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Capacity Building within the Field of Higher Education

eACCESS Project

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EXECUTIVE SUMMARY

One pillar developing by eACCESS project is laboratory. As a member of eACCESS project supported by Erasmus+, Soegijapranata Catholic University (SCU) proposes a laboratory focused on microgrid. This is due to the fact that issues related to renewable energy which is more interested if it is combined with existing grid. Electrical Engineering Department of SCU has a major that focus on renewable energy technology, so the proposed laboratory will be capable to support the major. In this document, the existing laboratory and the proposes laboratory are described. Recently, SCU has some laboratory includes : Basic Electronic Lab, Electric Circuit and Measurement Lab, Electric Drive Lab, Electric Power Supply Lab, Energy Conversion Lab, Power Electronic Lab, Control System Lab, Electronic Lab, Microprocessor Lab and Basic Telecommunication Lab. Microgrid Lab as the proposed laboratory consists of PV modules as renewable energy, battery as energy storage system, loads and SCADA based communication. The microgrid can be connected to the existing grid or disconnected (islanding mode). Some features can be implemented in the proposed laboratory, includes: two modes of operation under grid connected without battery, one mode of operation under grid connected with battery and two modes of operation under islanding. Some courses are also designed related to the proposed laboratory.

PEL (Power Electronics Laboratory)
Soegijapranata Catholic University - eACCESS

1. INTRODUCTION

Indonesia has the potential for renewable energy that is spread throughout the territory of Indonesia, including solar energy sources, hydro and micro-hydro energy sources, wind energy sources, geothermal energy sources, ocean wave energy sources, and biomass energy sources. Initially the electrical systems used generation systems that were built centrally close to an energy sources although far from consumers. This condition requires the construction of transmission systems which results in significant power losses. Renewable energy-based generation can be built anywhere with a small size so that it can be built in a scattered manner. For the nature of this type of generation systems are intermittent, connection with conventional generation systems are still required. To make the combination of the two system more efficient, a microgrid system can be implemented.

A microgrid is a self-sufficient energy system that serves a discrete geographic footprint, such as a college campus, hospital complex, business center, or neighborhood. Within microgrids are one or more kinds of distributed energy (solar panels, wind turbines, combined heat & power, generators) that produce its power. In addition, many newer microgrids contain energy storage, typically from batteries. Some also now have electric vehicle charging stations. Interconnected to nearby buildings, the microgrid provides electricity and possibly heat and cooling for its customers, delivered via sophisticated software and control systems.

Electrical department of SCU has two major fields, these are industrial electronic (IE) and renewable energy technology (RET). The second major field (RET) was established in 2018 requires some support in practical activity, one of these is a knowledge of microgrid. The microgrid laboratory can be used to train the students, it can used for lecturers to do researches.

2. DESCRIPTION OF EXISTING LABORATORIES

The Faculty of Engineering, Soegijapranata Catholic University, Semarang, Indonesia is operating at the moment the following physical laboratory facilities included in the Electrical Engineering Undergraduate Program:

2.1 Basic Electronic Laboratory:

The objective of this laboratory is to developed practical skills in the design, prototyping and testing basic electronic circuits.: micro controller based Led Blinking, micro controller based 7 segments, micro controller-based LCD display.

Figure-1 Basic Electronic Laboratory

2.2 Electric Circuit and Measurement Laboratory:

The objective of this laboratory is to observe and analyse the circuit configurations and do the measurements

Figure-2 Electric Circuit and Measurement Laboratory

2.3 Electric Drive Laboratory:

The objective of this laboratory is to learn how to control and analyze operation of various electric drives.

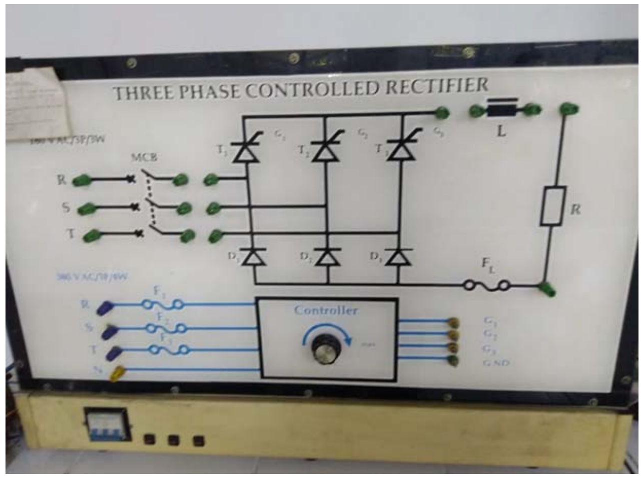

Figure-3 Electric Drive Laboratory

2.4 Electric Power Supply Laboratory:

The objective of this laboratory is to design, develop and tests various types of power electronic converters as switching power supply

Figure-4 Electric Power Supply Laboratory

2.5 Energy Conversion Laboratory:

In this laboratory students have the possibility to study in practice operation of DC motors, DC generators, synchronous generators, induction motors, universal motor and power transformers.

Figure-5 Energy Conversion Laboratory

2.6 Power Electronic Laboratory:

In this laboratory students have the possibility to study in practice operation and control methods of AC-DC, DC-DC, DC-AC and AC-AC converters

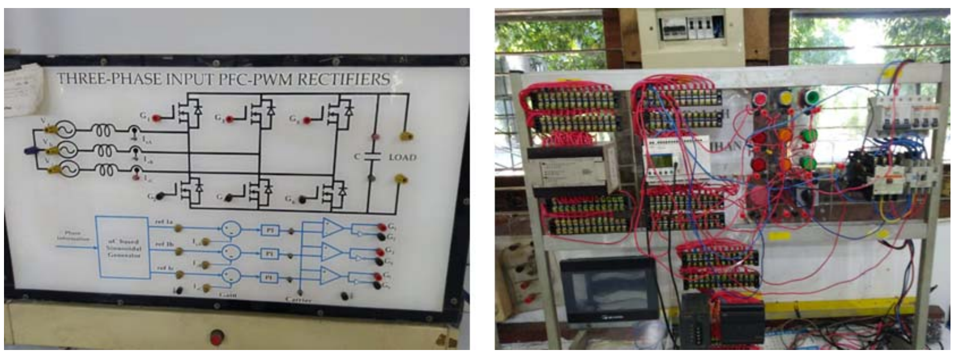

Figure-6 Power Electronic Laboratory

2.7 Control System Laboratory:

In this laboratory students have their hands-on experience regarding control system including bang-bang control, P, PI, PD and PID controller design, settings and operation

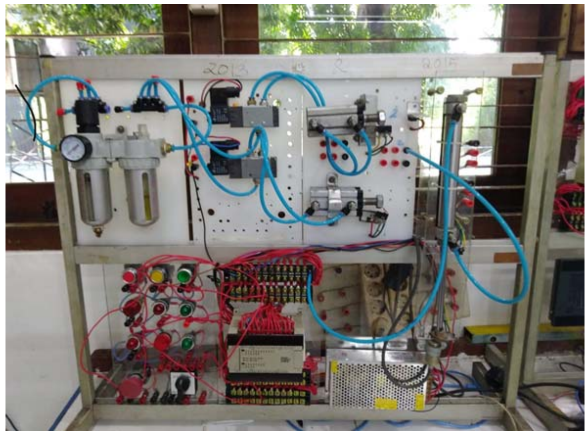

Figure-7 Control System Laboratory

2.8 Electronic Laboratory:

In this laboratory students have the possibility to do experiment with the basic electronic components.

Figure-8 Electronic Laboratory

2.9 Microprocessor Laboratory:

The purpose of this laboratory is to give students the opportunity to work with microprocessor components, design systems based on microprocessors and to develop programming skills

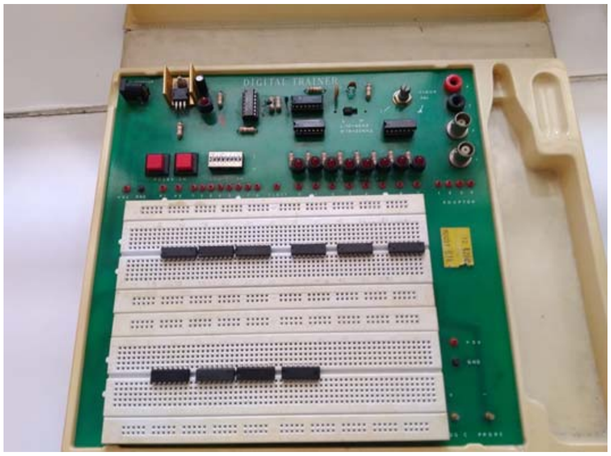

Figure-9 Microprocessor Laboratory

2.10 Basic Telecommunication Laboratory:

In this laboratory students have the possibility to do experiment related analog filter and modulation

Figure-10 Basic Telecommunication Laboratory

3. FREQUENCY AND VOLTAGE REGULATION IN MICROGRID

Distributed Energy Resources (DER) including Distributed Generation (DG) and distributed storage (DS), are sources of energy located near local loads and can provide a variety of benefits including improved reliability if they are properly operated in the Electrical distribution system. By generating electricity in smaller amounts closer to end-users, we can dramatically increase energy efficiency, reduce carbon pollution, improve grid resiliency, and curtail the need for new transmission investments. Distributed generation (also called on-site generation or decentralized generation) is a term describing the generation of electricity for use on-site, rather than transmitting energy over the electric grid from a large, centralized facility (such as a coal-fired power plant).

