# ROOFTOP SOLAR CELL SYSTEM DESIGN FOR GRID CONNECTED

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by

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# Abstract

The solar cell system as the online energy source in the house, they assist in partial energy supply from the public energy source. In this project, students must design and install the 6 modules of PV on the rooftop. The dc output power of the PV will track the maximum power by using the MPPT controller for optimizing the power supply each day. From the optimum DC power of the MPPT controller, they will be inverted to the AC power by using an inverter portion at 50 Hz and 230 Volt. And then its output is paralleled to the public grid by using a grid-tie controller. The energy generated by the solar cell power source system will be directly sent to the load, every sending of electrical power must report to the PC for forecasting the monthly and yearly energy profile. The payback time estimation creates a monthly report. The benefit will display in the electricity bill, this profile may cause the creative idea of strategies in the ways of payback time reduction.

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# Chapter 1
# Introduction

## 1.1 Project Background

Natural gas, coal, and fuel oil are causing the problem of generating electricity as non-renewable energy. Low reliability of the electricity system causes easy blackouts in rural areas and has high electricity costs. This project is interested in the above problems to solve by solar energy that is renewable energy gained from the sun by using technologies. Solar energy is a very useful renewable energy that has many benefits like generating electricity, heating water, increasing the temperature of households, photosynthesis and use in industries. Solar energy has two types which are active solar and passive solar. To mention generating electricity by solar energy, there are two main types to consider for generating electricity by PV or photovoltaic which uses sunlight and solar thermal electricity by heating from the sun. Nowadays, the famous method is photovoltaic (PV) or solar cells. Photovoltaic systems control the solar energy between two semiconductors that receive light then the current is flowing in different voltages. This is a short explanation of PV generating electricity from solar energy. The project is using solar energy as renewable energy for generating electricity in daytime and storage batteries. In night time, the project is using batteries to generate electricity for lighting and DC loads for increasing the safety and reliability.

## 1.2 Project Objective

1. To decrease electricity costs.
2. To reduce the payback time of PV systems.
3. Can show the real time maximum power point tracking on application.
4. Can forecast the monthly and yearly energy profile.
5. To provide VME students the knowledge needed for their future career.

## 1.3 Goal of the project

1. Solar power is used.
2. Improving reliability of the electricity system.
3. Decreasing payback time.

# Chapter 2
# Project Overview

## 2.1 System

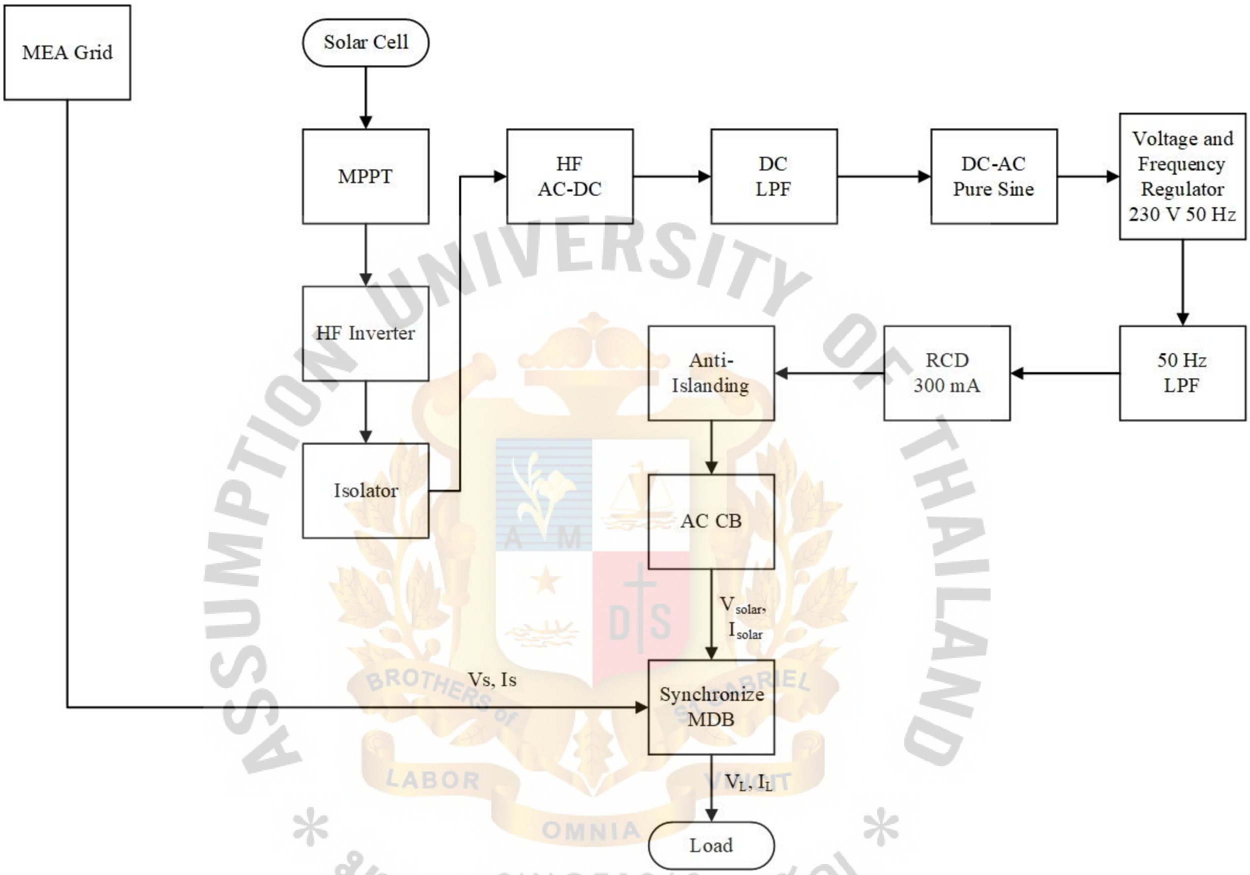


**Figure 2.1 Schematic Diagram of the AC Grid.**

MPPT stands for Maximum Power point Tracker. Its function is in the modern photovoltaic inverters which is to maximize the energy available on the connected solar arrays at any time during its operation.

A solar module is a DC limited energy supply that has an internal impedance that varies throughout the day, depending on the level of solar irradiation on the module face and cell temperature. In daytime, DC current and voltage are generated by solar panels and DC voltage, current flow through inverters which are DC-DC MPPT that detect peak DC current and voltage and maintain the maximum power throughout the day. DC current and voltage from MPPT pass DC-AC high frequency inverter that converts DC to AC for step up in toroid transformer and isolated by ground. AC voltage and current from the secondary side of the toroid transformer pass AC-DC rectifier for converting AC-DC and it flows DC Low pass filter (LPF) for filter 0 HZ DC frequency. DC current and voltage from LPF that 325V varied by sunlight flow to IGBT inverter that converted DC-AC and pure sine wave and also voltage and frequency regulator for constant AC voltage 230V 50Hz and varied current and power. AC 230V from an IGBT inverter is passed through AC LPF for filter 50 Hz frequency to constant frequency 50Hz AC. RCD protection for leakage current not more than 300mA to protect the electrical devices. And AC voltage and current with not more than 300mA flow to anti-islanding protection which connected parallel with the current transformer through the MEA grid current for protection of current flow back through MEA and increasing the human safety and reliability.

