Chapter 1

1. Introduction

1.1. Wind power status and challenges

Wind farms have become a familiar sight around the world for a wide variety of reasons including their economic, environmental, and social benefits. Unlike other forms of electricity generation where fuel is shipped to a processing plant, wind energy generates electricity at the source of fuel. Wind is a native fuel that does not need to be mined or transported, which take two expensive aspects of long-term energy costs. Though wind plants provide numerous advantageous over fossil fuel plants, wind power production introduces more uncertainty in operating a power system. It is technically possible to integrate very large amounts of wind capacity in power systems; the limits arising from how much can be integrated at socially and economically acceptable costs [1]. However, some studies reveal that the maximum wind penetration level is limited by the allowable frequency deviations [2], where in Sri Lankan point of view the allowable frequency deviation is stated as ±1% in the Electricity Act and strictly adhered during the system operations.

Induction generators are often used for wind power projects and they require adequate amount of reactive power compensation at the grid substations for excitation. Different types of wind turbine generators behave differently during transmission grid disturbances, so extensive modelling of the dynamic electromechanical characteristics of a new wind farm is required to ensure predictable stable behaviour during system faults.

The Government of Sri Lanka has declared the development of renewable energy to be of high priority, in line with the national policy of maximizing indigenous sources and ensuring fuel diversity. Sri Lanka has exploited hydropower resources to almost its maximum economical potential. Only a limited number of small and medium scale hydropower plants are yet to be developed, and these are already in various stages of development. Therefore, the country's increasing electricity demand in the future will have to be met with increased imports of fossil fuel. Wind is one of the promising renewable energy options available for grid connected power. A special standardized tariff for small wind power plants has been published by the Ministry of Power & Energy, Sri Lanka to encourage the development of wind power by the private sector. The extent of wind energy potential in Sri Lanka was identified during the Wind Resources Assessment Study conducted by the National Renewable Energy Laboratory of USA in 2002. The technical and economic feasibility of harnessing this resource for power generation to its maximum potential is required to be studied. The technical ability of the Sri Lankan Power System to absorb wind-based generation has been identified as a major concern in developing wind power.

This study is an attempt to model wind power plants around Kalpitiya area using doubly fed induction generators and analyzes the issues related to the above wind integration such as grid limitations, stability effects and voltage impacts. Adequate load flow and dynamic simulation models that are necessary to evaluate the impact on the power system due to the above wind integration will be carried out during this study.

The outcome of this study will be a figure for maximum amount of wind power, which can be integrated in to the power system around Kalpitiya area without disturbing the stability and reliability of the system. Further this study will identify the power system strengthening requirements to increase the wind power penetration level at the steady state.

1.2. Background study

1.2.1. World wind picture

At the end of year 2007, global installed capacity of wind-powered generators was 93.8 gigawatts. Wind energy is used in more than 70 countries [3]. Although wind produces around 1% of worldwide electricity requirement, it accounts for approximately 19% of electricity production in Denmark, 9% in Spain and Portugal, and 6% in Germany and the Republic of Ireland [4].

World interest on wind energy increased rapidly during the past few years. 19.7GW of wind energy were added to the system during year 2007 that was 27% growth compared to the total installed capacity in year 2006 (74MW) [4].

The total installed wind energy capacity and prediction (1997-2010) and Worldwide Wind Energy by Continents is illustrated in figure1.1 and figure 1.2.

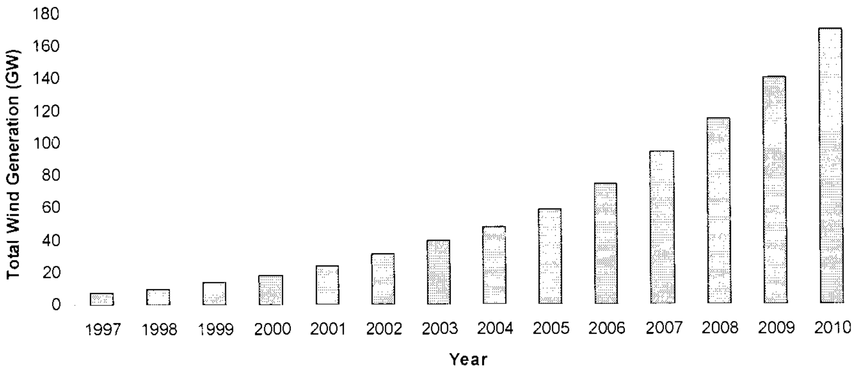

Figure 1.1: Worldwide wind energy by continents

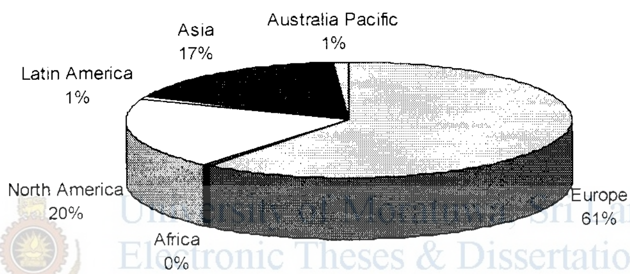

Figure 1.2 : Worldwide wind energy by continents

As the power sector is encouraged in moving towards green energy concept, the existing targets for wind power anticipate a quite high penetration in many countries.