Microgrids are systems that have at least one Distributed Energy Resource and associated loads and can form intentional islands in the electrical distribution systems. To understand how a microgrid works, it is good to understand how the grid works. The grid connects homes, businesses and other buildings to central power sources, which allow us to use appliances, heating/cooling systems and electronics. But this interconnectedness means that when part of the grid needs to be repaired, everyone is affected. This is where a microgrid can help. A microgrid generally operates while connected to the grid, but importantly, it can break off and operate on its own using local energy generation in times of crisis like storms or power outages, or for other reasons. A microgrid can be powered by distributed generators, batteries, and/or renewable resources like solar panels. Depending on how it's supply and how its requirements are managed, a microgrid might run indefinitely.

A microgrid connects to the grid at a point of common coupling that maintains voltage at the same level as the main grid unless there is some sort of problem on the grid or other reason to disconnect. A switch can separate the microgrid from the main grid automatically or manually, and it then functions as an island. A microgrid not only provides backup for the grid in case of emergencies, but can also be used to cut costs, or connect to a local resource that is too small or unreliable for traditional grid use. A microgrid allows communities to be more energy independent and, in some cases, more environmentally friendly.

Within microgrids, loads and energy sources can be disconnected from and reconnected to the area or local electric power system with minimal disruption to the local loads. Any time a microgrid is implemented in an electrical distribution system, it needs to be well planned to avoid causing problems.

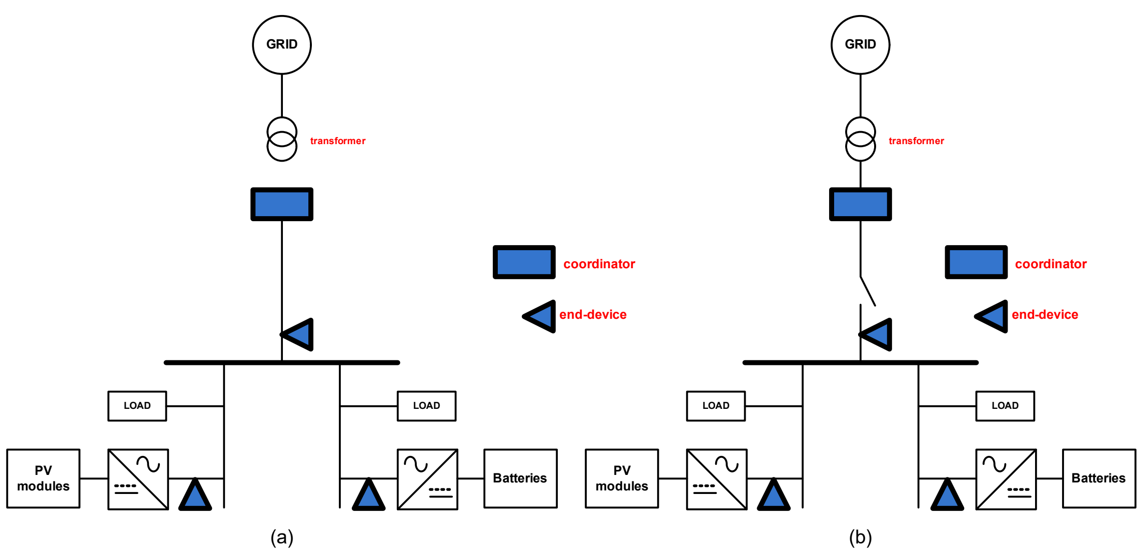

Figure-11 Microgrid under (a) grid connected mode (b) islanding mode

Figure-11 is the schematic diagram for the islanding detection proposed solution. Each sensor (end device) is assigned to a dedicated generation units all over the microgrid. This generation units can be a small solar system or a diesel generator in big microgrids. The coordinator is assigned to monitor the network voltage at the grid side (V) and send it to all sensors in the network in each time step instantaneously. If end users are in the communication range of coordinator, they can exchange information using one-hop communication. This is the preferred method when the microgrid is small.

In a microgrid, renewable energy sources plays a vital role and the energy produced is not adequate to meet the demand because of the intermittent nature of wind and solar and the system frequency becomes oscillatory. The control of active power in response to the system frequency is accomplished by coordinating wind turbine generators (WTGs) with the real power outputs from diesel generation (DG), microturbine (MT), aqua electrolyser (AE), fuel cell (FC), battery energy storage system (BESS), or flywheel (FW).

When a microgrid and main grid are interconnected, microgrid exports power to the grid as there is a surplus power generation and imports power when there is a power deficit. Thereby, system frequency deviations are controlled. But, when the microgrid operates in an isolated mode, it should satisfy the demand. With the presence of renewable energy sources, frequency control becomes an issue. In a microgrid system, frequency deviation is an indication of a real power deficit. Considering the intermittent nature of the renewable energy sources and load variations, effective control methods have to be implemented for the proper generation of power from microgrid sources such as DG, FC, AE, BESS, FW, and MT to meet the demand and regulate the frequency.

As microgrid comprises renewable energy sources which are intermittent in nature, the generation–load balance becomes significant. Non- renewable energy sources have to be incorporated to maintain the frequency deviation within the limits. Hence, an appropriate control scheme has to be implemented for the microgrid sources.

Droop control method is one of the techniques to control the frequency deviations of the microgrid. Generally, a reference frequency is set as a small percentage of the actual frequency of the system. As the load increases, the actual frequency of the plant decreases which is caused by the reduced power generation. Hence, the difference between the reference frequency and the actual frequency increases the working fuel input to the plant to generate more power to meet the load. Briefly, the power generation of a system should change in proportion to the frequency deviations. This is executed by the droop constant R. Figure-12 shows the P/f droop characteristics.

When microgrid is connected to the main grid, the frequency regulation is taken care of by the main grid. When MG is disconnected from the grid, the frequency control becomes an issue. To solve this problem, BESS and/or supercapacitors are coordinated using the droop controller. When the load increases, the frequency falls because of the fall in generation. During this time, BESS and/or supercapacitor discharge accordingly with the variation of the frequency. Moreover, BESS combines with PV and adopts the adaptive droop control to act as a voltage source. During the charging period of BESS, the electrical load is shared among other sources. PV system supplies enough power to load when solar irradiance is at its peak.

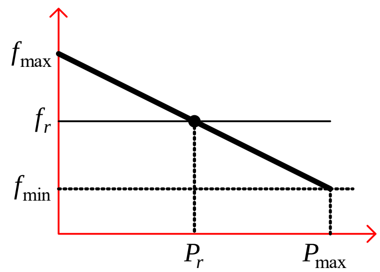

Figure-12 P/f droop characteristic

4. DESCRIPTION OF PROPOSED LABORATORIES

The PEL (Power Electronics Laboratory) which will be set up in SCU and supported by eACCESS consists of a microgrid system with three power sources, these are utility, Photovoltaic and battery as energy storage system.

Figure-13 shows the microgrid system for SCU that consists of a Photovoltaic arrays, these are PV string (about 5.4 kWp), it is used to convert solar energy into electrical energy in the DC form. Then the electric energy produced by PV string then is converted into 220 V / 50 Hz voltage by using 3 phase 4 kW inverter, then it is connected to Busbar-1. This Busbar is also connected to some loads, include critical loads and dummy loads. Another Busbar (Busbar-2) is connected to the utility via “home manager” and the output of battery inverter (3 x 1 phase inverter) whose input is form batteries (Lead acid batteries 12V 100 Ah with 14.4 kWh capacity). The battery inverter must be able to operate in reversible mode, this means that it can be operated as rectifier in charging battery and inverter mode in supplying the Busbar-2.