An inverter which has AC 230V with 50Hz flow to ACCB in solar MDB for protection short of AC solar current. The solar current flows through MTF for measuring current and voltage to calculate efficiency, energy (KWh) and displaying efficiency (PF), energy (KWh), voltage, current, and power. Solar current and AC voltage 50Hz flow through MDB to synchronize with system current from the grid.

This system is designed to be used in house so the safety of the system must concern, the project uses the method of Islanding protection to protect the electric spark or flashback from our system.

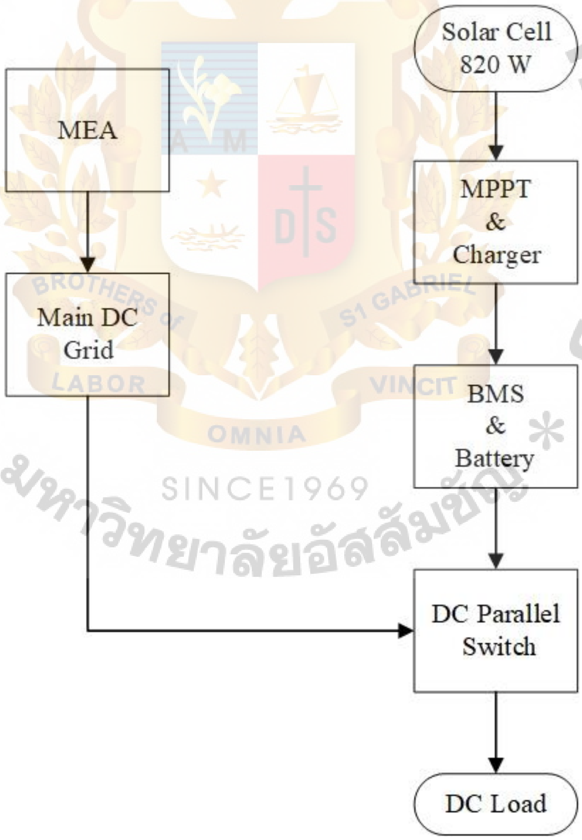


**Figure 2.2 Schematic Diagram of the DC Grid.**

Two solar panels were connected to the MPPT controller like the AC grid to detect the maximum power point to charge the battery then the BMS will balance the voltage in each to be equal before sending the power to load.

## 2.2 Study/ Theory

### 2.2.1 Cuk Converters

Cuk-converter is studied  for proving the good point of this system. First thing is the advantage of Cuk having continuous input current that makes low THD around less than or equal to 5%. The next advantage is isolated between input and output by ground that make high stability and reliability. The last is low ripple output voltage that makes high efficiency around 98%. For this project, the cuk converter is the part of the inverter that is a commercial product.[1],[2]

### 2.2.2 MPPT

MPPT stands for Maximum Power point Tracker. This function is in the inverters to maximize the energy available on the connected solar panel at any time during its operation.

A solar module is a DC limited energy supply that has an internal impedance that varies throughout the day, depending on the level of insolation from the sun and cell temperature. An inverter without an MPPT circuit would result in the voltage condition 220 V and it will damage the battery and inverter. MPPT circuits control the voltage and current. It has driven the operating point of the inverter to the maximum power point of the array, which resulted in the highest energy produced.[3],[4]

### 2.2.3 MPPT Control Algorithms

MPPT will maintain the power at maximum power at any time. Hill Climbing Method is used to find the maximum power tracking from the increasing load. It also involves perturbation in the duty ratio of the power by increasing load then collecting the value of power. The project can observe from the graph of PV that the graph is like a mountain climber from 8.00 am then the graph slightly increasing until the maximum point tracking or maximum power is around 12.00 am then slightly decreasing.[3],[4]

### 2.2.4 Battery Management System (BMS)

BMS or Battery Management System is a device to maintain the voltage or energy of the batteries to be balanced for all cells and to protect the batteries from damage of overcharging and oversupplying. BMS will control the input and output current that go to the batteries. When each cell of the battery has a different voltage, a higher voltage cell will charge the battery that has a lower voltage until all batteries have the same voltage level. Then all cells will discharge at the same time which makes the batteries have a longer life and higher efficiency.[5],[6],[14]

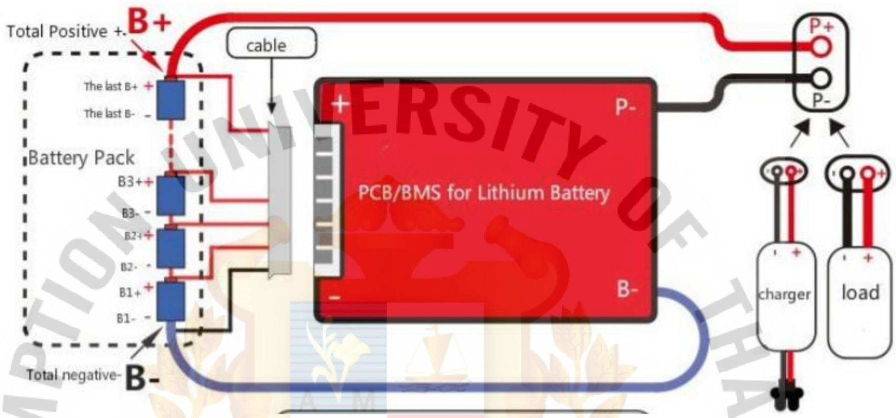


**Figure2.3 Connection of BMS with Battery**

### 2.2.5 Lithium Iron phosphate ($LiFePO_4$) Battery

Lithium Iron phosphate ($LiFePO_4$) has a lot of benefits compared to other Lithium ion batteries. It has high safety, long life period, no need to maintain much, high efficiency of charging and discharging, and lightweight.[7],[8],[9]

### 2.2.6 Anti-Islanding Protection

Islanding is an interconnection of power grid with distributed generation like in DC microgrid a common load is shared between Grid and distributed generation such as solar, wind etc, Islanding protection is needed by the law that any inverter must have for the situation like when grid is down or black out but some homes are still providing energy to the grid, sending power back into the otherwise inactive electricity supply lines that will dangerous to the workers fixing the electricity grid and to safe the equipment of the grid hardware like transformers and others.[10],[11]

### 2.2.7 IGBT

IGBT or Insulated Gate Bipolar Transistor is a switching device that combines the advantages of MOSFET and BJT together. That is high switching frequency and high input impedance from MOSFET and low input voltage from BJT. The operation of IGBT is to stop the power flow when being off-state and allow the power flow when being on-state. The controller of ON/OFF state comes from a metal oxide semiconductor gate structure. The IGBT has a low voltage drop, low saturation voltage characteristics and high efficiency. This project needs the IGBT with inverter to control high DC voltage and current at 50 Hz to convert to AC before going to the grid from MEA.[12],[13]

### 2.2.8 Microgrid

Microgrid is a low-to-medium voltage system with a small electrical system that includes electrical generating system, loads, information system, communication system, storage system and automation system. They all are working together and like the same system which connects to the main grid from MEA. The Microgrid mainly operates to maintain the generating and consuming electricity to be efficient which in itself system and using the main grid for increasing reliability of the microgrid. Small wind turbines, solar cells, fuel cells, combined heat and power generators can be a source of producing electricity in the Microgrid. The microgrid can operate in islanding mode and grid-connected mode. The concept of Microgrid was invented for compensating when the problem occurs with the main power plants, distribution system or any fault occurs in the transmission line. When a fault occurs, Microgrid can detect the fault and automated cut off from the main grid to save the other components and also supply the energy to the highest priority loads which is the energy from storage systems or other generators.

