CHAPTER THREE

METHODOLOGY

3.1. Introduction:

Photovoltaic systems can be designed to provide DC and/or AC power service, can *operate* interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems. In this System we will use PV only to generate electrical power.

3.2 On grid PV system:

This system connects to with a grid. This system is designed to operate in parallel with grid to supply the load. This solar system you can export excess power to the grid, you can reduce your electricity bill. Whenever grid goes, the system will automatically shut down. This system is less cost compare to other types of solar system because no battery banks so any recurring cost. The primary component in PV systems is the inverter. The inverter converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized.

In order to design PV system connected to a distribution grid an acceleration modeling and simulation are required, at this research path type of acceleration and simulation are used, acceleration by mathematical equation for system sizing and simulation for testing the oration of the designed system and performance of the system when connected to the grid.

3.3. System Sizing:

System sizing is the process used for determining the minimum panel for solar cells needed to deliver the required electrical energy to the load. As mentioned in the previous chapter, solar PV power is a concept of generating electricity from the sun light and converting it to the AC energy that we use in our daily lives. PV modules are installed on fixed metallic support structures arranged in long rows, adequately spaced themselves, facing south (in the Northern Hemisphere) with an appropriate tilt, or deployed on tracking devices to follow the sun. In this chapter an explanation of the methodology to design a on grid PV system, in order to apply it in a case study for Wairau group company. This will be clear in the upcoming chapter. In a brief description of the design, PV modules are electrically connected together in series or parallel configurations. Then, connection goes though inverters in order to provide AC load with power. This power must be sufficient to cover the power consumption of the load.

3.4 Quotation document:

When providing a quotation to a potential customer, the designer should provide (as a minimum) the following information:

- Full Specifications of the system including quantity, make (manufacturer) and model number of the solar modules and inverter.
- An estimate of the yearly energy output (yield) of the system. This should be based on the available solar irradiation for the tilt angle and orientation of the array. If the array will be shaded at any time the effect of the shadows must be taken into account when determining the yearly energy output.
- The money savings (in local currency) this represents based on existing electrical energy pricing.

- A firm quotation which shows separately the equipment, installation material and installation labor costs and charges.
- Warranty information relating to each of the items of equipment.

3.5. Inverter Selection:

The selection of the inverter for the installation will depend on:

- The power output of the array.
- The matching of the allowable inverter string configurations with the size of the array in kW and the size of the individual modules within that array.
- Whether the system will have one inverter or multiple (smaller) inverters.

3.5.1 Why multiple inverters?

1. If the array is spread over a number of roofs that have different orientations and tilt angles then the maximum power points and output currents will vary from roof to roof. If economic, installing a separate inverter for each section of the array which has the same orientation and angle will maximize the output the total array. This could also be achieved by using an inverter with multiple maximum power point trackers (MPPT's).That is, the section of the array connected to one MPPT could be on a separate roof (and orientation) to another section of the array mounted on another roof orientation and connected to another MPPT within the same inverter.
2. Multiple inverters allow a portion of the system to continue to operate if one inverter fails.
3. Allows the system to be modular, so that increasing the system involves adding a predetermined number of modules with one inverter.

The potential disadvantage of multiple inverters is that in general the cost of a number of inverters with lower power ratings is generally more expensive than one single inverter with a higher power rating [60].

3.6. Array sizing:

When designing a grid-connected PV system the properties of both the chosen PV module type and the chosen inverter type have to be taken into account. In order to produce at optimal power output the array has to be matched to the inverter. The following steps are used to size the array:

1. Match the array to the inverter voltage specifications.
2. Match the array to the inverter current rating.
3. Match the array to the inverter power rating.

3.6.1. Matching the Array to the inverter voltage specification:

To make sure the array voltage does not exceed the maximum DC voltage of the inverter and PV array, the minimum and maximum modules operating temperature of the location is used to find the PV module Voltage for that particular temperature. This is used to find the minimum number of modules in series so that the array VMP does not fall below the minimum inverter voltage. The inverter would then operate away from the MPP and produce lower power. If too many modules are connected to a string the array's open circuit voltage may exceed the maximum allowed input voltage for the inverter or the maximum module system voltage, this could cause an over voltage and damage both the inverter and the module.

