A NEW VOLTAGE & CURRENT BOOSTER FOR RENEWABLE ENERGY

By

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CERTIFICATION OF APPROVAL

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Approved:

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September 2012

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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AZRUL HAYAT BIN TUMPANG

ABSTRACT

World today is facing a very huge environment problems which is global warming that effect to the green house. One of the major factors that lead to this kind of situation is thinning ozone layer causes by Carbon Monoxide (CO) produced by vehicles around the globe. Nowadays, we can say that most vehicles powered by fossil fuel as a source of energy. Not only vehicles, some of machines also rely on fossil fuel as an energy source and from what we know about this energy sources outrun day by day and their effect is not environment friendly. As an effort to save the world, alternative energy sources has already been introduced and become one of important power sources today. Renewable energy such as solar, wind, wave, hydro and etc is the practical ways in order to create new energy without effecting the environment. Besides that, the alternative energy sources also introducing the green technology. By using the idea, the purpose of this project is to introduce and to produce and electrical energy by using Hydrogen gas. This project will demonstrate on how Hydrogen gas can be converted to produce electricity by using fuel cell technology and electricity produced by that particular process can be a direct supplier or also as a backup power supply. This project can be categorized as a green technology because there is no product effect when producing electricity. By referring the fuel cell theory, voltage and current produced by interaction at the special cell membrane which is Polymer Electrolyte Membrane Fuel Cell (PEMFC) that involving Hydrogen ion travel through the cell membrane and electron will flow on the electrical rod to produce electricity. Other than that, the solar panel also connected together in parallel in order to multiply the input power produce. The major problem of harvesting technology is the electrical output voltage and current is small in value. This problem will cause a difficulty to trigger any loads connected with any renewable source. Therefore, to overcome the problem this research will present a voltage and current booster that improvise the output of harvesting technology. The expected voltage and current output for this project is use to operate electrical and electronics devices such as DC motor, radio and etc.

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

PEMFC	Polymer Electrolyte Membrane Fuel Cell
FYP	Final Year Project
EMF	Electromagnetic Field
MEA	Membrane Electrode Assembly
DC	Direct Current
AFC	Alkaline Fuel Cell
DMFC	Direct Methanol Fuel Cell
SOFC	Solid Oxide Fuel Cell
CAD	Computer Aided Design

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background of study

The fuel cell technology already been recognized since early in 1800's where the founder Sir William Grove has discover this kind of technology back in 1839. Time by time and century by century, the scholars and scientists all around the globe try hard with their own way to develop fuel cells using much kind of fuels and electrolytes. This hard work come for the first served as a foundation of a system that use in Gemini and Apollo space craft back in the first half of 20th century in United State of America. However, this technology finally successfully demonstrated the first fully operational fuel cell by Francis T. Bacon in 1959.

NASA was the first user who tried this technology where the first Proton Exchange Membrane Cell in the 1960's as part of Gemini space program and they has been use for their next seven mission onward. Those fuel cells mainly use pure oxygen and hydrogen as a main supply because the other reactant gases were extremely expensive and not commercial viable. NASA is very committed going through this technology and they work very hard for further development as did the energy crisis occurred and affect the world in 1973. Since then, fuel cells research has continued widespread and this kind of technology have been successfully used in many applications nowadays [1].

1.2 Problem statement

1.2.1 Problem Identification

Lot of manufacturers produce new vehicles, electrical and electronic appliances every year to make our life easier. All of these products are depending to the fossil fuel and electricity as a source of energy. The emission of CO gas from industries and vehicles will increase green house effect which is very dangerous for us especially to the environment. Therefore, new approach is required to improve the alternative energy in order to replace the current energy source in order to save our world.

Nowadays, a lot of alternative energy has been produced to reduce the usage of the fossil gas but only minority of people are fully utilized this alternative energy. Even though the alternative energy maybe expensive compared to the current source of energy but it makes the environment safe and clean. By improvising the available fuel cell by adding special features and design, it will encourage people to use this new technology since it only use hydrogen gas as sources to produce electricity. Moreover, we can harvest sun energy and converted to electricity by using solar panel. Thus, this can be the best alternative way to produce clean and renewable energy without affecting the environment.

1.2.2 Significant of the Project

This new innovation can be used as a power supply and as the backup supply in emergency cases. This innovation focuses to those who required continuous power supply. The application of the power supply produced by this innovation can be used with any loads as long as they are operating in DC voltage. Thus, this green innovation absolutely clean with less emission of the greenhouse gas and become one of the efficient alternative energy.

1.3 Objectives

Some objectives set and satisfy the scopes of study that have been highlighted, which are relevant to the requirement to complete the FYP. The objectives of this project are as follows:

1. Design, fabricate and construct the voltage & current booster circuit in order to amplify output current.

2. Design the hybrid and portable prototype renewable energy system model using the PEMFC and solar.

1.4 Scope of study

The scope of study will consists of three major parts which are:

1. Research and survey on the fuel cell unit application. The research is to give some ideas and relevant solutions to create and improve new application especially for the green technology.

2. The experimental work is analysis, data gathering and identifying the processes and disturbance model of the application.

3. Design the prototype model to operate with high efficiency and performance especially when we talk about output power delivered.

4. Design the current booster circuit to amplify the output of PEMFC.

1.5 Relevancy of the Project

The clean technology has been a familiar topic that people spoke everyday. The effect of the Green House are one of the problems that contribute in developing this project. Because of that crucial issues, the use of hydrogen and solar as a energy sources as one alternative way to produce a clean energy is highly relevant. Before the commissioning of the project, an investigation has been done to determine the true operation of PEMFC itself.

1.6 Feasibility the Project within Time Scope and Time Frame

The project has been given to student during Final Year of their study. In order to complete the project, 2 semesters already has been assigned and divided to FYP1 and FYP2. During FYP1 period, the project is going to the paperwork detail. Anything and everything that related to the project must be written in detail in a proposal report. For the FYP2 period, the prototype design will be made. All result that will be recorded must be attached together with the proposal report and combined them to make a final report. Detailed activities will be explained in the Gantt chart (Appendix A & B).

CHAPTER 2

LITERATURE REVIEW

2.1 Fuel Cell Theory

Fuel cell is the electrochemical cell that uses hydrogen gas to convert the chemical reaction directly to the electrical energy. The components of a fuel cell consist of an electrolyte layer, electrodes and conductor wire. The electrolyte is assembled together in between the anode and cathode electrode. Figure 1 shows the diagram of a fuel cell with the reactant gases which are hydrogen and oxygen gas and ion flow directions through the cell.

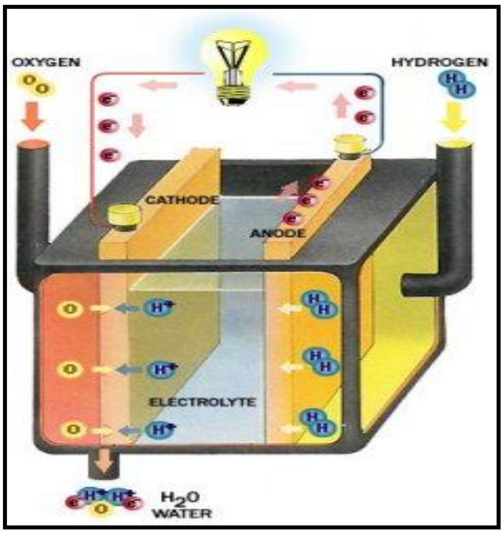


Figure 1: Fuel cell unit [5]

In the fuel cell, gaseous fuel which is hydrogen gas is fed continuously to the anode which is the negative electrode and oxygen gas from air is fed continuously to the cathode that means it is on positive electrode. At these two electrodes, the electrochemical reactions will occur to produce an electrical power and water. The higher concentrations and pressure of gaseous fuels are fed into the cell, the higher voltage can be generated. Figure 2 shows the effect of different pressure given to the fuel cell. The voltage drop increases when the pressure of hydrogen gas increases for the certain limit to avoid the electrolyte layer from damage.

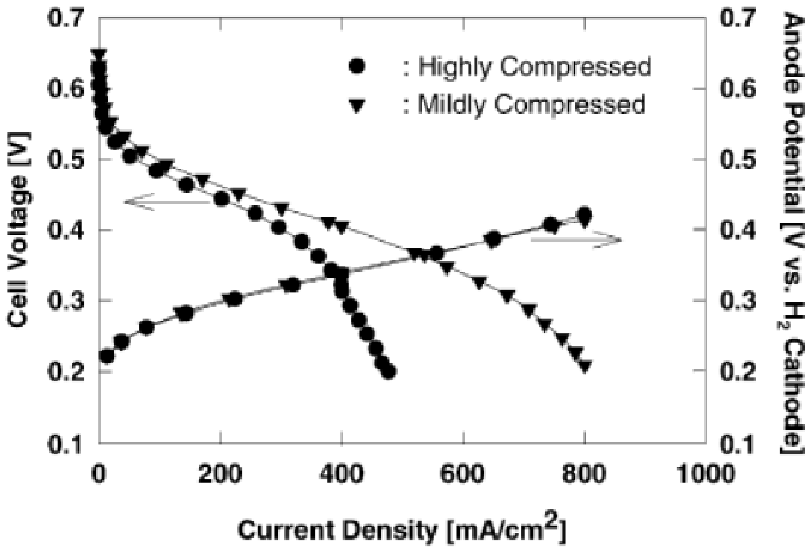


Figure 2: Effects of pressure on the cell [6]

The equation to calculate the voltage can be obtained from the Nernst equation:

$$E = E° + \frac{RT}{2F} \ln \left(\frac{\alpha \beta^{\frac{1}{2}}}{\delta} P^{\frac{1}{2}} \right)$$

$$E = E° + \frac{RT}{2F} \ln \left(\frac{\alpha \beta^{\frac{1}{2}}}{\delta} P^{\frac{1}{2}} \right) + \frac{RT}{4F} \ln P \qquad (1)$$

Where

R= Gas constant = 8.314 J/mol·K

F = Faraday constant = 96485 C / mol

T =Temperature in Kelvin = 25+273 = 298K

E^0 is the electromagnetic field (EMF), 1.229V at standard pressure and P is the pressure of the system. Note that the symbol of α, β and δ are the constant that depend on the molar masses and concentrations of hydrogen gas, H_2, oxygen gas, O_2 and water, H_2O. From the equation above, it shows that the fuel cell depends on the concentration and pressure of the hydrogen gas flow. If the partial pressure of O_2 and H_2O are unchanged and the H_2 partial pressure changes pressure change from the cathode to the anode, we can determine the above formula to be approximately as [6]:

$$\Delta V = \frac{RT}{2F} \ln\left(\frac{P_2}{P_1}\right) \tag{2}$$

Where

ΔV= Voltage drop

R= Gas constant = 8.314 J/mol·K

F = Faraday constant = 96485 C / mol

T =Temperature in Kelvin = 25+273 = 298K

P_2/P_1= Pressure change from the cathode to the anode

The voltage is produced from the electrochemical reaction in the fuel cell by splitting the hydrogen molecule to the positive ion hydrogen, H^+ and electrons, e^-. These electrons will flow from anode to cathode through the conductor wire to produce electricity to the load. There are many type of fuel cells available in the market such as Alkaline Fuel Cell (AFC), Molten Carbonate Fuel Cell and Direct Methanol Fuel Cells (DMFC) and Polymer Electrolyte Membrane Fuel Cell (PEMFC). Although all fuel cells are electrochemical energy conversion devices and operate on similar principle, each fuel cell type mentioned earlier has different operating characteristics, different materials of construction, different range of operating temperatures, and different applications [7 , 8].

2.2 Polymer Electrolyte Membrane Fuel Cell (PEMFC)

Polymer Electrolyte Membrane Fuel Cell (PEMFC) is also known as Proton Exchange Membrane Fuel Cell. In particular, among the available fuel cells, PEMFC fuel cells offer excellent features, such as compact structure, high power density, solid electrolyte, low-operating temperature (50^0C–100^0C), relatively fast start-up, low sensitivity to orientation, favourable power-to-weight ratio, long cell and stack life and low corrosion [9 , 10].

