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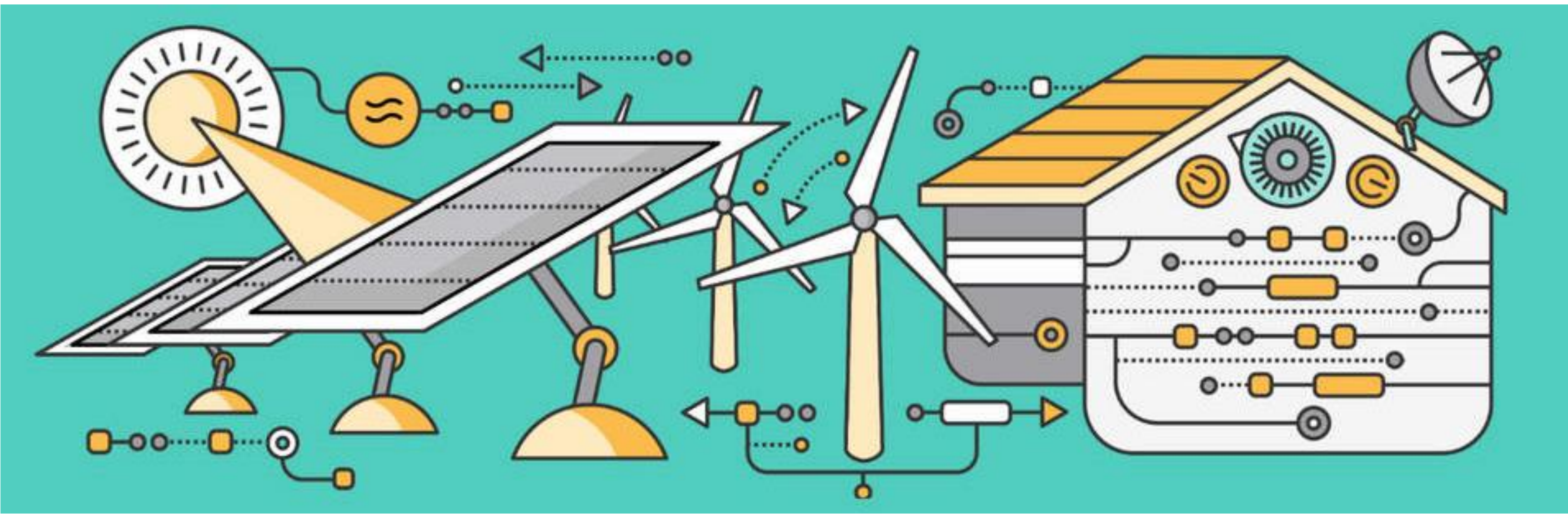

ACT Smart Community

Micro-grid System Project

The Australian National University

ENGN 8100 Introduction to Systems Engineering

Group 16

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Glossary and acronyms.

ACT – Australian Capital Territory
ADMS – Advanced Distribution Management System
AER – Australian Energy Regulator
ARENA-The Australian Renewable Energy Agency
AS 3000 – Wiring Rules
AS60038 – Australian Standard® Standard voltages
AS61000.3.100 – Australian Standard® Electromagnetic compatibility (EMC)
AS/NZS 61000.2.2:2003 – Australian/New Zealand Standard™ Electromagnetic compatibility (EMC)
CPD – Central Power Distribution
CPDN – Central Power Distribution Network
CSP-Concentrating Solar Power
DG – Distributed Generation
DMS – Distribution Management System
DRMS – Demand Response Management System
EMS – Energy Management System
IPDT – Integrated Product Development Team
IRENA – International Renewable Energy Agency
FBD – Function Block Diagram
FFBD – Functional Flow Block Diagram
HoQ – House of Quality
Hz -Hertz
GWh– Gigawatt-hour
kWh – Kilowatt-hour
LCOE – Levelized Cost of Electricity
MG – Microgrid
MGMS – Microgrid Management System
MW - Megawatt
NEM – National Energy Market
NSW – New South Wales
OMS – Outage Management
ORG – Organizational
PM – Project Management
PV – Photovoltaic
RIOS-Recycling Industry Operation Standards
SCADA – Supervisory Control and Data Acquisition
SS – Sub-System
Tech – Technology
TPM – Technical performance measure
UPS – Uninterruptible Power System
USE – Unserved Energy

Executive Summary

On May 2, Group 16 received the contract of designing a microgrid system project in ACT from our client Jochen Trumpf. It was decided that Group 16 shall submit an initial concept design report of microgrid system to the client for reviewing.

Throughout the design phases, a process of system engineering is adopted. Firstly, the needs and benefits of this project are identified, then based on the conversation with our client, a deep analysis of requirements are processed: customer requirements, system requirements, functional and performance requirements. Furthermore, four sub-systems are included in this project: power generation, power distribution, power storage, and management subsystems.

Processed with a comprehensive concepts comparison of each subsystem, the final solutions for each subsystem are determined such as solar panel, lead-acid battery, decentralized distribution and Siemens Spectrum Power Microgrid Management System (MGMS). Risk management process as one vital section in any project is included in this report, while at this initial stage of design only a brief risk management process is included. Later detailed and comprehensive risk monitor plan will be provided. As expenditure is one of client's primary concern, budget plan is also provided.

The Microgrid System is designed for the individual household (on an average of 4 persons per household), which can then be scalable to any number of houses based on the requirements. As per the client requirements this design can be scalable to 50-300 premises. After analysis, some recommendations have been provided for the steering committee to consider, with which better support from key stakeholders could greatly enhance the quality of this project.

1. Project Introduction

1.1 Project Background.

With the increasing demand of energy and electricity, the central power station in ACT carries a huge burden. This could be aggravated especially after the ACT government has approved the further development of several new suburbs. If all the house-holds in the new suburban areas connect to the central power distribution network (CPDN) or the national electricity market (NEM), before the actual utilization, urban development committee and the government need to improve the electricity infrastructure for distributing the power to the new households, which is costly. However, the connections between household to city central power grid inevitably leads to the increase of the dependency of households on the CPDN and CPDN's burden.

However, utilizing other power generation methods to supply power for individual community or suburb could enable the higher efficacy and better utilization of central power which could supply continuously to the large and significant projects only. In this way, the level of dependency could decrease, which is beneficial for both parties.

And, one large real estate organization investor finds our client, Jochen, to discuss this opportunity, and the project they proposed to our team is that: for the new and future suburbs adopting micro-grid system to power the house-holds in that area, and MG system could sell extra electricity back to the market.

A microgrid, as defined by U.S. Department of Energy, is "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. It can connect and disconnect from the grid so as to enable it to operate in both grid-connected or island-mode".[1]

1.2 Benefit of the Project.

From our analysis and investigation [2] the following benefits can be gained from the MG project.

- Cost competitive and efficient;
- Minimize greenhouse gas emissions by maximizing clean and renewable energy generation;
- Increased citizens' (end-use) participation;
- Increase the quality and security of the electricity usage;
- Increase the feasibility and convenience of the maintenance;
- Improve the further planning and development of future new suburbs;
- Explore the possibility of the usage of micro-grid in other disciplines.

1.3. Project High-level Objectives.

- Optimize the power utilization of the central power grid network in further new suburbs.
- Reduced future house-holds' dependency on central power distribution.
- Increased the generation of sustainable and renewable energy.

1.4 Stakeholder Analysis.

Clear stakeholder identification and corresponding communication plan are revealed in the following Table 1, and their influences and interests level are being underpinned.

Table 1. Stakeholder Identification and Communication Plan.

ID	Stake holders	Description	Interests	Power	Communication/engagement plan
SH-1	Customer	Jochen (representative of a large-scale residential project building company)	High	High	Face-to-face meeting once a week; PID, SRS documents and final design report are required.
SH-2	Final Project owner	A large real estate organization investor	High	High	Report meeting once a month. Dashboard report, risk register, and final design report
SH-3	ACT Electricity Dealer	Evoenergy and ActewAGL	High	High	Face-to-face meeting, when ever needed; Integration process need huge cooperation, and settle the agreements.
SH-4	End user	Residence in the suburb in future	High	Low	Survey or interview of Canberra citizens can be conducted to ensure the design tackles their concerns and benefit for the marketing process.
SH-5	Regulators	1. The Australian Energy Regulator (AER)	High	High	Have meeting with AER when necessary, because our design is under supervision. Necessary formal and legal documents are required.
		2. The Australian Energy Market Operator	High	High	Communicate with AEM operator, to make sure our design can work within the AEM. Formal and legal documents are required.
SH-6	Suppliers	The supplier of all the material for MG systems;	High	Low	Quotation process and negotiation process shall be included. Better logistic options can be discussed; Agreement is needed.
SH-7	Team members for design phase	Group 16	High	High	Communicate with each other every week to make sure everyone exchanges their thoughts without trouble. Related document exchange is necessary to ensure the consensus.
SH-8	Workers in other phases.	Staff in other phases, such as: construction, operation, maintenance and property selling.	Low	Low	Communication and training are needed; certain documents for training shall be prepared.
SH-9	ACT Government	Environment and Planning Directorate	High	High	Face-to-face meeting is required whenever it is needed; Evaluation report of our project shall be presented; Dashboard report and final design report shall be submitted.
SH-10	Australian Government	Clean Energy Regulator	Medium	High	Face-to-face meeting is required (1-2 times). To make sure the design is supported by government. Evaluation report of our project shall be presented;

SH-11	External consultants	The Australian Renewable Energy Agency (ARENA)	Medium	Medium	Have a meeting or phone call with consultants whenever needed to make sure the efficiency and safety design.

1.5 Economic Feasibility Research.

From our past experience, the micro-grid project is always a great investment choice with mature technology development support. The Garden Island Microgrid Project invested by ARENA, $2.5million investment generated the total project value to $7.3 million [3]. Also, microgrid projects are expanding in Australia [4], such as Melbourne suburb of Mooroolbark's neighbor sharing project run by AusNet Services [5].

And the overall environment is promising. Taking the solar panel used in microgrid as an example. Figure 1 shows that the solar energy is abundant in Canberra and Australia, and Figure 2 shows that the cost of solar PV generator is very low, and this system is very stable now.

For our company, enough manpower and robust experience are equipped to deliver the project.

