

Chapter 1

Introduction

1.1 Background

As we know that, the electricity plays an important role for the developments of any country, to fulfill the all the demand of electricity is very difficult task for any country due to limited resources. In 2019, the global electricity consumption grew at a much slower rate than in recent years due to a slowdown in the economic growth. The global electricity consumption are shown in Fig. 1.1. It can be observed that the electricity consumption gradually increases. The electricity consumption in India is shown in Fig. 1.2. It can be seen that the electricity consumption in India exponentially increases from year 2000 to 2019, and the total electricity consumption in India is 1230 *TWh* (Terawatt-hour). Since the large amount of electricity is generated through the conventional energy resources (coal, natural gas, petroleum) and these resources are the limited and . Hence, it is very important that we have to pay attention to other energy resources like non-conventional energy resources.

Renewable energy has become one of the important factors and hope for the world to preserve the pristine environment and the planet's resources for future generation. With the rapid development of renewable energy technologies such as hydro-power plants, wind power and photovoltaics (PVs), the combination of distributed generations (DGs) and large power grid is the development direction of the future power system. Many countries have developed corresponding policies to reduce the proportion of fossil energy. Since, the total power generation capacity of India as on 31.12.2019 is 368,788 *MW*. The total power generation of different sectors are shown in Fig. 1.3, in which the maximum

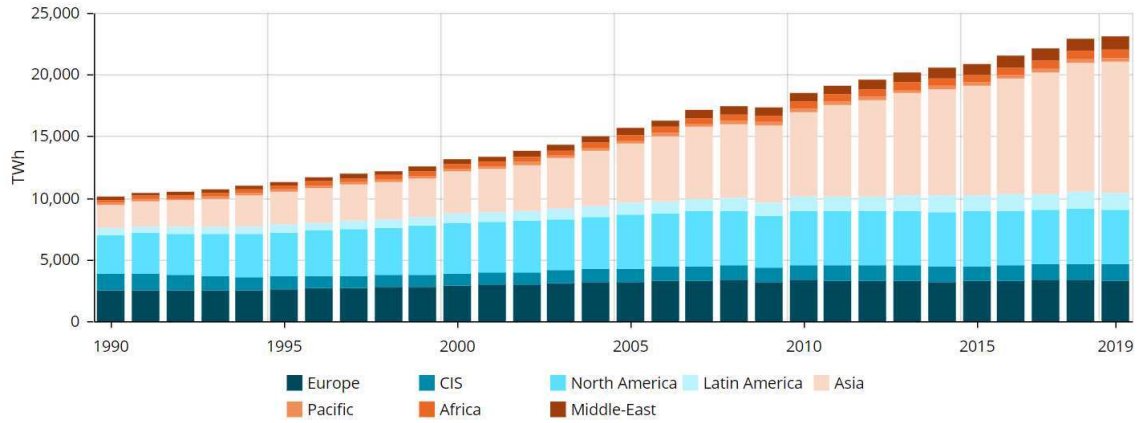


Figure 1.1: Global electricity consumption.

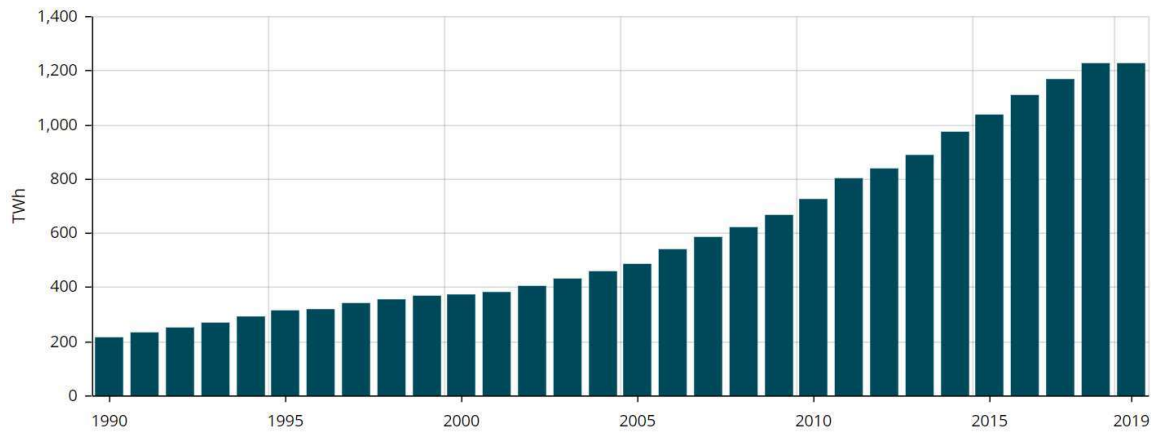


Figure 1.2: Electricity consumption in India.

