Overview of IEC Recommendations for renewable energy and hybrid systems for rural electrification

ENG470 Engineering Honours Thesis project
by

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A thesis submitted to Murdoch University
to fulfil the requirements for the degree of
Electrical Power and Renewable Energy Engineering
in the discipline of
Engineering Honours

Murdoch, 2017

Author’s Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

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Abstract

The International Electrotechnical Commission (IEC) is a universal company having a major mission to arrange International standards. IEC TS 62257 introduced herein is one of those series. It concerns about rural electrification which is further away from the national main power line. It is very expensive to get a few single users to utilise a grid to meet cost-effective. Therefore the stand-alone electrical systems are taken into account to serve better situations. In these days, rural electrification is played one of the important strategies to maximise comfort to those people in rural area as well as rural economic expansion.

This thesis focuses on overview of IEC TS 62257. The project purpose concerns to five significant points. Firstly, to investigate and enable the choice of renewable energy based electrification systems to meet the requirements of customers in the field of decentralised rural electrification project. Secondly, to provide a technical specification for renewable energy and hybrid systems. Thirdly, to evaluate the minimum sufficient requirements, relevant to the field of application that is: renewable energy and hybrid off-grid systems corresponding to the high standard safety. Fourthly, to review the methodology in the standard IEC TS 62257 to achieve the best technical and economic conditions for acceptance, operation, maintenance and replacement of equipment and complete system life cycle. Lastly, to learn about the combination of diesel generator system and solar energy during the project.

To attain an achievement of the five purposes as above mentioned, Rottnest Island case study was taken as an example of rural or remote Electrification in order to compare it with IEC TS 62257 series in term of similarity and difference between them. Although this project is completed, Rottnest power electrification is still a lot more to discover.

Regarding to the most efficiency of the rural power project, the selection in which part of IEC TS 62257 should be taken to an appropriate consideration.

Acknowledgements

First, I would like to thank my supervisor, Dr. Ali Arefi for his advice, expertise, and assistance during this thesis project. I would also like to thank Dr. Martin Anda, for his arrangement of Rottnest Island visit for me to do a case study. Thanks also to Dr. GM Shafiullah and Dr.Farhad Shahnia for their knowledge in the electrical system during Rottnest Island site visit. It was helpful to my thesis. I would also like acknowledge and appreciate Mr. Dino Ajid who worked for Programmed Facility Management on Rottnest Island, for his answers about the setting up of Rottnest Island power system and the Island standard, Laura Senge who worked for the Rottnest Island Authority, for her Island power network tour.

I also would like to thank my family and friends who have encouraged and supported me toward to the end of my thesis.

Dedication

I dedicate this thesis to my family, my teachers and my friends who have supported me along the Engineering Studies road.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AS	Australian standard
AOMR	Actions acceptance, operation, maintenance and replacement actions
BMS	Battery management system
CCT	Circuit
CES	Collective Electrification System
CFL	Compact fluorescent lamp
DUT	Device under test
$DWQI_T$	Daily weighted quality of service
EBS	Equipotential bonding system
ELV	Extra-low voltage
FWHM	Full width half maximum
GS	General Specification
HMPS	Hybrid micro-power system
IEC TS	The international Electro-technical Commission Technical specification
IES	Individual Electrification System
IF	Identification file
$I_{MOD\_REVERSE}$	The current a module can withstand the reverse direction to normal without damage to the module
IP	Ingress protection
$I_{SC\ ARRAY}$	The short circuit current of a PV array at Standard test Condition
$I_{SC\ MOD}$	The short circuit current of a PV module or PV string at Standard test Condition
$I_{SC\ S\text{-}ARRAY}$	The short circuit current of a PV sub-array at Standard test Condition
LED	Light emitting diode
LPS	Lightning protection system
lux	SI Unit of luminance

P	Active power
PCU	Power conditioning unit
PE	Protective conductor
PEL conductor	Conductor combining the functions of both a protective earthing conductor and a line conductor
PELV	Protected extra-low voltage
PEM conductor	Conductor combining the functions of both a protective earthing conductor and a midpoint conductor
PEN Conductor	Conductor combining the functions of a protective earthing conductor and a neutral conductor
PV	Photovoltaic
QI	Quality of service index
RE	Renewable Energy
REN	Renewable Energy
S	Apparent power
S_{bad}	Service ratio under unfavourable conditions
S_d	Daily service ratio
SELV	Safety extra-low voltage
S_{good}	Service ratio under favourable conditions
SPD	Surge Protection Device
SPD	Surge Protective Device
STC	Standard test condition
THD	Total harmonic distortion
TWI_T	Total weight quality of service
$V_{OC\ ARRAY}$	The open circuit voltage at Standard Test Conditions of a PV array
$V_{OC\ MOD}$	The open circuit voltage of a PV module at the coldest expected operating condition

Chapter 1 Introduction

1.1 Objectives of this thesis

This thesis overviews IEC TS 62257 standard series and has various aims. The first aim is to investigate the choice of renewable energy based electrification systems that is able to meet the requirements of customers in the field of decentralized rural electrification project (IEC 2015a). Secondly, provide a technical specification for renewable energy and hybrid systems(IEC 2008c). Thirdly, evaluate the minimum sufficient requirements, relevant to the field of application that is: renewable energy and hybrid off-grid systems corresponding to the high standard safety (IEC 2015d). Fourthly, review the methodology in the standard IEC TS 62257 to achieve the best technical and economic conditions for acceptance, operation, maintenance and replacement of equipment and complete system life cycle (IEC 2015f). Lastly, the author would like to learn about the combination of diesel generator system and solar energy during the project.

1.2 The connection of IEC TS 62257 series

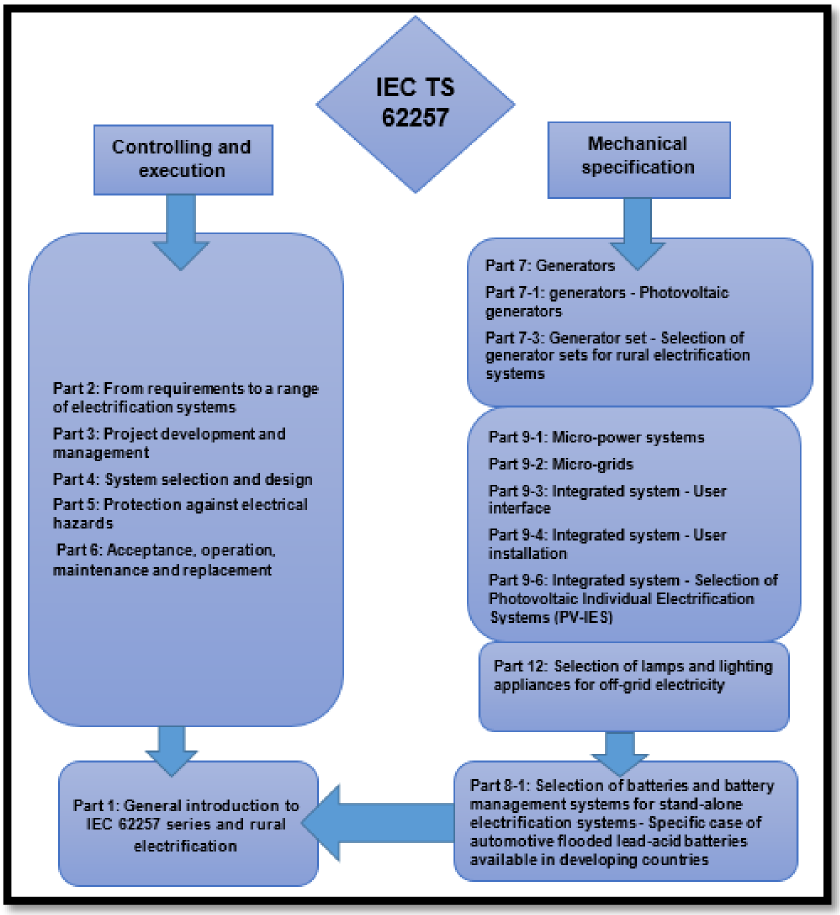

Figure 1 the connection of IEC TS 62257 standards (IEC 2015a)

Figure 1 is stated that IEC TS 62257 divided into two main pathways that is monitoring the system and mechanical specification. In the series of this standard, there are sixteen books in total. Each of these books is specified a different in content of rural electrification. The linkage of them are such that: the controlling and execution (monitoring path) is included the standard part 2 to part 6. The Mechanical specification path is involved the standard part 7 to 12. This section is also allocated individual three groups of electrification system namely; Generators from part 7 to 7-3, micro-system and integrated system in part 9-1 to 9-6 and lastly, lamp and lighting appliances in part 12. Part 8-1, Selection of battery is based on the requirements from part 7 to part 12. Hence it is located at the bottom of the flow diagram in figure 1. Part 1 of IEC TS 62257 is stated the general introduction of this standard referred to every standard in the series.

Chapter 2 Background

2.1 The importance of IEC TS 62257 series

It is invented to direct and suggested to small renewable energy and hybrid systems for rural electrification. The intention of IEC TS 62257 is to support Renewable Energy Engineers, project managers, system designers and technician to decide the correct system for the correct venue, outline the network, execute the system and preserve the network (IEC 2015a).

2.2 Decentralized rural electrification (DRE)

It is a power structure targeted to supply electricity to public, which stayed no power grid connected to the central power urban zone. The functions were needed to be able to modify to different kind of utility demand including to venue-restricted conditions (Transenergy).

For two examples;

1. Spread towns with houses, DRE will support using standalone photovoltaic generators (Transenergy).

2. For the intense of populations, then the electrification supply is given by solar, hydro, wind or hybrid power plants coupled to micro-grids (Transenergy).

2.3 The difference in developing countries and developed countries

The developed countries are self-governing succeeded though the developing countries are rising as a developed country (S 2015). Developing Countries are the country that expertise improvement for the first time (S 2015). If we discuss about developed countries, they are post-industrial economies (S 2015). Consequently, The different between the two are being the rank of the excellency of service and the demand energy magnitude that the client will be able to pay for (IEC 2015a).

2.4 Case Study – Rottnest Island

Rottnest Island is located 19 kilometres off the coast of Fremantle in Western Australia (ExperiencePerth.com 2017). It is a destination for tourist attraction near Perth, the capital city of Western Australia. Hence the most demanded in electricity is the visitors.

Since the electrification system in Rottnest is off-grid to the main land. It is then an excellent place to use for a study case to this thesis project. Rottnest Island electrification is relied on Australian standard ASN3000. Hence after been studied on IEC TS 62257, it is become an opportunity to observe the similarities and any differences between existed power system on the island to IEC TS 62257.

Phenomenon solar and constant wind resource is described as Rottnest Island weather condition (Australia 2017). The solar farm and wind turbine are empowered to meet 45% of the island's electricity demand from renewable sources (Australia 2017).

8000 photovoltaic modules are connected on a secure array (Australia 2017). 98 percent performance is usually in the morning. The production of power form those modules are 500 kW (Australia 2017). A 600 kW Enercon wind turbine is produced energy that chopping the solar energy. If wind energy is increased, the solar energy is then decreased. The seven diesel generator is produced energy during night time and when renewable source is not given energy to meet the need. 18000L truck is brought in diesel which was shipped from the mainland. 20 inverter is converted ac to dc and dc to ac for wind to utility grid as well as dc to ac for solar to utility grid. The Electricity was fed into the Island cable using an underground distribution system.

2.5 Summary

The intention of IEC TS 62257 was to support Renewable Energy Engineers, project managers, system designers and technician to decide the correct system for the correct venue, outline the network, execute the system and preserve the network (IEC 2015a).

DRE is a power structure targeted to supply electricity to public, which stayed no power grid connected to the central power urban zone. The functions were needed to be able to modify to different kind of utility demand including to venue-restricted conditions (Transenergy).

The different among the two are being the rank of the excellency of service and the demand energy magnitude that the client will be able to pay for (IEC 2015a).

Rottnest Island's electrification system has been chosen as a study case to the thesis. The Island is relied on Australian standard ASN3000. The solar farm and wind turbine are empowered to meet 45% of the island's electricity demand from renewable sources (Australia 2017).

Chapter 3 To meet the customers requirement in decentralised electrification

3.1 Off-grid electricity: which entrance to select?

IEC TS 62257-1 is stated that predicting the target condition in the medium term (10 years) and long term (20 to 30 years) needed to consider the following;

1. Master plan for this region is built to outline the lowest life cycle cost solution (IEC 2015a).
2. Grid extension and independent system solution are taken into justification (IEC 2015a).

3.1.1 Master plan

Master plan is specified as National/regional or decentralized system and to define most appropriate timeframe to perform the work (IEC 2015a).

The sociological, economical and geophysical data is required to study. Expected variations in the power requirements as function of the future economic expansion is searched for the demand essential (IEC 2015a). The data from each village, urban development and the demographic (**important**) is investigated (IEC 2015a). It is helped to receive the finest electrification which is judged the capital investment (IEC 2015a).

Decentralized system and GIS (graphical presentation of the master plan) is installed cost-effectively (IEC 2015a). The village is identified by colour codes representing the equivalent type of power supply (IEC 2015a).

In term of Master plan, is prioritized for future arrangement of charge of electrification on annually or 5 years period (IEC 2015a). The value of cost is taken as one of the most important criteria (IEC 2015a). It is less significant in developed world but was vital in developing countries (IEC 2015a).

Simulation is fluctuated all the applicable factors (IEC 2015a). The complete financial analysis of the chosen network is received from there (IEC 2015a). The greatest cost-effective solution is from economic calculation (IEC 2015a). The central of the village with micro-power stations and micro-grids (electrification systems) is electrified (IEC 2015a).

It is resulted that the cost per user to micro-grid was higher than the cost of the individual electrification system (IES) (IEC 2015a).

3.1.2 Remote electrification requiring a variety of systems

In rural area, decentralized system of electrification is provided power to the required area that is not cost-effective linked to national grids (IEC 2015a). It is depended on each remote area to choose the most conventional electrification system to suit the area. Each remote area are not randomly picked any system from all the existed product available.

3.1.3 Category of demand

Specific processes, isolated homes, collective facilities, business activities were those type of demand that IEC TS 62257 is identified (IEC 2015a).

3.1.4 Decentralized systems

1. Collective Electrification system (CES) is supplied electrical energy to several consumption spots (from one or multiple source point)(IEC 2015b).

2. Individual Electrification system (IES) is sent electricity to consumption spots (usually with one single energy resource point)(IEC 2015b).

CES is matched for rural as it is quite highly peopled areas (IEC 2015b).

IES is matched for rather thinly peopled areas and/or remote homes (IEC 2015b).

Single user joining two subsystems is for IES namely;

- An electrical power production subsystem,
- A subsystem for consuming this electrical power (IEC 2015b).

Moreover CES is for many users that incorporating three system namely;

- An electrical power production subsystem,
- A secondary grid for sharing/distributing this power,
- A demand subsystem with the in-house wiring and user's electrical applications (IEC 2015b).

IES and CES is displayed the network similarly to the general configuration of an electrification system in Figure 2.