Average Daily Production

City	1 kW system	1.5 kW system	2.0 kW system	3.0 kW system	4.0 kW system
Adelaide	4.2 kWh	6.3 kWh	8.4 kWh	12.6 kWh	16.8 kWh
Alice Springs	5.0 kWh	7.5 kWh	10.0 kWh	15.0 kWh	20.0 kWh
Brisbane	4.2 kWh	6.3 kWh	8.4 kWh	12.6 kWh	16.8 kWh
Cairns	4.2 kWh	6.3 kWh	8.4 kWh	12.6 kWh	16.8 kWh
Canberra	4.3 kWh	6.45 kWh	8.6 kWh	12.9 kWh	17.2 kWh
Darwin	4.4 kWh	6.6 kWh	8.8 kWh	13.2 kWh	17.6 kWh
Hobart	3.5 kWh	5.25 kWh	7.0 kWh	10.5 kWh	14.0 kWh
Melbourne	3.6 kWh	5.4 kWh	7.2 kWh	10.8 kWh	14.4 kWh
Perth	4.4 kWh	6.6 kWh	8.8 kWh	13.2 kWh	17.6 kWh
Sydney	3.9 kWh	5.85 kWh	7.8 kWh	11.7 kWh	15.6 kWh

Figure 1. Average daily production of solar PV cells in Australia.

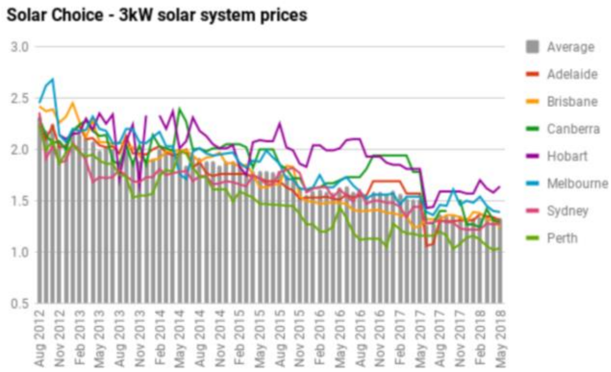

Figure 2. The price of the solar system in Australia [6]

2. Project Requirements Analysis

2.1 Project Constrains and Assumptions.

2.1.1 Constrain.

The cost shall be no larger than 10,000$/ per premise more than a standard grid installation and_operating costs.

2.1.2 Assumptions.

- Enough manpower for this team.
- Related certificates have obtained from the authorities.
- Jochen has accepted our proposal.
- Money is available already from the customers.
- Our project is in ACT Australia.
- Each household has 4 residents on an average.
- The average electricity consumed for per household in the ACT is 18.2kWh per day throughout the whole year [7], and the average electricity in each season is: 14.4 kWh in summer, 17.3kWh in Autumn, 23.0 kWh in Winter and 18.3kWh in Spring [7].
- A large real estate organization invests in this project.

2.2 Customer Requirements

Table 2. Customer Requirements

ID	Customer Requirements
CR1	The MG design shall reach at least the same level of reliability as existing solutions
CR2	The total design of the project shall be affordable.
CR3	The capacity of the MG shall able to scalable for 50 to 300 households.
CR4	The MG design shall able to sell surplus electricity back to the market.
CR5	The MG design shall reduce dependency on central power distribution.

2.3 System Requirements.

2.3.1 Identify System Requirements

Table 3. System Requirements

SR ID	Resource	System Requirement
SR1	CR1	The MG system shall connect to the central power distribution (CPD).
SR2	CR1	The MG design shall have installation and verification procedures in accordance to Electrical installation standards.
SR3	CR1	The MG system shall connect to each household.
SR4	CR1, CR3	The MG system shall able to monitor household electricity power usage.
SR5	CR4, CR5	The MG system shall have power generation unit.

SR6	CR3, CR5	The MG system shall be able to fit for the fluctuation (50-300 premises, peak time, low time)
SR7	CR5	The continuous reliability of the MG.
SR8	CR2	The MG system shall have a long-life service term.
SR9	CR1	The MG system shall be standardized with CPD.
SR10	CR3	The MG system shall able to be easy to use (pay bill, control by individual).
SR11	CR4	The MG system shall have a robust system to monitor the capability and status of the MG and related systems.
SR12	---	The MG system's design, operation and maintenances shall comply with the acts and regulations: [8] 1. Electricity Supply Act 1995 (NSW) 2. Electricity Supply (General) Regulation 2014 (NSW) 3. Electricity Supply (Safety and Network Management) Regulation 2014 (NSW) 4. Electricity Feed-in (Renewable Energy Premium) Act 2008 5. Work Health and Safety Act 2011 6. Work Health and Safety Regulation 2011 7. Code of Practice – Electricity Transmission and Distribution Asset Management
SR13	---	The following standards are deemed applicable to ensure the safe delivery of electricity to consumers: AS60038; AS 61000.3.100; AS/NZS 61000.2.2:2003; AS 3000.

2.3.2 Functional and Performance Requirements

Table 4. Functional and Performance Requirements

Functional Requirement ID	Performance Requirement ID	Description	Resource
FR 1	---	The MG system exemption of registration should be provided by the clients.	CR1
FR2	---	The MG system shall operate when the system switch is on.	CR1
---	PR1	The MG shall generate enough power to accommodate the electricity usage for 50-300 households.	CR1
FR3	PR2	The MG system shall have sufficient level of reserves to meet the high peak.	CR1
FR4	---	During the outage, the MG system should link the NEM to the household	CR1
FR5	---	During the outage, the MG system could send alert to operation team for maintenance.	CR1
---	PR3	The MG system shall multi-work on power generating, power supplying, power storing and power collecting.	CR1
---	PR4	The MG system shall not increase the frequency and Voltage when supplying excess power to CG	CR1
---	PR5	The MG system and its subsystem shall be safe and hard to crack from outside or cyber-attack.	CR1
FR6	PR6	The MG system shall protect its own safety in case other external	CR1

		and internal damage.	
---	PR7	The usage or damage of the MG shall not damage the usage of NEM.	CR1
FR7	PR8	The MG shall handle the electricity peak within one day and the seasonal change.	CR1
---	PR9	The MG shall not break down during the extreme weather.	CR1
FR8	PR9	The MG system shall convert the high voltage to the voltage of 240V and 50 Hz for the household appliances usage.	CR1
---	PR10	The MG control center should be intelligent (no human monitor).	CR2CR5
---	PR11	The maximum expected unserved energy (USE) in this region over a financial year, as a percentage of total energy, shall not over 0.002%. (USE is measured in gigawatt hours GWh)	CR2
---	PR12	The cost of power generator installed on a premises shall not be greater than $5000.	CR2
---	PR13	The cost of power storage equipment shall not be greater than $2500 per premises	CR2
---	PR14	The bill of annual of the electricity shall not surpass $2100.	CR2
FR9	PR15	The MG system shall provide power to the household at a minimum of 50.	CR3
FR10	PR16	The MG system shall provide power to the household at a maximum of 300.	CR3
FR11	---	The MG shall Trace the excess amount of power generated from the Renewable Generators	CR4
FR12	PR17	Renewable Generators must generate more power than demand.	CR4CR5
FR13	---	The MG system shall convert the power back to the NEM.	CR4
FR14	---	The MG system shall provide reliable reserved power for a period time.	CR5
FR15	---	The MG system shall have a community electricity network.	CR5
FR16	---	The MG system shall have display interface for each house.	CR5
FR17	---	The MG system shall have control interface for each house.	CR5
FR18	---	The MG system shall have a control center for the community.	CR5
FR19	---	The MG power generator should use green energy.	CR5
FR20	---	The MG system shall have emergency power supply.	CR5
FR21	---	The MG system shall connect to NEM	CR5
FR21	PR18	The MG shall generate at least 25 kWh power for each household per day.	CR5

2.4 Life Cycle Analysis.

The life-cycle in the system engineering, as identified in Table 5, could help us better break customer requirements down to functional and operational system requirements, and design a comprehensive system with a consideration of system lifecycle.

Figure 3. Life Cycle Process

Table 5. Life Cycle Analysis

ID	Phases Name	Tasks have to be performed
1	Identification of needs	Identify stakeholders; Identify customers' need; Identify target outcomes; Identify requirements; Identify project scope
2	Conceptual and preliminary design	Develop functional requirements; Functional allocation Design subsystems; Analyze the risks
3	Detailed design and verification	Physical architecture of subsystems; Prototyping Detailed Design Reviews; Manufacturing plan Assembling plan; Integration; Analyze the feasibility
4	Production, construction.	Procurement; Construction & installation; Testing
5	Deployment, training, operation and dispose.	System Deployment; User training; System is put into operation; Regular Maintenance should be taking every three months; This system has not retirement date. Once decided abandoned, this system should be disassembled and partly recycled, the rest parts should be processed comply RIOS (Recycling Industry Operation Standards).

3. Functional Analysis and Allocation.

3.1 Function Identification.

After the requirement identification and deep discussion, seven major functions are identified that the system shall perform, presented in Table 6, with specification elaboration of each function.

Table 6. Function Identification and Specification.

