

	First Attempt		Second Attempt		Third Attempt	
	Initial Voltage (V)	Final Voltage (V)	Initial Voltage (V)	Final Voltage (V)	Initial Voltage (V)	Final Voltage (V)
Ultra capacitor 1	2.23	3.28	2.08	3.03	2.12	3.12
Ultra capacitor 2	2.90	1.12	2.22	1.04	2.34	1.18
Ultra capacitor 3	2.13	0.91	1.8m	1.22	2.24	3.02
Ultra capacitor 4	2.37	3.24	0.69	1.96	1.94	2.83
Ultra capacitor 5	2.35	3.23	7.7m	1.22	2.26	2.54
Ultra capacitor 6	1.13	0.25	4.3m	1.20	2.01	1.26
Ultra capacitor 7	1.98	0.67	1.16	12.8m	2.31	0.63
Ultra capacitor 8	1.94	3.04	0.93	2.12	2.14	3.12

From the result of each experiment, the final voltage of each ultra capacitor may vary. Most of the ultra capacitor has charge up but there are some ultra capacitor is vice versa which is discharge. Some of the ultra capacitor is decreased in voltage reading at the end of the experiment. It can be say that for charging of ultra capacitor in parallel will result in uneven charging for each of it. The reason of this phenomena is not determined.

4.5 DISCUSSION AND ANALYSIS FOR CHARGING OF ULTRA CAPACITOR BANK

In charging of ultra capacitor, we could see the voltage stored is easily increase to higher value based on the experiment conducted for both series and parallel. Even there are uneven distribution of charging in parallel case, most of the ultra capacitor is charge up. The ultra capacitor could be charge fast because the characteristics of the ultra capacitor itself which have higher rate of charging. This can be proved by referring to the journal written by Chris Woodford (2016) state in Chapter 3. The ultra capacitor can be charge faster compare to battery because the ultra capacitor store energy in electrostatically while batter store energy in chemically. When comparing the reaction process of chemical and electrical, it is surely the electrical reaction process is higher compare to chemical process because it involve in the movement of positive and negative charge inside the ultra capacitor. Chris Woodford stated that when the ultra capacitor is charged, the positive charges will be form at one plate and negative charges are on the other side of plate which will create the electric field between them or also known as electric double-layer. This will resulting the voltage will be generate and stored inside the ultra capacitor when charging process is conducted.

4.6 DISCHARGING PROCESS OF ULTRA CAPACITOR IN ELECTRIC MOTOR

In experiment of discharging of ultra capacitor process, the apparatus needed are as shown in Figure 4.11. For discharging of ultra capacitor, the experiment use electrical unicycle. The unicycle is actually based from bicycle but the frame and other part of body is removed for easier handling of the experiment. For this discharging experiment, we need to accumulate the ultra capacitor to reach at least 24V to run the unicycle. As there are insufficient ultra capacitor and connector, only experiment for series is conducted.

