# CHAPTER 5

# PHOTOVOLTAIC SYSTEM DESIGN

## 5.1 Introduction

So far in the development of this research, the focus has been to estimate the available insolation at a particular location on the earth's surface and then analyzed the characteristics of a photovoltaic generator and a photovoltaic network. The purpose of this chapter is to examine all the necessary steps and key components needed to design and build a photovoltaic power plant.

## 5.2 Site Selection

The factors which influence the selection of a particular site to build a photovoltaic power plant include the following:

1. Insolation: It is the most important factor used in selecting a site to build a photovoltaic power plant. The energy output of a photovoltaic system is directly proportional to the insolation input. Other climatic and environmental factors such as temperature extremes, precipitation, wind and land topography, will limit and constrain a PV plant but these factors are all secondary when compared with the availability of insolation.

2. Land Area Requirements: Photovoltaic plants generally require large areas for solar arrays. Larger areas are required in order to space the arrays for minimum inter-array shadow effects. Simpler arrays such as fixed, south-tilting, east-west arrays require smaller areas compared to the two-degree-of-freedom tracking arrays.

3. Economic Factors: Economic consideration in site selection must account for the cost of land required, the cost of site preparation and the cost of access to the site. While all these costs are important, it should be noted that land and site preparation costs are generally a minor part of the overall cost of a photovoltaic power plant. The access cost, however, has an additional significance since remote access will contribute to the operation and maintenance cost over the years.
4. Institutional Factors: Institutional criteria involve considerations of land use requirements and social activities. Population density is a prime determinant in choosing sites.

## 5.3 System Design Procedures

### 5.3.1 Load Profile

The first task in designing a photovoltaic system is to estimate the system load. This is achieved by listing the power demand of all loads, number of hours of use per day, and operating voltage. From the load current in ampere-hours, and the given operating voltage for each load, the power demand is calculated. The recommended voltage for a stand-alone photovoltaic system is determined by considering information obtained by grouping the loads by type and operating voltage and calculating the power demand for each group. The operating voltage selected for a stand-alone photovoltaic system is usually the voltage required by the largest loads. When ac loads dominate, the dc system voltage should be selected for compatibility with the inverter input. If dc loads have the largest power demand, the voltage accompanying the largest load is selected.

### 5.3.2 Photovoltaic Array Sizing

Three items need to be addressed when sizing a photovoltaic array and they are:

1. Module Selection: Module selection is based on the specifications provided by the manufacturer. Specifications such as performance, physical size and cost must be compared between different modules before the decision on which module(s) to use is made.
2. Number of Modules: The number of modules to be connected in parallel in order to produce the design current must be determined. Since this number is rarely a whole number a decision has to be made whether to round up or round down. In making this decision, system availability requirements must be considered. The number of series-connected modules needed to produce the design voltage must be calculated. This calculation involves dividing the system voltage by the nominal module voltage. For stand-alone pv systems, 12-V modules are commonly used.
3. Orientation: A photovoltaic array can be mounted at a fixed angle from the horizontal or on a sun-tracking mechanism in order to increase energy production. A tilt angle near the location's latitude will give the most energy annually. Tilt angles of Latitude $\pm 15^{o}$ will increase energy production toward winter or summer respectively.

### 5.3.3 The Power Conditioning Unit

Power Conditioning Units (PCU) are very important components in any stand-alone pv system that powers ac loads. The choice of PCU will impact the performance and economics of the system. The PCU is the third largest cost component lagging only behind the array and battery.

#### 5.3.3.1 PCU Characteristics

PCU’s are often categorized according to the type of waveform produced. The output waveform depends on the conversion method used and the filtering to smooth the waveform and eliminate spikes and unwanted frequencies that occur when the original switching occurs. Three of the most common waveforms include [18];

1. The square wave PCU: It produces a switched ac output with little output voltage control, limited surge capability, and considerable harmonic distortion.