1.2.2. Sri Lanka's power system

Ceylon Electricity Board (CEB), the state owned electricity utility established in 1969 is responsible for Power Transmission and most of the Generation and Distribution of electricity in Sri Lanka. At present Sri Lanka's power system consists of CEB owned medium and large hydro power plants of 1205MW and oil-fired thermal power plants of 548 MW. In addition, oil-fired thermal power plants of 720 MW capacity connected to the national grid are operated by the Independent Power Producers. The first coal-fired power plant (300 MW) is presently under construction. Apart from the above, small power plants of 172 MW , (mainly mini hydro) owned and operated by the private sector are connected to the 33kV distribution network as embedded generators [5]. CEB has issued letter of Intent to the private sector for the development of mini hydro and other embedded generators of about 200MW. Further, CEB has been operating a 3MW pilot wind power plant in the southern part of the country since 1999. Other wind power plants of 30MW are presently under construction by private developers in the north-western part of the country. In addition, proposals have been submitted to connect wind power plants of more than 100MW. Most of these wind farms are in the Kalpitiya peninsula in north western Sri Lanka. CEB operates a 220kV/132kV transmission network with a total length of approximately 2100 km [6]. Maximum demand so far met by the CEB is 1922MW with an annual generation 9900GWh.

1.2.3. Sri Lanka wind potential

In the Sri Lankan contest, the country is now clearly at a cross road as far as future power generation is concerned. The energy demand is increasing at around 6% per annum. Most of the energy generated is from imported fossil fuels. As the prices of petroleum based fossil fuels have been on the rise, the seriousness of the situation prompts the necessity of moving towards wind, the most promising and indigenous energy source available for future.

The wind-mapping results for Sri Lanka show many areas that are estimated to have good -to excellent wind resources (Refer Appendix A). These areas are concentrated largely in two major regions. The first is the northwestern coastal region from the Kalpitiya Peninsula north to Mannar Island and the Jaffna Peninsula. The second region is the central highlands in the interior of the country, largely in the Central Province and also in parts of Sabaragamuwa and Uva Provinces [7]. This report is basically focused on analyzing the wind penetration capability of the Sri Lankan power system around Kalpitiya Peninsula (Refer Appendix B for wind speed and power data at Narakkalliya site in Kalpitiya area).

1.2.4. Wind turbine generator technologies

A Wind Turbine Generator (WTG) typically consists of two or three blades connected to a hub to form the rotor assembly. The rotor hub connects to a shaft which turns a generator, usually through a gearbox. The electrical output of the generator is then fed to the grid either directly or through a system of power electronics that converts it to the correct grid frequency and voltage.

Three common technologies are used for wind turbine generators. The main differences between the three concepts are the generating system and the way in which the aerodynamic efficiency of the rotor is limited during high wind speeds. All wind turbines installed at present use one of the following systems, depicted in the figure 1.3.