3.6.1.1. Minimum number of modules string:

Solar modules have the lowest voltage at warm weather. The array has to be designed so the array VMP at the highest operating temperature does not fall below the minimum MPPT voltage of the inverter.

Firstly knowing the ambient temperature for proposed location with advances in technology, we can have this data available on line and any one can use it. Then we can get the maximum effective cell temperature by increasing 25°C to ambient cell temperature. Secondly, from modules specifications we get MPP voltage and Voltage temperature co_ efficient. Then the voltage will reduce and we determine reducing in voltage at the maximum effective cell temperature as following:

$$V_{mp} @ °\mathrm{C} = [\mathrm{MPPV} - [V_{\mathrm{co\_efficient}} \times [T_{\max} \_25°]]] \times \eta_{dc} \qquad (3.1)$$

Where:

MPPV: Maximum power voltage.

$V_{\mathrm{co\_efficient}}$: Voltage temperature co _efficient.

$T_{\max}$: The maximum effective cell temperature

η_{dc} : The Efficiency of dc cable.

Thirdly, from inverter specification we can get the MPPT range @ operating voltage and then it will be multiple by 10% (Safety factor is recommended 10%).So the minimum voltage allowed at inverter is determined as following:

$$V_{\min\_inv} = MPPT \times 1.1 \qquad (3.2)$$

Where:

$V_{\min\_inv}$: minimum voltage allowed at inverter

Fourthly we can determine the minimum number of module string by dividing equation (3.2) by equation (3.1). The result is always rounded up to avoid producing under the minimum input voltage.

3.6.1.2. Maximum number of modules string:

The maximum number of modules is calculated with the coldest temperature when the module Voices at its highest. V_{co} Is used instead of VMP because it is higher and it is the maximum voltage supplied to the inverter when the array is connected or operating. In early morning, at first light, the cell temperature will be very close to the ambient temperature because the sun has not had time to heat up the module. Therefore the lowest daytime temperature for the area where the system is installed shall be used to determine the maximum V_{co}.

Firstly knowing the minimum temperature for proposed location Then we can get minimum effective cell temperature by decreasing minimum temperature from 25°C.Secondly from modules specifications we get open circuit voltage and voltage temperature coefficient. Then the voltage will increase and we determine the increasing at minimum effective cell temperature as following:

$$V_{co}@°C = V_{co} + [\, V_{\text{co\_efficient}} \times [25°C - T_{min}]] \tag{3.3}$$

Where:

V_{co}: Open circuit voltage of module.

$V_{\text{co\_efficient}}$: Voltage temperature co _efficient.

T_{min}: Minimum effective cell temperature.

Thirdly from inverter specification we can get max PV array open circuit voltage (V_{co}) and then it will be reduce by 5% (safety factor is recommended 5%). So maximum voltage allowed at inverter is determined as following:

$$V_{\max\_inv} = V_{co} \times 0.95 \tag{3.4}$$

Where:

$V_{\max\_inv}$: Maximum voltage allowed at inverter

V_{co}: PV array open circuit voltage

Fourthly we can determine maximum number of modules by dividing equation (3.4) by equation (3.3).The result is always rounded down to avoid producing over the maximum input voltage.

3.6.2. Matching the Array to Inverter current Rating:

It is important to ensure that the maximum current produced by the array is lower than the inverter maximum DC current input. The number of parallel strings the array can consist of is calculated by using the short circuit current (I_{sc-mo}) formula:

$$I_{sc-mo} = I_{SC\_STC} + [\, I_{\text{sc\_co\_efficient}} \times [T_{max} - 25]]. \qquad (3.5)$$

Where:

I_{sc-mo} : The short circuit current (I_{sc-mod}) formula:

I_{SC_STC} : The short-circuit current at STC.

$I_{\text{sc\_co\_efficient}}$: The I_{sc} temperature co _efficient.