Functions	Function specification	
Generate power	➢ Can generate power for a household to use.	
Store power	➢ Can store the power generated from the power generator.	
Distribute power	➢ Can distribute the power to each household. ➢ Can send power back to NEM.	➢ Can send the power from power generator to power storage SS;
Control power	➢ Can manage and shift the loads; ➢ Can control all the connections with MG system	➢ Can achieve frequency regulation. ➢ Can regulate voltage
Monitor power	➢ Can monitor how much electricity used by each household and the whole community; ➢ Can monitor the status of all other subsystems.	➢ Can monitor the weather status; ➢ Collect data from various ways, ➢ Can transmit data;
Protect power	➢ Can prevent system and subsystems from various attack: human, weather, cyber; ➢ Can prevent the system and subsystems from hurting other objects: household, residence;	➢ Can collect the data from various resources and make decisions based on that;
Sell Power	➢ Can sell power back to market; • Measure the amount. • Calculate the price.	➢ Can let the residences pay the bill. ➢ Can store the data;

3.1.1 Functional Block Diagram (FBD)

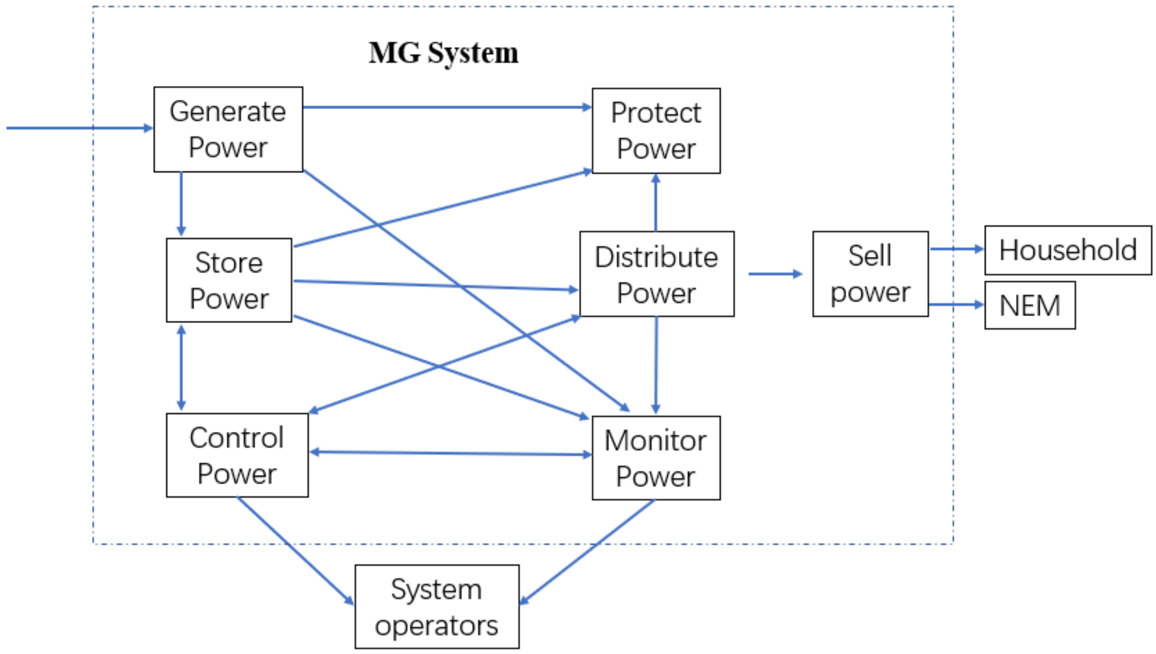

Figure 4. Functional Block Diagram

3.2 Function Allocation and Interface Identification.

Four subsystems, shown in Table 7, would be enough to perform seven functions identified in Section 3.1.

Table 7. Subsystem Identification and Function Allocation.

Sub-system (SS)	The Function they perform.
Power generation SS	Generate power and protect power.
Power distribution SS	Distribute Power and protect power.
Power storage SS	Store power and protect power.
Management SS	Monitor, control, sell and protect power.

3.2.1 Components of subsystems

In order to build the consensus of the team and further design, specification of the components in each sub-system is presented in Table 8.

Table 8. Components of Subsystems

Power Generation Subsystem	Generator, cable, arc-fault circuit interrupter, voltage regulators, inverter;
Energy Distribution Subsystem	small circuit breakers, medium & large switchgear breakers, distribution panels, Underground cables, Transformers, Inverter; earth leakage circuit breaker; arc-fault circuit interrupter
Power storage subsystem	Battery, inverter, transformer, battery calculator; shield; earth leakage circuit breaker; arc-fault circuit interrupter
Management Subsystem	Sensor, control and management application (software), load controller, generator controller, storage controllers

3.2.2 Sub-Systems and Interfaces

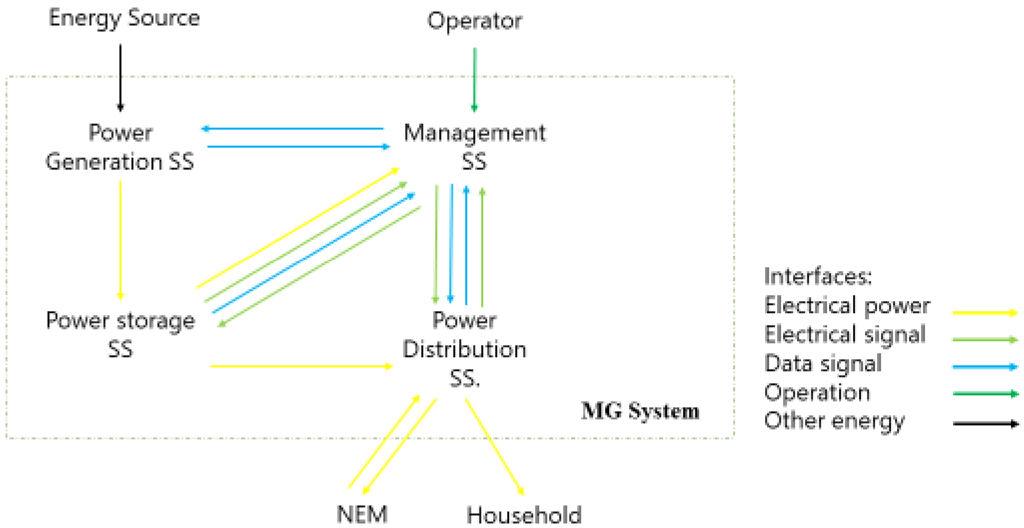

Figure 5. The Interfaces between Each Subsystem.

3.3 Subsystems Requirements

3.3.1 Requirements for Management Subsystem.

Pinpointing the detailed functions and requirements is needed, and here the Management Subsystem is taken as an example, which is presented in Table 9. Later, it can be served as a functional baseline for this specific subsystem.

Table 9. The Requirement of Management Subsystem

No.	Input/ output/ design	Requirement
1	Input	The mgmt. system shall receive the signals of sensors from other subsystems.
2	Input	The mgmt. system shall be operated by operator.
3	Design	The mgmt. system shall monitor, record and calculate how much electricity used by each household and the whole community.
4	Design	The mgmt. system shall display the information received from sensors.
5	Design	The mgmt. system shall monitor the status of operation
6	Design	The mgmt. system shall regulate frequency and voltage.
7	Design	The mgmt. system shall make decisions to respond the malfunction.
8	Design	The mgmt. system shall recognize the feedback of signal receiving.
9	Design	The mgmt. system shall sell power back to market;
10	Design	The mgmt. system shall send the bill to each household.
11	Design	The mgmt. system shall receive and track household payment.
12	Design	The mgmt. system shall protect its own safety.
13	Output	The mgmt. system shall send the signal to controllers.

Controller

No.	Input/ output/ design	Requirement
1	Input	The controller shall receive signals.
2	Design.	The controller shall process and execute the signal.
3	Output	The controller shall send the feedback of signal receiving.

Sensors

No.	Input/ output/ design	Requirement
1	Input	The sensors shall detect the current, electricity quantity, and other physical conditions of the working environment.
2	Design.	The sensor shall transform the detection to electrical signal
3	Output	The sensor shall transmit electric signal to the operation system.

3.4 Function Flow Block Diagram (FFBD).

To help the customer and ourselves to have a better understanding of the system itself, FFBDs with three levels are presented: Figure 6 shows the first two levels and Figure 7 is an example of level 3 break down.

