CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

There has been a continuous enhancement of power generation from renewable energy sources in recent years in developing countries. The increasing demand of electricity due to developments at a faster rate further widens the gap between supply and demand. Hence, it is becoming difficult to fulfil the increasing demand of electricity only with conventional sources. The main advantages of renewable energy sources of power generation are no fuel consumption in most cases, sustainable and eco-friendly, but suffer from the disadvantage of their fluctuating nature. The renewable energy sources such as wind, solar and micro/mini hydro etc. are generally integrated with diesel system to supply reliable power to isolated loads (Lipman 1989, Hunter and Elliot 1994, Abbey and Joss 2009, Shaahid 2010). The diesel gensets with synchronous generators and renewable sources are operated in parallel to meet load demand through a small distribution network.

There are many remote and isolated places in the world, which are still without electrical power and low generation capacity of the grid connected systems, especially in developing countries. The mismatch between supply and demand can be minimised if some of the locations have stand-alone / isolated power systems to meet local load requirements (Abbey and Joss 2009). Moreover, wind power is expected to be economically attractive when the wind speed of the proposed site is considerable for electrical
generation and electric energy is not easily available from the grid (Ackerman 2005). This situation is usually found on islands and/or in remote localities.

In most remote and isolated areas, electric power is often supplied to the local communities by diesel generators. Due to the environmental and economic impacts of a diesel generator, interest in alternative cost efficient and pollution free energy generation has grown enormously (Hunter and Elliot 1994). To reduce dependence of fuel for electric power generation, an appropriate power generation technology is required in conjunction with the diesel based system (Lipman 1989). By virtue of geographical location, renewable energy sources like wind; small hydro streams etc. are available in abundance in most areas of the world. There has been a considerable advancement in the wind turbine and micro hydro technology for power generation. The alternate renewable energy in parallel operation with diesel based systems forms a suitable power generation system which may be economically viable. Such systems are called isolated or stand alone hybrid power system.

Wind power is intermittent due to worst case weather conditions, so wind power generation is variable and unpredictable. Wind power is not fully controllable and its availability depends on daily and seasonal patterns. As a result, conventional energy sources such as diesel generators are integrated with renewable energy for reliable operation. The hybrid wind power with diesel generation has been suggested by Lipman (1989) and Hunter and Elliot (1994) to handle the above problem. A hybrid wind-diesel system is very reliable because the diesel acts as a cushion to take care of variation in wind speed and would always maintain an average power equal to the set point. To meet increasing load demand for an isolated community, expansion of this hybrid power system is required. A micro hydro generating unit is added in parallel where water streams are abundantly
available (Ashok Sinha 1993). The resulting wind-micro hydro-diesel hybrid power system must provide good quality service to the consumer load, which depends mostly on the type and action of the generation controller (Bhatti et al. 1997b).

The hybrid power systems (eg. wind-micro hydro-diesel) capacity wise are very small as compared to conventional power systems in different countries. But they are very important as they are the only source of electrical supply for the communities in the areas where the conventional grid supply is not available (Nayar et al. 2007, Hrayshat 2009). In India, there are applications of diesel gensets for irrigation, mobile communication towers. The defence organisation of India (military) has diesel gensets for supplying power to the contingents consists of radar communication, offices and residences. Also there is large number of industrial units running purely or partially on diesel gensets due to non-availability or non-continuity of grid supply. India is very rich in wind resources, also has huge solar potential and vast untapped potential from biomass sources. Hence, efforts are going on by different agencies (government/private) to have hybrid systems for economical power generation as well as to avail carbon credits.

The unsteady nature of wind and frequent change in load demands may cause large and severe oscillation of power. The fluctuation of output power of such renewable sources may cause a serious problem of frequency and voltage fluctuation of the grid (Hunter and Elliot 1994, Ackerman 2005). It is therefore necessary to have a proper control strategy for maintaining the scheduled frequency. An effective controller for stabilising frequency oscillations and maintaining the system frequency within acceptable range is significantly required. The system may lose stability if the system frequency cannot be maintained in the acceptable range. As a result, proper frequency controller is greatly expected.
1.2 LOAD FREQUENCY CONTROL

The load frequency control (LFC) damps out the frequency deviation and maintains dynamic performance of the system. The mismatch between generated power and load causes deviation in system frequency from the nominal value. Different strategies (Woodward 1980, Mitani et al. 1988, Davies et al. 1988, Lipman 1989, Dettmer 1990, Nayar et al. 1993, Bhatti et al. 1995) can be adopted to reduce the mismatch between generation and load and thereby controlling the system frequency deviation. The strategies are dump load control (Woodward 1980), priority switched load control (Lipman 1989), fly wheel (Davies et al. 1988, Dettmer 1990), superconducting magnetic energy storage (Mitani et al. 1988) and battery energy storage system (Nayar et al. 1993). These schemes/strategies have their own limitations and are quite expensive without saving in fuel. In the hybrid system, power balance can be achieved by controlling the generation instead of output power and is called load frequency control (Tripathy et al. 1984, Kamva 1990). The load frequency controller generates a control signal based on load disturbance, and transfers it to the speed-gear changer of the diesel engine, which in turn changes the generation to match the load. Therefore the system performance depends upon the controller.

