CHAPTER 1

INTRODUCTION

1.1 ENERGY AND ITS IMPORTANCE

Energy is the ability to do work. Energy sources are divided into two groups namely renewable and nonrenewable energy sources. Renewable and nonrenewable energy sources are used to produce secondary energy sources including electricity and hydrogen.

Nonrenewable energy sources are derived from ground in the form of liquids, gases and solids. Crude oil is the only natural liquid commercial fossil fuel. Natural gas and propane are normally gases, and coal is a solid. Coal, petroleum, natural gas, and propane are all considered as fossil fuels because they are formed from the buried remains of plants and animals that lived millions of years ago. Uranium ore, a solid, is mined and converted to a fuel. These energy sources are considered as nonrenewable because they cannot be replenished in a short period of time.

As a result of human activities, greenhouse gases are increasing in the earth’s atmosphere. Many in the scientific community now believe that this increase in carbon dioxide (CO$_2$), methane (CH$_4$) and other greenhouse gases is causing the earth’s temperature to rise, and that this increase in greenhouse gases will lead to even greater global warming during this century.
1.2 MOTIVATION AND GOAL

Renewable energy resources are clean and environmental friendly. They provide many immediate environmental benefits by avoiding the emission of greenhouse gases and to help conserve fossil resources as electricity supply for future generations.

The entire countries world wide is encouraging the development of renewable energy to make the world clean and eco friendly and also self sufficient in the energy sector. Therefore, the Government of India is encouraging the development of renewable energy in the anticipation that it will provide 10% of electrical energy by 2010 in India. The Government also aims for a major reduction in CO$_2$ emission by that period.

Renewable energy plays an important role in electric power generation. Renewable energy can be replenished at the same rate at which it is used. Renewable energy sources contribute around 25% of human energy used world wide. Various renewable energy sources such as solar energy, wind energy, geothermal energy, etc. are harness for electric power generation. The prime source of renewable energy is solar radiation, “sunlight”. The solar energy is directly converted into electrical energy by solar photovoltaic (PV) module.

In India and other developing countries, the gap between Power Demand and Power Supply is gradually rising. Moreover, conventional energy sources are gradually depleting. Further the environmentalists are effectively campaigning against certain environmentally harmful sources of energy. The Government of India and other countries have seriously debated that the abundant availability of solar energy in tropical countries can be utilized efficiently.
Developments in global policies have seen the push for greater use of renewable energy sources. This leads to the increase in usage of medium sized PV arrays in residential and businesses.

Solar energy is the energy force that sustains life on the earth for all plants, animals, and people. The earth receives this radiant energy from the sun in the form of electromagnetic waves, which the sun continually emits into space. The earth-atmosphere system supports approximately $5.4 \times 10^{24}$ joules per year in the solar radiation cycle. The earth is essentially a huge solar energy collector receiving large quantities of this energy which manifests itself in various forms, such as direct sunlight used through photosynthesis by plants, heated air masses causing wind, and evaporation of the oceans resulting as rain which can form rivers. This solar energy can be tapped directly as thermal and photovoltaic, and indirectly as wind, biomass, and hydroelectric energy.

1.3 RENEWABLE ENERGY – INTERNATIONAL SCENARIO

Deployment of solar power depends largely upon local conditions and requirements. As all industrialised nations share a need for electricity, it is clear that solar power will increasingly be used to supply a cheap, reliable and eco friendly mode of electricity supply.

Figure 1.1 shows the utility of the world renewable energy sources in the year 2006. From the diagram, it is seen that the large hydro projects stands first with 58.23% where as the solar thermal energy generation works out to 6.83% and solar photovoltaic energy generation works out to 0.42% of the total energy production in the world.
Figure 1.1 World Renewable Energy 2006

Figure 1.2 shows the different insolation level of solar energy radiation on the earth’s surface from the sun. This figure clearly indicates that the maximum insolation level of the solar energy falls on South East Asian countries next to Africa.
Upto 2004, Japan had installed 1200 MW through solar power generation. Japan currently consumes about half of worldwide production of solar modules, mostly for grid connected residential applications. In terms of overall installed PV capacity, India stood fourth after Japan, Germany, and the United States (Indian Ministry of Non-conventional Energy Sources 2004). Government support and subsidies have been major influences in its progress. India's very long-term solar potential may be unparalleled in the world because it is one of the few places with an ideal combination of both high solar power reception and a large consumer base in the same place. India's theoretical solar potential is about 5000 TW-h per year (i.e. 600 GW), far more than its current total consumption.