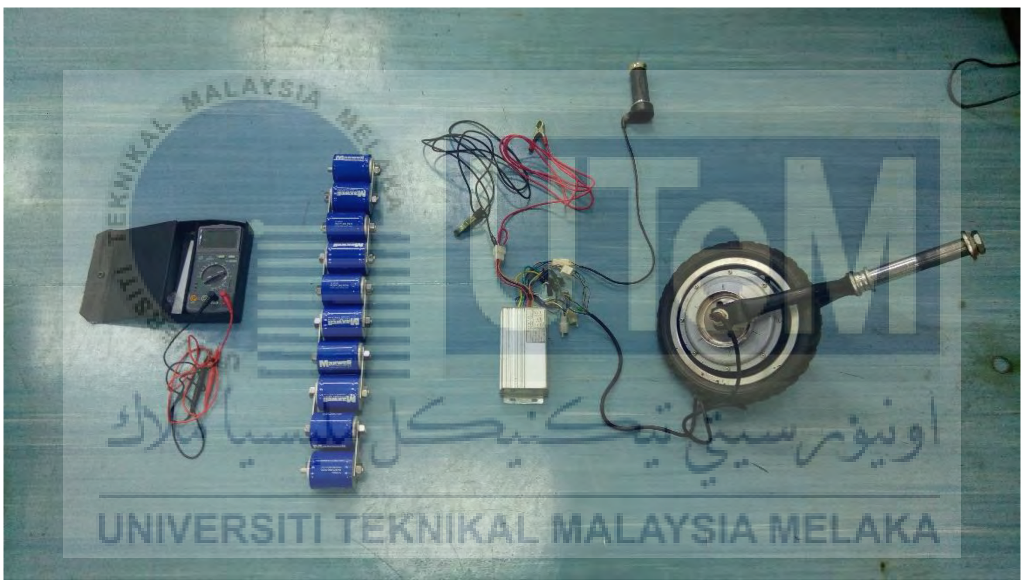

Figure 4.11: Equipment for discharging process.

To start moving or rotating the unicycle tire, it will need at least 24V of power supply. If it is not reach the specific voltage, the tire will not rotate. At the beginning of experiment, it is tested at 21.83V. It is assume that if there is slight shortage of voltage can rotate the tire but slower revolution. Unfortunately, it would not rotate at all. The unicycle only vibrate even at free load. It is conclude that, if we want to start moving the electric motor such as the unicycle, the minimum voltage of 24V must be reach.

In this discharging experiment, the setup is as shown in Figure 4.12. The unicycle is clamp on the the table to let the tire move freely without any load. Every connection need to connect correctly to make sure the tire will move smoothly. As the minimum voltage required is 24V, the experiment will consume at least 9 fully charge of ultra capacitor which will supply 24.3V theoretically. But in this experiment, we cannot assume all ultra capacitor have the same voltage. This is because the voltage of ultra capacitor may vary within another. Therefore, the overall voltage of series of ultra capacitor need to be measure before conducting the experiment to ensure the minimum voltage is achieved.

Figure 4.12: Set up experiment for discharging process.

The result of discharging ultra capacitor bank experiment is as shown in Table 4.8 and Table 4.9 respectively. The total time that ultra capacitor could deliver power supply to the electric motor is recorded. Then, the discharge rate is calculated.

Table 4.8: Voltage reading of discharging process for first attempt.

	Initial Voltage (V)	Final Voltage (V)
Ultra capacitor 1	2.93	2.36
Ultra capacitor 2	2.57	1.94
Ultra capacitor 3	2.71	2.13
Ultra capacitor 4	2.95	2.37
Ultra capacitor 5	2.82	2.24
Ultra capacitor 6	2.09	2.32
Ultra capacitor 7	2.71	2.21
Ultra capacitor 8	2.95	2.35
Ultra capacitor 9	3.02	2.44
Total	25.70	20.35

For the first attempt, the initial voltage accumulate is 25.7V and the tire totally stop when the decrease to 20.35V. It is 5.35V voltage difference and the electric unicycle could move and rotate freely for 10 minutes and 14 second.

Discharge rate: $\frac{5.35}{614} = 0.00871\text{Vs}^{-1}$

Table 4.9: Voltage reading of discharging process for second attempt.

	Initial Voltage (V)	Final Voltage (V)
Ultra capacitor 1	2.84	2.37
Ultra capacitor 2	2.39	1.91
Ultra capacitor 3	2.97	2.52
Ultra capacitor 4	2.72	2.26
Ultra capacitor 5	2.89	2.43
Ultra capacitor 6	2.42	1.93
Ultra capacitor 7	2.94	2.47
Ultra capacitor 8	2.67	2.18
Ultra capacitor 9	2.88	2.43
Total	24.84	20.51

For the first attempt, the initial voltage accumulate is 24.84V and the tire totally stop when the decrease to 20.51V. It is 4.33V voltage difference and the electric unicycle could move and rotate freely for 8 minutes and 13 second.

Discharge rate: $\frac{4.33}{493} = 0.00878\text{Vs}^{-1}$

Based on this experiment, the discharge rate is about 0.008V to 0.009V. This shown that the ultra capacitor could act as power supply such as battery. But for battery, it could hold on and move the electric unicycle much more longer compare to the ultra capacitor.