The proposed microgrid system must be able to operate under different mode of operation :

- Mode of Operation without Battery
  - Grid connected for $P_{PV} < P_{Load}$
  - Grid connected for $P_{PV} > P_{Load}$
- Mode of Operation with Battery Supply
  - Grid connected for $P_{PV} < P_{Load}$
  - Grid disconnected for $P_{PV} < P_{Load}$
  - Grid disconnected for $P_{PV} > P_{Load}$

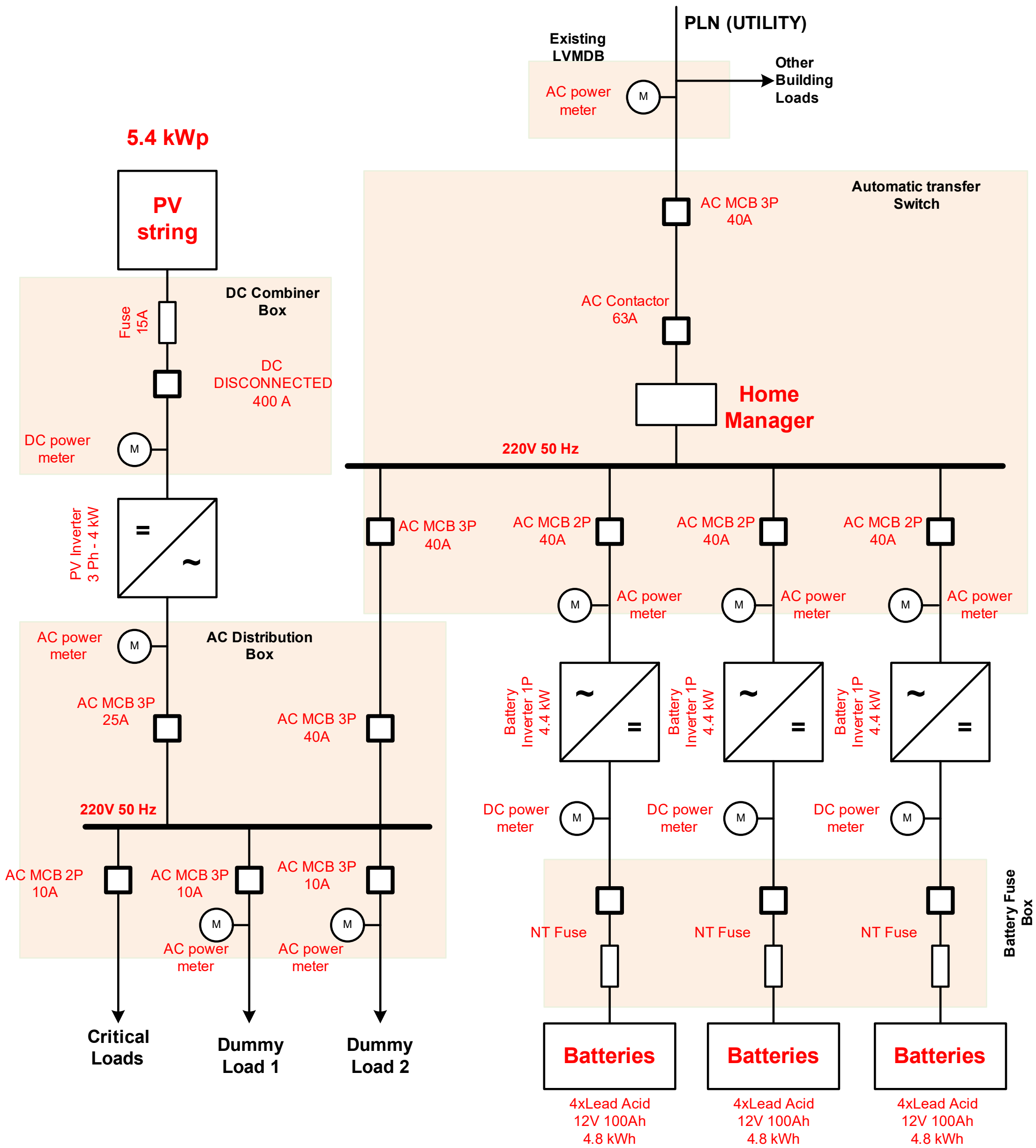

Figure-13 Single-line diagram of microgrid laboratory for SCU

4.1 GRID CONNECTED WITHOUT BATTERY MODE FOR $P_{PV} < P_{Load}$

In mode the power absorbed by the loads is greater than the power generated by PV modules so it requires utility supply. The power flow of this mode is depicted in Figure-14, PV-inverter will operate to convert DC voltage as output of PV modules into AC voltage and then transfer this power to the 220V 50Hz busbar. Another supply comes from the utility is also sent into 220V 50Hz as the PCC (point of common coupling) for the loads.

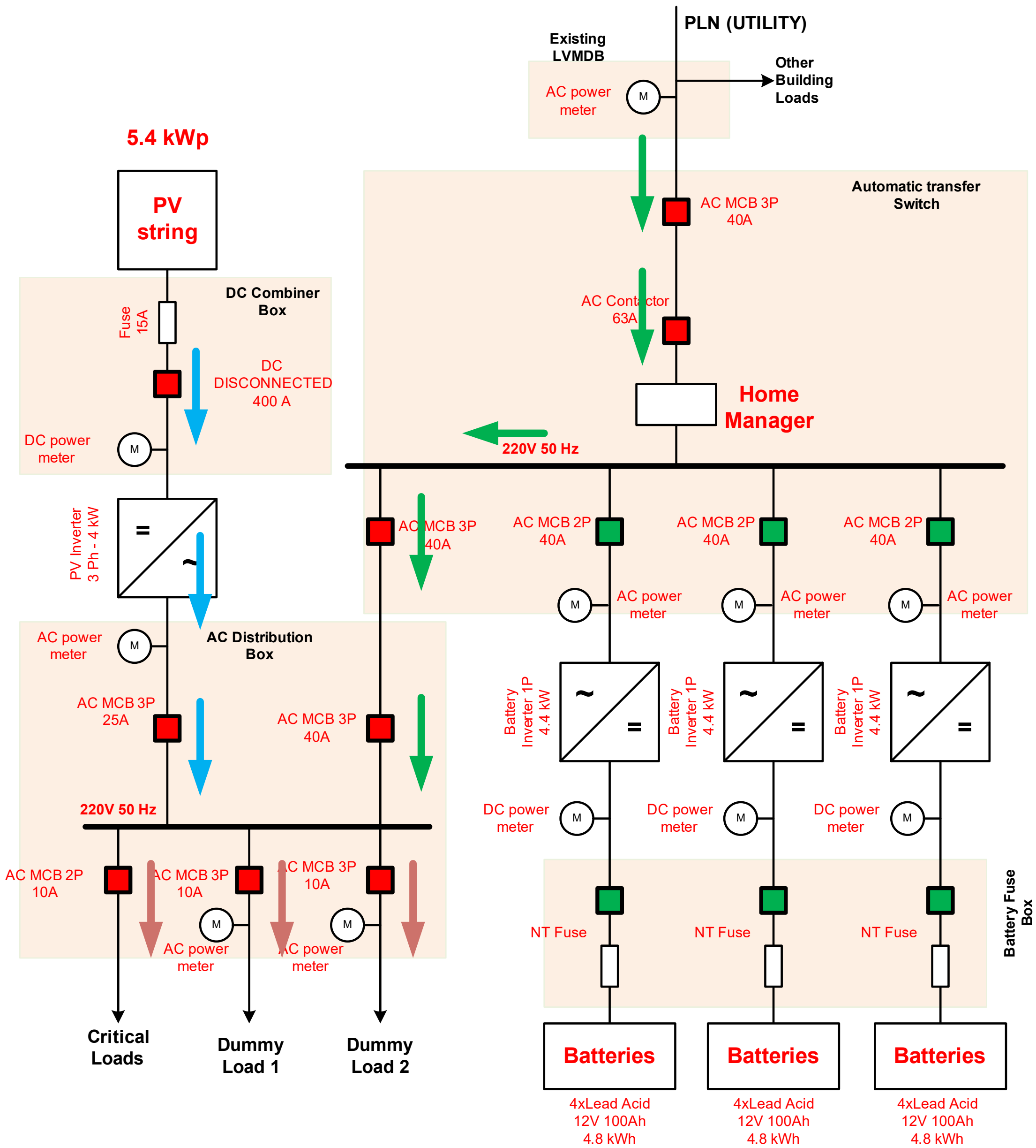

Figure-14 **Power flow for microgrid system under operation mode without battery, grid connected and $P_{PV} < P_{Load}$**

4.2 GRID CONNECTED WITHOUT BATTERY MODE FOR $P_{PV} > P_{Load}$

In this mode, the power generated by the PV modules is greater than the power absorbed by the loads so part of the power from the PV modules is also sent to utility. The utility will receive power from the microgrid so this power can be used by other loads outside the microgrid. This condition can reduce the usage bill than must be paid to the utility company. The power flow under this mode is shown in Figure-15.