In 2005, the Israeli Government announced an international contract for building a 100 MW solar trough plant to supply the electricity needs of more than 200,000 Israelis living in southern Israel. The plan
eventually allows the creation of a gigantic 500 MW power plant, making Israel a leader in solar power production.

The 12MW photovoltaic system in Gut Erlasse, Arnstein, Bavaria, Germany is the world's largest PV system. The 10 MW Bavaria Solarpark in Germany is another largest PV systems in the world, covering 25 hectares with 57,600 photovoltaic panels. A large solar PV plant is planned for the island of Crete. Research continues into ways to make the actual solar collecting cells less expensive and more efficient.

The Plataforma Solar de Almería (PSA) in Spain, part of the Center for Energy, Environment and Technological Research (CIEMAT), is the largest center for research, development, and testing of concentrating solar technologies in Europe. The 11 MW solar power plant, comprising 52,000 photovoltaic modules, is under progress as a single unit at Serpa, Portugal, 200 kilometers southeast of Lisbon in one of Europe’s sunniest areas.

The largest solar power station in Australia is the 400 kW array at Singleton, New South Wales. Other significant solar arrays include the 220 kW array on the Anangu Pitjantjatjara Lands in South Australia, the 200 kW array at Queen Victoria Market in Melbourne and the 160kW array at Kogarah Town Square in Sydney. A building-integrated photo voltaic (BIPV) installation of 60 kW in Brisbane has an uninterruptible power supply (UPS) which gives around 10-15 minutes worth of emergency power in the event of the loss of electricity supply. Any power not used by the UPS is connected to the grid and goes towards reducing the building's overall power bills. Numerous smaller arrays have been established, mainly in remote areas where solar power is cost-competitive with diesel power.
The world's largest solar power plant, the solar trough-based Solar Energy Generating Systems, is located in the Mojave Desert. Solel, an Israeli company, operates the plant, which consists of 1000 acres of solar reflectors and produces 354 MW. This plant produces 90% of the world's commercially produced solar power.

A photovoltaic system installed in Boston, Massachusetts, produces 25% less electricity than it would in Albuquerque, New Mexico, but yields roughly the same savings on utility bills since electricity costs more in Boston. Congress recently adopted the first federal tax breaks for residential solar since 1985 -- temporary credits available for systems installed in 2006 or 2007. Fifteen states also offer tax breaks for solar, and two dozen states offer direct consumer rebates.

On August 11, 2005, Southern California Edison announced an agreement to purchase solar-powered Stirling engines from Stirling Energy Systems over a twenty year period and in quantities sufficient to generate 500 MW of electricity. These systems are to be installed on a 4,500 acres solar farm and use mirrors to direct and concentrate sunlight onto the engines which will drive generators. Less than a month later, Stirling Energy Systems announced another agreement with San Diego Gas & Electric to provide between 300 and 900 megawatts of electricity.

1.4 INDIAN SCENARIO - AN OVERVIEW

Electric power generation in India now accesses four basic energy sources: Fossil fuels such as oil, natural gas and coal; Hydroelectricity; Nuclear power; and Renewable energy sources such as bio-fuels, solar, biomass, wind and ocean. The renewable energy potential in India and so far exploited, are listed in Table 1.1.
Solar Photovoltaic’s is a possibility based on the solar energy to the tune of 5,000 trillion Kwh/year reaching our country, during an estimated 300 sunny days. It is more than the total energy consumption of the country in a year. The cost of photovoltaic is progressively coming down. It is used in households, agriculture, telecommunications, defense, railways etc. It is a convenient source for domestic needs in remote areas.

### Table 1.1 Renewable Energy Potential in India

<table>
<thead>
<tr>
<th>Source/Technology</th>
<th>Potential/Availability</th>
<th>Potential Exploited</th>
</tr>
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<tbody>
<tr>
<td>Biogas Plants Biomass–based</td>
<td>$12 \times 10^6$</td>
<td>$2.7 \times 10^6$</td>
</tr>
<tr>
<td>Power Efficient Wood</td>
<td>$17,000$ MW</td>
<td>$69.5$ MW</td>
</tr>
<tr>
<td>Stoves</td>
<td>$120 \times 10^6$</td>
<td>$20 \times 10^6$</td>
</tr>
<tr>
<td>Solar Energy</td>
<td>$5 \times 10^{15}$ Whr/yr</td>
<td>$25$ MW</td>
</tr>
<tr>
<td>Small Hydro (upto25MW)</td>
<td>$15,000$ MW</td>
<td>$1,729$ MW</td>
</tr>
<tr>
<td>Wind Energy</td>
<td>$45,000$ MW</td>
<td>$4,220$ MW</td>
</tr>
<tr>
<td>Ocean Thermal</td>
<td>$50,000$ MW</td>
<td>Nil</td>
</tr>
<tr>
<td>Sea Wave Power</td>
<td>$20,000$ MW</td>
<td>Nil</td>
</tr>
<tr>
<td>Tidal Power</td>
<td>$9,000$ MW</td>
<td>Nil</td>
</tr>
</tbody>
</table>