(a). Squirrel cage induction generator

(b). Direct drive synchronous generator

(c). Doubly fed induction generator

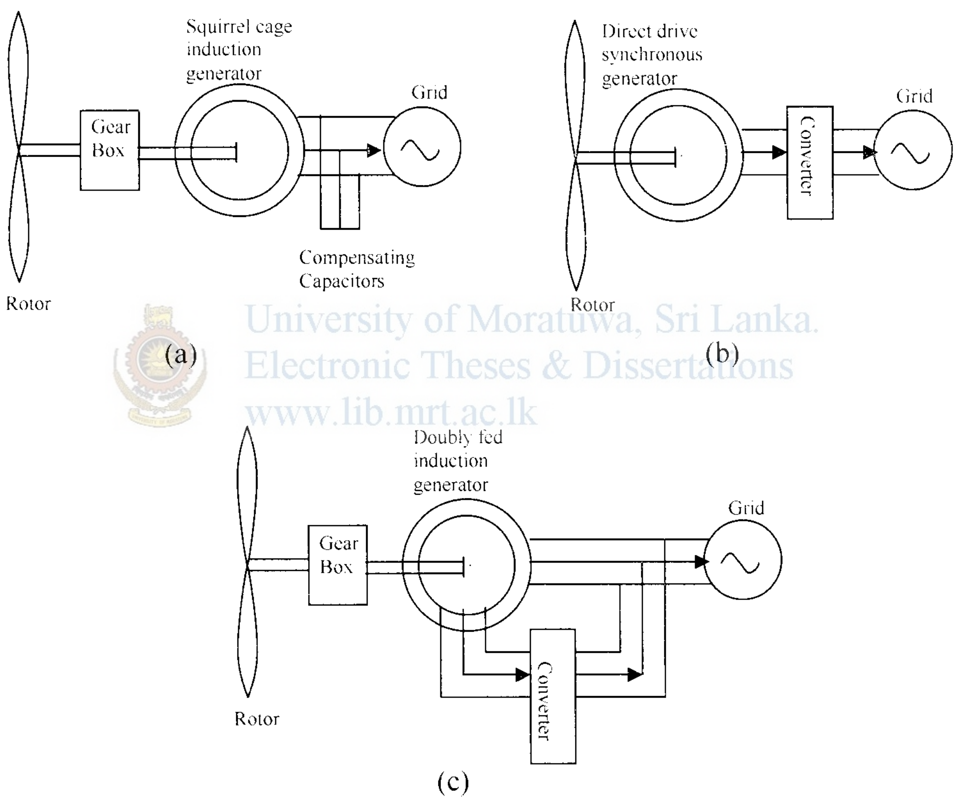

Figure 1.3: Generating systems used in wind turbines: (a) Squirrel cage induction generator, (b) Direct drive synchronous generator and (c) Doubly fed induction generator

The squirrel cage induction generator is the oldest technology, and it is a directly grid coupled conventional induction generator. The power delivered can be varied by varying the rotor speed and hence the slip, but those rotor variations are very small (approximately 1-2%). Therefore this wind turbine type is normally referred to as fixed speed turbines. This type of generators always consumes reactive power and in most cases the reactive power consumption is fully compensated by using capacitors. In addition, there exist semi variable speed systems where the rotor resistance of the squirrel cage induction generator is varied by using power electronics. By changing the rotor resistance, the torque/speed characteristic of the generator can be shifted and approximately 10% of speed variation is achievable at relatively low cost.

The other two generating systems depicted in figure 1.3 are variable speed systems. To achieve variable speed operation, the mechanical rotor speed and the electrical grid frequency should be decoupled. In doubly fed induction generator, the rotor is decoupled from the grid by using partially rated back to back voltage source converter and in direct drive synchronous generator, the generator is completely decoupled from the grid by power electronics converter [8].

1.2.5. Impacts of wind power on the power system

Impacts of wind power on the power system can be broadly divided into two sectors as local impacts and system wide impacts. The aspects coming under those sectors are depicted in the table below:

Local impacts	System wide impacts
1. Branch flows and node voltages	1. Dynamics and stability
2. Protection schemes, fault currents and switchgear ratings	2. Reactive power/ voltage control possibilities
3. Harmonics	3. Frequency control and dispatch of the remaining conventional units
4. Flicker	

Table 1-1: Local and system wide impacts of wind power

The first two aspects coming under local impacts should always be investigated when connecting new generating capacity to a power system, and the issues are therefore not specific for wind power [9].

The way in which wind turbines affect the voltages at nearby nodes varies with the wind turbine generator technology used. The induction generator with squirrel cage rotor cannot control its terminal voltage. Therefore, additional equipment such as capacitor banks or SVCs (Static Var Compensators) are necessary for voltage controlling. On the other hand, variable speed turbines have the capability of varying the reactive power at a given active power, rotor speed and terminal voltage, but the range over which the reactive power can be controlled depends on the size of the power electronic converter.

Direct drive variable speed turbines have an advantage here because they already have large converters and some extra capacity can be added to allow reactive power control at a marginal cost. However doubly fed induction generators already have an advantage of using small converters and adding converter capacity to control reactive power tends to cancel this advantage.

The contribution of wind turbines to the fault currents is also different in three main wind turbine types. Directly grid coupled squirrel cage induction generators contribute to the fault currents and rely on conventional protection schemes. DFIG also contributes to the fault currents, but is quickly disconnected when a fault occurs due to the sensitivity of power electronics used. Direct drive generators hardly contribute to the fault currents because the power electronic converter which the turbine is equipped with cannot carry a fault current.

The harmonic effects are important when generators are coupled to the grid through power electronic devices; therefore this is mainly applied to variable speed turbines. However, in case of modern power electronic converters with high switching frequencies, advanced control algorithms and filtering techniques, the harmonic issue should not be a major problem.

