IMPROVING BATTERY RUN-TIME IN ELECTRICAL APPLIANCES WITH ULTRA-CAPACITOR

by

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CERTIFICATION OF APPROVAL

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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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CHE NURJAIDY BIN CHE NASTIA

ABSTRACT

As technology advances, batteries still remain as one of the most important power sources in the world. Batteries are widely used in electrical appliances because it is one of the best competent energy storage devices available today. However, batteries have limitations that need to be improved such as limited cycle life, high equivalent series resistance (ESR) and contribute to environmental issues. The project investigates the capability of the ultra-capacitor in an attempt to improve the current runtime of the battery for electrical appliances. The main activity of this project is to design a suitable equivalent circuit model for the battery/ultra-capacitor combination. Data Studio software with the combination of ScienceWorkshop 750 interface is used to verify the graph of the peak current produced in the equivalent circuit model of the battery/ultra-capacitor combination. The experiment is conducted using the breadboard and then the selected circuit equivalent circuit is constructed on the veroboard to make sure the components or hardware connected firmly. This model circuit of battery/ultra-capacitor combination is expected to increase the current runtime of the battery 3-15% compared to the conventional battery. The circuit also is applied to the vehicles such as motorcycle and car to improve the fuel consumption. The project has the potential in contributing to the environment, world economy, reduce the energy waste and improve the power source of the electrical appliances.

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LIST OF ABBREVIATIONS

ESR	Equivalent Series Resistance
LED	Light Emitting Diode
AC	Alternating Current
DC	Direct Current
rms	Root Mean Square
VTH	Thevenin's Voltage
RTH	Thevenin's Resistance
KVL	Kirchhoff's Voltage law
R	Resistance of the Resistor (ohm)
C	Capacitance of the Ultra-capacitor (Farad)
I	Magnitude Current of the Current Waveform (Ampere)
i	Current Flow in the Circuit (Ampere)
D	Duty Cycle of the Current Waveform
P	Power Available in the System (Watt)
η	Efficiency of the System (Percentage)
Δt	Battery Current Run-Time of the System (minutes)
U	Switch
s	Complex Variable

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Battery was invented over 200 years ago by a Professor of Natural Philosophy (physic) at the University of Pavia in Italy, Alessandro Volta (1754-1827). The first battery was invented in 1800 known as "Volta' pile" which was designed based on the combination a pile of silver with zinc discs [1].

Nowadays, battery becomes a conventional power source which stores energy and has a specific current runtime depending on its capacity. The current runtime of the battery defines time that devices can operate from using the energy stored in the batteries. Classically, people combined the multiple batteries together or having multiple rate of battery capacity in order to increase the battery current runtime. This method will increase the weight as well as the size of the batteries [2].

Over a few centuries ago (1745), the capacitor was known as a liquid-filled glass jar with a layer of foil wrapped around the outside. Early in the invention of the capacitor, it was just being as a laboratory curiosity, but throughout the improvement of technology it become one of the important laboratory instruments and today in twentieth century, the capacitor has already become a main component in electrical circuit [3].

The technology of capacitor has become more advanced with the creation of the ultra-capacitor or also known as super-capacitor. The ultra-capacitor was built in with thinner charge-separation distance. Technically, they are known as electrochemical double-layer capacitors.

The ultra-capacitor has low equivalent series resistance (ESR) which allows them to absorb and distribute high current. The lower value of the ESR means that the ultra-capacitor have the lower impedance compared to the battery. This advantage lead the ultra-capacitor to have better frequency responds than the battery thus have the ability to filter the electrical noise in any kind of circuit. Then, it also has greater energy density and power per pound as compared to electrostatic and electrolytic capacitor [4].

1.2 Problem Statement

Nowadays, batteries are widely used around the world as a common power source for household and industrial use. However, there are weaknesses of batteries which require attention and action in order to improve, due to environment issues such as mercury pollution which contain in batteries. If human beings are exposed to the mercury pollution, they may become paralyze, cripple and then to be killed [5].

1.2.1 Environmental Issues

After nearly two centuries, batteries have become one of the most popular power sources for electrical appliances such as mobile phones, notebooks and mini radios because of its portability, cost less than the other power sources and designed in a wide range of sizes. Unfortunately, it gives rise to environmental issues such as toxic metal pollution, soil pollution and groundwater pollution. Without proper disposal method of batteries, some dangerous elements such as lead, mercury and cadmium may enter the environment easily [5].

1.2.2 Energy Efficiency and Lifetime

Batteries contribute to surrounding temperature changes. The high and low temperature reduces its performance, thus contributing to inaccurate initial voltage of the battery. For the colder temperature, the battery produces low output voltage but as the temperature increases, the output voltage gets higher and stays longer. [6]

1.2.3 Cost Effective

Another concern about the batteries is that it needs to be replaced frequently. A user needs to spend on new batteries when the batteries do not function anymore. This point of view quite related to the lifetime of the batteries which means that the batteries have a specific lifetime when one uses them continuously.

1.2.4 Fuel consumption

Most of vehicles in the world used petrol as fuel to move from one place to another. The battery used as the power source to starting up the car or motorcycle actually affected the fuel consumption of the vehicles. User need to spend more money to refill the petrol thus lead to inefficient fuel consumption.

1.3 Objective

The objective of this project is to design an equivalent circuit model that combines batteries with ultra-capacitor to improve batteries current runtime performance when applied to electrical appliances such as mobile phones, notebooks and mini radio as well as the vehicles such as motorcycles and cars.

1.4 Scope of Study

This study focuses on designed ultra-capacitor circuit performance. All possible equivalent circuit models are designed in the laboratory to choose the best circuit that combines the ultra-capacitor and battery. All the software available such as Data Studio with the combination of ScienceWorkshop 750 interface is fully utilize to obtain the graph and table from the experimental circuits. This study will involve analytical calculations of electrical parameters to support the working prototype.

This project was divided into two parts known as first semester (first part) and second semester (second part) and expected to be complete within allocated time frame. The first part is to produce the prototype as well as the working and correct result from the analytical calculation and the simulation. The second part is to show the improved working prototype and advance application based new simulation results.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Battery

The battery stores energy electrochemically which converts the chemical energy into the electrical energy. The alkaline batteries or also known as alkaline manganese batteries is commonly used as the power supply for the electrical appliances such as mini radio, flashlight and alarm clock.

The alkaline batteries is enclosed in a nickel-plate steel that is also called as positive cathode contact. This nickel plate steel is separated from the negative anode contact at the bottom side of batteries by a cardboard insulator or separator as shown in **figure 1**. This alkaline battery contains the powdered graphite and manganese dioxide which is separate by a fabric separator to the powdered zinc. Then a tin-plated brass anode collector ("nail") is used to conduct the current from anode (powdered zinc) to the cardboard insulator. The plastic plug is used to hold the fabric separator and the tin-plated brass anode collector to make sure that these two parts maintain in the right position. The alkaline batteries generally have 1.5V cell storage and two years of shell life [7].

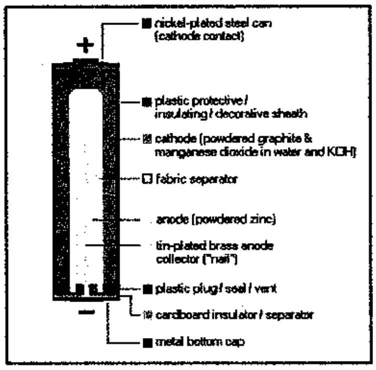

Figure 1: The Cross-Sectional view of alkaline cell battery [7]

The capacity of the battery depends on the charge and discharge rates as well as the surrounding temperatures. The designs of batteries come in a wide range of sizes such as AA batteries, AAA batteries, and 4.5-volt and 9-volt batteries. Batteries are divided into two groups; primary and secondary batteries. The primary batteries are useful only for once, and then they will be thrown away whilst the secondary batteries can be used after being recharged. The secondary battery also known as rechargeable battery which combines two or more chemicals substance together such as lead acid battery, lithium-ion (LI-ion) battery and nickel cadmium (NiCd) battery. The lead acid battery commonly used as the power source of the vehicles. It can produce 12.6V (fully charged) and consist of six cells connected in series inside molded polypropylene case. The electrolytes of lead acid battery consist of 65% of water and 35% of sulfuric acid. The chemical reaction between the water and sulfuric acid release the electron thus produce the electricity

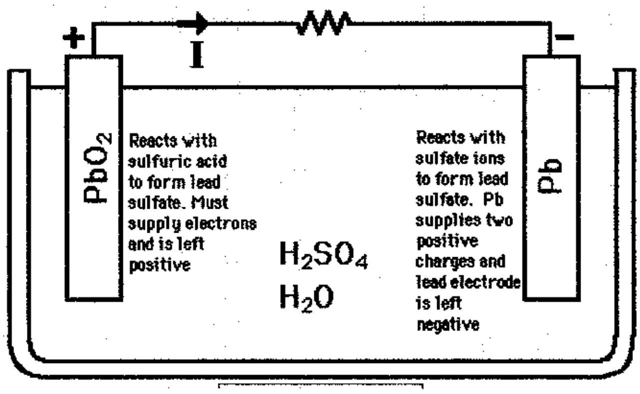

Figure 2: The cross sectional view of lead acid battery [8]

Batteries posses several advantages such as high energy density and low initial cost but the disadvantages of the batteries are lower power density, low cycle life, high equivalent series resistance (**ESR**) and inability to supplying efficient pulsating load [1].One of the weaknesses of the battery is high equivalent series resistance (**ESR**). This problem affected the consistency of the battery to supply the high power pulse. So it is complicated and inconvenient for the batteries to maintain the risk of performance failure at low level when supplying for the high current power pulse load. [9]. Battery also has low frequency response due to high equivalent series resistance thus reduce battery ability to handle the noise inside the electrical circuit such as electrical noise that occur in electrical control unit (ECU) of the vehicles.

2.2 Introduction to Ultra-capacitor

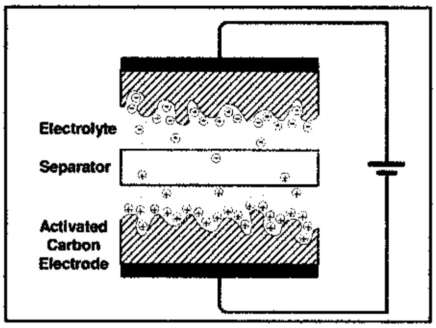

Figure 3: The Cross-sectional view of ultra-capacitor [10]

The ultra-capacitor (super-capacitor) is also classified as an energy storage device. An insulator is designed to separate two metal plates of the ultra-capacitor same as the conventional capacitor which is prevent the two metal plates from touching each other. The separator of the ultra-capacitor is soaked and porous in an electrolyte which allowed the positive and negative ion move freely in opposite direction to their respective electrodes. The characteristic of the electrode is not a smooth inner surface but it quite padded with activated carbon as shown in **figure 3.** This characteristic contributes to greater surface area which is about 100 000 times as large as the surface area of conventional capacitor [10]. The different of the conventional capacitor to the ultra-capacitor is when the direct current is passes through the capacitor, a positive charge is created on the one of the plate and negative charge will create on the other plate. The charge is remained at the plate until the capacitor is discharged [11].

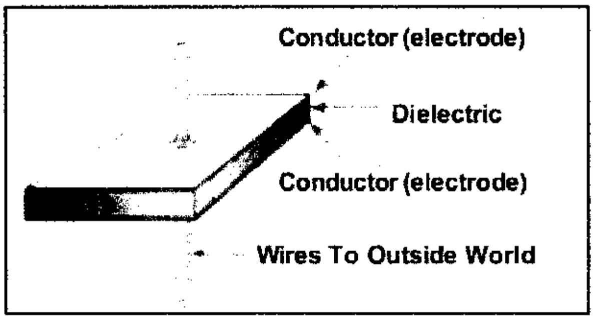

Figure 4: The cross-sectional view of the conventional capacitor [12]

The advantages of the ultra-capacitor have unlimited cycle life, rapidly charging property with simple charging method, cost effective energy storage and offers high capacitance in a small size. These characteristics offer the best option to improve the battery's current runtime. The ultra-capacitor distributes the short-term power simultaneously as the battery supplies the energy stored. The combination prolongs the current runtime performance, reduce the internal losses and improve the peak of output power. In this modern century, the ultra-capacitor becomes one of the most important components in the automotive and utility application as the energy storage components. In the automotive industries, ultra-capacitor is used as fuel cell in the hybrid vehicle. Then, they are also used in hospitals, banking centers and airport control towers to support the uninterruptible power sources which are located in the mentioned premises [13].

Another advantages posse by the ultra-capacitor is low equivalent series resistance (**ESR**). As the ultra-capacitor (super-capacitor) connected in parallel to the battery, it will improve the current handling in the equivalent circuit. High storage capabilities in a small size raise the ability of the ultra-capacitor to supply all the pulse current needed by the load. The rapidly changing characteristic provided advantages to the ultra-capacitor to recharge by the battery after deliver the pulse current thus lessen the battery stress as well as improve the life of the battery. [9] This method also will contribute to improve the fuel consumption in the vehicles when the ultra-capacitor connected in parallel to the vehicles battery.