From the Table 1.1 presented by Warrier (2008) the solar energy potential available in India is $5 \times 10^{15}$ Whr/Year where as the solar energy so far generated is only 25MW. Further Figure 1.2 shows that the maximum insolation level of the solar energy falls on India. There is ample scope for increasing the potential of solar energy generation in India.
“Solar Thermal” covers heating systems, cookers, drying applications, and solar thermal building designs. These technologies help to conserve energy. The 140 MW Integrated Solar Combined Cycle (ISCC) with a solar thermal component of 35 MW power project at Mathania neat Jodhpur in Rajasthan is under execution.

India has harnessed only a small fragment of the small hydropower (SHP) potential of 15,000 MW. Stations with capacities up to 15 MW have been in study in the country. The scheme that has found success in China is yet to gain ground in India. The Central Government has distributed portable micro-hydel sets of 5 to 15 kW capacities to local bodies/communities in seven states.

India is presently the sixth-greatest electricity generating country and accounts for about 4% of the world's total annual electricity generation. India is also currently ranked sixth in annual electricity consumption, accounting for about 3.5% of the world's total annual electricity consumption of both conventional and non-conventional energy sources. Overall, India's need for power is growing at a prodigious rate; annual electricity generation and consumption in India have increased by about 64% in the past decade, and its projected rate of increase for electricity consumption is one of the highest in the world.

Solar energy is a renewable resource that is inexhaustible and is locally available. It is a clean energy source that allows for local energy independence. The sun's power flow reaching the earth is typically about 1,000 Watts per square meter, although availability varies with location and time of year.
1.5 CHANGING STRUCTURE OF ENERGY SOURCES

The strategic goals for energy independence by 2030 would thus call for a shift in the structure of energy sources. First, fossil fuel imports need to be minimized and secure access to be ensured. Maximum hydro and nuclear power potential is to be tapped. The most significant aspect, however, is the power generated through renewable energy technologies target to 20 to 25% against the present generation of 5%. It is also evident that for true energy independence, a major shift in the structure of energy sources from fossil to renewable energy sources is mandated.

1.5.1 Solar Farms

Solar energy in particular requires unique, massive applications in the agricultural sector, where farmers need electricity exclusively in the daytime. This could be the primary demand driver for solar energy. Farmers demand for electric power today is significantly high to make solar energy economical in large scale.

Shortages of water, both for drinking and farming operations, can be met by large scale sea water desalination and pumping in land using solar energy, supplemented by bio-fuels wherever necessary.

1.6 ELECTRICITY FROM SUNLIGHT – SOLAR PHOTOVOLTAICS

Electricity can be produced from sunlight through direct heating of fluids to generate steam for large scale centralized electrical generation. Electricity is alternatively produced from sunlight through a process called
photovoltaics (PV), which can be applied, in either a centralized or decentralized fashion.

1.6.1 History of Photovoltaics

The first conventional photovoltaic cells were produced in the late 1950s, and throughout the 1960s were principally used to provide electrical power for earth-orbiting satellites. In the 1970s, improvements in manufacturing, performance and quality of PV modules helped to reduce costs and opened up a number of opportunities for powering remote terrestrial applications, including battery charging for navigational aids, signals, telecommunications equipment and other critical, low power needs.

In the 1980s, photovoltaic’s became a popular power source for consumer electronic devices, including calculators, watches, radios, lanterns and other small battery charging applications. Following the energy crises of the 1970s, significant efforts also began to develop PV power systems for residential and commercial uses both for stand-alone, remote power as well as for utility-connected applications. During the same period, international applications for PV systems to power rural health clinics, refrigeration, water pumping, telecommunications, and off-grid households increased dramatically, and remain a major portion of the present world market for PV products.