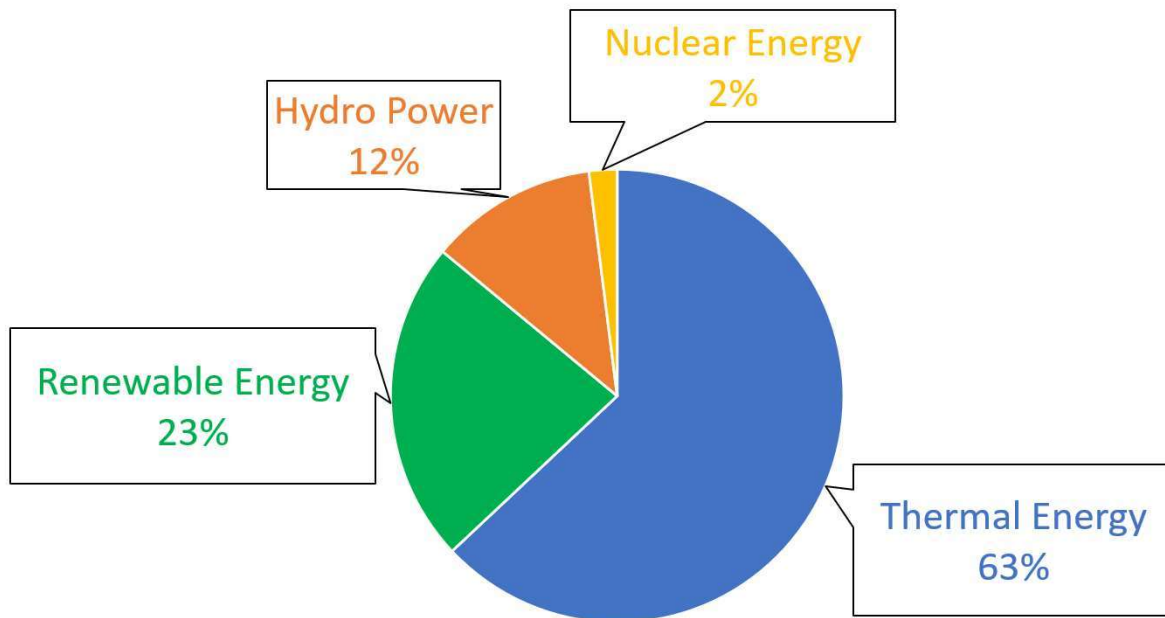


Figure 1.3: India - source wise installed power generation capacity.

power generated through the thermal power generation is around 63% of total generation and only 23% through the renewable energy resources, 12% through hydro-power and 2% through nuclear energy. Due to that, the environmental pollution increases and as a result the global warming increases in the world. In present day, nearly 72% of CO_2 emission in the world through the power generation sector [1]. Hence, it is required that to reduce the environmental pollution, the power generations are more focus on renewable energy resources. Thus, the United Nation (UN) is requesting every country in world to comply with Sustainable Development Goals (SDGs) [2]. To reduce the effect of global warming, they are proposing to adopt renewable energy resources for power generation [1].

1.2 Photovoltaic Power Generation

Due to the growing demand on electricity, the limited stock and rising prices of conventional sources (such as coal and petroleum, etc.), photovoltaic (PV) energy becomes a promising alternative as it is omnipresent, freely available, environment friendly, and has less operational and maintenance costs [3]. Therefore, the demand of PV generation systems seems to be increased for both standalone and grid-connected modes of PV systems. The word photovoltaic is a combination of the two words photo, which means light, and voltaic, which implies the production of electricity. The photovoltaic is best known as a method for generating electric power by using PV cells to convert energy from the sun light into a flow of electrons by the photovoltaic effect.

Although PV generated power benefit both the economy and the environment at a long run compared to that of conventional energy resources such as coal and oil but unfortunately, at present PV power generation is not economically beneficial [4]. Therefore, a lot research opportunities exist on PV power generation aspects. The conversion of solar insolation into electricity is based on the photovoltaic effect, which is a physical phenomenon of converting energy carried by optical electromagnetic radiation into electrical energy. A scientist E. Becquerel in 1839 was found that, some materials generate generate electric current when exposed to sun light. The first silicon solar cell was developed by the Bell laboratories in 1954 with 6% efficiency, which was further improved to 10% [5]. The PV cells are made with semiconductor materials for absorbing the large amount of solar spectrum.

