CHAPTER 4

PHOTOVOLTAIC NETWORK

4.1 Introduction

A photovoltaic power plant, like any other energy generating source has to be designed to meet certain load demand. The solar cell discussed in the previous chapter, produces only a small amount of current and voltage. In order to meet large load demands, solar cells have to be connected into modules and the modules connected into arrays. In this chapter, we will discuss the connection of photovoltaic modules and arrays.

4.2 Definition

4.2.1 Photovoltaic Module

A Photovoltaic Module is the connection of solar cells either in series or in parallel in order to meet specified power output requirements.

4.2.2 Photovoltaic Array

A photovoltaic array is defined as a mechanical integrated assembly of photovoltaic modules together with support structure, as required to form a direct-current power supply unit [10].

4.3 The Photovoltaic Module

The photovoltaic module is the key to designing a solar power plant. The module is the smallest complete, environmentally protected assembly of solar cells designed to generate dc power. The objective in designing photovoltaic modules, is to ensure an adequate operating life-time in the terrestrial environments and also to protect personnel from unnecessary electrical hazards. As a result the module is an encapsulated circuit of solar cells that only needs to be electrically connected to other modules and then mounted to produce electricity. The encapsulation is a laminate of different materials to mechanically support and environmentally isolate the solar cell circuit. There are two predominant designs for module construction. These

are the superstrate design which uses a top-surface material, such as glass to provide the structural strength for the solar cells and the substrate design which uses a structural material, such as plastic or steel, to provide support for the solar cells from underneath [19].
The overall objective of module encapsulation includes [19];

1. Protecting the solar cell from environmental stresses such as;
- Wind and Snow
- Hail
- Differential Expansion
- Humidity

2. Maximizing the amount of sunlight reaching the solar cells by:
- Optical Transmission
- Low soiling

3. Protecting the user from safety hazards such as:
- Electrocution
- Fire

4. Maintain a twenty-year lifetime, and

5. Maintain low area cost.

4.3.1 Performance and Ratings of Photovoltaic Modules

The amount of power photovoltaic modules produce over time, energy, is the most important aspect of a photovoltaic system. Energy production is affected by energy input and efficiency of the power conversion. The efficiency of a photovoltaic module is given by [19];

$$\eta = \frac{Power \quad Output}{Solar \quad input \quad per \quad unit \quad Area \ \times \ Area} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.1$$

At peak power, the efficiency is given by [18];

$$\eta_p = \frac{Power \quad Rating}{1000 \quad W/m^2 \ \times \ Module \quad Area} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.2$$

Since efficiency cannot be measured directly, the power output of the device under a given set of conditions is used instead. The power output normally used is the power output at peak rating conditions and these conditions are;

i. $1000 \ W/m^2$ at 1.5 air mass
ii. $25^{o}C$ cell temperature

The output power at peak rating conditions can be used with the module area to calculate the peak efficiency, η_p, as shown above. This peak efficiency can then be converted to an operating efficiency (η_{op}) under certain conditions at any particular site by simple manipulations. Efficiency has been found to decrease with increasing temperature.

The most useful temperature for a photovoltaic module, is the weighted average temperature at which most of the power is produced. This temperature is called nominal operating cell temperature (NOCT). This temperature is obtained at reference conditions and in a specific mounting configuration to estimate the temperature at which a particular module will operate. The difference between $25^{o}C$ (the temperature at which peak rating is obtained) and NOCT is used along with a coefficient of energy loss per ^{o}C, τ, which is provided by the manufacturer to obtain the operating efficiency, η_{op}, as follows [19] ;

$$h_{op} = h_{p} - t\left(NOCT - 25^{o}C\right) \qquad 4.3$$

Although two other sets of conditions exists, a designer of photovoltaic systems needs only to understand the peak rating conditions.

4.4 The Photovoltaic Array

We have seen in section 3.2.3 that the power output of a module is seriously affected when the module is partially shadowed or has one or more damaged cells. Since modules are generally composed of solar cells in series, this problem has to be prevented for the photovoltaic array to perform efficiently. To alleviate this problem for a single solar cell, a diode can be connected in parallel with the solar cell. This configuration will ensure that the solar cell will not produce energy and will not be a supplementary load to the system. Thus the load current is not reduced. The choice of the diode is made such that the value of the diode threshold voltage must be as small as possible, and its current rating should be able to carry the generated current within the series string. In the practical world, one does not put a diode in parallel with each solar cell but the protection is carried out on the module level. The protection of photovoltaic modules in series is achieved by connecting bypass diodes in parallel with the modules and the protection of photovoltaic modules connected in parallel is achieved by connecting the bypass diodes in series with the modules. Figure 4.1 below shows the protection of a photovoltaic array composed of a series-parallel connection of modules.