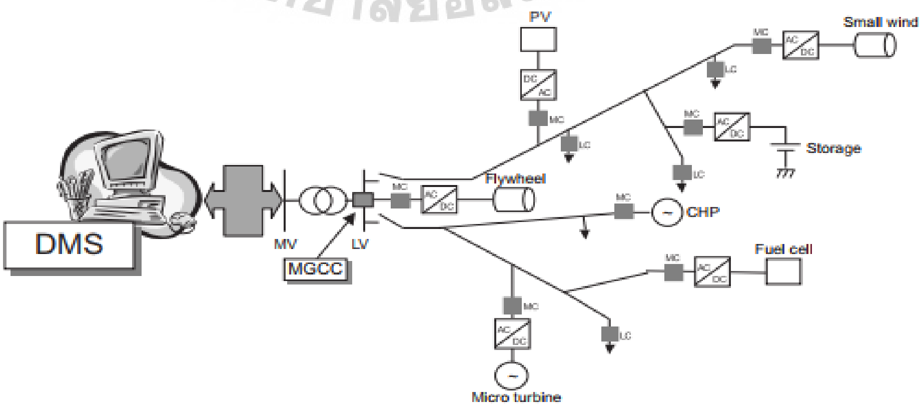


**Figure 2.2** Microgrid

The Microgrid can also compensate for the peak demand of electricity consumed at a short time and it can also reduce transmission and distribution losses. Normally the power plants are far away from the city and the transmission lines needed to be long enough to supply to the consumers. Long transmission lines affect high losses that Microgrid can help reduce these losses as it can construct in the city.[15],[16]

### 2.2.9 Inverter

An inverter is a power converter that converts a power resource as solar power in the form of direct current into an alternating current called DC-AC inverter. Grid-tie inverter contains the safety algorithm to maintain the shut-off of the system for protecting the repairing processes in the utility network. Grid-tie inverters need to include Ground Fault Detection and Interruption(GFDI) that detects current in the ground system and commonly Arc Fault Detection and Interruption(AFDI) device that detects the arc in system. Grid-tie inverter is the generation of voltage and frequencies for maintaining the optimal frequency and voltages for driving electric appliances efficiently that is the central type of grid-tie inverter for battery backup in solar systems connected to the grid and providing power when the grid has problems. [24],[25],[26]

# Chapter 3

# Method of implementation

## 3.1 Electrical engineering work

This part of the work relates to the solar-cell system installation.

In the daytime, the output power is paralleled to the public grid. The energy generated by the solar cell power source system will be directly sent to the load, every sending of electrical power must report to the application for forecasting the monthly and yearly energy profile. The payback time estimation will create and report every month.

The benefit of this part will display in the electricity bill.

**Figure 3.1 Installation of solar panel base**

## 3.2 Electronics Engineering Work

This part of the work relates to safety and reliability improvement.

In the night time, the battery energy storage system will supply the power for the lighting system. The maximum power point tracking algorithm will manage the battery charging system in the daytime.

The benefit of this part is the emergency lighting system during dark periods and blackout.

