CHAPTER 3

PHOTOVOLTAIC GENERATOR

3.1 Introduction

In 1839, Becquerel discovered a photovoltage was developed when light was directed onto one of the electrodes in an electrolyte solution. Forty-eight years later, Adams and Day observed a photovoltaic (PV) effect in solid selenium. Other researchers such as Lange, Grondahl and Schottky also did pioneering work on selenium and cuprous oxide PV cells. However, the rest of the scientific world was not aware of these developments until 1954 when the use of PV effect in energy conversion processes were published in scientific literature. Within the last forty years, tremendous progress has been made in this field including improved efficiency and longer durability of solar cells.

3.2 The Generator

3.2.1 The Solar Cell

The solar cell is the basic unit of the photovoltaic generator. The solar cell is the device that transforms the sun’s rays or photons directly into electricity. There are various models of solar cells made with different technologies available in the market today. These models have varying electrical and physical characteristics depending on the manufacturer. The element most commonly used in the fabrication of solar cells is silicon. In this research, we will not elaborate on the various fabrication processes or techniques. This subject is covered in great detail in any text dealing with solid-state electronics.

3.2.2 Solar Cells Characteristics

A solar cell is simply a diode of large-area forward bias with a photovoltage. The photovoltage is created from the dissociation of electron-hole pairs created by incident photons within the built-in field of the junction or diode.
The operating current of a solar cell is given by [10];

$$I = I_{ph} - I_D \quad \text{..................} \quad 3.1$$

$$= I_{ph} - I_o \left[\exp\left(\frac{q(V + R_s I)}{AK_B T} \right) - 1 \right] - \frac{V + R_s I}{R_{sh}}$$

where I_{ph} is the photocurrent in Amperes
I_D is the diode current in Amperes
I_0 is the saturation current in Amperes
q is the electronic charge in Coulombs
K_B is the Boltzman constant in Joules per Kelvin
T is the junction temperature in Kelvin
R_s is the series resistance in ohms
R_{sh} is the shunt resistance in ohms
A is the ideality factor

Under darkness, the solar cell is not an active device. It functions primarily as a diode. Externally, the solar cell is an energy receiver that produces neither a current nor a voltage. Under this condition, if the solar cell is connected to an external supply, theory shows that the voltage and current are related by the diode equation given by [10] ;

$$I_D = I_0 \left[\exp\left(\frac{q(V + R_s I)}{AK_B T} \right) - 1 \right] \quad \text{..................} \quad 3.2$$

Since the ultimate photovoltaic generator will be composed of N cells in series and M cells in parallel, the I-V characteristics of the whole generator can be derived by scaling the I-V characteristics of one cell with a factor of N in voltage and M in current. This approach is correct only when the cells are identical.

3.2.3 Electrical Characteristics of Solar Cells

The graph of current as a function of voltage (I = f(V)) for a solar cell passes through three significant points as illustrated in figure 3.1 below.

