Photovoltaic Power Systems

An Online Continuing Education Course for Engineers

Course Number: R-4008

Credit: 4 Hours / 4 PDH / 4 CPD

Photovoltaic Power Systems

Lee Layton, P.E.

Introduction

The world is closing in on the notion that global warming may be a real threat and we must find ways to reduce carbon emissions to protect the environment. As a result, there is a heightened interest in renewable energy production that can reduce the future demand for coal and natural gas fired power plants. Renewable power production technologies such as wind farms, photovoltaics, geothermal, hydroelectric, and biomass systems are all receiving a lot of attention.

In this course, we will look at photovoltaic systems. The term *photovoltaic* is derived from the Greek term "photo", which means "light" and from name of the Italian physicist, Alessandro Volta, who developed the electric battery and for whom the term "volt" is derived. Photovoltaic systems use solar cells to generate electricity from the power of the sun. These systems are quiet, unobtrusive, and require very little maintenance.

Photovoltaic systems are not new. The concept was first discovered by the French physicist, Alexandre Becquerel in 1839. As a footnote to history, Alexandre's son, Henri, is often – and incorrectly - given credit for this discovery. It was not until 1954 that photovoltaic systems were developed that could generate any useful amount of electricity. These early photovoltaic systems, which were developed by Bell Labs, were used in applications such as satellites.

The energy crisis of the 1970's created interest in more widespread use of photovoltaics for energy production, but the systems of that era were prohibitively expensive with prices of over $1,000 per peak watt. Since the 1970's, the industry has continued to research and design more cost effective solar cells for photovoltaic systems. By the year 2000, the cost of photovoltaic systems had dropped to about $8.00 per peak watt and the cost continues to decline. In 2017, it was around $3.25 per watt. Installed costs for a small 5,000-watt residential application is around $16,000. These prices are generally higher than traditional generation sources and some claim that the cost of manufacturing solar cells may use more energy than the solar cells will ever produce, but the technology continues to evolve and may become a viable generation source for general applications. Photovoltaic systems have already found applications for remote radio repeaters and other sites where grid connected power is not available.

I. Overview

The term "solar power" can be used to denote either solar thermal systems or photovoltaic systems. Solar thermal systems use the heat generated by sunlight to heat air or water. Photovoltaic systems do not depend on sun's heat to generate electricity.

Photovoltaic systems generate electricity by using the interaction of sunlight with a semi-conducting material, which frees electrons in the material to create an electric current.

The solar cells used in a photovoltaic system are made from a semi-conducting material that will produce a voltage and current when exposed to sunlight. The current generated by a photovoltaic solar cell is a direct current (DC) like the current that is generated from a common household battery. The amount of current produced by a solar cell is directly proportional to the amount of sunlight falling on the solar cell.

In general, a photovoltaic solar cell is a small silicon disk about ½-inch in diameter. Many cells are connected in together either in parallel to increase the current capacity, or in series to increase the voltage. These modules of solar cells are further connected with other modules to create a solar array of the proper voltage and current rating. Most solar arrays are set at a fixed relationship to the sun to gather the most sunlight. However, some large sophisticated solar arrays have tracking systems that continuously adjust the tilt of the array to maintain an optimum relationship with the sun throughout the day.

In addition to the actual solar array, a photovoltaic system will also include several other components such as a charge controller, storage batteries, an inverter, a disconnect device, and metering equipment. These items are sometimes referred to as the balance-of-system (BOS) equipment. The specific components are included in a system are based on the type of photovoltaic system employed.

There are three primary types of photovoltaic systems. They are,

- Stand-Alone DC System
- Stand-Alone AC System

- Gird Interactive AC System

We will discuss each of these systems briefly.

Stand-Alone DC System

The simplest form of photovoltaic system is a stand-alone DC system. A block diagram of a stand-alone DC system is shown in Figure 1. This system includes the solar array, charge controller, and storage battery. The DC current generated by the solar array is used to either directly serve the DC load, such as a lighting system, or to recharge the storage battery for later use.

One popular consumer application of stand-alone DC systems is outdoor accent lighting for residential homes. These systems often use low power LED's for lighting, are relatively inexpensive (less than $100.00), and use common sized rechargeable batteries for storage.