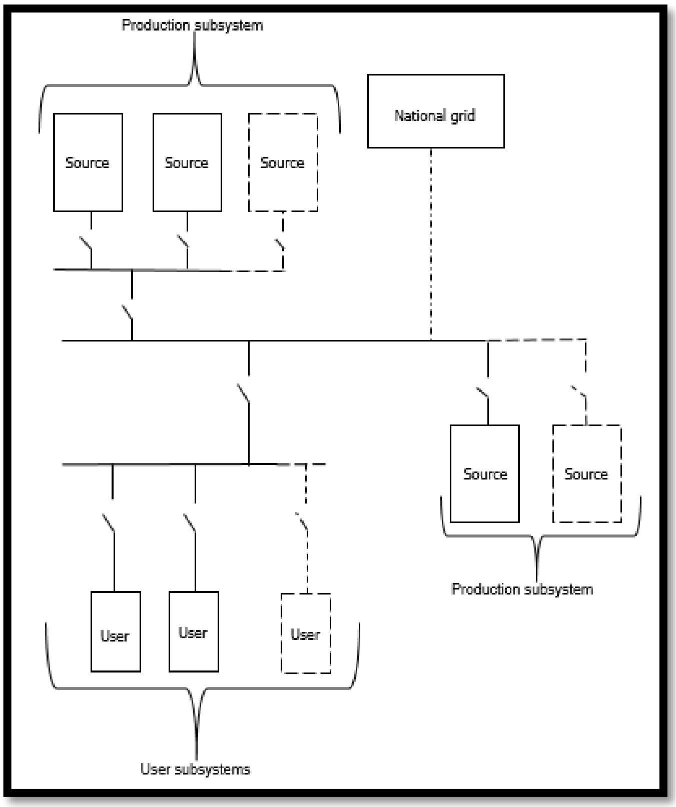

Figure 2 general configuration of an electrification network (IEC 2015b)

The answer of CES or IES is justified through calculation the discount (IEC 2015b). As well as the appropriate sociogical and cultural characteristics is taken into consideration(IEC 2015b). Other consideration is effected final decision (IEC 2015b). For example operating time of gensets is often operated limited intervals throughout the day (IEC 2015b).

3.1.5 Place and role of initial studies in a dispersed rural electrification project

It is insensible to present an electrification project in opposition to the desires of the local resident and organization(IEC 2015b). It is suggested to understand the requirements and desires of the local residents such as their demand, their capacity and their prepared to pay for a current energy deal. Once, all socio-economic data are accessible (IEC 2015b). Then those data are properly collected and managed for this purpose (IEC 2015b). If this is not happened, the suggestion of a preliminary study is recommended (IEC 2015b). That is the first stage in the recognized of feasibility study for dispersed rural electrification project (IEC 2015b). The job is to gain more understanding in the region through several project specialists. In term of the data needed for technical evaluations, economic, financial and legal analyses and for carrying project in general are then accessible (IEC 2015b). Some of those are then obtained from intellectual organization prior to specific sites visits (IEC 2015b).

3.2 Summary

The option to select off-grid electricity is based on a method called “master plan” (IEC 2015a). The plan is outlined the lowest life cycle cost solution (IEC 2015a). Therefore it is needed to study sociological, economical and geophysical data in the particular remote area to adjust capital investment for the finest electrification (IEC 2015a). The most cost-effective solution is received from economic calculation that the micro-power stations and micro-grids are run (out of national grids) (IEC 2015a).

Decentralised systems are divided into two categories namely; Collective Electrification system (CES) and Individual Electrification systems (IEC 2015b). CES is electrified power from one or multiple resource point (IEC 2015b). It is suited for highly population area (IEC 2015b). Whereas IES is usually supplied power with a single energy resource point (IEC 2015b). It is suited for sparsely people area (IEC 2015b).

The electrification project is needed to follow the desires of the local residents and organisations for a present energy deal (IEC 2015b). If the social-economic data are not accessible then a preliminary study is suggested (IEC 2015b). It is helped to gain more understanding in the area through several project specialists (IEC 2015b). Some of the data such as technical evaluation, economic, financial and legal analyses are obtained from intellectual organization before specific sites visits (IEC 2015b).

Chapter 4 Minimum sufficient requirements to the field of application corresponding to high standard safety

4.1 Useful description of a distribution subsystem

Complete functions are achieved through a distribution subsystem (or rural micro-grid) (IEC 2015d). An electric power distribution service is delivered consisting of connecting the rural micro-power plant to the application points (IEC 2015d). This function is assembled everything (IEC 2015d). So it is guaranteed that the terminal application points generating from the rural micro-power plant energy supply point, while adjusting to the energy requirements of the different forms of customer (individuals, economic activities, local collective authorities, public lighting, etc.) (IEC 2015d).Comprised and set up the Method is then observed rural micro-grid distribution losses (IEC 2015d).

4.1.1Presentation of the costs

It is significant that the costs allied to the project presented in a way visibly identify by the comprised organisations (IEC 2015d).

Cost is broken down into four areas:

1. Initial investment cost (equipment, infrastructure and installation);
2. Operating costs (labor and expandable material);
3. Replacement costs (equipment and installation);
4. Recovery and dismantling cost (equipment and installation) (IEC 2015d).

All cost calculations are varied subject to the organisation for whom the cost calculations are delivered (IEC 2015d). The battery replacement cost is not expected to recognize who is leasing a particular system (IEC 2015d). Since, this is the concern of the lease issuer (IEC 2015d). Thus the only object that delivering to the consumer is the monthly service fee (IEC 2015d).

The purchaser of a complete system is required to recognize all of the associated costs over the system life to relate this to other electrification choices (IEC 2015d).

Costs supplied to the user are delivered in at least four formats:

1. Yearly cash flow;
2. Yearly cash flow;
3. Total life cycle cost;
4. Levelised cost of energy;
5. Annualised maintenance, operating, and replacement expense (IEC 2015d).

All these cost are deliberated in calculating the actualized discounted cost (IEC 2015d). It is run down not only the different costs mentioned above, but also the income from sale of energy during the life of the installation (IEC 2015d).

It is allowed the run down difference (income-cost) comparing for diverse technical solutions studied (IEC 2015d).

4.1.2 Data to be collected

It is the relationship of the different demands of info as presented above, table 1 is listed the minimum data that is collected from the power system (IEC 2015d).

Table 1 Minimum set of data to be collected (IEC 2015d)

Data	
Voltage at battery terminal	●
Battery current	●
Battery temperature	(●)
REN sources voltage	(●)
REN sources current	●
Generator set voltage	(●)
Generator set current	●
Application supply voltage	●

Data	
dc and/or ac applications supply current	●
Genset starting status	(●)
Genset operating status	(●)
Genset fuel consumption	(●)
Battery temperature	(●)
Ambient temperature	(●)
Generator set running time	●
● Information requested as a minimum to allow the management of the system **(●) Information requested for a better comfort or a better accuracy in the management of the system**	

4.2 Protection against electrical hazards

4.2.1 Protection against overcurrent

Protective devices are offered to break any over-current flowing in the cct conductors (IEC 2015e). It is prior such a current causing a danger due to thermal of mechanical effects or a temperature increase and made harmful to insulation, joints, and termination (IEC 2015e).

4.2.2 Protection against overload currents

The operating characteristics of a device is defended a cable against overload current. It is satisfied the two following conditions:

$$I_B \leq I_n \leq I_z$$

$$I_2 \leq 1.45 \leq I_z$$

where

I_B is the design current of the circuit;

I_z is the continuous current-carrying capacity of the cable;

I_n is the rated current of the protective device;

I_2 is the current ensuring effective operation in the conventional time of the protective device (IEC 2015e).

4.2.3 Protection against short-circuit

For cable and isolated conductors, each short-circuit protective device is seen both of the following state:

- The breaking capacity is not less than the potential short- circuit current at the place of its installation, excluding where another protective device taking the necessary breaking capacity and coordinated characteristics is fit upstream (IEC 2015e).
- All current is produced by a short-circuit happening at any spot of the circuit should be interrupted in a time not exceeding that which brings the conductors to the admissible limit temperature (IEC 2015e). For short- circuit with interval up to 5 s, the time t, in which a given short- circuit current is increased the conductors from the highest allowable temperature in normal duty to the limit temperature can, as an estimate, calculating from the formula:

$$\sqrt{t} = K \times \frac{S}{I} \qquad \text{Eqn 1)}$$

Where

t is the duration in s;

S is the cross-sectional area, in mm^2

I is the effective short-cct current, in amperes, expressed as r.m.s. value;

K is a factor raking account of the resistivity, temperature coefficient and heat capacity of the conductor material, and the appropriate initial and final temperatures (IEC 2015e).

4.2.4 Protection against risk of fire

Where there is a risk of personal injury or property is harm due to fire causing by an earth fault in the system, a residual current protective device is delivered at least at the origin of the user's installation (IEC 2015e). The rated operating residual current is less than or equal to 300 mA. Such a device is shifted all live conductors (IEC 2015e).

4.2.5 Protection against effects of lighting

Choices for lightning protective provision (lightning rod, surge protective devices, etc.) is based on risk assessment, taking reason of the lightning frequency statistics, the characteristics and position of the structures, the length of the overhead lines, if any, the cost and the demanded accessibility of the equipment (IEC 2015e).

4.2.6 Protection against overvoltage

Where protection against overvoltage (for example due to indirect lightning) is demanded, an SPD(s) is connected both at the distribution board of the micro-power plant, and at the origin of the user's installations or associated with each socket-outlet (IEC 2015e).

Minimizing the voltage is induced by lightning, the zone of all wiring loops are as small as possible (IEC 2015e).

4.2.7 Protection against direct lightning

Where protection against direct lightning is required. The following necessities are applied:

- in case of wind powered generation, the lightning is connected at the summit of the mast (IEC 2015e).
- where PV generation is coincided with wind-powered generation, protection against direct lightning is general achieved by placing the panels inside the pick-up zone of the wind powered generator mast (IEC 2015e).

- where PV generation is alone, the panels are protected by installing a protective wire above the PV panel or lightning rod/s with an appropriate pick-up area (IEC 2015e).
- protection is finished by the installation of SPDs between conductors and between conductors and earth, with suitable features (IEC 2015e).

4.3 Over-current protective devices

Fuses (gPV types) or circuit -breakers with appropriate range of instantaneous tripping are used (IEC 2015e). Protective devices are preferably of a type ensuring in protection (IEC 2015e). The range of installation tripping for a circuit -breaker is selected referring to the potential of short- circuit current (IEC 2015e).

Overcurrent protective devices are preferably of a type ensuring protection against both overload and short circuit current and capable of acting as isolating switch in the open position (IEC 2015e).

Special care is rewarded to over-current protective devices installed in series, ensuring that a suitable coordination is attained (IEC 2015e). The selection between protective devices in series are preferably be total (IEC 2015e).

4.3.1 Earth termination (electrode) of lightning protection system.

Dispersing the lightning current into the earth without causing dangerous overvoltage, the shape and the dimensions of the earth termination system of an LPS are more significant than the value of the resistance of the earth electrode (characteristic applicable for dc or low frequency phenomena) (IEC 2015e).

The earth termination system was composed of:

1. either conductors of the same nature and same cross-section as the down-conductor is laid out in the form of a large crow’s foot: 3 conductors 7m to 8 m long buried horizontally at a depth of at least 0.60 m (IEC 2015e),
2. or a set of 3 vertical rods 2 m in length is coupled together and set off at the tips of an equilateral triangle with sides measuring about 2 m (IEC 2015e).

The earth termination system of the LPS is joined to the earthing arrangement with short connections (IEC 2015e).

4.4 Composition of a micro-power plant

A micro-power plant is included one or several generators, a storage devices (if needed) and connected charge controller, other equipment, such as

- energy management device;
- energy converter;
- telecommunication equipment (if any);
- main board;
- interfaces (between generator, between the micro-power plant and the micro-grid or the application, between the micro-power plant and the operator);
- switches;
- protection devices such as equipotential bonding and earthing system;
- civil works (IEC 2008c).

4.4.1 Interconnection of generators

It is depended on the category of energy sources and the type suiting of equipment to deliver (IEC 2008c) through more than one generator is used. And their outputs are connected in common at an ac or a dc bus (IEC 2008c).

4.5 Composition of a micro-grid

It is depended on the maximum active power value required and the topography of the areas serving (IEC 2006a).

Single-phase power system output is a single – phase feeder with multiple single phase distribution (IEC 2006a) (see figure 3).

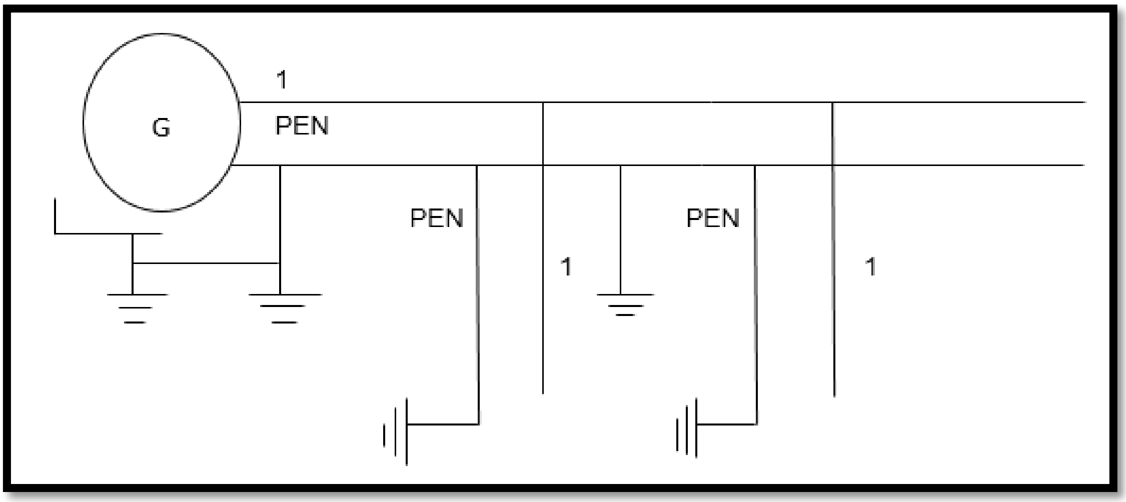

Figure 3 Micro-grid consisting of a single-phase feeder (IEC 2006a)

4.5.1 Connections and accessories

Connections between conductors and between the conductors and other equipment are ensured electrical continuity and suggesting appropriate mechanical resistance (IEC 2006a).

The choice of the connection is meant to take into consideration;

1. The material of the conductors and their insulation,
2. The number and the shapes of the conductor cores (IEC 2006a).

4.5.2 Isolating devices

It is included for the isolation of the micro-grid to allow servicing, checking, fault location and repairs (IEC 2006a).

Isolation is set on all of the conductors (IEC 2006a).

Isolation is carried out by a device installed for other purposes (cct-breaker, etc.) (IEC 2006a).

Isolation devices are armed with a suitable locking device namely; earthing arrangement, protective conductors and protective bonding conductors (IEC 2006a).

The PEN conductor is earthed at both ends of the network and repeatedly every 200 m as displayed in figure 4 (IEC 2006a).