1.6.2 PV Terminology

Solar Cell: The PV cell is the component responsible for converting light to electricity. Some materials (e.g., silicon is the most common) produce a photovoltaic effect, where sunlight frees electrons striking the silicon material. The freed electrons cannot return to the
positively charged sites ("holes") without flowing through an external circuit, thus generating current. Solar cells are designed to absorb as much light as possible and are interconnected in series and parallel electrical connections to produce desired voltages and currents.

**PV Module:** A PV module is composed of interconnected solar cells that are encapsulated between a glass cover and weatherproof backing. The modules are typically framed in aluminum frames suitable for mounting.

**PV Array:** PV modules are connected in series and parallel to form an array of modules, thus increasing total available power output to the needed voltage and current for a particular application.

**Peak Watt (Wp):** PV modules are rated by their total power output, or peak Watts. A peak Watt is the amount of power output a PV module produces at Standard Test Conditions (STC) of a module operating temperature of 25°C in full noontime sunshine (irradiance) of 1,000 Watts per square meter.

A thin silicon cell, four inches across, can produce more than one watt of direct current (DC) electrical power in full sun. Individual solar cells can be connected in series and parallel to obtain desired voltages and currents. These groups of cells are packaged into standard modules that protect the cells from the environment while providing useful voltages and currents. PV modules are extremely reliable since they are solid state and there are no moving parts. Silicon PV cells manufactured today can provide over thirty years of useful service life.

PV systems are made up of a variety of components, which aside from the modules, may include conductors, fuses, disconnected controls,
batteries, trackers, and inverters. Components will vary somewhat depending on the application. PV systems are modular by nature, thus systems can be readily expanded and components easily repaired or replaced if needed. PV systems are cost effective for many remote power applications, as well as for small stand-alone power applications in proximity to the existing electric grid.

1.7 SCOPE AND OBJECTIVE OF THE THESIS

Photovoltaic power is considered as a prime source of energy in many countries with high solar power density. Optimum utilization of the available power from PV arrays is essential and can considerably reduce the size, weight and cost of the power system. The aim of this thesis is to build up knowledge around PV-systems. The present study is mainly focused on:

a. To improve the output of the PV system using maximum power point tracking by using static model.

b. To study the system output, since the energy delivered by PV-installations is low.

c. To examine the combination of bipolar and unipolar switching of a single-phase inverter as a suggested switching strategy, by using alternative algorithms.

The main reasons for the low electrical efficiency of photovoltaic systems are the nonlinear variation of the output voltage and current with solar radiation levels, operating temperature, aging and load current. To overcome these problems, the maximum power point of the PV system (at a given condition) is tracked using on-line or off-line algorithms and the system operating point is forced towards this optimal condition.
The following are the main objective of the thesis.

a. To study the characteristics of PV generation and the operating characteristic of the solar cell, the inverter and their associated controller by using simulation model.

b. To investigate static models of PV generators for maximum power point tracking using neural network.

c. To incorporate the PV generator model using fuzzy logic controller for maximum power point tracking during sudden changes in irradiance.

d. Based on the results obtained using fuzzy logic, measures to mitigate the negative effects due to the sudden change in irradiance, using neuro-fuzzy technique.

e. To improve the output of maximum power point tracking, the hill climbing algorithm is used to trigger the switching device, which reduces the lower order harmonics at the output of the inverter.

1.8 ORGANISATION OF THE THESIS

The overall philosophy behind this thesis is to generate high quality maximum amount of energy from the solar array and distribute it to the loads. The objective of this thesis is to develop new and competitive techniques for maximum power point tracking and to improve power quality.

Chapter 2 summarises the review of the literature surveyed towards this thesis.
Chapter 3 describes the characteristic of photovoltaic generation. Its operating behaviour and associated control are discussed along with its simulation results.

Chapter 4 discusses the response of a static model PV generator for maximum power point tracking using neural network.

Chapter 5 discusses the PV generator model using fuzzy logic controller for maximum power point tracking during sudden changes in irradiance. The simulation results are carried out caused by rapid changes in irradiance.

In Chapter 6, the Neuro-Fuzzy technique is used for maximum power point tracking. The simulation results are carried out in order to mitigate the negative effects caused by rapid changes in irradiance as described in Chapter 5.

In Chapter 7, the output of maximum power point tracking is improved using hill climbing algorithm. A prototype model is set and the algorithm is used to trigger the switching device, which reduces the lower order harmonics at the output of the inverter.

Chapter 8 analysis the results of the various algorithms developed for MPPT.

In Chapter 9, the conclusion from the research thesis is summarized and topics for further research are outlined.