The ultra-capacitor applications become famous in the automotive industry such as for the hybrid car technology. The hybrid technology is the car fuel technology which is to get the best from fuel and to produce better performance of the car itself. One of the examples of the hybrid car is the Toyota Prius that is released in 1997 and known eco friendly car. The main characteristic of the car is, the hybrid system reduced the exhaust emission and use energy in efficient as possible [14]. The ultra-capacitor was used in the hybrid car technology by combining with the battery to improve the power densities of the hybrid supply. The combination reduced the current drain of the battery while facing the heavy load conduction thus contribute to prolong the hybrid power supply life as well as increase the efficiency of the supply [15]. Another application of ultra-capacitor is cordless power drill and electric wheelchair [16]. The research of the ultra-capacitor to the electrical appliances would lead to eco-friendly electrical appliances which is improved human life, thus saving the earth for next generations.

Figure 5: Cordless Drill Powered by Ultra-capacitor [16]

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

3.1.1 Part 1

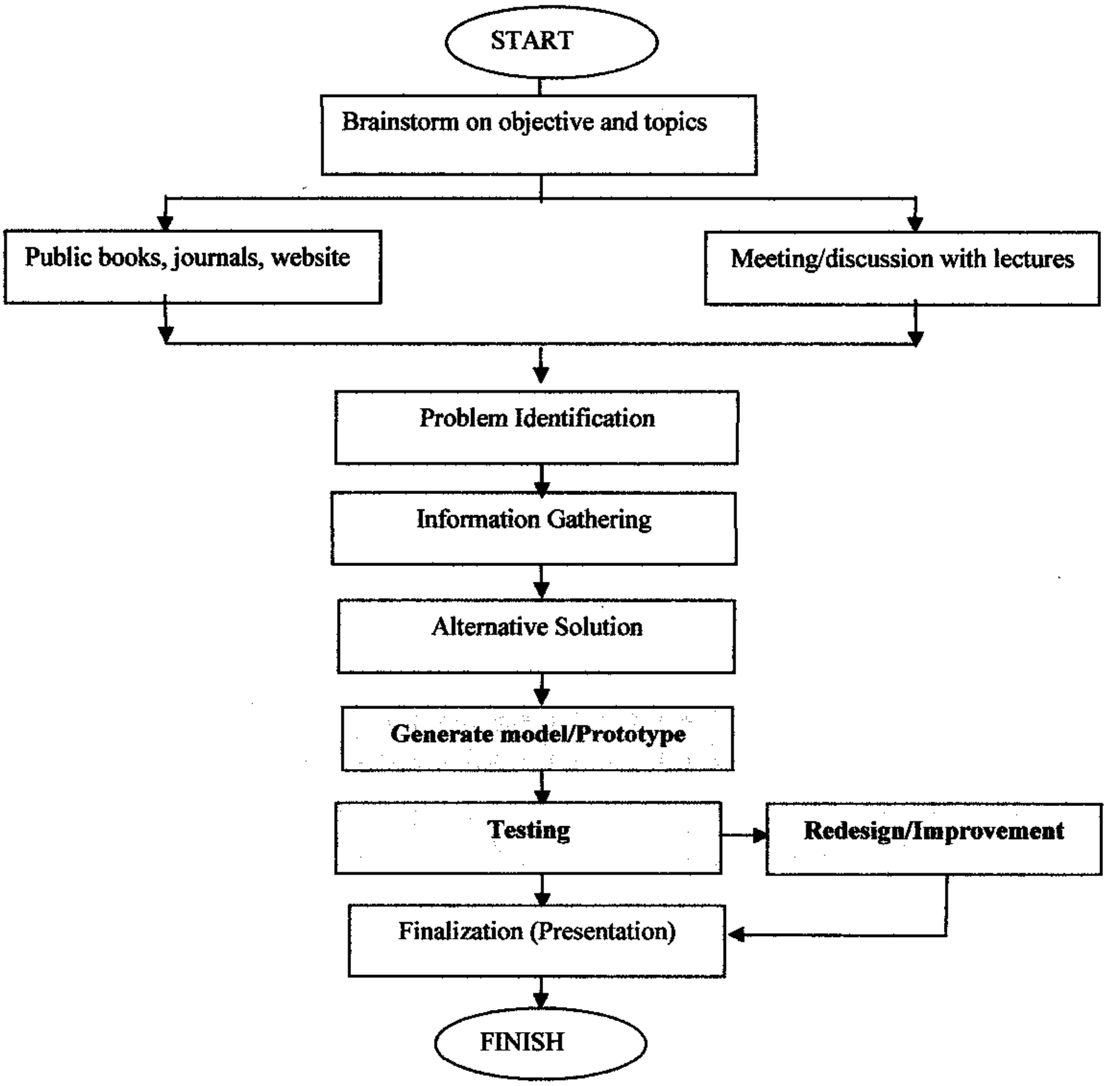

Figure 6: Flow chart of the project part 1

3.1.1 Part 2

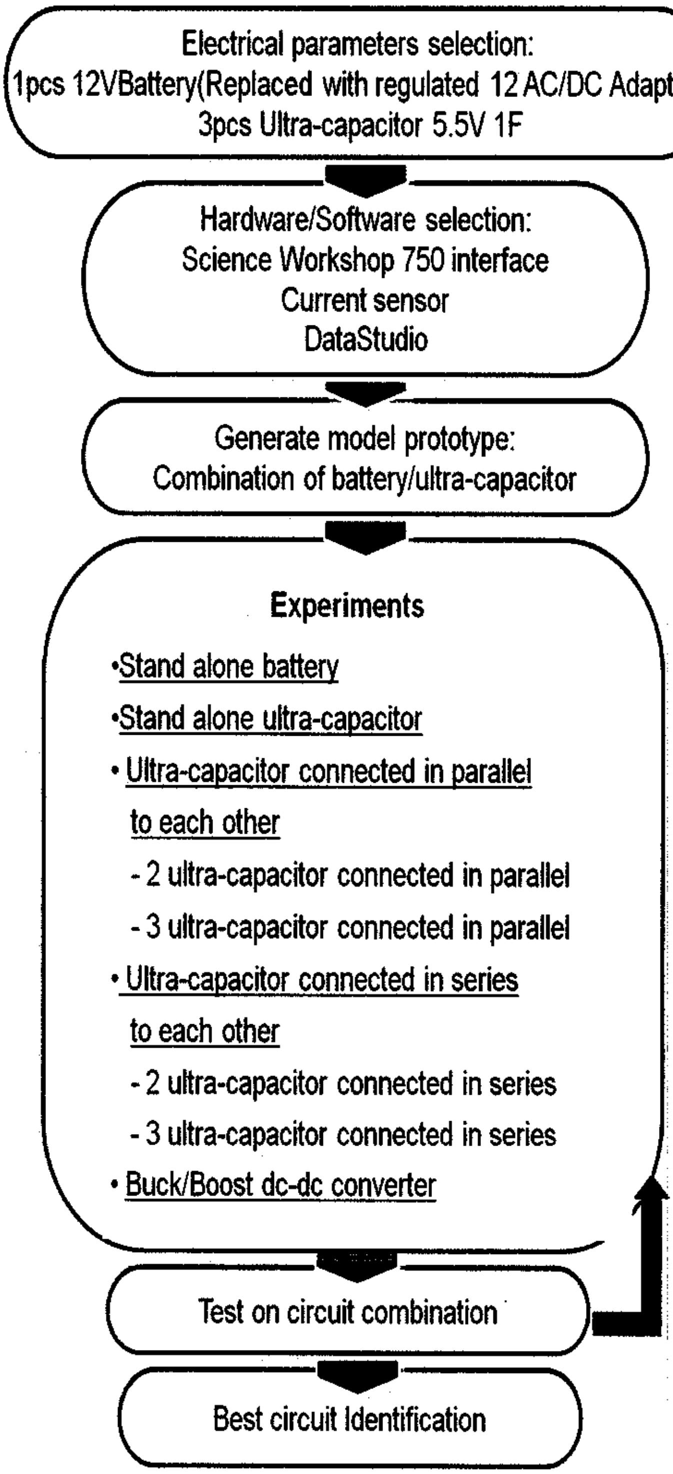

Figure 7: Flow chart of the project part 2

3.2 Design Approach

3.2.1 Project Experiments

The experiment of this project is conducted in four stages. The first stage is by connecting the stand alone ultra-capacitor to the battery. From this experiment, the discharging time of the ultra-capacitor is investigated by using the different value of the capacitance of the ultra-capacitor.

Average discharging time of the ultra-capacitor:

$$T_{average} = (t_1 + t_2 + t_3 + \ldots + t_n)/n \ldots\ldots\ldots (1)$$

The next stage is to investigate the output current waveform of the ultra-capacitor when 3 ultra-capacitors (connected in parallel to each other) are combined with the battery. The value of the peak current waveform gained from the experiment is used in the calculation to determine the extension current runtime of the battery. The rating voltage and the value of the capacitance when the ultra-capacitor connected in parallel to each other are determined by using equation (2) and (3).

$$Veq = V_1 = V_2 = V_n \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$Ceq = C_1 + C_2 + C_n \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The third stage is to investigate the output current waveform when 3 ultra-capacitors (connected in series to each other) are combined with the battery. The peak current waveform of this circuit combination is compared to the experiment done in previous stage. The rating voltage and the value of the capacitance when the ultra-capacitor connected in series to each other are determined by using equation (4) and (5).

$$Ve = V_1 + V_2 + V_n \ldots\ldots\ldots (4)$$

$$... \quad Ceg = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_n} \quad \dots\dots (5)$$

The regulated A.C/D.C adaptor is used as the power source to replace the battery due to cost reduction.

The last stage is to design the buck/boost converter in order to investigate its capability to combine with battery/ultra-capacitor combination circuit. The buck/boost converter will be triggered by using the Pulse Wave Modulation (PWM) in order to switch on and off the switching transistor inside the step up/step down converter.

After completing all the experiment, the best circuit combination is identified. The prototype is designed and the entire electrical component such as ultra-capacitor and the buck/boost converter is soldered on the veroboard. The prototype is installed to the battery of the car in order to investigate the extension current runtime of the battery and the improvement of the fuel consumption of the car.

3.2.2 The current runtime of the battery/ultra-capacitor combination circuit

Thevenin's theorem states that "a linear two-terminal circuit can be replaced by an equivalent circuit consisting of a voltage source ***Vth*** in series with resistor ***Rth***, where ***Vth*** is the open circuit voltage at the terminal and ***Rth*** is the input or equivalent resistance at the terminals when the independent sources are turned off "[17]. Based on the Thevenin's theorem, the impedance and voltage of the simplified circuit is derived. The equation showed below:

$$R_{th}(s) = \frac{sR_1R_2 + \frac{R1}{C}}{s(R_1 + R_2) + \frac{1}{C}} \dots\dots\dots (6)$$

$$V_{th}(s) = V_i \frac{sR_2 + \frac{1}{C}}{s(R_1 + R_2) + \frac{1}{C}} + V_{C1} \frac{s^2C^2R_1R_2 + sCR_1}{s^2C^2(R_1R_2 + R_2^2) + (C_s + 1)(R_1 + 2R_2)} \dots\dots\dots (7)$$

*Note that s is the complex variable.

The battery/ultra-capacitor circuit is expected to reduce the equivalent impedance of the system thus reduce the voltage ripple as well as increase the supply currents to the circuit.

After completed the design of the battery/ultra-capacitor combination circuit, the experiment is continued to investigate the output current waveform for each combination circuit. The value of peak currents gained from the experiment is used to calculate the internal losses in the battery/ultra-capacitor connection. The internal loss of the combination circuit is given by equation **(8)**:

$$P_{loss,source-C} = R_1 I^2_{source,rms} + R_2 I^2_{ultracapacitor,rms} \text{ ……… } (8)$$

The root mean square (**rms**) current of the source (***I*** *source*) and the rms current of the ultra-capacitor (***I*** *ultracapacitor*) obtained from the output current waveform produce by the combination circuit. Then the losses in the conventional circuit without the ultra-capacitor can be calculated based on the equation below:

$$P_{loss,source} = R_1 I_{load} \sqrt{D} \text{ ……… } (9)$$

Refer to the equation **(8)** and (9), the power losses in the circuit with combination of battery and ultra-capacitor is different with the power losses in the circuit without the ultra-capacitor. The power loss reduction defined as the subtraction of the power loss in the circuit without the ultra-capacitor to the power loss in the circuit with ultra-capacitor. Thus the power loss reduction is given by the following equation:

$$\Delta P = P_{loss,source} - P_{loass,source-ultracapacitor} \text{ ……… } (10)$$

The normalized power loss defined as the ratio of the power loss reduction to the power loss in the circuit without the ultra-capacitor. Thus the normalized power can be calculated by using the equation **(11)**:

$$\Delta P_n = \frac{\Delta P}{P_{loss,,source}} \text{ ……… } (11)$$

Power means the rate of time to expend or absorb the energy in the system [17]. Thus the output power of the system is defined as the multiplication of the voltage across the load with current across the load and the duty cycle. The output power of load given by:

$$P_{out} = V_{load} I_{load} \sqrt{D} \ldots\ldots\ldots (12)$$

The equation **(10)** and **(12)** validated the losses in the battery which related to the losses in the load. The current runtime of the battery refer to the output power of the load can be express according to the following equation,

$$\Delta t = \frac{\Delta P}{P_{out}} \ldots\ldots\ldots (13) \quad [18]$$

The current runtime extension in the battery/ultra-capacitor circuit combination is obtained by dividing the power loss reduction (***ΔP***) in the circuit with the output power (***P_{out}***) produced from the system.

