CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Today society is largely dependent on its energy supply. Electricity forms the basic source of energy. Lighting, heating, cooling, communication, transportation, manufacturing, processing industries, are all dependent on electricity. Economic development of a country is dependent on energy. Economic growth worldwide has tripled the electricity consumption in the past three decades. Future economic growth of a country depends on the availability of energy that is affordable, accessible and environmentally friendly. India’s and China’s requirement for power is on the increase due to their fast growth. The primary energy source for producing electricity are coal, natural gas, hydro and nuclear fission. Each source has limitations, the fossil fuels due to its limited supply, greenhouse gases, and are non-renewable sources, hydro power is dependent on the rainfall for power generation. New power generation technologies are developed to overcome the disadvantages of the non-renewable sources and hydro power. Renewable energy technologies such as wind power, solar power, tidal, geothermal is used for energy generation. The uses of renewable-energy sources are increasing rapidly in the recent years.

1.2 INDIAN ENERGY SCENARIO

India ranks fifth in the world in total energy consumption. The energy sector growth is crucial, for the development of economic growth. Due to rapid growth on India’s economy, energy demand grows at an average of 3.6% per annum. Though the country has rich deposits of coal, it has very small crude oil and natural-gas reserves.
Thermal power plants are the major contributors of electricity. Figure 1.1 shows the Indian power generation installed capacity in MW, and Table 1.1 gives the power generated by various sources in percentage (http://www.cea.nic.in).

![Figure 1.1 All India Power Generation Installed Capacity in MW](image)

**Table 1.1 Power Generations through Different Sources**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>65.16</td>
</tr>
<tr>
<td>Coal</td>
<td>54.79</td>
</tr>
<tr>
<td>Gas</td>
<td>9.71</td>
</tr>
<tr>
<td>Oil</td>
<td>0.65</td>
</tr>
<tr>
<td>Hydro</td>
<td>21.18</td>
</tr>
<tr>
<td>Nuclear</td>
<td>2.61</td>
</tr>
<tr>
<td>Renewable Energy Sources</td>
<td>11.03</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

Coal is the dominant source for power production in India, generating more than 50% of the total electricity. India has huge coal reserves, and is the fourth largest producer of coal and lignite in the world. Oil and natural gases account for 10% of electricity production, with hydro power contributing 21% and nuclear
power about 2.6%. India has 10 nuclear reactors for electricity generation and more nuclear reactors have been approved for construction. The break up of the electricity consumption is as shown in Figure 1.2.

![Image of electricity consumption](image)

**Figure 1.2 Break Up of Electricity Consumption**

The growth of economy has increased the demand for electricity. Power demands have forced the governments to increase load shedding. Plans to increase the capacity and power management are being explored. Drastic measures are required to increase the power-generation capacity to reduce the imbalance between the power demand and supply. Figure 1.3 shows the demand supply forecasts (India Energy Handbook, 2011).
1.3 RENEWABLE ENERGY SCENARIO IN INDIA

India has an enormous supply of renewable-energy resources. Ministry of New and Renewable Energy (MNRE) has launched many ambitious plans for renewable energy. Renewable energy law which reinforces the National Action Plan on Climate Change targets 15% renewable energy for India by 2020.

The key factors due to which renewable energy is focused on are as follows:

- The demand-supply gap which increases proportionally as population increases
- A large unexploited potential
- Concern for the environment
- The need to strengthen India’s energy security
- Pressure on high-emission industry sectors from shareholders
- A feasible solution for rural electrification
According to the MNRE, the share of renewable based capacity is approximately around 11% (excluding large hydro) of the total installed capacity of 170 GW in the country. This includes 13,065.78 MW of wind, 2,939 MW of small hydro power, 1,562 MW of (bagasse based) cogeneration, 997 MW of biomass, 73.46 MW of ‘waste to power’ and 17.80 MW of solar PV for grid connected renewables at the end of 2010 (http://www.mnre.gov.in). The various renewable sources are discussed in this section.