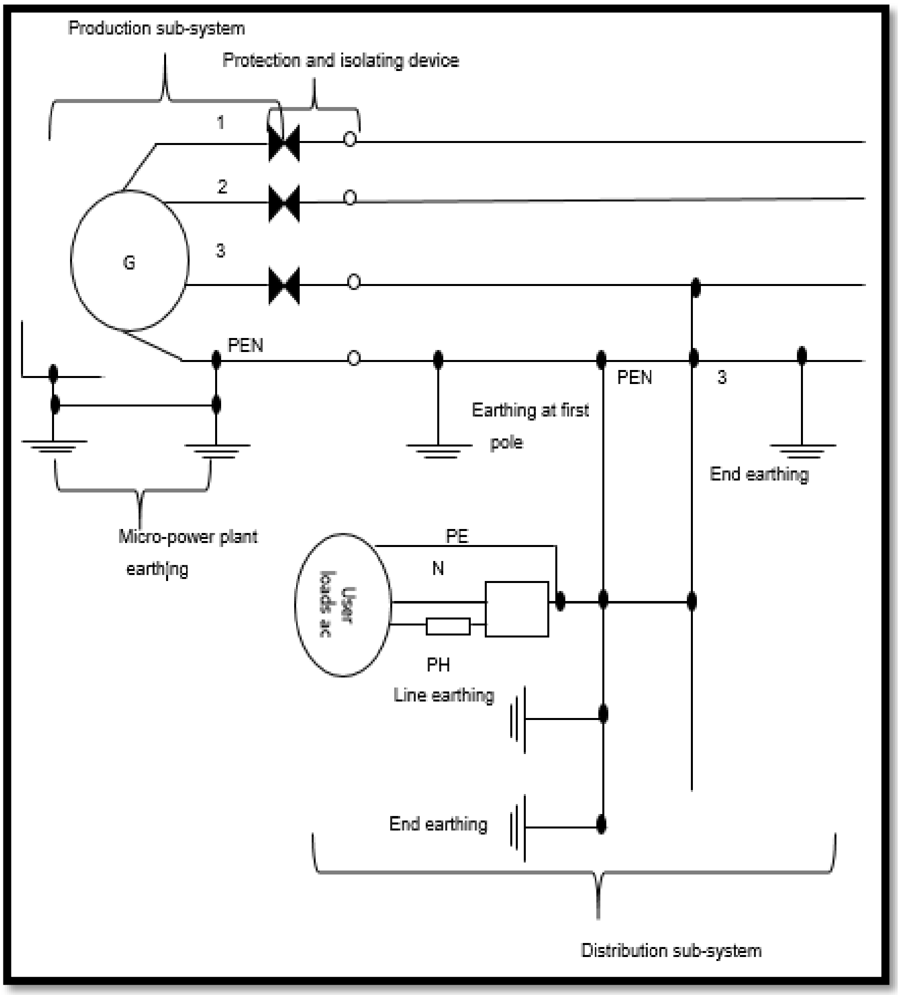

Figure 4 Micro-grid earthing scheme (IEC 2006a)

Table 2 Functions ensured by various types of user interface (IEC 2006b)

Function	Description
A	Connection to electricity sources
B	Isolation from the electricity sources
C	Protection against electric shocks
D, D1	Protection against overloads and short-ccts
E	Contract management if relevant
F	Earthing terminal
G	Distribution of ccts

Figure 5 and 6 are illustrations of setting up and functions ensuring by the user interface (signified technical functions were not contractually binding)(IEC 2006b).

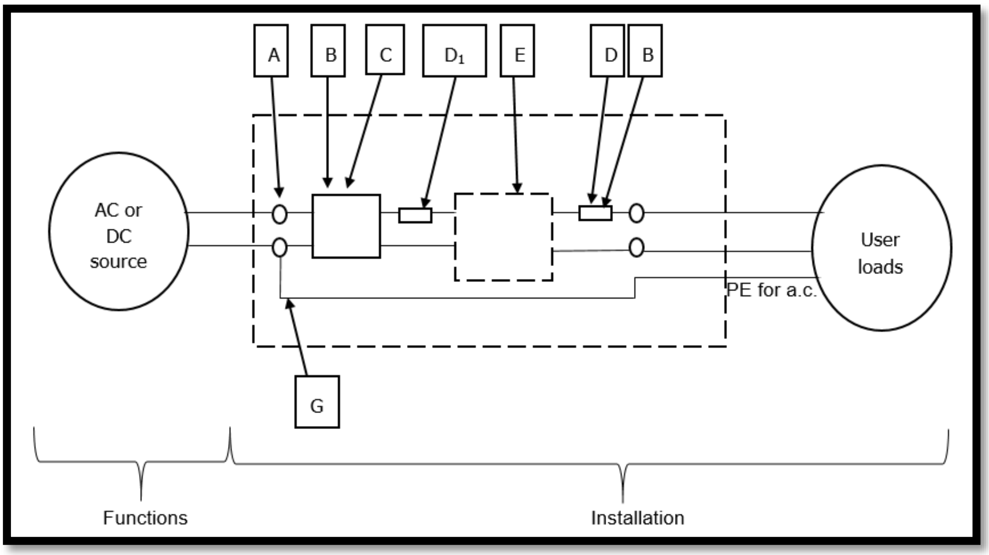

Figure 5 interface for user installations was supplied from an ac or a dc source (IEC 2006b)

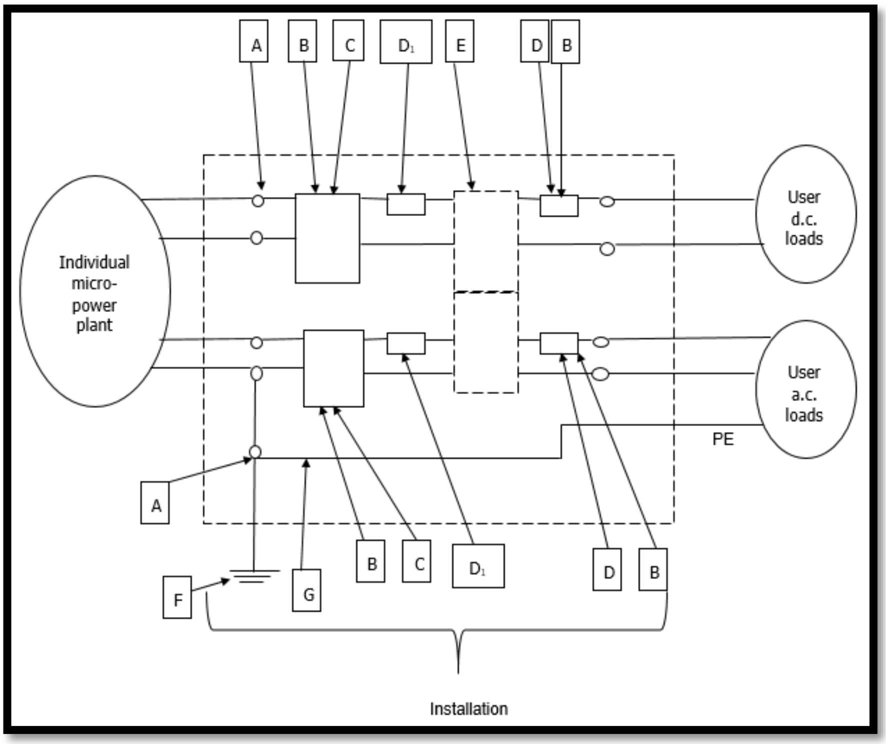

Figure 6 interface for user installations were supplied locally from ac or dc sources (not from a micro-grid) (IEC 2006b)

4.5.3 Housing

All the equipment for the user's interface whose functions are defined earlier in one container, including the interfaces for the set of cables connecting the electrical power source and the user's ccts (IEC 2006b).

The housing is not be in contact with the active parts of the equipment which it was contained; the housing is fulfilled the obligation of protection index IP54 and IK 4 for mechanic effect (IEC 2006b).

The protection index of housing is not distressed by the mounting system or by penetration of cables. The housings are armed with pre-shaped inputs equipped with accessories for path of the cables (IEC 2006b).

4.5.4 Requirements for dc parts of installation

Simple separation, at least, is not provided between the dc side and the ac side of a standalone installation (IEC 2006c).

4.5.5 Requirements for ac parts of installation

If the features of the protective devices are fault of negligible impedance occurring wherever in the connection between a phase conductors and a protective conductor or exposed conductive part, auto disconnection of supply is arisen within 0.4 s (IEC 2006c).

A residual current protective device, with a rated operating residual current not exceeding 30 mA is delivered as extra protection for each connection (IEC 2006c). It is positioned in the user's interface housing (IEC 2006c).

4.6 Voltage drop

The maximum voltage drop is not greater than those shown in table 3 (IEC 2006c).

Table 3 Maximum acceptable voltage drop values in connections (IEC 2006c)

Type of installation	Lighting and socket outlets
Installation from supplied from a 120 V or 230 V distribution micro-grid or standalone installation with an ac source	3%
Standalone installation with a dc source	5%

4.7 Specific rules to wiring systems buried in earth

Wiring system is covered up in earth (IEC 2006c). It is protected by conduits or sleeves or by comparable devices against mechanical corrosion (IEC 2006c). The diameter of the conduits is at least three times the diameter of the cables (IEC 2006c). After laying the cable, the ends of the sleeve are secure to avoid jam (IEC 2006c).

The compensation for the effects of the settling of the soil, the cables are buried at a depth of at least 60 cm in zones unapproachable by motor vehicles and at a depth of 1 m in areas reachable to vehicles (IEC 2006c). A red plastic grid is placed 10 cm above the conduits (IEC 2006c). It is indicated the electrical conduits (IEC 2006c).

These depths are less in rocky terrain or if sleeves are used designing to make sure that the cables did not intend to endure the settling effect of the soil (IEC 2006c).

4.8 User interface

The PE protection conductor is linked to the PEN conductor or the micro-grid in the user interface housing upstream of the RCD, on a terminal provided for this purpose (IEC 2006c).

4.8.1 General operating conditions

The project implementer is defined the operating conditions to which the PV-IES was shown. For example of such condition are in table 4 (IEC 2006c).

Table 4 Climate condition (example) (IEC 2006c)

	Nominal operating range	Storage - Transport
Temperature (degree Celsius)	-10 to + 50	-40 to + 80
Humidity at 28 degree Celsius (%)	5 to 95	
Atmospheric pressure (hPa)	860 to 1060	

4.9 Summary

The complete power systems are achieved through rural micro-grid (IEC 2015d). The terminal application points generating from the rural micro-power plant energy supply point with adjusting the energy requirements to the different forms of customer (IEC 2015d). It is also considered distribution losses (IEC 2015d).

All calculation are varied due to the organization whom delivered (IEC 2015d). The only subject to customer is monthly service fee (IEC 2015d).

The protection against electrical hazards are prevented from overcurrent, short-cct, risk of fire, effect of lighting, overvoltage and direct lighting (IEC 2015e).

Over-current protective devices are preferably of a type that making sure in protection from potential short-cct current such as fuses or circuit –breakers with appropriate range of instantaneous tripping (IEC 2015e).

Composition of a micro-grid is depended on the maximum active power value serving (IEC 2006a). The connection between the conductors to conductors and other equipment are for electrical continuity and suggesting appropriate mechanical resistance (IEC 2006a). Isolating devices is for checking, fault location and repair (IEC 2006a).

All equipment for the user's interface are in one container called housing (IEC 2006b). It is not allow to be in contact with the active parts of the equipment which it is contained (IEC 2006b).

In the ac parts of installation, if protective devices are exposed conductive part then auto disconnection will arise within 0.4 second (IEC 2006c). In the other hand of dc parts of installation is a simple separation, at least is not provided the dc side and the ac side of a standalone installation (IEC 2006c).

The maximum voltage drop is less than 3 % installation from supplied from a 120 or 230 V distribution micro-grid grid and 5 % of standalone installation with dc source (IEC 2006c).

The specific rules to wiring systems hidden in earth, the cable shall be buried at a depth of at least 60 cm in zones unapproachable by motor vehicles and at the depth of 1 m in areas reachable to vehicles (IEC 2006c).

Chapter 5 The methodology to achieve the best technical and economic condition

Stand-alone power system is built to generate power to isolated communities or loads in the rural area with no connection to the national grid (IEC 2015f).

These systems are divided down into three classes:

1. process electrification systems (for example pumping);
2. individual electrification system (IES) (single user, load or application);
3. collective electrification systems (CES) (multiple user load or application) (IEC 2015f).

   In order to fulfil the various energy requirements both in terms of quality and quantity, six AOMR actions are presented in Table 5 (IEC 2015f).

Table 5 AOMR actions (IEC 2015f)

Acceptance	• Checking the process ensure that the system installation meets the requirement set forth in the implementation contract between the project developer and the project implementer • Testing the process to ensure that the micro-power system run referring to the functional part of the implementation contract • After the parties come to agreement, transfer the responsibility of the network
Operation	• Managing the business of system operation • Monitoring normal system operation • Managing system electrical operation = executing actions on electrical ccts • Response to abnormal operating condition= to provide service outside of the boundaries of the implementation contract • Response to abnormal system operation, corrective actions, troubleshooting and repair system or system components ; fault finding = to service the plant and restore it operating conditions following an unpredictable failure • Guaranteeing safety while performing actions on the plant • Performing analysis and retrofit of the system to account for new operating conditions
Maintenance	• Preventive maintenance: keeping and maintaining the system to it normal operating state • Corrective maintenance: adjusting, fixing or replacing components after fault recognition • Conducting periodic tests and inspection
Replacement	• Replacing the equipment on normal life cycle completion • Replacing the equipment for upgrading purposes • Dismantling and recycling at end of life cycle

5.1 Organizational issues

In this area, it is stated system limit description of the AOMR domain. An understandable definition of the physical limits of the three parts of the system (production, distribution, demand) related to operation, maintenance and replacement actions are made (IEC 2015f). The identification of the appropriate personnel or companies accountable for the diverse subsystems is necessary (IEC 2015f). This is required for both categorises and safety bases (IEC 2015f).

5.2 Maintenance actions

Within most micro-power systems maintenance is to complete on each component as well as the system as a whole. In most cases, equipment manufacturers are provided maintenance guidelines for their specific component but no general maintenance guideline was provided for the complete system (IEC 2015f).

5.3 Replacement factors

In most circumstances, replacement actions are needed for distinct power plant sections as linked to the whole network (IEC 2015f). An individual factor is replaced possibly with a diverse but well-matched component if is essential to preserve system performance condition, but the rest of system is leave out no charge (IEC 2015f). Irregularly the whole micro-power network is necessity to experience replacement. A quantity of circumstances is classified as follows:

a) expiration of the serviceable lifecycle of most of the system: if most of the scheme components are got to the end of their serviceable lifecycle, it is more cost effective to replace the complete power system comparing to the substitution of each individual component (IEC 2015f).

b) Quality of the supply is not at satisfactory anymore: variations in the society are vital to a better quality of supply than is delivered through the earlier network (IEC 2015f).

c) Load was increased: the community loads were increased to the level that the network is not be able to accomplish generating adequate power. This illustration is more cost effective to replace the whole power system. The old power system is then moved to a new community with lower power demands (IEC 2015f).

d) Step change in technology: a step change in technology is merited to the replacement of the whole system with a technology that is delivered higher quality of service at a lower budget (IEC 2015f).

e) Change in plant site: if the plant site is altered for any intention (IEC 2015f).

5.3.1 Replacing equipment

a) Prior replacing a piece of apparatus, the first thing to do is disjointed it from all sources of power. In case of small systems, lead to the turn-off of the entire network and hence facility operators are required to be qualified in conduct all parts of the system. In bigger network, service staff is able to isolate objects from the rest of system without needing to shut down the entire network (IEC 2015f). The system documents are stated in IEC TS 62257-4 that needed to check to ensure this is conceivable (IEC 2015f);

b) Prior removing equipment, a copy of all logged data, parameter settings, status memories and hardware settings (e.g. by jumpers, switches, potentiometers, etc.) are made (IEC 2015f). If this are not completed through an electrical interface, but are made through noting all reachable data that found in display menus and by checking internal switches, settable device, etc. (IEC 2015f). All the latest settings is then known and noted (IEC 2015f). The recording of configurable parts inside the device is only be completed after the device was correctly separated from the system (IEC 2015f);

c) Brand, model, type and serial number data from the fundamental and replacement equipment are classified and noted (IEC 2015f);

d) After any new device is connected, the hardware conformation is carried out reference with the records as earlier made (IEC 2015f). For devices regulated through software, the software conformation is connected as earlier recorded (IEC 2015f). It is regularly that devices are partially attached to the network for this reason (IEC 2015f). The commands are given in the manufacturer's technical documentation is follow (IEC 2015f). If apparatus is not in good condition, it is then be the duty of the service technician designing the new apparatus appropriately and noted the settings (IEC 2015f);

e) After appropriately arrange and connect into the network, as requested in the manufacturer's commands, an acceptance process, as stated in the applicable technical specification achieve (IEC 2015f);

f) The replacement of a certain component is required system level acceptance testing to guarantee good system process (IEC 2015f);

g) Environmental issues criteria are essential followed to for the appropriate removal of uninvolved apparatus (e.g. proper disposal of sulphuric acid from replaced batteries)(IEC 2015f).