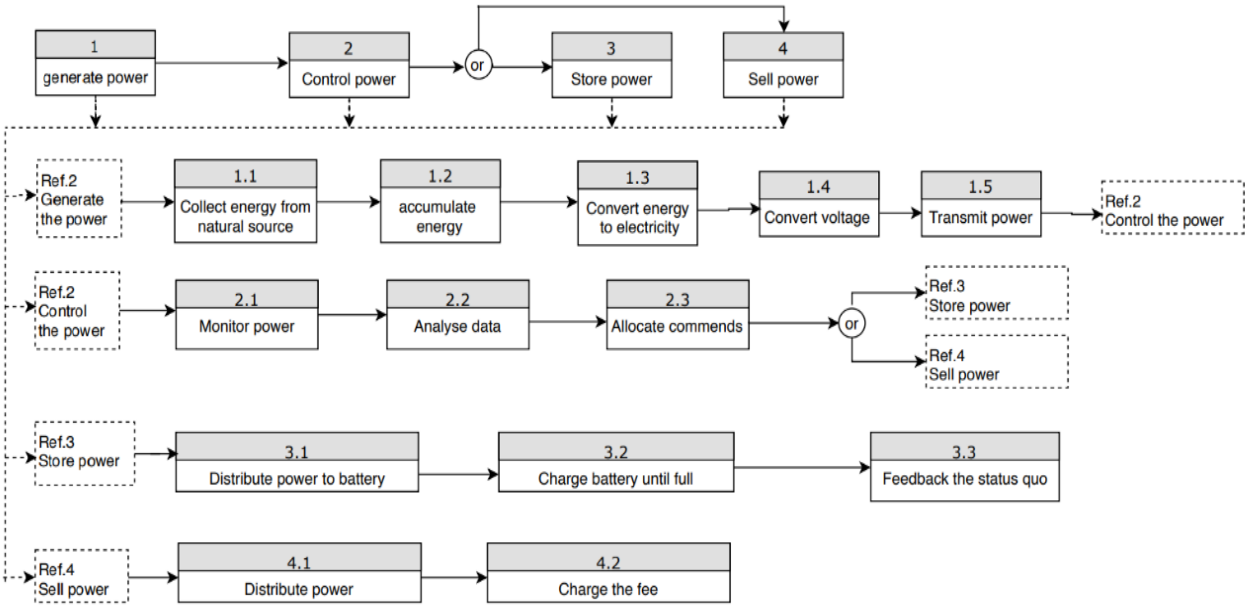

Figure 6. Level 1 and Level 2 FFBD

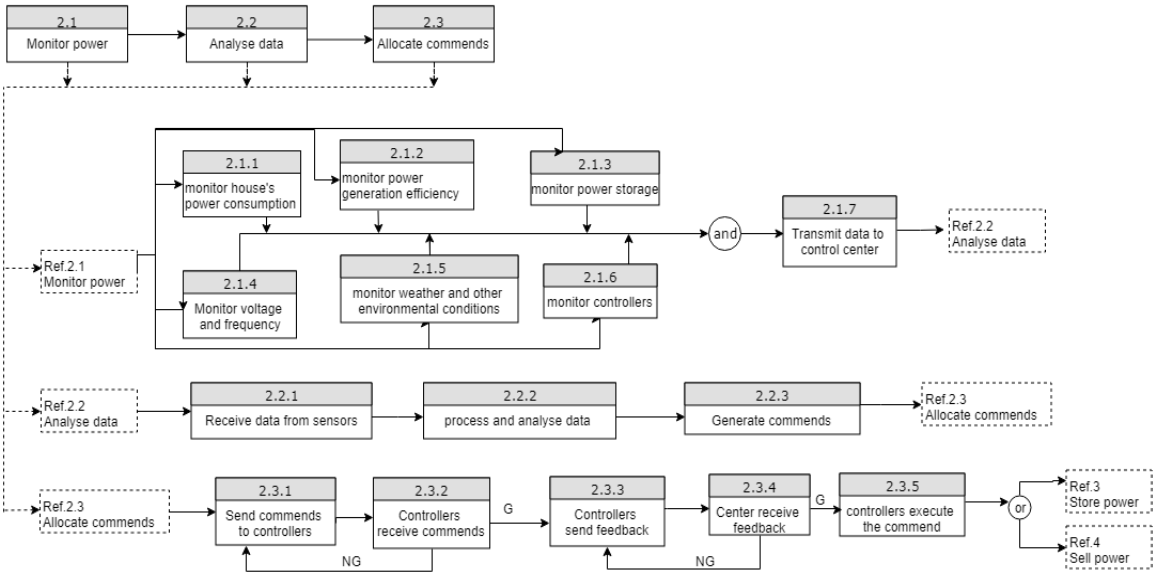

Figure 7. Level 3 FFBD for Function 2.

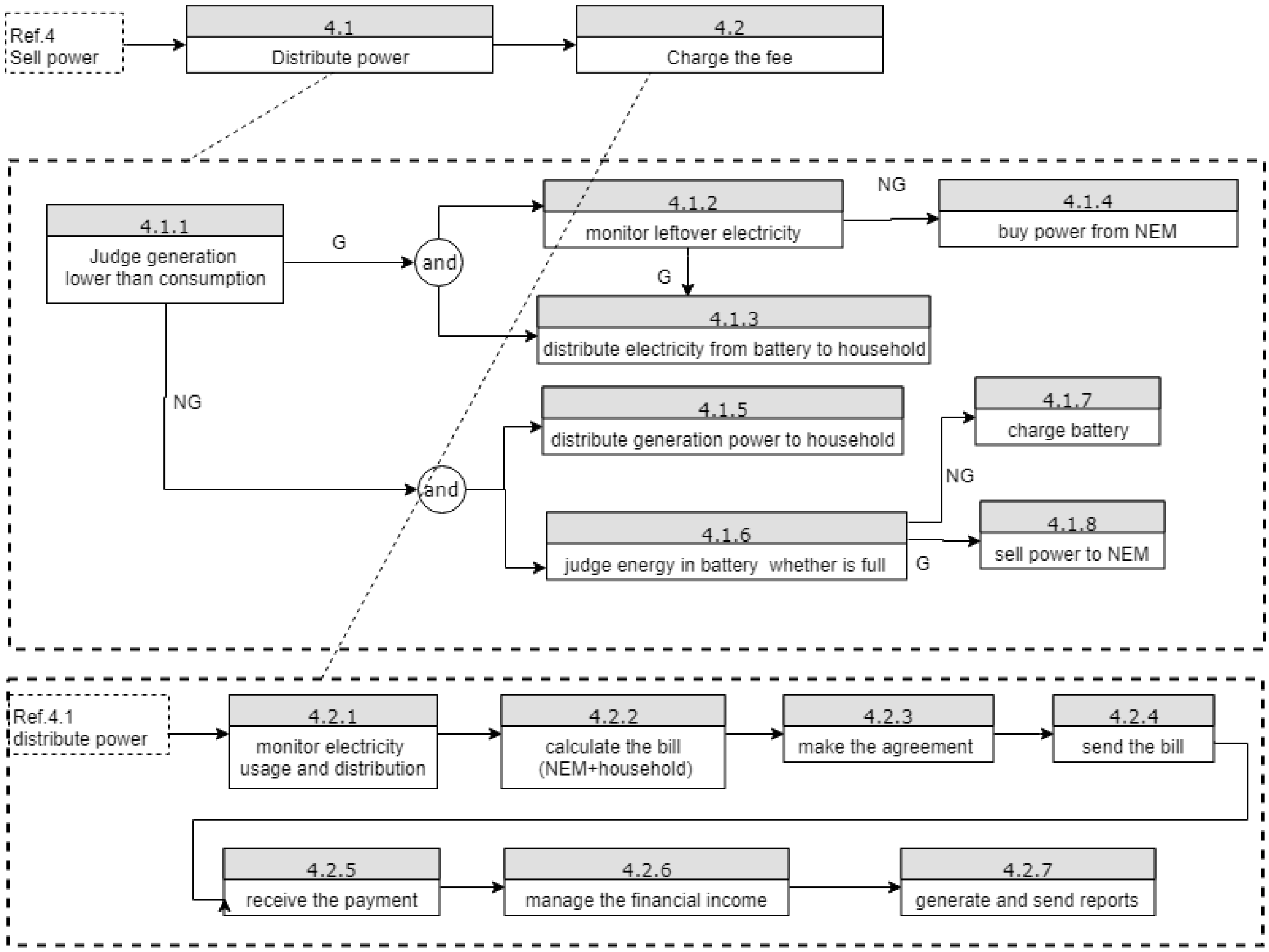

Figure 8. Level 3 FFBD for Function 4

3.5 TPM for Whole System.

Table 10. TPMs for Whole System

Power Generation						
TPM	**DoI**	**Metric**	**Target**		**Bench mark**	**Comment**
			Min	**Max**		
Microgrid total generation	+	kWh/day	25	-	25	According to Australian Government, on an Average 4 household consumption
Reliability	+	Percentage	90%	100%	100%	To reduce dependency on central grid for longer period
Power Storage						
TPM	**DoI**	**Metric**	**Target**		**Bench mark**	**Comment**
			Min	**Max**		
Battery Capacity	+	Ah	539	-	530	As per the daily avg. Consumption of household
Monitor Power Flow						
TPM	**DoI**	**Metric**	**Target**		**Bench mark**	**Comment**
			Min	**Max**		
Voltage	o	V	230	240	240	Supply Voltage at household end

Power	o	kW	5.2	-	5	Supply Power at Household end
Frequency	o	Hz	50	50	50	According to Australian Standard - AS2926-1987
Protect power						
TPM	**DoI**	**Metric**	**Target**		**Bench mark**	**Comment**
			Min	**Max**		
Circuit Breakers	o	Ampere	18	20	18	According to AS/NZS 3000:2007
Fuses	o	Ampere	5	15	10	According to AS/NZS 3000:2007
Distribution						
TPM	**DoI**	**Metric**	**Target**		**Bench mark**	**Comment**
			Min	**Max**		
Nominal Voltage	o	V	230	240	240	According to Australian Standard - AS2926-1987
Nominal Frequency	o	Hz	50	50	50	According to Australian Standard - AS2926-1987
Power line poles	-	meters	10	15	10	This is the height of the transmission pole.
Power Supply	+	kWh/year/house	25	-	25	Australian Government, on an average household consumption with 4 people.
Inverter	o	kW	5	5	5	According to the Power generated
Durability	+	years	15	-	20	According to an average life of a microgrid
Costs						
TPM	**DoI**	**Metric**	**Target**		**Bench mark**	**Comment**
			Min	**Max**		
Maintenance Cost	-	$/year	-	200	200	2% of the capital Cost annually
Levelized Cost	-	Cent/kWh	-	96.14	22	According to ACT Electricity Prices
Capital Cost		$	-	10,000	10,000/ house	According to the client

4. Design Phase

4.1 Power Generation Subsystem Concept Comparison.

4.1.1 Concepts Description.

There are four different types of power generation:

Concept 1. Thermal power plant.

This type of power generation involves heat energy converted to the electrical energy. The bigger scale of this generation is the burning of coal to produce heat energy. The heat is used to raise the temperature of water to steam and use it to turn the turbine attached to the alternator which converts into electrical energy.

Another form of the thermal plant is using diesel fuel generators. In this form, the energy stored in the fuel is converted to mechanical energy and to electrical energy through combustion of diesel fuel in the engine chamber.

Concept 2. Potential energy from falling water

This is to use the potential energy from the falling water to turn the turbine, which is called Hydropower plant. The turbine is connected to an alternator and convert the energy to the electrical energy which then supplies to the loads.

Concept 3. Wind energy

Wind power involves generation of electricity from wind: wind push the movement of the wind turbine which connected to the alternator [9], then the movement could convert to electrical energy.

Concept 4. Solar energy

Solar power is the conversion of solar energy into the electricity: using solar panels which receive sunlight and generate current and the current are then collected by a conductor which supply energy to the load.

Concentrating Solar Power (CSP) uses thermal energy of the sun to convert it into the electrical energy. There are several types of CSP: Fresnel reflectors, Solar Dish, Solar Heater, Solar Power Tower etc.

4.1.2 Compare Concepts

Table 11. Comparing Different Power Generators

Types	Advantages	Disadvantages	Comments
Thermal Generator/ Diesel Generators	1. Steady Load	1. High maintenance and operational costs. 2. Noise pollution 3. Greenhouse gas emission	Suitable for the Microgrid applications.
Hydro Power Plants	1.Renewable Energy 2. No emission of Green House Gases 3.Less Environmental Impact	1.High capital cost for construction 2.Power generation must be located near a river	This is not suitable. ACT is not located close to any river. It will be very costly to construct a transmission line from the source to the suburb even if this option is considered.

Wind Power	1. Renewable Energy 2. Negligible environmental impact	1 High capital cost of construction. 2 Amount of power generation depending on strength of wind	This is not suitable for the MG given that the client wants the MG to supply a suburb which is an area that has low wind strength, also the transition towers are large cost.
Solar power Generation	1. Renewable energy 2. Low maintenance and operation cost 3. No noise pollution 4. Power generation can be located anywhere exposing to the sun irradiation	1. Depends on the weather condition 2. Can only generate power in the daytime 3. Unsteady output 4. Takes up a lot of space	Suitable for project. Because of the low construction and operational cost. According to IRENA [10], there is 73% huge fall in the cost of photovoltaic (PV) projects since 2010, compared to all other power generation in terms of capital cost.