The efficiency of the system is defined as the total output power (***Pout***) produced in the system to the input power (***Pin***) given by the battery as the power supply. The equation **(14)** is used to calculate the efficiency of the system:

$$\eta = \frac{P_{out}}{P_{in}} x100\% \ldots\ldots\ldots (14)$$

For this experiment, the waveform of the current across the load, current across the ultra-capacitor and current across the battery with installation of the ultra-capacitor is obtained using the ScienceWorkshop 750 Interface and the DataStudio software.

3.2.3 Investigate the capability of the ultra-capacitor to reduce the battery voltage drop

The experiment also provides the information which is can be used to calculate the voltage drop of the battery without the installation of the ultra-capacitor in the electrical system. Equation (**15**) is applied to calculate the desired voltage drop of the battery

$$\textbf{Total voltage drop} = [\, V_d = I * IR] \ldots\ldots\ldots (15)$$

The battery/ultra-capacitor combination circuit is expected to reduce the voltage drop in the combination circuit. Equation (**16**) is applied to investigate the voltage drop in the battery/ultra-capacitor combination circuit.

$$\textbf{Total voltage drop} = [V_d = I * ESR + \Delta t * {}^{I}/_{C}] \ldots\ldots\ldots (16)\ [9]$$

A working prototype is installed to the battery of the car in order to investigate the capability of ultra-capacitor with combination of the buck/boost converter to improve the fuel consumption of the vehicles. The noise occur in the electrical control unit (ECU) of the car is converted to the power which can be used by the electronic or electrical system of the car. The power can be calculated by using the equation below:

$$P = i^2 R \ldots\ldots\ldots (17)$$

3.3 Tools and Equipments Used

3.3.1 Hardware

The equipments used to design the equivalent circuit of the battery/ultra-capacitor combination is battery, ultra-capacitor, regulated 12V AC/DC adaptor, current sensor, ScienceWorkshop 750 Interface, multimeter, **LED** (load), breadboard, and veroboard.

The AA battery size, rated at 1.5V and 9V battery is used as the power supply to the equivalent circuit model as shown in the **figure 8**. The AA battery and 9V battery are widely used as the power source to the electrical appliances such as remote control, mini radio, digital clock, smoke detector and multimeter as well as very ease to get in the market with reasonable price.

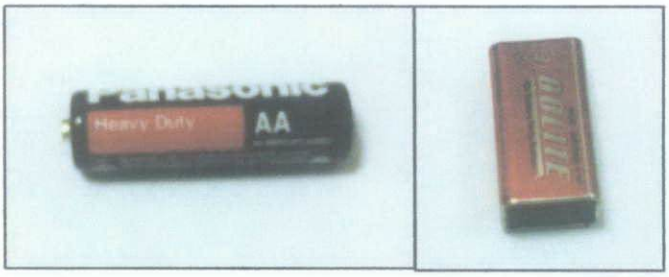

Figure 8: The AA battery (1.5V) and 9V battery (Heavy duty battery)

The Universal A.C/D.C adaptor/charger (**figure 9**) is used to replace the usage of the AA battery and heavy duty battery due to cost reduction. The AA battery and 9V battery is not suitable for the experimental works because of the lifecycle limitation and need to be replaced frequently. The Universal A.C/D.C adaptor has the input voltage (A.C voltage) 240V with 50 Hz frequency and the output voltage (D.C voltage) is 1.5V, 3V, 4.5V, 6V, 7.5V, 9V and 12V. The maximum value of current produced by the A.C/D.C adaptor is 500mA.

The variable output voltage gives an advantage during the experiment. It is easier to set the desired voltage needed by the equivalent circuit.

Figure 9: Regulated A.C/D.C adaptor/charger

The ultra-capacitor (super-capacitor) classified as the energy electrical storage devices [19]. The ultra-capacitor (**figure 10**) work as the charging component, but at the same time the batteries supply the power source into the circuit. When dealing with the ultra-capacitor, a proper handling methodology and management need to take into consideration especially always refer to the specific datasheet to avoid any unexpected situation such burning component.

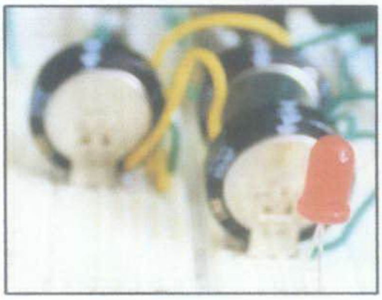

Figure 10: The 1F, 5.5V Ultra-capacitor

The current sensor shown in **figure 11** used to investigate the current across through it by measuring the voltage across the internal resistor rated at 1.00 ohms. The maximum current allowed to be measure is up to 1.5A and the maximum differential voltage allowed for this device is 1.5V [20]

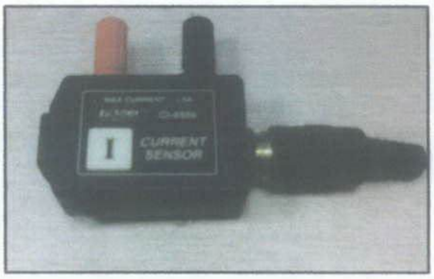

Figure 11: Current Sensor

The ScienceWorkshop 750 Interface has shown in **figure 12** works as a connection medium between the sensor and the computer to display the experimental result. The current sensor is connected to the available port at the ScienWorkshop 750 interface and then the results are displayed in term of graph and table at the computer's screen. [21]

Figure 12: ScienceWorkshop 750 Interface

The multimeter has shown in **figure 13** is widely used as the electronic or electrical tester instrument. It usually can be set up to measure the voltage (Volt), resistance (ohm) and the current (ampere) in Alternating Current (**AC**) or Direct Current (**DC**) mode. The multimeter is used to determine the current (ammeter) across in the circuit as well as the maximum voltage (voltage) supply to the ultra-capacitor [22].

Figure 13: Digital Multimeter

The light emitting diode (**LED**) red color with 1.8V forward voltage [23] is used as the DC load in the equivalent circuit. **LED** is connected in parallel to the power source and ultra-capacitor act as reference to observe the brightness when the batteries is supply the voltage (switch on) into the circuit and the batteries is cut off (switch off) from the circuit. **LED** is used as the **DC** load because it can be installing easily into the desire electrical circuit. **Figure 14** show the picture of **LED** in red color.

Figure 14: Light Emitting Diode

3.3.2 Software

DataStudio is a data collecting and analysis software and fully compatible with the ScienceWorkshop 750 Interface [24]. The data that gathered from the experimental circuit can be display by the data studio in the computer in form of graph and table. **Figure 15** show the browser of the DataStudio software.

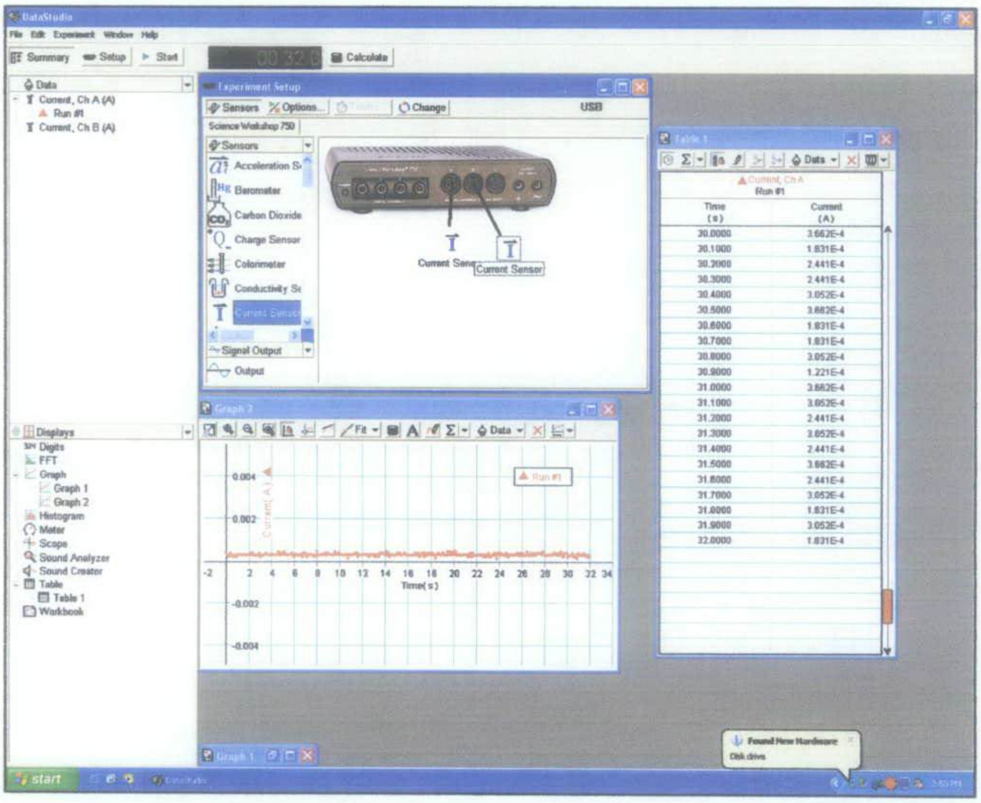

Figure 15: Browser of DataStudio

CHAPTER 4

RESULT AND DISCUSSION

4.1 Circuit Arrangement

4.1.1 Investigate the Discharging Time of the Ultra-capacitor

Figure 16 showed the equivalent circuit model for batteries/ultra-capacitor combination. Two batteries rated at 1.5V each connected in parallel with ultra-capacitor (super-capacitor) with capacitance 1.5 Farad. One light emitting diode (**LED**) connected in parallel used as **DC** load with limiting resistor 100 ohms. The Ammeter (multimeter) is used as an electronic measuring instrument to measure the current across the battery, current across the ultra-capacitor and current across the load.

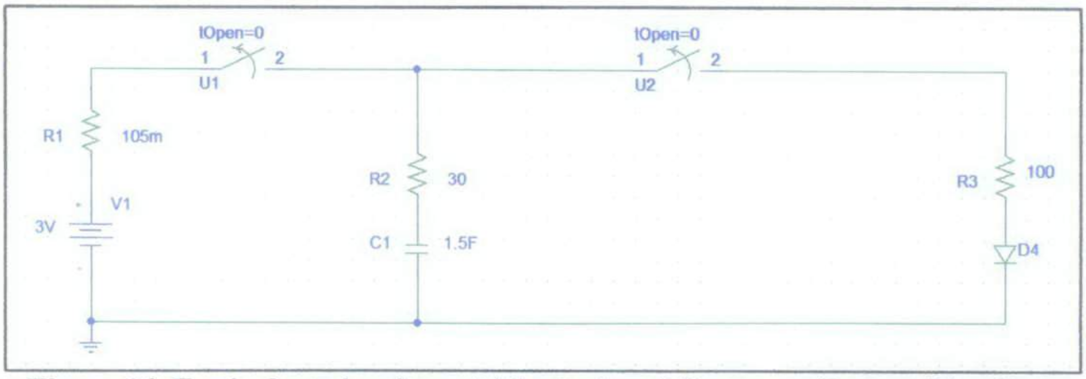

Figure 16: Equivalent circuit model for battery/ultra-capacitor combination

The batteries or power supply noted as **V1** supply the voltage to the circuit and at the same time V1 also charging the ultra-capacitor for a certain time. After the switch 1 (**U1**) is opened, the batteries stopping from supplying the voltage to the circuit so that the loop become an open circuit but at the same time, the ultra-capacitor continue to supply the voltage into the circuit and then the Ammeter determines the current runtime right after the **U1** is opened.