4.7 DISCUSSION AND ANALYSIS DISCHARGING OF ULTRA CAPACITOR AND APPLICATION

In discharging process, the fully charged ultra capacitor bank is used as a power supply to power up the electric unicycle. Based on the experiment conducted, we could see that the ultra capacitor is also succeed in supply energy in term of electricity to electric motor. But it can only supply not for so long. This is because the ultra capacitor has higher specific power when comparing to battery based on graph provided by Stefen Workstetter (2015) in Chapter 2. Higher specific power means that the ultra capacitor have higher capacitance value. When the power supply have higher capacitance, the energy discharge will also increase. This is also can be proved from the equation stated in Chapter 2 which is:

$$\mathrm{C} = \frac{Q}{V}$$

where C = Capacitance

Q = Charge flow

V = Voltage

When the value of capacitance is increase, there will be higher number of charges flow in the circuit. Therefore it will drain the power contain from the ultra capacitor itself. On the other hand, even when the discharging process of ultra capacitor is higher than battery, it still can be used for electric motor as the experiment conducted smoothly but only in a small period of time. In addition, if the ultra capacitor is used for application of electric motor such as the unicycle or even a bicycle, usually a person will not use it for too long in time except in under some cases. Even if the electric motor is run out of power, it still can be charge for few seconds only. Therefore, if the ultra capacitor is choose to be used as power supply, the number of ultra capacitor or the overall power should be higher than expected demand so that it can stand longer.

4.8 EFFECT AND IMPLICATION OF ULTRA CAPACITOR

There is consequences when using ultra capacitor instead using battery. It may affect for some application when we are considering using the ultra capacitor bank as a power supply. In this section, it is discussed about the implication of using ultra capacitor as power supply by itself and when combine it together with conventional battery.

First of all, at the very beginning of experiment which is the process of charging ultra capacitor, the temperature of wire used for charging will keep rising. This rising of temperature only happen when charging a single ultra capacitor. On the other hand, when the experiment for charging ultra capacitor in series or parallel, the wire only felt a little warmth. Not as hot as charging a single ultra capacitor. As shown in Figure 4.13 and Figure 4.14, the heat that generate within the wire sometime could burn the rubber that surrounding the wire when it is too hot. It conclude that it is considered safer to charge the ultra capacitor bank compare to single ultra capacitor.

Figure 4.13: Rubber cable that hold the wire melt due to heat generate.

Figure 4.14: Wire burnt as too hot and connecting with the clip holder.

When related to the temperature generate within the wire, it also can be related to other cause that could make it happen which is spark. Spark that happen throughout experiment can affect the reason why the temperature of wire increase. This is because spark can produce high temperature due to high power dissipation in the circuit. If spark occur, it can be relate to short circuit. Short circuit is the current travel along unintended path with very low electrical impedance. In charging experiment, spark could happen between the connector of ultra capacitor when charging 2 or more ultra capacitor. If the both connector touch each other at the same pair of ultra capacitor, spark may be happen. The higher voltage contain in ultra capacitor, the higher park could happen. The damage that spark could deliver is as shown in Figure 4.15. To prevent spark from happen, the installation of connector between ultra capacitor must be installed cautiously and at the right way.

Figure 4.15: Implication of spark and short circuit to clip holder.

Throughout this experiment, the effect of ultra capacitor to the voltage of battery level is also studied. The initial and final voltage of battery level is recorded for each charging process is conducted. The result is as shown in Table 4.10 and Table 4.11 respectively.

Table 4.10: Initial and final battery voltage for charging process for series.

	Initial Battery Voltage (V)	Final Battery Voltage (V)
First attempt	12.43	12.43
Second attempt	12.43	12.42
Third attempt	12.39	12.38

Table 4.11: Initial and final battery voltage for charging process for parallel.