1.3 Challenges in Photovoltaic (PV) System

In a PV system, the PV module converts the solar insolation into electrical energy. The P-V and I-V characteristics of the PV system shows a nonlinear behavior, hence to control the power flow a nonlinear controllers are required. To study and analyze the transient-state responses of the PV system, a precise mathematical modeling is required that includes the nonlinear aspects of the PV system. A robust mathematical models are required for the development of PV module [5].

The output characteristics of PV cell are nonlinear, hence the for the output power varies largely due to sudden change in solar insolation. Therefore, it is difficult to design a accurate controller for PV system. The main difficulty to achieve the demand is the lack of efficient and economical power converters and one more problem is variation of solar insolation and temperature with time and locality. Therefore, it requires an efficient and economical power converters. Another drawback of PV systems is that, these are not cost effective when compare to the conventional power generation techniques. The average power conversion efficiency of PV modules are very low around 10% to 20%. The efficiency of PV system can be improved by using the efficient maximum power point tracking (MPPT) techniques. The MPPT algorithms are implemented using microcontrollers and FPGAs. The availability of advanced processors in microcontrollers and FPGAs allowed faster execution of control algorithms, but also the interfacing with the sensors and signal conditioning. Microcontroller has reduced the size of the PV system, improved EMI and EMC compliance, measurement errors and cost of the system [6]. Therefore, research on digital MPPT techniques has got a great significance in improving the efficiency of the PV systems.

1.4 Photovoltaic (PV) Cell or Solar Cell

A photovoltaic cell is an electrical device that converts light directly into electricity. The PV cells are classified depending on the fabrication materials and the technology used for for fabrication. The PV cell is composed of semiconductor materials. There are several different types of semiconductor materials used in PV cells such as crystalline silicon (c-Si), amorphous silicon (a-Si), gallium arsenide (GaAs), Cadmium telluride (CdTe). When the semiconductor materials are exposed to sun light, it absorbs the energy of light and

transferred to the electrons of the material. This energy force the electrons to flow through the material as an electric current. The efficiency of a PV cell is defined as the ratio of energy output from the PV cell to input energy from the sun. The efficiency depends on the intensity of light and the temperature of solar cell.

1.5 Types of PV Cell

PV cells can be fabricated in many different ways and from a variety of different semiconductor materials and most common material is silicon. Some PV cells can be manufactured using wafer-based and thin-film technology. There are mainly three types of PV cell technologies that dominated in the world as follows:

- Monocrystalline PV cell
- Polycrystalline PV cell
- Thin-film PV cell

1.5.1 Monocrystalline PV Cell

The first PV cells available for commercial purpose were Monocrystalline silicon, which is an extremely pure form of silicon. The monocrystalline PV cells have been fabricated using thin wafers prepared by the Czochralski (CZ) crystal growth process and doped to about one part per million with boron during ingot growth [7]. To produce a PV cell, boron doped starting wafers generally have phosphorus diffused at high temperatures a fraction of a micron into the surface to form the $p - n$ junction required. Metal contacts to both the p-type and n-type side of the junction are formed by screen printing a metal paste that is then densified by firing at high temperature. The maximum voltage generated by single PV cell is around $0.5 V$ to $0.6 V$. Hence large number of series and parallel connection of PV cells are required for a large voltage output. The efficiency of this cell is in the range 12-16%. A monocrystalline PV cell is shown in Fig. 1.4.

1.5.2 Polycrystalline PV Cell

Polycrystalline PV cells are fabricated from cast square ingots. These PV cells are less expensive, but less efficient than the monocrystalline cell. Instead of a single uniform

crystal structure polycrystalline PV cells contain many small grains of crystals as shown in Fig. 1.5. Another method used for polycrystalline cell fabrication is known as edge-defined film fed growth [8]. Conversion efficiency is in the range 11-14%, efficient at good light conditions.

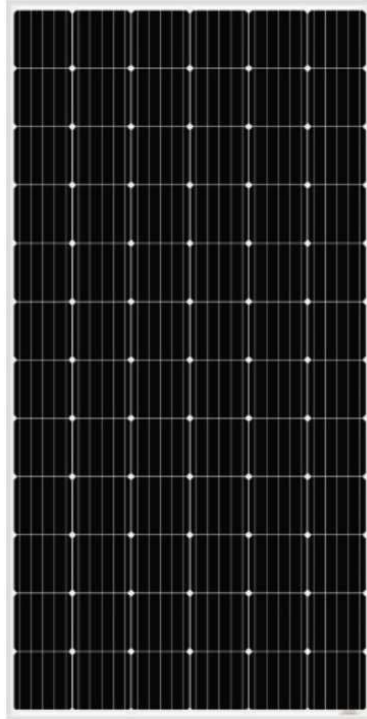


Figure 1.4: Monocrystalline PV module.