5.4 Physical ingress protection

This is provided an explanation of the degree of protection from the disturbance of foreign objects (IEC 2015g). A product's enclosed space is provided in terms of IP class. Physical ingress protection is vital for user safety along with product functionality (IEC 2015g).

5.5 Current total harmonic distortion (THD)

The current total harmonic distortion is the calculated of harmonic content in device's current waveform (that was how much the current waveform was diverged from a real sine wave) (IEC 2015g). High levels of harmonic current is affected heating in power generation and distribution apparatus waveform, negatively impacting the functioning of other equipment coupled to the electricity network (IEC 2015g).

5.6 Colour Characteristics

The colour features of light are involved the colour rendering index(CRI), a degree of how accurately the light renders colours, and the correlated colour temperature (CCT), a degree of the colour of the light conveyed as a temperature in kelvin (IEC 2015g).

5.7 Summary

Stand-alone power system is built to generate power to isolated communities (IEC 2015f). The systems are divided down into three classes; process electrification system, individual electrification system and collective electrification system (IEC 2015f). Six AOMR actions are displayed energy requirements in terms of quality and quantity (IEC 2015f).

Organisation issue is accountable for the diverse subsystem safety (IEC 2015f). Maintenance action, equipment manufacturers are provided maintenance guidelines for specific component (IEC 2015f). Replacement is needed for distinct power plant sections as linked to the whole network (IEC 2015f). Irregularly the whole micro-power network is necessity to experience replacement (IEC 2015f).

Physical ingress protection is an explanation of the protection from the disturbance of foreign objects. It is provided in term of IP (IEC 2015g).

Current total harmonic distortion is indicated how much the current waveform is diverged from a real sine wave (IEC 2015g).

Colour Characteristics are involved two types namely; CRI is a degree of how accurately the light renders colours, and the correlated colour temperature CCT, a degree of the colour of the light conveyed as a temperature in kelvin (IEC 2015g).

Chapter 6 The combination of diesel generator system and solar energy

6.1 Generator boundaries

Figure 7 is shown the place of the generator in an electrification network.

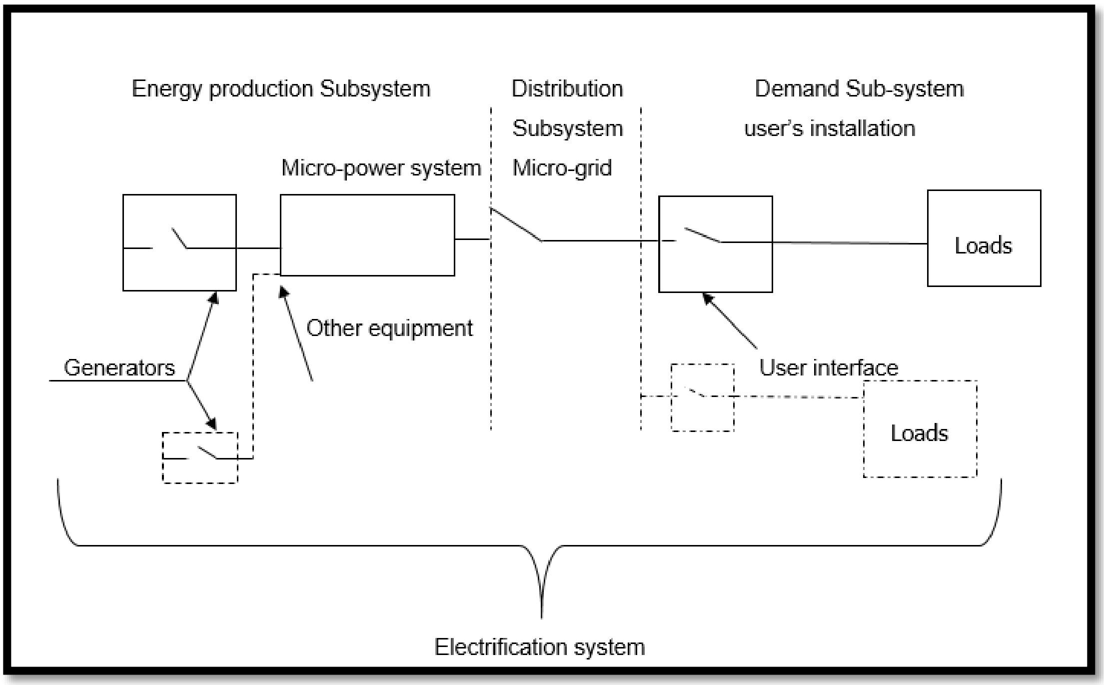

Figure 7 general electrical configuration of a collective electrification system (IEC 2008a)

The generator is expressed entirety essential to make electric power consistent to the needed features of voltage, frequency, harmonics, power and consumption of the clients, referring to the required value of facility (IEC 2008a).

Figure 8 is clarified the general functional configuration of a PV powered system. The localisation of the performance is described in table 7.

6.2 Generator requirements

When defining the generator characteristic the following "inputs" and "outputs" are taken into attention as showed in Table 6 (IEC 2008a):

Table 6 General inputs and outputs to be considered for generator specification (IEC 2008a)

Input requirement (constraints)	Generator characteristics	Output requirements (results)
	Technology	
Primary energy resources (Sun, wind, water flow head, fuel)	Size Weight	Electrical performances (voltage, current, power, frequency)
	Volume	
Environmental conditions (air pressure/ humidity/ temperature)	Protection Housing	Safety (people, equipment)
	Civil engineering	
Signal (start/stop, synchronisation)	Maintenance requirements Internal control	Environmental impacts (exhaust, heat, noise)
Regulations/ Standards Assessment of energy demand		
Assessment of energy quality requirement		

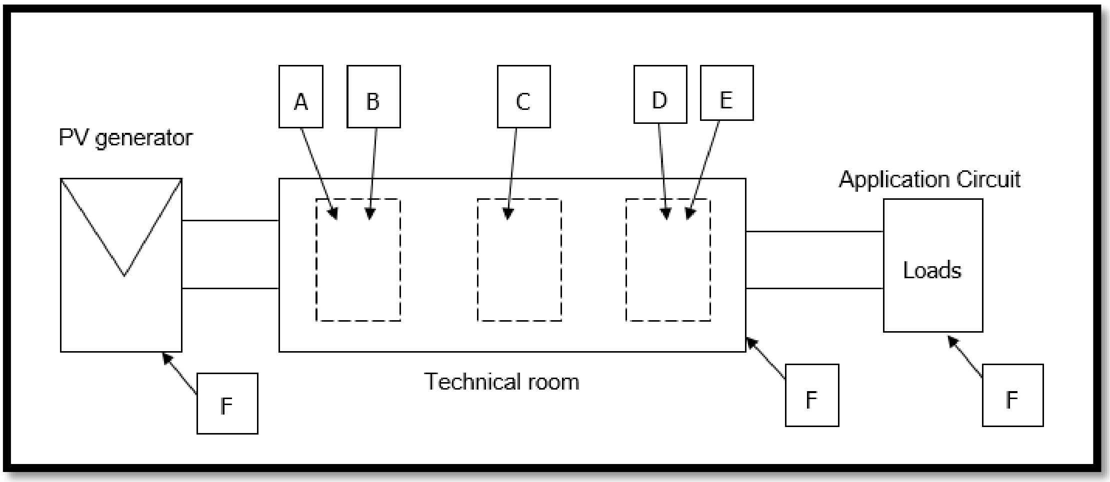

Figure 8 General functional configuration of a PV system (IEC 2010)

Table 7 Functions fulfilled by the technical room (IEC 2010)

Function	Description
A	Interface: connection between PV generator and technical room
B	Interface: isolation of the technical room from the PV generator
C	Other functions of the technical room + energy conversion, energy management, storage, if any
D	Interface: isolation of the application cct from the technical room
E	Interface: connection between technical room and the application cct
F	Earthing of exposed conductive part if required

6.3 Equipotential bonding

It is requested as soon as PV array is connected to another AC generator. It is used to avoid irregular potentials as overvoltage across them (including lightning overvoltage) (IEC 2010). The cable of the equipotential bonding between the generators and the technical room is linked as physically close as possible to live conductor to keep away from any wiring loops that are caused perturbations in the circuits (IEC 2010).

The connections to earth is made as close as possible to the equipment to earth (IEC 2010).

6.4 Considerations due to operating temperature

PV modules ratings are specified at standard temperature conditions (25 degree Celsius). Under normal operating conditions, 25 degree Celsius is a usual steady state temperature increasing with regard to the ambient temperature for crystalline silicon PV modules operating at the maximum power point under 1000 W/m^2 and when modules are operating on a very hot day (IEC 2010).

The two main requests on the PV array strategy are developed from this operating feature of PV modules.

a) For some PV technologies, the competence is decreased as the operating temperature rising.

(For crystalline silicon solar cells the maximum power is fallen between 0.4 and 0.5% per each degree Celsius increase in operating temperature). Therefore satisfactory exposure to the sun of the PV array is a strategy aim, certifying best performance for both modules and related apparatuses (IEC 2010).

b) All the components and equipment that in direct contact or near the PV array (conductors, inverters, connectors, etc.) are required to capable of resisting the expected maximum operating temperature of the PV array (IEC 2010).

c) The voltage is increased in cold state, crystalline silicon technology based cells (IEC 2010).

6.4.1 Insulation

The insulation cables are used inside the PV array were intended to:

- A voltage is at rating of at least $V_{OC\ ARRAY}$,
- A temperature is at rating referring to the tender,
- If it is exposed to the location, and is needed to UV-resistant, or is secured from UV light through proper protection, or the cables are set up in UV-resistant conduit;
- It is fire resistant (IEC 2010).

6.4.2 Fuse holders

Fuse holders are obeyed with the following necessities:

- voltage is rating identical to or more than $V_{OC\ ARRAY}$;

- current rating is identical or more than the equivalent fuse;
- a degree of protection is not smaller than IP 2X (IEC 2010).

6.4.3 By-pass diodes

By-pass diodes are used to avoid PV modules from being reverse biased and consequent hot spot heating. If by-pass diodes are used, and not fixed in the PV module encapsulation, they are intended to obey with the following obligation:

- A voltage rating is at least 2× $V_{OC\ MOD}$ of the secured module;
- A current rating is at least 1.45 × $V_{SC\ MOD}$;
- It is fitted referring to module manufacturing's suggestions;
- It is fitted so no live parts are unprotected;
- It is secured from degradation due to environmental influences (IEC 2010).

6.4.4 Blocking diodes

It is intended to use but they are not a standby for overcurrent protection (IEC 2010).
In network that is obtained battery. It is suggested that some components is built to get out of reverse current leakage from the battery into the array during night time (IEC 2010). A number of explanations are occurred to attain this as well as blocking diodes (IEC 2010).
If blocking diodes are used therefore needing to obey with following requested:

- A voltage rating is at least 2 × $V_{OC\ ARRAY}$;
- A current rating is at least 1.45 times the short current at STC of the cct. It is intended to protect;
    - 1.45 × $I_{SC\ MOD}$ for PV strings;
    - 1.45 × $I_{SC\ S\text{-}ARRAY}$ for PV sub-arrays;
    - 1.45 × $I_{SC\ ARRAY}$ for PV arrays;
- It is installed so no live parts are exposed;
- It is secured from degradation due to environmental factors (IEC 2010).

If it is a special recommendation from the manufacturer or from resident rule to use blocking diodes in PV strings of the PV array, these diodes are connected as displayed in figure 9 (IEC 2010).

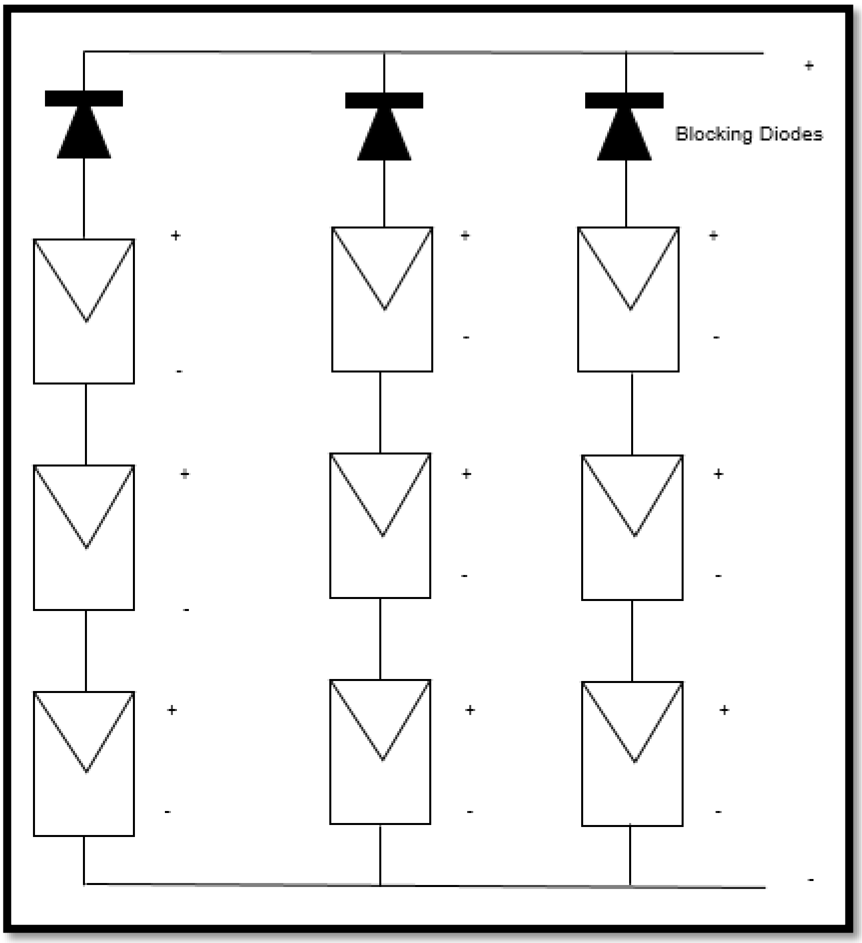

Figure 9 Blocking diode implementation (example) (IEC 2010)

6.4.5 Location and installation requirements

- Disconnecting means

It is delivered in PV arrays according to table 8 and table 9 to separate the PV array from the power conditioner and vice versa and letting preservation and review jobs to perform safely (IEC 2010).

- Installation

The appropriate rated circuit-breakers are considered for overcurrent protection. It is supported load breaking separating services (IEC 2010). Other disconnection and isolation devices are got the features as stated prior could been used as disconnections means (IEC 2010).

Fuse network is taken for overcurrent protection. Those are acceptable non-load breaking disconnecting means, in the case that they were changeable fusing element, rather using a disconnection mechanism (fuse-combination unit) (IEC 2010).

According to the location of disconnection devices in table 8, it is specified with detail of the network formation where the disconnecting mean is intended to build and using this connecting mean type (IEC 2010).