T_{max}: The module temperature at a specified temperature.

From inverter specification we can get the maximum power(P_{max}) , power factor(PF) and max PV array open circuit voltage(V_{co}).So maximum dc input current by equation:

Where:

E_{array}= $£_{pv\_inv}$ × output power from equation (3.10)

$$I_{max} = P_{max} / [V_{co} \times \text{PF}] \qquad (3.6)$$

P_{max}: The inverter maximum power

PF: Power factor

V_{co}: Max PV array open circuit voltage

I_{max}: Maximum dc input current

Finally we can determine the number of strings by dividing equation (3.6) by equation (3.5).The result is rounded down to avoid over current in the inverter.

3.6.3. Matching the Array to the inverter power rating:

When matching an array to an inverter, calculations for current, voltage and power need to be made to ensure the correct sizing of the PV system. The calculations for current and voltage done in this Section give a specific value so the array can be sized with a number of strings and modules in a string The power calculations are done to find the maximum number of modules allowed in the system. With the chosen inverter and module, the maximum number of modules in the array is:

$$Array_{size} = P_{\max\_inv\_rated} \times P_{mod} \qquad (3.7)$$

Where:

$P_{\max\_inv\_rated}$: Maximum inverter rated power

P_{mod}: Module power

The power calculations are necessary to ensure that a PV system is not oversized.

3.7. Cable Sizing:

Wiring is an important part of the PV system design, both for safety and efficiency reasons. It is important that the conductor and the electrical insulation is correctly sized since undersized cables could cause a fire hazard. If cables are correctly sized, the voltage drop will be minimal and current in cables will never be greater than the cable safe current handling capability.

3.7.1. PV Array Cable:

The PV array cable is the connection between the string and the inverter and is often the longest cable in the system. We must get the voltage drop over the array cable.

3.7.2. Ac Cable:

The AC cable is dimensioned to carry more than the maximum current possible for the inverter to produce and is also dimensioned with the intention of a future upgrade. We must get the voltage drop over Ac Cable [5].

3.8. Energy Yield:

For a specified peak power rating (kW power) for a solar array a designer can determine the systems energy output over the whole year. The system energy output over a whole year is known as the systems "Energy Yield".

The average yearly energy yield can be determined as follow:

$$E_{system}=P_{Array\_stc} \times F_{tem} \times F_{man} \times F_{dirt} \times H_{tilt} \times £_{inv} \times £_{pv\_inv} \times £_{inv\_sb}$$

(3.8)

Where:

E_{system}: Average yearly energy output of the PV array, in watt-hours.

P_{Array_stc} : rated output power of the array under standard test

Conditions, in watts temp: temperature de-rating factor, dimensionless (refer next section).

f_{MAN}: De-rating factor for manufacturing tolerance, dimensionless (refer next section).

f_{dirt}: De-rating factor for dirt, dimensionless (refer next section).

h_{tilt}: Yearly irradiation value (kWh/m2) for the selected site (allowing for tilt, orientation and shading).

£ $_{inv}$: Efficiency of the inverter dimensionless.

$£_{\frac{pv}{inv}}$: Efficiency of the subsystem (cables) between the PV array and the inverter.

$£_{\frac{inv}{sb}}$: Efficiency of the subsystem (cables) between the inverter and the switchboard.

How to understand and apply this formula is explained in the following section.

3.9. Ac Energy output:

The AC energy output of a solar array is the electrical AC energy delivered to the grid at the point of connection of the grid connects inverter to the grid.

The output of the solar array is affected by:

- Average solar radiation data for selected tilt angle and orientation.
- Manufacturing tolerance of modules.
- Temperature effects on the modules.
- Effects of dirt on the modules.
- System losses (e.g. power loss in cable).
- Inverter efficiency.

3.9.1. Solar Irradiation data:

Solar irradiation data is available from various sources; some countries have data available from their respective meteorological department. One source for solar irradiation data is the NASA website: http:/eosweb.larc.nasa.gov/see/. RETSCREEN, a program available from Canada that incorporates the NASA data, is easier to use. Solar irradiation is typically provided as kWh/m2 However it can be stated as daily peak Sun hours (PSH). This is the equivalent number of hours of solar irradiance of 1kW/m2.