Electrical parameters used in the equivalent circuit model:

Power supply **V1**	= 3V
Ultra-capacitor **C1**	= 5.5V, 1500 mF and 0.33F
Resistor **R1**	= 105m ohms(x2) [25]
Resistor **R2**	= 0.24 ohms [26]
Resistor **R3**	= 100 ohms
LED forward voltages at 20mA	= ~1.8V [23]

4.1.2 Battery/ultra-capacitor combination circuit determination

From **figure 17**, it showed that the circuit contains battery, ultra-capacitor and load connected in parallel to each other. In this project, several types of circuit arrangement will be studied. The first experiment is done by connecting the stand alone of the ultra-capacitor into the equivalent circuit. Then the ultra-capacitor will be connected in parallel and in series to each other. This ultra-capacitor arrangement will be the determinant for selecting the most suitable equivalent circuit

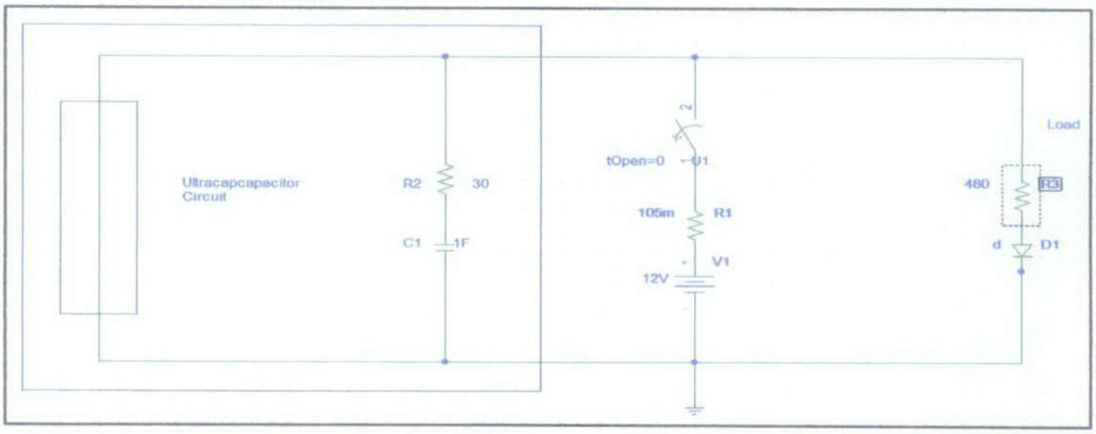

Figure 17: Circuit arrangement of the battery/ultra-capacitor equivalent circuit

4.1.3 *Investigate the Output current waveform of battery/ultra-capacitor combination equivalent circuit*

Figure 18 showed the equivalent circuit model for batteries/ultra-capacitor combination. A battery rated at 12V connected in parallel with an ultra-capacitor (super-capacitor) rated at 5.5V 1F. The circuit consist a voltage regulator to protect the ultra-capacitor form experiencing the over-voltage situation. One light emitting diode (**LED**) also connected in parallel used as **DC** load with limiting resistor 480 ohms. The current sensor connected to the **ScienceWorkshop 750 Interface** is used as an electronic measuring instrument to measure the current flow through the load, current flow through the battery in the battery/ultra-capacitor combination circuit, and current flow through the ultra-capacitor.

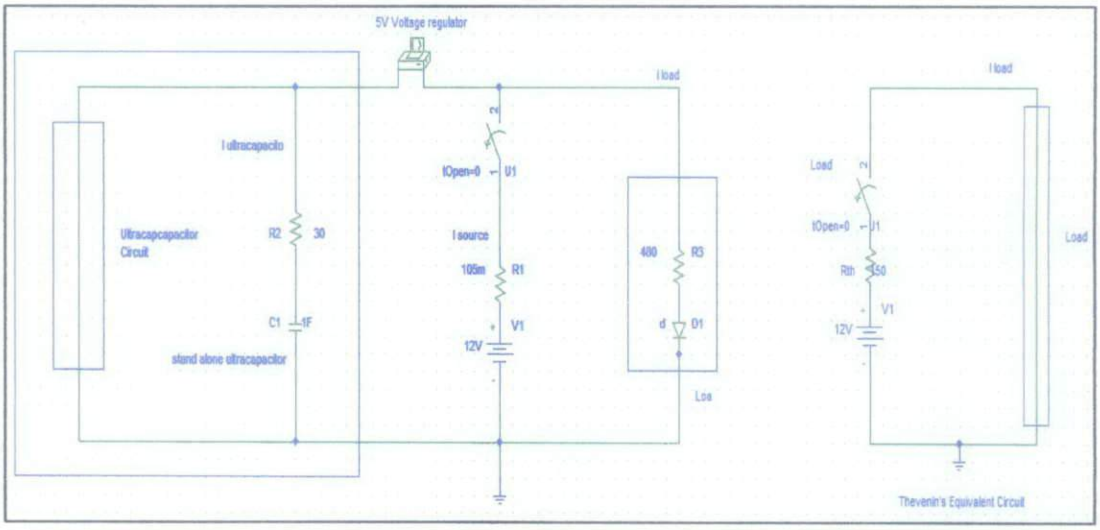

Figure 18: The battery/ultra-capacitor combination circuit

The output current waveform gained from this experiment is discussed in the section *4.2.3*.

Electrical parameters used in the equivalent circuit model:

Power supply **V1**	= 12V
Ultra-capacitor **C1**	= 5.5V, 1 F
Resistor **R1**	= 0.525 ohms [27]
Resistor **R2**	= 0.24 ohms [26]
Resistor **R3**	= 480 ohms
LED forward voltages at 20mA	= ~1.8V [23]

4.1.4 Investigate the Output Waveform of the Equivalent circuit when the ultra-capacitor connected in parallel to each other

The second experiment is done to investigate the effect of parallel connection among the ultra-capacitor to the equivalent circuit. The parallel connection increased the value of the capacitance of the ultra-capacitor depending on the number of the ultra-capacitor used while the rated voltage remains constant at 5.5V.

a) Two ultra-capacitors connected in parallel

This circuit arrangement (refer **figure 19**) consist of two ultra-capacitors with same rated voltage and capacitance (5.5 V, 1.0F each) connected in parallel to each other. This connection affects the value of the capacitance as shown below:

Rated Voltage for the parallel ultra-capacitor : 5.5V

Capacitance produced for the parallel ultra-capacitor: 2.0 F

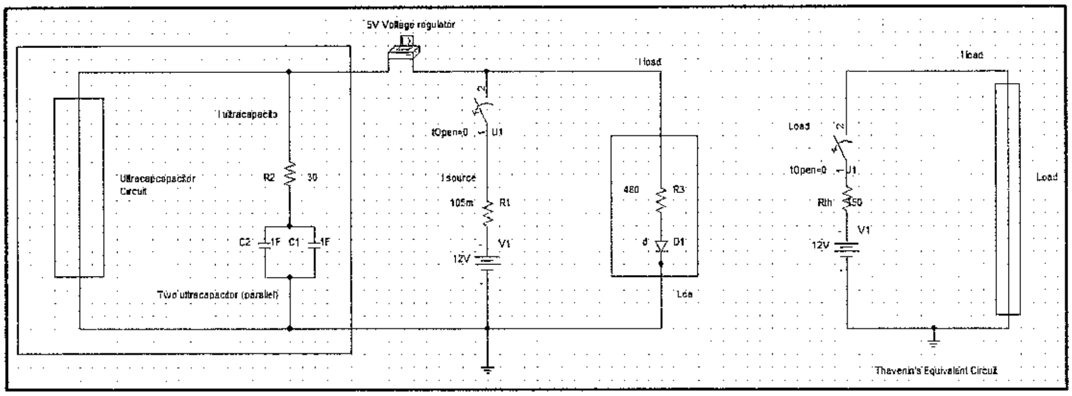

Figure 19: Two ultra-capacitors connected in parallel to each other

b) Three ultra-capacitors connected in parallel

This circuit arrangement (refer to **figure 20**) consist of three ultra-capacitor with same rated voltage and capacitance (5.5V, 1.0F each) connected in parallel to each other. The connection affects the value of the capacitance as shown below.

Rated Voltage of the ultra-capacitor : 5.5V

Capacitance produced by the ultra-capacitor: 3.0 F

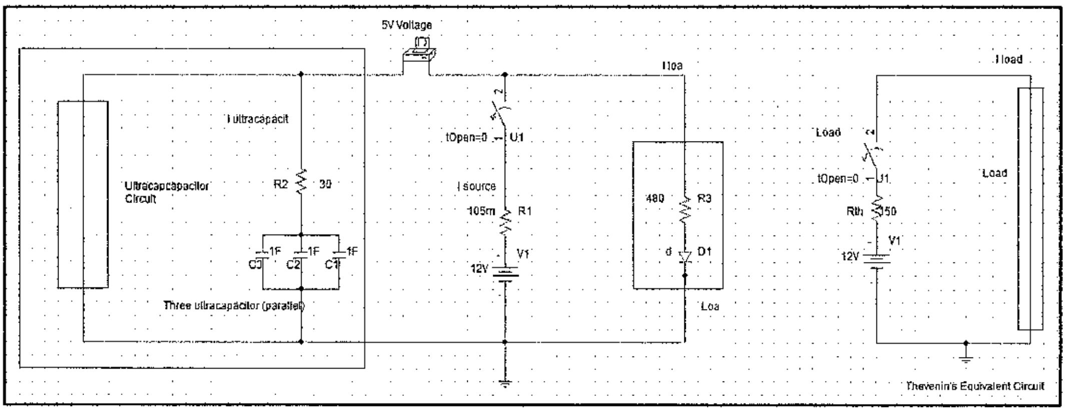

Figure 20: Three ultra-capacitors connected in parallel to each other

From this experiment, the discharging time of the ultra-capacitor when connected in parallel to each is showed in the graph in the section *4.2.3*.

4.1.5 Investigate the Output Waveform of the Equivalent circuit when the ultra-capacitor connected in series to each other

The circuit arrangement will be equipped with two and up to three ultra-capacitors connected in series to each other. All the ultra-capacitor used has same rated voltage and same capacitance (5.5V, 1F each). The series connection increased the rated voltage depending on the number of ultra-capacitor connected but at the same time the value of capacitance is reduced.

a) Two ultra-capacitors connected in series

This circuit arrangement (refer to **figure 21**) consist of two ultra-capacitor with same rated voltage and capacitance (5.5 V, 1.0F each) connected in series to each other. The circuit provided with 10V voltage regulator to prevent the over-voltage of the ultra-capacitor. This connection affects the rated voltage as well as the value of the capacitance.

Rated Voltage of the ultra-capacitor for the series connection: 11V

Capacitance produced by the series connection : 0.5 F

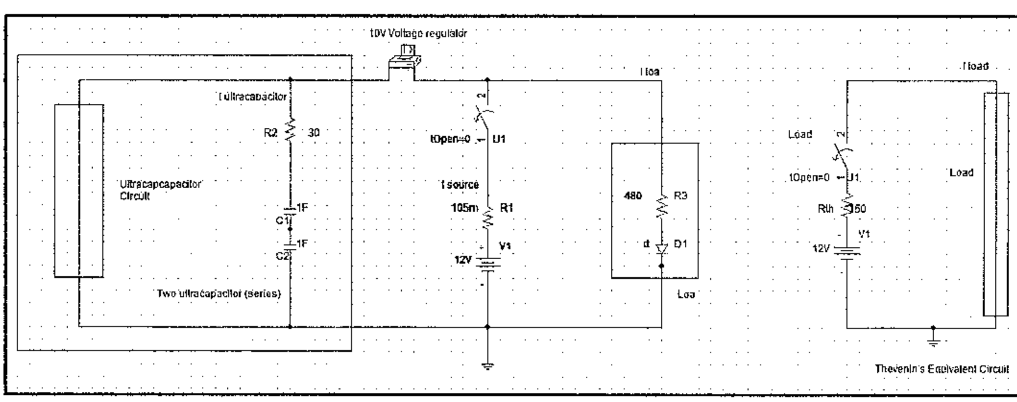

Figure 21: Two ultra-capacitors connected in series to each other

b) Three ultra-capacitors connected in series

This circuit arrangement (refer to **figure 22**) consist of three ultra-capacitor with same rated voltage and capacitance (5.5V, 1.0F each) connected in series to each other. For this circuit, there is no voltage regulator used since the rated voltage of the ultra-capacitor increased up to 16.5V which greater than the supply voltage (12V). This connection affects the value of the voltage and the capacitance as shown below.

Rated Voltage of the ultra-capacitor for the series connection: 16.5V

Capacitance produced by the series connection : 0.33 F

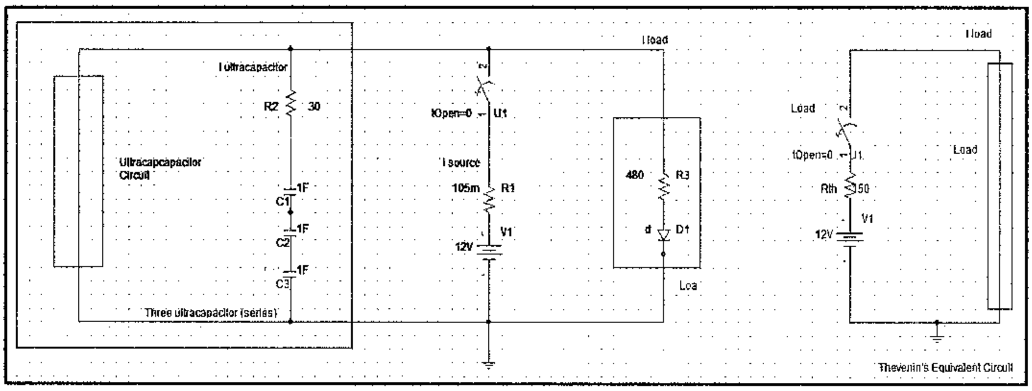

Figure 22: Three ultra-capacitors connected in series to each other

From this experiment, the discharging time of the ultra-capacitor when connected in series is showed in the section ***4.2.3***.