Table 8 Disconnecting means requirement in PV array installations (IEC 2010)

PV array Voltage	Cct or sub-cct	Type of disconnection device	Requirement
ELV	String cable	Disconnection device	Recommended
	Sub-array cable	Readily available disconnection device	Required
	Array cable	Readily available load-breaking disconnection device	Required
LV	String cable	Readily available disconnection device	Required
	Sub-array cable	Readily available load-breaking disconnection device	Required
	Array cable	Readily available lockable[a] load-breaking disconnection device	Required[b]

<table>
<tr><th>PV array Voltage</th><th>Cct or sub-cct</th><th>Type of disconnection device</th><th>Requirement</th></tr>
<tr><td colspan="4">[a] ‘Lockable’ disconnection device is a switch or cct breaker that has provision for insertion of a mechanical device to prevent the switch being closed by an unauthorised person. A Mechanical device in this context could constitute sealing with plastic cord, a pin, a wire or other device that prevents operation of the switch.
[b] A lockable disconnection device is not required if the whole cct is visible from the location of the switch</td></tr>
</table>

Table 9 Location of disconnection devices according to system configuration, where required (IEC 2010)

<table>
<tr><th></th><th colspan="3">Location of disconnecting devices</th></tr>
<tr><th>System configuration</th><td>PV string cables</td><td>PV sub-array cables</td><td>PV array cable</td></tr>
<tr><th>Unearthed PV array</th><td colspan="2" rowspan="2">On all live conductor[a]</td><td>On all live conductors</td></tr>
<tr><th>Earthed PV array</th><td>On all current carrying conductor [a,c]</td></tr>
<tr><td colspan="4">[a] Live conductors are those not directly connected to earth.
[b] The disconnection device is required in this situation to interrupt the earth conductor so that earth fault currents may be interrupted.
[c] In earthed arrays the earthed conductor is a current carrying conductor and needs to be able to be disconnected to allow for interruption of any earth fault condition.</td></tr>
</table>

6.5 Location: accounting for shadow

- Environmental

Shadowing of the PV array is lessened or rather removed over the whole day with reflection given to all periods of the year (IEC 2010).

A shadow blanking off a PV cell is made defeat of about the entire assembly of this module, meaningfully dropping the performance of the string modules (IEC 2010).

- One line of PV modules over the other

On flat roofs, PV modules are positioned in rows (IEC 2010). The first row fully is uncovered to sunlight and therefore the shadow is created disturbing the next row and so on (IEC 2010). As a rule of thumb, no shadow would be produced from one row to the next (IEC 2010).

- Wiring loops

The reduction of the value of lightning-induced over-voltages, the PV array wiring is placed in a term that the space of conductive loops is at least as possible, e.g. by laying cables in parallel as displayed in figure 15 (IEC 2010).

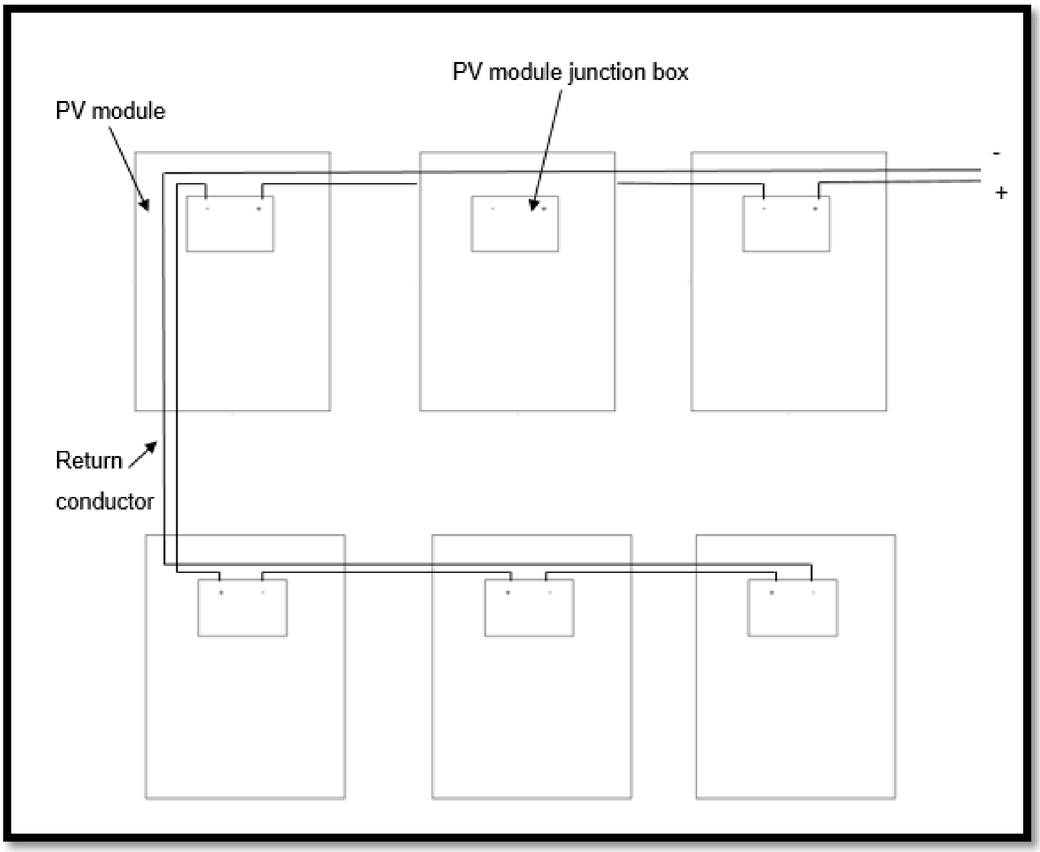

Figure 10 PV string wiring with minimum loop area (IEC 2010)

- String wiring

Among the modules, they are completed without laying lines in conduit, offering that the resulting requirements are encountered:

- Insulated and enclosed lines are applied, and
- Cable is secured from mechanical loss, and
- The line is secured to let go strain to avoid the conductor from pending free from the joining (IEC 2010).

* Wiring fitting in junction boxes

The following necessities are related to the setting up of wiring network in junction boxes: Wherever conductors are go into a junction box without conduit (IEC 2010). A tension relief network is got to avoid cable disconnections inside the junction box (e.g. by using a gland connector) (IEC 2010).

All cable entrances, when it is connected in tending to maintain the IP rating of the enclosure (IEC 2010).

For LV PV arrays, where some return conductor is directed over module junction boxes (IEC 2010). Those return conductors are intended to be a single-core double-insulated cable, and the cable and its insulation are mean to preserve double insulation status over its whole length, mostly through junction boxes (i.e. these running was also related to any linkages) (IEC 2010).

6.6 Selection and erection generator

Many of technologies are existed on the market of machines. From the modest to the most complicated (IEC 2008b).

For small size (below 5 kVA) the most frequently use technology is gasoline engines.

For greater size, the most frequently used technology is diesel engines (IEC 2008b).

Other fuels can used are oil or ethanol (IEC 2008b).

The engine is made either for 3000 rpm (for small machine) or 1 500 rpm (for larger machine) at 50 Hz case (IEC 2008b).

The other technologies such as small fuel turbines are intended to be in existing (IEC 2008b).

The project implementer is meant to choose the suitable technology consistent to the requested level of quality of the service, the skill of the maintenance staff, the level of equipment available at the maintenance centre, the spare parts that easily obtained, and all exact restrains of the project (IEC 2008b).

6.6.1 Generator set sizing

Generator set sizing are taken two primary requirement:

a) The alternator is skilled of delivering the nonstop and surge load apparent power (VA):
b) The engine is skilled of sending the power requested of the alternator and the mechanical losses of the entire system (alternator + coupling system) (IEC 2008b).

It is for the project designer to exactly describe the generator set minimum operating circumstances:

- the environmental state;
- the maximum nominal productions, the matching interval and load issue;
- the electrical load features (power factor, permitted voltage range, current harmonic content, high starting currents, etc.) (IEC 2008b).

The collection and sizing of generator set are intended to the deliberation of the supplied electrical load and the construction of the micro-grid (IEC 2008b).

6.6.2 Derating factors

The generator set is requested on to function, so forth be its manner of setting up. It is possibly to disturb its certified characteristics (IEC 2008b). It is in the story through the project implementer and the manufacturer (IEC 2008b).

If the location state are unidentified and vice versa specified, the subsequent nominal conditions using are regarded to ISO 8528-1 (IEC 2008b):

- total barometric pressure 89.9 kPa;
- air temperature 25 degree Celsius;
- relative humidity 30%;
- temperature coolant for the boosting air 25 degree Celsius (IEC 2008b).

6.7 Design of the erection site

The generator set was connected to both in the open air or in a surrendered building (IEC 2008b).In case of the service was an individual electrification system. It was then fit outside the house (IEC 2008b).In all situations, the flooring of the site was intended to let the generator sets to limit from movement through normal process (IEC 2008b).

6.8 Ventilation

As far away as achievable from the engine gas exhaust, especially the fresh air entry (IEC 2008b). The withdrawal of hot air is built through the upper ventilation and the fresh air entry across the lower one (IEC 2008b).

Ventilation grates should keep clean

For a generator set that is set up in an surrounded and soundproofed area, the room is then allowed appropriate delivering to the combustion engine and cooling air (IEC 2008b). It is also supported the generator set at the ambient temperature restraining to when it is stated.

The generator set air consumption is informed through the constructor (IEC 2008b). If it is not, the subsequent principles are intended to operate as a reference (IEC 2008b).

The air intake cross-section is intended to be the same as that of supply and define as follows:

- radiator or air cooler 80 m^3/h per kVA,
- additional fan 40 m^3/h per kVA,
- speed inducting 4 m s^{-s} (IEC 2008b).

6.9 Fuel storage

The size of the minor fuel storage is used in the generator set room being sufficient for two or three days of the independence generator set (IEC 2008b). The dominant fuel storage is intended to build in alternative building or tank that is situated at three meters away from the generator set room (IEC 2008b).

The capacity of the main tank is capable to support the essential independence reference of the generator set size, the length of the service and the local potentials of refuelling (IEC 2008b). For instance, in some locations it is likely to refuel throughout the rainy period. The volume of the main tank is calculated in regarded (IEC 2008b).

The fuel storage is intended to fulfil with the local guidelines if there is any (IEC 2008b). If the local guidelines are not appeared, the following requests were then observed:

- The class of diesel fuel that stored in the generator set room, are not suggested from IEC TS 62257 to go beyond 500 I, if the quantity stored is over 500 I, the storage are then be in a special room (IEC 2008b).
- The class of petrol that kept in the generator set room is not intended to above 25 I referring to the suggested maximum power of such generator limited to 5 kVA.

  The volume of C liters of the minor fuel storage, a drip tray with capacity of (c+20%) I was intended to build in the generator set room meaningly a 600 I tray for a 500 I storage (IEC 2008b).

  The main fuel storage tank is obeying with the following keys:

- double sided if the tank is suppressed;
- storage site ground is intended to hydrocarbon leak proofed (coating, sheet, etc.);
- opening at top position;
- generator set fuel is provided a cut-off equipment situated outdoor;
- generator set fuel is provided by electric or manual pump;
- pump and alarm trigger switch (if electrically-powered);
- tank earthed and equipotential bonded with the exposed-conductive parts of the generator set room (IEC 2008b).

Both minor and main fuel storage tanks are intended to stay at least one meter away from any heat supply or apparatus that producing arcs sparks or hot particles. The tanks location is intended to get away from any dripping or leak fuel on hot sections (IEC 2008b).

6.10 Summary

The generator boundary is showed entirety essential to make electric power consistent to the needed features of voltage, frequency, harmonics, power and consumption of the clients, referring to the required value of facility (IEC 2008a). In table 6 is stated general inputs and outputs to be considered for generator specification (IEC 2008a).

Equipotential bonding is used to avoid irregular potentials as overvoltage across them (IEC 2010). The earth is made as close as possible to the equipment to earth (IEC 2010).

Standard temperature condition is at 25 degree Celsius (IEC 2010). It is a normal operating condition (IEC 2010). The temperature will increase with regard to the maximum operating point at 1000 W/m^2 in a hot day (IEC 2010). All components are required resisting the expected maximum operating temperature of the PV array modules (IEC 2010).

Insulation, fuse holders, by-pass diodes and blocking diodes are used to prevent PV module to get any fault such as hot spot heating, burning and securing from degradation (IEC 2010).

Disconnection mean is referred to table 8 and 9. It is to separate PV array from the power conditioner and review jobs to perform safely (IEC 2010).

The considerations on accounting for shadow of the PV array are environmental, one line of PV modules over the other, wiring loops, String wiring and wiring fitting in junction boxes (IEC 2010).

The generator below 5 kVA (small size) is usually used gasoline engine (IEC 2008b). The greater size of generator is usually used diesel engines (IEC 2008b).

Generator set sizing have had two primary requirement such as alternator and engine (IEC 2008b). The alternator is to deliver the nonstop and surge load apparent power (IEC 2008b). The engine is to send the power requested of the alternator and the mechanical losses of the entire system (alternator and coupling system) (IEC 2008b).

Derating factors are possibly manner to disturb the generator characteristics. These are regarded to ISO 8528-1 (IEC 2008b).

In order to produce good ventilation, the withdrawal of hot air is built through the upper ventilation and the fresh air entry across the lower one (IEC 2008b).

The main fuel storage is intended to build in alternative building that is sit 3 meters away from the generator set (IEC 2008b). The tank is supported to capable to handle the potentials of refuelling (IEC 2008b). The tanks location is intended to be far away from any dripping or leak fuel on hot sections (IEC 2008b).

Chapter 7 Rottnest Island case study

Chapter 7 is illustrated a case study of electrification in a remote area in Western Australia, Rottnest Island. Its electrification system is based on ASN3000 standard. Hence it is a good opportunity to learn how power system is setting up on the island. In this chapter is explained the power system details of the island that is matched to IEC TS 62257.

7.1 System selection and design

The function of Island power distribution subsystem is included energy conversion from primary energy, electric conversion from dc to ac, and energy measurement (IEC 2015d).

Presently, there is no energy storage in the system. A functional diagram for rural micro-grid of Rottnest Island is gotten the same impression as figure 11 but more complicated than as shown. Those diagrams that represented the Rottnest Island power system is referred to Appendix A1.

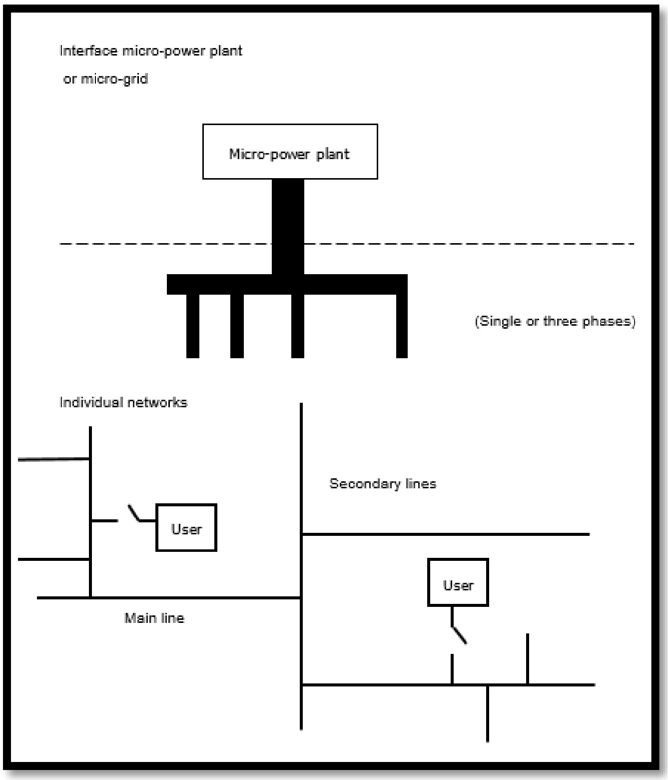

Figure 11 Functional diagram of a radial structure for rural micro-grid

In the case of recycle, they are normally organized for every 32 years period. It is depended on RIA (Rottnest Island Authority) the owner of this power system.

For the operating temperature, normally the condition to operate generator set is about 25 degree Celsius (IEC 2015d).

In summer, both sides of the door must be opened to get natural air run the system at normal state. In a hot day, a loss of voltage is about 1-2 V each time when there is a person in the operating room for example from 415 V to 413 V.

