CHAPTER 1

INTRODUCTION

Energy is vital for the progress of a nation and it has to be conserved in a most efficient manner. Not only the technologies should be developed to produce energy in a most environment-friendly manner from all varieties of fuels but also enough importance should be given to conserve the energy resources in the most efficient way. Energy is the ultimate factor responsible for both industrial and agricultural development. The use of renewable energy technology to meet the energy demands has been steadily increasing for the past few years, however, the important drawbacks associated with renewable energy systems are their inability to guarantee reliability and they are lean in nature. Import of petroleum products constitutes a major drain on our foreign exchange reserve. Renewable sources are considered to be the better option to meet these challenges.

It is obvious that the known resources of fossil fuels in the world are fast depleting. The importance of renewable energy sources was recognized in the early 18th century. During the past three decades, a significant effort has gone into the development, trial and induction of a variety of renewable energy technologies for the use in different sectors. Energy consumption has been growing rapidly in developing countries like India where, about 15% of the world’s population live. But the consumption of energy is still a small fraction of the global energy production in comparison with rising energy needs of the developing world and limited or declining non-renewable resources. The utilization of solar, wind and other
renewable energy resources becomes very important especially for the rural and remote areas where access to power lines is difficult. Renewable energy resources such as solar thermal, photovoltaic, wind, hydro, geothermal, biomass and ocean thermal can play a significant role in providing energy needs as well as sustaining the environment resources. These resources, along with fuel economy measures will certainly become the proper choice of appropriate technology option for an effective energy management. The major areas where renewable energy technologies can be profitably employed are the solar photovoltaic, wind, micro-hydro power and biomass energy conversion.

More than 200 million people live in rural areas without access to grid-connected power. In India, over 80,000 villages remain un-electrified and particularly in the state of Tamil Nadu, about 400 villages (with 63% tribes) are difficult to electrify due to inherent problems of location and economy. The costs to install and maintain the distribution lines are considerably high for remote areas. Also there will be a substantial increase in transmission line losses, in addition to poor power supply reliability. Like several other developing countries, India is characterized by severe energy deficit. In most of the remote and non-electrified sites, extension of utility grid lines experiences a number of problems such as high capital investment, high lead time, low load factor, poor voltage regulation and frequent power supply interruptions. There is a growing interest in harnessing renewable energy sources since they are naturally available, pollution free and inexhaustible. It is this segment, that needs special attention and hence concentrated efforts are continually provided in implementing standalone PV, wind, bio-diesel generator and integrated systems at sites that have a large potential of either solar, wind or both. Traditionally, electrical energy for remote villages has been derived from diesel generators characterized by high reliability, high running costs, moderate efficiency and high maintenance.
Hence, a convenient, cost-effective and reliable power supply is an essential factor in the development of any rural area. It is a critical factor in the development of the agro industry and commercial operations, which are projected to be the core of that area’s economy.

1.1 **SOLAR PV ENERGY**

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately $1.8 \times 10^{10}$ MW, which is thousands of times more than the present rate of energy consumption on earth. Solar energy could supply all the present and future energy needs of the world on a continuous basis, which is one of the most promising non-conventional energy sources and it is an environmentally clean source of energy that is available over almost all parts of the world.

The sun provides the basis for life on earth and sufficient energy to meet all our needs. Photovoltaic is a technology to convert sunlight directly into electrical energy. It has many advantages like, no noise and wear due to absence of moving parts, environmentally benign operation, suitable source for remote applications. Photovoltaic systems are prominently suitable for remote places where there is no grid power supply. Also space programmes have proved the technical feasibility of photovoltaic system, because of its high performance and reliability.

Photovoltaic generation is gaining an increased importance as renewable energy source due to its innate advantages like absence of fuel costs, fuel supply problem and system reliability with little or no maintenance. Performance and reliability of photovoltaic systems have been demonstrated in a large variety of small and medium scale standalone application as well as MW grid connected power stations. The main obstacle
for using multi MW scale photovoltaic system is the very high initial cost of the module. The solar photovoltaic systems may be operated in several modes such as standalone system with or without storage battery, hybrid and grid connected in accordance with their several applications. The ultimate objective of the solar photovoltaic system design procedure is to obtain the size of photovoltaic array and the battery bank, which can deliver power to load without failure. The performance of the system exclusively depends upon the solar resource at the site, system configuration and load parameters. The input energy for solar photovoltaic systems is the incident solar radiation, which depends on the location, time of the day, day of the year as well as solar energy receiving angle and other relevant environment conditions. The solar photovoltaic (SPV) array output also depends on the solar cell operating temperature, which is affected by the ambient air temperature. These parameters continue to change hourly, daily, monthly and yearly.