1.5.3 Thin-film PV Cell

A thin-film PV cell is fabricated by depositing one or more thin layers of PV material on a supporting material such as glass, plastic, or metal. There are two main types of thin-film PV semiconductors on the market today: cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS). Both materials can be deposited directly onto either the front or back of the module surface [9]. Energy conversion efficiency is 6-12%, efficient at poor light conditions and environment friendly.

PV cells are connected electrically in series and/or parallel circuits to generate higher voltage, current and power. The PV module consist of many PV cells in series and/or parallel connections and many PV modules are connected to form a PV array to meet the desired power demands. The formation PV array from PV cell is shown in Fig. 1.7.

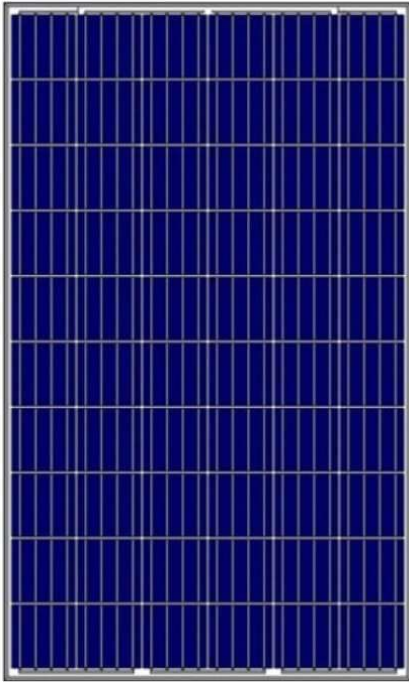


Figure 1.5: Polycrystalline PV module.

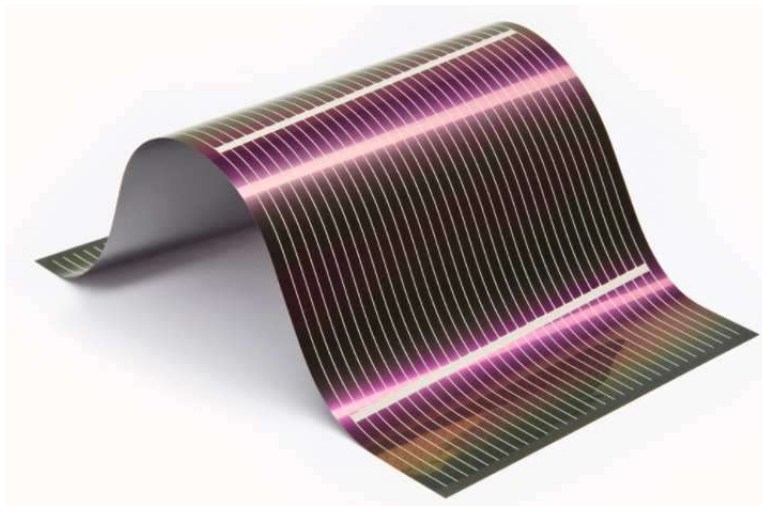


Figure 1.6: Thin-film PV module.