7.2 Protection against electrical hazards

Rottnest Island is used TN systems, TT systems, Double or reinforced insulation and Extra-low-voltage for protection against electric shock, overcurrent, overload currents, short circuit, the risk of fire, the effect of lightning, overvoltage and direct lightning (IEC 2015e). This is based on Australian standard ASN3000.

The electrical system at the terminals of any user’s electrical equipment at Rottnest Island is AC voltage, 0.9 x 230 V < U (AC) < 1.10 x 230 V (IEC 2015e).

The island is consumed Renewable energy and hybrid type of generator (IEC 2015e).

At this point, battery is not in used at Rottnest Island.

Surge protection devices of the Island are relied on Australian standard ASN3000.

The earth termination system is constituted of either conductors of the same nature and the same cross-section as the down-conductor is laid out in the form of a giant crow's foot; 3 conductors 7 m to 8 m long buried horizontally at a depth of at least 0.60 m (IEC 2015e) whereas sandy condition is needed to dig deeper.

Protection bonding conductors are executed in parallel to and contacted as closest as possible with DC cables and AC cables and accessories (IEC 2015e).

7.3 Generator- PV generators

Protection against lightning overvoltage was at all times compulsory when the linear distance between the PV array and the mechanical room is about 15 meters (IEC 2010). The surge arrester is positioned as close to the PV array and the mechanical room (IEC 2010). In Rottnest case, everything is 11 kV earth to the ground. This was the ability that the earthing would be handled any fault from the network.

System earthing arrangements in Rottnest Island is matched to figure 12 and 13 below from IEC standard. By an additional wind turbine and a generator connecting to this Hybrid IES or CES – PV generator + inverter and another generator – d < 15.

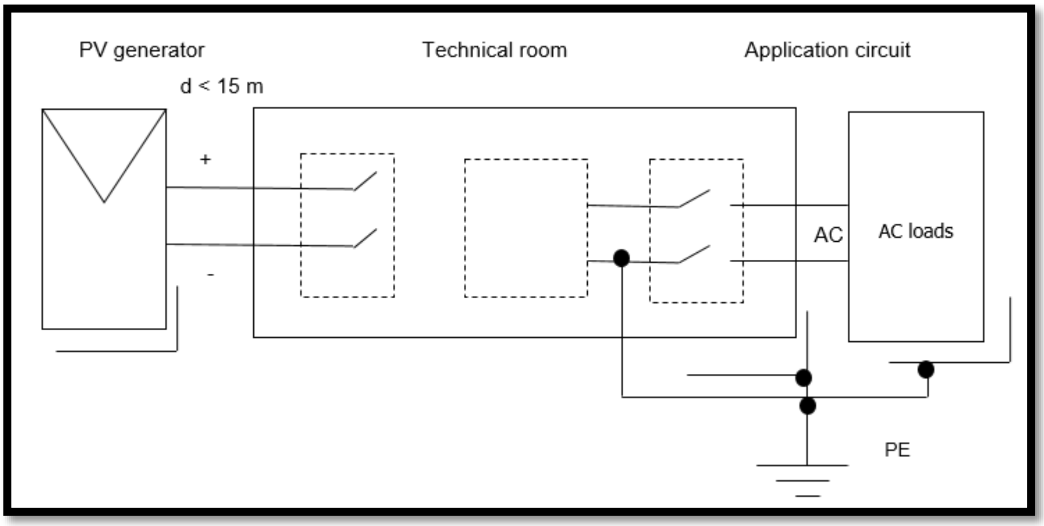

Figure 12 Configuration C and E –PV alone IES or CES – P< 500W – with inverter – d < 15 m (IEC 2010)

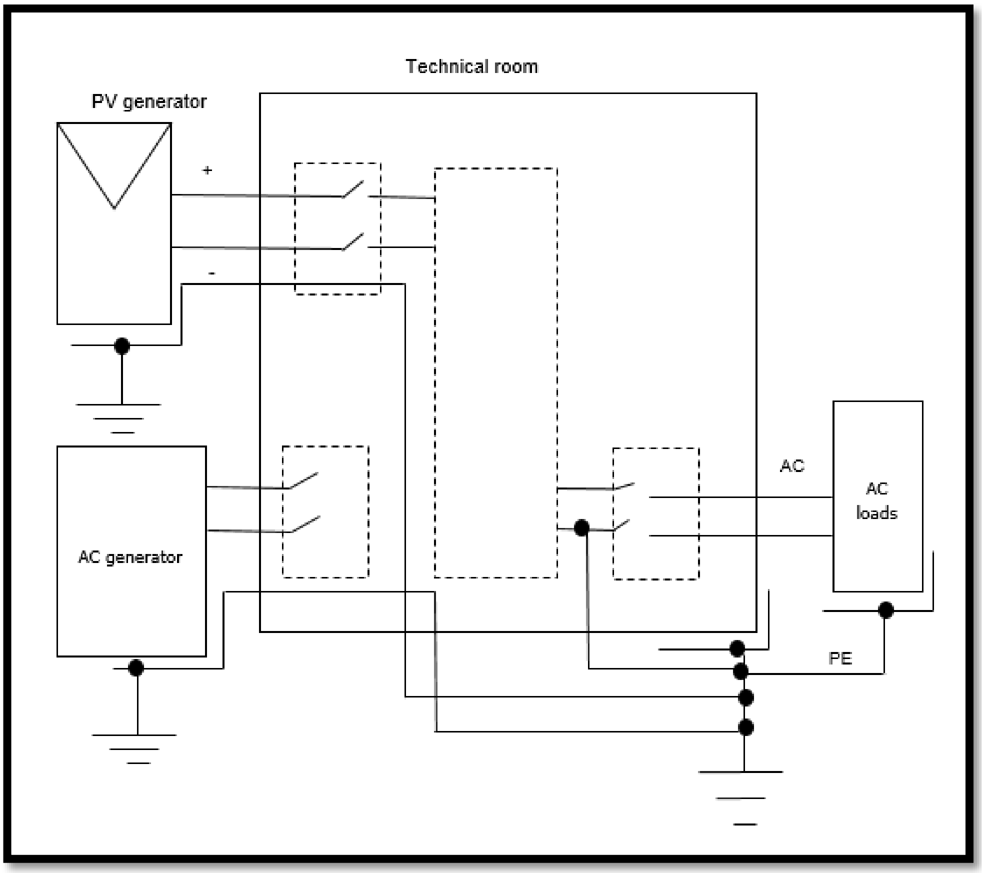

Figure 13 Configuration D and F – Hybrid IES or CES – PV generator + inverter and another generator – d < 15 m (IEC 2010)

The Rottnest PV array diagram was a multi-string case as in figure 14 (See appendix A.2). Island protection will trip if there was a fault.

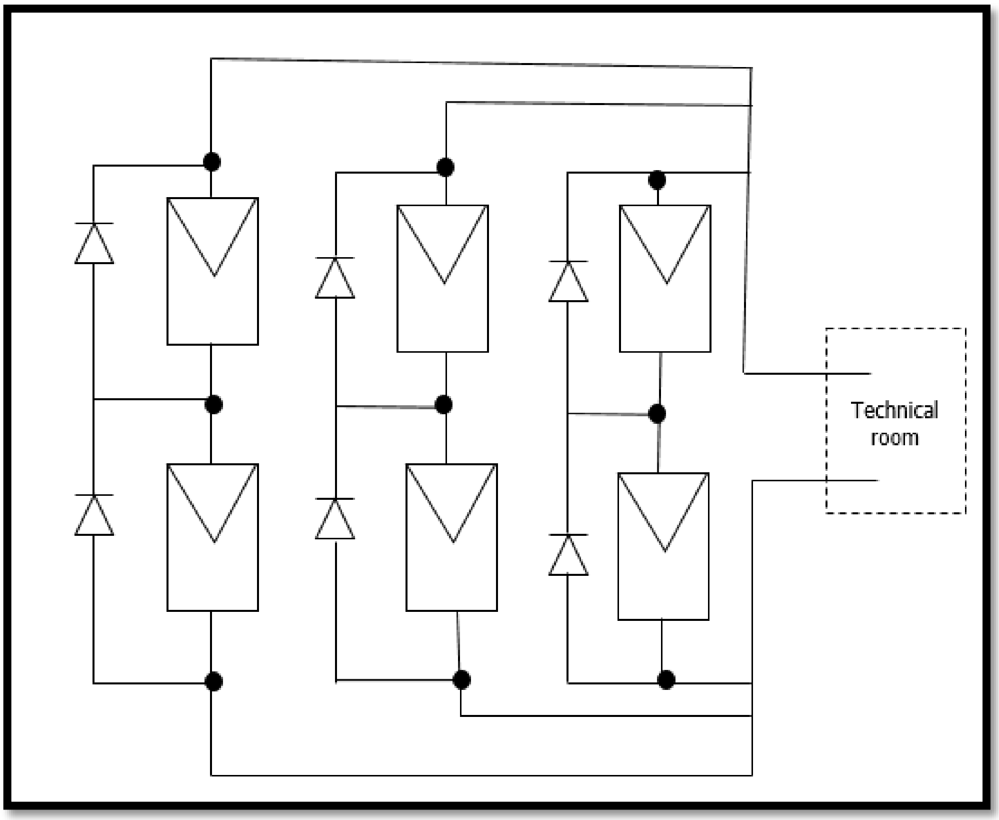

Figure 14 PV array diagram – multi-string case (IEC 2010)

The island was using thin film Cadmium telluride (CdTe) as they are given from other renewable energy site. Its photovoltaics at the maximum power point under 1000 W/m^2 .Even though IEC TS 62257 is recommended to use to use Crystalline Silicon (IEC 2010). These two types of PV modules is gotten the same maximum power point hence it is acceptable to use thin film Cadmium telluride (CdTe) photovoltaics. The specification of PV multi string module is pictured in the real system on the island referring to Appendix A.2.

7.4 Selection of generator sets for rural electrification system

Generators are run 1500 rpm with the set type of Coupled (two or more generator sets are connected electrically)(IEC 2008b).

Derating factors for generator sets refer to ISO 8528-1. The details are

- total barometric pressure 89.9 kPa;
- air temperature 25 degree Celsius;
- relative Humidity 30%
- temperature coolant for the supercharging air 25 degree Celsius"(IEC 2008b).

Table 10 Examples of derating factors for generator sets (IEC 2008b)

Air temperature		**Derate 2.5% for every 5 ℃ above 25 ℃**
Altitude		**Derate 3% for every additional 300 m above 300 m altitude**
Humidity	Air temperature between 30℃ and 40 ℃	Derate 0.5 % for every 10 % above 60 % humidity
	Air temperature between 40℃ and 50 ℃	Derate 1.0 % for every 10 % above 60 % humidity
	Air temperature above 50℃	Derate 1.5 % for every 10 % above 60 % humidity

On the island is used Detroit and Cummins generators see appendix A3. For set noise levels, they are gotten less noise levels than both values on the table. As the Island is passed noise level test when the authorities tested it.

Table 11 Generator set permitted noise levels (IEC 2008b)

Generator electrical P	Permitted noise level dBA
P ≤ 2 kVA	102
2 kVA < P < 240 kVA	100

4 doors of opening exit from generator set area at the island is suited to IEC TS 62257 saying that “Access space for generator sets

Adequate space provides near a generator set on all sides where people are to pass in order to enable all equipment to safely and effectively operate and adjust” (IEC 2008b).

At Rottnest Island case is acceptable to “The size of doors and opening (height, width (m)) for the generator set are from a generator set area with a height of not less than 1.98 m from the floor or walked-on surface and a width of not less than 0.75 m” (IEC 2008b) from IEC 62257 standard.

7.5 Ventilation (air intake cross-section, speed-inducting)

From IEC 62257 standard “The generator set the manufacturer notifies air consumption. If not, the following values may use as a reference.

The air intake cross-section should be the same as that of delivery and determine as follows:

- radiator or air cooler 80 m^3/h per kVA,
- additional fan 40 m^3/h per kVA,
- speed inducting 4 m s^{-s}”(IEC 2008b).

The generator at Rottnest Island is used all of these for ventilation.

From generator to main switchboard the island is used the connecting cables for a three-phase 230/400 V generator set, a cable length of 10 m and an ambient temperature of 40 degree Celsius (IEC 2015c).

The island is used the same variable as table 12 from generator to main switch board.

Table 12 Cross-section of power cables (IEC 2008b)

Power kVA	Cross-section/ phase mm^2
20 and 30	6
40	16

Power kVA	Cross-section/ phase mm^2
50	16
60	25
80	35
100	35

7.6 Cross-section of power cables

There is residual current of protection devices allowed a use of 30 mA residual current device to protect the user against electric shocks (IEC 2008b).

7.7 Battery management system of a generator

In Rottnest Island, it is checked the battery electrolyte by automatic colour code reading in which it is linked to a generator. In this case, there is no needed water filling and last for a year.

7.8 Micro-power System

Micro plant system limit (composition of micro plant) is gotten the same item as the figure 15. The generator is generated power to micro-power system. Then the power is run through micro-grid to the end of the line that is loaded. Generator is included such as wind energy, solar energy or fuel. Wind energy and solar energy are operated chopping off each other. Meaningly when the wind energy is in used, the solar is not.

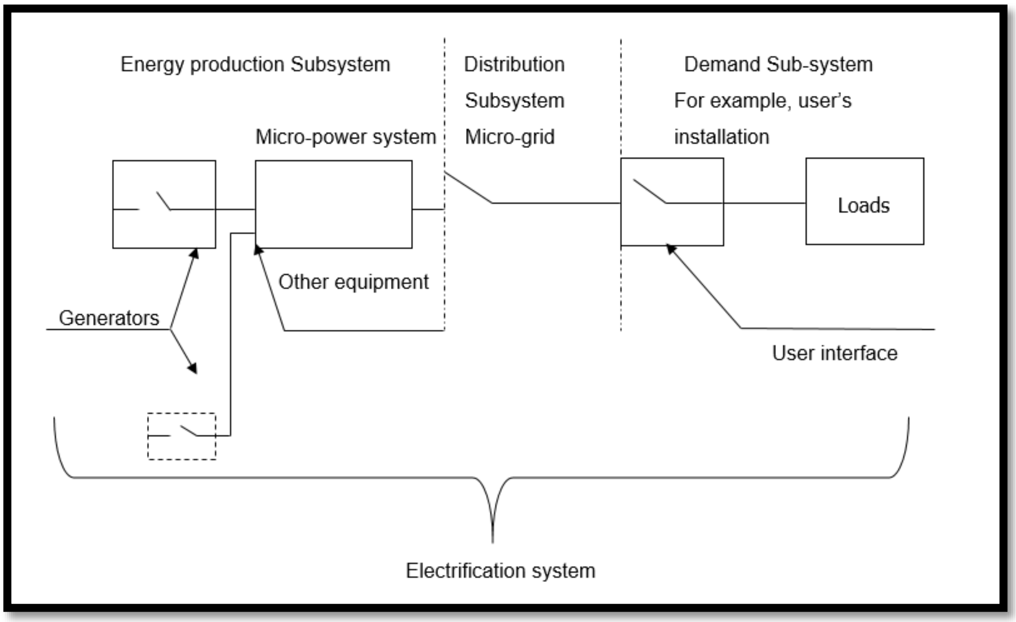

Figure 15 Micro-power system limits (IEC 2008c)

7.9 Functional layout for a micro-plant

In Rottnest Island Case, the application is different from the following that is illustrated in figure 16 because the battery system is not available.