1.3.1 Solar Power

India is rich in solar energy resource and amounts to an average of 200 MW/km square or six KWH/sq.mt/day, thus an 60 km X 60 km area can produce 1,00,000 MW of power. The first Indian solar thermal power project is in Phalodi (Rajasthan), and the largest solar photovoltaic power plant is situated at Yalesandra village in Karnataka. Large projects are proposed in the solar-energy sector. A $19 billion plan was started during 2009 with the aim to produce 20 GW of solar power by 2020. An ambitious project of using 35,000 km2 area of Thar Desert for solar power projects which can generate 700 to 2,100 GW is in the pipeline. Cost-effective photovoltaic technologies will lead to an increased activity in the solar power sector as a solar thermal power plant cost 4 times as much as the coal-based steam thermal power plant.

In the bid for complete electrification of rural area, where lying of conventional electricity lines is not feasible, solar photovoltaic based systems are being installed. The solar photovoltaic generates power for running irrigation pumps, home and street lighting. The MNES promotes the use of photovoltaic technology to provide lighting in villages as shown in Table 1.2.
### Table 1.2 Photovoltaic Power Distribution for Various Systems

<table>
<thead>
<tr>
<th>Type of System</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community lighting systems</td>
<td>Capacity usually 1kW to 2.5 kW</td>
</tr>
<tr>
<td>Portable solar lanterns</td>
<td>Small 10Wp SPV module connected to a 12V7AH battery lighting 7 W CFL lamp for 3 hours a day</td>
</tr>
<tr>
<td>Street lights</td>
<td>Built around a 75Wp SPV module charging a 100-130AH battery to run a 11W CFL lamp for dusk to dawn operation.</td>
</tr>
<tr>
<td>Fixed home lighting systems</td>
<td>Based on 35-50Wp SPV module, powering two CFLs each of 9 or 11W to work 4-5 hours per day. Some systems also incorporate facility to run a small TV set or a fan from the power supply.</td>
</tr>
<tr>
<td>Water Pumping</td>
<td>Typically 1KW DC motor based pumping for shallow pumping.</td>
</tr>
</tbody>
</table>

#### 1.3.2 Wind Power

Wind energy is the fastest growing renewable energy sector in the country and is in the fifth position globally in wind power generation. The time required to set up an operational wind turbine is less when compared to thermal or hydro power project. The increased reliability and performance of windmills is another important reason for the growth of wind power generation in India. At present, wind energy accounts for almost 70% of the installed capacity in the renewable energy sector (Indian Wind Energy Outlook 2011) with a cumulative deployment of over 13,000 MW capacities. Wind power generation is mainly in Tamil Nadu, Maharashtra, Goa, Karnataka, Rajasthan, Gujarat, Madhya Pradesh and Andhra Pradesh. Samana wind farm in Gujarat is the largest wind project in India. An additional capacity of 2000 MW is expected to be installed in the current year. Wind power accounts for 6% of India's total installed power capacity, and it generates 1.6% of the country's power. MNRE’s support has helped in accelerated development of wind energy through policy and regulatory interventions.
Indian Wind Energy Association has estimated that the potential for utilization of wind energy for electricity generation is of the order of 65,000 MW. The Indian Wind Atlas 2010 published by the Centre for Wind Energy Technology shows potential sites with annual average wind power ranging from 200 W/m² to 500 W/m² at 50 Meters Above Ground Level (MAGL). The unexploited resource availability has the potential of supporting the growth of the wind energy sector in India in the years to come. With the improvement in technology and increase in the hub height of the wind turbine, it has become possible to generate more electricity than estimated.

### 1.3.3 Biomass Power

Biomass has been a key player in energy generation even before the industrial revolution. Biomass power generation has gained momentum because of environmental concern due to Green House Gas emissions and also due to the technological developments relating to the conversion. The latest technologies enable production of energy through biomass at lower cost and with higher conversion efficiency.

