CHAPTER 1

INTRODUCTION
Electricity has been considered as an important aspect for the economics of countries and it is also important for daily life of world population. The electricity demands of consumers are met by means of generation, transmission and retailing of electricity. Further, the variable demand of consumers requires consistent and continuous supply of electricity otherwise there will be big loss of income to both generators as well as consumers. Therefore the reliability of generation, transmission and distribution of electricity has been considered as crucial for continuous supply of electricity to meet the variable demand of consumers. The reliability of the system is also an important aspect for system planners for planning and forecasting the load and plant capacity addition to meet the load demand and required level of reliability.

In this study the system reliability has been analyzed using reliability indices. The main difficulty of integrating large amount of renewable resources is the variability of natural resources which is also known as intermittency of resources, therefore it was decided that The focus of this study to analyze the effects of wind generation on system reliability.

1.1 Grid-Based Renewable Energy in Developing Countries

1.1.1 Renewable Energy in the Power Sector

Total world electric power capacity stood at 3,400,000MW in 2000, with about 1,500,000MW (45%) of this in developing countries (see Table 1). This capacity represents a cumulative investment of perhaps $3-4 trillion and annual fuel costs perhaps $150-250 billion. Globally, fossil fuels account for about two-thirds of generating capacity, with the remaining third being large hydro (20%), nuclear (10%) and renewable energy (3%). Electricity consumption in developing countries continue
to grow rapidly with economic growth, raising concerns about how these countries will expand power generation in coming decades. According to some estimates, developing countries will need to more than double their current generation capacity by 2020 (Manohra Bruno, 2000).

<table>
<thead>
<tr>
<th>Technology</th>
<th>All Countries (MW)</th>
<th>Developing Countries (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small hydro power(^a)</td>
<td>43,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Biomass power(^b)</td>
<td>32,000</td>
<td>17,000</td>
</tr>
<tr>
<td>Wind power</td>
<td>18,000</td>
<td>1,700</td>
</tr>
<tr>
<td>Geothermal power</td>
<td>8,500</td>
<td>3,900</td>
</tr>
<tr>
<td>Solar thermal power</td>
<td>350</td>
<td>0</td>
</tr>
<tr>
<td>Solar photovoltaic power (grid)</td>
<td>250</td>
<td>0</td>
</tr>
<tr>
<td>Total renewable power capacity</td>
<td>102,000</td>
<td>48,000</td>
</tr>
<tr>
<td>Large hydropower</td>
<td>680,000</td>
<td>260,000</td>
</tr>
<tr>
<td>Total world electric power capacity</td>
<td>3,400,000</td>
<td>1,500,000</td>
</tr>
</tbody>
</table>

Table 1.1: Renewable Grid-Based Electricity Generation capacity installed as of 2000, Megawatts (Source: Martinot et al. 2002)

Notes: (a) Small hydro is usually defined as 10MW or less, although the definition varies by country, sometimes up to 30MW; (b) Biomass figures omit electricity from municipal solid waste and landfill gas; commonly, biomass and waste are reported together.

1.1.2 Power Sector Restructuring and Renewable Energy

Power sector is the driver of growth of country. India has an inadequately developed infra-structure in respect of Electrical Energy. About two Billion population of the world is reported have no access to enjoy the benefits of Electrical Energy. In India about 360 Million people still deprived of enjoying direct benefits of Electrical power (Mallick, 2011).
Traditionally, power utilities have been state-owned monopolies or privately-owned monopolies, either regulated by government agencies or “self-regulated” without much oversight. Their traditional mission has been an engineering one: expanding supply, improving technical efficiency, and ensuring or improving reliability and access (Martinot Eric et al. 2002). In developing countries, many utilities have been and remain in poor financial condition and have limited borrowing ability to make investments and expand service (Martinot, Eric et al. 2002). During 1990s, waves of restructuring have washed over utilities worldwide, with profound effect on technologies, costs, prices, institutions and regulatory frameworks. Restructuring has changed the traditional mission and mandates of utilities in complex ways, and has had large impacts on environmental, social and political conditions. At the same time, new regulatory approaches are being found for reducing environmental impacts from restructured power sectors (Gupta, Ajit 2000). Restructuring is resulted in independent power production and competition in generation, decentralization, privatization, unbundling of generation and transmission, and even competition in distribution. Along with these changes are a broad variety of new institutional and contractual forms within the power sector. As restructuring takes place, environmental considerations are often overlooked, either because policy makers and their advisors perceive their priorities to be elsewhere, or because they assume that restructuring will automatically lead to environmental improvement (Matrinot Eric 1998).