1.2 WIND ENERGY

Wind energy is an important part of solution for world energy demand and pollution problems. With an average wind speed of 7.1 m/sec, annual wind energy production is estimated as almost 60 million kWh, enough to supply 20,000 house holds with clean electricity. In other words, the wind turbine avoids discharging to the environment 50,000 tonnes of CO₂, 200 tonnes of SO₂ and 2,500 tonnes of ash as a consequence of operating thermal power plants, in order to produce same amount of energy. Wind has emerged as the most suitable candidate as a renewable energy source in the immediate future. Technology for wind electricity generation has nearly matured. Wind energy output depends on wind velocity and swept area. However, the output varies with the climatic conditions. In India, wind velocity depends on the monsoon circulations namely, the strong south-west summer monsoon commencing from June and the north-east winter monsoon
commencing from October. Extensive wind resource assessment comprising wind monitoring and wind mapping include complex terrain projects that was taken up in 1985 covering all the states and union territories of India. The projected conservative estimate of the potential is about 60,000 MW.

1.3 BIO-DIESEL ENERGY

Bio-diesel, an alternative fuel is made from renewable biological sources such as vegetable oils and animal fats. It is bio-degradable, non-toxic and clean fuel. Oils from coconut, soyabean, sunflower, peanut, linseed and palm are used depending upon the growth rate. In the United States, the primary interest is on soyabean oil that can be used as a bio-fuel while many European countries are concerned with rape seed oil. However, countries with tropical climate prefer to utilize coconut oil or palm oil. Furthermore, other sources of bio-diesel studies include animal fat and used frying oil. The bio-diesel from Jatropha oil and Pongamia oil has now become more economical as a substitute to diesel in India. It is less harmful to the environment, for it contains practically no sulphur and substantially reduces emission of unburnt hydrocarbons, carbon-monoxide, sulphates and particulate matter. It has appreciable fuel properties inline with diesel and because of this, it can be mixed with diesel and used in diesel generator sets without any modification. Fortunately, there is a vast of degraded forest land and unutilized public land, field boundaries and fallow lands of farmers, where non-edible oil-seeds can be grown. In India, it is estimated that the cost of bio-diesel production by trans-esterification of oil obtained from Jatropha Curcas oil-seeds shall be approximately same as that of diesel. The bi-products of bio-diesel from Jatropha seed are the seed oil cake and glycerol, which have good commercial value. Bio-diesel in diesel generator-sets becomes a cost effective, environmental friendly and renewable energy system as compared to a conventional diesel system.
1.4 HYBRID SYSTEM

At present, standalone solar photovoltaic, wind systems, bio-diesel 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, standalone solar photovoltaic energy system cannot provide reliable power during non-sunny days. The standalone wind system cannot satisfy constant load demands due to significant fluctuations in the magnitude of wind speeds from hour to hour throughout the year. Similarly, continuous supply of bio-diesel fuel is difficult because of low-commercialization of bio-diesel generator fuel. Therefore, energy storage systems will be required for each of these systems in order to satisfy the power demands. Usually the storage system is expensive and its size has to be minimised to make the renewable energy system cost effective. Integrated hybrid power system can therefore be used to reduce energy storage requirements.

Integrated or hybrid system is a combination of one primary energy system with one or more secondary energy systems for power supply. In photovoltaic hybrid system, PV system is the main source of energy and a variety of other energy sources namely bio-diesel generator, wind turbine generator and biomass gasifier can be combined as secondary energy systems.

There are many different hybrid options, which are preferred according to demand and availability. They are photovoltaic with diesel generator, photovoltaic with wind turbine generator and photovoltaic with bio-diesel generator.

A well designed PV-wind hybrid energy system will provide a reliable service without any need for fossil fuels for long periods of operation.
It also requires only relatively low maintenance. In this hybrid combination, wind generator depends largely on natural cycles. Hence, it can be used only in specific seasons and terrain, when wind speed is sufficient to generate power.

Diesel generator system is independent of natural cycles and it is cost effective above 150 kWh/day (IREDA 1996). Though the capital cost of diesel generation systems are low, the operating and maintenance costs are relatively high. PV system is equipped with diesel generator to meet the peak load demand, when there is a deficit of available energy. It can be used during almost all the seasons for Indian conditions most effectively. This hybrid option is more reliable and excellent.