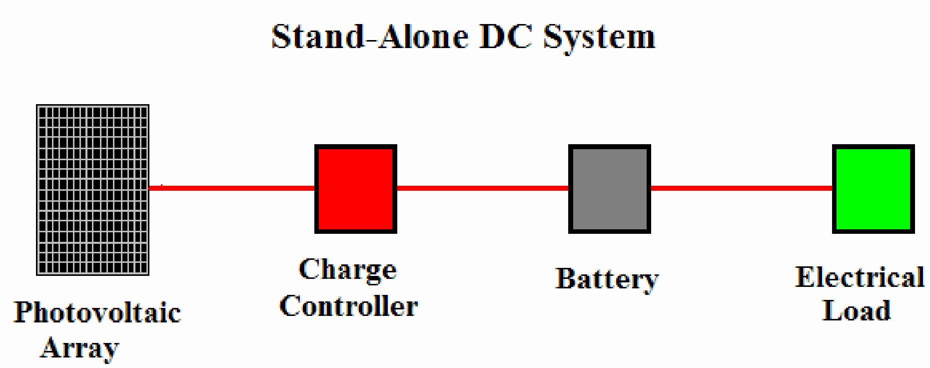

Figure 1

Stand-Alone AC System

Most electrical loads use alternating current (AC), therefore a photovoltaic system that can supply AC power is more versatile than a DC-only system. A stand-alone AC system is similar to a DC system, except for the addition of an inverter to convert the DC power to AC power. An inverter is a solid state electronic device, but some energy – up to 15% - is lost in the conversion from DC and AC power. In the United States, inverters are designed to convert the DC voltage to either 120 VAC, 60Hz or 240 VAC, 60Hz. Figure 2 shows a typical stand-alone AC system. The load is served from the battery through the inverter and the charge controller regulates the flow of power into the battery.

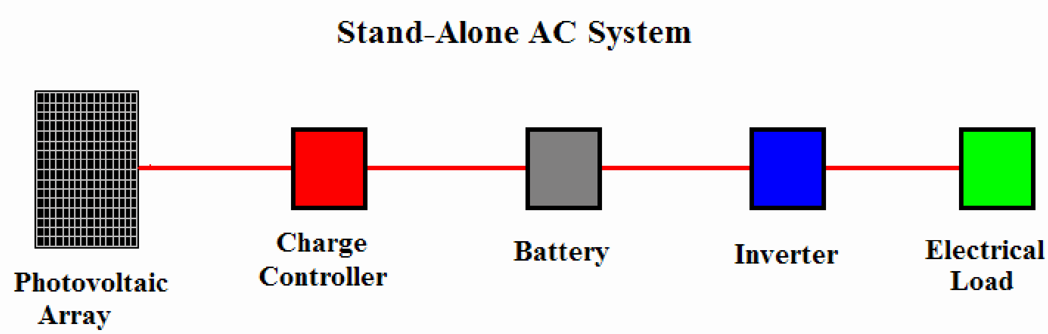

Figure 2

Grid Interactive AC System

A more complicated approach is the grid interactive AC system. This system is similar to a stand-alone AC system except the system must be designed to utility-grade standards for interconnection to the electrical grid. Additional equipment is required to interconnect, and the equipment must be capable of disconnecting from the grid during faulted conditions. Figure 3 is an example of a grid interactive system.