	Initial Battery Voltage (V)	Final Battery Voltage (V)
First attempt	12.41	12.39
Second attempt	12.35	12.31
Third attempt	12.31	12.28

From the table, it can be observed that the battery voltage is decrease. But comparing the series and parallel charging process, it can be conclude that for parallel it consume more voltage. It is assume that this is occur due to the number of ultra capacitor that need to be charge even the overall voltage is same. In series, only 4 ultra capacitor need to be charge while in parallel, 8 ultra capacitor are used to charge up. So, for application that need to combine both ultra capacitor and battery, the best installation is using series circuit to make the usage and lifespan of battery much more longer. However, parallel circuit can be helpful if application that need more power output is needed. But it is hardly to see parallel circuit is use in today application. This is because, usually manufacturer will produce the ultra capacitor based on the requirement needed.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From this project, experiment of charging and discharging process of ultra capacitor bank is carried out to evaluate the rate of output and input voltage against time. From the charging test, we can conclude that when the number of ultra capacitor is increase, the charging rate will be decrease. This can be proved when comparing the average charging rate for charging a single ultra capacitor and 4 ultra capacitor in series are $0.349Vs^{-1}$ and $0.234Vs^{-1}$ respectively. For the rate of charging for parallel is still unknown as the reading of initial and final voltage cannot be determined by using the multimeter and voltmeter. In addition, there are uneven charging of ultra capacitor for parallel cases. Even most of the ultra capacitor has charge up, there is still some are discharge. Therefore, it is assume that it is not applicable to use ultra capacitor in parallel. While for the discharging test, the ultra capacitor bank is proved that it can serve as power supply to electric motor. After accumulate enough minimum voltage of electric motor requirement, the ultra capacitor will provide the electricity and power needed so that the electric motor can be run smoothly. But, using ultra capacitor as power supply may not convenient as it cannot stand as long as battery even at the same voltage. From the experiment, the ultra capacitor bank with 25.7V and 24.84V can move the electric motor for 614 seconds and 493 seconds respectively. It is only about 10 9 to 10 minutes which when comparing to 24V of battery, it is very comprehensive.

5.2 RECOMMENDATION

First of all, every charging process will need a power supply. So it need to make sure that the power supply must have enough power to charge up the load. As stated in early stage of experiment, we used motor and generator as power supply. It can be observed that when the ultra capacitor is connected to the generator, the motor will automatically shut off which is due to the motor could not generate enough power to rotate the conveyer belt that connect to generator when ultra capacitor is connected together. So the generator will not produce electricity and the ultra capacitor will not charge up. So, it is recommended to change the motor used that can produce higher power so that it can rotate the conveyer belt and the generator will provide enough electricity. Other solution that can be done is by changing the power supply to device that can deliver more electricity. In this case of project, we change the power supply from using the motor and generator to car battery.

Besides that, as observed and investigation from the experiment conducted, the main problem for charging the ultra capacitor is the heat generate within the wire when charging process occur. Therefore, it is strongly recommended to use thicker wire rubber so that it can withstand the temperature to connect the ultra capacitor and power supply. Other solution than using thicker rubber, it also can slightly overcome by charging the ultra capacitor with higher number. This is because based on our observation from the experiment, the heat generation by charging higher number of ultra capacitor is lower compare to charging single ultra capacitor. This may not resolve problem much, but it can reduce huge amount of temperature that generate. On the other hand, it may consume more time for charging. Therefore, if this solution is used, it is recommended that charging the ultra capacitor only for a period of time and let it cool down for few minutes as the temperature may increase slowly when charging process is conducted.

Apart from that, it is highly recommend that if the ultra capacitor is used as power supply in any application, we suggest that the ultra capacitor will combine together its role with the battery. This is because the ultra capacitor can only operate for limited time compare to the battery. As known from this project, the ultra capacitor can charge up very fast. On the other hand, it is also could deliver a lot amount of voltage in seconds. It can be conclude that the usage of ultra capacitor can be used for some critical time. As example, the combination of battery and ultra capacitor can be apply in electric appliance such as photovoltaic(PV) solar panel. As we all known, the time for PV panel to function is only on day when hot. So, it may consume a lot of time to fully charge up a power supply if only battery is used. Therefore, with the presence of ultra capacitor, it may help the operation to reach higher efficiency of overall operation by getting the ultra capacitor fully charge with lower time consumption. Then, the fully charge of ultra capacitor can be used to charge the battery at night.