As one of the type of fuel cells, it produces electricity energy from the chemical reaction of the hydrogen gas in the cell. The structure of PEMFC is similar to the other fuel cells which have two electrodes coated with the platinum catalyst separated by a polymer electrolyte membrane (PEM) in the middle. The combination of the electrodes and the PEM is called as membrane electrode assembly (MEA).

The function of platinum catalyst is to split the hydrogen gas molecule into hydrogen ions and electrons. It is very stable and will not easily oxidized compare to the other noble metals such as nickel and silver. So, the output power of the PEMFC that uses the platinum catalyst is high due to its stability from oxidized. The chemical reaction that will occur at the anode and cathode electrode can be represented in the half reactions:

$$\text{Anode reaction: } 2H_2 \rightarrow 4H^+ + 4e^- \quad (3)$$

$$\text{Cathode reaction: } O_2 + 4e^- + 4H^+ \rightarrow 2H_2O \quad (4)$$

At the anode, the hydrogen molecule is split into the hydrogen ions and electrons. The PEM will allow the hydrogen ions to flow from the anode to the cathode while the electron will flow through the external wire to produced electrical power. The hydrogen ions will combine with the oxygen gas and the electrons at the cathode to produce water.The PEM only allows the hydrogen ion, H^+ to pass through it while preventing the electron conduction. It is made from the Nafion because of the effectiveness as a membrane. Nafion polymer has excellent chemical stability while at the same time allowing ion transport [11].

The process to split the hydrogen molecule is exothermic which produce heat. So, there is a limitation to the membrane performance because for Nafion the operating temperature is only from 50^0C -120^0C [8 , 9].

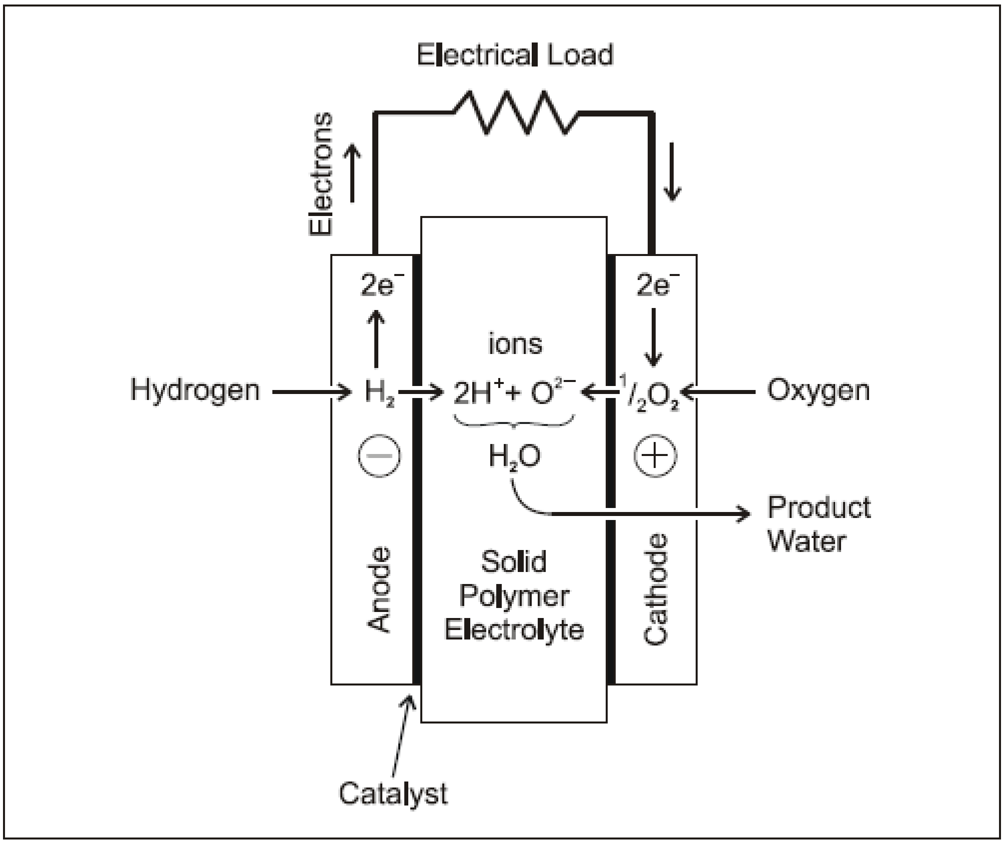


Figure 3: Internal reaction of PEMFC [1]

Advantages of PEMFC [1]

- PEMFC are the tolerant of carbon dioxide that can unscrubbed air as oxidant and reformate as fuel.
- Can operate in low temperature. This can provide quick start up and increase safety.
- Are compact and rugged.
- Simple mechanical design.
- The electrolytes are non corrosive.
- The material constructions are stable.
- The electrolytes are solid and dry.

Disadvantages of PEMFC [1]

- Expensive membrane
- Expensive platinum catalyst
- Can tolerate only a few ppm of total sulphur compounds
- Can only tolerate about 50 ppm carbon monoxide.

2.3 PEMFC Stack Efficiency

A PEMFC produces electical energy from the flow of the hydrogen gas through the MEA. The electrons produced from the chemical reaction will generate the current and voltage. By using only one stack of PEMFC , the voltage produced is very small. So, to achieve a higher voltage, many stack cells need to be connected in series just like battery series connection.

At zero current the voltage is the highest which is the open circuit voltage. Usually at the standard condition, the value for the hydrogen-oxygen couple is 1.23 V but under real conditions the open-circuit will settle at values slightly below 1 V. To achieve a high output power of fuel cell stack, it should be operated at high current densities. However, the current cannot be increased at will, as the power output will reach a maximum due to the voltage drop. After this maximum the power output will decrease with increasing current. Figure 5 shows the characteristics of the performance of PEMFC. Therefore, the max power of a PEMFC stack is most certanly depend on its operating parameters [12].

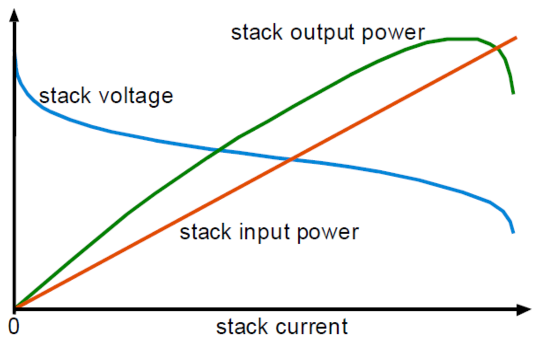


Figure 4: Stack voltage with input and output power [13]

The efficiency of a PEMFC can be defined as:

$$\eta = \frac{P_{OUT}}{P_{IN}} \tag{5}$$

$$\eta = \frac{V_{stack} \ x \ I_{stack}}{I_{stack} \ x \ N_C \ x \ 1.481} \tag{6}$$

where

V_{STACK}= Stack voltage

I_{STACK}= Stack current

N_C = Number of stack

From the equation above, the number of the stack current, i_{stack} is in the numerator and denominator, so the efficiency become a function of stack voltage only [13].

$$\eta = \frac{V_{stack}}{N_C \ x \ 1.481} \tag{7}$$

There are many operating parameters that affect the performance and efficiency of PEMFC but the most critical parameters are:

- Pressure feed air

Air is provided to the fuel cell cathode at low pressure using a blower. Besides, air compressor also can provide high air pressure. When the pressure feed gas is high thereby the cell operating pressure is high too. Higher cell operating pressure results in more even distribution of the local current density due to the high oxygen concentration at the catalyst layer [14]. Increasing the pressure of the air improves the kinetics of the electrochemical reactions and leads to higher power density and higher stack efficiency [9]. However, a higher air flow rate means a higher power consumption of the air compressor, which influences the net power available [15]. So, the required pressure need to be determined in order to optimizes the overall PEMFC performance for each current density.

- Humidity of air

The value of humidity in air of PEMFC is the most important thing to make sure the electrolyte not drying [16]. From the fuel cell reaction, the water will exist but it must be removed from the exhaust gas, stored, and pumped to a pressure suitable for the various operations [9]. A low air flow rate increases the humidity of the membrane, which decreases the electrical resistance and improves the performance of the fuel cell, while a high air flow rate increases the rate of water removal that causes drying of the membrane which increases the electrical resistance. However, a high air flow rate increases the availability of oxygen at the cathode membrane which improves the performance of the fuel cell [17 , 18]. With the high humidity, the efficiency of the PEMFC decreases possibly due to the fuel cell beginning to flood and the quantity of oxygen gas available in the cell also decreases [16].

2.4 Current Amplifier / Booster

According to book Microelectronic Circuit (5th edition) written by Adel S.Sedra and Kenneth C. Smith, the signal source for current amplifier is easily can be state and represented by its Norton equivalent because the input signal in current amplifier itself is essentially a current. The feedback network should sample the output current because of the output quantity that important is certainly a current. Therefore, it should be in a current form in order to mix in shunt with the source current. Thus, the current-mixing current-sampling topology is most suitable topology for the construction of current amplifier. This type of topology also known as shunt-series feedback because the input is connected in parallel / shunt and the output is connected in series. The result of this type of topology will come out with lower input resistance and higher output resistance, both desirable properties for a current amplifier and also can stabilizes the current gain. [2]

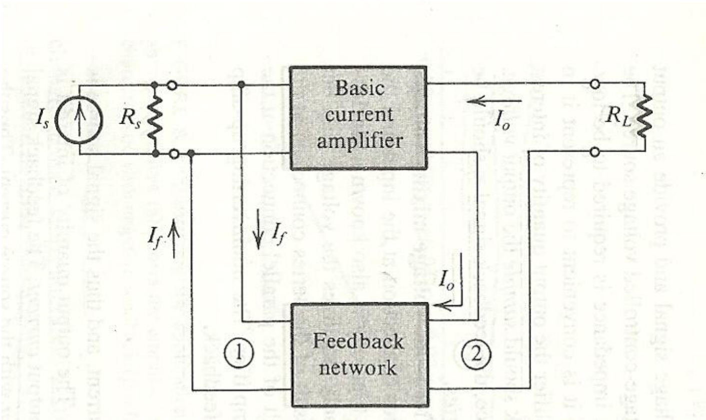


Figure 5: Current-mixing current-sampling [2]

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In order to achieve the goals of the project, researches have been done on a lot of resources including books, journals and internet. The important works need to be done during the FYP duration are:

1. Defining problem:

   The emission of the green house gas is increasing every day. Majority of people still depend on the fossil fuel as a main source of energy. All of this phenomena will affected to the global warming which is very dangerous for anything live on the Earth. So, this project will use the hydrogen gas and solar as the sources to produce electricity energy by using the PEMFC and solar panel.

2. Research and analysis:

   The understanding of the fuel cell concept is very important in this project since the prototype model need to be designed to convert the chemical reaction of the hydrogen into electricity. The solar panel chosen also need to be concern because each type of solar panel given different electricity output and efficiency. The research must be done correctly in order to get the high efficiency of the power supply. Besides, the criteria and specifications of the prototype model are constructed according to the size, performance, material, quality and the most important is the production of the green energy.

3. Results:

   From the prototype model design, the testing will be conducted to determine the performance of the PEMFC and solar panel to generate electrical energy to supply the any DC voltage load. The results will indicate whether the objective is achieved or not to produce electrical energy.

3.2 Project Activities / Workflow

The workflow need to be done during this FYP period is shown in Figure 6. The objective of having this project workflow is to ensure that the prototype model is designed according to the plan.