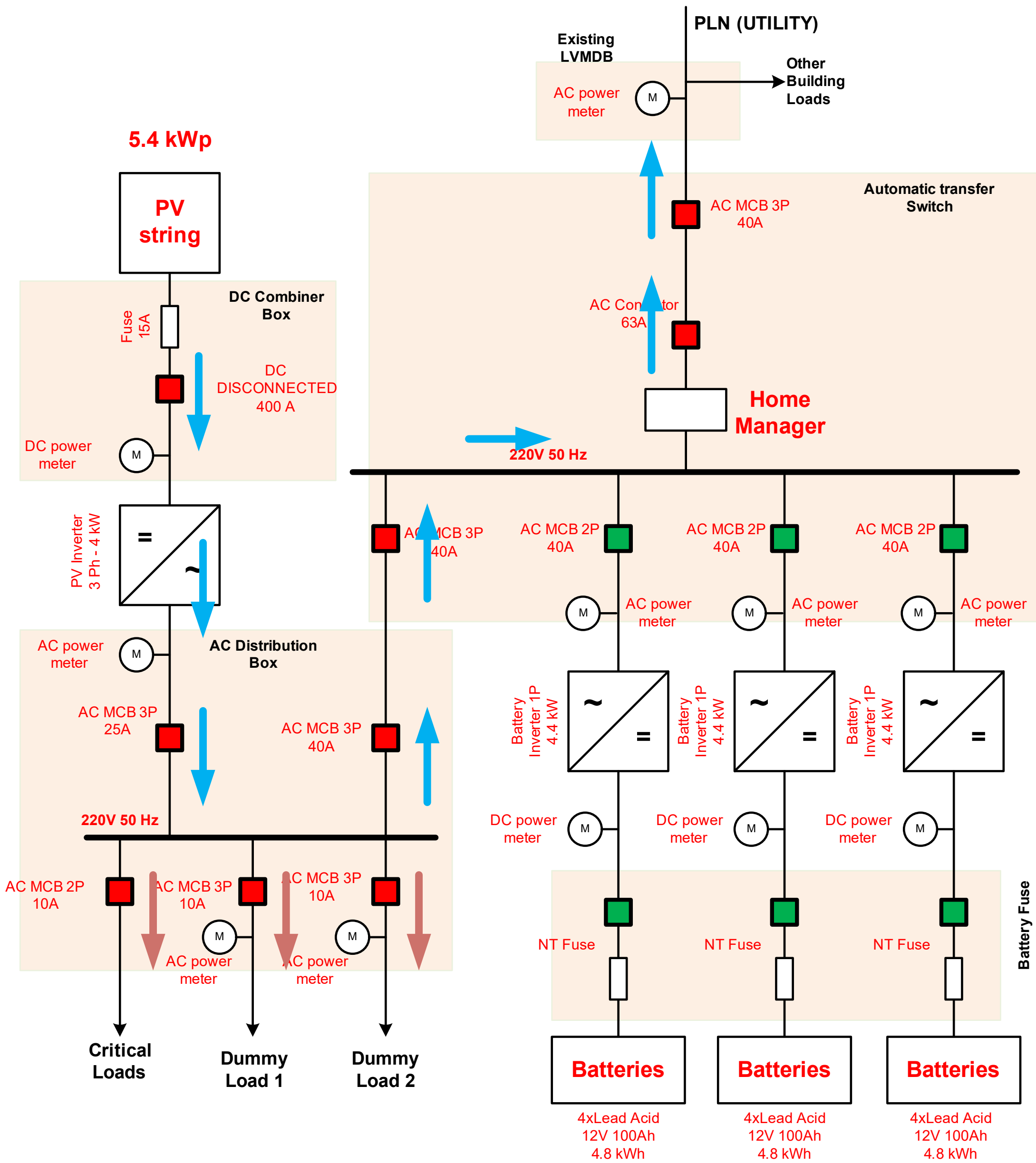

Figure-15 **Power flow for microgrid system under operation mode without battery, grid connected and $P_{PV} > P_{Load}$**

4.3 GRID CONNECTED WITH BATTERY MODE FOR $P_{PV} < P_{Load}$

This mode uses the battery and the power absorbed by the loads is greater than the power generated by the PV modules. In this mode, all power from the PV modules must be transferred in to the loads, then the rest of power needed by the load can be supplied by the utility and the battery. The power flow under this mode is shown in Figure-16.

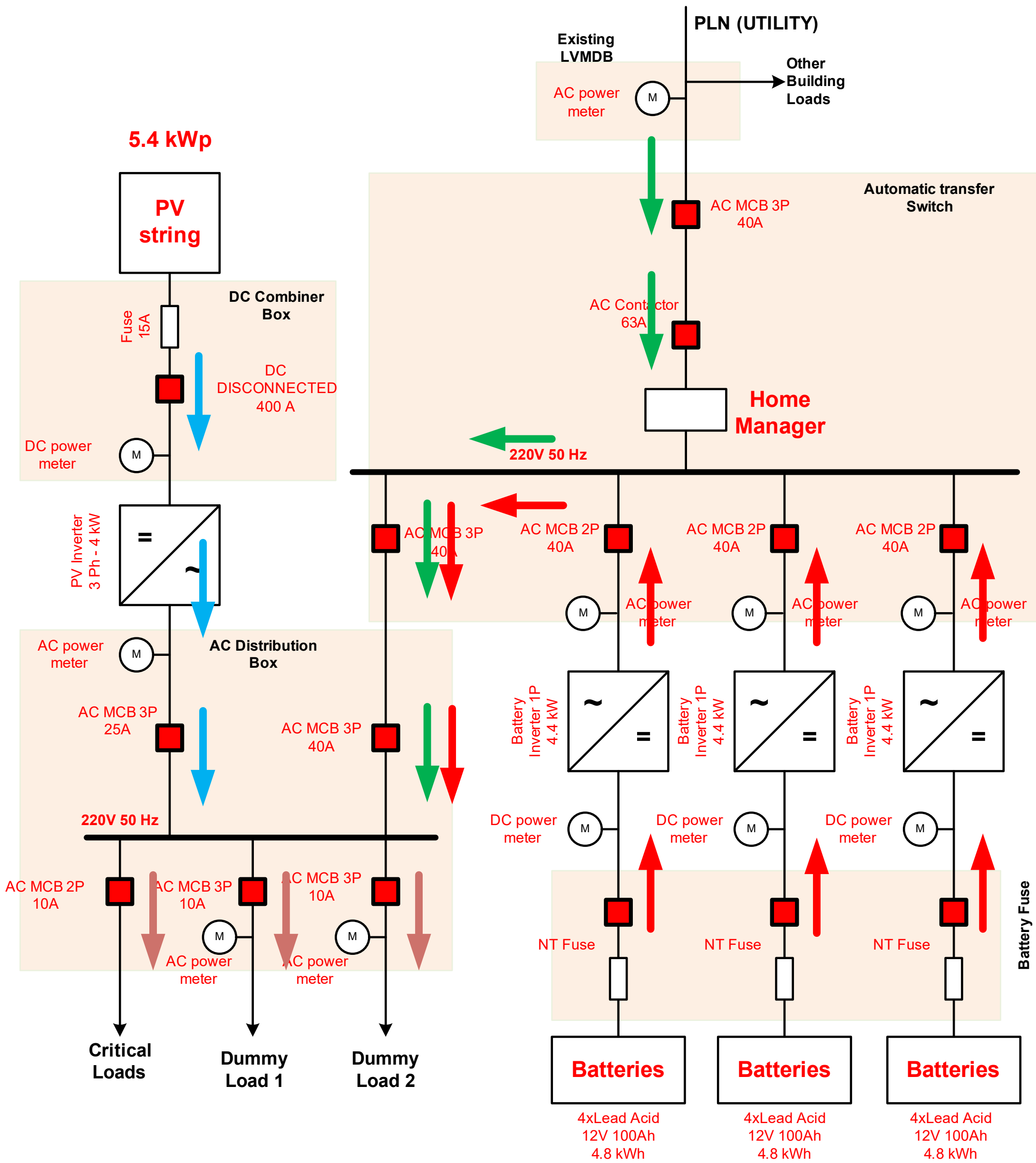

Figure-16 Power flow for microgrid system under operation mode with battery supply, grid connected and $P_{PV} < P_{Load}$

4.4 ISLANDING MODE FOR $P_{PV} < P_{Load}$

In this mode, the utility is disconnected from the microgrid so there are only two power sources : PV modules and the battery as energy storage. When the power absorbed by the loads is greater than the power generated by the PV modules, then the battery will supply the power to the loads through the battery inverter. The power flow under this mode is shown in Figure-17.