3.9.2. Effect of orientation and tilt:

When the roof is not orientated true north (southern hemisphere) or south (northern hemisphere) and/or not at the optimum inclination the output from the array will be less than the maximum possible. When system is located on a roof that is not facing true north (or south) or at an inclination equal to the latitude angle then the designer can use the peak sun hour data for their particular country to determine the expected peak sun hours at the orientation and tilt angles for the system to be installed.

3.9.3. Effect of shadows:

Shading is a factor with a significant potential of affecting the output power of the module. This is a hard value to predict and has unique values for every location, dependent of the surroundings. If an accurate value for the shading loss is wanted, then detailed analyses should be made on the roof for at least one year to count for summer and winter conditions. This is however, not done in this project.

3.9.4. De-rating module performance:

3.9.4.1. Manufacturers Output Tolerance:

The output of a PV module is specified in watts and with a manufacturing tolerance based on a cell temperature of 25 degrees C. Historically this has been ±5% but in recent years typical figures have been ±3% so when designing a system it is important to incorporate the actual figure for the selected module.

3.9.4.2. De-rating due to dirt:

The output of a PV module can be reduced as a result of a build-up of dirt on the surface of the module. The actual value of this de-rating will be dependent on the actual location but in some city locations this could be high due to the amount of car pollution in the air or in coastal regions during long periods of no rain then salt could build up on the module.

3.9.4.3. De-rating due temperature:

A solar modules output power decreases with temperatures above 25°C and increases with temperatures below 25°C. The average cell temperature will be higher than the ambient temperature because of the glass on the front of the module and the fact that the module absorbs some heat from the sun. The output power is determined by the following formula:

$$P_{0ut\_pv} = T_{\mathrm{co\_efficient}} \times T_{\mathrm{a.day}} \qquad (3.9)$$

Where:

$T_{\mathrm{co\_efficient}}$: Temperature co _efficient de-rating

$T_{\mathrm{a.day}}$: The daytime average ambient temperature for the month that the sizing is being undertaken.

3.9.5. Dc energy output from array:

$$E_{array\_act} = P_{out\_mod\_r} \times N_{mod} \times IR \qquad (3.10)$$

Where:

E_{array_act}: The actual DC energy from the solar array

$P_{out\_mod\_r}$: The de-rated output power of the module

N_{mod}: Number of modules

IR: Irradiation for the tilt and azimuth angle of the array.

If the irradiation figure is provided for the year then the above calculation will determine the annual DC energy output of the array. If it is a daily irradiation figure (daily PSH) then the calculation will determine the daily DC energy output of the array.

3.9.6. Dc system losses:

The DC energy output of the solar array will be further reduced by the power loss in the DC cable connecting the solar array to the grid connect inverter. That is, a voltage drop in the cable is equivalent to a power loss (and therefore energy loss) in the output of the array that is delivered to the input of the inverter.

Therefore the DC energy from the array that will be delivered to the input of the inverter will be determined as following:

$$E_{array} = £_{pv\_inv} \times P_{out\_mod} \qquad (3.11)$$

Where:

E_{array}: DC energy from the array

$£_{pv\_inv}$: Efficiency of the subsystem (cables) between the PV array and the inverter.

P_{out_mod}: The de-rated output power of the module

3.9.7. Inverter efficiency:

The DC energy delivered to the input of the inverter will be further reduced by the power/energy loss in the inverter. Therefore the AC energy delivered from the output of the inverter will determine as following:

$$E_{ac\_inv} = £_{inv} \times P_{out} \qquad (3.12)$$

Where:

E_{ac_inv}: AC energy delivered from the output of the inverter

$£_{inv}$:Inverter efficiently

P_{out}: The de-rated output power

3.9.8. Ac system losses:

The AC energy output of the inverter will be further reduced by the power loss in the AC cable connecting the inverter to the grid, say switchboard where it is connected. That is, a voltage drop in the cable is equivalent to a power loss (and therefore energy loss) in the output of the array that is delivered to the grid connection point.