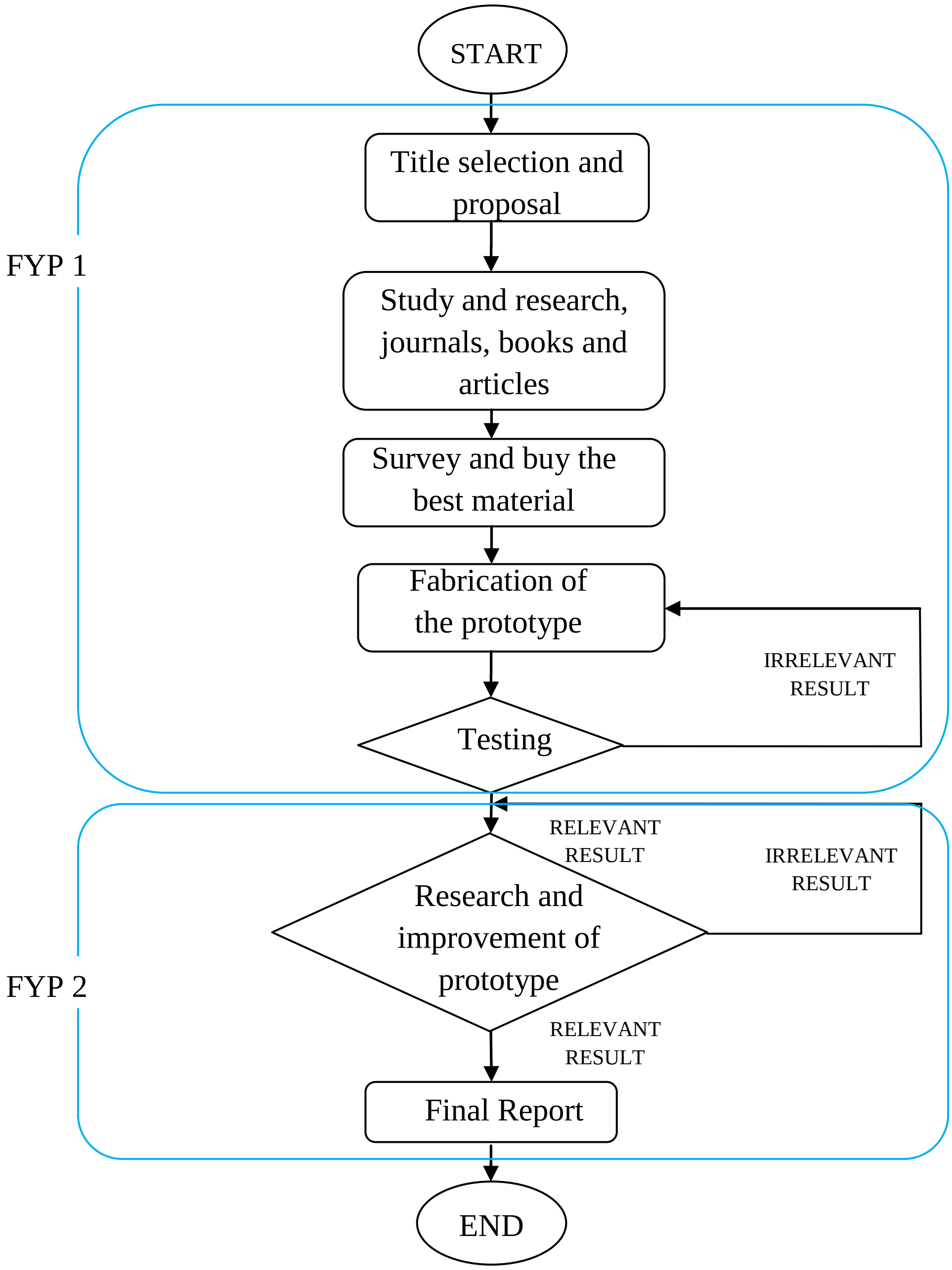


Figure 6: Project workflow

3.3 Key Milestone

In this project, there are several parts and material that are very crucial in order to ensure the success of this project. Hydrogen supply is the most needed material in this project. In the case of solar energy, data gathering must be taken at peak time of the day to get full capacity of electrical energy. Besides, the bigger challenge about this project is how we can increase the output voltage and output current to supply for the bigger applications.

3.4 Gantt Chart

Please refer to Appendix A & B

3.5 Tools and Equipments Required

3.5.1 Fuel cell unit

Fuel cell is like a generator but it uses hydrogen gas as a fuel to generate electricity. There are many type of fuel cell that can be used in this project such as Solid Oxide Fuel Cell (SOFC), Phosphoric Acid Fuel Cell (PAFC), Direct Methanol Fuel Cell (DMFC) and Proton Exchange Membrane Fuel Cell (PEMFC). All of these fuel cells use a different fuel to generate electrical energy. For example, DMFC uses methanol as a fuel while PEMFC uses hydrogen gas as a fuel. Both types of fuel cell can produce electricity but the PEMFC is more efficient compare to the DMFC. So, this project uses PEMFC to convert the chemical reaction energy to the electrical energy. The PEMFC is used in many fuel cell applications because of fast start-up and response times. In addition, the operating temperature is less than 100ºC, which allows rapid start-up [9] [10]. Nafion is used as a membrane which is very stable material. For other type of fuel cell the operating temperature can be up to 1000^0 C and above which is not convenient for this project. If we use the DMFC, the consumption of methanol arises because the boiling point of methanol is low which will easily vaporise. So, by using the PEMFC the consumption of hydrogen fuel is very efficient due to the lower kinetics of hydrogen oxidation. Besides that, the efficiency of the PEMFC is much better compare to the DMFC. According to the Figure 7 shown below, the power produced by PEMFC is higher than the DMFC which prove that the PEMFC is very efficient to be used in this project.

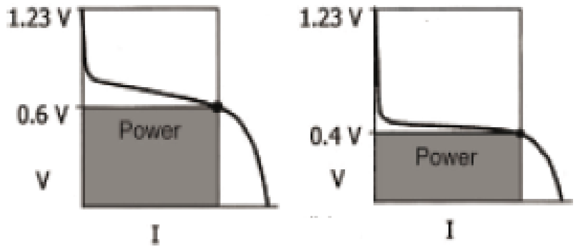


Figure 7: Performance differences of PEMFC and DMFC [6]

After done some researches and surveys, the best solution to use in this project is using the PEMFC. The specification of this PEMFC is just like below. The properties of the PEMFC are:

- Convert hydrogen gas directly into electricity
- The project is 4 stack cells, 3.6 V
- Hydrogen pressure 0.3 bar
- Solid state device with no moving parts

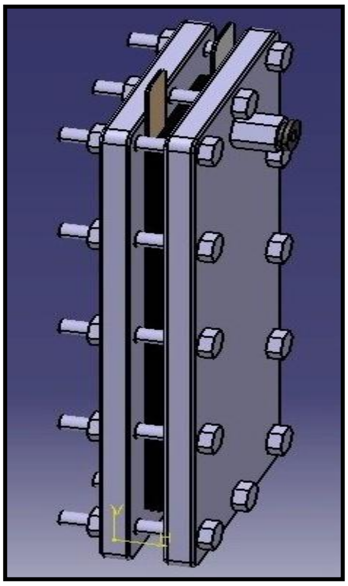


Figure 8: CAD design of PEMFC unit

3.5.2 Construct the portable power supply PEMFC

The PEMFC cannot operate without other main components such as gas storage tank, tube, cooling fan and wiring cable. All of these components will be assembled together to produce electrical energy. For the PEMFC unit construction, the combination of PEM, electrodes and platinum catalyst will form a stack of cells which is called MEA. In this project, we are using the open cathode PEMFC with four stack cells are combined together in series to produce the desired output 3.6 V as shown in CAD drawing design in Figure 9. The design surface area is 21.5 cm x 7 cm and the total thickness of MEA is 2 cm.

There will be a fitting hole at the anode electrode for the hydrogen gas inlet. The tube is connected to the fitting of the inlet to flow the hydrogen and from the storage tank to the PEMFC. For the output connection, two plates with 0.2 cm x 3.5 cm surface area of anode and cathode electrode will be connected with the two conductor wires for the positive and negative terminals. Figure 9 shows the CAD design of the PEMFC with the storage tank and terminal anode and cathode connectors.

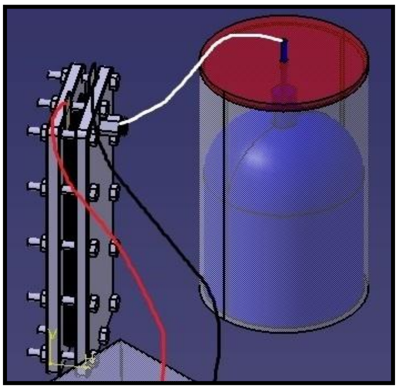


Figure 9: CAD design of PEMFC with storage tank

The cooling fan is not only used to reduce the temperature of the PEMFC but it also used to remove the water and feed the oxygen gas to the cell. The size of cooling fan depends on the size of the PEMFC. In this project, two units of 12 V cooling fan are used and it will be installed at the side of the cell. Figure 10 shows the cooling fans used in this project.

Figure 10: Cooling fans

Figure 11 shows the complete design of PEMFC after the fabrication process. So, the design of this fuel cell is complete and ready to be used to generate electricity.

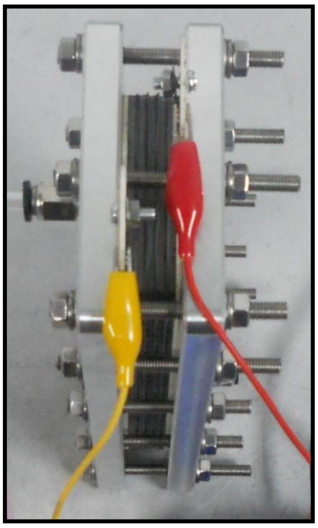


Figure 11: Real PEMFC unit

3.5.3 Solar Panel

The solar panel selection must be done correctly in order to achieve the high efficiency of the output. The solar panel type used is Mono-crystalline as it has the highest output efficiency among the other types of solar panel as refer to table 1.

Table 1 : Type of solar panel and the efficiency

Cell Type	**Typical efficiency (%)**
Monocrystalline Silicone	12-15
Polycrystalline Silicone	11-14
Thin film	7-10
Amorphous Silicon	6-8
Dye-synthesized Solar cell (DSSC)	5-8

The materials used for this solar panel are built in highest quality, high-transmission tempered glass with enhanced stiffness and impact resistance. It also has ultra reliable bypass diodes that prevent damage through overheating due to shaded or defective cells. The specifications of solar panel are shown in Table 2.

Table 2: Solar panel specifications

Peak power (Pmax)	10 W
Weight	1.7 kg
Maximum power Voltage (Vmax)	17.82 V
Maximum power Current (Imp)	0.57 A
Open circuit Voltage (Voc)	21.96 V
Short circuit Current (Isc)	0.63 A

3.5.4 Current Booster

In order to get the regulated output voltage, normally the output current 78xx series IC's can be maximum until 1 A. (in reality, it only can go up to 0.6 A). Volt regulators such as the LM712, and LM317 series and others sometimes need to provide a little bit more current then they actually can handle. If that is the case, this little circuit can help out. A power transistor such as the 2N3772 or similar can be used. The power transistor is used to boost the extra needed current above the maximum allowable current provided via the regulator. Current up to 1500mA (1.5amp) will flow through the regulator, anything above that makes the regulator conduct and adding the extra needed current to the output load. It is no problem stacking power transistors for even more current as shown in Figure 12. Both regulator and power transistor must be mounted on an adequate heatsink.

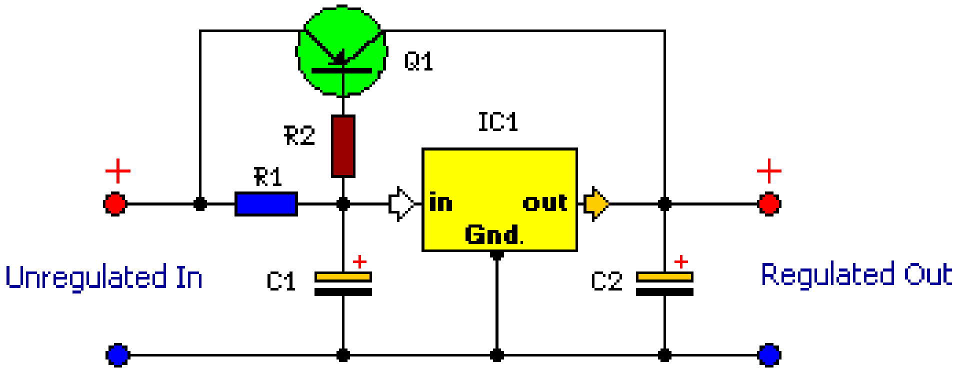


Figure 12: Current Booster circuit [3]

3.5.5 Voltage Booster

The voltage booster circuit is constructed using LM 2577 and LT 1073 which is a versatile micro power DC/DC converter that can easily be configured as a buck or boost converter. In this project, it is basically used to step up 1.5 V of voltage to 5 V of output and after that 5 V input to 12 V output. The schematic design of the voltage booster circuit used in this project is shown in Figure 13. In the steady-state analysis, the output filter capacitor is assumed to be very large to ensure a constant output voltage [4].