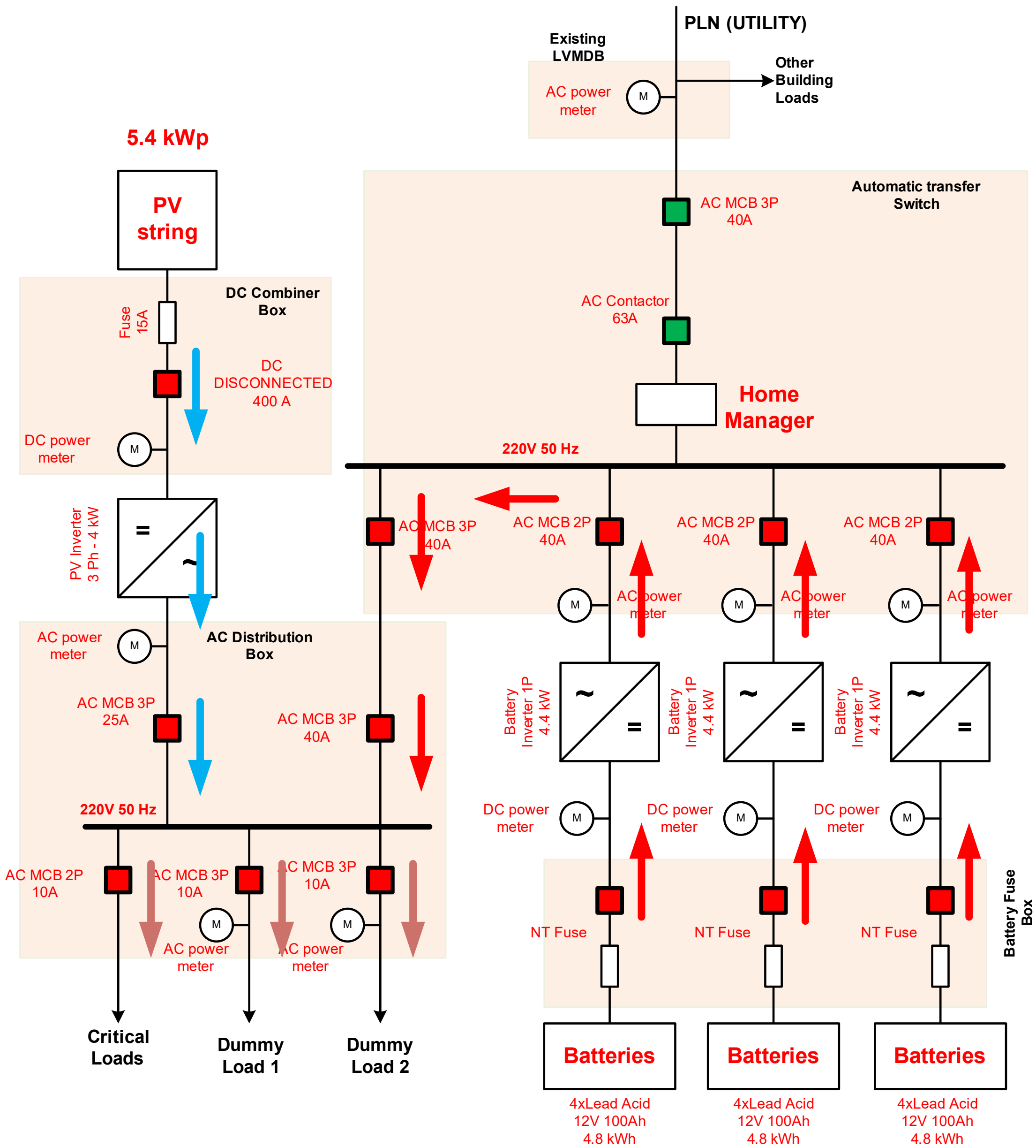

Figure-17 Power flow for microgrid system under islanding mode and $P_{PV} < P_{Load}$

4.5 ISLANDING MODE FOR $P_{PV} > P_{Load}$

In this mode, the power generated by the PV modules is greater than the power absorbed by the loads, so the rest of power can be sent to charge the battery. In this mode the battery converter will be operated as a rectifier to charge the battery. The power flow under this mode is shown in Figure-18.

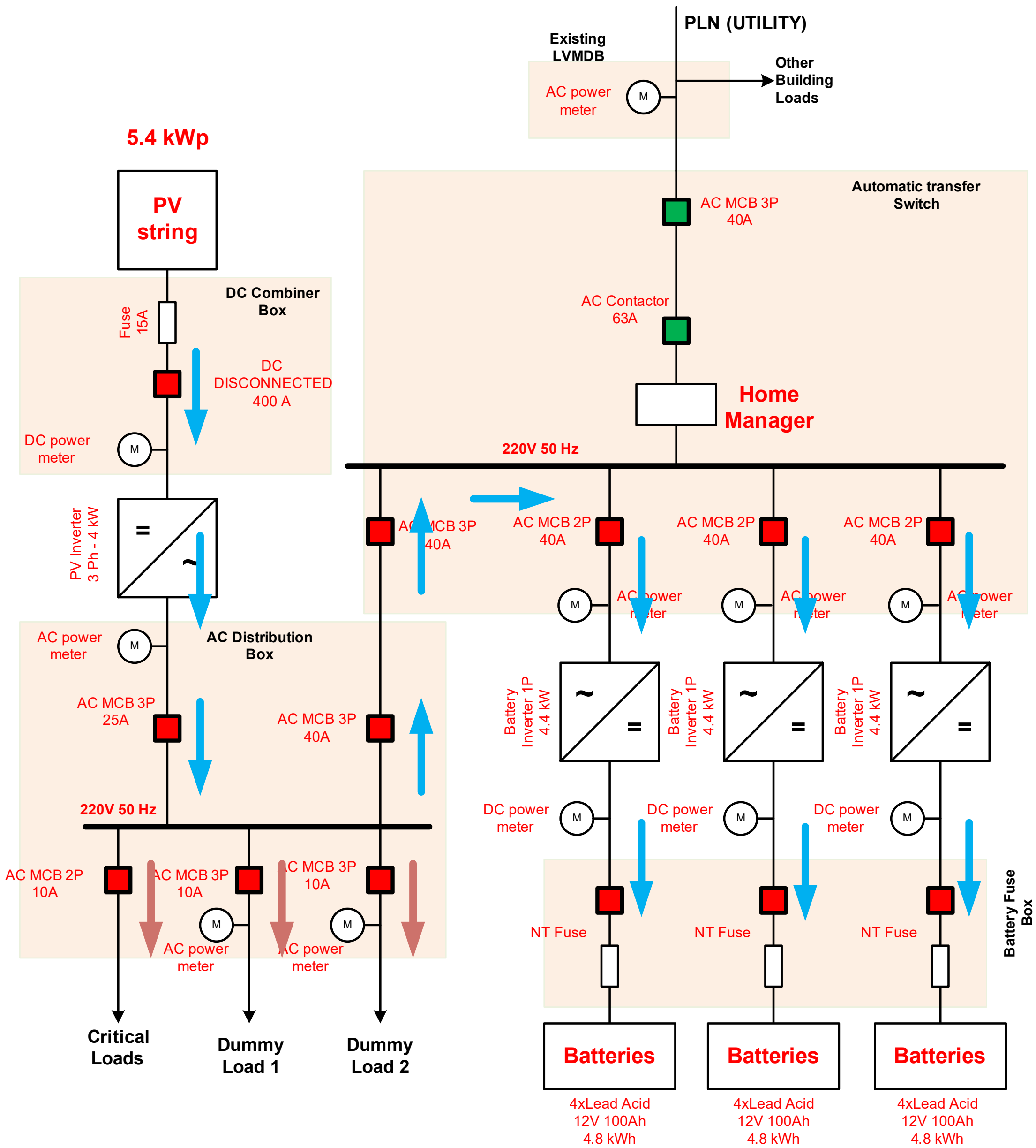

Figure-18 Power flow for microgrid system under islanding mode and $P_{PV} > P_{Load}$

COMPONENTS OF THE SYSTEM

PV MODULES

This PV Modules operate to produce electric energy from solar energy. The electric energy is on the form of DC quantity so in this application, a converter which can convert this DC voltage into AC voltage is required.