Therefore the AC energy from the inverter (and originally from the array) that will be delivered to the grid will determine as following:

$$E_{ac\_inv\_grid} = \eta_{inv\_sub} \times P_{out} \qquad (3.13)$$

Where:

$E_{ac\_inv\_grid}$: AC energy from the inverter delivered to the grid

η_{inv_sub}: Is efficiency of subsystem (cables) between the inverter and the grid (switchboard).

P_{out}: The de-rated output power

3.10. Specific energy yield:

The specific energy yield (S) is expressed in kWh per kW power and it calculated as follows:

$$S=E_{sys} / P_{array\_stc} \quad (3.14)$$

Where:

S: The specific energy yield expressed in kWh per kW

E_{sys}: The AC energy of the solar array delivered to the grid.

P_{array_stc} : The actual STC rating of the array.

3.11. Performance Ratio (PR):

The performance ratio (PR) is used to access the installation quality. The PR provides a normalized basis so comparison of different types and sizes of PV systems can be undertaken. The performance ratio is a reflection of the system losses and is calculated as follows:

$$P_R=E_{sys}/E_{ideal} \quad (3.15)$$

Where:

P_R: Performance ratio

E_{sys}: Is actual yearly energy yield from the system.

E_{ideal} : is the ideal energy output of the array

System losses are determined as following:

E_{ideal} =$P_{\text{array\_stc}}$ × H_{tilt} (3.16)

Where:

E_{ideal} : is the ideal energy output of the array

H_{tilt} : Yearly average daily irradiation, in kWh/m2 for the specified tilt angle.

$P_{\text{array\_stc}}$: rated output power of the array under standard test conditions, in watts.

$System_{loss}$ =1 - P_R (3.17)

Where:

P_R: Performance ratio [6]

3.12 Modified IEEE 9 BUS RADIAL testing grid:

The testing grid shown in figure has been modified by adding 4 capacitors parallel with the far load buses from generation. And the load have been reduced as shown in table [7]

3.13 PV system Installation:

You will need to select a contractor to install your solar PVsystem.Your contractor will appoint a Licensed Electrical Worker ("LEW") who will be responsible for the design, installation, testing, commissioning, and maintenance of your solar PV system.

In the case of non-residential electrical installations that require an electrical installation license, the appointed LEW who supervises the electrical work ("Design LEW") may not be the one who takes charge of your electrical installation ("Installation LEW"). The Design LEW will then have to work with the Installation LEW to work out the technical issues.

3.13.1 Getting Started:

First, compile a list of potential solar PV system contractors. Next, contact the contractors to find out the products and services they offer.

3.13.1.1 Get an experienced and licensed contractor:

Experience in installing grid-connected solar PV systems is invaluable, because some elements of the installation process, particularly interconnection with the grid, are unique to these systems. A contractor with years of experience will also demonstrate an ability to work with consumers, and price their products and services competitively. It is also important to get a contractor who is an LEW.

3.13.2. Choosing between bids:

If there are several bids for the installation of a solar PV system (it is generally a good practice to obtain multiple bids), consumers should take steps to ensure that all of the bids received are made on the same basis. Comparing a bid for a solar PV system mounted on the ground against another bid for a rooftop. Bids should clearly state the maximum generating capacity of the solar PV system [measured in watts peak (Watt or kilowatts peak (kW power)]. If possible, the bids should specify the system capacity in AC watts, or specify the output of the system at the inverter. Bids should also include the total cost of getting the solar PV system components, including hardware, software, supporting structure, meter, installation, connection to the grid(if applicable), permitting, goods and services tax, warranty, and future maintenance cost (if applicable).