4.1.3 Recommend and Determine the Concept

To be able to select which power generator is suitable for powering the MG from four different concepts, 'House of Quality', a part of Quality Function Deployment, can be used. Refer to Figure 9 below, on the left side there are customer needs or requirements. Design attributes are the designed factors or features that the generators must have.

		Design attributes	1	2	3	4	5					
			per residence	More power generated	Steady power supply	Storage of power	Norminal Voltage	Benchmark soultion	Planned design	Improvement ratio	Absolute weight	Relative weight
	Customer Needs	Importance										
1	Affordability	5	9		9	3	3	5	4	0.80	4.00	0.13
2	Steady load/Reliabilty	4		9	9	9	9	5	5	1.00	4.00	0.13
3	No Environmental impact	4	3				3	4	4	1.00	4.00	0.13
4	No restriction to location	5		9	3	1		4	4	1.00	5.00	0.17
5	Low Maintenance cost	5	9		3			4	4	1.00	5.00	0.17
6	Power can be sell to Central Grid	3	9	9	9			3	4	1.33	4.00	0.13
7	Easy maintenance	3	3					3	4	1.33	4.00	0.13
	Technical Performance Measures										30.00	
	Absolute importance		4.70	3.90	4.60	1.77	2.00	16.97				
	Relative importance		0.28	0.23	0.27	0.10	0.12					

Figure 9. The HoQ-1 of Power Generation

Figure 10 below shows the concept scoring where each generator is compared with reference to the design attributes, one with the highest concept score is the one should be used for the MG system. It is obvious that solar power generator concept has the highest score, therefore, the generator using solar energy has been selected for the MG system.

Selection Criterion		DoI	Metric	Target Min	Target Max	Benchmark	Importance	Diesel Generators Score	Diesel Generators Weighted	Potential Energy from Score	Potential Energy from Weighted	Wind Energy Score	Wind Energy Weighted	Solar Score	Solar Weighted
1	per residence	-	$/residence		10,000.00	10000	0.28	3	0.83	1	0.28	1	0.28	6	1.66
2	More power generated	+			20	20	0.23	6	1.38	6	1.38	6	1.38	5	1.15
3	Steady power supply	0	Hz			50	0.27	6	1.63	5	1.36	3	0.81	5	1.36
4	Storage of power	+	KW/h	20		20	0.10	2	0.21	3	0.31	4	0.42	5	0.52
5	Norminal Voltage	0	V	230	240	240	0.12	6	0.71	6	0.71	5	0.59	5	0.59
									4.75		4.03		3.48		5.28

Figure 10. The HoQ-2 of Power Generation

4.2 Power Distribution Subsystem Concept Comparison.

4.2.1 Concepts Description.

Figure 11 and Figure 12 show two concepts (Concept 1.1, Concept 1.2) to layout the distribution for the generation and storage parts. The directions of the arrows describe the distribution of electricity.

<u>Concept 1.1</u>

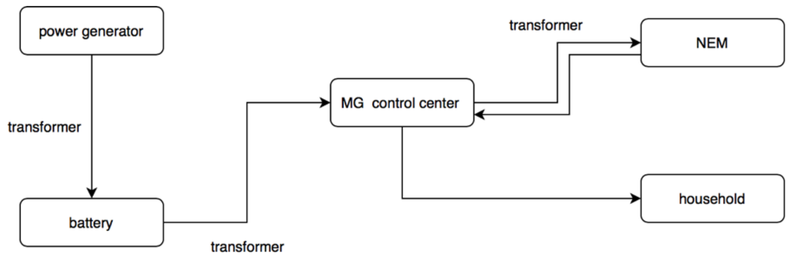

Figure 11. Concept 1.1 of Power Distribution

Figure.11 shows that the generated power will be distributed to the battery directly. The battery stores electricity from the power generator. Then the MG control center will take the electricity from battery whenever required by the residents. If the battery does not have enough electricity to cope with residents' consumption, MG control center will get electricity from NEM to satisfy the residents' requirements.

<u>Concept 1.2</u>

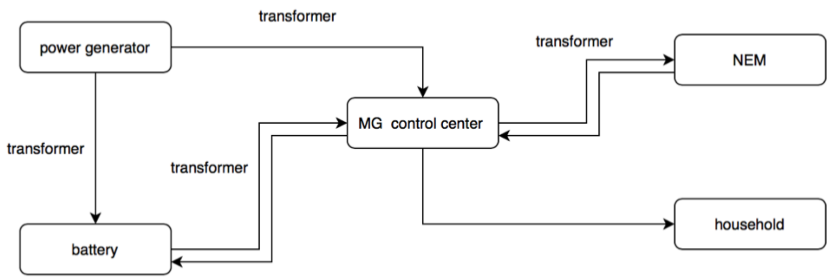

Figure 12. Concept 1.2 of Power Distribution

Figure 12 shows that the generated power can be distributed to battery and a MG control center. MG control center will monitor the power flow from the generator, battery and the consumption automatically.

When the battery is full, or residents have requirements, the generated power will be distributed to MG control center directly. Then MG control center will distribute the electricity to household or sell it to NEM. When the generated power is more than the demand or the battery is not full, the extra electricity will be distributed to battery until the battery is full. When the generated power is less than the residents' requirements, MG control center will distribute the generated power to NEM. In an emergency, MG control center will get power from NEM to support the residents' requirements.

Figure 13 and Figure 14 show two different concepts (concept 2.1, concept 2.2) to distribute the electricity to different households.

<u>Concept 2.1</u>

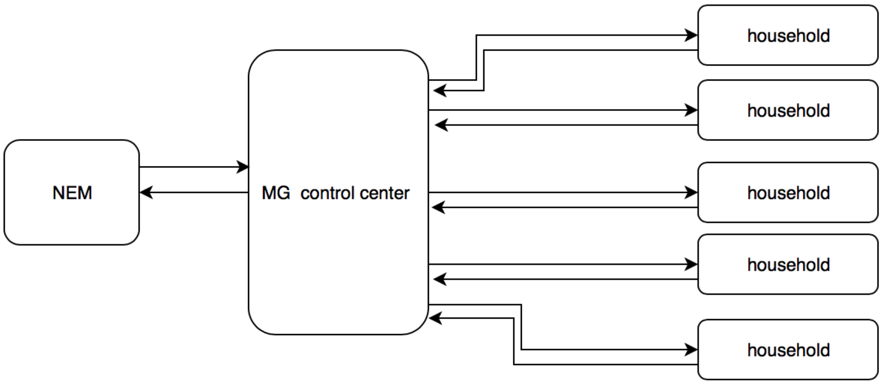

Figure 13. Concept 2.1 of Power Distribution

Figure.13 shows that all the households in the community connect to a common MG control center which is further connected to NEM. Households must make an agreement with the aggregator/retailer in order to buy or sell power. When households generate excess amount of power they can sell to NEM via a MG control center, similarly they can also buy the electricity from NEM when they ran out of power.

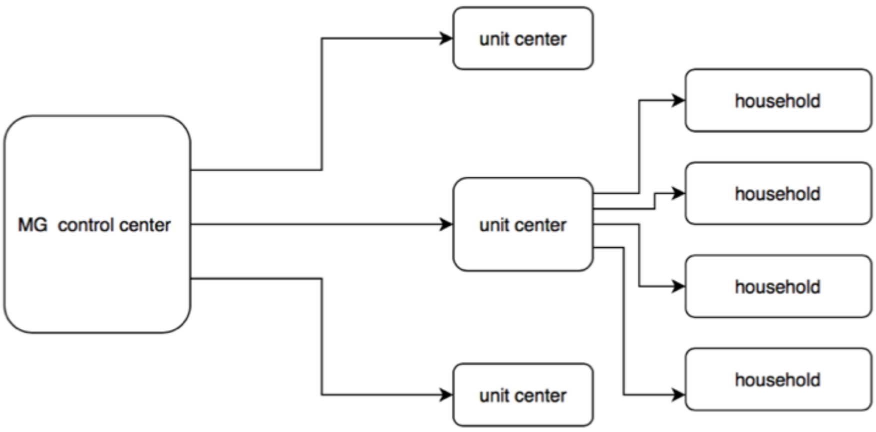

Figure 13. Concept 2.2 of Power Distribution

Figure.14 shows that a group of households are connected to an unit center and each has a connection with MG control center. The main difference between these two concepts is while selling or buying power through the unit centers can be more reliable and acquire less maintenance costs but the overall price or capital costs will be high due to an additional infrastructure..

4.2.2 Compare Concepts

			1	2	3	4	5	6		7					
		Design attributes	Transmission rate	Transmission capacity	counstructoin cost	serveice cost	the total length of the wires	maintained life	resist external damage effectiv	unit amount	Benchmark soultion	Planned design	Improvement ratio	Absolute weight	Relative weight
Customer Needs		Importance													
1	reduce waste during the distribution	4	9	3			6			9	4	4	1.00	4.00	0.11
2	safe in the distribution process	5			6	3	3		9	6	4	5	1.25	6.25	0.17
3	easy to serveice when distribution h	4				9	6	3		3	4	5	1.25	5.00	0.14
4	easy to adjust the electric vloume in	3		9						6	4	5	1.25	3.75	0.10
5	low cost of manufacturing the distrit	4			9	9		3		6	4	5	1.25	5.00	0.14
6	mutidirectional about distribution	3			6						4	5	1.25	3.75	0.10
7	maintaince of distribution part	4			6	6		9		6	4	5	1.25	5.00	0.14
8	strong bearing capacity	3		9						3	4	5	1.25	3.75	0.10
	Technical Performance Measures													36.50	
	Absolute importance		0.99	2.18	3.70	3.80	1.99	2.05	1.54	4.99	21.25				
	Relative importance		0.05	0.10	0.17	0.18	0.09	0.10	0.07	0.24					