Monocrystalline Solar Panels (Mono-SI)

This type of solar panels (made of monocrystalline silicon) is the purest one. They can be easily recognised from the uniform dark look and the rounded edges. The silicon's high purity causes this type of solar panel has one of the highest efficiency rates, with the newest ones reaching above 20%. Monocrystalline panels have a high power output, occupy less space, and last the longest. Of course, that also means they are the most expensive of the bunch. Another advantage to consider is that they tend to be slightly less affected by high temperatures compared to polycrystalline panels.

Polycrystalline Solar Panels (Poly-SI)

these panels can be quickly distinguised because this type of solar panels has squares, its angles are not cut, and it has a blue, speckled look. They are made by melting raw silicon, which is a faster and cheaper process than that used for monocrystalline panels. This leads to a lower final price but also lower efficiency (around 15%), lower space efficiency, and a shorter lifespan since they are affected by hot temperatures to a greater degree. However, the differences between mono- and polycrystalline types of solar panels are not so significant and the choice will strongly depend on your specific situation. The first option offers a slightly higher space efficiency at a slightly higher price but power outputs are basically the same.

Thin-Film Solar Cells (TFSC)

Thin-film solar panels are manufactured by placing one or more films of photovoltaic material (such as silicon, cadmium or copper) onto a substrate. These types of solar panels are the easiest to produce and economies of scale make them cheaper than the alternatives due to less material being needed for its production. It has low efficiency (around 7%-10%),
They are also flexible—which opens a lot of opportunities for alternative applications—and is less affected by high temperatures. The main issue is that they take up a lot of space, generally making them unsuitable for residential installations. Moreover, they carry the shortest warranties because their lifespan is shorter than the mono- and polycrystalline types of solar panels. However, they can be a good option to choose among the different types of solar panels where a lot of space is available.

BATTERY

The batteries are functioned as energy storage elements. When the system under islanding mode, the system relies on energy from the batteries and PV modules. The batteries can be charged by energy from utility or from PV-modules. There are some types of rechargable batteries in the market.

NICKEL CADMIUM BATTERIES

The active components of a rechargeable NiCd battery in the charged state consist of nickel hydroxide (NiOOH) in the positive electrode and cadmium (Cd) in the negative electrode. For the electrolyte, potassium hydroxide (KOH) is normally used. Due to their low internal resistance and the very good current conducting properties, NiCd batteries can supply extremely high currents and can be recharged rapidly. These cells are capable of sustaining temperatures down to -20°C. The selection of the separator (nylon or polypropylene) and the electrolyte (KOH, LiOH, NaOH) influence the voltage conditions in the case of a high current discharge, the service life and the overcharging capability. In the case of misuse, a very high-pressure may arise quickly. For this reason, cells require a safety valve. NiCd cells generally offer a long service life thereby ensuring a high degree of economy.

NICKEL METAL HYDRIDE BATTERIES

The active components of a rechargeable NiMH battery in the charged state consist of nickel hydroxide (NiOOH) in the positive electrode and a hydrogen storing metal alloy (MH) in the negative electrode as well as a potassium hydroxide (KOH) electrolyte. Compared to rechargeable NiCd batteries, NiMH batteries have a higher energy density per volume and weight.

LITHIUM ION BATTERIES

The term lithium ion battery refers to a rechargeable battery where the negative electrode (anode) and positive electrode (cathode) materials serve as a host for the lithium ion (Li+). Lithium ions move from the anode to the cathode during discharge and are intercalated into (inserted into voids in the crystallographic structure of) the cathode. The ions reverse direction during charging. Since lithium ions are intercalated into host materials during charge or discharge, there is no free lithium metal within a lithium-ion cell. In a lithium ion cell, alternating layers of anode and cathode are separated by a porous film (separator). An electrolyte composed of an organic solvent and dissolved lithium salt provides the media for lithium ion transport. For most commercial lithium ion cells, the voltage range is approximately 3.0 V (discharged, or 0 % state-of-charge, SOC) to 4.2 V (fully charged, or 100% SOC).

SMALL SEALED LEAD ACID BATTERIES

Rechargeable small sealed lead acid (SSLA) batteries, which are valve-regulated lead acid batteries, (VRLA batteries) do not require regular addition of water to the cells, and vent less gas than flooded (wet) lead-acid batteries. SSLA batteries are sometimes referred to as “maintenance free” batteries. The reduced venting is an advantage since they can be used in confined or poorly ventilated spaces.

PV-INVERTER

This inverter has capability to convert the DC voltage as the output of PV modules into AC voltage which will be transferred into the busbar. The inverter must also be functioned as maximum power point tracker to maximize the PV output power. There three different types of inverters used to convert PV output into AC.

String Inverters

String inverters are the most cost-effective inverter option available in the U.S. Traditionally, solar installation companies generally offered systems with string inverters if your roof had limited shading throughout the day and did not face in multiple directions (such as a gabled roof). However, recent hardware and software updates from the major string inverter companies now make them applicable in a wider set of circumstances.

Your solar panels are arranged into groups connected by “strings”, hence their name. Multiple strings of panels can be connected to a single inverter, which transforms the DC electricity produced by the panels into appliance-friendly AC electricity. String inverter technology has been used for decades. It is a very reliable, tried-and-true technology, though may not be suitable for certain types of installations. Although modern solar technology allows individual panels to continue producing power even if a part of the panel is shaded, without module level power electronics, string inverters can only optimize power output at the string level, not at the individual panel level. This means string inverter systems may not be right for homes that are prone to shading throughout the day. However, their ease of install and lower price point make them attractive to many homeowners and installers. One of the most common reasons for individual solar panels to produce less power or stop producing power altogether is shading from nearby objects. If your roof is prone to shading throughout the day or in certain seasons, you could either remove the source of the shade (e.g. cut down a tree) or install the panels where they will not be shaded.

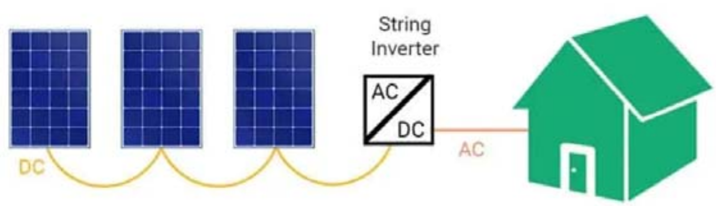

Figure-19 String inverter

Microinverters

Microinverters, another form of module level power electronics, are gaining popularity, particularly for residential solar systems. Microinverters tend to be more expensive than string inverters or power optimizers, however recent declines in their costs have made them a more competitive option.

Microinverters are installed on each individual panel in a solar energy system. They convert the DC electricity from your solar panels into AC electricity on your roof, with no need for a separate central inverter. In many cases the microinverters are mounted onto the back of the solar panel itself, but they may also be mounted next to the panel on your solar panel racking system.

Microinverters take MLPE (module level power electronics to the logical conclusion: while power optimizers aggregate the electricity from your panels and send it to a central inverter for the DC to AC conversion, microinverters make the DC to AC inversion right at each individual solar panel. As a result, as with power optimizer systems, microinverters also allow you to monitor the performance of individual solar panels.

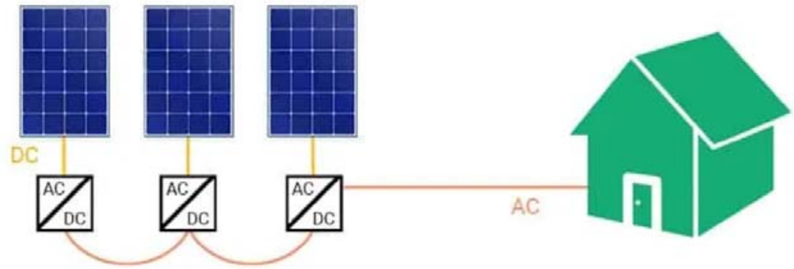

Figure-20 micro-inverter

Power optimizers

Power optimizers, a type of module level power electronics, offer many of the same benefits as microinverters, but tend to be slightly less expensive. Power optimizers are often considered a compromise between more expensive microinverters and the standard string inverter.