2. The modified sine wave PCU: It can handle larger surges and has less harmonic distortion in it’s output.

3. The sine wave PCU: It produces an ac waveform which is comparable to most utilities.

The following characteristics should understood before selecting a PCU for the system;

1. Power Conversion Efficiency: This is the ratio of output power to input power of the PCU. Efficiency of a stand-alone PCU varies significantly with the type and amount of load.
2. Rated Power: It is an indication of how many watts of power the PCU can supply during standard operation. The PCU rated power should be at least 125 percent of peak load demand. This will allow some growth in load demand for the system.
3. Duty Rating: This is the amount of time the PCU can supply the maximum load. Exceeding this time may cause hardware failure which is another reason why the PCU should be oversized.
4. Input Voltage: This is determined by the total power required by the ac loads. The higher the load demand, the higher the operating voltage of the PCU.
5. Surge Capacity: PCU’s do exceed their rated power for limited periods of time, usually in seconds, thus surge capacity needs to be determined for some loads.
6. Voltage Regulation: It indicates the variability in the output voltage. Better PCU’s will produce a nearly constant root-mean-square (RMS) output voltage over a range of loads.
7. Voltage Protection: A PCU can be damaged if dc input voltage levels are exceeded. Since battery voltage can far exceed nominal voltage if the battery is overcharged, it is advisable to select PCU’s that have sensing circuits which will disconnect the unit from the battery if either high or low levels are present at the input.
8. Frequency: Knowledge of the load frequency is required in selecting a PCU. In the United States most loads require 60 hertz whereas in other parts of the world, 50 hertz is commonly used. Variations in frequency can cause poor performance of clocks and electronic timers within the system.
9. Modularity: It is sometimes advantageous to have multiple PCU’s in some pv systems. These can be connected in parallel or used to service different loads.
10. Power Factor: This is the cosine of the angle between the current and voltage waveforms produced by the PCU. This value varies with the load. The power factor should be very close to one.

### 5.3.4 Battery Sizing

Battery sizing is the capability of a battery system to meet the load demand with no contribution from the photovoltaic system. For a stand-alone photovoltaic system, the principal goal of battery storage is to ensure that the annual minimum photovoltaic system energy output equals the annual maximum load energy input. The photovoltaic system must also maintain a continuous energy supply at night and on cloudy days when there is little or no solar energy available. The amount of battery storage needed will depend on the load energy demand and on weather patterns at the site. Having too much energy and storage capacity will increase cost, therefore there must be a trade-off between keeping the cost low and meeting the energy demand during low-solar-energy periods. Some trade-off possibilities include:

i. Using the surplus solar energy to perform various tasks that can be switched on when excess energy is available.

ii. Undersizing the storage capacity and array and meeting periods of deficiency with auxiliary power such as a generator. ( Not applicable to this research. )

iii. The load may have to diminish or cease its energy demand during brief periods when solar energy is low.

The following is a list of battery characteristics that should be understood before selecting a battery to use for the pv system:

1. Depth of Discharge: This is the percentage of the rated battery capacity that is withdrawn from the battery. The capability of a battery to withstand discharge depends on its construction.
2. Temperature Correction: The performance of a battery decreases with temperature. Temperature correction is needed to correct the lowest temperature that the battery will be subjected to during its operation and the discharge rate expected.
3. Rated Battery Capacity: This is the maximum amount of energy that a battery can produce. The same discharge rate must be used when comparing battery capacity.
4. Seasonal Depth of Discharge: It reduces the array current used for system sizing.
5. Battery Life: The lifetime of a batteries is very difficult to predict because it is dependent on several factors. These factors may include, the charge and discharge rate,the number of charge and discharge cycles, and operating temperature extremes.

#### 5.3.4.1 System Availability

System availability is defined as the percentage of time that a photovoltaic system is capable of meeting load requirements over a specified period. System availability depends primarily on the size of the battery system. Generally, failure and maintenance time are the primary contributors which lower system availability for most energy systems but availability takes on added uncertainty in the case of photovoltaic systems because of the variability of the systems fuel (sunlight). A system availability of 95 percent means that the photovoltaic system should meet load requirement for 8,322 out of the 8,760 hours available in an average year. Two levels of system availability are generally used in designing photovoltaic systems. These levels are:

i. Noncritical 95.0 percent
ii. Critical 99.0 percent.

The common practice for most applications is to size the system for noncritical availability and, if necessary, increase the array and (or battery storage) after cost and availability of product are known.