India is very rich in biomass with power generation potential as follows:

- 16,881MW from agro-residues and plantations
- 5000MW from bagasse cogeneration
- 2700MW of energy recovery from waste

Biomass power generation generates more than 5000 million units of electricity (Singh J, 2010).

### 1.3.4 Geothermal Energy

Geothermal energy is enormous, underused power resource in India. Though the geothermal is reliable system of power generation with miniscule emission of
GHG, it is underutilized mainly due to the availability of coal at cheaper costs. The potential geothermal for production of 10,600 MW is available.

**1.3.5 Tidal Wave Energy**

Electricity is produced by rotating turbines using the high energy of sea tides. The identified potential sites for tidal power in India are Gulf of Cambay and Gulf of Kutch with capacity of about 8000-9000 MW.

**1.4. WIND ENERGY CONVERSION SYSTEM**

The kinetic energy of the wind is captured and converted to electrical energy by Wind Energy Conversion System (WECS). The major components of a typical WECS consist of a wind turbine, generator, interconnection apparatus and control systems, as shown in Figure 1.4 (Chandra Has et al., 2011). Wind turbines can either be of vertical axis type or the horizontal axis type. Most commercial wind turbines use a horizontal axis configuration with three blades, operating either down-wind or up-wind.

![Figure 1.4 Structure of a Typical Wind Energy Conversion System](www.ee.iitb.ac.in)

The most commonly available commercial WECS are designed for 225 kW, 450 kW, 650 kW or 1 MW. The parameters of a 1 MW unit are given in Table 1.3. (www.ee.iitb.ac.in).
### Table 1.3 Parameters of Typical 1 MW WECS

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor diameter</td>
<td>61 m</td>
</tr>
<tr>
<td>Blade length</td>
<td>30 m</td>
</tr>
<tr>
<td>Rotor speeds</td>
<td>13 RPM / 22 RPM</td>
</tr>
<tr>
<td>Tower height</td>
<td>60 m</td>
</tr>
<tr>
<td>Wind speed range</td>
<td>3 m/s to 25 m/s</td>
</tr>
<tr>
<td>Power control</td>
<td>Active blade pitching</td>
</tr>
<tr>
<td>Type of generator</td>
<td>Induction generator</td>
</tr>
<tr>
<td>Generator speed</td>
<td>1000 rpm / 1500 rpm</td>
</tr>
<tr>
<td>Generator rating</td>
<td>1 MW</td>
</tr>
<tr>
<td>Annual Energy Output</td>
<td>1.8 to 2 GWh</td>
</tr>
</tbody>
</table>

A wind turbine is designed for a constant speed or variable speed operation. Variable speed wind turbines run at different speed at different wind speed whereas constant speed wind turbines runs at constant RPM irrespective of wind speed. Two speed wind turbines run at two different constant RPMs, a lower RPM for low wind speed and a higher RPM for high wind speed. Energy output is higher in variable speed wind turbines but requires power electronic converters to provide a fixed frequency and voltage to their loads. Direct drive configuration, where a generator is coupled to the rotor of a wind turbine directly, offers high reliability, low maintenance, and possibly low cost for certain turbines.

#### 1.4.1 Induction Generators used in Wind Energy Conversion Systems

The major component of the WECS is the generator. The generators can be induction generators, including the squirrel cage type and wound rotor type, synchronous generators and permanent magnet generators. Squirrel cage induction generator and permanent magnet generators are often used for small to medium power wind turbines due to reliability and cost advantage factors. Induction generators,
permanent magnet synchronous generators and wound field synchronous generators are used in high-power wind turbines.