1.1.3 Wind and Small Hydro Power in India

In India, GEF support for wind power occurred in parallel with the explosive markets growth that emerged in the mid-1990s fueled by favorable investment tax policies and
a supportive regulatory framework. Besides investment tax credits, transparent power purchase tariffs, transmission wheeling, third party sales, guarantees for local utility power-purchase contracts and power “banking” all contributed to the development of the market. By 2000, almost 1200MW of wind capacity had been installed in India, virtually all of that by the private sector. In addition, dozens of domestic wind turbine manufacturers had emerged; many of them collaborated with foreign partners. Exports of turbines began and high technology turbine designs with variable speed operation were being produced. During the 1990s, the GEF and World Bank directly financed 41MW of wind turbines installations and 45MW of mini-hydro capacity in India through the Renewable Energy Development project (Mannoha, Bruno 2000). More importantly, the India project also strengthened the capabilities of the India Renewable Energy Development Agency (IREDA) to promote and finance private-sector investments. As a result, more than 360MW of wind projects and 65MW of mini-hydro projects have been financed through IREDA. Another 65MW of mini-hydro capacity is scheduled for financing and completion through 2001. The project also helped to raise awareness among investors and banking institutions of the viability of wind power technology and helped to lobby for lower import tariffs for wind systems. During the 1990s, many financial institutions decided to offer financing for wind farms, which was a key project goal. One lesson from the India case is that it is difficult to separate the influence of GEF interventions from other trends and forces at work. The net results, in terms of existing manufacturing capacities, financing and volume of installed capacity, comes from a complex set of many influences of which the GEF is just one. Certainly the investment tax credits have been a powerful stimulus to technology transfer and market development while the credits existed. Another
lesson is that more understanding is needed about the relative effectiveness of production-based incentives relative to capacity-based incentives. In the 1990s, one-year 100% investment tax depreciation provided large economic gains for installation of wind farm capacity, regardless of the electricity generation from that capacity. This incentive is shifting, as capacity-based tax incentives have decreased due to the reduction in marginal corporate tax rates from 55% in 1992/93 to 35% in 2000, at the same time that power tariffs, production-based incentives, have continued to rise. In addition, IREDA offers incentives for wind farms it have financed to achieve higher capacity factors (Matrinot Eric et al. 2000).

The recent decline in wind farm development in Tamil Nadu, for example, has been attributed to variety of factors. In addition to financial and policy factors, the decline has been attributed to inadequate capacity of substations, weak distribution connections, poor maintenance, inadequate facilities for repair, rotor blade failures due to manufacturing defects and lighting, control system failures due to disregard for grounding regulations and lightning protection, and inadequate wind speed data resulting in differences in actual and expected energy production. Additional hydro capacity was under development in 1999 and 2000, and a second World Bank renewable energy project for India, which would finance additional mini-hydro, was approved in 2000.