Figure 14. The HoQ-1 of Power Distribution

				Target				conept 1.1		concept 1.2	
Selection Criterion		DoI	Metric	Min	Max	Benchmark	Importance	Score	Weighted	Score	Weighted
1	Transmission rate	+	kW	150	-	150	0.05	2	0.09	5	0.23
2	Transmission capacity	+	premose	10	-	10	0.10	3	0.31	3	0.31
3	counstructoin cost	-	AUD	-	10,000	3.2	0.17	3	0.52	2	0.35
4	serveice cost	-	AUD/year	-	5,000	11	0.18	3	0.54	4	0.72
5	the total length of the wires	X	m	0	-	200	0.09	4	0.38	3	0.28
6	maintained life	+	years	8	-	10	0.10	3	0.29	4	0.39
7	unit amount	X	number	1	30	5~30	0.24	1	0.24	1	0.24
									2.36		2.51

Figure 15. Scoring Matrix of Concept 1.1 and 1.2

				Target				concept 2.1		concept 2.2	
Selection Criterion		DoI	Metric	Min	Max	Benchmark	Importance	Score	Weighted	Score	Weighted
1	Transmission rate	+	kW	150	-	150	0.05	4	0.19	4	0.19
2	Transmission capacity	+	premose	10	-	10	0.10	4	0.41	4	0.41
3	counstructoin cost	-	AUD	-	10,000	3.2	0.17	5	0.87	2	0.35
4	serveice cost	-	AUD/year	-	5,000	11	0.18	4	0.72	3	0.54
5	the total length of the wires	X	m	0	-	200	0.09	5	0.47	2	0.19
6	maintained life	+	years	8	-	10	0.10	5	0.48	4	0.39
7	unit amount	X	number	1	30	5~30	0.24	3	0.71	3	0.71
									3.84		2.76

Figure 16. Scoring Matrix of Concept 2.1 and 2.2

The value of TPMs are calculated based on 10 households.

Concept 1.1 is cheaper and easier to implement, but it is not as feasible as Concept 1.2. Concept 1.2 is quite expensive since it requires more wires and more intelligent control system. It can distribute electricity to MG control system directly without passing to the battery, which can enhance the battery life. Concept 1.2 is more recommended than 1.1 since that has a potential to work for longer duration.

Concept 2.2 has a greater control on distributing power, lower maintenance over a period and easy emergency handling. Even though Concept 2.2 has a quite good benefits, Concept 2.1 is recommended because of the additional infrastructure and added capital costs of unit centers in Concept 2.2.

4.2.3 Recommend and Determine the Concept

In conclusion, combining Concept 1.2 and Concept 2.1 are selected in distribution sub-system.

4.3 Power Storage Subsystem Concept Comparison.

4.3.1 Concepts Description

At present, the main energy storage methods contain the following three types: mechanical storage, chemical storage, and electrical storage.

Concept 1: Mechanical Storage

Concept 1.1: Pumped hydro-power storage

The pumped hydro-power storage uses the electric energy at the low-electric-load time to pump water to the upper reservoir, and discharge water at the peak-electric-load time to generate electric energy, which means that it transfers electric energy to gravitational potential energy when storing the energy and doing the reverse process when generating the energy. It is suitable for frequency modulation, phase modulation and stabilizing the voltage of the system.

Concept 1.2: Compressed air energy storage

The compressed air energy storage refers to the energy storage method that uses the electric energy at the low-electric-load time to compress the air and releases the compressed air at the peak-electric-load time to promote turbine power generation. In this case, it transfers electric energy to thermal energy when storing the energy and transfers thermal energy to electric energy during energy-generating process.

Concept 1.3: Flywheel energy storage

The flywheel energy storage is an energy storage device for electric-mechanical energy conversion. During energy storage phase, electric energy drives the motor, while the motor drives the flywheel to accelerate rotation, which finishes the energy conversion from electric energy to mechanical energy. The energy is stored in the high-speed rotating flywheel. After that, the flywheel maintains a constant speed until the energy-releasing signal. During energy generating phase, the high-speed rotating flywheel drives the motor to generate electricity.

Concept 2: Chemical Storage

Concept 2.1: Lead-acid battery

The lead-acid batteries are quite mature technology and have been used for more than 150 years. The active material on the anode is lead dioxide, while the active material on the cathode is pure lead. The electrolyte is diluted sulfuric acid. During the lead-acid batteries' charging and discharging phase, the conversion of electric energy and chemical energy is achieved, relying on the chemical reactions between active materials on the electrode plate and diluted sulfuric acid.

Concept 2.2: Sodium Sulfur battery

The Sodium Sulfur batteries consist of anode, cathode, electrolyte and shells. The active material on the anode is liquid sulfur, and the active material on the cathode is molten sodium. Dislike traditional chemical batteries, the electrolyte of sodium sulfur batteries is solid. The energy conversion process depends on the chemical reactions between liquid sulfur, molten sodium and electrolyte.

Concept 2.3: Lithium-ion battery

The anode material of Lithium-ion batteries is made of Lithium compounds, and the cathode material is made of graphite. When charging the Lithium-ion batteries, the Lithium-ion is generated on the anode and move to the cathode through the electrolyte. When discharging the Lithium ion batteries, the Lithium-ion behaves inversely.

Concept 3: Electrical Storage

Concept 3.1: Electrochemical capacitors storage

Electrochemical capacitors storage is a new type of devices that store energy through a formed layer between an electrode and an electrolyte. When the electrode is in contact with the electrolyte, a stable and opposite-signed double-layer charge appears at the solid-liquid due to Coulomb force and intermolecular forces. The double-layer charge is where store the energy.

4.3.2 Compare Concepts

The main characteristics of the 7 concepts above are presented in the table below.

Table 12. Storage concepts comparison

Storage Concept	Typical rated power	Energy conversion efficiency	Advantage	Disadvantage	Application condition
Concept 1.1 Pumped hydro-power storage	100 - 5000 MW	70% - 85%	High power, large capacity	Strict by geographical location, long construction cycle	Stabilize the voltage, frequency and phase modulation
Concept 1.2 Compressed air energy storage	100 - 300 MW	40% - 50%	High power, large capacity	Strict by geographical location	Backup power
Concept 1.3 Flywheel energy storage	5kW - 10MW	80% - 90%	Long service life	Low power density	UPS
Concept 2.1 Lead-acid battery	1kW - 50MW	60% - 70%	Recyclable, mature technology, UPS	Low power density, not environmental-friendly	Backup power, UPS
Concept 2.2 Sodium sulfur battery	100KW - 100MW	70% - 80%	Large capacity, high power density	High maintain cost	Stabilize the voltage, backup power
Concept 2.3 Lithium ion battery	100kW - 100MW	70% - 80%	High energy conversion efficiency, eco-friendly, UPS	High cost, poor safety	Stabilize the voltage, backup power
Concept 3.1 Electrochemical capacitors	10kW - 1MW	70% - 80%	Long service life, high power density	High cost, short working duration	Short-time electricity quality adjustment

According to research, [7] a household in ACT consumes 15 to 25 kWh per day. In this case, Concept 1.1 and Concept 1.2 are not suitable for MG systems since these two concepts are mainly feasible for larger power storing projects.

The remaining concepts, HoQ are used to determine the chosen concept. The result is shown in Figure 18 and Figure 19.

	Customer Needs	Importance	1 Energy transform efficiency	2 Reliability rate	3 Battery capacity	4 Maintain cost	5 Recycling efficiency	6 Battery service life	7 Material cost	8 Technical maturity	Benchmark soultion	Planned design	Improvement ratio	Absolute weight	Relative weight
			Design attributes												
1	low construction cost	5	3		6	6	3		9	3	4	4	1.00	5.00	0.23
2	low maintain cost	4				9	3		3		4	4	1.00	4.00	0.18
3	safe to use	4		9						6	4	5	1.25	5.00	0.23
4	reliable in energy storage and releas	5	3	6						9	4	4	1.00	5.00	0.23
5	easy to recycle	3					9				4	4	1.00	3.00	0.14
	Technical Performance Measures													22.00	
	Absolute importance		1.36	3.41	1.36	3.00	2.45	0.00	2.59	4.09	18.27				
	Relative importance		0.07	0.19	0.07	0.16	0.13	0.00	0.14	0.22					

Figure 17. The HoQ-1 of Power Storage

			Target				Concept 1.3		Concept 2.1		Concept 2.2		Concept 2.3		Concept 3.1	
Selection Criterion	DoI	Metric	Min	Max	Benchmark	Importance	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Energy transform efficiency	+	%	40	90	70	0.07	4	0.30	3	0.22	3	0.22	5	0.37	4	0.30
Reliability rate	X	%	0	100	60	0.19	3	0.56	5	0.93	4	0.75	4	0.75	3	0.56
Battery capacity	-	kVA	1	1000	300	0.07	4	0.30	3	0.22	5	0.37	4	0.30	3	0.22
Maintain cost	-	A$	20	50	30	0.16	3	0.49	4	0.66	3	0.49	3	0.49	2	0.33
Recycling efficiency	+	%	0	40	20	0.13	2	0.27	4	0.54	4	0.54	3	0.40	3	0.40
Battery service life	X	year	1	5	3	0.00	4	0.00	3	0.00	4	0.00	4	0.00	4	0.00
Material cost	X	A$	390	15500	2000	0.14	2	0.28	5	0.71	4	0.57	3	0.43	4	0.57
Technical maturity	+	year	5	170	50	0.22	2	0.45	5	1.12	4	0.90	4	0.90	3	0.67
								2.65		4.40		3.84		3.63		3.05

Figure 18. The HoQ-2 of Power Storage

Safety and cost are the most concerned requirements from customers for energy storage sub-system, which can be concluded from HoQ: Technical maturity (positive correlation with safety), reliability rate and material cost are the design attributes with highest importance. In this case, concept 2.1, lead-acid battery, is the most competitive concept, since it has the highest score. The cost of lead-acid battery is relatively the lowest among the five concepts. It is helpful to reduce the whole budget in this project. Moreover, lead-acid battery has developed for more than 150 years. Its technology is the most mature one compared with other concepts, which means safer and more reliable. Therefore, lead-acid is chosen for energy storage sub-system.

4.3.3 Recommend and Determine the concept

In conclusion, lead-acid battery is selected for this project.