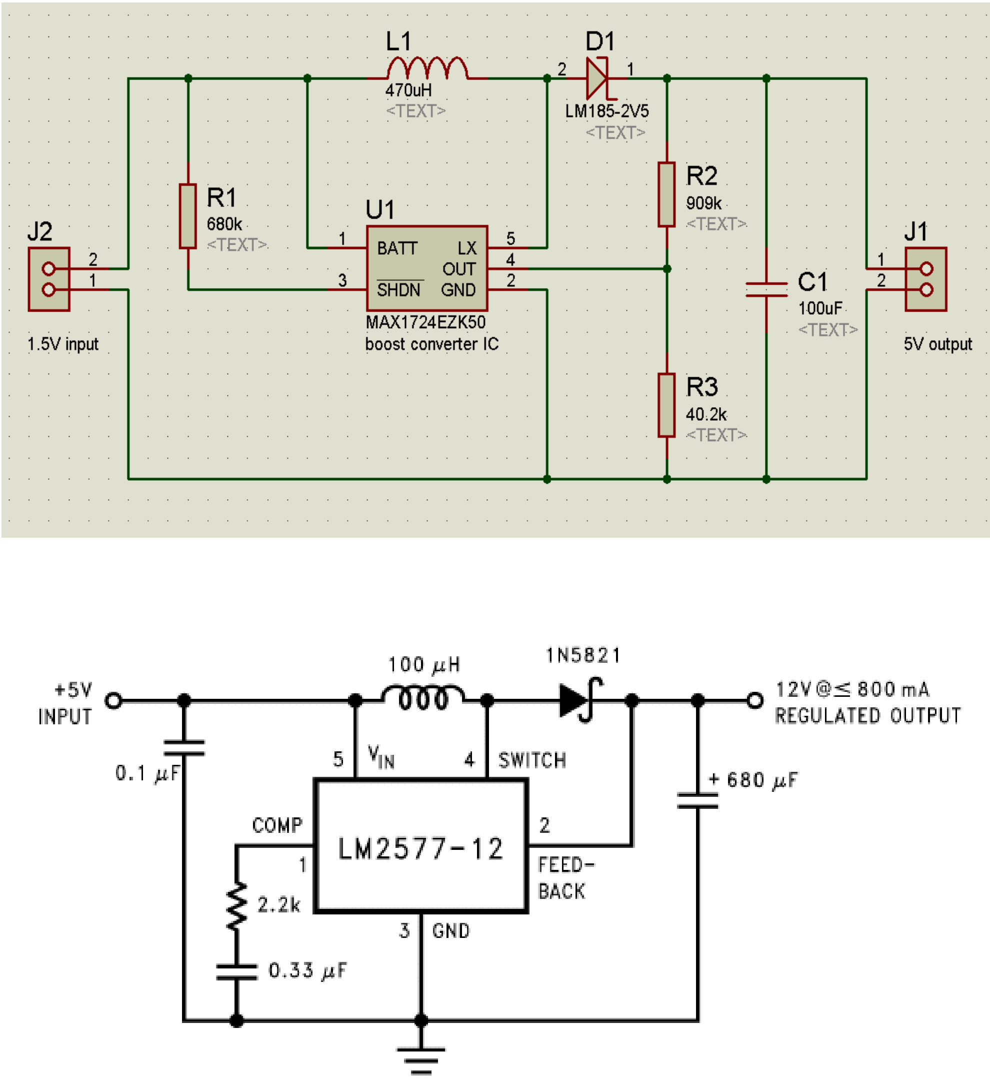


Figure 13: Voltage Booster circuit [4]

CHAPTER 4

RESULTS AND FINDINGS

The experiment was conducted to test and identify the operational of the circuit boosting system. In this project, the hybrid system is a combination of hydrogen and solar as the power sources. The experiment is tested using two solar panel mono-crystalline type producing output voltage 19 Vdc and 2 Vdc as an input and Polymer Electrolyte Membrane Fuel Cell (PEMFC) producing output voltage 3.2 Vdc as another input source. For the loads, this experiment is using 12 V Brush DC motor 4 poles and 12 Vdc bulb, as shown in Figure 14, 15 and 16 respectively.

There are two inputs inlet which is one of the inputs is for the input voltage below 5 Vdc and another input inlet is for voltage 5 Vdc and above. Based on experimental data recorded, the result of boosting system can be categorized as below:

<u>Voltage Booster</u>

1. Step-up voltage from 1.5 Vdc (min) to 5.7 Vdc (max).
2. Step-up voltage from 3.7 Vdc (min) to 15.26 Vdc (max).
3. Regulated voltage from 15.26 Vdc to 12 Vdc ++

<u>Current Booster</u>

1. Make loads functioning.
2. Provide high starting current above specification.
3. Maintaining supply current when loads are running.

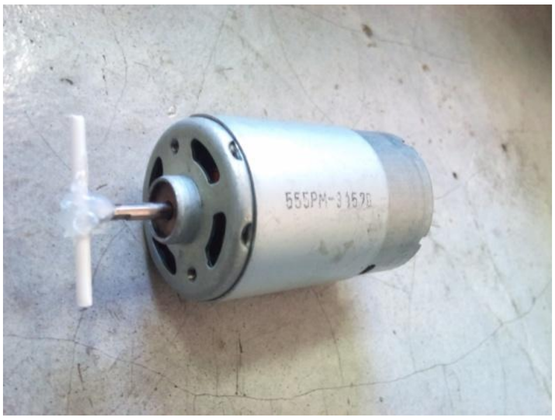


Figure 14: 12 Vdc Brushes motor

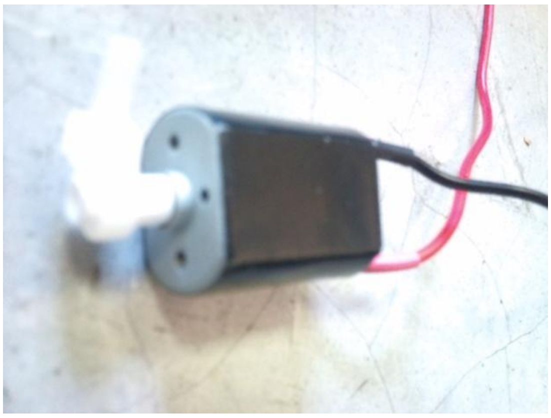


Figure 15: DC motor

Figure 16: 12 Vdc bulb

4.1 Full System Flow diagram

In this project, there are two input inlets which are input #1 for voltage below 5 Vdc and input #2 for voltage above 5 Vdc as shown in Figure 17. There are two sources are tested. Source #1 which is Hydrogen gas or known as PEMFC is generating 3.2 Vdc. Because of the low voltage produced, voltage booster is needed to increases the voltage up to 5 Vdc. Whereas source #2 is solar panel that is originally generate voltage up to 19.7 Vdc.

Since the system minimum requirement to operate is 5 V, after 5 Vdc achieved for source #1 then only voltage booster in the system is ready to use. The voltage booster in the system generates voltage from 5 Vdc to 15 Vdc. However, in current booster circuit, it has voltage regulator that is able to regulate the output voltage at 13 Vdc.

Output from source #2 which is solar panel already generated 19.7 Vdc were just passed through voltage booster in the system since the maximum requirement for the booster to operate is below 12 Vdc. So, the voltage will only be regulated to 13.4 Vdc at current booster circuit.

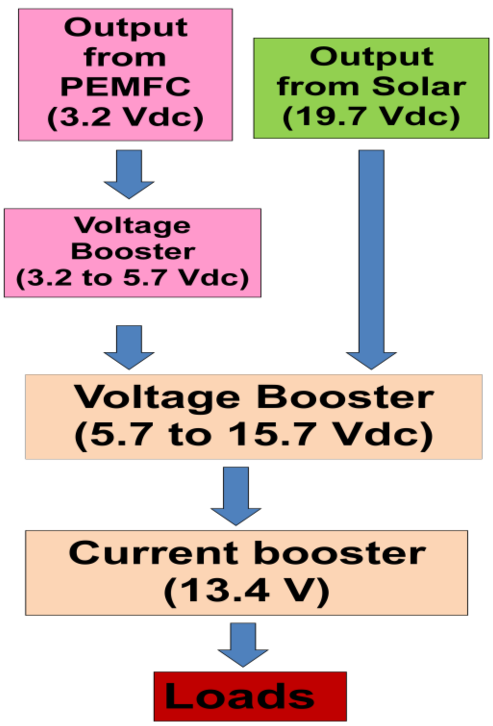


Figure 17: Flow diagram full system operation

4.2 Voltage booster 5 Vdc to 12 Vdc

The experiment has been conducted on breadboard for voltage booster of 12 Vdc. The output voltage can be adjusted by using different regulator value of regulator. In this project, a regulator type of LM2577-12 is used in order to produce 12 Vdc output voltage. The selection of output voltage is rely on the loads requirement. The output and circuit connection on breadboard is shown in Figure 18.

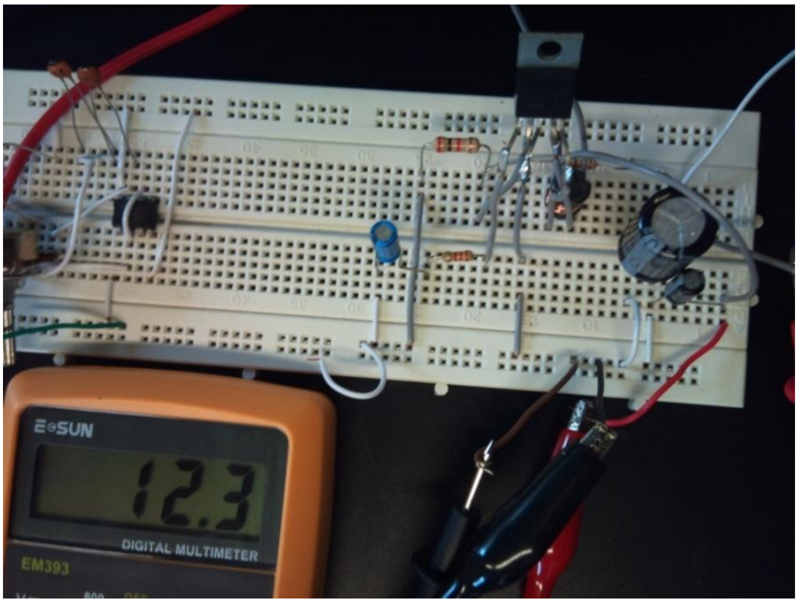


Figure 18: Voltage Booster (5 V – 12 V)

The components shown in Figure 18 have been chosen following the criteria for circuit boosting theory.

- INDUCTOR: Wire coil inductor 100 uH, 3.2 A and the DC parasitic resistance of the coil is 57 mΩ.
- INPUT CAPACITOR: In order to limit the equivalent series resistance (ESR) two electrolytic capacitors have been used in a parallel configuration. The capacitance of each capacitor is 0.1 uF and 0.33 uF respectively.
- OUTPUT CAPACITOR: To ensure a constant output voltage, capacitor with capacitance of 680 uF have been employed.

4.3 Simulation Test Current Booster Circuit

The experiment is conducted using MULTISM software. The circuit is supply with 12 Vdc with input current setting is 1 A. As the result, the current produce based on this simulation is 3.134 A. The simulation is conducted using different power transistor which is MJE 12058 instead of the original transistor which is TIP 2955 or 2N3772. We have to use this type of power transistor because TIP 2955 components does not exist in MULTISM master library. Hence, by using MJE 12058 provide the output because of its characteristic is almost similar to TIP 2955 or 2N3772. The simulation result is illustrated in Figure 19.