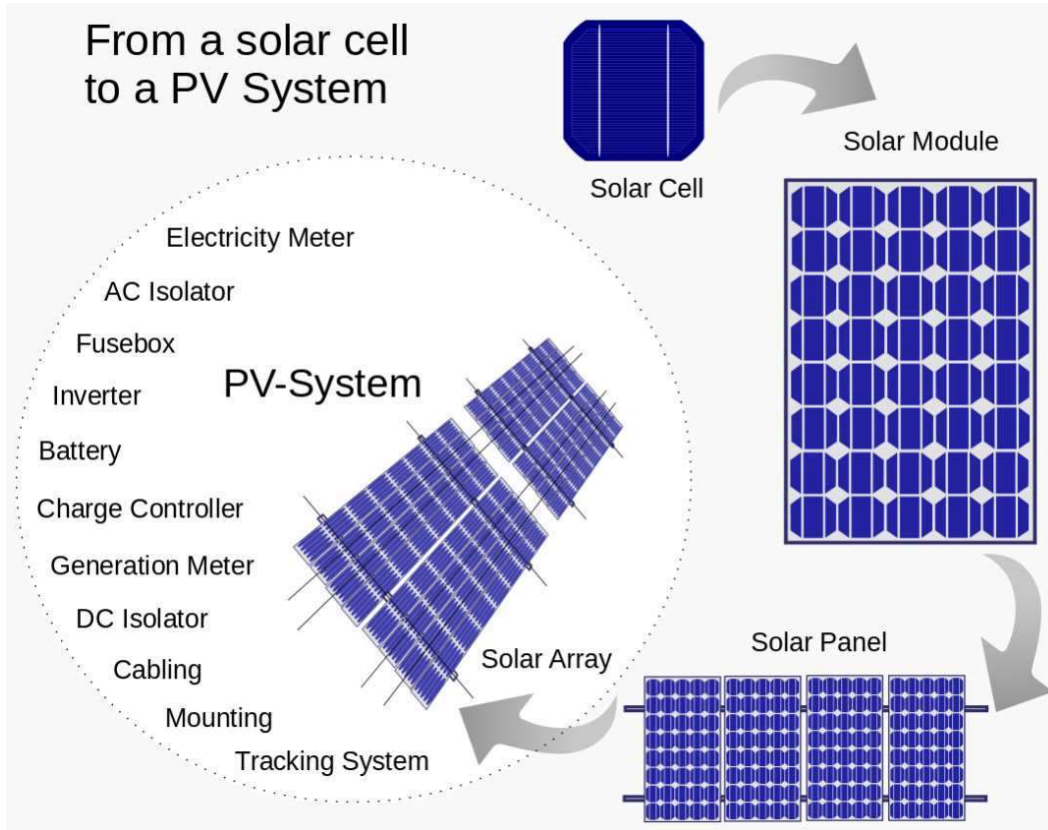


Figure 1.7: Formation of PV array from a PV cell.

1.6 Photovoltaic Energy Conversion Technology

In Fig. 1.8 the basics of photovoltaic power generation are presented. Photons include different quantity of energy corresponding to the different wavelengths of light. From the energy equation $E = h\nu$, where ν is the frequency of photon and h is the Planck's constant, it can be observed that the energy of photon decreases with increase in wavelength. When a semiconductor material are exposed to the sun light, the photons within a certain energy band can be absorbed and rest of the photons may reflected back. The energy of photon will be transferred to the electrons of semiconductor material. Different semiconductor materials have different optical absorption coefficients.

A PV cell is fabricated of thin wafer consisting of an thin layer of n-type silicon on the top of a thick layer of p-type silicon. An electrical field is created near the top of the cell at the junction of p-type and n-type silicon. When the sun light strikes the surface of a cell, this electric field provides momentum and direction to the light generated electrons, resulting in a flow of current when the PV cell is connected to an electrical load as shown in Fig. 1.8.

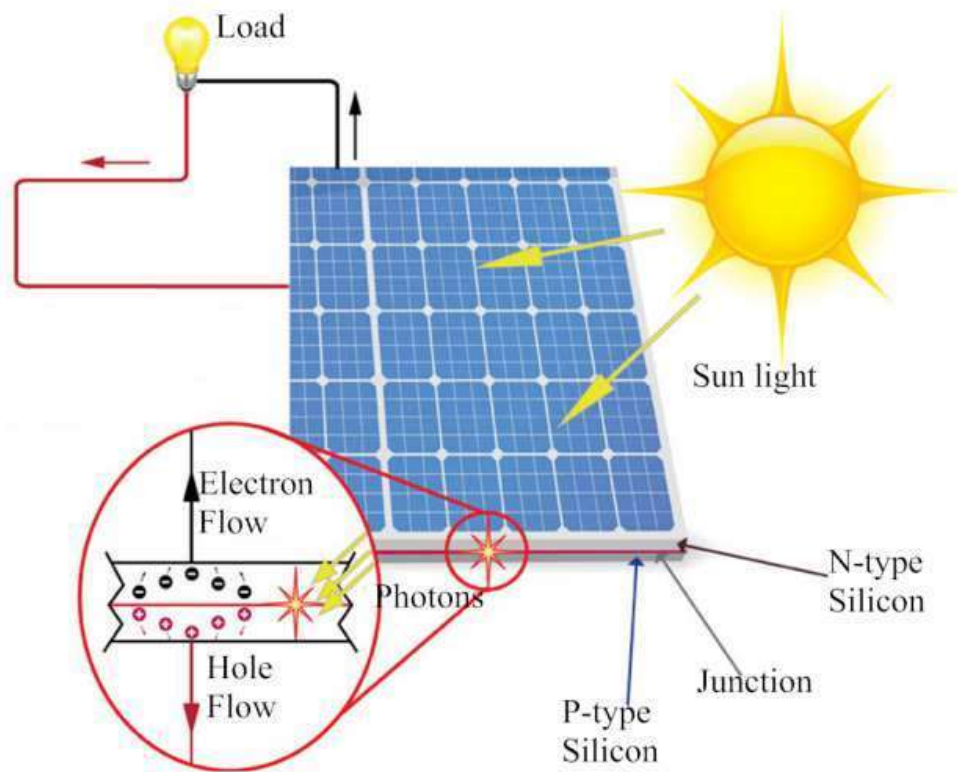


Figure 1.8: Conversion mechanism of solar insolation into electricity.