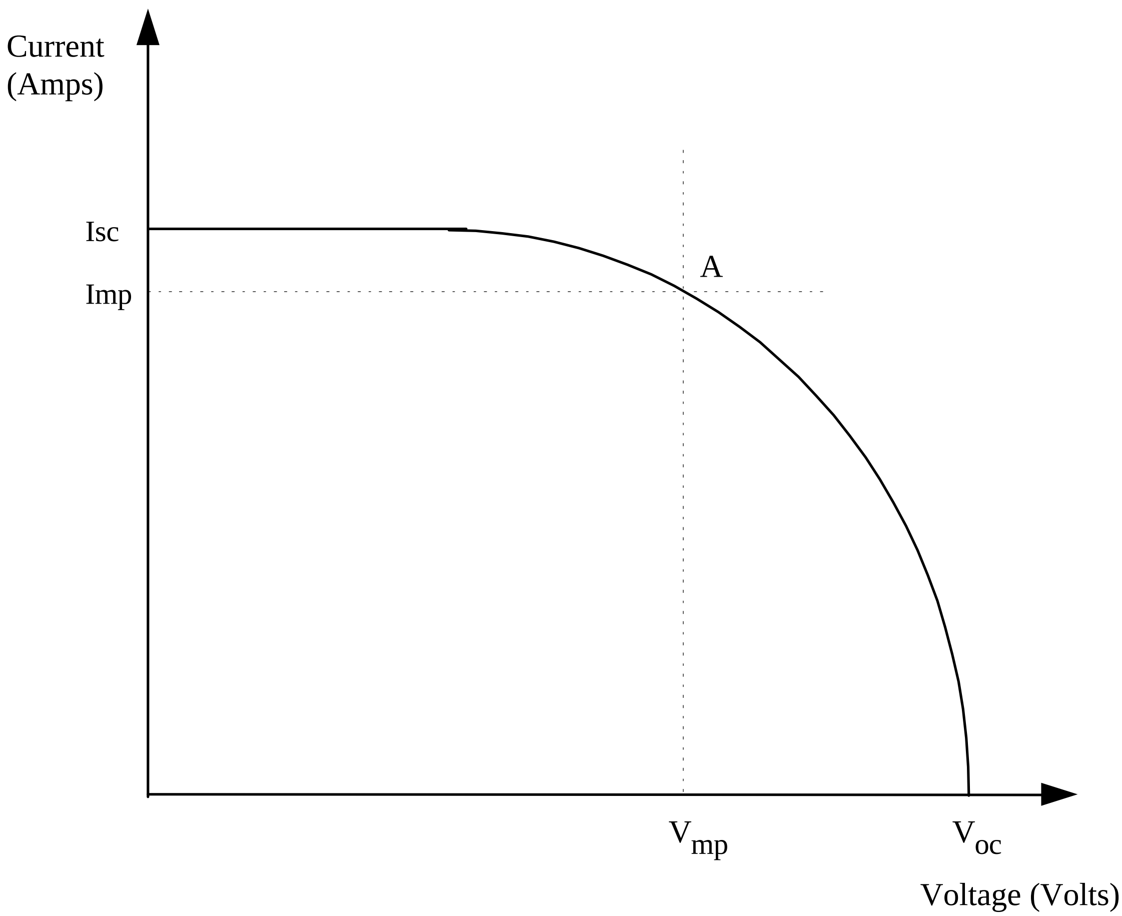

Figure 3.1: Solar cell I-V Characteristics [17].

1. Short-Circuit Current

The short circuit current, I_{sc} , occurs on a point of the curve where the voltage is zero. At this point, the power output of the solar cell is zero.

2. Open-Circuit Voltage

The open circuit voltage, V_{oc}, occurs on a point of the curve where the current is zero. At this point the power output of the solar cell is zero.

3. Operation at Maximum Power

The maximum power output occurs at point A on the curve. The point A is usually referred to as the " knee " of the I - V curve. The electrical characteristics of solar cells are based on their I - V curves. The I -V curve is based on the cell being under standard conditions of sunlight and cell temperature, and assumes there is no shading in the cell. Standard sunlight conditions on a clear day are assumed to be 1000 Watts of solar energy per square meter ($1000 Wm^{-2}$ or $1 KWm^{-2}$). This condition is sometimes called " one sun " or " peak sun." When the cell is operating in conditions less than one sun, the current output of the cell is reduced as shown in figure 3.2 below. Since pv cells are electrical semiconductors, partial shading may cause the cell to heat up. Under this condition, the cells act as an inefficient conductor rather than an electrical generator. Partial shading may ruin shaded cells and also affect the power output of the cell. Figure 3.3 below, shows the I - V characteristics of a shaded and unshaded cell.