1.4.1.1 Squirrel Cage Induction Generators

The squirrel cage induction generator is the most widely used generator due to the simplicity of design, high reliability with low-cost and maintenance (Singh, S.P.et al, 1993). The major advantages of these induction generators are that an excitation system or slip rings are not required, and the disadvantage is that a reactive power source is required to establish the rotor magnetic field. The above mentioned disadvantage is overcome with the use of power electronics with a single capacitor to provide the reactive power (Seyoum, D. et al., 2003). Power is generated only when the generator is rotated above the synchronous speed. But with the use of a drive, the generator can produce power at sub-synchronous speeds. Figure 1.5 shows a squirrel cage induction generator coupled with a drive. The variable-speed wind power generation depends on the drive of the generator, else squirrel cage induction generator produce power only when the rotor is rotated above the synchronous speed.

![Figure 1.5 Squirrel Cage Induction Generator Coupled with a Drive](image)

1.4.1.2 Wound Rotor Induction Generators (Doubly Fed Induction Generator)

In a wound rotor induction generator, both the stator and the rotor can give power simultaneously at certain speeds (Fernández1, L.M.et al, 2005). The stator is connected to the power grid, and the rotor is connected to the drive as shown in Figure 1.6.
Figure 1.6 Wound Rotor or Doubly Fed Induction Generator

The magnetic-field rotation speed is fixed in the stator windings and rotor side drive function help to synchronise the rotation to the stator. The working is similar to the synchronous generators without the slip between stator and rotor. At low wind, the rotor runs at the sub-synchronous speed, the drive will adjust the frequency to produce the effect of running at the synchronous speed. The drive borrows power from the grid, and the stator will add that power to the power from the turbine, thus the wind system will be supplying power to the grid. The reverse action takes place during high wind, thus both rotor and stator produce real power.

The advantages of doubly fed induction generators (DFIG) are its ability to output more than its rated power without becoming overheated and to transfer maximum power both in sub- and super-synchronous modes. In WECS, with the rotor connected to the grid through an AC-AC converter, the DFIG has the following advantages:

- Only the electric power injected by the rotor needs to be handled by the converter (Peterson Andreas, et al, 2005), implying a less cost AC-AC converter
• Improved system efficiency and power factor control can be implemented at lower cost; the converter has to provide only excitation energy (Muller, S. et al., 2003)

Thus, WECS equipped with DFIG systems for variable speed wind turbine are one of the most efficient configurations for wind energy conversion.

1.4.1.3 Permanent Magnet Generator (PMG)

The permanent magnet generators doesn’t require any external source to establish rotor magnetic field. The permanent magnets present in the generator provide the required magnetic-field (Polinder, H. et al, 2005). The permanent magnet generators may be coupled with drive to produce power at a wider range of wind speed. The generator produces power only when the wind speed is high without drive. When wind speed is too low, the PMG will act as a motor consuming power from the network. PMG is mainly used in new small-scale turbine designs as it allows for smaller blade diameter and higher efficiency.

1.4.1.4 Synchronous Generator (SG)

The synchronous generator (SG) employs Direct Current windings to provide the rotor magnetic field. The operation of this type of generator is very similar to the permanent magnet generators with the difference that the rotor DC field is controllable in the SG while it is not in the permanent magnet generators. The output voltage of the SG is controlled by the controllable DC field in the rotor while a drive or inverter is used in other generators for the same. It is preferred for fossil fuel or nuclear-based generation.

1.5 PHOTOVOLTAIC SYSTEM

Photovoltaic (PV) is the direct conversion of light into electricity at the atomic level using semiconductors. Certain semiconductors absorb photons and release electrons, which are captured and electric current is produced. This property of
absorbing photons of light and releasing electrons is known as the photoelectric effect. Figure 1.7 illustrates the operation of a basic photovoltaic cell, also called a solar cell. Semiconductor materials like monocrystalline silicon, polycrystalline silicon, copper indium gallium selenide exhibit photoelectric property are used in solar cells (Antonio Luque, et al., Handbook of Photovoltaic Science and Engineering, 2003). A thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other, when light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current. This electricity can then be used to power an electric load.