1.2 Global Renewable Energy Markets

The fastest growing renewable energy markets are for wind power and solar photovoltaic, a handful of developed countries, notable Japan, Germany and Spain, with a recent resurgence in United States. These markets have seen annual growth
rates of 15-40% in recent years. Solar hot water markets in a few countries have been
growing equally rapidly, with more modest investments in geothermal, small hydro
and biomass (Beck, Fred et al. 2004). Overall, technology shares for the $17 billion
total invested in 2002 are estimated at wind 42%, solar photovoltaic 22%, solar hot
water 17%, geothermal heat production 8%, small hydro power generation 6%,
biomass power generation 2% and geothermal power generation 2%. In developed
countries, the leading applications of renewable energy are for power generation from
power-grid-connected wind and biomass and from decentralized rooftop and remote
solar photovoltaic (Matrinot Eric et al. 2002).

The most commercial markets continue to be solar photovoltaic power for remote
telecommunications stations and for highway services and signs. But grid-connected
wind power has also “come of age”. Germany now has over one-third of worldwide
wind power installations, and other leading countries are Spain, Denmark and United
States, with several other European countries also expanding (Albizzatia, et al. 1997).

Growth in all of these countries is expected to continue, with perhaps the exception of
Denmark. Germany and Japan lead the household rooftop solar photovoltaic market,
now numbering hundreds of thousands of homes. The use of biofuels for transport is
significant and growing in some countries. Germany leads the world in biodiesel use-
more than 2 billion liters per year. Other countries using biodiesel include Austria,
Belgium, France, Italy, Indonesia and Malaysia (Dijk A.L. Van et al. 2003). Brazil
leads the world in ethanol use, about 14 billion liters in 2000, followed by the United
States and Canada, with much smaller use in a few European countries. Mature and
commercial solar hot water markets are also expanding in several countries,
particularly China, which alone accounted for half of global installations in 2001 and
saw double-digit annual market growth in the early 2000s. Japan, the United States, Germany, Greece, Israel and Australia are also active solar hot water markets. Driving growth in several countries are mandates that new home construction include solar hot water notably in Japan, Greece, Israel and parts of Australia. In developing countries, renewable energy markets are more diverse than in developed countries (Matrinot Eric, 2003).

1.3 Research Goals and Objectives

The Goals and objective of this thesis are:

1. To identify an analytical method for determining the reliability of conventional generation system.
2. To analyse various methods for modelling the intermittent renewable generation system.
3. To identify a technique that can be used for planning of generation capacity expansion.
4. To analyse the effects of wind penetration level diversity, inter-annual data variation on the reliability of the system.

1.4 Objective of Work

The objective of the work is to analyse the capacity contribution of wind from various locations and its effect on reliability of the system. It is expected that the technique can be useful for the future study of planning for capacity addition using intermittent renewable generation.
1.5 Literature Review

A modern power system can be divided into appropriate functional areas that can be analyzed separately (Billion ton et al.1996) These functional areas are: generation, transmission and distribution.

The focus of this study is to cover the system reliability evaluation for generation system adequacy considering intermittent generation. This work has particularly focused on how intermittent wind generation contributes to the generation system adequacy planning and the effects on system reliability. The focus is kept on wind because wind offers the greatest potential for expansion in both developed and developing countries among all renewable technologies in short to medium term.

According to Nedic et al.2005, it is expected that wind power will play a key role in achieving 2010-20 targets for renewable generation (Nedic et al.2005).

The system reliability is one of the major factors in planning design, operation and maintenance of electric power system. According to Edrenyi 1978, if an improvement in system reliability is required; it can be affected either by using better components or by a system design incorporating more redundancy i.e., the installation of more generating capacity than normally required.

According to Wang et al.1994, the process of evaluation of power system reliability starts by creating a mathematical model of a system or a sub-system and then proceeding with a numerical solution.

According to Prada (1999) probabilistic methods can provide more meaningful information to be used in design and resource planning and allocation.

Loss of load occurs when the system load exceeds the generating capacity available for use. Loss of Load Probability (LOLP) is a projected value of how much time in long
run, the load on a power system is expected to be greater than the capacity of available generating resources.