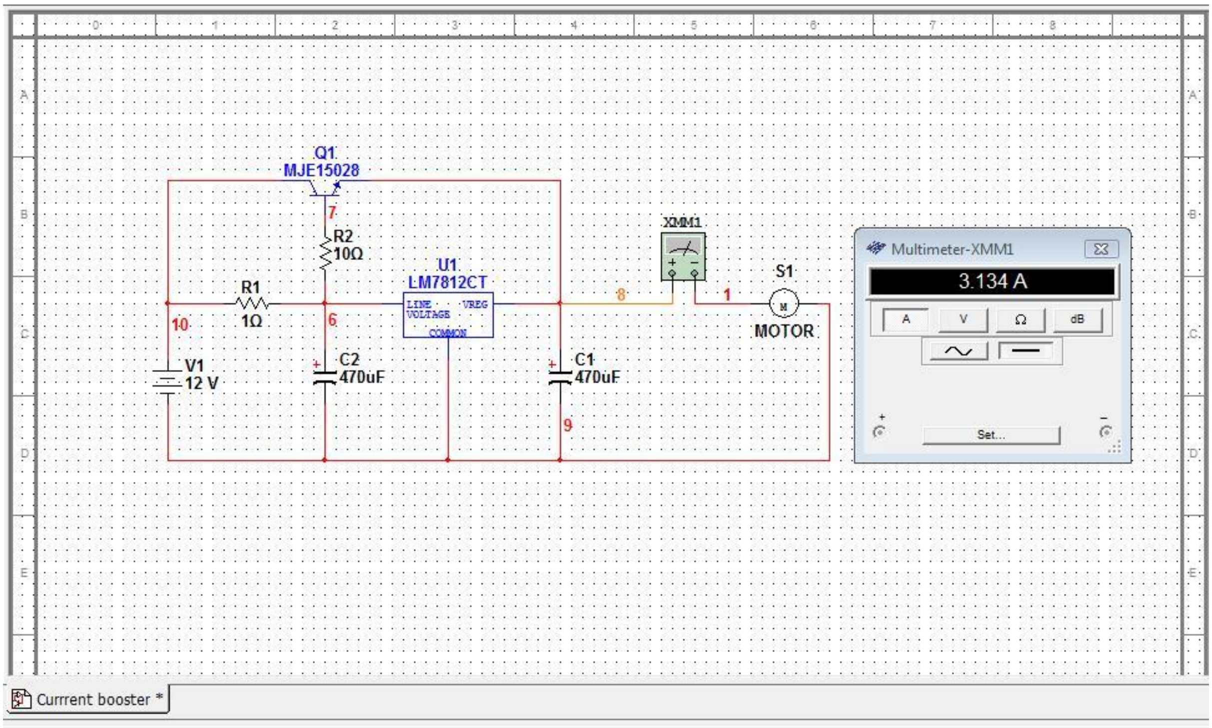


Figure 19: Current Booster using MULTISM

4.4 Open Circuit Test for PEMFC

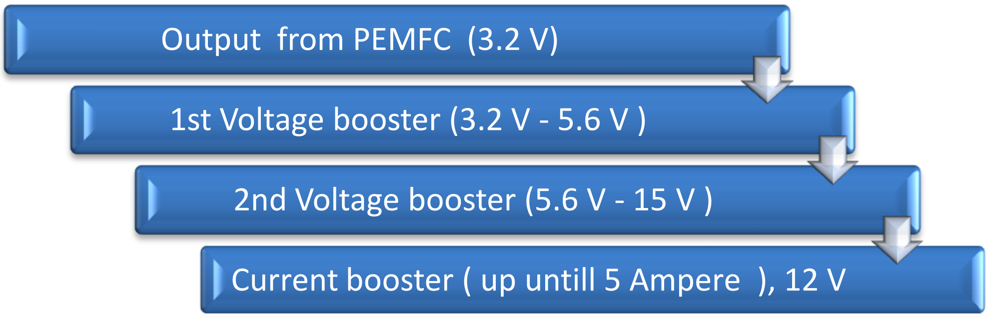
This experiment will test the PEMFC without supplying the hydrogen gas to the cell. Four stacks of cell is used and connected with series to produce more voltages. The result of this experiment is tabulated in Table 1. At this level, the more stack is connected in series, the larger is the output voltage can be produced. The maximum voltage produce after 4 stacks used is 3.6 Vdc. Therefore, 5V voltage booster must be used in order to supply to another voltage booster.

Table 3: PEMFC stacks connected in series experiment

No of stacks	Output Voltage (V)		
	1st reading	2nd reading	Average
1	0.902	0.902	0.902
2	1.801	1.799	1.800
3	2.698	2.697	2.698
4	3.596	3.597	3.597
Using voltage boost	5.6	5.6	5.6

4.5 Experimental Test using Polymer Electrolyte Membrane Fuel Cell (PEMFC)

The tests are using purified Hydrogen gas and directly connected to fuel cell using a hose. There are only 4 stacks in our fuel cell. So, any pressure coming from the hydrogen gas tank does not effect the output voltage produced by fuel cell which is 3.26 Vdc (max). Because of that, only small amount of Hydrogen is used which is ± 1 Bar to supply to fuel cell. Full operation of PEMFC is summarized in flow diagram below:



In order to prove the functioning of the system, the experiment is done step by step from 1st voltage booster until current booster circuit. Output from PEMFC which is 3.26 Vdc is connected directly to 1st voltage booster and step-up the voltage to 5.6 Vdc. Then, output from 1st voltage booster connected in series with 2nd voltage booster and gives the output of 15 Vdc. Lastly, the circuit booster also connected in series to give out the regulated voltage 12 Vdc and maintaining the current. Figure 20 illustrate the full system.

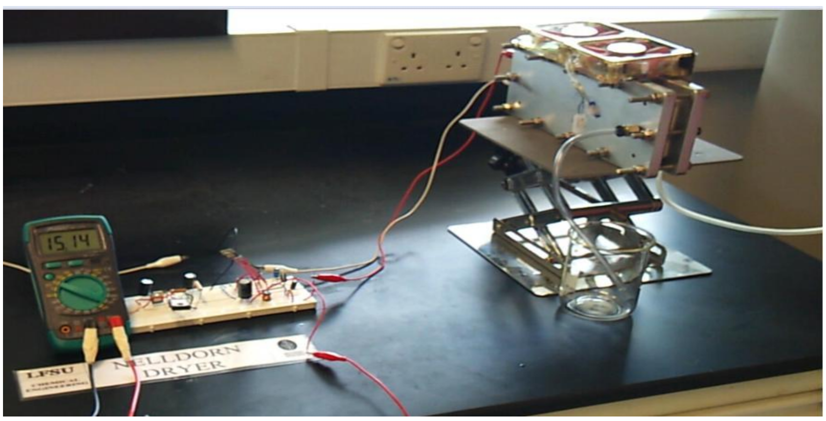


Figure 20: Polymer Electrolyte Membrane Fuel Cell (PEMFC)

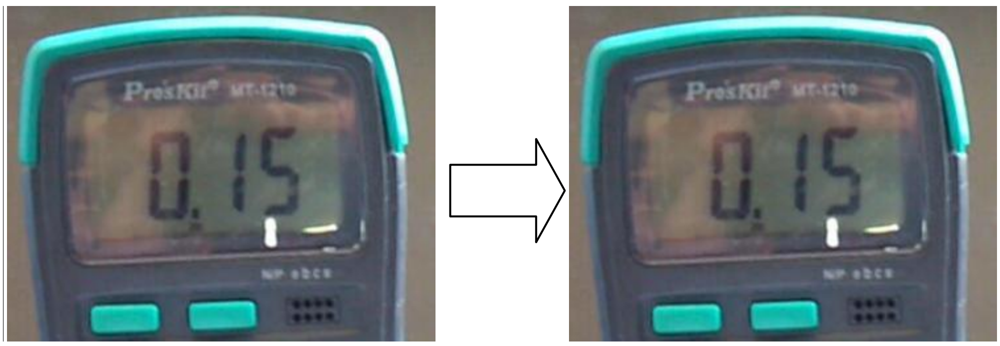
4.5.1 Direct connected solar panel with load (DC motor)

In this experiment, DC motor is directly connected to the output of PEMFC. The objective of this experiment is to test the ability of PEMFC to rotate the load. The result shows that the motor is working but in slow rotation. Table 1 shown the minimum voltage and current required to rotate the motor. This is because the motor itself have low starting torque. In order the motor to give its maximum capacity, the supply voltage and current must be 12 Vdc and at least 0.18 A.

Table 4: Current drawn by motor from PEMFC

Supply Voltage , V_{dc}	Current Draw, A
3.26	0.15

The important part of this project is actually to boost up the voltage and current and also to observe the starting current phenomena to start the motor. There should not be a problem to start the motor when directly connected with PEMFC output. So, we can only observe the starting current phenomena and its behaviours. For this particular experiment, Figure 21 show the starting current recorded was 0.15 A before it settle down to 0.15 A. As we can see, what ever the value of current gives by the supply will drawn by the motor.



Starting Current Current drawn

Figure 21: Starting current & Current Drawn from Solar Panel

4.5.2 Full System operation (PEMFC, voltage booster, current booster and load)

Finally, the experiment is conducted by applying full system of this project to identify feasibility of this renewable energy system. The output of PEMFC is connected in series to voltage booster to boost up the voltage. Then the output from voltage booster is connected in series with current booster circuit before connect it to the motor. The output voltage of system which is 13.38 Vdc is shown in Figure 22.

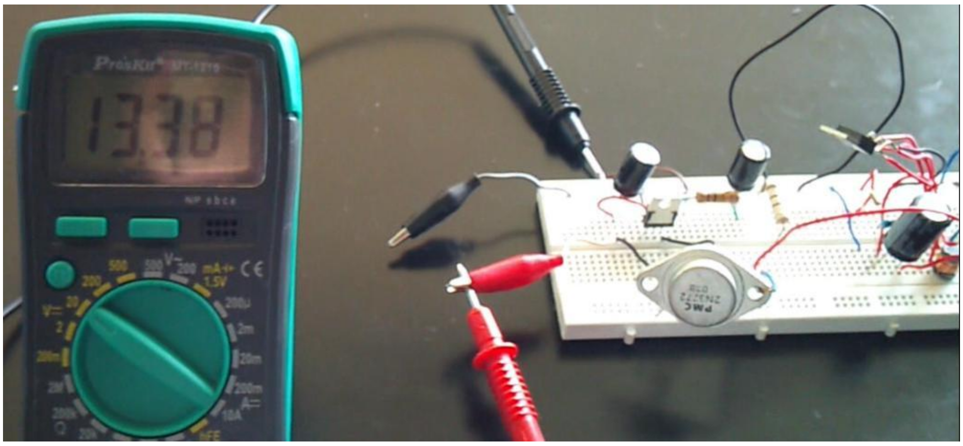


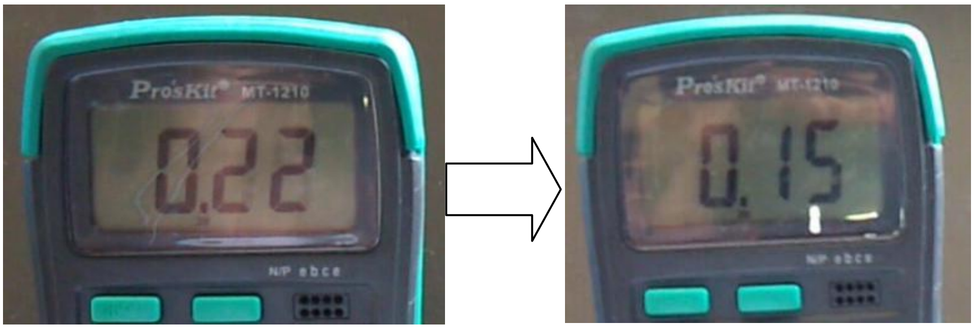
Figure 22: Output voltage of full system

From section 4.5.1, the current produced by the PEMFC is ±0.15 A and it is enough to start the motor with slow speed. By applying the full system, the output voltage produce is 13.38 Vdc and when the motor is connected to the system the motor is rotating faster than before and the current drawn by the load is still same which is 0.15 A as shown in Table 2. Based on the result, it shown that the PEMFC only supplying current not more than 0.15 A.