4.1.6 Investigate the effect of the battery/ultra-capacitor with buck/boost converter to the current runtime and fuel consumption of the vehicles

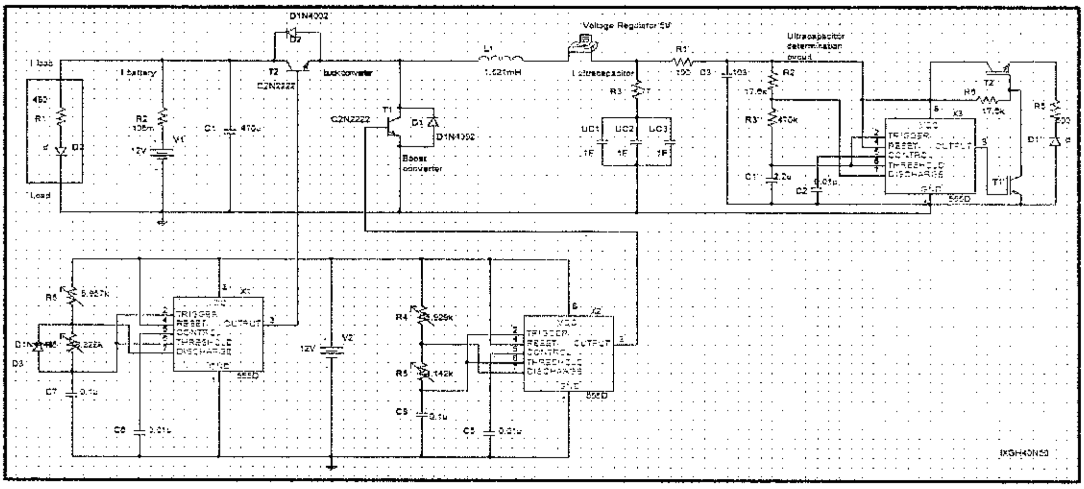

Figure 23: Full diagram battery/ultra-capacitor combination circuit with buck/boost converter

Figure 23 showed a full diagram of battery/ultra-capacitor combination circuit. This circuit consists of three ultra-capacitors connected in parallel to each other supplied by 12V DC source. The combination circuit also has the buck/boost converter in between of ultra-capacitor and the 12 DC source (battery) to transfer the energy between the battery and ultra-capacitor alternately. The buck/boost converter triggered by the Pulse Wave Modulation (PWM) to switch on and off the switching transistor inside the buck/boost converter. This circuit was used as the final design for battery/ultra-capacitor combination circuit. The final prototype was installed to the real car battery in order to investigate the effect of battery/ultra-capacitor to the current runtime as well as the improvement of the fuel consumption of the vehicles.

Under normal condition without battery/ultra-capacitor combination, the car was filled up with RM10 of fuel and the mileage meter is reset to zero. The total mileage of the car can be driven is recorded. Then the prototype was installed to the car battery. The car was filled up again with RM10 of fuel and the mileage meter is reset to zero. The total mileage of the car can be driven is recorded again. Both of this experiment was conducted for three times and the average number of mileage was taken as the final answer.

The electrical parameters gained from this experiment was used to investigate the voltage drop occur in the normal circuit without the installation if the ultra-capacitor. The calculation to get the value of voltage drop was continued by using all the parameters gained from the battery/ultra-capacitor combination circuit with installation of the buck/boost converter.

4.2 Results

4.2.1 The Discharging Time of the Ultra-capacitor

An experiment is done to investigate the discharging Time of the in the ultra-capacitor by using the battery as the power source (supply **DC** current). The 1.5F, 5.5V ultra-capacitor was used to investigate the possible discharging time right after the switch at the power source is open. The experiment was continued by using 0.33F, 5.5V ultra-capacitor to investigate the effect of the capacitance to the discharging time of the ultra-capacitor. The charging time for both ultra-capacitors is varied starting from 1 minutes, 3 minutes, 6 minutes, 9 minutes, 12 minutes and 15 minutes. All the data obtained from the experiment is gathered in **table 1**.

Table 1: The discharging time of the two ultra-capacitors right after the switch 1 (U1) is opened.

Charging time (minutes)	Discharging time (minutes) using 1.5F Ultracapacitor	Discharging time (minutes) using 0.33F Ultracapacitor
1	11.16	5.16
3	11.26	5.18
6	11.25	5.19
9	11.28	5.19
12	11.30	5.18
15	11.29	5.15

From the table above, the average discharging time for 1.5F, 5.5V ultra-capacitor is 11.26 minutes while the average discharging time for 0.33F, 5.5V ultra-capacitor is 5.18 minutes.

4.2.2 The Discharging Time of the Ultra-capacitor in three different circuit arrangement

An experiment is done to investigate the discharging time of the ultra-capacitor by using the A.C/D.C adaptor/charger as the power source to replace the battery (reduce cost) .The 5.5V, 1F ultra-capacitor was used to investigate the possible discharging time right after the switch at the power source is switch off. The experiment was continued by using the circuit which the ultra-capacitor is connected in parallel and series to each other. All the data obtained from the experiment showed in the figure.

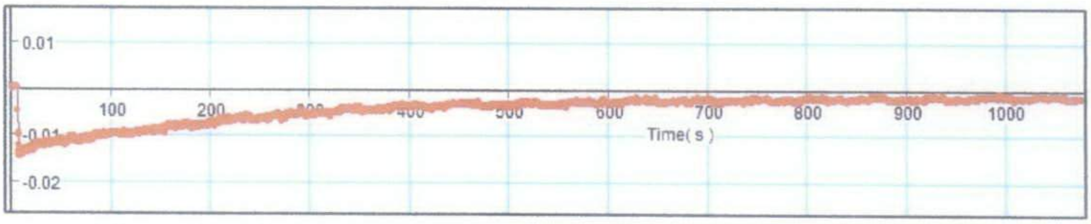

Figure 24: The discharging time of the stand alone ultra-capacitor

Figure 24 showed the graph of the discharging time of the stand alone ultra-capacitor rated at 5.5V, 1F. From the graph, the discharging time is 1000 seconds (16.67 minutes).

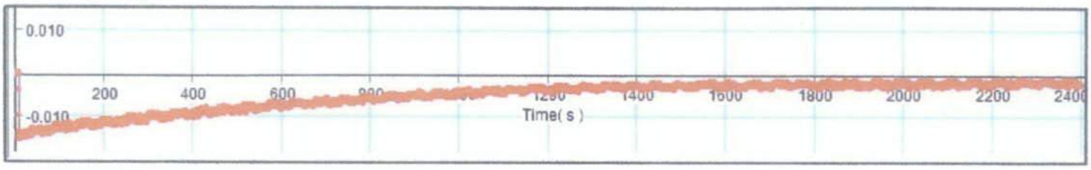

Figure 25: The discharging time of the three ultra-capacitors connected in parallel to each other

According to the **figure 25**, the discharging time of the ultra-capacitor connected in parallel (3 ultra-capacitors connected in parallel to each other) is 2400 seconds (40 minutes).

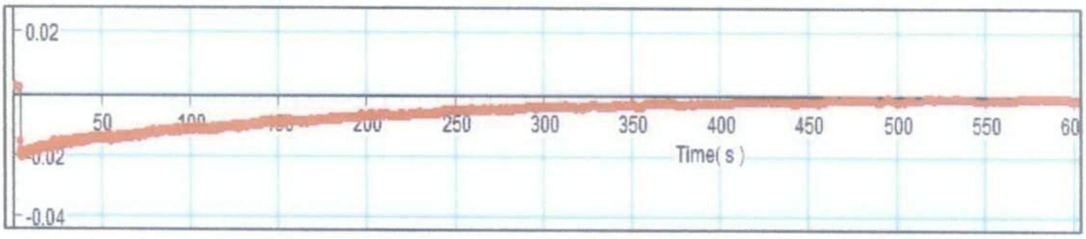

Figure 26: The discharging time of the three ultra-capacitors connected in series to each other

Refer to the **figure 26**, the discharging time of the ultra-capacitor connected in series (3 ultra-capacitors connected in series to each other), the discharging time is 500 seconds (8.3 minutes).

4.2.3 Current Waveform of the Equivalent circuit with stand alone ultra-capacitor

a) Waveform of current flow through the load.

   The waveform showed that the highest peak is current is 0.016 A at time equal to 67.5 seconds. **Figure 27** showed the waveform of current flow through the load in battery/ultra-capacitor equivalent circuit:

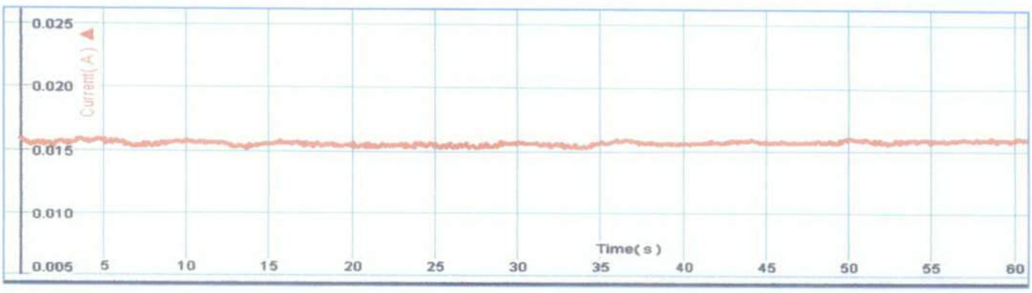

Figure 27: The waveform of current flow through the load

The waveform is rising when the ultra-capacitor was charged by the battery until it reaches the maximum value then the waveform is falling down when the ultra-capacitor was discharge. But refer to **figure 27**, the characteristic of the current waveform produce by this circuit is quite smooth compared to the other current waveform.

b) Waveform of current flow through the ultra-capacitor

Highest peak current through the ultra-capacitor: 4.3 mA

Time: 2 seconds.

Figure 28 showed the waveform of current across the ultra-capacitor in battery/ultra-capacitor equivalent circuit:

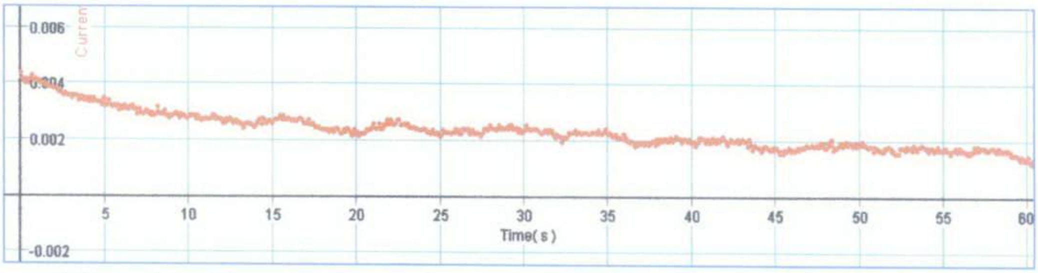

Figure 28: The waveform of current flow through the ultra-capacitor (standalone ultra-capacitor)

c) Waveform of current across the battery in battery/ultra-capacitor combination circuit.

Highest peak of current that flow through the battery: 7.81 mA

Time: 32.5 seconds.

Figure 29 showed the waveform of current across the battery in battery/ultra-capacitor equivalent circuit:

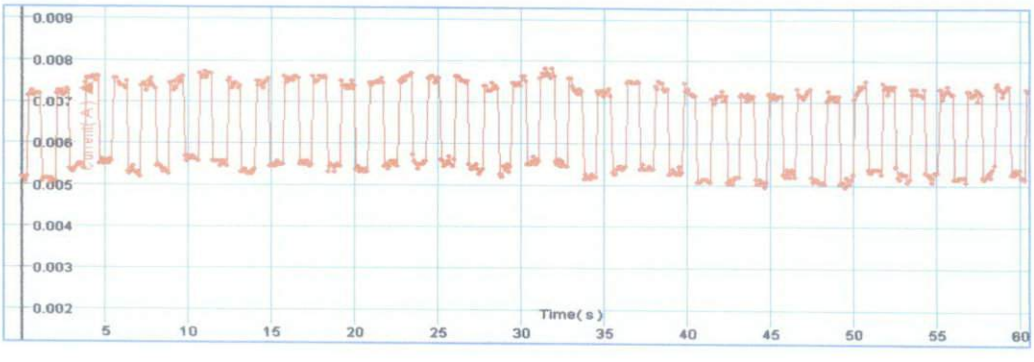

Figure 29: The waveform of current flow through the battery (standalone ultra-capacitor)

4.2.4 *Current Waveform of the Equivalent circuit, ultra-capacitor connected in parallel to each other*

i) Two ultra-capacitors connected in parallel to each other

a) Output waveform of current flow through the ultra-capacitor

Highest peak current flow through the ultra-capacitor: 9.583 mA

Time: 0.7 seconds.

Figure 30 showed the waveform of current across the ultra-capacitor in battery/ultra-capacitor equivalent circuit:

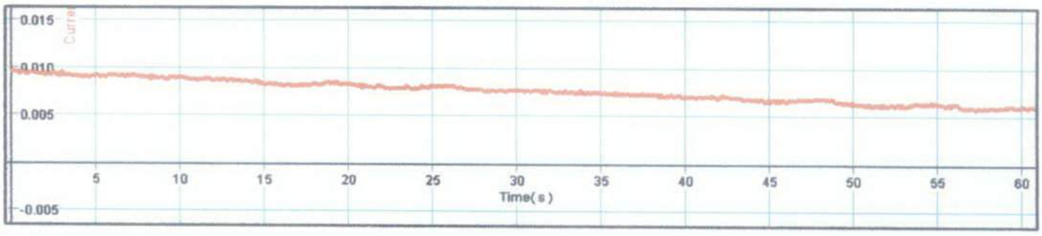

Figure 30: The waveform of current flow through the ultra-capacitor (2 ultra-capacitors connected in parallel)

b) The output waveform of current flow through the battery in battery/ultra-capacitor combination circuit.