1.7 Types of PV system

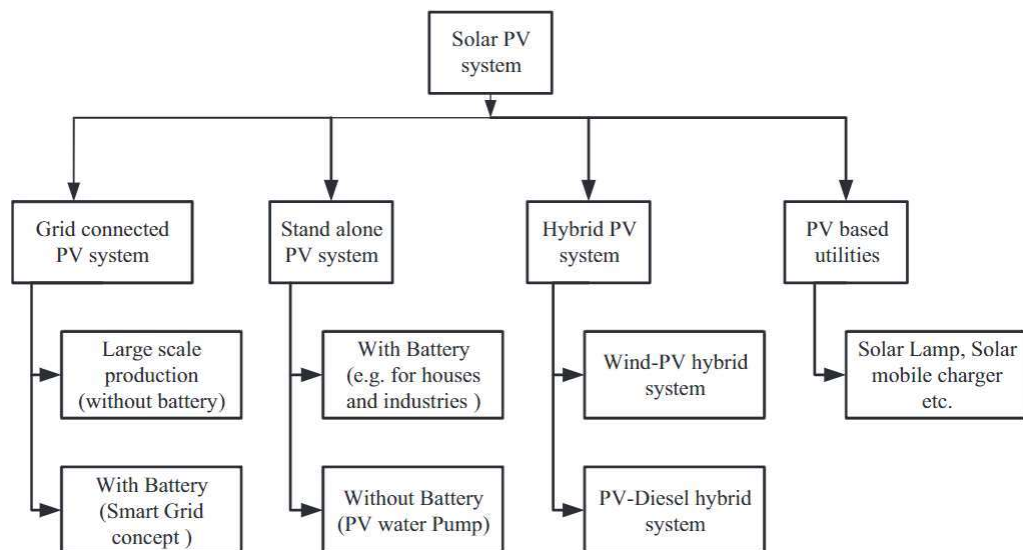


Figure 1.9: Classification of PV systems.

PV systems are mainly classified according to their configurations, connection topology and functions [10]. Two main classifications are stand-alone and grid connected PV

systems. PV systems can be designed to supply DC and AC loads and also connected with energy storage systems and other energy source The classification of PV system is shown in Fig. 1.9.

1.7.1 Grid-Connected PV System

A grid-connected PV system is shown in Fig. 1.10 [11]. The main components of this system are PV module, power conditioning unit, and an on site distributed panel. PV array generates DC power and the power conditioning unit converts the DC output power into AC power, according to voltage magnitude, frequency and power quality requirements of grid.

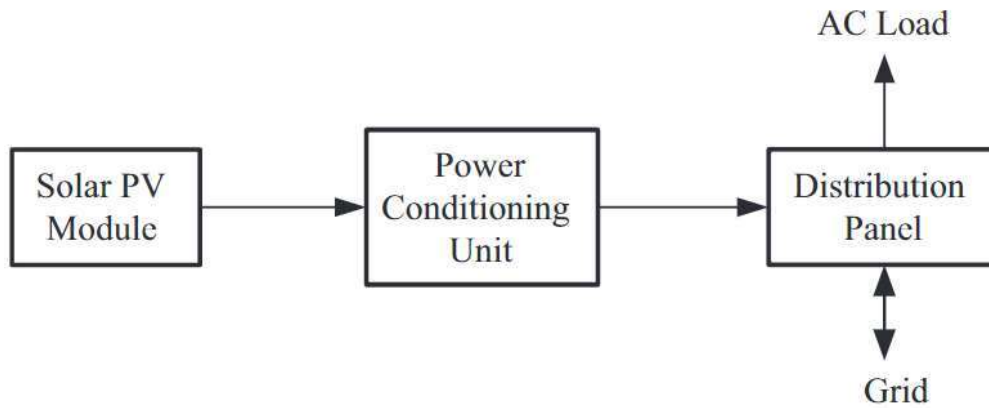


Figure 1.10: Block diagram of grid-connected PV system.