PV–bio-diesel hybrid system can be used for low, medium and high load demands. The capital cost of the above system is high, but unit cost of electricity is low. It is highly suitable for meeting peak loads and long term energy requirements. The initial investment could only be justified with a relatively high power generation capacity. The schematic representation of standalone and hybrid PV systems is shown in Figures 1.1 and 1.2.

![Schematic diagram of standalone PV system](image_url)
An integrated renewable energy system combines the generation of power through solar and wind systems installed to meet the load demand of a particular location blessed with adequate solar insolation and wind velocity. In PV-wind hybrid system, either wind or PV system forms the primary source of energy depending upon the span of availability of wind/solar energy in the location. A variety of other energy sources namely bio-diesel, diesel, diesel-biomass can also be combined as a secondary source of energy. In the renewable energy sources, the performance of both solar and wind systems depends largely on natural cycles and topology of the chosen location. Hence, it can be used only when wind speed and solar insolation are sufficient to generate power. Batteries are charged during periods of excess power generation and are discharged whenever there is a deficiency in power developed with respect to the local demand.

In recent years, attention has been given to various renewable energy based mini-grid solutions involving mini-hydro, producer or biogas fuelled diesel generator, bio-diesel, wind and solar photovoltaic. The photovoltaic, wind deserve more attention because of their inherent attractive features.
1.5 OBJECTIVES

The objectives of the present work are

i) To design PV-wind hybrid systems for rural electrification for the required load at specified Deficiency of Power Supply Probability (DPSP).

ii) To develop an optimization model for PV-wind hybrid system for rural electrification based on DPSP and Relative Excess Power Generated (REPG).

iii) To carry out techno-economic analysis of PV-wind hybrid system based on life cycle cost or levelised energy cost or life cycle unit cost and pay back period.

iv) To carry out economical comparison of PV-wind hybrid system with respect to grid line extension power.

v) To conduct sensitivity analysis for various parameters of PV-wind hybrid system for an economic evaluation.

1.6 ORGANIZATION OF THESIS

The thesis has been divided into the following chapters:

Chapter 1: In this chapter a brief introduction about the prevailing energy scenario locally and globally is highlighted. The importance of renewable energy like solar PV system, wind systems and bio-diesel are discussed in detail. The merits and limitations of standalone solar PV and wind systems are elaborated. The need and types of hybrid system, its benefits are presented.
Chapter 2: In depth literature is carried out and detailed in this chapter. The existing models available for standalone solar PV systems and their cost analysis are listed. Similarly the models pertaining to the standalone wind system and their corresponding cost analysis are discussed. The various types of hybrid systems namely solar photovoltaic wind hybrid systems, solar photovoltaic diesel hybrid systems, wind diesel hybrid systems, SPV wind diesel hybrid systems and their modeling procedures, performance studies, operating strategies, economic analysis and case studies are presented in detail. Based on the literature survey specific objectives to be focused is arrived.

Chapter 3: This chapter deals with the procedure to develop a new methodology for design and optimizing of PV-wind hybrid system. A new method for optimization of PV-wind hybrid system for a specific location employing an iterative scheme based on Deficiency of Power Supply Probability (DPSP), Relative Excess Power Generated (REPG), Life Cycle Cost (LCC), cost of power generation and pay back period is evolved. Also the influence of the DPSP, REPG, Energy to load ratio (ELR), Battery to Load Ratio (BLR), fraction of PV and wind energy and coverage of PV and wind energy over system size and performance, are presented. A simulation model has been developed to carryout the analysis for optimizing the size of PV-wind and battery systems for a hybrid unit at a given location with help of distribution of load, wind speeds and insolation are enumerated. Economic aspects of solar PV-wind hybrid systems are also discussed in detail.

Chapter 4: This chapter focuses on the comparison of the model using real time data collected from a hybrid plant installed at Chunnambar, Pondicherry. The inferences are interpreted in the form of percentage of deviation of power generated. Performance and cost analysis for PV-wind hybrid system was conducted and results are discussed for locations
Poompuhar and Ottapidaram. The variation in deficiency of power supply probability with respect to life cycle cost for stand alone photovoltaic, wind and hybrid systems for a given load are discussed. The optimum combination of solar PV-wind hybrid system is obtained at solar energy to load ratio for a given DPSP are highlighted. A comparative cost of grid line extensions energy source with PV-wind hybrid system is discussed in detail. The sensitivity analysis have been presented for life-cycle cost of PV-wind hybrid system through the simulation analysis to determine how it varies for the key parameters such as discount rate, escalation rate, PV module cost, insolation, wind velocity and module efficiency.

**Chapter 5:** The summary of the work and conclusions drawn from it and future directions for investigations are given in this chapter.