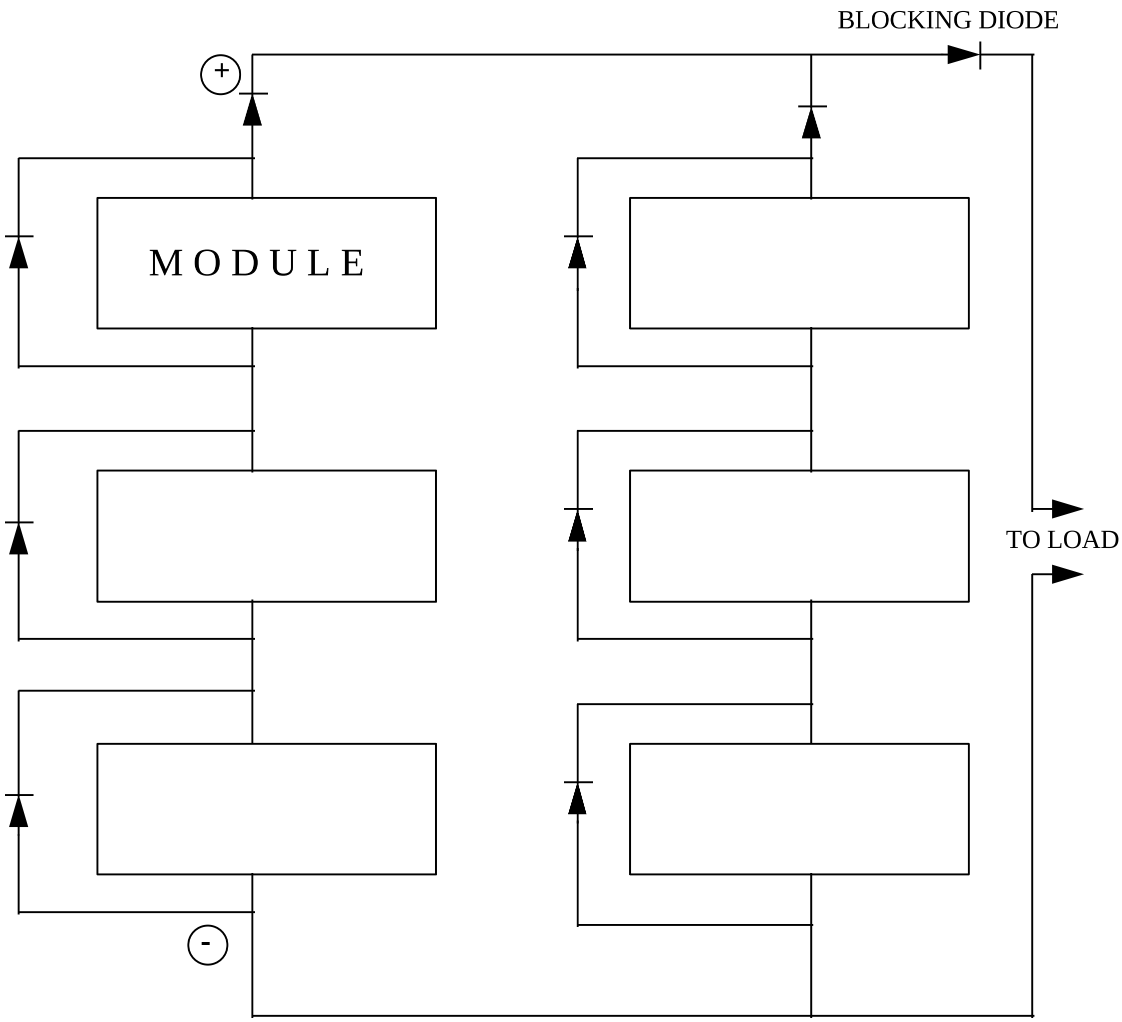

Figure 4.1: Protection of PV Array Composed of Series-Parallel Connection of Modules.

4.4.1 Types of Photovoltaic Arrays

There are several types of pv arrays in application today. Among these are:

1. Flat-Plate Stationary Arrays: These are the most common arrays in use today and their tilt angle from the horizontal can be adjusted several times throughout the year. Although stationary arrays may use more modules and not capture as much energy as tracking arrays, their reliability is what makes them appealing to pv designers. It is highly recommenced to use this type of array in locations that are remote or dangerous.

2. Tracking Arrays: These are arrays that follow the sun across the sky either in one or two axis. Tracking arrays perform best in areas with very clear climates because following the sun yields significantly greater amounts of energy when the sun's energy is predominantly direct.

One axis tracking arrays normally follow the sun from east to west throughout the day. The angle between the modules and the ground does not change and the modules do not necessarily have to point exactly up to the sun at all times.

Two axis tracking arrays follow the sun from east to west and change their angle from the ground throughout the day. The modules face straight at the sun throughout the day. Two axis tracking is more complicated than one axis tracking.

There are three basic tracking methods used by tracking arrays. The first method uses a simple motor, gear and systems to move the array. The system is designed to mechanically point the modules in the direction of the sun. There are no sensors or devices that actually confirm that the modules are facing the sun.

The second tracking method uses photovoltaic cells as sensors to orient the larger modules in the array. This is done by placing a cell on each side of a small divider, and mounting the package so that it faces the same way as the modules. An electronic device is constantly used to compare the small current flow from both cells. If one cell is shaded, the electronic device triggers a motor to move the array until both cells are exposed to equal amounts of sunlight. During the night or cloudy weather, the output of both sensor cells is equally low and no adjustments are necessary. When the sun rises in the morning, the array moves back to the east and follows the sun again.

The third tracking method uses the expansion and contraction of fluids to move the array. The system works by using a container filled with a fluid that vaporizes and expands considerably when it is in the sun. When it is in the shade, the system condenses and contracts. Other components that are used with pv arrays are reflectors and concentrators. Reflectors are sometimes installed with pv arrays to increase the amount of solar energy striking the modules. Although reflectors are highly desirable because of their ability to provide increased solar energy to the modules, not all modules are however designed to withstand the higher temperatures associated with reflectors. Performance and physical structure of many modules will suffer if reflectors are used with them. Performance suffers because higher module temperatures mean lower output voltages. Reflectors are most effective in clear climates because they work with sunlight coming directly from the sun. By increasing the overall surface area of the array, reflectors also increase the array's wind loading characteristics. Concentrators use lenses or parabolic reflectors to focus light from a larger area on to a photovoltaic cell of smaller area.

Only modules containing cells with the ability to withstand high temperatures are used with concentrators. Arrays using concentrators must have heat removal system to keep module temperature down and output voltages up. Concentrators have the same disadvantages like reflectors