4.4 Power Management Subsystem Concept Comparison.

In the light of the complexity of this microgrid projects, partnering with reliable company with Microgrid management software platform would be a great facilitator for the project. The market leaders in this filed are: Siemens, ABB and Schneider [8]. While, with the growing awareness of using sustainable and robust energy, in Australia, several software companies have experienced great development with great support from local government: deX and Power Ledger [11], which could enable localized and customized agreement making process.

4.4.1 Concepts Description.

<u>Concept 1. Siemens Spectrum Power Microgrid Management System (MGMS)</u>

The MGMS is a software solution developed by Siemens for optimal microgrid management and control. The basic functions of this system include: resynchronization; emergency demand response; power quality; supervisory control, sequence of operation, archiving, frequency and voltage regulation and data acquisition & communication. This is a model-based application, which can be tailored and extended for the operational demands, and it can be integrated with existing IT systems. It is deployable with the new microgrid [12] [13] [14].

Concept 2. Schneider Electric Advanced Distribution Management System (ADMS)

Advanced Distribution Management System (ADMS) is developed by Schneider Electric company. This software equips with six basic parts: PCS, EMS, SCADA, DMS, OMS and DRMS.

4.4.2 Compare Concepts

After reviewing the functions of two software, they can perform: power control, energy management, SCADA, Demand Response Management, outage management and mid-to-long term forecasting.

Both of them are feasible for small-scale like our project to other large-scale projects, and they all are good at information integration with corporation. From the features of two software [15] [16] and customer's expectation, 10 criteria are used to evaluate two systems, shown in the Table 13.

Table 13. Selection Criteria for Management System.

ID	Selection Criteria	Siemens (MGMS)	Schneider (ADMS)
1	24/7 monitoring	✓	✓
2	Security	✓	✓
3	Multifunction:	✓	✓
4	Related experience in AUS	✓	X
5	After-sale service:	✓	✓
6	Training.	✓	✓
7	Maintenance duration (15 years)	✓	X (10 years)
8	With user interface	✓	✓
9	Trade energy	✓	X
10	Easy to expand (functions increase based on module)	✓	✓

However, in 2017, from Gartner evaluation, it is said that Schneider Electric has higher completeness of vision and higher ability of execution than Siemens [16] [17]. While, that is not a deciding factor, instead related experience is considered as more important. From research, Siemens' great experience in Australia Micro-grid project, Barangaroo microgrid project [8], could be highly useful as well as their cooperation with Australia software company, deX [18], which has a close relationship with ACT government. Furthermore, Siemens could fulfill the energy trading function by itself [12].

4.4.3 Recommend and Determine the Concept.

Thus, after comparison and evaluation, for the management system, Siemens Spectrum Power Microgrid Management System (MGMS) is recommended.

4.5 System Architecture

The system architecture of this design is shown as Figure 20.

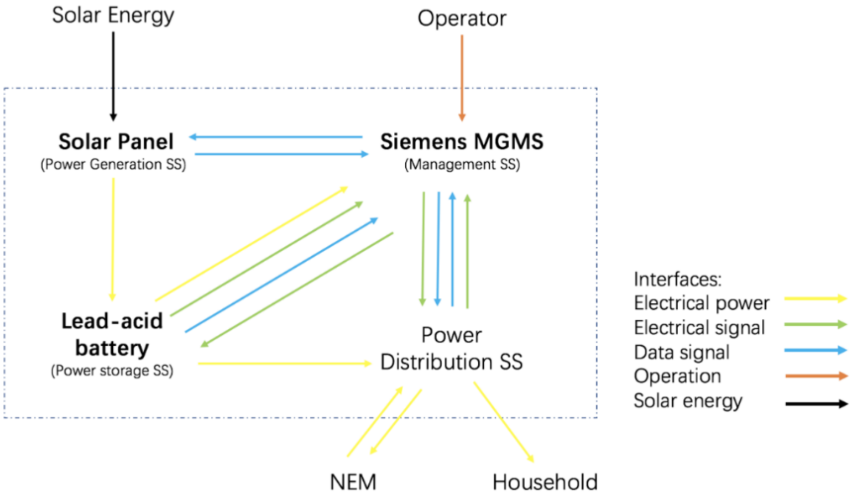

Figure 19. System Architecture

5. Risk Management.

5.1 Risk Identification

Risk management process is a continuous process throughout the project. In this initial stage of the planning, major risks in 4 categories are considered: technology (Tech), external influences (EX), organizational (ORG) and project management (PM), presented in the Figure 21.

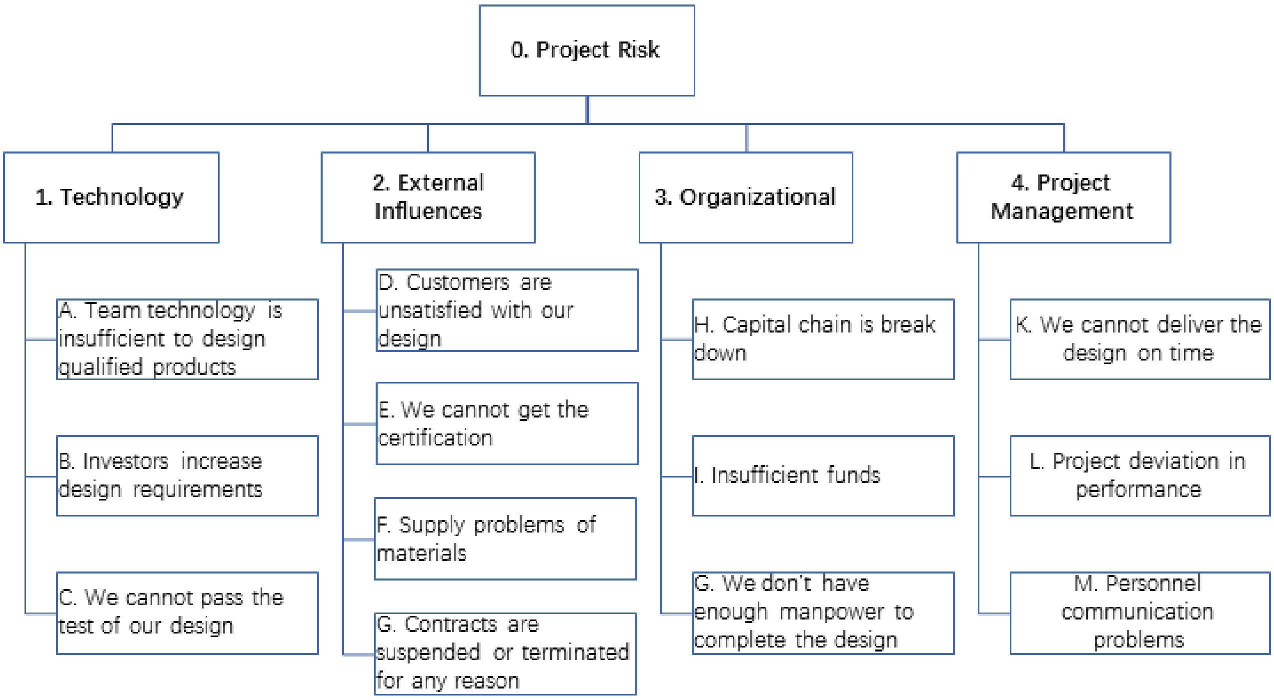

Figure 20. Risk Breakdown Structure.

5.2 Risk Analysis and Control.

Firstly, the scale and threshold of likelihood and the impact are defined in Table 14 and Table 15, then each risk are analyzed based on that, and put into the matrix, presented in the Table 16.

Table 14. Scales for Likelihood

Scales	Probability of occurrence
5	Greater than 70%
4	50%~70%
3	30%~50%
2	10%~30%
1	Below 10%

Table 15. Scales and Definition for Impact

Scale	Overall	Cost	Schedule	Scope
5	Have a catastrophic impact on delivering MG system project	>26% cost increase	Postpone >16 weeks	Catastrophic change of outputs
4	Have a major impact on delivering MG system project	21%~25% cost increase	Postpone 10-15 weeks	Major scope deterioration

3	Have a moderate impact on delivering MG system project	16%~20% cost increase	Postpone 6-9 weeks	Moderate scope deterioration
2	Have a minor impact on delivering MG system project	11%~15% cost increase	Postpone 3-5 weeks	Minor scope deterioration
1	Have an insignificant impact on delivering MG system project	<10% cost increase	Postpone <2 week	Slight scope deterioration

Then the likelihood and impact are determined and put into Risk Likelihood-Impact Matrix, presented in Table 16.

Table 16. Risk Likelihood-Impact Matrix

Likelihood	5	High	High J	Extreme C	Extreme K	Extreme
	4	Moderate	High A& M	High H&K	Extreme D	Extreme H
	3	Low	Moderate F&L	High	Extreme E	Extreme
	2	Low	Low	Moderate B	High I	Extreme
	1	Low	Low	Moderate	High	High G
		1	2	3	4	5
		Consequences				

The next step is trying to identify and explore any mitigation plan can be used for that specific risk, and all the content is put in to the Risk Register, presented as **Appendix 1**.

6. Cost and Budget.

Based on the HOQ and the results obtained shows that, the solar generation has been used since it is most preferred and has more value and importance. The following are the cost analysis done on the solar power generation and finally Levelized Cost of Electricity (LCOE) is determined.

1. The suburb, the MG will be installed, is in ACT. To design the Solar Power Generating system, it is important to determine and choose the location coordinates of ACT. The location at which the generating system has to be build has the Latitude and longitude of -35.25° & 149.12° respectively [19].

2. The average household with 4 people consumes 25kWh/day [7]. The Solar Power Generator output is so volatile and in order to meet the demand at all times, the minimum solar power generator plant shall be 5.2 kW.

3. Solar Panel brand/model of Si-poly CS3U KUMAX 345 P [20][21] (Power Rating of 345W) and Inverter model of Sunny Boy 5000 TL-21[22] (Power Rating of 5kW) will be used in the designed Micro Grid system to meet the requirements. Two units of battery model of BAT-001 Trojan 250Ah, 12V are selected for the system which has a storage capacity that could meet the entire day consumption [23].

4. PV System software has been used for designing the Solar Photovoltaic (PV) Plant at the Micro Grid System. The following data are obtained, please refer to Appendix 2 and Appendix 3. Total minimum number of panels are 16 and the number of inverters required are 1.