Figure 1.7 Basic Photovoltaic Cell

A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as 12 volts. A typical photovoltaic array is shown in Figure 1.8. The current produced is directly dependent on how much light strikes the module. Multiple modules are wired together to form an array. In general, the larger the area of a module or array, the more electricity will be produced. Photovoltaic modules and arrays produce Direct-Current (DC) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.
Simple PV applications in society today include calculators and wristwatches. Other complicated systems provide power for communications, satellites, water pumps, lights, appliances and machines in homes and workplaces. Many road and traffic signs along highways are now powered by PV.

PV systems produce electric current when the sun shines, but more power is produced when there is intense sunlight which strikes the PV modules directly (when rays of sunlight are perpendicular to the PV modules). PV does not use the sun's heat to produce electricity. Here electrons from the interaction between sunlight and PV semiconductor materials produce an electric current. PV modules are less tolerant of shading. When setting a PV system, it is necessary to minimize PV modules being in any shade. PV produces electricity from a clean and renewable source, without noise or air pollution.

The block diagram of a PV system is shown in Figure 1.9. Specific PV system components could include a DC-AC power inverter, battery bank, system and battery controller, auxiliary energy sources, and occasionally specified electrical load (appliances). In addition, an assortment of balance-of-system hardware, including wiring, over-current, surge protection and disconnect devices, and other power processing equipment might also be included. The following block diagram illustrates the relationship between individual components.
1.5.1 Types of PV Systems

Photovoltaic power systems are usually classified according to functional and operational requirements, component configurations, and how equipment is connected to other power sources and electrical loads. The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems. Photovoltaic systems can be utilized to provide either DC and/or AC power, operate interconnectedly or independently of the utility grid. They can also be connected to other energy sources and energy storage systems.

1.5.2 Grid Connected Systems

The block diagram of a Grid connected PV system is shown in Figure 1.10. Grid-connected or utility-interactive PV systems operate in parallel and are connected to the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts PV array produced DC power to AC power in keeping with the voltage and power quality requirements of the utility grid, and automatically stops power supply to the grid when the utility grid is not energized. A bi-directional interface exists between the PV system AC output circuits and the electric utility network, commonly at an on-site distribution panel or service entrance, which allows PV system produced AC power to either supply on-site electrical loads, or to back-feed the grid when the PV system output is
more than on-site load demand. At night and during periods when electrical loads are higher than the PV system’s output, the balance of power required by the load is received from the electric utility. This safety feature is a must in all grid-connected PV systems, and ensures that it will not continue to operate and feed back into the utility grid when the grid is down for either service or repair.

Figure 1.10 Block Diagram of Grid-Connected Photovoltaic System

1.5.3 Stand-Alone Photovoltaic Systems

Stand-alone PV systems are designed to operate independent of the electric utility grid and are usually designed and sized to supply certain DC and/or AC electrical loads. Such systems could be powered by a PV array alone or they could use wind, an engine-generator or utility power as an auxiliary power source which is now referred to as a PV-hybrid system. The simplest stand-alone PV system is a direct-coupled system, shown in Figure 1.11 where the DC output from a PV module or array is directly connected to a DC load. As there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates when sunlight is available, making these designs suitable for certain applications like ventilation fans, water pumps and small circulation pumps for solar thermal water heating systems. Matching the electrical load impedance to the maximum power output of the PV array is a critical part of designing a good direct-coupled system. For certain loads like positive-displacement water pumps, an electronic DC-DC converter
called a maximum power point tracker (MPPT), is used between load and PV array to utilize the maximum power output of PV array.

![Figure 1.11 Block Diagram of Direct-coupled PV System](image1)

In many stand-alone PV systems, batteries store energy. Figure 1.12 shows the diagram of a typical stand-alone PV system powering DC and AC loads.

![Figure 1.12 Block Diagram of Stand-Alone PV System](image2)

### 1.6 WIND-PV HYBRID SYSTEM

The term hybrid power system is used to describe any power system that combine two or more energy conversion devices or two or more fuels for the same device, that when integrated, overcome limitations inherent in either.