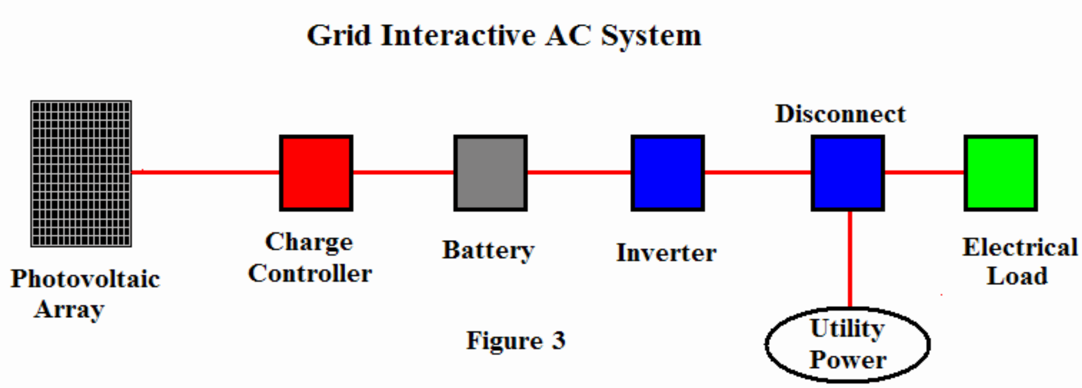

Figure 3

In this application, the photovoltaic system supplies the load and if the solar generated power is not sufficient to supply the load, the utility power will supply the deficiency. When the electrical load is not present, or if the solar generated power exceeds the electrical load, then the excess solar generated power is supplied onto the grid to the electric utility company.

In most cases, the electric utility is required to buy the excess power from the photovoltaic system. There are two ways the utilities buy power from renewable sources such as a photovoltaic system. The most common method is to sell power to the customer at the company's full retail rate, which includes generation, transmission, distribution, and service costs. The photovoltaic supplied power is purchased by the utility at its "avoided" generation cost, which does not include transmission, distribution, and service costs since these costs must still be recovered by the utility. Some utilities are beginning to buy renewable energy using a "net metering" arrangement where the electric utility meter effectively is run backwards when excess solar power is generated, giving the customer full retail credit for any solar generation. The net metering concept shifts utility infrastructure costs to other ratepayers, but promotes renewable energy projects.

II. Solar Radiation

Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy. About one-half of the solar radiation is in the form of visible light with the remainder being infrared and a little ultraviolet radiation.

Sunlight reaches every spot on the Earth's surface at least sometime during the year. The amount of solar radiation that reaches any given location is dependent on several factors including the geographic location, time of day, season, local landscape, and area weather.

Because the Earth is round, the sun strikes the surface at different angles ranging from 0º (just above the horizon) to 90º (directly overhead). When the sun's rays are vertical, the Earth's surface gets all the energy possible. The more slanted the sun's rays are, the longer they travel through the atmosphere, becoming more scattered and diffuse.

The 23.5º tilt in the Earth's axis of rotation is a significant factor in determining the amount of sunlight striking the Earth at a particular location. Tilting results in longer days in the northern hemisphere from the spring equinox to the fall equinox. Days and nights are both exactly 12 hours long on the equinoxes, which occur each year on or around March 23rd and September 22nd.

The United States, which lies in the middle latitudes, receives more solar energy in the summer because the days are longer, and the sun is nearly overhead. The sun's rays are far more slanted during the shorter days of the winter months. Cities like Denver, Colorado, receive nearly three times more solar energy in June than they do in December.

The rotation of the Earth is responsible for hourly variations in sunlight. In the early morning and late afternoon, the sun is low in the sky. Its rays travel further through the atmosphere than at noon when the sun is at its highest point. On a clear day, the greatest amount of solar energy reaches a solar collector around solar noon.

The photovoltaic industry defines two standard terrestrial solar spectral irradiance distributions. They are: the direct normal spectral irradiance and the standard total global spectral irradiance. The direct normal spectrum, which is also known as direct beam solar radiation, is a component of the total spectrum. The ... on that reaches the Earth's surface without being diffused ... *ion*. As sunlight passes through the atmosphe... d. This scattering is caused by air molecule... s, and volcanoes. This is called *diffuse solar ra*... radiation may be reduced by 10% due to ... cloudy days there may not be any direct beam ... solar radiation is called global solar radiat...

The *solar constant* is the ... n per unit area measured on the outer su... dicular to the rays and is 1,366 watts per squ... vn as solar insolation and is one-fourt...

Insolation is the amount of ... ver a period of time and is measured in kilo...). *Irradiance* is the amount of solar power received on t... the earth at a given time and is measured in kilowatts per square meter (kW/m^2).

Insolation is greatest when the surface is normal to the Sun. As the angle increases beyond a direction normal to the surface and the sunlight, the insolation is reduced in proportion to the cosine of the angle.

Table 1 on the right shows the average annual solar radiation for several cities in the United States. From the table, we see that Atlanta, GA can expect 5.1 kWh/m^2/day of solar radiation. In comparison, Anchorage, AK only receives 3.0 kWH/m^2/day.