Like microinverters, power optimizers are devices located at each panel. However, instead of converting the DC electricity to AC electricity at the panel site, they "condition" the DC electricity and send it to a string inverter. In scenarios where your roof is shaded, the panel level optimization afforded by power optimizers results in higher system efficiency than using a string inverter alone. Similar to microinverters, power optimizers reduce the impact of panel shading on system performance, and also offer panel-level performance monitoring. Systems that use optimizers are often more affordable than those that use microinverters.

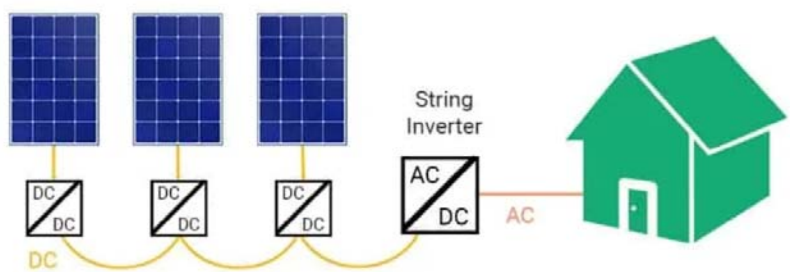

Figure-21 Inverter with power optimizer

BATTERY-INVERTER

To charge or discharge energy into or from batteries, bidirectional converter is reguired. To charge the batteries, such a converter is operated as a rectifier while to discharge the batteries or to to supply the busbar, such a converter must be operated as an inverter.

HOME MANAGER

This will monitors all energy flows in the system, automatically identifies potential savings and facilitates efficient use of solar energy. Intelligent energy management is thus becoming even easier and more cost-effective

SCADA SYSTEM

SCADA system must be capable to function for monitoring and controlling the system on different modes of operations. The quantities of voltages, currents, real power, reactive power, temperature and irradiation of the system must be able to be displayed on monitor graphically or in measurement numbers. Based on the measurements as the data, SCADA controls the status of the circuit breaker via the PLC.

Supervisory Control and Data Acquisition (SCADA) is a system of collecting information or data from the results of electricity measurements and then sending it to a central computer which will regulate, process, and control the data. The SCADA system is needed to handle a plant system by controlling, monitoring, marking, recording and retrieving data with a high level of complexity. The proposed SCADA system consists of a Master Terminal Unit (MTU), Human Machine Interface (HMI), Front End Processor (FEP), Data Communication Media, Remote Terminal Unit (RTU), and plants.

This SCADA system is formed by four components that have synergistic functions with each other, these components are:

- Transducer, instrumentation equipment in the form of sensors used to read analog or digital signals that are measured in the form of current, voltage, irradiance, temperature or other measurements
- Actuators (controlled contactors) are used to control equipment such as power flow connected to a PLC (RTU).
- Remote Terminal Unit (RTU), computer-based equipment that is placed at certain locations and places in the field. The RTU acts as a local data collector that gets its data from sensors and sends commands directly to the equipment in the field which functions to control the actuators and read signals from the sensors and communicate with the control center.
- The communication network is used to connect the RTU with the central station for MTU control, which can be a cable or radio network
- The Master Terminal Unit (MTU) is a computer that is used as a central processing unit for the SCADA system. This MTU provides a Human Machine Interface (HMI) for the user, and automatically adjusts the system according to the input from the sensor received.

Supervision and control functions in the SCADA system:

- Tele-signalling (TS) functions for sending signals to changes in state on the sensors that have been placed (current, voltage, irradiance, temperature). With this, it is expected that the real power, reactive power, power flow and irradiance conditions and temperature can be known in real time.
- Tele-control (TC) functions to operate the desired power flow and respond to what is desired

- Tele-metering (TM) which functions to read the desired data. The results of this monitoring are not only used as data loggers for the operation of the power flow, but can also be used in relation to remote control

One of the important things in a SCADA system is data communication between the remote system (remote station / RTU) and the control center. Communication on SCADA systems uses a special protocol, although there are also general protocols that are used. One of the protocols used in the SCADA system for electric power systems must comply with IEC Standards including IEC 60870-5-101 which is based on serial communication and IEC 60870-5-104 which is based on Ethernet communication.

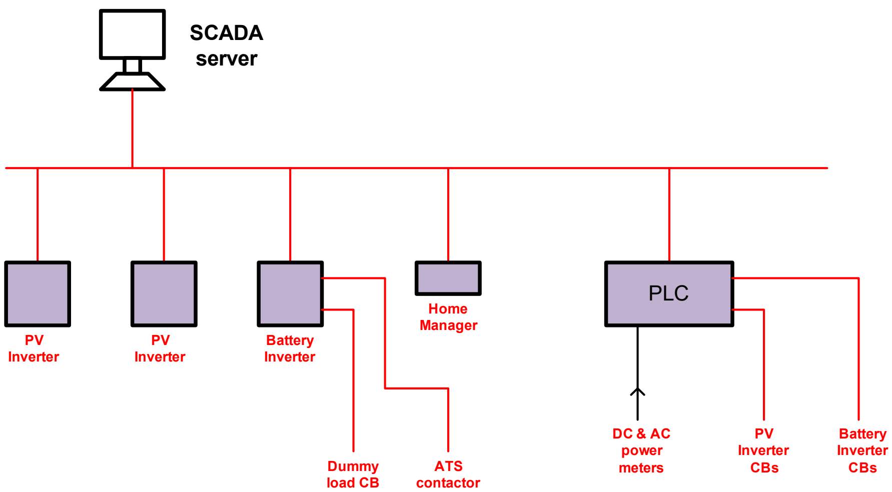

Figure-22 Communication and Monitoring System

Figure-23 Locations for PV arrays and indoor system for SCU Microgrid Laboratory

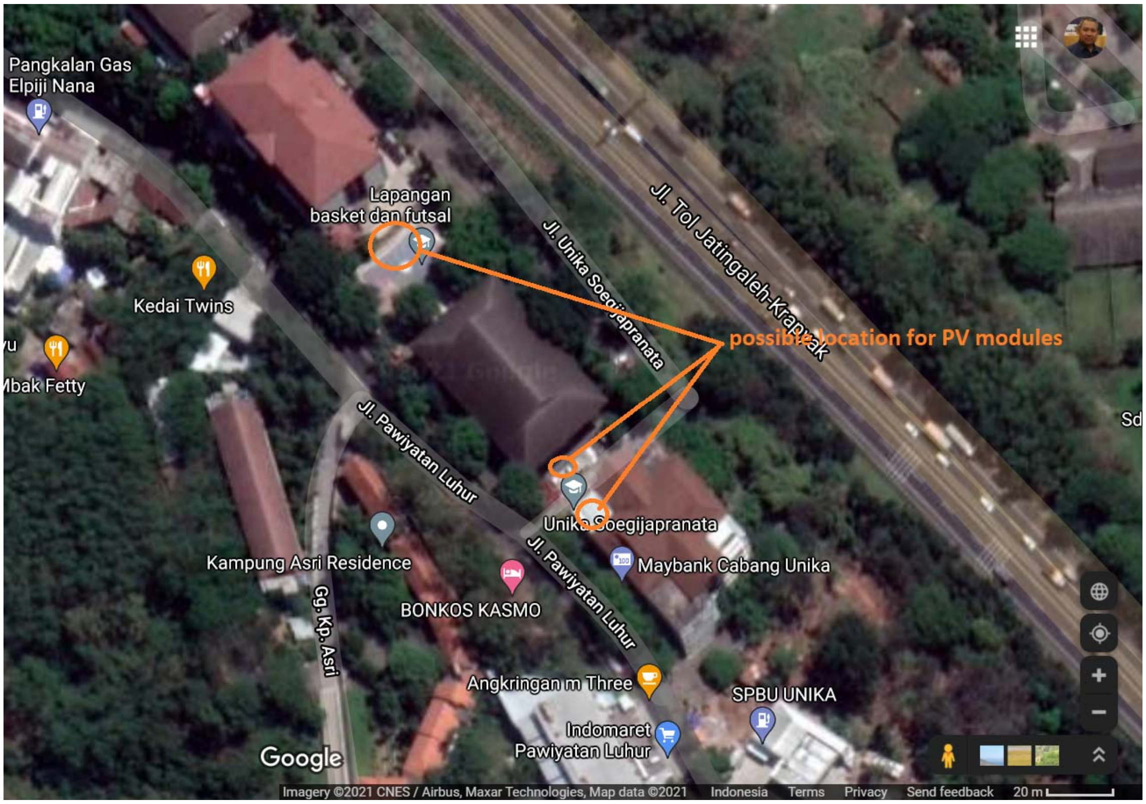

Figure-24 Locations for PV arrays

5. LABORATORY CAPABILITY

The proposed Microgrid Laboratory for SCU will be operated to support practical activity for students and lecturers. Some practices which can be conducted are