At present, stand-alone solar photovoltaic and wind systems have been promoted around the globe on a comparatively larger scale. These independent systems cannot provide continuous source of energy, as they are seasonal. For example, stand-alone solar photovoltaic energy system cannot provide reliable power during non-sunny days. The stand-alone wind system cannot satisfy constant
load demands due to significant fluctuations in the magnitude of wind speeds from hour to hour throughout the year. Therefore, energy storage systems will be required for each of these systems in order to satisfy the power demands. Usually storage system is expensive and the size has to be reduced to a minimum possible for the renewable energy system to be cost effective. Hence Hybrid power systems can be used to reduce energy storage requirements. Figure 1.13 shows how a typical PV hybrid system could be configured.

![Block Diagram of Photovoltaic Hybrid System](image)

**Figure 1.13 Block Diagram of Photovoltaic Hybrid System**

### 1.7 MOTIVATION

The literature survey shows that research has been carried out in the area of terminal voltage stabilization of Self Excited Induction Generator, different excitation schemes, steady state and dynamic performance analysis of Self Excited Induction generators and STATCOM based voltage compensation. The research work on the comparison of performance of WECS with Squirrel cage induction generators and wound rotor induction generators shows that the WECS using Squirrel cage induction generators have the advantages of simplicity of design, high reliability, low cost and maintenance.

Much work has not been carried out on the analysis of WECS with Squirrel cage induction generator during fault conditions. Hence, in this research an attempt
is made to analyse the dynamic behavior of a WECS with Squirrel cage induction generators during different fault conditions. The dynamic performance of the same system with STATCOM is simulated and analysed. In this research, a hybrid Wind – PV system is modelled and simulated. The performance of the hybrid system is compared with that of WECS with and without STATCOM.

1.8 OBJECTIVES OF THE THESIS

This research focuses in the following areas

- Model and Analyse the performance of a 6 MW wind farm using MATLAB/Simulink under different fault conditions
- Analyse the performance of a 6 MW wind farm with STATCOM during fault conditions
- Develop a model of a Hybrid Renewable Energy System comprising of a PV system and wind energy conversion system using MATLAB
- Develop a VLSI based Fuzzy Logic Controller for the Hybrid Renewable Energy System that efficiently manages the power flow to the load from the two sources
- Analyse the harmonic contents of the output of a distributed PV system

1.10 SCOPE OF THE STUDY

As the conventional energy sources are depleting at a faster rate, the renewable energy sources has achieved global significance. Harnessing wind power is now gaining popularity but the problem of maintaining a stable electric power system is to be addressed. And also issues of incorporating different sources of energy such as hydro, thermal, nuclear and solar in the power system are to be addressed. For uninterrupted power supply, the grid connecting to the wind farms play a critical role. Hence it has become necessary to address the merits and demerits associated with the integration of different renewable energy sources. The investigations carried out on the performance of Hybrid Renewable Energy Systems in this research have got wide
scope as the future generation systems will be an integration of conventional and non-conventional energy.

**1.11 ORGANISATION OF THE THESIS**

The thesis is organized into seven chapters.

Chapter 1 presents an introduction to the different Renewable Energy Schemes and particularly about the Wind Energy Conversion Systems and Hybrid Wind – PV System.


Chapter 3 deals with the modelling and analysis of the performance of a 6 MW wind farm using MATLAB/Simulink under different fault conditions.

Chapter 4 deals with the analysis of the performance of a 6 MW wind farm with STATCOM during fault conditions.

Chapter 5 deals with the modelling and analysis of a Hybrid Renewable Energy System comprising of a PV system and Wind Energy Conversion System using MATLAB and development of a VLSI based Fuzzy Logic Controller for the Hybrid Renewable Energy system that efficiently manages the power flow to the load from the two sources.
Chapter 6 deals with the Harmonic Analysis of output from a Distributed PV System.

Chapter 7 concludes the research work with the scope for future work.