Table 5: Current drawn by motor through full circuit system

Supply Voltage , V_{dc}	Current Draw, A
13.38	0.15

On the other hand, the starting current for the full system is 0.22 A as shown in Figure 23. Therefore, we can said that this system are very useful and practical for the application that required high starting current especially when there are several load connected together.



Starting Current   Current drawn

Figure 23: Starting current & Current Drawn from full system

4.6 Experimental Test using 19 Vdc Solar Panel

The full testing on solar panel has been worked on and the finding is successful. Data recorded process has been implemented in the afternoon (2 pm- 3 pm). The full system solar shown in Figure 24 below:

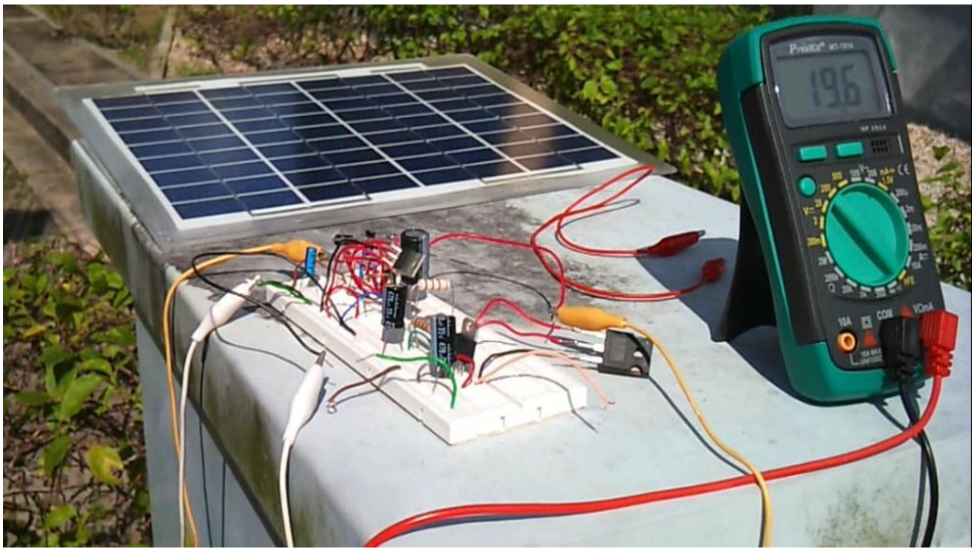
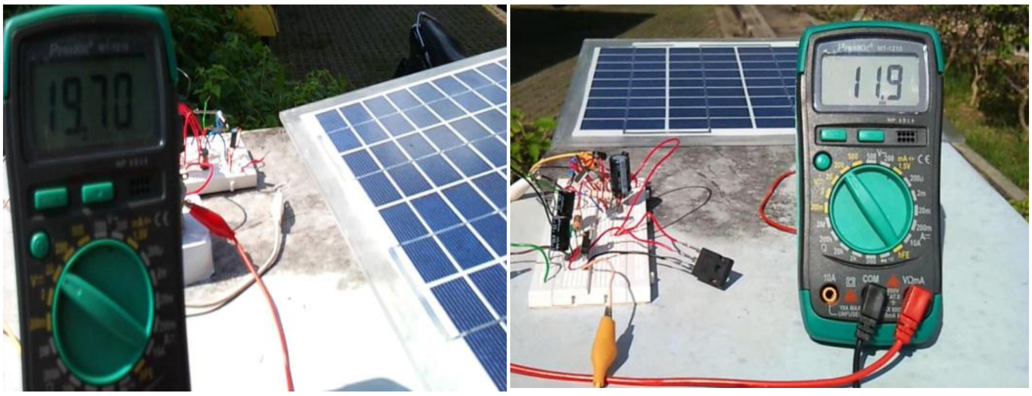


Figure 24: Solar System

One of the main objectives for this project is to design the hybrid system for alternative energy and one of the sources is solar energy. The solar panel itself produce 19.7 Vdc output voltage during the peak time in the afternoon (2 pm-3 pm) but the system is design to regulate at 12 Vdc for its output voltage as shown in Figure 25.



Output voltage of solar panel Output voltage of full system

Figure 25: Output Voltage from solar panel & circuit system

The experiment is tested by using brushed DC motor, 4 poles, 12 V supply as a load. By using laboratory power supply, the typical (default) current drawn for this motor referred to Table 4:

Table 6: Typical (default) current drawn by DC motor

Supply Voltage , V_{dc}	Current Draw, A
12.6	0.18
19.7	0.23

The experiment testing is taking part by part starting from data gathering directly from solar panel and through the circuit system.

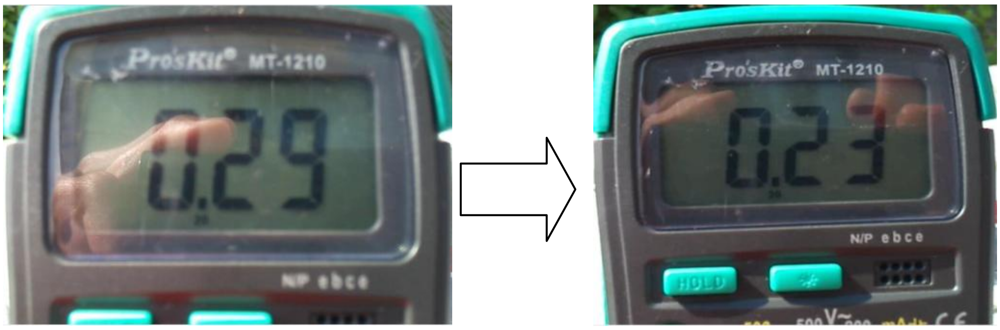
4.6.1 *Direct connected solar panel with load (DC motor)*

First of all, the experiment is done by directly connected the DC motor with the solar panel in order to measure the value of output current drawn by the motor. Note that the supply voltage directly from solar panel is 19.7 V_{dc}. The result recorded same as default value which is 0.23 A.

Table 7: Current drawn by motor from Solar panel

Supply Voltage , V_{dc}	Current Draw, A
19.7	0.23

The important part of this project is to observe the starting current phenomena to start the motor. In order for the motor to work, the supply current must be at least 0.18 A for 12 V supply voltage. For this experiment, Figure 26 shows the starting current recorded was 0.29 A before it remain at 0.23 A.



Starting Current

Current drawn

Figure 26: Starting current & Current Drawn from Solar Panel

4.6.2 Half System operation (Solar panel, voltage booster and load)

After that, the experiment is continued by applying the voltage booster circuit before come to the load. Pay attention that the voltage booster circuit will only operate when the supply voltage is below the output required which is 12 Vdc. Because of the supply voltage from the solar panel is 19.7 Vdc, the circuit only let the voltage passing through without any voltage drop as shown in Figure 27. Then, the output voltage from the voltage booster is equal with the output voltage with solar panel. As a result, Figure 28 shows the starting current and current drawn from the motor is same with before.

Figure 27: Output Voltage from voltage booster

Table 8: Current drawn by motor through voltage booster

Supply Voltage , V_{dc}	Current Draw, A
19.7	0.23

Starting Current

Current drawn

Figure 28: Starting current & Current Drawn from Half system

4.6.3 Full System operation (Solar panel, voltage booster, current booster and load)

Finally, the experiment is conducted by applying full system of this project to identify feasibility of this alternative energy system. The output of solar panel is connected in series to voltage booster to boost up the voltage (if needed) and then output from voltage booster is also connected in series with current booster circuit before connect it to the motor.

The output voltage of system is not similar with the solar panel output voltage because the voltage is regulated fixed to 12 Vdc as shown in Figure 29. Even though the solar panel gives the output of 19 Vdc, the system will regulated the output voltage to Vdc in order to supply the motor that have the voltage rating which is 12 V.

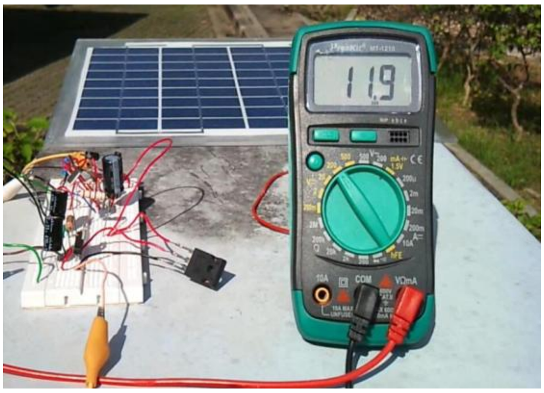


Figure 29: Output voltage of full system

The beauty of this system is that it will provide high starting current for the load. Starting current is very subjective matter. This phenomena also called rush current phenomena. Some people said that this phenomenon is not good for the loads because the high starting current will cause damage to the loads if it is not controlled and also can cause tripping especially for three phase system in industry. So, the relay setting must not be too sensitive otherwise the circuit breaker will always trip every time the load is applied especially when the motor start.

On the other hand, high starting current is very useful when there is a lot of loads are start together and connected in series. For instance, if system containing several of load (motor) and the starting current only sufficient for one load, the rest of the load cannot be started because there is not enough current to start them. In order to operate, the loads need high starting current. Hence, motor or loads that have low torque but high starting current really need this phenomenon in order to operate. For this system testing, the data was recorded as shown in Table 7:

Table 9: Current drawn by motor through full circuit system

Supply Voltage , V_{dc}	Current Draw, A
11.9	0.18

Starting Current

Current drawn

Figure 30: Starting current & Current Drawn from full system

From the result shown in Figure 30, the boosting system is practically provided good starting current up until 5 times from its current that supposed to drawn. Therefore, we can said that this system are very useful and practically for the application that required high starting current especially the loads related to motor applications.

4.7 Experimental Test using Laboratory Power Supply

The purpose of this experiment is to prove and identify the other functions of the boosting circuit of this Renewable Energy system. After done doing the test on PEMFC and solar panel, the experiment already proved that the boosting circuit system can boost up the voltage as low as 2 Vdc to 15 Vdc (max). It is also shown that the circuit system can provided more current from its rating in starting up process. In this experiment, there are two more functions of the system need to be identify which are:

1. Maintaining the supply current
2. Several loads testing

4.7.1 Maintaining the supply current

The experiment is conducted by using the laboratory power supply as shown in Figure 31. The supply voltage and current can be control depending on the output requirement. This experiment is to prove that the supply current can be maintain even load is applied and in this case which is DC Brushes motor.

Figure 31: Laboratory power supply

This test is done by direct connecting the load with power supply. The input voltage and current is varies. The data gather from this experiment is shown in Table 8.

Table 10: Current drawn by motor direct from power supply

Input Voltage (V)	Input Current (A)	Current Drop form input (A)	Output Current (A)	Output Voltage (V)
5	0.20	0.18	0.16	4.81
	0.25	0.18	0.16	
	0.30	0.18	0.16	
	0.35	0.18	0.16	
6	0.20	0.18	0.16	5.82
	0.25	0.18	0.16	
	0.30	0.18	0.16	
	0.35	0.18	0.16	
7	0.20	0.18	0.16	6.83
	0.25	0.18	0.16	
	0.30	0.18	0.16	
	0.35	0.18	0.16	
8	0.20	0.18	0.16	7.79
	0.25	0.18	0.16	
	0.30	0.18	0.16	
	0.35	0.18	0.16	
9	0.20	0.18	0.16	8.76
	0.25	0.18	0.16	
	0.30	0.18	0.16	
	0.35	0.18	0.16	

As we can see, the experiment is conducted from 5 Vdc to 9 Vdc and every input voltage has different value of current tested. Refer to data taken we can see that when the load is applied, there was a slightly decrease or current drop from the input supply. The supply current will drop to 0.18 A in every voltage tested. This happen because the internal designs of the motor itself that contain coil that related to force, magnetic field and etc. Refer to formula $F = Bil$, motor will need current in order to works. In this case, it will draw as many of current from the supply for it to works. That does tell us what actually happen why the supply current is drop when motor is connected.