**Solar Cell Grid-tie Inverter System**

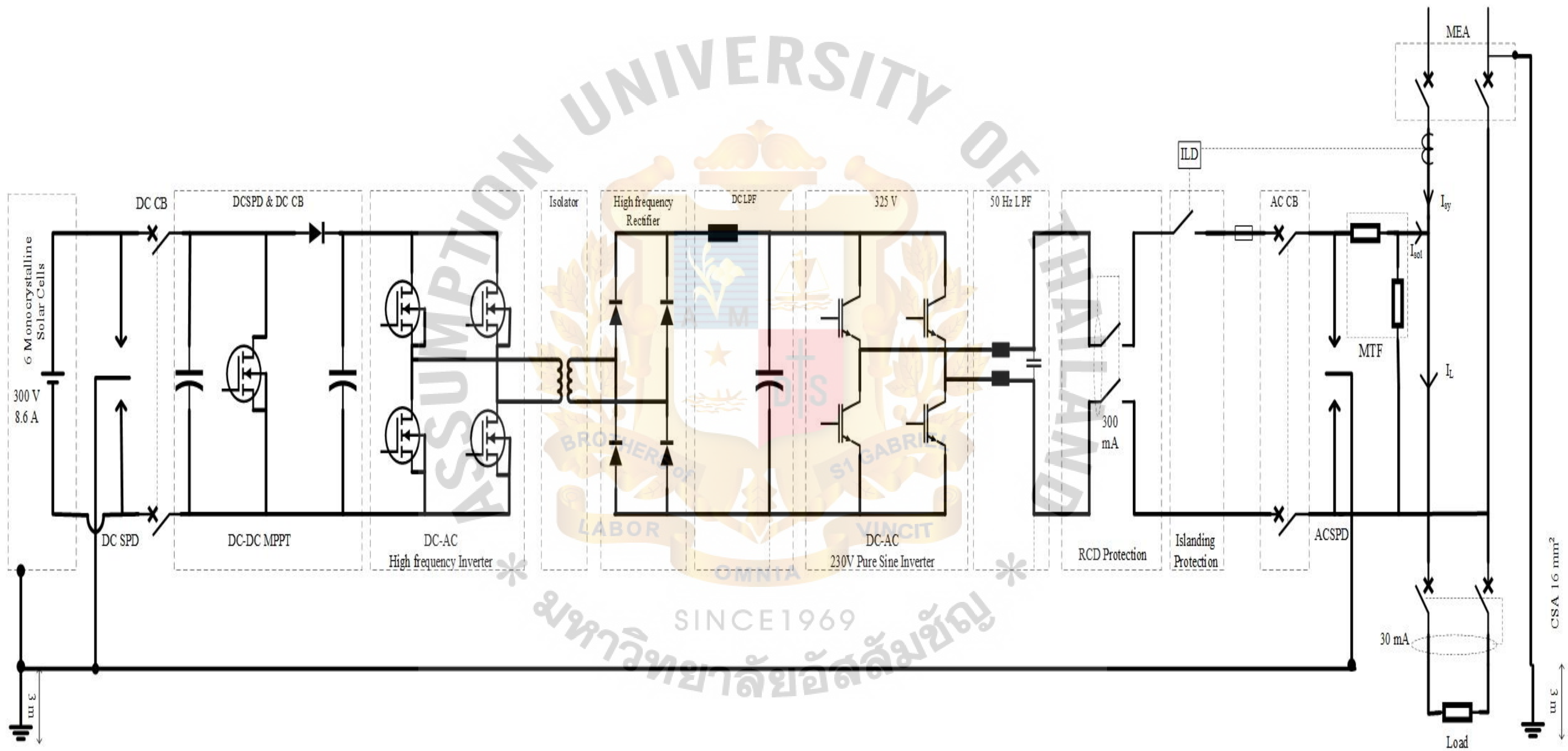


**Figure 3.1 Solar Cell Grid-tie Inverter System**

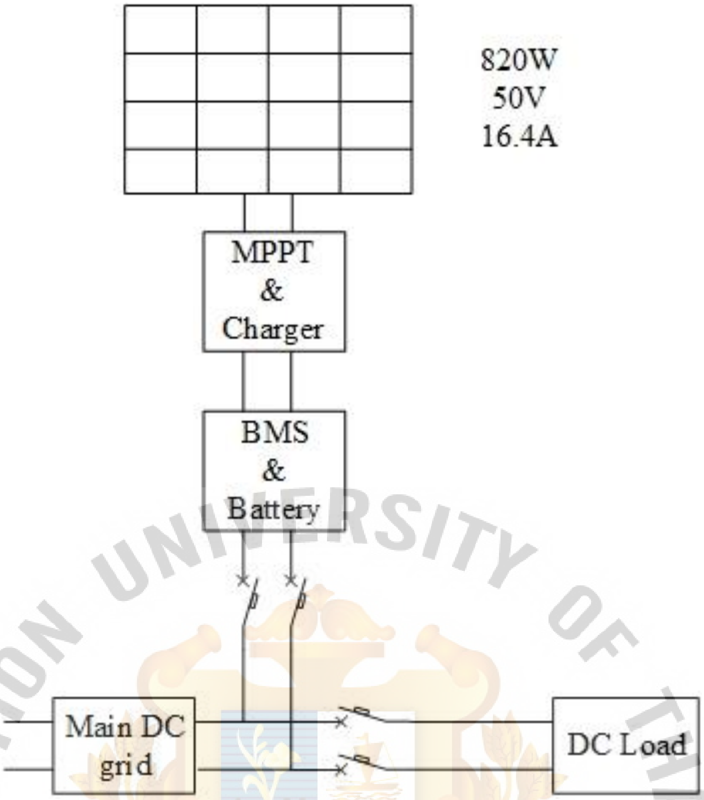


**Figure 3.2 Storage System and DC Loads Design**

# Chapter 4

# Experiment and Results

## 4.1 Test the voltage with the MPPT

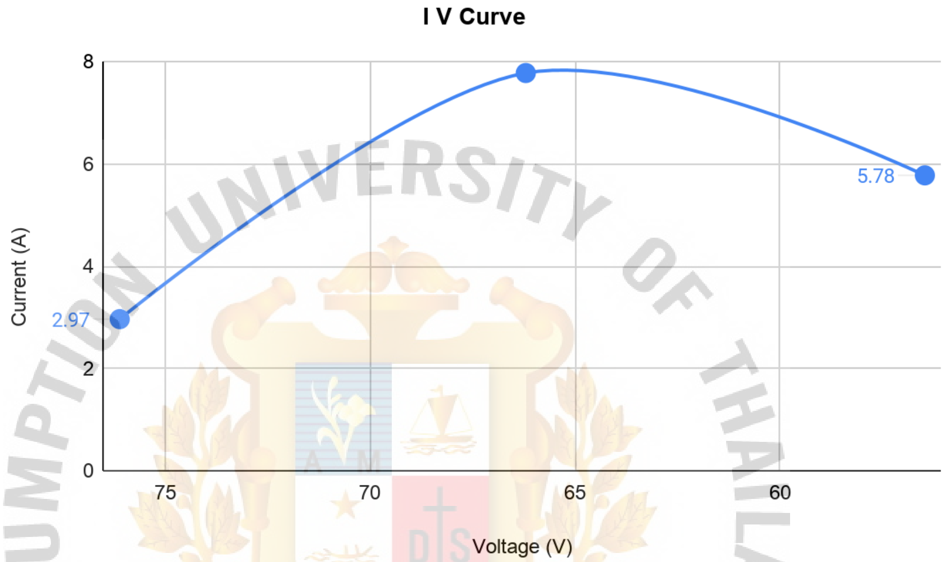


**Figure 4.1 IV Curve**

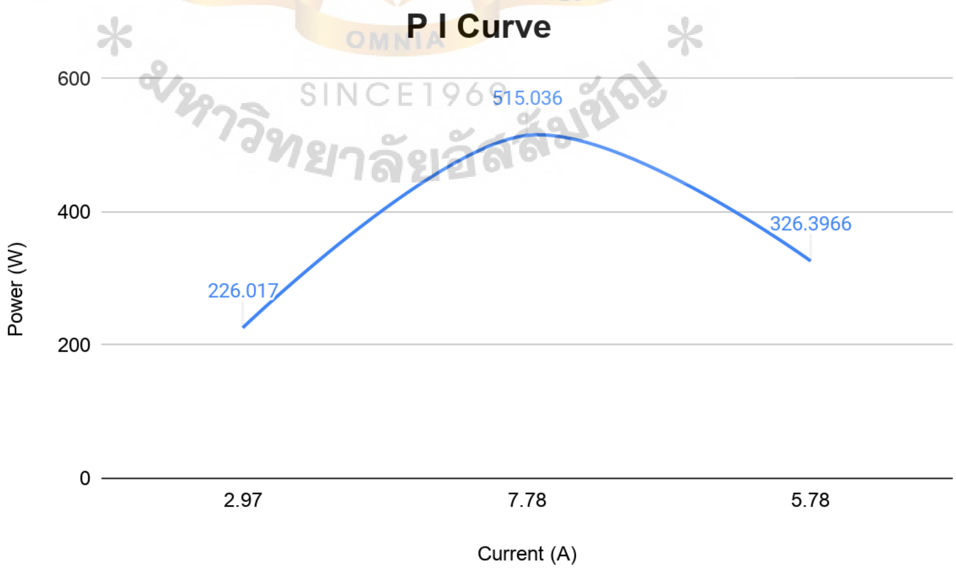


**Figure 4.2 PI Curve**

## 4.2 Test the load

**Figure 4.3 Testing load**

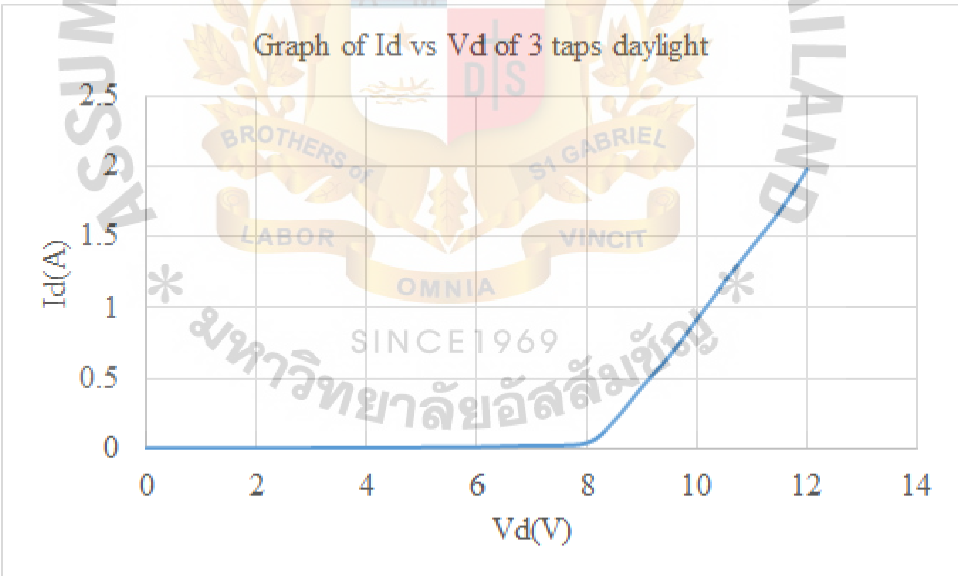


**Figure 4.4 Graph Id vs Vd of 3 taps daylight**

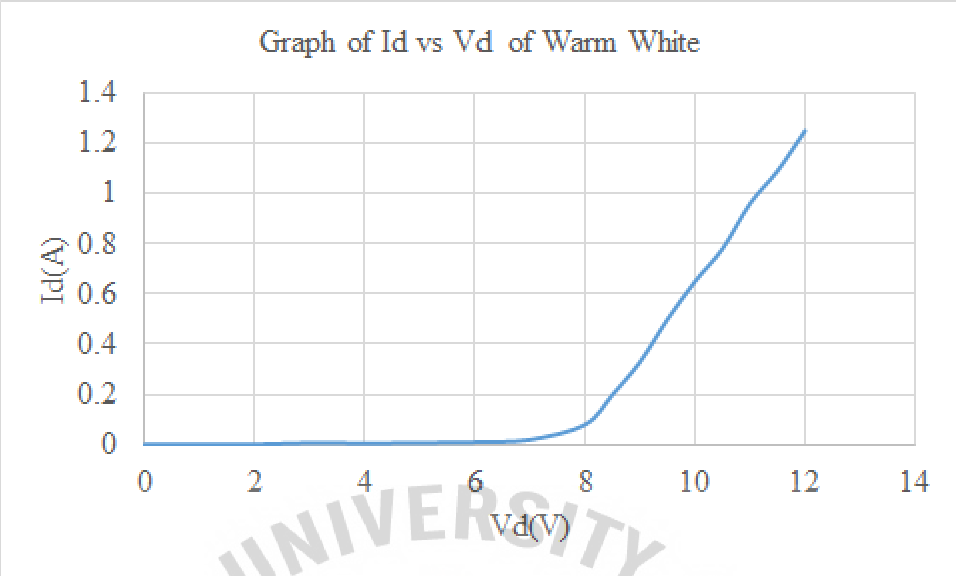


**Figure 4.5 Graph $I_d$ vs $V_d$ of warm white**

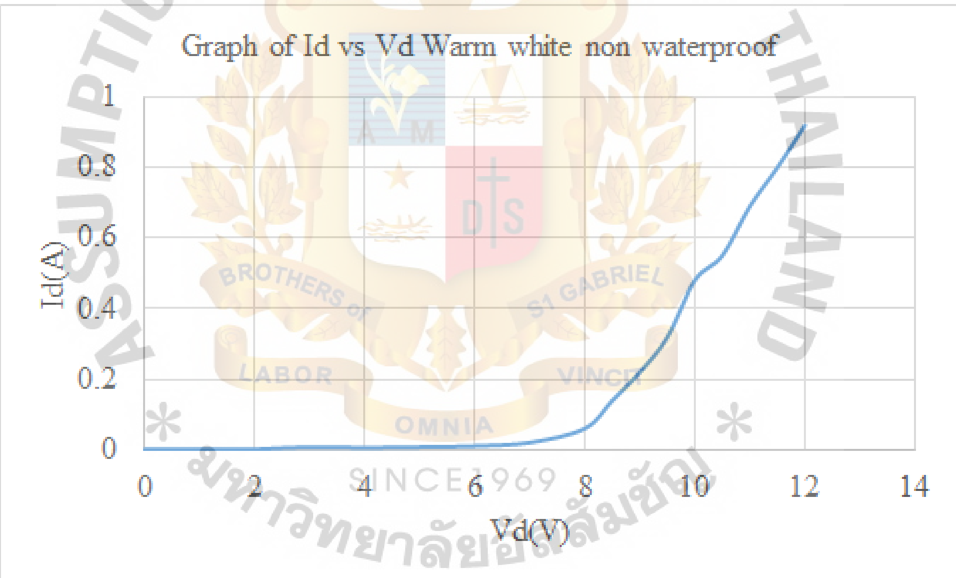


**Figure 4.6 Graph $I_d$ vs $V_d$ of warm white non-waterproof**

## 4.3 DC loads Calculation

DC load included LED stripped Warm white 1tap type, LED stripped Warm white 3 tap type and LED stripped Warm white 1 tap non waterproof type.

**Calculation**

LED stripped Warm white 1tap type

From the experiment result, we selected at 10 V

Input power $P_{in} = V_{led}*I_{led}$ = 10*0.65=6.5 W

LED stripped Warm white 3 tap type

From the experiment result, we selected at 10 V

Input power $P_{in} = V_{led}*I_{led}$ = 10*0.92= 9.2 W

LED stripped Warm white 1 tap non water proof type

From the experiment result, we selected at 10 V

Input power $P_{in} = V_{led}*I_{led}$ = 10*0.48= 4.8 W

Total lighting system power consume 6.5+9.2+4.8 = 20.5 W

For 1 night 6.00pm to 6.00 am for 12 hrs

Lighting system need energy to use 12hrs*20.5W = 246 Wh

Then the system needs battery 246*2 = 492 Wh

Reserve margin 28% for expandability factor

Then the system needs battery 492*28% = 137.76+492=629.76 Wh

Battery LiFePO4 available at market 3.2 V, 6.0 Ah

Energy of battery = 3.2*6 =19.2Wh

Then the system need battery 629.76/19.2=32.8 cells

### 4.4 Designing and testing the battery $LiFePO_4$


**Figure 4.7 Testing Battery**

From the above calculation the system used $LiFePO_4$ 32 cells and connected the battery by the two cells battery (1 set) was connected in parallel and connected in series 16 sets. Then testing the battery voltage and got the value 52.52 V.