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APPENDIX A

Charging Process	
Time (second)	Voltage (V)
0	9.10
2	9.64
4	10.07
6	10.51
8	10.82
10	11.09
12	11.32
14	11.38
16	11.48
18	11.55
Stabilizing Process	
Time (seconds)	Voltage (V)
60	11.48
120	11.44
180	11.42
240	11.41
300	11.38
360	11.37

420	11.36
480	11.34
540	11.33
600	11.32
660	11.31
720	11.30
780	11.29
840	11.28
900	11.27
960	11.27
1020	11.26
1080	11.25
1140	11.25
1200	11.24
1260	11.24
1320	11.24

Table: Full table of charging for series and the stabilizing process in first attempt.

Charging Process	
Time (second)	Voltage (V)
0	5.40
2	6.58
4	7.85
6	8.81
8	9.69
10	10.22
12	10.54
14	10.84
16	11.08
18	11.31
20	11.49
Stabilizing Process	
Time (second)	Voltage (V)
60	11.34
120	11.28
180	11.23
240	11.19
300	11.16
360	11.12
420	11.11
480	11.09

540	11.07
600	11.05
660	11.03
720	11.02
780	11.01
840	10.99
900	10.98
960	10.96
1020	10.96
1080	10.95
1140	10.93
1200	10.93
1260	10.93

Table: Full table of charging for series and the stabilizing process in second attempt.

Charging Process	
Time (second)	Voltage (V)
0	5.3
2	6.51
4	7.56
6	8.33
8	8.98
10	9.61
12	10.01
14	10.20
16	10.52
18	10.69
20	10.83
22	11.02
Stabilizing Process	
Time (second)	Voltage (V)
60	10.62
120	10.48
180	10.35
240	10.27
300	10.21
360	10.15
420	10.10

480	10.06
540	10.03
600	10.00
660	9.98
720	9.95
780	9.94
840	9.94
900	9.94

Table: Full table of charging for series and the stabilizing process in third attempt.

APPENDIX B

Figure: Motor generator used for experiment in early stage.

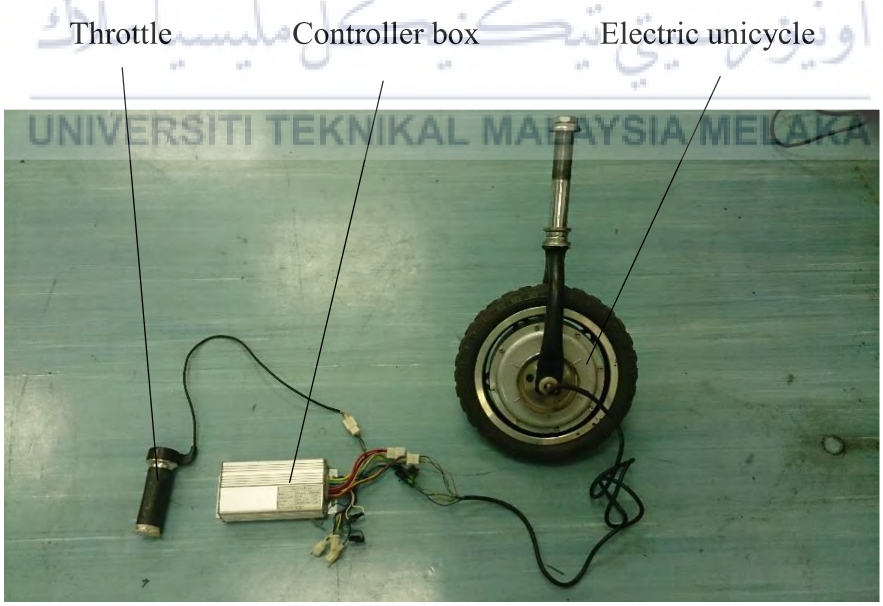

Figure: Part of electric unicycle.

Figure: Ultra capacitor bank.