Then, the experiment continues by connecting the boosting circuit system to the power supply. The data gather from this experiment is shown in Table 9.

Table 11: Current drawn by motor through full circuit system

Input Voltage (V)	Input Current (A)	Current Drop form input (A)	Output Current (A)	Output Voltage (V)
3	0.15	0.15	0.13	0.97
	0.20	0.20	0.13	2.27
	0.25	0.25	0.13	2.92
	0.30	0.30	0.13	3.25
5	0.20	0.20	0.14	1.96
	0.25	0.25	0.14	2.69
	0.30	0.30	0.14	3.26
	0.35	0.35	0.14	3.83
6	0.20	0.20	0.14	1.96
	0.25	0.25	0.14	2.69
	0.30	0.30	0.14	3.27
	0.35	0.35	0.14	3.88
7	0.20	0.20	0.14	1.99
	0.25	0.25	0.14	2.70
	0.30	0.30	0.14	3.27
	0.35	0.35	0.14	3.89
8	0.20	0.20	0.14	1.96
	0.25	0.25	0.14	2.71
	0.30	0.30	0.14	3.30
	0.35	0.35	0.14	3.93
9	0.20	0.20	0.14	2.02
	0.25	0.25	0.14	2.71
	0.30	0.30	0.14	3.31
	0.35	0.35	0.14	3.94

Based on data taken, we can compare the result with the result before which is very interesting result. Any supply current given to the load, there are no current drop in the supply and the system can maintain the supply current even the motor is running. Also, even the supply voltage is 3 Vdc and the supply current is 0.15 A, the motor still functioning. This phenomena is very useful when more loads are connected and for sure the loads will works because of there is enough current from the supply. Even though this system can maintain the supply current, there are voltage drop in the output because of internal resistance exist in the circuit. The problem solutions maybe can be done in the future development for this project.

4.7.2 Several loads testing

The entire tests have shown the functions and advantages for the boosting circuit of this Renewable Energy system. What will happen when there are several loads tested. This experiment will show and prove when there are several connected the loads still can functioning even in small amount of supply voltage and current. The experiment is conducted by using laboratory power supply and shown in Figure 32 below:

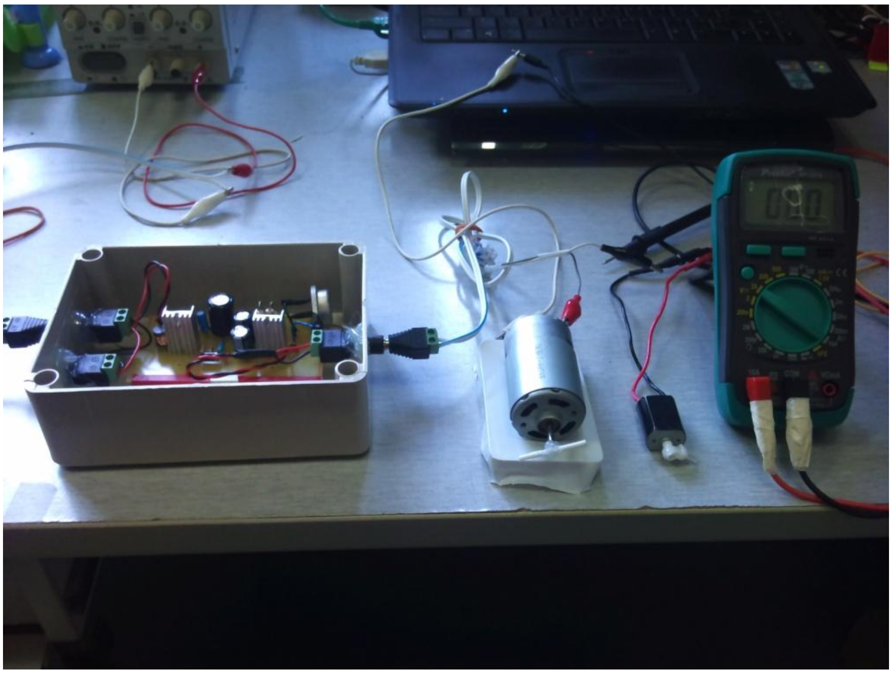


Figure 32: Two motor connected in series

From the past experiment, we know that this system will provide voltage boost-up until 15 Vdc (max), high starting current and maintaining supply current. With all those advantages combination, now we can operates several loads which is two DC motor connected together in series.

The result is shown in table 10 and 11 respectively:

Table 12: Two motors connected directly to power supply

Input Voltage (V)	Input Current (A)	Output Current (A)	Motor #1	Motor #2
3	0.20	-	OFF	OFF
	0.25	0.15	ON	OFF
	0.30	0.15	ON	OFF
5	0.20	-	OFF	OFF
	0.25	0.16	ON	OFF
	0.30	0.16	ON	OFF
6	0.20	-	OFF	OFF
	0.25	0.16	ON	OFF
	0.30	0.16	ON	OFF
7	0.20	-	OFF	OFF
	0.25	0.17	ON	OFF
	0.30	0.17	ON	OFF

Table 13: Two motors connected through the boosting system

Input Voltage (V)	Input Current (A)	Output Current (A)	Motor #1	Motor #2
3	0.20	0.14	ON	ON
	0.25	0.14	ON	ON
	0.30	0.15	ON	ON
5	0.20	0.14	ON	ON
	0.25	0.14	ON	ON
	0.30	0.15	ON	ON
6	0.20	0.14	ON	ON
	0.25	0.14	ON	ON
	0.30	0.15	ON	ON
7	0.20	0.14	ON	ON
	0.25	0.15	ON	ON
	0.30	0.15	ON	ON

Refer to Table 10 & 11, we can see the advantages when we connected the loads through the boosting system. Even though we supply only 3 Vdc, 0.2 A, both motor still can function. By connecting directly from power supply, we can observe that only supply current above 0.25 A will turn on motor #1 and motor #2 cannot works in all condition due to insufficient supply current because its already drawn a lot by motor #1. Unlike when boosting system is applied, in all condition both motor will turn ON.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Recommendation

Although the experiment was successfully done, there a few things need to be added in order to increase the efficiency of this project in future. The project still needs to be improved to make sure its feasibility and durability can be guaranteed.

1. Output voltage drop

   The output voltage produced from the system constantly follows the theory part when it is generated voltage up until 15 Vdc. The problem occur when the loads is connected. The output voltage dropped until 3 Vdc and remains around that value but does not effect the output current. This situation happens when there is a lot of resistance and reactance cause by resistors, inductors and other components in the circuit. Deep study must be done regarding the voltage and current behaviour in the system and it must be taken seriously for the better performance in the future.

2. Hydrogen gas input regulator

   Other than that, for future development in this technology, the studies of Hydrogen inlet control to PEMFC also need to be reviewed. The hydrogen gas inlet must be control using gas regulator in order to avoid losses since the hydrogen is quite expensive. More than that, its also effecting the performance of PEMFC if the ratio comes in and out is not suitable with load and demand.

5.2 Conclusion

In conclusion, after several weeks of hard works and lot of researches to complete this project, all objectives are achieved which are design, fabricate and construct the voltage & current booster circuit in order to amplify output power and design the hybrid and portable prototype renewable energy system model using the PEMFC and solar.

As a result, PEMFC is the best green technologies that can be applied in our daily use. There are lot of advantages that PEMFC in order to improve human life. This type of alternative energy can be categorized as environmental friendly because this technology brings no harm to green house effect and ozone layer. As a result from the experiments done, the expecting output data from the theory is majority proven. To get stable output voltage up until 12 Vdc with sufficient current is not an easy works. There are a lot of combination uses of electrical and electronic parts in order to run this technology.

In addition, solar panel that connects in parallel with PEMFC in order to get better output. The combination of these green technology applications can provide the better future in energy industry. Since they are clean and environmental friendly, they are most suitable method to replace the fuel energy consumption and make this world better for living for our future generation.

Hence, the development of boosting system for this renewable energy has shown positive cultivation. The theory of current boosting has been proved with the experimental result by using solar panel and PEMFC where it is provide high starting current for the motor as a load. Besides, two motor connected also can start rotating even with small amount of input voltage and current.

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APPENDICES

APPENDIX A

GANTT CHART FYP 1

PROJECT ACTIVITIES	WEEK													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Select the topics from FYP lists														
Confirmation of the topic														
Study on literature review of the topic														
Work on Preliminary Report														
Material research and design														
Methodology analysis														
Work on Project Defence and Progress Evaluation														
Fabrication of PEMFC														
Finalization of PEMFC model														
Work on Final Report														

APPENDIX B

GANTT CHART FYP 2

PROJECT ACTIVITIES	**WEEK**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Testing (air pressure and humidity effects)	■	■	■	■											
Hardware synchronization			■	■	■	■									
Completion of application model						■	■	■	■	■	■	■			
Submission of progress report								■							
Submission of draft report													■		
Submission of dissertation (soft copy)														■	
Submission of technical paper														■	
Oral presentation (Viva)															■
Submission of final report (hard bound)															■

APPENDIX C

LM 2577

National Semiconductor

June 1999

LM1577/LM2577 Series
SIMPLE SWITCHER® Step-Up Voltage Regulator

General Description

The LM1577/LM2577 are monolithic integrated circuits that provide all of the power and control functions for step-up (boost), flyback, and forward converter switching regulators. The device is available in three different output voltage versions: 12V, 15V, and adjustable.

Requiring a minimum number of external components, these regulators are cost effective, and simple to use. Listed in this data sheet are a family of standard inductors and flyback transformers designed to work with these switching regulators.

Included on the chip is a 3.0A NPN switch and its associated protection circuitry, consisting of current and thermal limiting, and undervoltage lockout. Other features include a 52 kHz fixed-frequency oscillator that requires no external components, a soft start mode to reduce in-rush current during start-up, and current mode control for improved rejection of input voltage and output load transients.

Features

- Requires few external components
- NPN output switches 3.0A, can stand off 65V
- Wide input voltage range: 3.5V to 40V
- Current-mode operation for improved transient response, line regulation, and current limit
- 52 kHz internal oscillator
- Soft-start function reduces in-rush current during start-up
- Output switch protected by current limit, under-voltage lockout, and thermal shutdown

Typical Applications

- Simple boost regulator
- Flyback and forward regulators
- Multiple-output regulator

Ordering Information

Temperature Range	Package Type	Output Voltage 12V	15V	ADJ	NSC Package Drawing	Package
$-40°C \le T_A \le +125°C$	24-Pin Surface Mount	LM2577M-12	LM2577M-15	LM2577M-ADJ	M24B	SO
	16-Pin Molded DIP	LM2577N-12	LM2577N-15	LM2577N-ADJ	N16A	N
	5-Lead Surface Mount	LM2577S-12	LM2577S-15	LM2577S-ADJ	TS5B	TO-263
	5-Straight Leads	LM2577T-12	LM2577T-15	LM2577T-ADJ	T05A	TO-220
	5-Bent Staggered Leads	LM2577T-12 Flow LB03	LM2577T-15 Flow LB03	LM2577T-ADJ Flow LB03	T05D	TO-220
$-55°C \le T_A \le +150°C$	4-Pin TO-3	LM1577K-12/883	LM1577K-15/883	LM1577K-ADJ/883	K04A	TO-3

SIMPLE SWITCHER® is a registered trademark of National Semiconductor Corporation.

 www.national.com

LM1577/LM2577 Series SIMPLE SWITCHER Step-Up Voltage Regulator

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	45V
Output Switch Voltage	65V
Output Switch Current (Note 2)	6.0A
Power Dissipation	Internally Limited
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C
Maximum Junction Temperature	150°C
Minimum ESD Rating ($C = 100$ pF, $R = 1.5$ kΩ)	2 kV

Operating Ratings

Supply Voltage	$3.5V \le V_{IN} \le 40V$
Output Switch Voltage	$0V \le V_{SWITCH} \le 60V$
Output Switch Current	$I_{SWITCH} \le 3.0A$
Junction Temperature Range	
LM1577	$-55°C \le T_J \le +150°C$
LM2577	$-40°C \le T_J \le +125°C$