1.7.2 Stand-Alone PV System

Fig. 1.11 [12] shows the block diagram of a stand-alone PV system with provision of battery to supply AC and DC loads. The charge controller regulates the output current of PV system and controls the battery voltage from exceeding the maximum level. The output of charge controller is connected to DC load as well a battery with a dual DC cut-off switch. Which disconnects the PV array and load simultaneously during faulty conditions. The controller thus ensures that the DC output from PV array is sufficient to sustain the connected load while battery sizing.

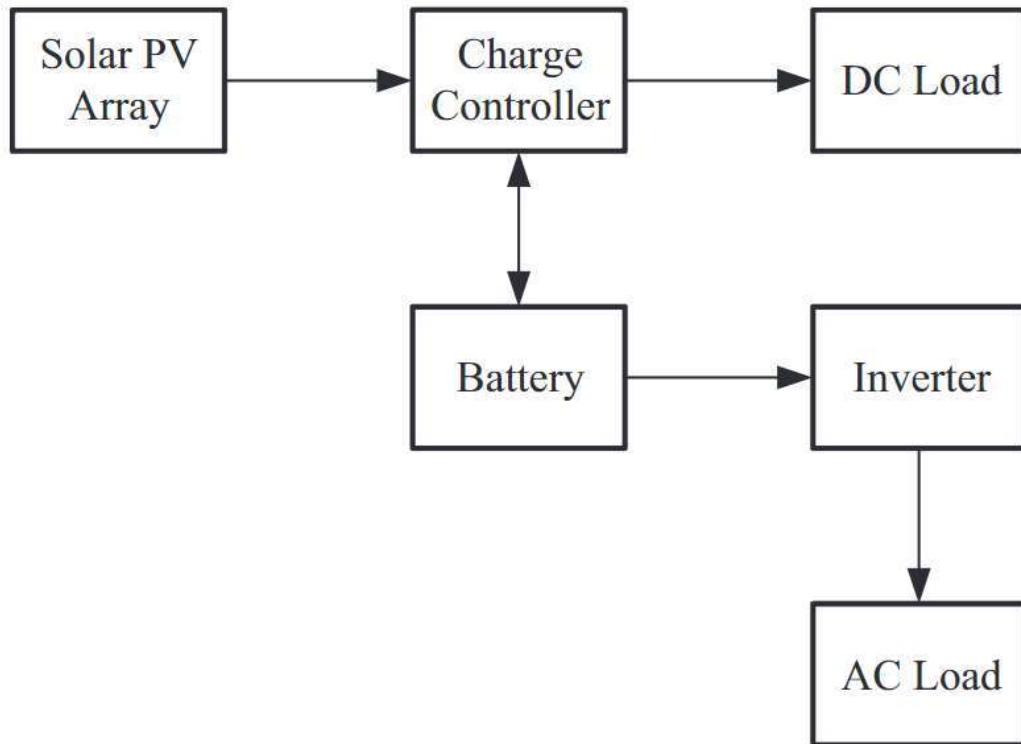


Figure 1.11: Block diagram of stand-alone PV system with battery storage.

1.7.3 Hybrid PV System

Hybrid PV system commonly refers to PV systems integrated with wind turbines, diesel generators, or any other non conventional or conventional energy sources. A block diagram of a Hybrid PV system is shown in Fig. 1.12 [13]. In this system, PV is generally sized to supply a base load demand, where as the alternative source is used for conditions when the load demand reaches its peak value. This helps in achieving low operation and maintenance costs, in addition to a reliable supply. Hybrid systems can also be useful in situations where demand peaks are significantly higher than the base load demand. It makes little sense to size a system to meet demand entirely with solar PV in a case where, say normal load is only 10% of the peak demand. By the same rule, a diesel generator-set sized to meet the peak demand would be operating at inefficient part-load for most of the time. In such a situation, a PV-diesel hybrid would be a good option.