Highest peak of current that flow through the battery: 8.24 mA

Time: 15.45 seconds.

Figure 31 showed the waveform of current across the battery in battery/ultra-capacitor equivalent circuit

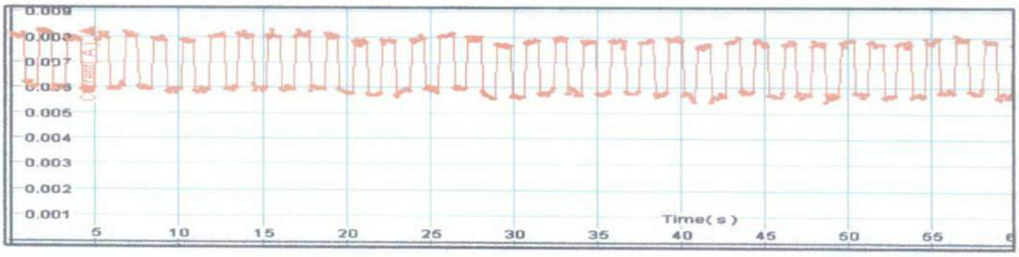

Figure 31: The waveform of current flow through the battery (2 ultra-capacitors connected in parallel)

ii) Three ultra-capacitors connected in parallel to each other

a) Output current waveform of current flow through the ultra-capacitor

   Highest peak current flow through the ultra-capacitor: 2.99 mA

   Time: 3.4 seconds.

   Figure 32 showed the waveform of current flow through the ultra-capacitor in battery/ultra-capacitor equivalent circuit

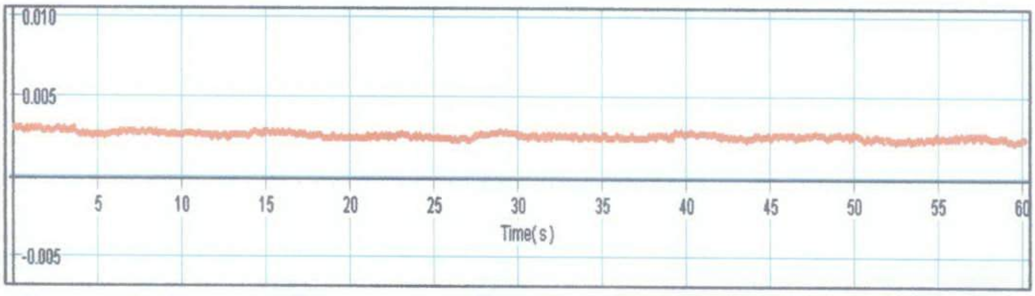

Figure 32: The waveform current flow through the ultra-capacitor (3 ultra-capacitors connected in parallel)

b) Waveform of current flow through the battery

   Highest peak of current that flow through the battery: 8.97 mA

   Time: 35.2 seconds.

   Figure 33 showed the waveform of current flow through the battery in battery/ultra-capacitor combination circuit

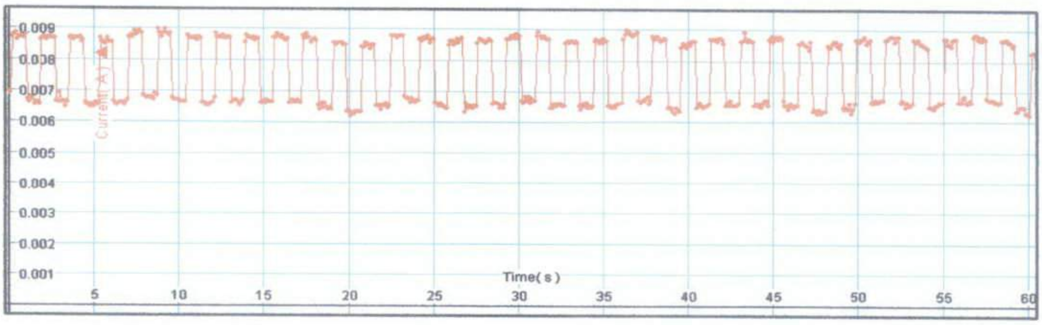

Figure 33: The waveform of current flow through the battery (3 ultra-capacitors connected in parallel)

4.2.5 *Current Waveform of the equivalent circuit, ultra-capacitor connected in series to each other*

i) Two ultra-capacitors connected in series to each other.

a) Waveform of current flow through the ultra-capacitor

Highest peak current flow through the ultra-capacitor: 0.019 A

Time: 3 seconds.

Figure 34 showed the waveform of current flow through the ultra-capacitor in battery/ultra-capacitor combination circuit.

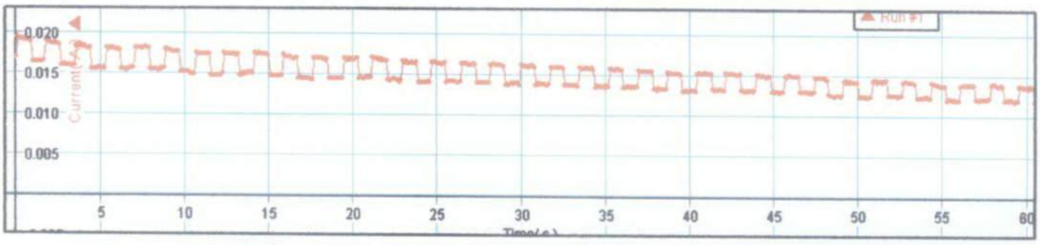

Figure 34: The waveform of current flow through the ultra-capacitor.

b) Waveform of current flow through the battery in battery/ultra-capacitor combination circuit.

Highest peak of current that across the battery: 7.26 mA

Time: 15.1 seconds.

Figure 35 showed the waveform of current across the battery in battery/ultra-capacitor equivalent circuit.

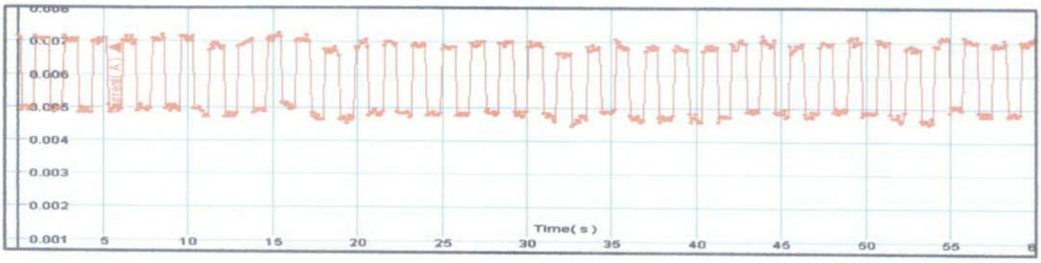

Figure 35: The current waveform across the battery.

ii) Three ultra-capacitors connected in series to each other

a) Waveform of current flow through the ultra-capacitor

Highest peak current flow through the ultra-capacitor: 0.02 A

Time: 2.5 seconds.

Figure 36 showed the waveform of current flow through the ultra-capacitor in battery/ultra-capacitor equivalent circuit

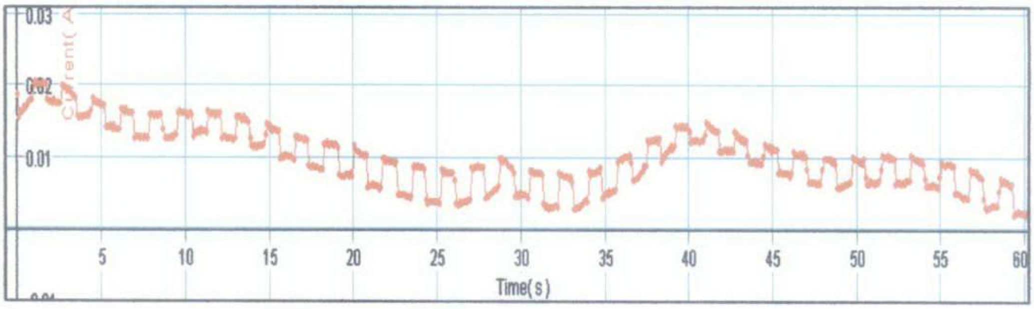

Figure 36: The waveform of current flow through the ultra-capacitor

b) Waveform of current flow through the battery

Highest peak of current that flow through the battery: 7.75 mA

Time: 15.5 seconds.

Figure 37 showed the waveform of current flow through the battery in battery/ultra-capacitor equivalent circuit

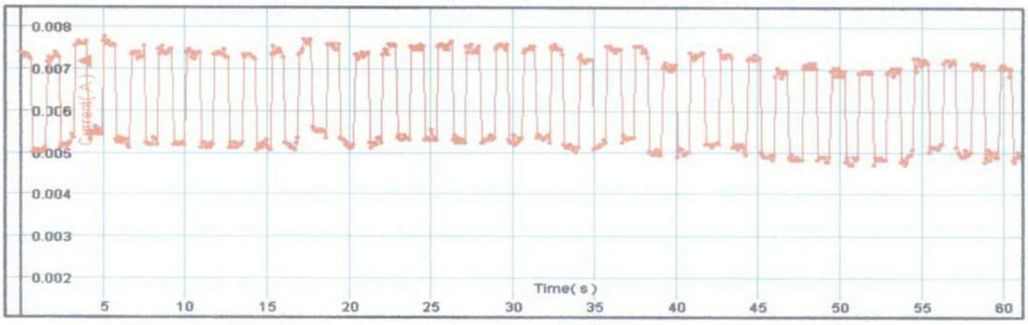

Figure 37: The waveform of current flow through the battery

4.3 Discussion

According to the result obtain from **section 4.2**, there are few approaches will be discussed in this section which focusing on the battery current runtime improvement. The analysis is based on the discharging time of the ultra-capacitor, the current waveform of the equivalent circuit of the combination between battery and ultra-capacitor, the voltage in the battery/ultra-capacitor combination circuit as well as the prototype installation.

4.3.1 Analysis of the discharging time of the ultra-capacitor

Based on the result obtained in **section 4.2.1**, the average rate of the discharging time for 1.5F, 5.5V ultra-capacitor is 11.26 minutes right after the switch at the power source was opened. For 0.33F, 5.5V ultra-capacitor the average rate of discharging time is 5.18 minutes right after the power source is cut off. The discharging time for the 1.5F, 5.5V ultra-capacitor is longer than the discharging time of 0.33F, 5.5V ultra-capacitor.

The charging time for 1.5F, 5.5V and 0.33F, 5.5V ultra-capacitor does not affect the discharging time of the ultra-capacitor. Although the charging time is varied from 1 minute, 3 minutes, 6 minutes, 9 minutes, 12 minutes and 15 minutes; but the discharging time remains constant

Refer to the output current waveform obtained in **section 4.2.2** the discharging time of the ultra-capacitor is filled in the **table 2.**

Table 2: The discharging time of the ultra-capacitor

Circuit arrangement	Stand alone ultra-capacitor	3 ultra-capacitors connected in parallel to each other	3 ultra-capacitors connected in series to each other
Capacitance	1F	3F	0.33F
Discharging time	1000s	2400s	500s

From **table 2** the discharging time of the three ultra-capacitors connected in parallel to each other (3F) is longer than the discharging time of the stand alone ultra-capacitor (1F) and three ultra-capacitors connected in series to each other (0.33F). The value of capacitance affects the discharging time of the ultra-capacitor; as the capacitance of the ultra-capacitor is increased, the longer the discharging time of the ultra-capacitor.

As the three ultra-capacitors connected in series to each other, the values of the capacitance drop to from 1F to 0.33F. This condition reduces the ability of the ultra-capacitor to hold the charge inside the ultra-capacitor longer than 1F capacitance. The circuit that provide the longer discharging time has the potential to use as the prototype.

4.3.2 Analysis of the output current waveform

Referring to the results obtained in **section 4.2.3**, there are three types of current waveforms for each circuit arrangement were taken into consideration to investigate the battery current runtime in the appearance of the ultra-capacitor. Based on the current waveforms from **figures 27 to 37**, the average amplitude of the current is considered for the calculation of the root mean square (**rms**) value. **rms** value known as effective value which is used to calculate the average value of periodic quantity over one complete cycle [28].

Table 3 showed the **rms** current for each current waveform obtained from the experiment for all three kind of circuit. The **rms** current across the battery and ultra-capacitor is used in equation number **(8)** to get the power losses in battery/ultra-capacitor combination circuit.

Table 3: The rms current for each current waveform

Current	Standalone ultra-capacitor	Parallel connection (2 ultra-capacitor)	Parallel connection (3 ultra-capacitor)	Series connection (2 ultra-capacitor)	Series connection (2 ultra-capacitor)
Capacitance	5.5V, 1F	5.5V,2F	5.5V, 3F	11V, 0.5F	16.5V, 0.33F
Current across load with no ultra-capacitor (A)	0.016	0.016	0.016	0.016	0.016
rms current (A)	0.016	0.016	0.016	0.016	0.016
Current across ultra-capacitor (A)	4.3 m	9.58m	2.99m	0.019	0.02
rms current(A)	2.119m	7.54m	2.5m	0.015	9.806m
Current across battery with ultra-capacitor (A)	7.8m	8.24m	8.97m	7.26m	7.75m
rms current (A)	6.35m	6.84m	7.623m	5.883m	6.213m

According to the **Table 3,** the peak current of the output waveform was affected by the rated voltage of the ultra-capacitor. For the standalone and parallel connection, the rated voltage remains constant at 5.5V. The peak current for each output waveform almost reach the same peak value. When the ultra-capacitor connected in series, the rated voltage is increased depending on the number of the ultra-capacitor. The peak current for this circuit arrangement is slightly different from the peak current in standalone and parallel connection of the ultra-capacitor.