Electrical Characteristics — LM1577-12, LM2577-12

Specifications with standard type face are for $T_J = 25°C$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5V$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-12 Limit (Notes 3, 4)	LM2577-12 Limit (Note 5)	Units (Limits)
SYSTEM PARAMETERS Circuit of *Figure 1* (Note 6)						
V_{OUT}	Output Voltage	$V_{IN} = 5V$ to $10V$ $I_{LOAD} = 100$ mA to 800 mA (Note 3)	12.0	11.60/**11.40** 12.40/**12.60**	11.60/**11.40** 12.40/**12.60**	V V(min) V(max)
$\frac{\Delta V_{OUT}}{\Delta V_{IN}}$	Line Regulation	$V_{IN} = 3.5V$ to $10V$ $I_{LOAD} = 300$ mA	20	50/**100**	50/**100**	mV mV(max)
$\frac{\Delta V_{OUT}}{\Delta_{LOAD}}$	Load Regulation	$V_{IN} = 5V$ $I_{LOAD} = 100$ mA to 800 mA	20	50/**100**	50/**100**	mV mV(max)
η	Efficiency	$V_{IN} = 5V$, $I_{LOAD} = 800$ mA	80			%
DEVICE PARAMETERS						
I_S	Input Supply Current	$V_{FEEDBACK} = 14V$ (Switch Off)	7.5	10.0/**14.0**	10.0/**14.0**	mA mA(max)
		$I_{SWITCH} = 2.0A$ $V_{COMP} = 2.0V$ (Max Duty Cycle)	25	50/**85**	50/**85**	mA mA(max)
V_{UV}	Input Supply Undervoltage Lockout	$I_{SWITCH} = 100$ mA	2.90	2.70/**2.65** 3.10/**3.15**	2.70/**2.65** 3.10/**3.15**	V V(min) V(max)
f_O	Oscillator Frequency	Measured at Switch Pin $I_{SWITCH} = 100$ mA	52	48/**42** 56/**62**	48/**42** 56/**62**	kHz kHz(min) kHz(max)
V_{REF}	Output Reference Voltage	Measured at Feedback Pin $V_{IN} = 3.5V$ to $40V$ $V_{COMP} = 1.0V$	12	11.76/**11.64** 12.24/**12.36**	11.76/**11.64** 12.24/**12.36**	V V(min) V(max)
$\frac{\Delta V_{REF}}{\Delta V_{IN}}$	Output Reference Voltage Line Regulator	$V_{IN} = 3.5V$ to $40V$	7			mV
R_{FB}	Feedback Pin Input Resistance		9.7			kΩ
G_M	Error Amp Transconductance	$I_{COMP} = -30$ μA to $+30$ μA $V_{COMP} = 1.0V$	370	225/**145** 515/**615**	225/**145** 515/**615**	μmho μmho(min) μmho(max)
A_{VOL}	Error Amp Voltage Gain	$V_{COMP} = 1.1V$ to $1.9V$ $R_{COMP} = 1.0$ MΩ (Note 7)	80	50/**25**	50/**25**	V/V V/V(min)

TIP 2955

TIP2955
TIP3055

COMPLEMENTARY SILICON POWER TRANSISTORS

- STMicroelectronics PREFERRED SALESTYPES
- COMPLEMENTARY PNP - NPN DEVICES

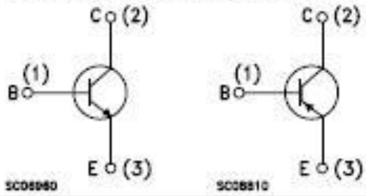
TO-218

DESCRIPTION

The TIP3055 is a silicon Epitaxial-Base Planar NPN transistor mountend in TO-218 plastic package. It is intented for power switching circuits, series and shunt regulators, output stages and hi-fi amplifiers.

The complementary PNP type is the TIP2955.

INTERNAL SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter		Value	Unit
		PNP	TIP2955	
		NPN	TIP3055	
V_{CBO}	Collector-Base Voltage (I_E = 0)		100	V
V_{CEO}	Collector-Emitter Voltage (I_B = 0)		60	V
I_C	Collector Current		15	A
I_B	Base Current		7	A
P_{tot}	Total Dissipation at $T_c \leq 25$ °C		90	W
T_{stg}	Storage Temperature		-65 to 150	°C
T_j	Max. Operating Junction Temperature		150	°C

For PNP types voltage and current are negative.

August 1999 1/4

TIP2955
TIP3055

THERMAL DATA

$R_{thj-case}$	Thermal Resistance Junction-case	Max	1.4	°C/W

ELECTRICAL CHARACTERISTICS (T_{case} = 25 °C unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{CEX}	Collector Cut-off Current (V_{BE} = -1.5V)	V_{CE} = 100 V V_{CE} = 100 V T_J = 150 °C			1 5	mA mA
I_{CEO}	Collector Cut-off Current (I_B = 0)	V_{CE} = 30 V			0.7	mA
I_{EBO}	Emitter Cut-off Current (I_C = 0)	V_{EB} = 7 V			5	mA
$V_{CEO(sus)}$*	Collector-Emitter Sustaining Voltage (I_B = 0)	I_C = 30 mA	60			V
$V_{CE(sat)}$*	Collector-emitter Saturation Voltage	I_C = 4 A I_B = 0.4 A I_C = 10 A I_B = 3.3 A			1 3	V V
V_{BE}*	Base-emitter Voltage	I_C = 4 A V_{CE} = 4 V			1.8	V
h_{FE}*	DC Current Gain	I_C = 4 A V_{CE} = 4 V I_C = 10 A V_{CE} = 4 V	20 5		70	
h_{fe}	Small Signal Current Gain	I_C = 1 A V_{CE} = 10 V f = 1 KHz	15			
f_T	Transition-Frequency	I_C = 0.5 A V_{CE} = 10 V f = 1 MHz	3			MHz
 t_{on} t_{off}	RESISTIVE LOAD Turn-on Time Turn-off Time	I_C = 6 A I_{B1} = - I_{B2} = 0.6 A R_L = 5 Ω $V_{BE(off)}$ = - 4 V		 0.5 0.9		 µs µs

* Pulsed: Pulse duration = 300 µs, duty cycle 1.5 %
For PNP type, voltage and current value are negative.

7812

FAIRCHILD SEMICONDUCTOR®

September 2011

LM78XX/LM78XXA
3-Terminal 1A Positive Voltage Regulator

Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

General Description

The LM78XX series of three terminal positive regulators are available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

Ordering Information

Product Number	Output Voltage Tolerance	Package	Operating Temperature
LM7805CT	±4%	TO-220 (Single Gauge)	-40°C to +125°C
LM7806CT			
LM7808CT			
LM7809CT			
LM7810CT			
LM7812CT			
LM7815CT			
LM7818CT			
LM7824CT			
LM7805ACT	±2%		0°C to +125°C
LM7806ACT			
LM7808ACT			
LM7809ACT			
LM7810ACT			
LM7812ACT			
LM7815ACT			
LM7818ACT			
LM7824ACT			

Block Diagram

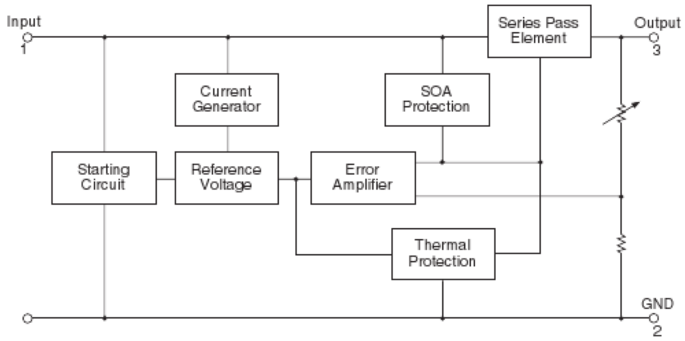


Figure 1.

Pin Assignment

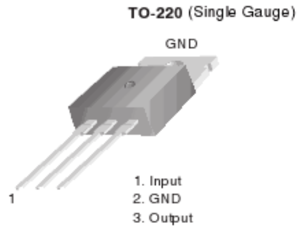


Figure 2.

Absolute Maximum Ratings

Absolute maximum ratings are those values beyond which damage to the device may occur. The datasheet specifications should be met, without exception, to ensure that the system design is reliable over its power supply, temperature, and output/input loading variables. Fairchild does not recommend operation outside datasheet specifications.

Symbol	Parameter		Value	Unit
V_I	Input Voltage	V_O = 5V to 18V	35	V
		V_O = 24V	40	V
$R_{\theta JC}$	Thermal Resistance Junction-Cases (TO-220)		5	°C/W
$R_{\theta JA}$	Thermal Resistance Junction-Air (TO-220)		65	°C/W
T_{OPR}	Operating Temperature Range	LM78xx	-40 to +125	°C
		LM78xxA	0 to +125	
T_{STG}	Storage Temperature Range		-65 to +150	°C

Electrical Characteristics (LM7812) (Continued)

Refer to the test circuits. -40°C < T_J < 125°C, I_O = 500mA, V_I = 19V, C_I = 0.33µF, C_O = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		11.5	12.0	12.5	V
		5mA ≤ I_O ≤ 1A, P_O ≤ 15W, V_I = 14.5V to 27V		11.4	12.0	12.6	
Regline	Line Regulation[11]	T_J = +25°C	V_I = 14.5V to 30V	–	10.0	240	mV
			V_I = 16V to 22V	–	3.0	120	
Regload	Load Regulation[11]	T_J = +25°C	I_O = 5mA to 1.5A	–	11.0	240	mV
			I_O = 250mA to 750mA	–	5.0	120	
I_Q	Quiescent Current	T_J = +25°C		–	5.1	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5mA to 1A		–	0.1	0.5	mA
		V_I = 14.5V to 30V		–	0.5	1.0	
$\Delta V_O/\Delta T$	Output Voltage Drift[12]	I_O = 5mA		–	-1.0	–	mV/°C
V_N	Output Noise Voltage	f = 10Hz to 100kHz, T_A = +25°C		–	76.0	–	µV/V_O
RR	Ripple Rejection[12]	f = 120Hz, V_I = 15V to 25V		55.0	71.0	–	dB
V_{DROP}	Dropout Voltage	I_O = 1A, T_J = +25°C		–	2.0	–	V
r_O	Output Resistance[12]	f = 1kHz		–	18.0	–	mΩ
I_{SC}	Short Circuit Current	V_I = 35V, T_A = +25°C		–	230	–	mA
I_{PK}	Peak Current[12]	T_J = +25°C		–	2.2	–	A

Notes:

11. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

12. These parameters, although guaranteed, are not 100% tested in production.

1N 5822

FAIRCHILD
SEMICONDUCTOR®

1N5820-1N5822

1N5820 - 1N5822

Features

- 3.0 ampere operation at $T_A = 95°C$ with no thermal runaway.
- For use in low voltage, high frequency inverters free wheeling, and polarity protection applications.

DO-201AD
COLOR BAND DENOTES CATHODE

Schottky Rectifiers

Absolute Maximum Ratings* $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Value			Units
		1N5820	1N5821	1N5822	
V_{RRM}	Maximum Repetitive Reverse Voltage	20	30	40	V
$I_{F(AV)}$	Average Rectified Forward Current 3/8 " lead length @ $T_A = 95°C$	3.0			A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	80			A
T_{stg}	Storage Temperature Range	-65 to +125			°C
T_J	Operating Junction Temperature	-65 to +125			°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.6	W
$R_{θJA}$	Thermal Resistance, Junction to Ambient	28	°C/W

Electrical Characteristics $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Device			Units
		1N5820	1N5821	1N5822	
V_F	Forward Voltage @ 3.0 A @ 9.4 A	475 850	500 900	525 950	mV mV
I_R	Reverse Current @ rated V_R $T_A = 25°C$ $T_A = 100°C$	0.5 20			mA mA
C_T	Total Capacitance $V_R = 4.0$ V, f = 1.0 MHz	190			pF