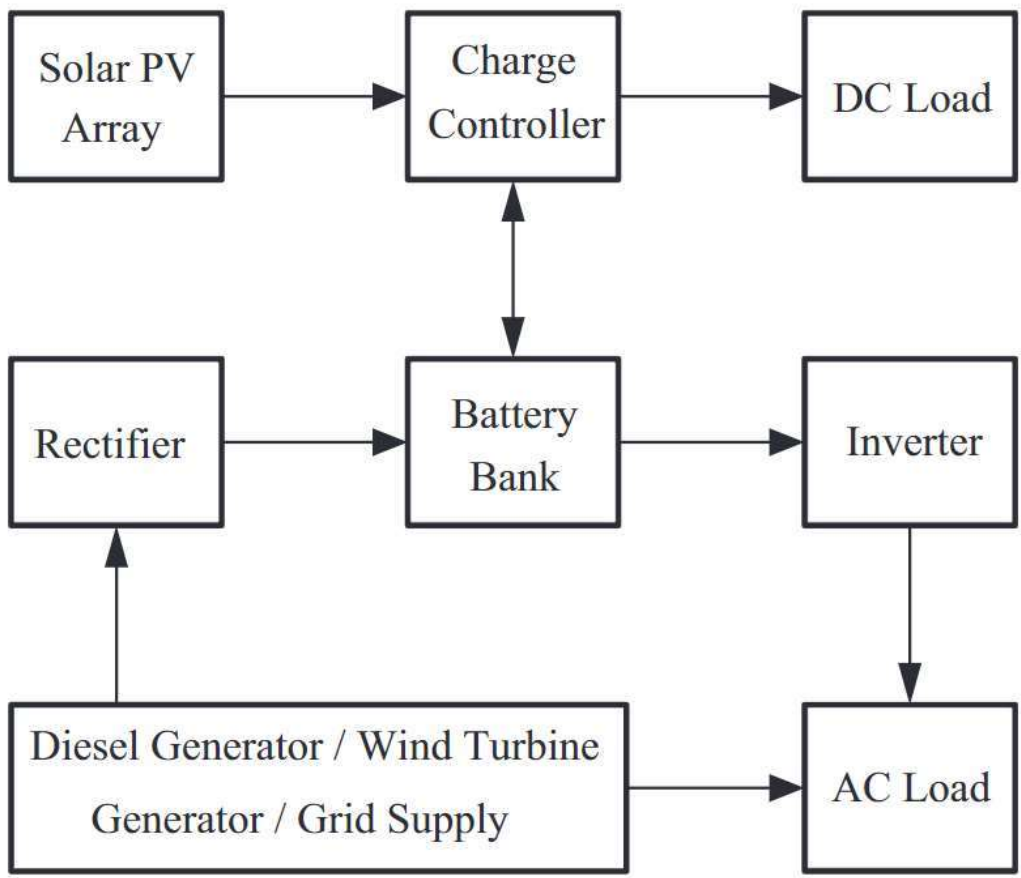


Figure 1.12: Block diagram of photovoltaic hybrid system.

1.8 DC-DC Converter

The location of operating point on the $P - V$ characteristics of PV module depends on the impedance match between PV module and the load. The direct connection between load and the PV module can not guarantee to run the system at MPP. Hence for impedance matching a DC-DC converter is used as interfacing device between the PV module and the load. The impedance matching is achieved by changing the duty-ratio (D) of the converter. Different DC-DC converter topologies, such as buck [14], boost boost [15], buck-boost buck-boost [16] and SEPIC [17–20] are generally used for stand-alone PV systems. In this thesis , SEPIC converter is used for the validation of the proposed MPPT techniques. It has many advantages over the conventional buck-boost converter like non-inverting output voltage polarity, continuous input current, works as buck-boost converter over wide range and low input current-ripple [20].

1.9 Motivation

Due to the increased energy demands PV power generation system gain so much popularity because of their merits such as pollution free, no noise, less maintenance required. This research work aims at designing more efficient and reliable MPPT techniques for stand-alone PV system. By developing an novel adaptive MPPT techniques using single voltage or current sensor, improves the convergence response of the PV system.

1.10 Aim of the Thesis

The aim of the thesis is to design and developed a current sensor based and load voltage based MPPT algorithms, developing the switching function for buck, boot, SEPIC converter, design of SEPIC converter, a load voltage based MPPT, Tracking efficiency calculations for a stand-alone PV system.

1.11 Structure of the Thesis

This thesis is arranged into five different chapters. A brief description of the chapters is as follows:

Chapter 1 introduces the need of PV systems which can be used as an alternating source of power supply. Subsequently, the chapter also reviews on different approaches to parameter extraction techniques of PV with MPPT at uniform conditions and partial shading conditions.

Chapter 2 a brief review on maximum power point tracking techniques, distributed MPPT techniques, selection criteria of important parameters for PV system and convergence responses.

Chapter 3 presented the single diode electrical equivalent model of PV cell, a current sensor based MPPT technique is described. Switching functions are derived for buck, boost and SEPIC converter, a novel adaptive MPPT technique is developed for current sensor based MPPT method, design of SEPIC converter also explained.

Chapter 4 discusses the newly proposed a load voltage based MPPT technique is developed for stand-alone PV system with fixed and adaptive step-size, transient analysis and design of SEPIC converter described.

Chapter 5 put forth the concluding remarks and suggestions for future work.