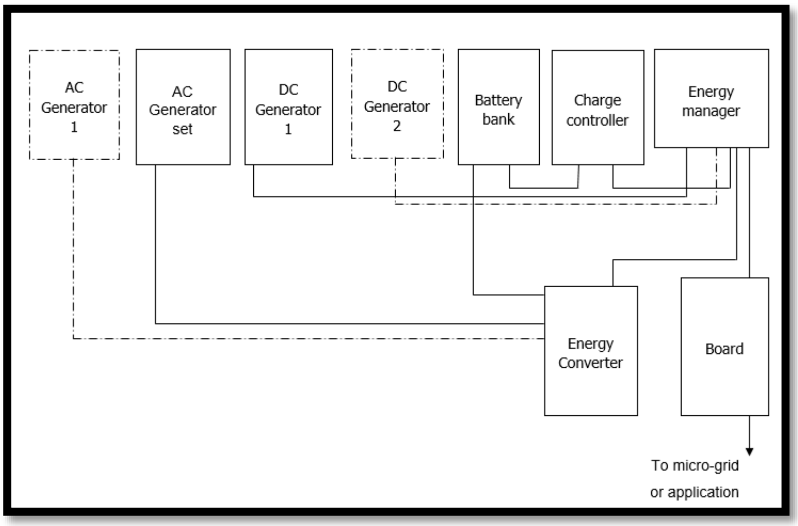

Figure 16 Example of functional layout for a micro-power plant supplying AC energy (IEC 2008c)

7.10 Interconnection of generators

Interconnection configuration with AC bus only in figure 17 is matched to the Rottnest Island case with an additional wind turbine at DC G2.

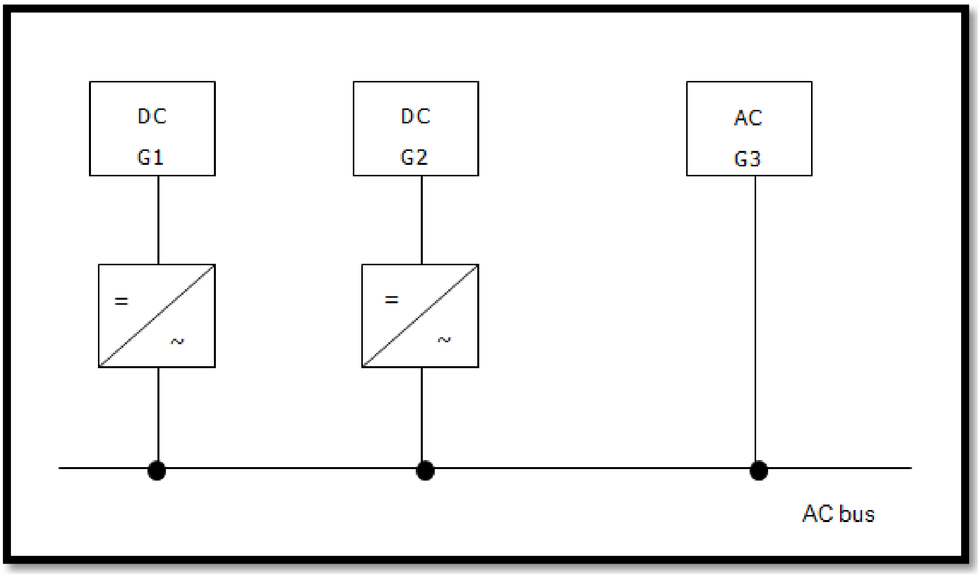

Figure 17 Interconnection configuration with AC bus only(IEC 2008c)

7.11 Micro-grids

Maximum value voltage drop in micro-grid is on individual service connection line (IEC 2006a). Rottnest Island configuration of micro-grid (diagram) and Micro-grid earthing scheme is shown in Appendix A.1. Installation of poles (arrangement, setting up) with 11 kV with 3 phase horizontal and 11 kV cable. Overcurrent protection device of the island is used Spag (overcurrent relay type)(IEC 2006a).

7.12 Integrated system – User interface

User interface system voltage in Rottnest is used micro-grid or a standalone generator, a dc generator and an ac generator supplying (IEC 2006b).

7.13 Integrated system – User installation

Protection of people in an installation supplied from a micro grid according to TN-C-S system and user's electrical installation are built according to a TN –S system as figure 18 (IEC 2006c).

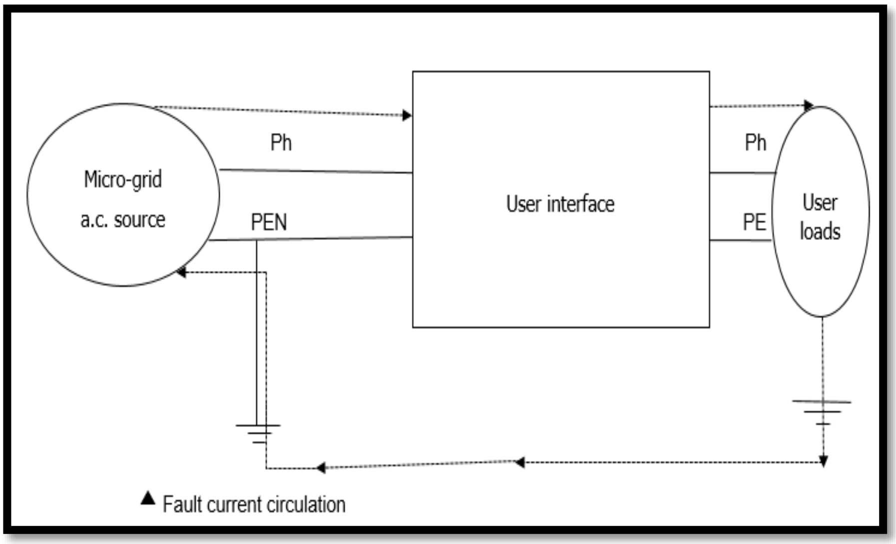

Figure 18 Protection of people in an installation supplied from a micro grid according to a TN-C-S system (IEC 2006c)

In Rottnest Island case MEN (multi earth neutral) is used. All MEN was set at 30 mA. If there any fault is occurred in the system, it then will be just feel it and gone.

7.14 Selection of PV- individual electrification system

Safety issue (Protection degree at minimum suggested value of IP and IK) in term of - Selection of Photovoltaic Individual Electrification Systems (PV-IES) (IEC 2008d). For the Rottnest Island case, it is all within the range of on table 13.

Table 13 Suggested minimum values for IP and IK (IEC 2008d)

Protection degree	Minimum suggested value
IP	**34**
IK	**8**

Rottnest Island’s IP was at about 65, see appendix A.4. The IK was passed the Australian standard when the authority people are at the island and conducted the testing.

7.15 Selection of lamps and lighting appliances for off-grid electrification systems

For selection of lamps and lighting appliances for off-grid electricity, categories that the Island was used such as;

- indoor/outdoor products design to use indoors or outdoors or both, depending on the user’s need (IEC 2015g).
- outdoor-only systems design specifically for outdoor use, meaning they intend to mount permanently or semi-permanently outdoors (IEC 2015g).

7.16 Lighting service targets

The third roll criteria on table 14 is matched to Rottnest Island case. Through the aspect of light distribution characteristics, at least 0.1 m^2 of the area is illuminated. At least 50 lux when a light appliance is self-supported from a surface (IEC 2015g).

Table 14 The Principles of Lighting service performance assessment (IEC 2015g)

Light output criterion	Aspects	Requirement
General illumination	**Luminous flux**	**≥ 25 lm**
Luminous efficacy	**Luminous efficacy**	**≥ 40 lm/W**
Task lighting service	**Light distribution characteristics**	**≥ 0.1 m^2 area of illumination** **≥50 lux when the lamp of lighting appliance is self-supported on the task surface or suspended from a 0.75 m distance from the surface.**

7.17 Summary

Rottnest Island in Western Australia is chosen as a case study in the thesis. The electrification on the island is based on ASN3000 standard. The comparison between Rottnest Island's power systems to IEC TS 62257 has been studied.

The functional diagram of a radial structure for rural micro-grid of the island has the same idea to IEC TS 62257 diagram as stated in figure 11.

In ASN3000 has the same electrical hazard protection systems to IEC TS 62257. In the Island are used TN, TT, Double and Extra low voltage systems.

Earthing system arrangement of the island is matched to IEC TS 62257 configuration C and E – PV alone IES or CES – P< 500W-with inverter- d< 15 m, and Configuration D and F-Hybrid IEC or CES-PV generator + inverter and another generator-d<m. Also PV array diagram in the island is used multi-string case.

In the Island set noise level is compiled to IEC TS 62257 generator set permitted noise levels in table 11.

Micro-power system of the island is the same idea as figure 15 micro-power system limits of IEC TS 62257.

Functional layout for a micro-power plant supplying ac energy of the Island is not the same as IEC TS 62257 as the Island's battery system is not available.

The Island's interconnection of generator is matched to configuration with AC bus only in IEC TS 62257 standard.

The protection degree at minimum suggested value in term of Selection of PV-IES is matched IEC TS 62257. It is within the range in table 4.

Categories that the island's lamp and lighting appliances is indoor/outdoor products design and outdoor-only systems (IEC 2015g).

At Rottnest Island lighting service targets, the aspect of light distribution characteristics is at least 0.1 m^2 of the area is illuminated. At least 50 lux when a light appliance is self-supported from a surface (IEC 2015g).

Chapter 8 Conclusion

This thesis has investigated the recommendations from IEC TS 62257 in term of off-grid electrification in the remote area. A case study of Rottnest Island has chosen to support the idea this system's type. The project has five aims. Each of the aims are explained in a separated chapter namely;

Chapter 3 has reviewed ways to set up the renewable energy system to meet the customers' requirements in rural area. In the chapter has presented a method called "master plan". The method is to collect important data for the upcoming remote electrical project to find cost-effective solution.

In chapter 4, the electrical network in term of minimum sufficient requirements of high standard safety to electrical power application has been review. Since No one would like to pay big money for less sufficient electrical system. Hence the project presentation such as cost and data to be collected from the power system has been specified in this section. The method to connect and access at the lowest cost to make system well arrange for micro-power plant, micro-grid and user interface is shown with requirements for dc and ac parts of installation. In order to fulfil satisfactory to people in the renewable energy project's area, the protection against electrical hazard such as; preventing from overcurrent, short-cct, risk of fire, effect of lighting, overvoltage and direct lighting are also determined in the chapter.

The technique to achieve the best technical and economic is shown in chapter 5. It is described a processed called "AOMR actions" to meet both quality and quantity energy requirements. This section has explained light's colour characteristics in details which involved two types namely; CRI is a degree of how accurately the light renders colours, and the correlated colour temperature CCT, a degree of the colour of the light conveyed as a temperature in kelvin. In addition, it has also stated the physical ingress protection in general to any enclosure involving in the rural electrification project.

The combination of diesel generator system and solar energy is explained in Chapter 6. It is shown generator boundary as well as things to consider due to operating temperature for these type of system. Those are insulation, fuse holders, by-pass diodes, blocking diodes and location and installation requirements. In order to reflect on the selection and election of a generator needed to cover on generator set sizing and deration factors. For these two combination to last long, a good ventilation and plenty of fuel storage is also a main point to study in this area.

In chapter 7 has illustrated Rottnest Island case study. It is explored most of IEC TS 62257 details to match the Rottnest power system. The recommendation of battery system in IEC TS 62257 is excluded herein since Rottnest Island battery network is not available. Mainly, the contents in this case study standard was similar to IEC TS 62257.

IEC TS 62257 series are a worldwide accepted and adapted to an area undertaking rural electrification project. In order to receive the most efficiency to the power project, the selection of which series should be taken to an appropriate consideration.

Chapter 9 Future work

Even though the overview of IEC TS 62257 on Rottnest Island is completed, there might be some advance work to accomplish about the Island.

First and foremost, in order to gain a more understanding in rural electrification economic. We needed to know “what are the best choices of power source to produce sufficient power as well as cost friendly?”. In fact, the most suitable programme for renewable energy finding is HOMER. It is famous for producing fuel curve, efficiency curve and excellence in data manipulation. Throughout this programme, the search for the best combination of energy source such as diesel generator only, solar energy only, wind energy only or a mix of both could be produced for Rottnest Island.

Second, the future research of Rottnest Island would be on load profile and the limitation on the island electricity system.

Third, an expansion of this thesis would be on the other criteria to this such as “is there anything that Rottnest Island power network does not meet the suggestion from IEC TS 62257?”

And last, it would be interesting in comparing between Australian standard ASN 3000 and IEC TS 62257 to see the similarity and any different between these two principles.