According to Endrenyi (1978), it is defined as the probability of the system load exceeding the available generating capacity under the assumption that the peak load of each day lasts all day. There are many difficulties with the use of LOLP for power system reliability evaluation:

- LOLP does not provide any indication of the frequency or duration of shortages and the extent of load shedding in MW or severity of potential shortages which are important reliability measures. As an expected value, it does not differentiate between one large shortfall and several small, brief ones.

- Different LOLP calculation methods can result in different indices for the same system. Some utilities calculate LOLP based on the hour of each day’s peak load (i.e., 365 computations), while other model every hour’s load (i.e., 8760 computations) (Kueck et al. 2004).

- LOLP does not include additional energy support that one control area or region may receive from another, or other emergency measures that control area operators can take to maintain system reliability (Kueck et al. 2004).

- Major loss-of-load incidents usually occur as a result of contingencies not modelled by traditional LOLP calculation. Often, a major bulk power outage event is precipitated by a series of incidents, not necessarily occurring at the time of system peak (when the calculated risk is greatest) (Kueck et al. 2004).

- The LOLP, in days per year, mainly indicates the number of days in the year in which generation system would not be able to meet the load. The frequency of load shedding may be higher than this figure in case double peaked daily load
curves and in systems which employ units with higher failure rates but short repair duration (Khatib, 1978).

- Since the load model used in loss-of-load method is often the cumulative curve of daily peak loads, the variation of load within a day are not recognized in it. This makes the LOLP value obtained by that method a rather crude approximation of true system failure probability, and prevents the calculation of the system failure frequency (Endrenyi 1978).

- It is not very useful for comparing the reliabilities of different utilities or national systems, particularly if they have different shapes of the load curve and peak duration (Khatib, 1978).

- It is argued that for the same system the use of the LOLP index would be adequate and correct for investigating different expansion plans and annual maintenance scheduling. This is only correct if the duration peak demand is static over years of study. This is not the case in many systems with the continuous increase in the middle of the day load being experienced in most cases, particularly in developing countries (Khatib, 1978).

- The vertically structured utility will build generation or enter into power purchase agreements to achieve the required LOLP, but LOLP is not necessarily an accurate predictor of the resulting incidence of electricity shortages (Kueck et al. 2004).

Capacity Credit (CC) is a measure of contribution that intermittent generation can make to reliability. According to Ford and Milborrow (2005), capacity credit is defined as the ratio of Capacity of thermal plant displaced to rated output of Wind Plant(Ford R. et al.2005).
According to Milligan (2005) the Firm Capacity method is based on the LOLP measure of the system reliability and incorporates LOLP calculations in such a way that adding a new generator is benchmarked against an ideal perfect reliable unit with 100% availability.

The capacity factor of Wind Plant can be used to approximate the Capacity Credit. According to Milligan (2001) from the planning perspective one could interpret the capacity factor as the ratio of statistically expected output divided by annual energy output. In fact this measure can be viewed as a first stage approximation to overall capacity credit.

Intermittent and variable output must be considered in relation to the role the generation source is providing. Butler (2001) suggested that the intermittent and variable generation sources may not be the best suited as base load plant but contributing more to ancillary services peak demand and seasonal variations.

1.6 Thesis Outline

In Chapter- 1 the objective of work is defined along with research goals and objective. In Chapter- 2 various techniques available to evaluate the reliability indices are discussed and different modelling approaches for conventional and wind generation system have also been described. All subsequent sections provide the current modelling approach and description of intermittent renewable generators and discussed the various factors that cause intermittency.

In Chapter- 3 intermittent wind generation has been modeled and incorporated into the system reliability evaluation programme and the capacity credit obtained from various modeling methods are analysed and compared.
In Chapter- 4 the various aspects of intermittent wind generation have on system reliability are examined in detail.

In Chapter- 5 the analysis of various effects on reliability of the system is given.

In Chapter- 6 the interpretations as well as comparison of results and conclusions have been discussed.