Table 3 also showed that for the standalone circuit arrangement of the ultra-capacitor, the peak current across the battery in the equivalent circuit without the ultra-capacitor is higher than the peak current of the current across the battery in battery/ultra-capacitor combination circuit. The peak current across the battery/ultra-capacitor combination circuit is decreased because the equivalent series resistance (ESR) of the battery is reduced due to combination with the ultra-capacitor. At this rate, the lower values of **ESR** maximized the potential of the remaining current in a discharging battery [29].

As the current across the battery in battery-ultra-capacitor equivalent circuit is decreased, the internal power losses in power supply (battery) are reduced. The equation **(13)** is used to calculate the current runtime by dividing the reduction in **power loss (ΔP)** with the **output power (P_{out})** at the load. The ultra-capacitor which was connected in parallel to the battery minimized the losses of the battery thus improve the battery current runtime as well as it efficiency [30]. From the output power obtain in the equation **(12)**, the efficiency of the system was determined by applying the equation **(14)**

From the calculation, the extension current runtime for battery and standalone ultra-capacitor combination circuit is *45.19ms*. The extension current runtime for battery/ultra-capacitors (3 ultra-capacitors connected in parallel to each other) combination circuit is *44.81ms* while the extension runtime for battery/ultra-capacitor (3 ultra-capacitors connected in series to each other) is *44.36ms*. From the calculation, the standalone ultra-capacitor circuit has better extension runtime compare with the other two combination circuit.

From the discussion above, the circuit that have three ultra-capacitor connected in parallel to each other was selected as the best circuit to combine with the battery and the buck/boost converter. This circuit has longer discharging rate as well as has better output current waveform (smooth output current waveform). Although this circuit model has higher current value flow through the battery but it has the lowest peak current flow through the ultra-capacitor. This circuit combination has less extension current runtime compare to the battery and standalone ultra-capacitor combination circuit but batter extension current runtime compare to the circuit when 3 ultra-capacitors connected in series to each other. By referring back to the discharging time and output current waveform gained from all the experiments, the circuit with capacity 3F still is the best combination circuit. A prototype was constructed by using this circuit model in combination with buck/boost converter and will be discussing further in the next section.

4.3.3 Ultra-capacitor reduce the voltage drop of the battery

i) Voltage drop without ultra-capacitor

From the experiment above, the rated voltage (**V_d**) of the battery operate in the conventional circuit equal to 12.6V with peak pulse current (**I**) equal to 0.016A. The typical lead acid battery internal resistance (**IR**) is 0.525 ohms. [27] The time pulse width (Δt) of the current waveform is equal to 0.02 seconds. By using the equation (**15**), the total voltage drop in the conventional circuit without the installation of the ultra-capacitor is 8.4mV.

ii) Voltage drop with ultra-capacitor

By connecting three ultra-capacitors in parallel to each other, the value of capacitance was increase. The capacitance (**F**) of the ultra-capacitor is 3F and the internal resistance is 0.08 ohms which is less than the internal resistance (**IR**) of the battery. [26] By applying the equation (**16**), the voltage in battery/ultra-capacitor combination circuit with buck/boost converter was reduced to 1.38mV.

From the statement above, the voltage drop in the circuit without the ultra-capacitor is higher (8.4mV) compare to the voltage drop in the circuit with ultra-capacitor (1.38mV). As the voltage drop is large, the battery will not function properly. As the number of voltage change in the battery will affect the internal layer of the lead acid battery as well as to the other type of battery. This condition will increase the number of leakage current thus contribute to shorten the battery life. By connecting the ultra-capacitor with the battery, the number of voltage drop is reduced. Then the leakage current also will be reduce thus prolong the lifespan of the battery. [9]

4.3.4 Analysis the effect of the battery/ultra-capacitor combination circuit with installation of buck/boost converter to the fuel consumption of the vehicles

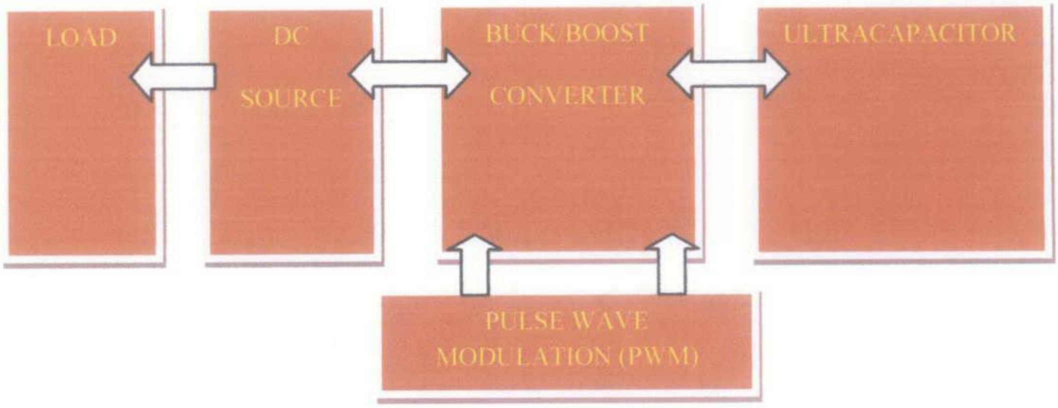

Figure 38: Block Diagram of battery/ultra-capacitor with buck/boost converter prototype

Block diagram (**figure 38**) showed the final prototype of battery/ultra-capacitor equivalent circuit with installation of buck/boost converter. All the main parameters are connected in parallel to each other. The pulse wave modulation (PWM) operates as the switching component for the buck/boost converter.

As the car in braking mode, the buck converter will operate thus the energy is transfer from the battery (DC source) to the load as well as to the ultra-capacitor. As the car is in accelerating mode, the boost converter will operate thus the energy stored in the ultra-capacitor will transfer back to the battery and load. The braking and accelerating mode of the car was determined by the electronic control unit (ECU) inside the car itself. The ECU will send the signal to the PWM so that the PWM can decide either to switch on the buck converter or the boost converter.

Under normal condition without battery/ultra-capacitor combination, the car was filled up with RM10 of fuel and the mileage meter is reset to zero. The total mileage of the car can be driven is recorded. Then the prototype was installed to the car battery. The car was filled up again with RM10 of fuel and the mileage meter is reset to zero. The total mileage of the car can be driven is recorded. Both of this experiment was conducted for three times and the average number of mileage was taken as the final answer.

Table 4: Average mileage of the car can afford with ultra-capacitor installation

	Fuel Cost	**Average number of mileage (3 times)**
Under normal condition	RM10	62.5km
Battery/ultra-capacitor combination circuit	RM10	78.5km

Table 4 showed that under normal condition the average mileage of the car can be driven is 62.5km while with the ultra-capacitor installation, the average mileage of the car can be driven is 78.5km. With ultra-capacitor installation, the car gained 16km (20%) more mileage compare to the normal condition.

As mentioned in previous chapter, the battery has high equivalent series resistance (internal resistance) thus lower the frequency response of battery to the electrical noise. The ultra-capacitor which has low equivalent series resistance can improve the frequency response of the battery thus filter out any electrical noise that occurs in the circuit. The electrical noise affect the performance of the electrical control unit of the car thus reduce the performance of the fuel ignition, reduce the performance of the audio system and increase the stress on the battery. By installing the ultra-capacitor to the battery, the internal resistance is reduced and the electrical noise was converted into the power and can be used by the electrical control unit of the car. The calculation can be done by using the equation (17).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As the conclusion on this study, a working equivalent circuit model for battery/ultra-capacitor combination was found. From the results of the experiment in **section 4.2.1** and **section 4.2.2**, the values of the capacitance (measure in Farad) affect the discharging time of the ultra-capacitor. The higher the value of the capacitance the longer the discharging time was recorded compared to the lower value of the capacitance. Then the parallel connection of the ultra-capacitor has better discharging time as compared to the standalone ultra-capacitor and series connection of the ultra-capacitor.

The battery/ultra-capacitor combination equivalent circuit provides less battery internal power losses which improve the battery current runtime in the equivalent circuit. Furthermore, the ultra-capacitor lowered the equivalent series resistance (**ESR**) of the battery which contributed to the better performance than the circuit without the ultra-capacitor.

As the prototype was installed to the car battery, the ultra-capacitor can provide better frequency response and better filtering circuit thus reduced the stress of the battery to the load. Instead of prolong the lifespan of the battery, the ultra-capacitor also has the ability to improve the fuel consumption of the vehicles as well as smoothing the electrical control unit (ECU) system of the car.

This experiment proved that the ultra-capacitor was compatible with combination of the battery to improve the battery current runtime. The finding from this project has the potential to reduce of the environmental issues that have been raised before and improve the power source for the electrical appliances.

5.2 Recommendations

The experiment will be conducted in the same surrounding temperature because the temperature affects the battery performance. This will avoid the inconsistencies of the supplied voltage from the battery and to maintain the same initial voltage produced by the battery

In order to get better output current waveform, the ultra-capacitor that has same rated value with the battery is used. This can be done by connecting the ultra-capacitor in series to each other. If more than three ultra-capacitors is connected in series to each other, a protective circuit must be install with the ultra-capacitor in order to prevent over-voltage.

As the researcher want to handle the electrical parameters, always refer to the datasheet in order to avoid any unwanted situations such as burning component and short circuit. This method will train the researcher to apply the safety and health environment in handling the electrical or electronic component.

The normal capacitor is used to reduce the noise in the equivalent circuit to get better output current waveform. The better output current waveform will provide better peak current value which used in the calculation.

The other available software such as MATLAB simulink and national instrument software is used for the simulation. This will produce better result for the simulation and also strengthen the results obtain from experiment.

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APPENDIX A

THE GANTT CHART FOR FYP 1 AND FYP 2

Gantt chart for the First Semester of 2-Semester Final Year Project.

	Detail/ Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Selection of Project Topic															
	-Identified the problem															
	-Conformation of title project															
2	Preliminary Research Work															
	-Collect all date required															
	-Identify the software and tools needed															
3	Submission of Preliminary Report															
4	Seminar 1 (optional)															
5	Project Work															
	-Experiment and circuit design															
6	Submission of Progress Report															
	-Literature review and theory															
7	Seminar 2 (compulsory)															
8	Project work continues															
	-Verify working prototype															
9	Submission of Interim Report Final Draft															
10	Oral Presentation															

Gantt chart for the Second Semester of 2-Semester Final Year Project.

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue															
2	Submission of Progress Report															
3	Project work continue															
4	Poster Exhibition (Pre-EDX)															
5	Engineering Design Exhibition (EDX)															
6	Submission of Draft Report															
7	Submission of Dissertation (soft bound)															
8	Oral Presentation															
9	Submission of Final Project Report															

APPENDIX B

THE DATA GAINED FROM THE EXPERIMENT

a) The discharging time of the stand alone ultra-capacitor

Current, Ch A
Run #1

Time (s)	Current (A)
1077.6000	-1.892E-3
1077.7000	-1.892E-3
1077.8000	-1.953E-3
1077.9000	-1.831E-3
1078.0000	-1.648E-3
1078.1000	-1.709E-3
1078.2000	-1.709E-3
Minimum	-0.015
Maximum	6.104E-4
Mean	-4.357E-3
Standard Dev.	3.102E-3
Count	10783

b) The discharging time of the three ultra-capacitors connected in parallel to each other

Table 1

Current, Ch A
Run #1

Time (s)	Current (A)
2400.0000	-2.380E-3
2400.1000	-2.380E-3
2400.2000	-2.319E-3
2400.3000	-2.319E-3
2400.4000	-2.319E-3
Minimum	-0.016
Maximum	4.883E-4
Mean	-5.194E-3
Standard Dev.	3.475E-3
Count	24005

c) The discharging time of the three ultra-capacitors connected in series to each other

Current, Ch A
Run #1

Time (s)	Current (A)
657.0000	-2.075E-3
657.1000	-2.136E-3
657.2000	-2.319E-3
657.3000	-2.319E-3
657.4000	-2.136E-3
657.5000	-2.136E-3
657.6000	-2.319E-3
657.7000	-2.075E-3
657.8000	-2.075E-3
Minimum	-0.022
Maximum	2.014E-3
Mean	-6.173E-3
Standard Dev.	4.723E-3
Count	6579

d) The Current Flow Through the load

Current, Ch A
Run #1

Time (s)	Current (A)
67.2000	0.016
67.3000	0.016
67.4000	0.016
67.5000	0.016
67.6000	0.016
67.7000	0.016
67.8000	0.016
67.9000	0.016
68.0000	0.016
Minimum	0.015
Maximum	0.016
Mean	0.016
Standard Dev.	1.630E-4
Count	681

e) The current flow through the ultra-capacitor (standalone ultra-capacitor)