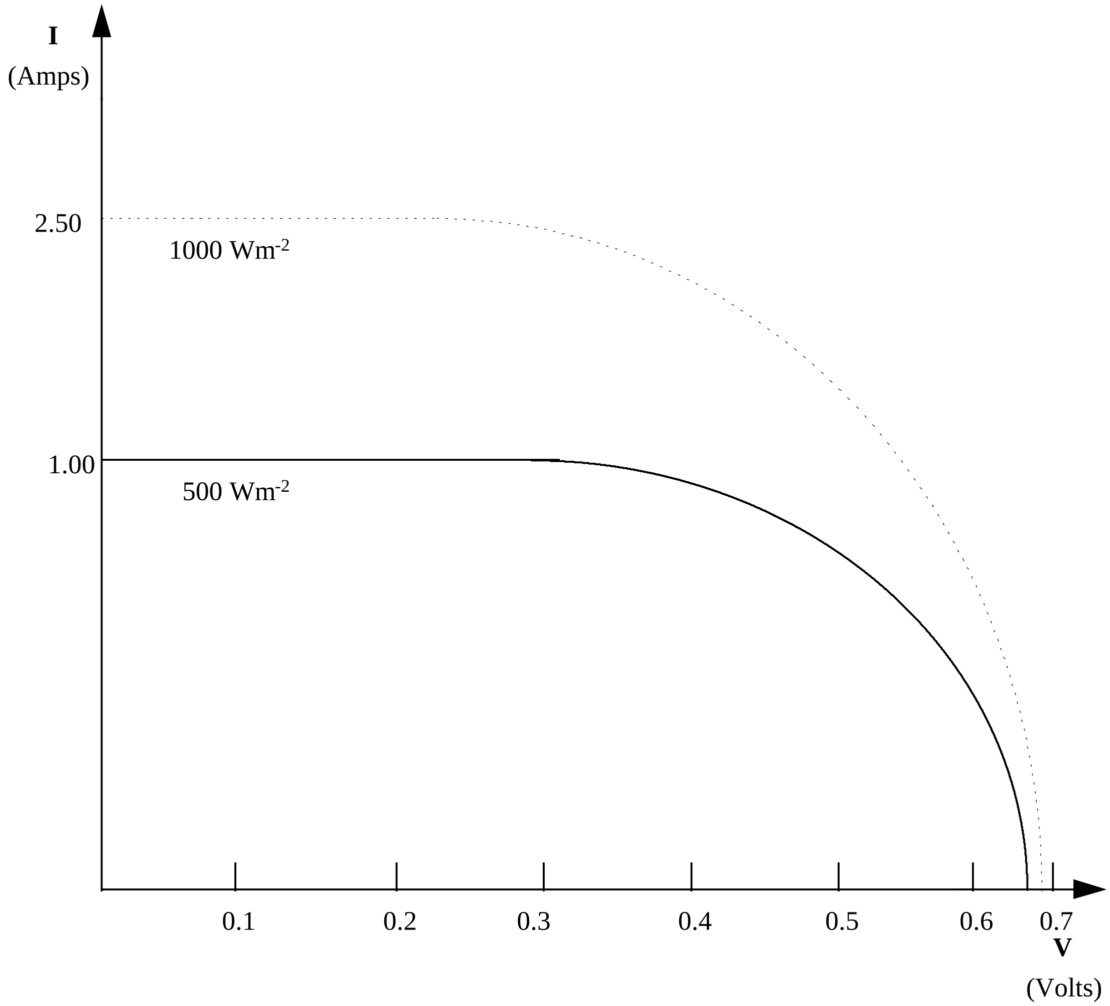

Figure 3.2: Solar Cell I - V Characteristics at One Sun and One-Half Sun [17].