3.13.3. Solar PV system Warranty:

- A solar PV system is an investment that should last a long time, typically two to three decades for grid-connected applications. The industry standard for a PV module warranty is 20-25 years on the power output. There are two main components to a PV module warranty
- A workman ship warranty that offers to repair, replace or refund the purchase in case of defects. The period varies from one to as long as ten years, depending on the manufacturer. Two to five years is typical
- A limited power output warranty that offers a variety of remedies in case the PV module's output under STC drops below certain level. Most manufacturers warrant at least 90% of the minimum rated output for 10ast 90% of the minimum rated output for 10 years, and 80% of the minimum rated output for 20-25 years. Take note that the minimum rated output is usually defined as 95% of the rated output to allow for manufacturing and measurement tolerances.

3.13.4. Cost of solar PV system:

The cost of your solar PV system will depend on many factors: system configuration, equipment options, lab our cost and financing cost. Prices also vary depending on factors such as whether or not your home is new, and whether the PV modules are integrated into the roof or mounted on the roof. The cost also depends on the system size or rating, and the amount of electricity it produces. Generally, solar PV systems entail high capital costs. With solar power, you can save on the purchase of electricity from the grid. But even with these savings, it will take a long time to recover the capital cost of the solar PV installation. The operating costs for solar PV installations are negligible, but the annual maintenance cost beyond the warranty period may amount to 0.5% to 1% of the capital cost of the warranty period may amount to 0.5% to 1% of the capital cost of the installation.

3.13.5. Solar PV system on building:

There are many examples overseas where PV modules are mounted on the roof and integrated into building façades. PV modules may be installed on sloped roof, flat roof.

3.13.6. Avoid shading in PV modules:

PV modules should be free from shade. Shading of any single cell of a crystalline silicon PV module will drastically reduce the output of the entire PV module.

3.13.7. Structural Safety:

To ensure safety, there are measures and steps that need to be taken or considered when installing a solar PV system onto a new or an existing building. For new building developments, the design of the structure must take into consideration the loading of the solar PV system installation, just like any other equipment mounted onto a building structure.

Ensure the structure for mounting is safe:

I. Additional loading by solar PV system is considered.
II. Wind loading is considered.
III. Waterproofing is not compromised during installation.

3.13.8. Mechanical Installation:

The modules were connected to the supporting aluminum beams with nuts, bolts and washers at tow and four points where it was possible. The holes in the supporting beam were not necessarily made for these modules, so new holes was needed to be drilled on the module frame making it possible to mount the modules and securely fasten them in the configuration given.

3.13.9. Electrical Installation License:

An electrical installation refers to any electrical wiring, fitting or apparatus used for the conveyance and control of electricity in any premises. The license requires the owner of the electrical installation to engage an LEW to take charge of the electrical installation and comply with the relevant safety standards and requirements.

3.13.10: Connection to the power Grid:

A grid-connected solar PV system operates in parallel with the power grid supply. The power grid supply is considered the source, and the electrical installation with the solar PV system connected is considered as the load. If a solar PV system is designed to meet only a fraction of the electricity load, the system will need to be interconnected with the power grid to meet the remainder of the consumer’s needs for electricity. If a solar PV system needs to be Grid-connected, interconnection is key to the safety of both consumers and electrical workers, and to the protection of equipment.

3.13.11. Get connected to the power grid:

If you intend to connect and operate your solar PV system in parallel to the power grid, your appointed LEW will have to consult your country Power Grid on the connection scheme and technical requirements.

3.13.12. Sale of PV electricity:

The excess electricity generated from a grid-connected solar PV can be sold back to the power grid. The arrangements needed to enable this sale of solar PV electricity vary, in some countries depending on whether you are a contestable or non-contestable consumer.