#### 5.3.4.2 Battery Types

There are many types of batteries available in the market for photovoltaic systems. The most commonly used batteries in PV systems are of the lead-acid type. These batteries are available with both liquid electrolyte and captive electrolyte. They are rechargeable, easily maintained, inexpensive and available in different sizes and options. Also available in the market are cadmium batteries specifically designed for photovoltaic systems applications. The predominant advantage of these batteries is their ability to withstand extreme weather conditions. Nickel cadmium batteries are also more tolerant to extreme charge and discharge and can thus eliminate the need for controllers in some applications thereby offsetting their high cost and increasing system reliability.

### 5.3.5 Controllers

Charge controllers are used in pv systems to protect the batteries from overcharge and excessive discharge. Most controllers function by sensing battery voltage and then take action based on voltage levels. Other controllers have temperature compensation circuits to account for the effect of temperature on battery voltage and state-of-charge. Controllers pose more problems than any other component in a stand-alone photovoltaic system. This is because they are complex devices that depend on the battery state-of-charge. The battery’s state of charge depends on many factors and is difficult to measure. The controller in a pv system must be sized to handle the maximum current produced. It is recommended to multiply the array short-circuit current by a factor of 1.25 or greater to allow for short-term insolation enhancement by clouds. The maximum current value and system voltage is the minimum needed to specify a controller. The following characteristics should also be considered before selecting a controller:

- Adjustable Setpoints

- High voltage disconnect
- Low voltage disconnect

- Temperature Compensation
- Low Voltage Warning
- Reverse Current Protection
- Maximum Power Tracking
- Voltage Meters.

The controller selected must ensure that current does not flow from the battery to the array at night. Another characteristic that should be considered before selecting a controller is the low voltage disconnection (LVD) protection. LVD protection is required to prevent excessive battery discharge.

### 5.3.6 Balance of System Components

Many problems that confront a PV system can be traced to improper sizing or installation of the balance-of -system (BOS) components. Making secure and durable connections is essential to the lifetime of a PV system. BOS components include;

1. Type of Wire and Size: The performance and reliability of a PV system is increased if the correct size and type of wire is chosen. Among the several types of wire available in the market today, only a few are recommended to be used in a stand-alone pv system. Copper wires are generally used in pv systems. Although aluminum wire is less expensive, it can cause very serious problems to the pv system if used incorrectly. When choosing the type of wire to use, the total current carrying capability of the wire must be considered along with the fuses used to protect the conductors. This information is essential because if the current level is exceeded, overheating, insulation breakdown and fires may occur. Other factors that should be considered before selecting a wire include, the voltage drop and power loss. Both of these factors are dependent on the resistance of the wire, the amount of current and the length of the wire.

2. Switches and Fuses: Fuses are used in PV systems to provide overcurrent protection when ground faults occur and switches are used to manually interrupt power in case of emergency or maintenance. Since the battery is the major current source of concern in a stand-alone pv system, a fuse has to be connected between the array and the controller. This fuse will ensure the protection of the modules from battery current should a ground fault occur when the controller is engaged. The array short-circuit current multiplied by a factor of 1.25 is generally used to size the fuse between the array and the controller. In a stand-alone pv system, safety switches are installed to isolate the array, battery, controller and load.

3. Connections: Poor connections are responsible for most problems in a stand-alone pv system. Poor connections may result to losses in system efficiency, system failure, and costly troubleshooting and repairs. System connections must be secure and able to withstand extreme weather and temperature. Connections must also be protected from vibration, animal damage and corrosion. To prevent against corrosion, copper conductors should be used for system connections.

### 5.3.7 System Installation

1. Mounting Scheme: Stand-alone pv systems have arrays which are ground mounted. Ground mounted arrays can be fixed or tracking. The greatest concern for most arrays that are ground mounted is the uplifting force of wind on the array. For this reason, most ground arrays usually employ some kind of sturdy base such as concrete. Other types of mounting schemes which are not generally applicable in large stand-alone pv systems are bracket mounting, pole mounting, and structure mounting.

2. Grounding Scheme: Grounding of a pv system provides a well-defined low-resistance path from selected points of the system to the ground. If the system malfunctions, the fault current is expected to travel through this path. For stand-alone pv systems, two types of grounding are essential and they are; systems ground and equipment ground. System grounding consists of one of the current carrying conductors, usually the negative conductor that is grounded at a single point. This configuration establishes the maximum voltage with respect to ground and also serves to discharge surge currents induced by lightning. Equipment grounding is done primarily for safety reasons.