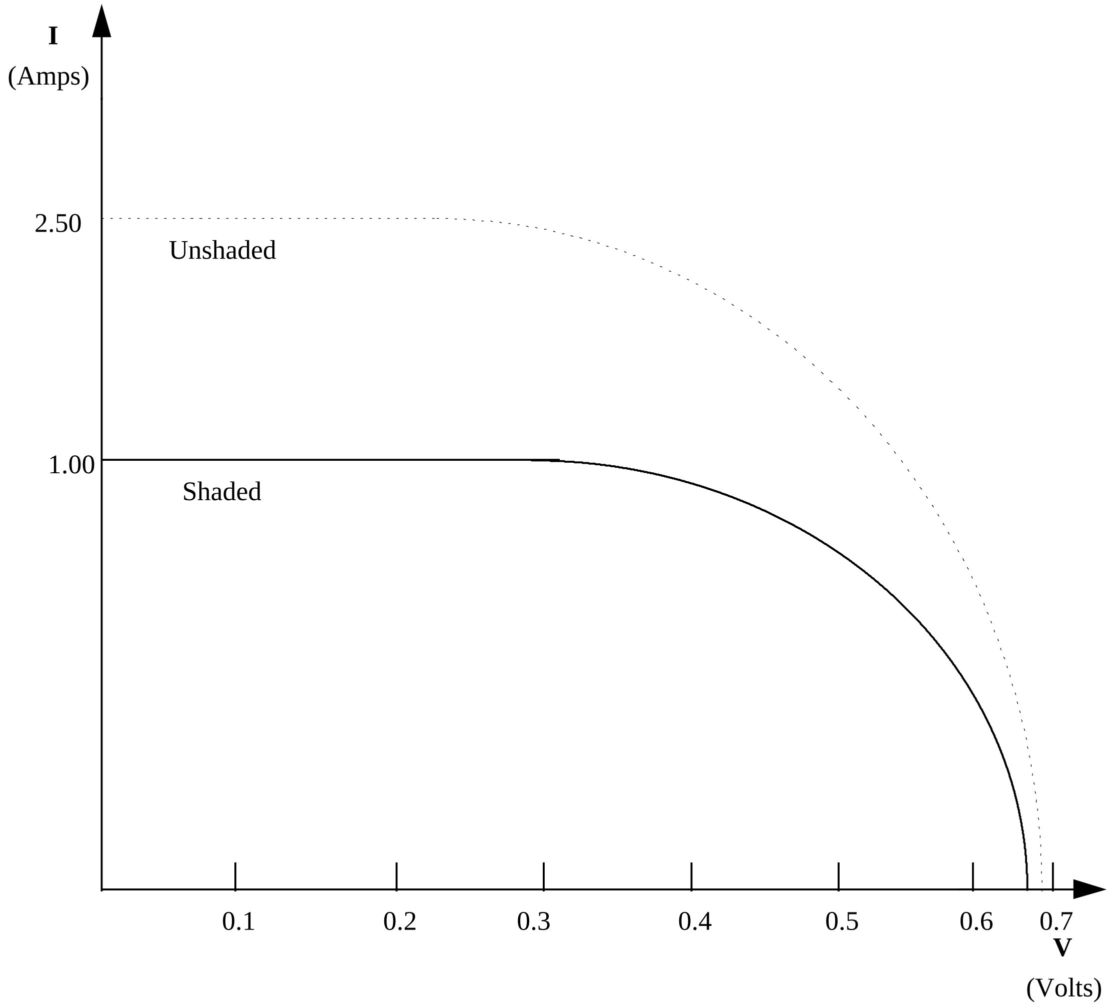

Figure 3.3 I - V Characteristics of a Shaded and Unshaded Solar Cell [17].

3.3 Solar Cell Terminology [10]

In this section, we present some definitions of certain properties of cells which are commonly used in industry and in the study of photovoltaic systems.

3.3.1 Peak Power

Peak power refers to the optimal power delivered by the cell for an insolation of $1 KWm^{-2}$ and a junction temperature of $25^{o}C$.

3.3.2 Conversion Efficiency

The conversion efficiency is the ratio of the optimal electric power, P_{opt}, delivered by the pv module to the solar insolation, E_e, received at a given cell temperature, T,

$$\eta = \frac{P_{opt}}{AE_e}$$

where the optimal power, P_{opt}, is in Watts, the insolation, E_e, is in Watts per square meter and the cell area, A, is in square meters. Typical values for η are 12 to 14 % for a single-crystal silicon cell and 9 % for a polycrystalline silicon solar cell.

3.3.3 Fill Factor (FF)

The fill factor, FF, is the ratio of the peak power to the product $I_{sc}V_{oc}$.

$$FF = \frac{I_{max}V_{max}}{I_{sc}V_{oc}}$$

The fill factor determines the shape of the solar cell I-V characteristics. Its value is higher than 0.7 for good cells. The series and shunt resistances account for a decrease in the fill factor. The fill factor is a useful parameter for quality control tests.