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Appendix A

A.1 Rottnest Island power system diagrams

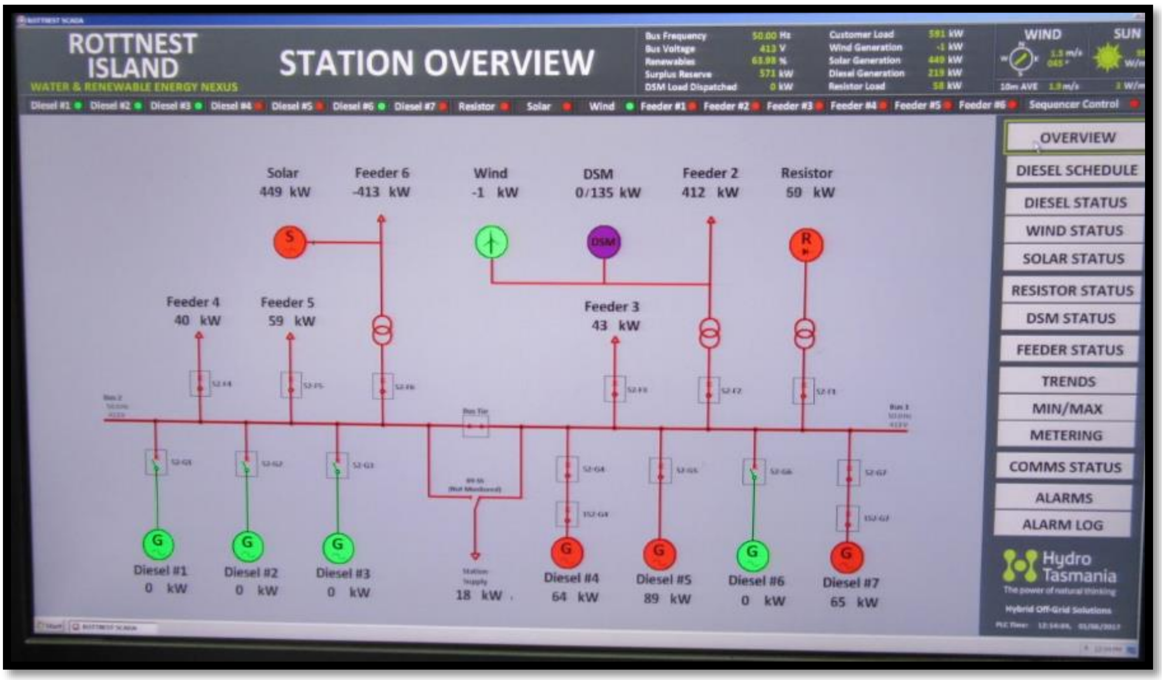

Figure 19 Rottnest Island power station overview

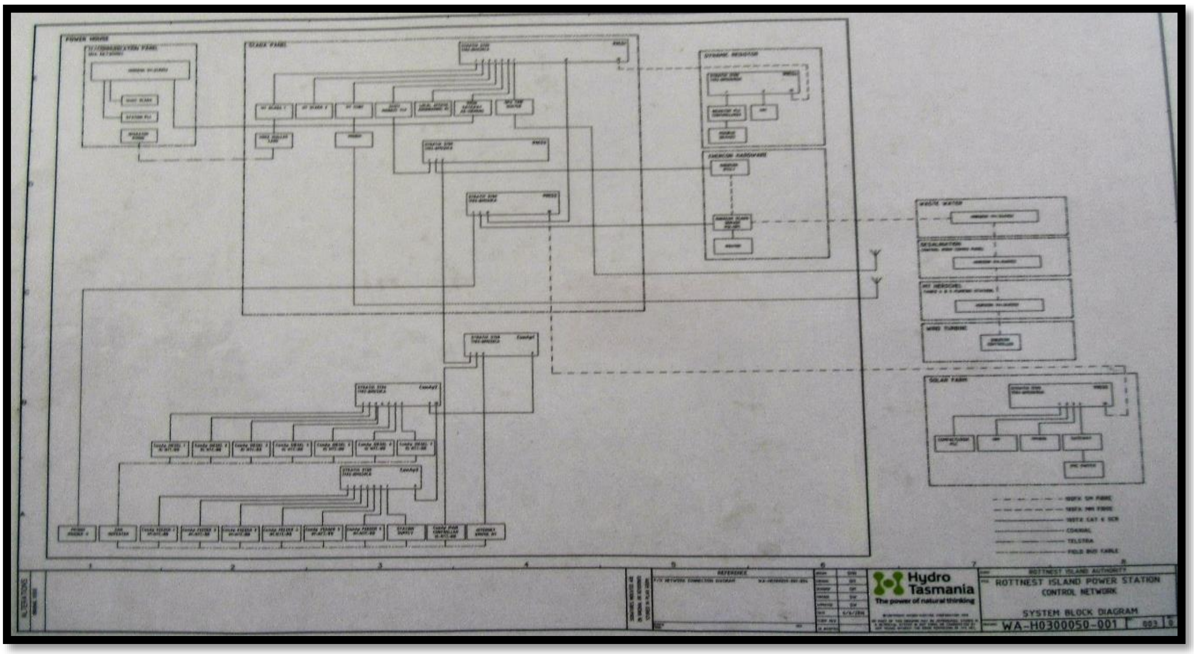

Figure 20 Rottnest Island Power Station Control Network

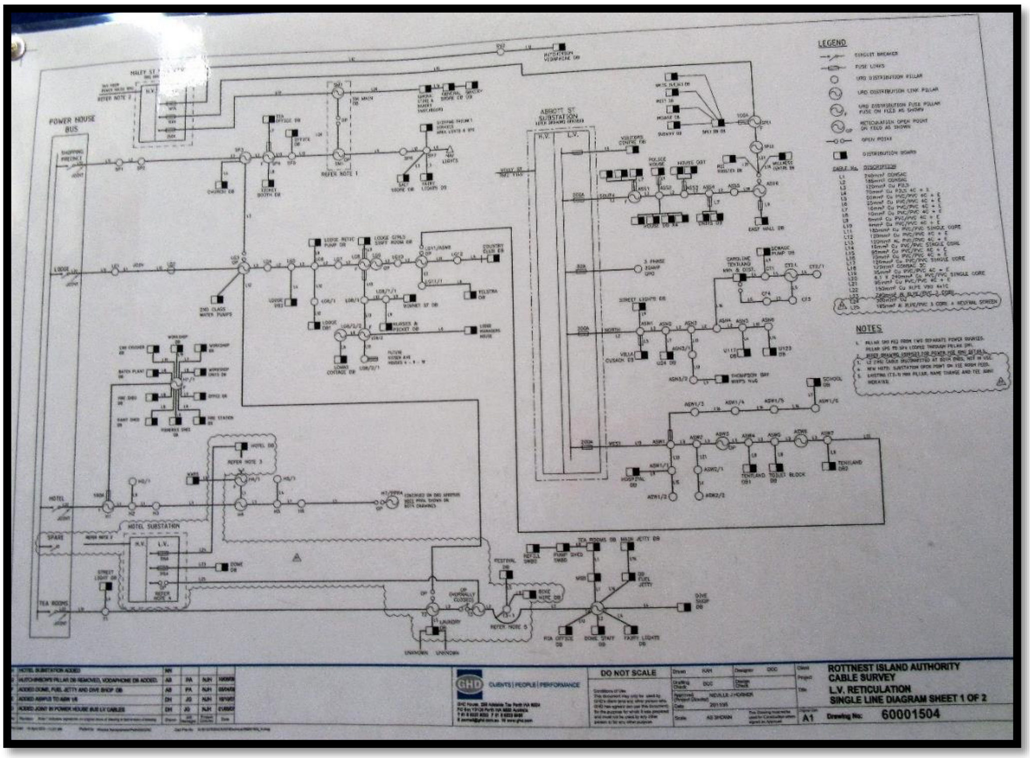

Figure 21 Rottnest Island Authority Cable Survey L.V. Reticulation Single Line Diagram 1 of 2

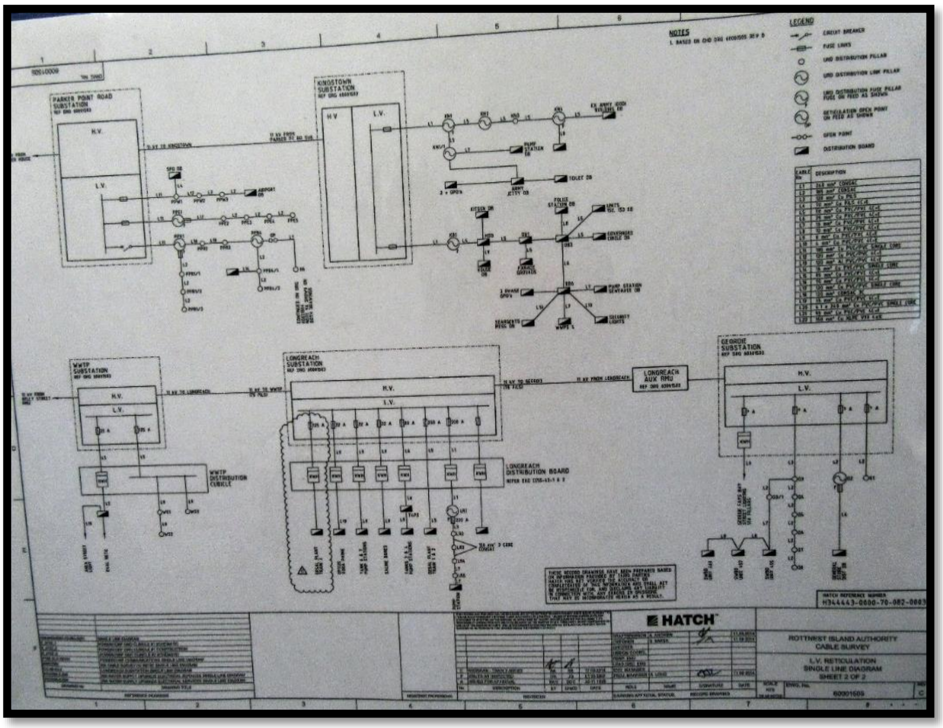

Figure 22 Rottnest Island Authority Cable Survey L.V. Reticulation Single Line Diagram 2 of 2

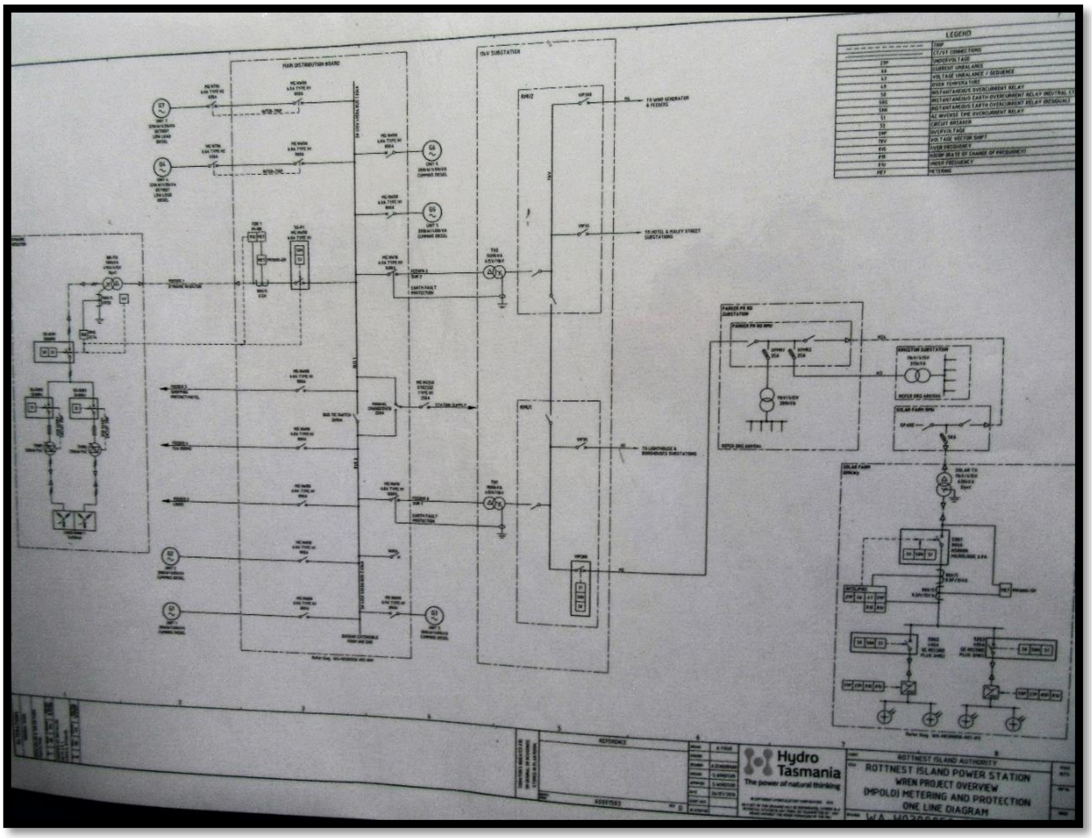

Figure 23 Rottnest Island power Station Metering and Protection

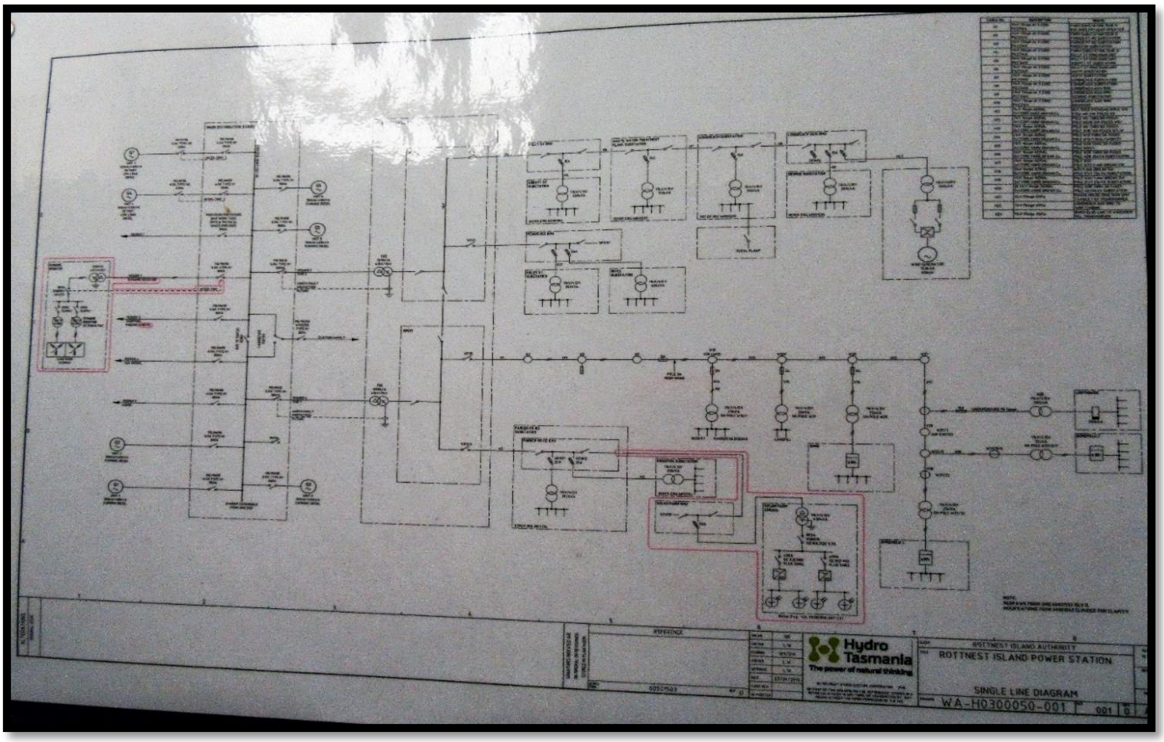

Figure 24 Rottnest Island Power Station

A.2 Rottnest Island PV modules

Figure 25 First Solar Specification (Rottnest Island Solar Panel)

Figure 26 Rottnest Island Solar farm

Figure 27 multi-string case PV at Rottnest Island

A.3 Rottnest Island generator

Figure 28 Rottnest Island fuel storage

Figure 29 Detroit Generator at Rottnest Island Power Station

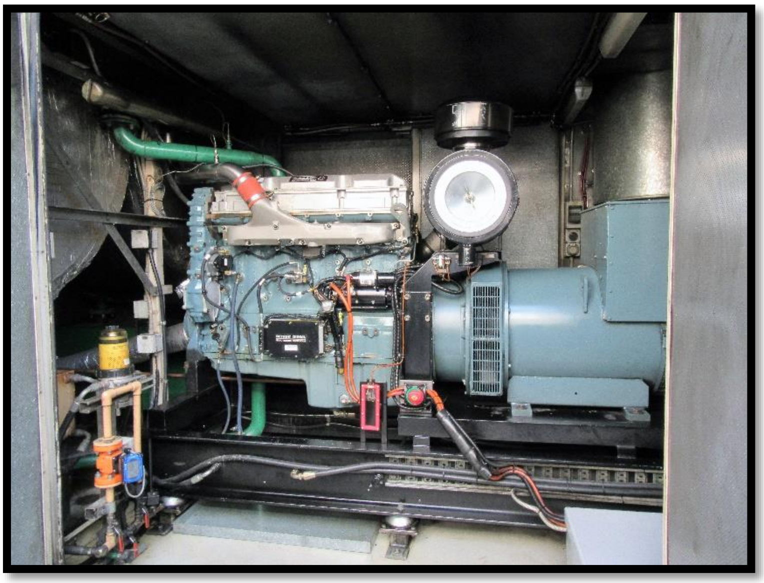

Figure 30 Cummim Generator at Rottnest Island power station

A.4 IP ingress

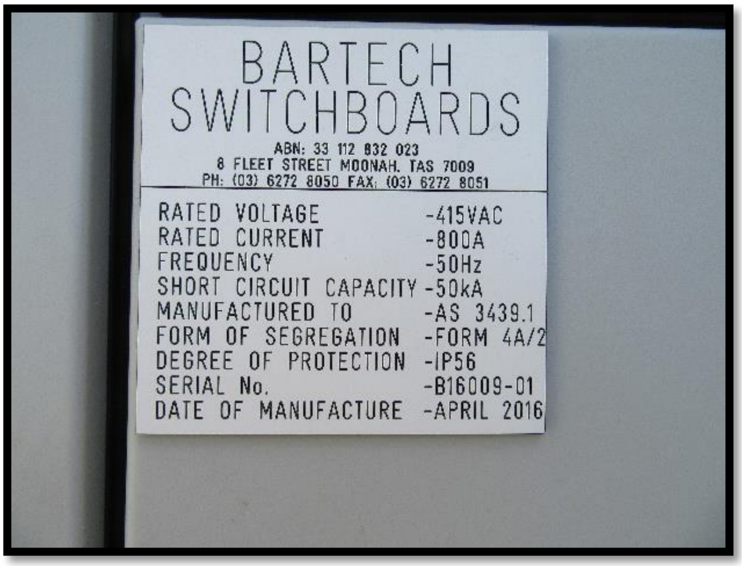

Figure 31 IP ingress shown on BarTech switchboards at Rottnest Island power station

The end