## 4.5 Test the BMS System

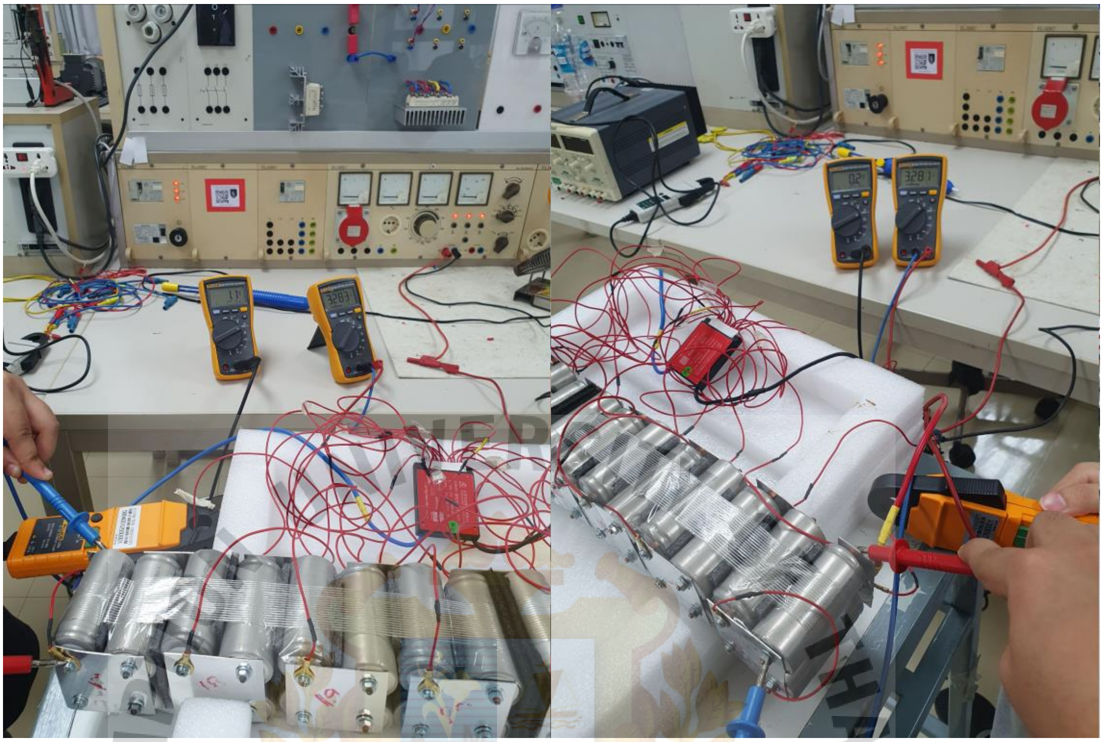

**Figure 4.8 BMS Testing**

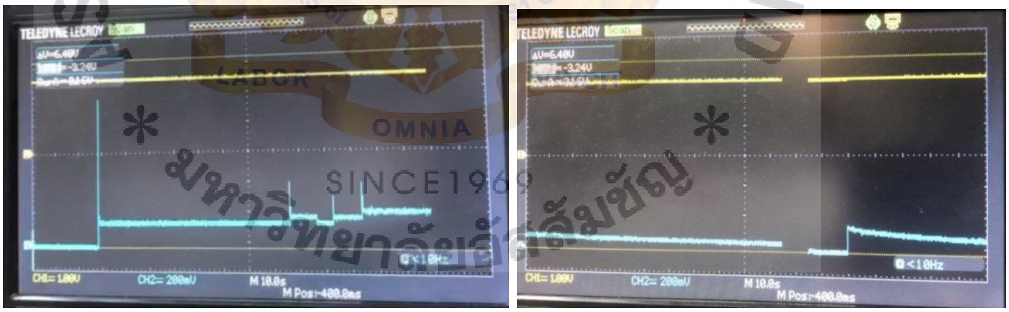


**Figure 4.9 Battery Profile**

## 4.6 Design the system before installation with MEA

**Figure 4.10 Electricals and Electronics System Design**

## 4.7 Overall System Testing

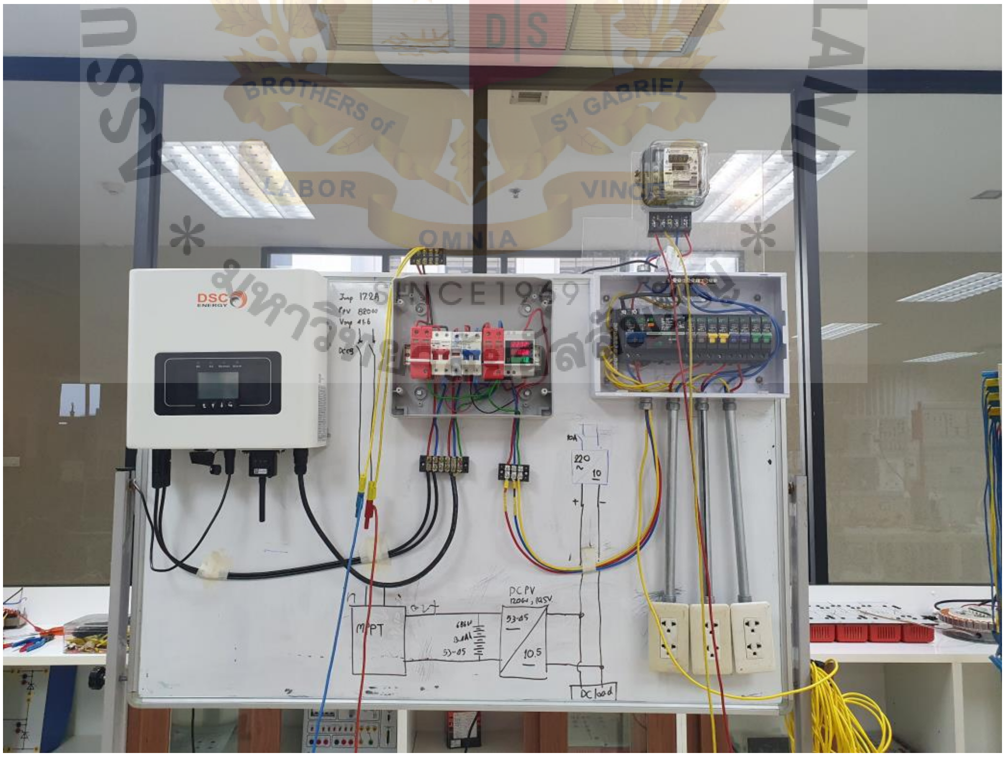

**Figure 4.11 Overall System Testing.**

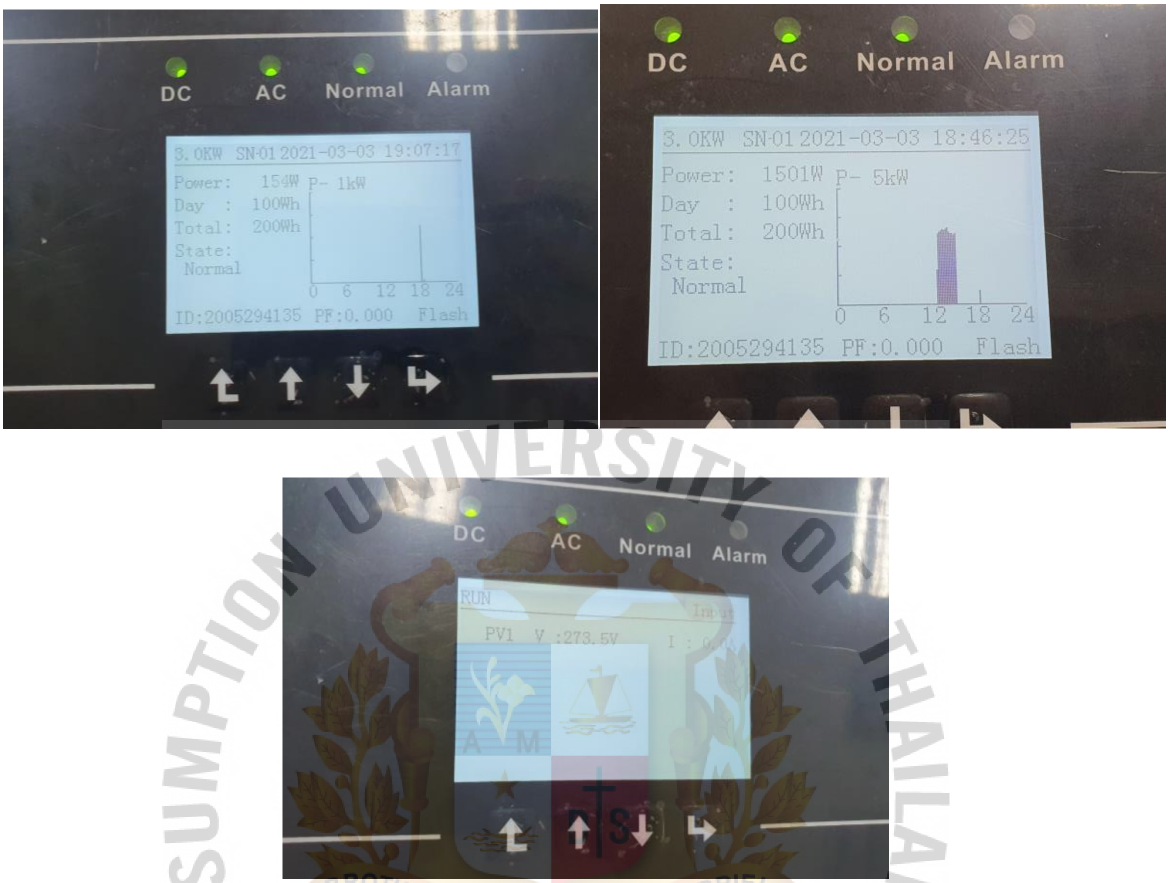


**Figure 4.12 Inverter's Display**

The display is showing the power that the load consumed per day. The 1st picture is showing the small bar of consuming energy. On the other hands, the 2nd picture is showing a bigger bar as the peak demand consuming energy at the instantaneous time. Also the last picture is showing the input voltage and current at real time.