5.1 Basic Solar PV Power Plant :

The objective of the module is to learn and practice the basic operation of photovoltaic

5.2 PV-Grid Connected System :

The objective of the module is to learn and practice the operation of photovoltaic in connection to utility

5.3 Microgrid under Grid Connected-1 :

The objective of the module is to learn and practice the operation of microgrid when the power generated by PV modules is less than the load power ($P_{PV} < P_{Load}$) without battery supply

5.4 Microgrid under Grid Connected-2 :

The objective of the module is to learn and practice the operation of microgrid when the power generated by PV modules is greater than the load power ($P_{PV} > P_{Load}$) without battery supply

5.5 Microgrid under Grid Connected-3 :

The objective of the module is to learn and practice the operation of microgrid when the power generated by PV modules is less than the load power ($P_{PV} < P_{Load}$) with battery supply

5.6 Microgrid under Islanding Mode $P_{PV} < P_{Load}$

The objective of the module is to learn and practice the operation of microgrid when the power generated by PV modules is less than the load power ($P_{PV} < P_{Load}$) with battery supply under grid-disconnected

5.7 Microgrid under Islanding Mode $P_{PV} > P_{Load}$

The objective of the module is to learn and practice the operation of microgrid when no connection to the utility and the power generated by PV modules is greater than the load power ($P_{PV} > P_{Load}$)

5.8 Unbalance and Reactive Power :

The objective of the module is to learn and practice the operation of microgrid under unbalance condition and impact of reactive power

6. EXTENDED POSSIBILITY

To extend the proposed microgrid laboratory, SCU plans to develop wind turbine-generator system. The extended system is depicted in Figure-25.

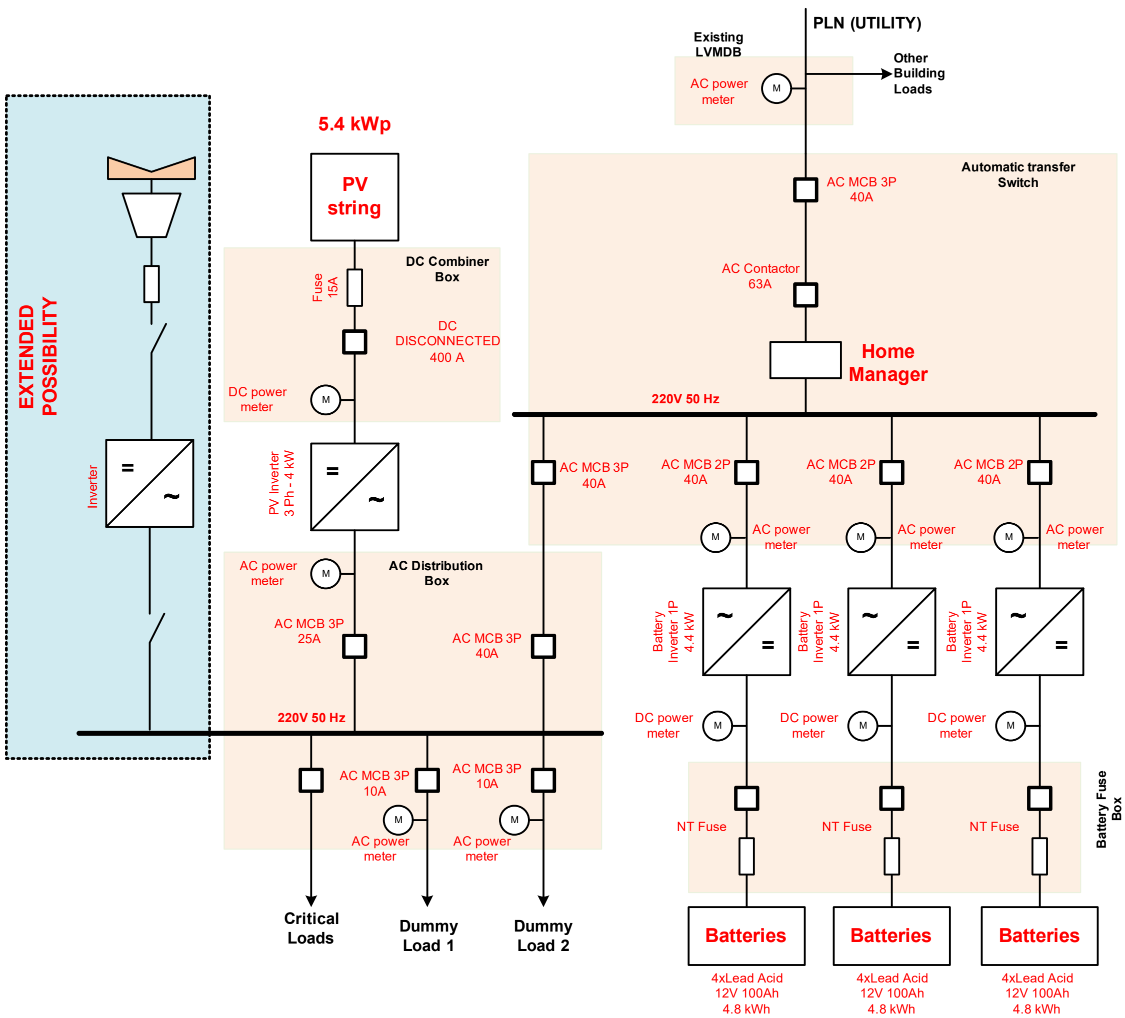

Figure-25 Extended possibility for SCU Microgrid Laboratory

7. LIST OF USED EQUIPMENTS

NO		DESCRIPTION	QTY	UNIT
1	**Solar Module**			
	a.	Solar PV Tier 1 module 540 Wp	10	unit
	b.	PV Mounting	1	lot
2	**Solar Inverter**			
	a.	Solar Inverter 3ph-4.4 kW	1	unit
	b.	Inverter Rack	1	lot
3	**Battery**			
	a.	Lead Acid Battery 12V 100Ah	12	unit
	b.	Battery Rack & Mounting	1	lot
	c.	Battery Connection Box	1	unit

4	**Battery Inverter**			
	a.	Battery Inverter 1ph-4.4 kW	3	unit
5	**DC Combiner Box**		1	unit
	a.	DC Combiner Box 1in-1out	1	unit
	b.	DC Power Meter	1	unit
6	**AC Combiner Box**		1	unit
	a.	AC Power Meter	3	unit
	b.	Load MCB 3P AC 10A	1	unit
	c.	Dummy Load MCB 3P AC 10A controllable	2	unit
	d.	Inverter MCB 3P AC 25A controllable	1	unit
	e.	Inverter MCB 3P AC 40A	1	unit
	f.	AC SPD Type I+II	1	unit
	g.	enclosure	1	unit
	h.	Accessories	1	unit
7	**Automatic Transfer Switch**		1	unit
	a.	Data Manager	1	unit
	b.	AC power Meter	3	unit
	c.	MCB battery Inverter 2P	3	unit
	d.	MCB AC 40A Controllable	1	unit
	e.	MCB AC 40A	1	unit
	f.	AC Contactor	1	unit
	g.	Enclosure	1	unit
	h.	Accessories	1	unit
8	**Cable & Accessories**		1	lot
	a.	PV Cable 1x6mm	200	m
	b.	PV Connector	2	set
	c.	Battery Cable	15	m
	d.	PV Inverter to AC Combiner Box	15	m
	e.	AC Combiner Box to ATS Box	15	m
	f.	Battery Inverter to ATS Box	15	m
	g.	ATS Box to Existing LVMDB	15	m
	h.	Cable Tray 100x50mm	25	set
	i.	Mounting Tray	25	set
	j.	Conduit Pipe/PVC Duct	50	m
9	**Weather Station**		1	lot
	a.	Pyranometer	1	unit
	b.	Temperature Sensor	1	unit
	c.	Ambient Sensor	1	unit
	d.	Modbus/Ethernet Gateaway	1	lot
	e.	Mini SCADA System	1	unit

10	**Lightning Protection**		1	lot
	a.	Tower Triangle 5m. guyed wire	1	unit
	b.	Lightning Protection Kit	1	unit
	c.	Monitoring Lightning Data	1	set
	d.	PE Cable	200	m