Consumers are classified, based on their average monthly electricity consumption, into:

- Contestable consumers: Thee consumers are the non-residential consumers who use more than 10,000kWh of electricity a month. Contestable consumers have a choice of who they wish to buy their electricity from. They may purchase electricity from a retailer, directly from the wholesale market (provided they are registered with the Energy Market Company as market participants) or indirectly from the wholesale market through utility Services.
- Non-contestable consumers: These consumers comprise all the residential electricity users and non-residential consumers who use less than 10,000kWh of electricity a month. These consumers are supplied with electricity by Utility Services.[8]

3.14 flow chart:

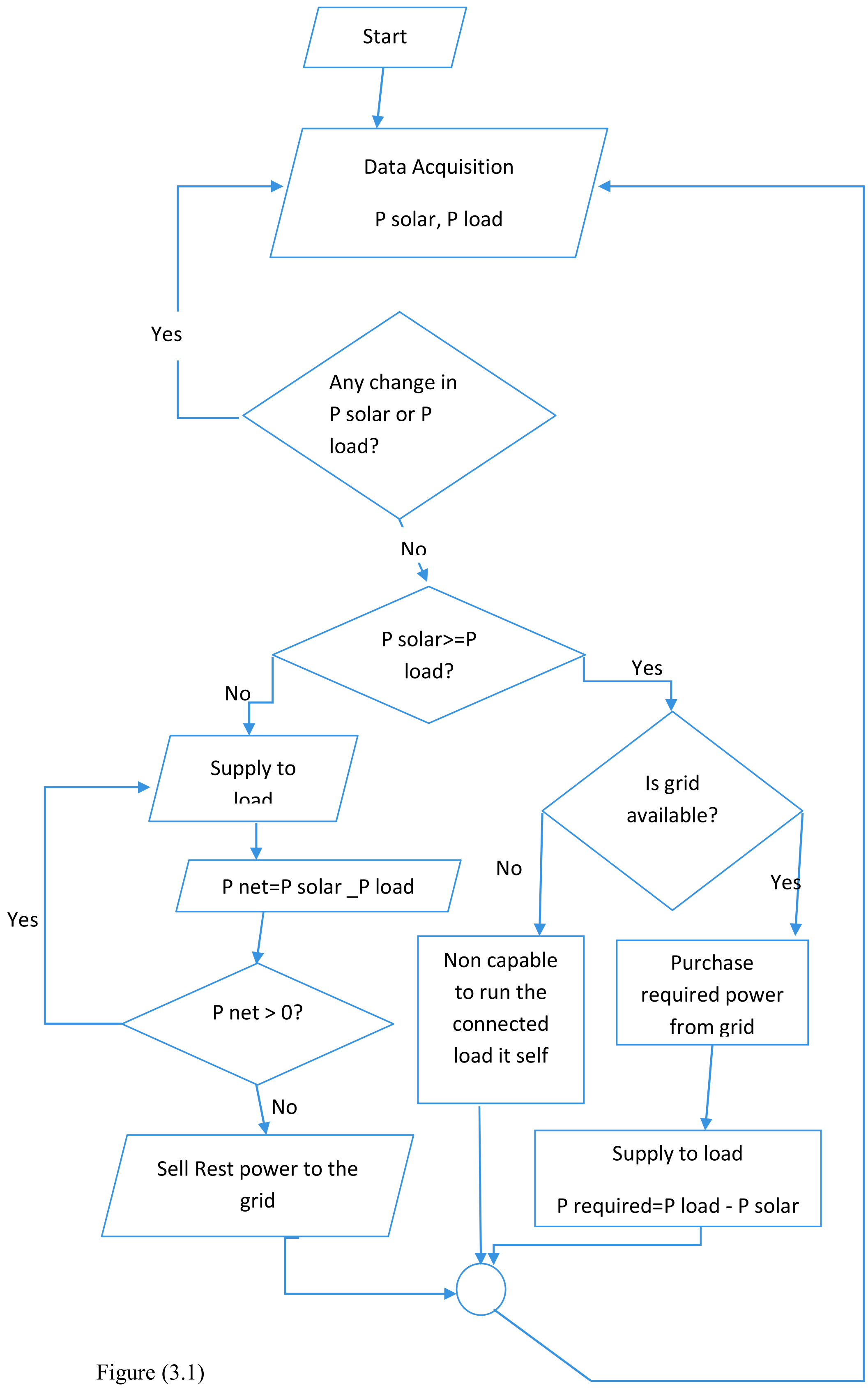

Figure (3.1)