The component system included:

1.SDB solar cell distribution board

2.MDB from MEA

3.Inverter

4.single pole

5.Watt hour meter

6.Battery

7. BMS

8. Solar Panels with Base Structure

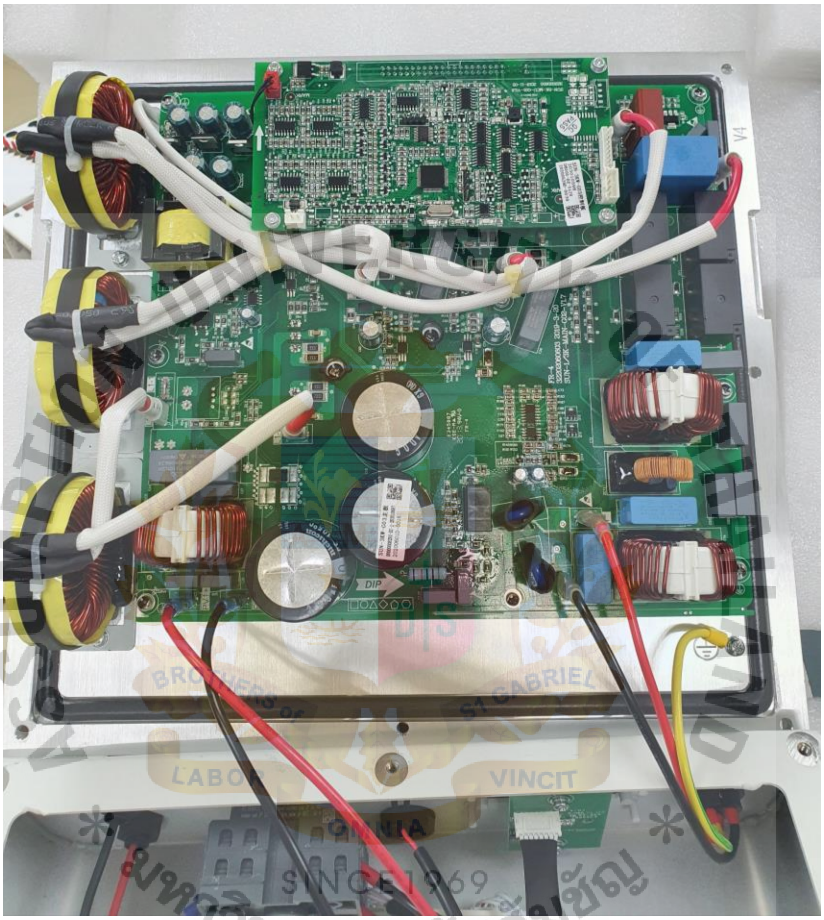



**Figure 4.13 Inside of inverter**

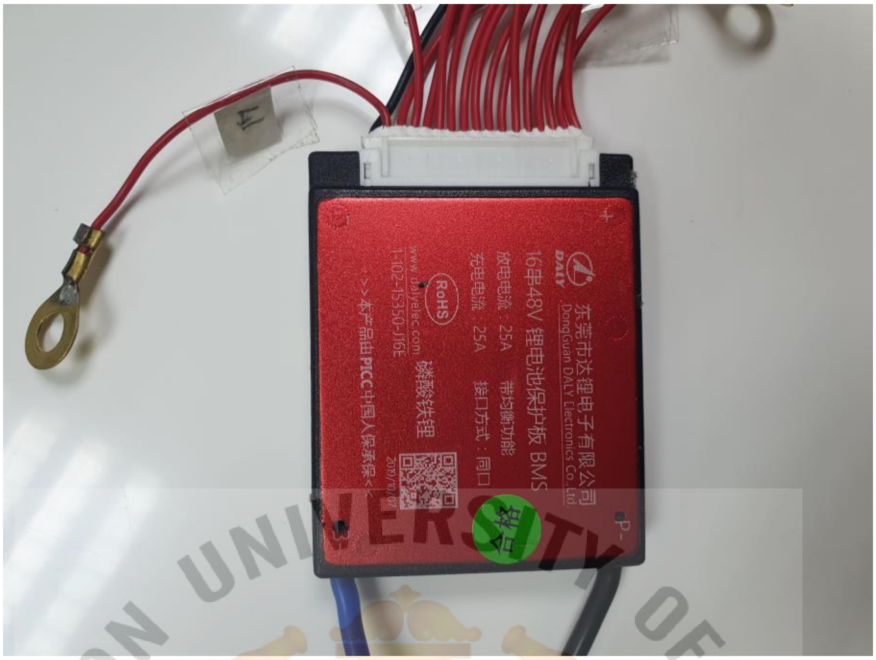


**Figure 4.14 Battery Management System -** Design for balancing the battery voltage and increasing lifetime of the battery.