Current, Ch A
Run #1

Time (s)	Current (A)
71.4000	1.099E-3
71.5000	9.766E-4
71.6000	9.766E-4
71.7000	9.766E-4
71.8000	9.766E-4
71.9000	1.099E-3
72.0000	1.038E-3
Minimum	9.156E-4
Maximum	4.334E-3
Mean	2.119E-3
Standard Dev.	6.909E-4
Count	721

f) The current flow through the battery (standalone ultra-capacitor)

Current, Ch A
Run #1

Time (s)	Current (A)
61.8000	5.127E-3
61.9000	5.249E-3
62.0000	5.188E-3
62.1000	7.202E-3
62.2000	7.324E-3
62.3000	7.263E-3
62.4000	7.324E-3
Minimum	4.944E-3
Maximum	7.813E-3
Mean	6.350E-3
Standard Dev.	1.037E-3
Count	625

g) The current flow through the ultra-capacitor (2 ultra-capacitors connected in parallel)

Current, Ch A
Run #1

Time (s)	Current (A)
59.9000	5.921E-3
60.0000	5.982E-3
60.1000	5.982E-3
60.2000	5.982E-3
60.3000	5.921E-3
60.4000	5.860E-3
60.5000	5.982E-3
60.6000	6.043E-3
60.7000	5.982E-3
Minimum	5.676E-3
Maximum	9.583E-3
Mean	7.540E-3
Standard Dev.	1.042E-3
Count	610

h) The current flow through the Battery (2 ultra-capacitors connected in parallel)

Current, Ch A
Run #1

Time (s)	Current (A)
61.8000	8.057E-3
61.9000	7.874E-3
62.0000	7.935E-3
62.1000	7.935E-3
62.2000	7.935E-3
62.3000	7.996E-3
62.4000	8.057E-3
62.5000	5.982E-3
62.6000	5.982E-3
Minimum	5.432E-3
Maximum	8.240E-3
Mean	6.840E-3
Standard Dev.	1.046E-3
Count	627

i) The current flow through the Ultra-capacitor (3 ultra-capacitors connected in parallel)

Current, Ch A
Run #1

Time (s)	Current (A)
59.4000	2.197E-3
59.5000	2.136E-3
59.6000	2.136E-3
59.7000	2.197E-3
59.8000	2.258E-3
59.9000	2.258E-3
60.0000	2.319E-3
60.1000	2.380E-3
60.2000	2.380E-3
Minimum	2.136E-3
Maximum	2.991E-3
Mean	2.500E-3
Standard Dev.	1.626E-4
Count	603

j) The current flow through the Battery (3 ultra-capacitors connected in parallel)

Current, Ch A
Run #1

Time (s)	Current (A)
60.0000	6.287E-3
60.1000	6.226E-3
60.2000	8.240E-3
60.3000	8.301E-3
60.4000	8.240E-3
60.5000	8.179E-3
Minimum	6.226E-3
Maximum	8.972E-3
Mean	7.623E-3
Standard Dev.	1.050E-3
Count	606

k) The waveform of current flow through the Ultra-capacitor.

Current, Ch A
Run #1

Time (s)	Current (A)
60.0000	0.014
60.1000	0.013
60.2000	0.014
60.3000	0.014
60.4000	0.014
60.5000	0.012
60.6000	0.012
Minimum	0.012
Maximum	0.019
Mean	0.015
Standard Dev.	1.758E-3
Count	607

l) The current flow through the Battery

Current, Ch A
Run #1

Time (s)	Current (A)
60.6000	5.005E-3
60.7000	5.127E-3
60.8000	5.066E-3
60.9000	5.066E-3
61.0000	7.263E-3
Minimum	4.456E-3
Maximum	7.263E-3
Mean	5.883E-3
Standard Dev.	1.064E-3
Count	611

m) The waveform of current flow through the Ultra-capacitor

Data ▲Current, Ch A Run #1

Time (s)	Current (A)
60.3000	5.982E-3
60.4000	5.982E-3
60.5000	5.676E-3
60.6000	5.982E-3
60.7000	5.676E-3
60.8000	5.676E-3
60.9000	5.737E-3
61.0000	5.676E-3
61.1000	5.615E-3
Minimum	1.770E-3
Maximum	0.020
Mean	9.806E-3
Standard Dev.	4.285E-3
Count	612

n) The current flow through the Battery

Data ▲Current, Ch A Run #1

Time (s)	Current (A)
62.4000	4.822E-3
62.5000	4.944E-3
62.6000	4.944E-3
62.7000	4.822E-3
62.8000	5.005E-3
Minimum	4.700E-3
Maximum	7.752E-3
Mean	6.213E-3
Standard Dev.	1.096E-3
Count	629

APPENDIX C

THE PROTOTYPE OF THE PROJECT

C.1 Full circuit configuration

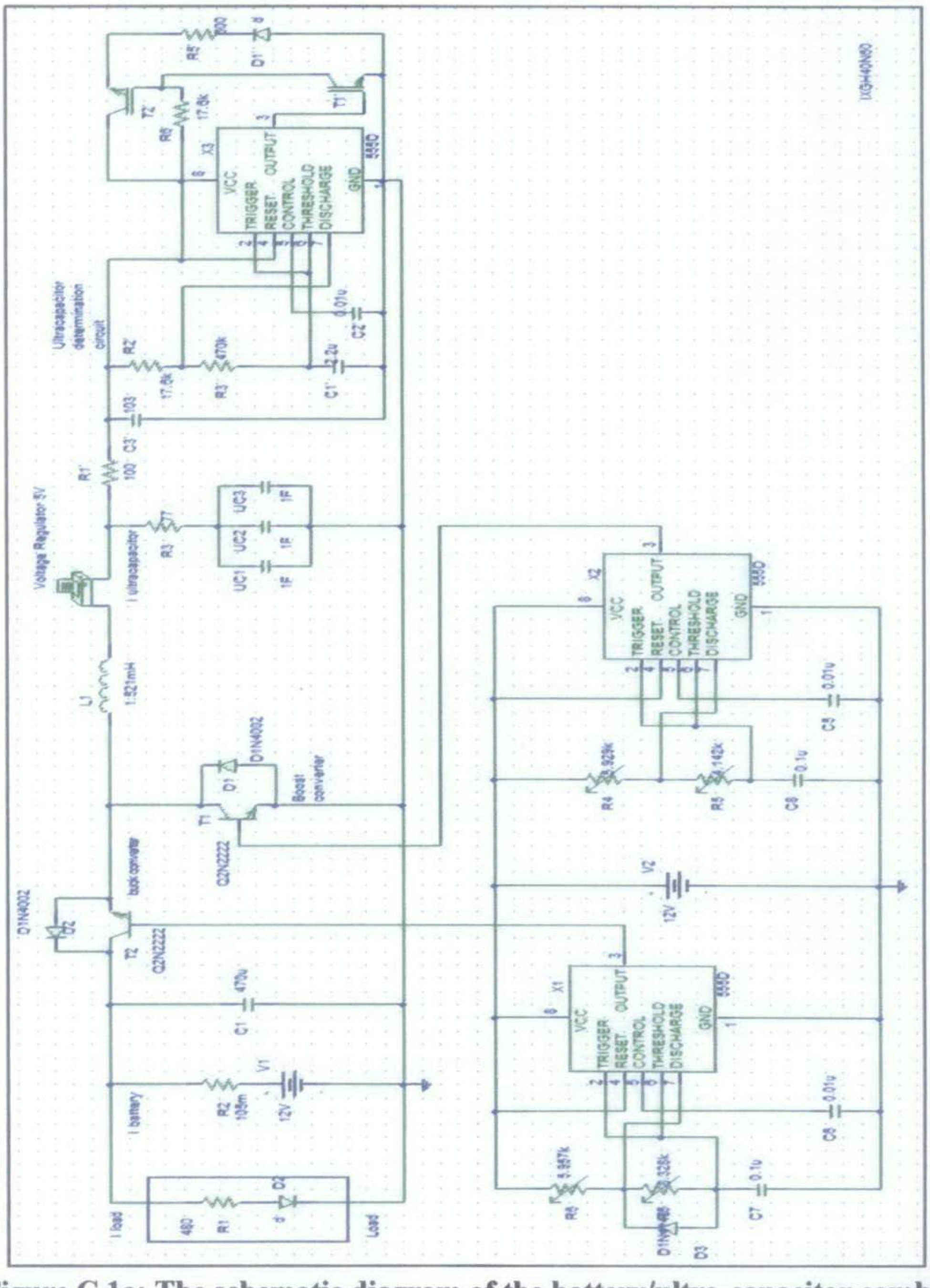

Figure C.1a: The schematic diagram of the battery/ultra-capacitor combination circuit with buck/boost converter

C.2 Prototype of the project For FYP 1 and FYP 2

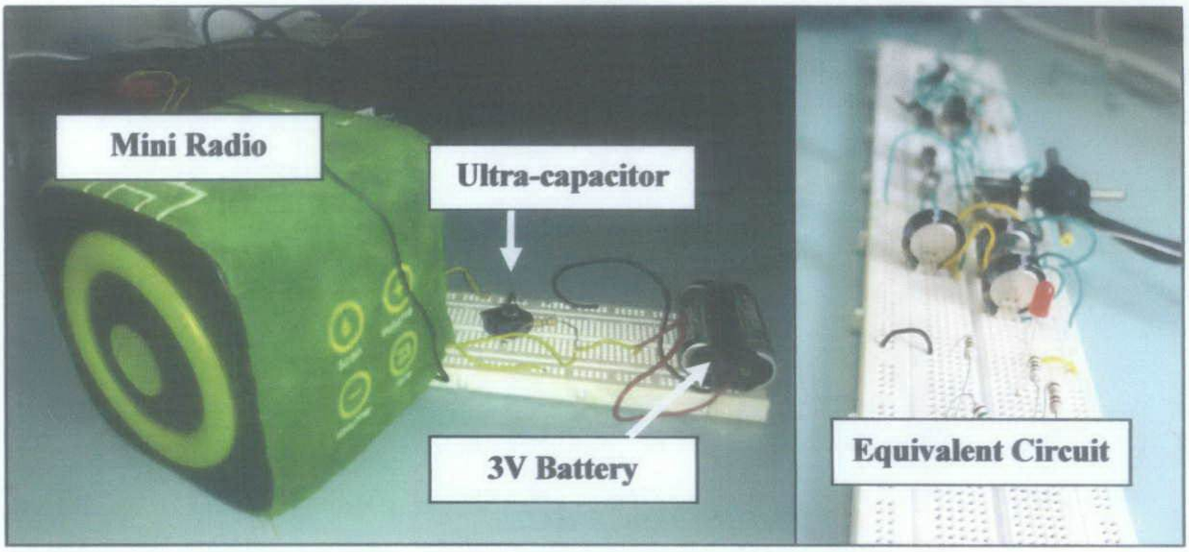

Figure C.2a: The prototype for FYP 1

Figure C.2b: The prototype for FYP 1

C.3 Prototype Installation to the battery of the car

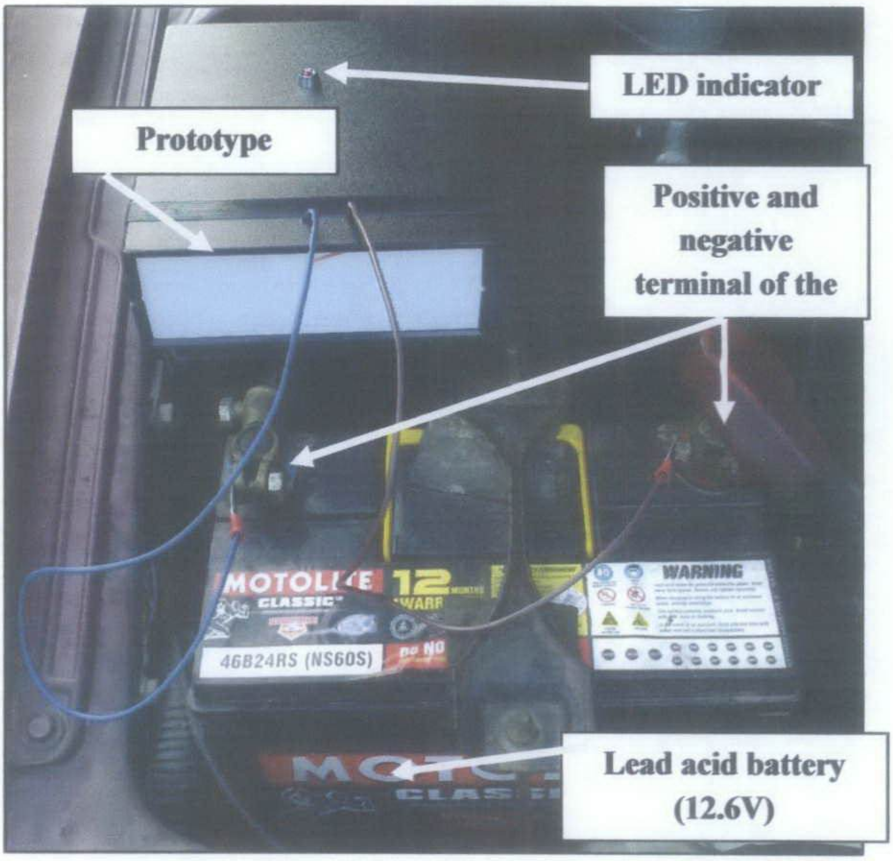

Figure C.3a: The prototype installation to the battery of the car