5. The LCOE calculations are done below, presented in Table 17, and the Levelized cost is determined around ¢18.67/kWh. This levelized cost shows how much the cost of electricity to be paid by a consumer for a kWh for power generated by the solar panels.

6.1 Capital Cost

Table 17. Costs and Budget

Components	Brand	Unit Cost	Quantity	Total Cost	Comment
Solar Panel	CS3U KUMAX 345W P	$ 281.7	16	$ 281.7 x 16 = $4,507	Canadian Solar, Poly-Crystalline Solar Module
Inverter	Sunny Boy 5 kW Solar Inverter	$ 1,500	1	$ 1500	5.2 kW solar system
Battery	BAT-001 Trojan 250 Ah, 12V	$ 610	2	$ 610 x 2 = $1,220	Power Backup required for a whole day
Smart Meter [24]		$300	1	$300	Each household need one smart meter to supervise the electric power flow and the
Construction of Solar Panel	-	$20	16	$320	We need 16 panels.
Internal Cable Costs and Connectors		$1700	1	$1700	The cable wires and connections between the components and end user interface. The costs of protection devices are also included.

Total Costs		$ 9,547	
Cable/ Busbar/Transformer (External)	Trade-offed. This item will not be included in the cost of individual household. During the standard grid installation, government or the central grid operator are required to install cable, transformer and busbar, thus, the costs for those items are counteracted.		
Management System Software (optional)	It is required when a group of houses together depend on one micro grid system for power. The initial cost for the construction and monitoring the power flow to all the houses will be high, and this cost would be shared among each household. Moreover, the cost of this system depends on the size.		

The total capital cost per premises is around $9,547, which is determined with the consideration of required components needed to install and to operate the MG.

6.2 Levelized Cost of Electricity (LCOE)

The LCOE is based on the per premise and the determined cost shows how much or the minimum cost of electricity to be paid for a kWh of power generated by the solar panels.

Table 18. Calculation of Levelized Cost

Description	Numbers	Comments
Initial Capital Cost ($)	9,547	This is the total capital cost based from the Table 18
Physical life of PV system-years	25	Standard life of PV systems
Discount rate-(%)	5%	This value is assumed at 5% as PV panels has a discount rate within the range of 3-8%.
<u>Occasional costs</u>		
Cost of replacing of inverter ($)	1,500.00	
Life of inverter (years)	12	Standard life of inverters
Present worth of cost of replacement ($)	835.26	
Annual operating costs ($)	1,000.00	For PV systems, annual operating cost is 1% of the capital cost.
Present worth of annual operating cost ($)	14093.94	
Total Energy generated MWh per year	9.3	Refer to the Appendix 2
Total present worth of all costs ($)	24,476.40	
Annual Levelized Cost $ /kWh	$0.187	¢18.67

(The above method of determining the LCOE is from ENGN4524/6524m [25])

The Levelized Costs continuously vary depending on the circumstances whether it is centralized power or decentralized power but generally when we compare the achieved levelized cost from the micro grid system with the central distribution power, there is a difference of around ¢8/kWh since the unit cost from the central power in Australia is around ¢ 27/kWh [26]. By installing the solar power generating system rather than relying on the central power distribution is more affordable as well as meets our major requirement.

7. Conclusion and Recommendation.

7.1 Conclusion.

The micro-grid system is designed to meet the necessary customer requirements. In the initial phase, stakeholders' needs are incorporated in the analysis process. The system requirements specifications assist the team to specify the major functions and subsystems. Then, PV panels for power generation, lead-acid battery for power storage and Siemens MGMS software for management system are adopted in this MG design. Moreover, with deep analysis, individual MG system for each household is determined, thus, the design is possible to be scaled up to multiple numbers of houses regardless of a fixed number. Furthermore, as mentioned in Section 6, designing this system is affordable, reliable, and it reduces the dependency on the central network.

7.2 Recommendations.

- Further property marketing is crucial for people to accept the underlying idea of this project;
- Certain training and welcome kit shall be provided to the residence to enhance the utilization of equipment;
- Better negotiation with PV panel suppliers and searching for better panel supplier could reduce the cost of the project;
- Include reference group could be useful to ensure the quality of project delivery, such as ARENA.

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Appendices

Appendix 1. Risk Register

Risk ID	Risk Description	Type	Likelihood	Impact	Risk Score	Mitigation Plan			
						Avoid	Transfer	Mitigate	Accept
A	Team technology is insufficient to design qualified products	Tech	4	2	8	N/A	Ask experts from outside for guidance	Organize in-depth training about professional knowledge	N/A
B	Investors increase design requirements	Tech	2	3	6	N/A	N/A	Clearly clarify that changes to the requirements in the contract in not allowed.	With permission of requirement changes, other aspects of project shall be discussed (extra time/budget/and resources.)
C	We cannot pass the test of our design	Tech	5	3	15	N/A	N/A	Change the limitation of the test in an acceptable range	Adjust the direction of design as possible
D	Customers are unsatisfied with our design	EX	4	4	16	N/A	N/A	Extensive investigation of expected product satisfaction during the design phase.	N/A
E	We cannot get the certification	EX	3	4	12	N/A	N/A	Communicate and engage with the institute that we get the certification from to make sure the design can get the certification finally.	N/A
F	Supply problems of materials	EX	3	2	6	Compare different kinds of material at the beginning	N/A	Choose other suppliers for backup.	N/A
G	Contracts are suspended or terminated for any	EX	1	5	5	Explicit the rule about suspend and terminate the contract in the contract	N/A	N/A	Revaluate the project; if second evaluation does not pass, then prepare for project infor delivery.

	reasons								
H	Capital chain is break down	ORG	4	3	12	Make sure sufficient funds is reserved;	Set aside some funds as emergency funds	N/A	Make loans to banks
I	Insufficient funds	ORG	2	4	8	Make sure sufficient funds is reserved;	Clarify the responsibility of providing sufficient funds;	Suggest the investors to find other consortium to invest more money; Embed the fund plan to the company overall budget plan.	Investors to increase the amount of investment and give up some of the shares
J	We don't have enough manpower to complete the design	ORG	5	2	10	Several candidates for the initial phase of the project as alternates	Reference group members can be used for our project.	Temporary recruitment of suitable candidates; Increase the contingency plan or increase the time lap in the project timeline.	N/A
K	We cannot deliver the design on time	PM	4	3	12	In the contract, clarify the permission status of late delivery.	N/A	During the weekly meeting, all the members are accountable for the process report, and inform the steering committee about the process; Ask external experts to evaluate and monitor the project timeline.	Communicate with steering committee for prove extra resources; Increase human resources to achieve on-time completion
L	project deviation in performance	PM	3	2	6	Use integrated product development team(IPDT) to check whether the design is on track	N/A	Request a weekly project progress report and show the results; Assign a specific project manager to monitor the scope and the performance.	N/A
M	Personnel communication problems	PM	4	2	8	Organize team building activities	N/A	Weekly regular meeting; Assign people to make sure related infor are exchanged among major team members.	N/A

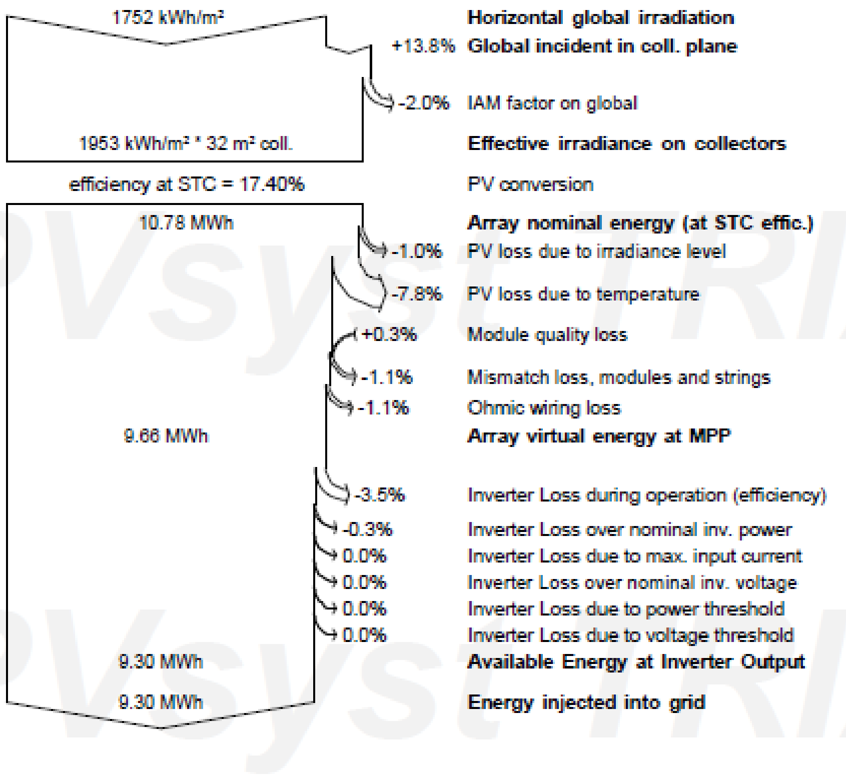
Appendix 2. PV Array Characteristics

PV Array Characteristics

PV module	Si-poly	Model	**CS3U-345P**		
Original PVsyst database		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	8 modules	In parallel	2 strings
Total number of PV modules		Nb. modules	16	Unit Nom. Power	345 Wp
Array global power		Nominal (STC)	**5.52 kWp**	At operating cond.	4996 Wp (50°C)
Array operating characteristics (50°C)		U mpp	279 V	I mpp	18 A
Total area		Module area	**31.7 m²**	Cell area	28.3 m²
Inverter		Model	**Sunny Boy 5000 TL-21**		
Original PVsyst database		Manufacturer	SMA		
Characteristics		Operating Voltage	175-500 V	Unit Nom. Power	4.60 kWac
Inverter pack		Nb. of inverters	2 * MPPT 50 %	Total Power	4.6 kWac
				Pnom ratio	1.20

The above figure shows us that the information about the PV Array Characteristics such as PV Module and Inverter information. It also shows how much capacity of the Inverter and generation is used, number of panels and the model of both components.

Appendix 3. Loss Diagram.



Yearly Generation after considering losses

The above figure shows that the yearly generation from the solar generator that will be installed and the losses that occurs from the generation.