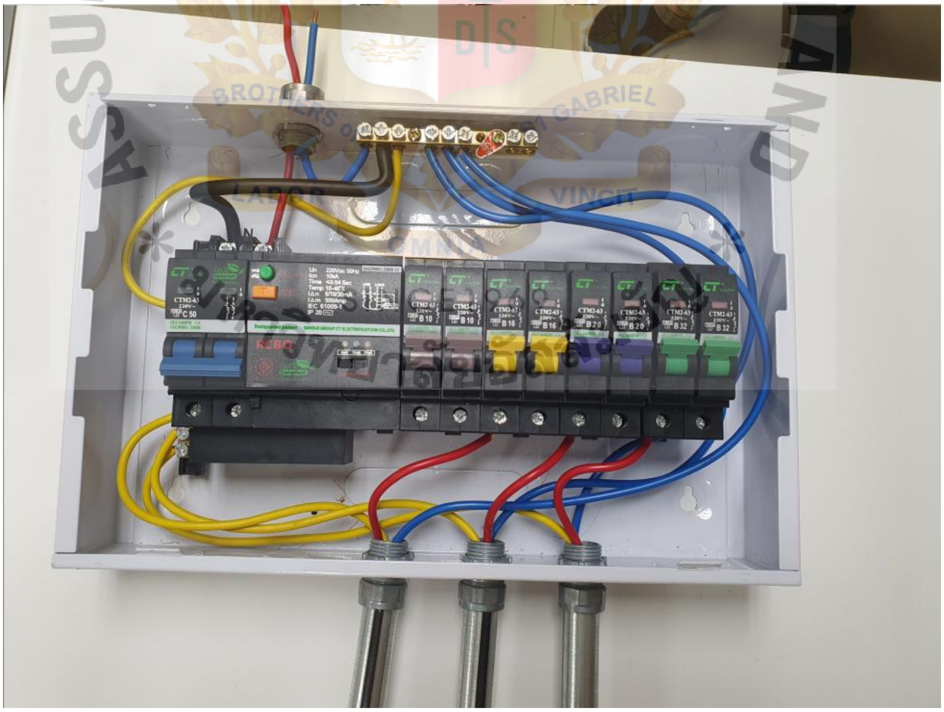

**Figure 4.15 MDB Box** - Design for service entrance from MEA

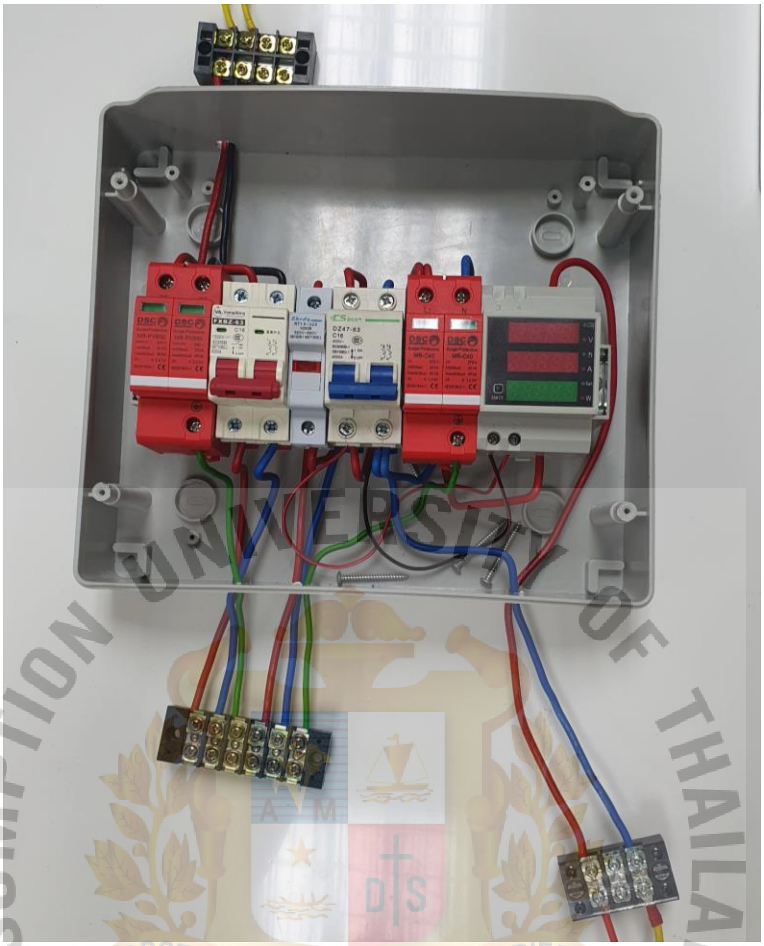

**Figure 4.16 Solar MDB Box-**Design for human safety and solar system.

### 4.7 Loads Calculation

| load | W | Hrs/Day | Unit/Day | unit/month |
|---|---|---|---|---|
| Kettle | 1,850 | 1 | 1.85 | 55.5 |
| Electric Pot | 400 | 4 | 1.60 | 48.0 |
| Microwave | 1,200 | 1 | 1.20 | 36.0 |
| Refrigerator | 70 | 24 | 1.68 | 50.4 |
| Notebook | 60 | 8 | 0.48 | 14.4 |
| Fan | 40 | 5 | 0.20 | 6.0 |
| Total | 3,620 | | 7.01 | 210.3 |

**Table 4.1 Load Calculation**

**Normal Electricity Bill**

| Electricity Bill | unit | Baht/Unit | total |
|---|---|---|---|
| Base Electricity Cost | 150.00 | 3.2484 | 487.26 |
| | 60.30 | 4.2218 | 254.57 |
| Service Cost | | 38.22 | 780.05 |
| Ft Cost | | | -32.17 |
| Vat7% | | | 52.35 |
| | | | |
| **Total** | | | **800.24** |

**Table 4.2 Normal Electricity Bill**

**Solar Saving**

| **Electricity Bill** | **unit** | **Baht/Unit** | **total** |
|---|---|---|---|
| Base Electricity Cost | 150.00 | 3.2484 | 487.26 |
| | 250.00 | 4.2218 | 1,055.45 |
| >400 | 42.8 | 4.4217 | 189.25 |
| Service Cost | | 38.22 | 1,731.96 |
| Ft Cost | | | -67.87 |
| Vat7% | | | 116.49 |
| | | | |
| **Total** | | | **1,780.57** |

**Table 4.3 Solar Saving**

## 4.8 Payback Time Calculation

| **Payback Time** | **Unit/Day** | **Unit/Month** |
|---|---|---|
| Monthly Consumption (KWh or Units) | 7.01 | 210.3 |
| Monthly Generation (KWh) | 14.76 | 442.8 |
| Monthly Savings (Inc VAT) (Baht) | | 1,780.57 |
| Installation Investment of Solar System | | 68,000 |
| Payback Period (Years) | | 3 |

**Table 4.4 Payback Time Calculation**

# Chapter 5

# Conclusion

The project is focused on Electrical design for Rooftop Solar Cell System for Grid Connected. The result shows that the solar system can generate electricity to compensate for the peak demand consumed by the highly watt loads like kettle, 200W light bulbs, notebook adapter, electric pot, fans, refrigerator, and etc. then the electricity bill has been reduced.

The project is assured that safety for electric appliances and humans. Isolated by ground separate the ground of the system which protected the system. Anti-islanding protection protects the reverse current from the solar system to MEA that will be affected directly by the repairing processes in the utility network. RCD protection protects leakage current less than 300mA for protecting the electric appliances. In addition, the designed system is legal as it has the limiter with the current transformer that prevents reverse current to the main service entrance.

Battery is the backup power when blackout so this part is increasing the reliability of the lighting system and consuming the power in the night time that using DC loads. Battery LiFePO4 is the majority of new home energy storage technologies which is more efficient than lead acid batteries and also has a longer lifespan. The DC grid system uses BMS for managing the battery charger to expand its life by managing the current and voltage that charging the battery at the same time with constantly.

The Installation of solar panel base is designed for the adjustment of solar cell angle to generate the maximum power point tracking in different angles that is suitable for the installation area and monthly. The testing load results for DC grid parts is showing the graph of $I_d$ vs $V_d$ for each load to adjust the optimum voltage and current of loads more efficiently than rated load power, then load can consume less power from battery and expand battery life.

The cost of the project is 68,000 Baht, it can generate electricity per month around 443 units. Calculation using MEA standard will save the maximum money 1,780.57 Baht/month which is 23,666.90 Baht/year. The payback time can be approximated in 3 years that the project will make the profit after this period of time. The application of the inverter can show the real time input and output voltage and current also it will calculate the power consumption both from MEA and loads. It also forecasts the monthly and yearly energy profile from the behavior of the usage. Beside the real time MPPT will be shown.

As this project can reduce electricity bills so installing rooftop solar recommends homes or factories that will have to pay electricity bills 3,000 - 4,000 baht per month or more. For homes or factories where there are people always using during the day time that needed electricity or home office. Moreover, this project can be used for appliances that need electricity when blackout such as water pumps, emergency lights, fence lights, UPS and CCTV. The solar rooftop system is renewable energy and no pollution so it is interesting to invest. In the future, Microgrid or new smart home technology is much more popular then the exchange of power will be traded with other homes by watthour meter to reduce the payback time. In addition, the installation of the solar cells should be mounted on the strong roof like a cement roof. Old Zinc or wooden roofs are not recommended for this project as the solar panel has a heavy weight around 20 kg per array which will damage the unstable roof and also the panel itself. The solar rooftop system is needed for maintenance and cleaning in the right way to maintain high efficiency.

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