The flicker issue is typical to wind turbines due to the intermittent nature of the wind resource. The problem is critical for fixed speed turbine generators as it is not possible to store the turbulence of the wind in the form of rotational energy in the rotor. For a variable-speed turbine, the power fluctuations caused by wind variations can be more or less absorbed by changing the rotor speed and thus power variations originating from the wind conversion and the drive train can be reduced. Depending on the strength of the grid connection, the resulting power fluctuations can result in grid voltage fluctuations, which can cause unwanted fluctuations in bulb brightness.

As wind turbine generators use different technologies other than that of conventional synchronous generators, analyzing the impact of dynamics and stability of the power system become important. Adequate modelling of turbine generating systems is essential to investigate those impacts.

The second aspect coming under system wide impact is the reactive power and voltage control possibilities. Wind power affects the reactive power generation and voltage control possibilities in the system mainly for following reasons.

- Wind turbine generating systems have very limited capability to vary their reactive power output
- Wind power plants cannot be flexibly located compared to conventional thermal power plants from the perspective of grid voltage control
- Wind power plants are weakly coupled to the grid at low voltages and distance sites

Due to the above facts, a comprehensive analysis on power system voltage control possibilities should be conducted when integrating wind power plants in to the power system.

Since the prime mover of the wind power cannot be controlled, it impacts on the frequency control and the dispatch of the remaining conventional units in the power system. Further the variability of wind on long term (> 15 min.) tends to complicate the dispatch of conventional units by varying the demand curve to be matched by those generating units.

All the above discussed effects become more severe at high wind power penetrations. The topic of this dissertation is focused on quantifying the wind penetration level in a particular area of the power system based on the limit at which system wide effects start to occur.

1.3. Motivation

The Government of Sri Lanka has declared the development of renewable energy to be of high priority in line with the national policy of maximizing indigenous sources and ensuring fuel diversity.

At present a large number of wind power development proposals have been submitted to CEB in order to get the approval to connect into the national grid. A clear idea about the power system's capability of absorbing wind power is essential when granting permission to develop those wind farms. This study is an attempt to figure out the wind absorption capability of the Sri Lankan power system around Kalpitiya peninsula.

1.4. Research approach

The topic being investigated in the research project is the impact of large wind integration on the power system both in the steady state and the transient state. The outcome will be a quantified wind penetration level in a particular area of the power system based on the limit at which the adverse effects of wind power starts to occur on the power system. Note that, in this dissertation, the penetration level is defined as the amount of wind power that can be absorbed in to the grid at a particular point in a given year.

The study will narrow down to Kalpitiya peninsula and the reasons for this are described below.

Large numbers of wind power development proposals around this area have already been submitted to the utility and it is assumed that they should be served as first come first serve basis.

Out of other resource areas (mainly Mannar, Jaffna and Central Hills), only Mannar is located on the same wind line with Kalpitiya where the system frequency concerns have to be handled together. However the access to the national grid from Mannar sites is not developed yet and there are no proposals to extend the national grid towards Mannar sites up to year 2016. Hence this research omits the possibility of developing Mannar wind sites within the study period (2010-2016).

The penetration levels of the other locations can be separately treated based on the fact that their wind patterns do not coincide with the studied region. But, it may further complicate the dispatch schedules of the remaining conventional units and hence more attention needs to be paid on the power system operational aspects.

Out of the three common wind generating technologies, this dissertation use doubly fed induction generator (DIFG) technology to model wind turbine generators as it is the most popular technology at present. Further, the adverse effects of directly coupled induction generators such as severe voltage fluctuations and limitations in reactive power capabilities should be eliminated to comply with the grid code. Hence, the impact of directly grid coupled generators on the grid can be assumed more or less similar to the DIFGs after adopting the eliminating techniques such as static var compensators, soft starters and rotor resisters to damp out input variations, which become compliment to comply with the grid code.

In this research project, the widely known power system simulation software package PSS®E was used. This program contains dynamic simulation models for wind turbines that have been successfully used by numerous PSS®E users around the globe.

The first step was to use load flow simulations to investigate network limitations at the steady state. The next step was to investigate the impact of wind power on the power system dynamic behaviour. Finally, quantified grid absorption capabilities for the years 2010, 2012, 2014 and 2016 were identified by analyzing the steady state and the stability study results.

1.5. Dissertation outline

This dissertation reflects the research approach discussed above. In chapter 2, the DFIG model and the various control models used will be discussed in more detail. Further, the system configurations and modelling approach will also be discussed in the same chapter.

Steady state system analysis including load flow, contingency and transmission transfer limits will be discussed in chapter 3.

Chapter 4 will present the frequency stability analysis, while chapter 5 presents the voltage stability part.

Chapter 6 will reinvestigate the transient stability of the power system with proposed wind integrations in chapter 4&5.

In chapter 7, the conclusions of the research project are summarized and topics for further research are indicated.