The load-frequency controller compares the actual value of the output frequency with the reference frequency (desired value), determines the deviation and produces control signal that will reduce the deviation to zero. The manner in which the load frequency controller produces the control signal is called the control action. In the proposed work, the control action of LFC is investigated with the application of intelligent techniques and compared with conventional control. In recent years, designing load-frequency controller has received great attention of researchers. The advent of modern intelligent techniques such as fuzzy logic, neural network, genetic
algorithm, simulated annealing, particle swarm optimisation etc. has solved the power system problems to a great extent.

1.2.1 Conventional Control

Depending upon the control action, the conventional type of load-frequency controller may be,

i) Proportional controllers
ii) Integral controllers
iii) Proportional-plus-Integral Controllers (PIC)
iv) Proportional-plus-Integral-plus-Derivative Controllers (PIDC)

As the proposed intelligent controllers in this work are simulated and compared with the conventional PI controller, here the control action of PI controllers are described.

1.2.1.1 Proportional-Plus-Integral (PI) control action

The combination of proportional control action and integral control action is termed as proportional-plus-integral control action. For a controller with proportional control action, the relationship between the output of the controller \( U(t) \) and the actuating error signal \( E(t) \) is

\[
U(t) = K_p \cdot E(t)
\]

(1.1)

(or in Laplace transformed quantities,

\[
\frac{U(s)}{E(s)} = K_p.
\]

(1.2)

where \( K_p \) is termed as proportional gain.
In a controller with integral control action, the value of the controller output \( U(t) \) is changed at a rate proportional to the actuating error signal \( E(t) \). That is

\[
\frac{dU(t)}{dt} = Ki \cdot E(t) \quad (1.3)
\]

(or)

\[
U(t) = Ki \int_0^t E(t) \, dt \quad (1.4)
\]

where \( Ki \) is an integral gain. The transfer function of the integral controller is

\[
\frac{U(s)}{E(s)} = \frac{Ki}{s} \quad (1.5)
\]

If the value of \( E(t) \) is doubled, the value of \( U(t) \) varies twice as fast. For zero actuating error, the value of \( U(t) \) remains satisfactory. Such an integral control action is sometimes called reset control. The block diagram of conventional PI controller is shown in Figure 1.1.

**Figure 1.1** Block diagram of conventional PI Controller

The control action of the proportional-plus-integral controller is defined by the following equation:

\[
U(t) = Kp \cdot E(t) + \frac{Kp}{\tau_i} \int_0^t E(t) \, dt \quad (1.6)
\]
(or) the transfer function of the controller is

\[
\frac{U(s)}{E(s)} = K_p \left[ 1 + \frac{1}{T_i s} \right]
\]

(1.7)

where \(K_p\) is the proportional gain, and \(T_i\) is called the integral time. Both \(K_p\) and \(T_i\) are adjustable. The integral time adjusts the integral control action, while a change in the value of \(K_p\) affects both the proportional and integral parts of the control action. The inverse of the integral time \(T_i\) is called the reset rate.

1.3 **BLADE PITCH CONTROL**

In this thesis, simulation of an isolated wind-micro hydro-diesel hybrid system includes wind turbine pitch control. Wind turbine blade angle pitch control has a significant impact on dynamic behaviour of the system (Das et al. 1999). Regulation of power delivered to rotor is achieved through turbine blade angle pitch control (Bossanyi 1987). Improvement in power quality can be achieved by continuously monitoring the wind turbine speed and altering the blade pitch angle according to an active feedback control system added to the turbine.

The pitch control system consists of a power measurement transducer, a power set point control, a PI feedback function and a hydraulic actuator which varies the pitch of the blades. Wind turbine rotors are generally either fixed or variable pitch. A variable pitch machine allows the angle between each blades chord line and rotor plane to change. This is usually utilised to regulate power and to control rotor over-speed and shutdown of the wind turbine. In this thesis, wind turbine system with blade pitch control (BPC) is considered for investigation. Under random wind
power input, the BPC in the wind side can be expected to be a cost effective device for reducing wind power deviation (Bhatti et al. 1997 a and Das et al. 1999).

1.4 SYSTEM CONFIGURATION

In the present work, an isolated wind-micro hydro-diesel hybrid system is considered for mathematical modelling under transient conditions. In the hybrid system considered, synchronous generator is connected on a Diesel-Generator (DG) and Induction Generators (IG) are connected on wind turbine (Allan 1960, Bansal et al. 2003c) and on hydro turbine. The blade pitch controller is installed in the wind side while the governor is equipped with the diesel side. The supplementary controller of the diesel generating unit, called the LFC is installed with intelligent techniques to satisfy the balance between the real power and load. The function of the controller is to generate a command signal to the diesel engine (Bhatti et al. 1997a, 1997b). In the wind turbine generating unit, novel intelligent controller is designed as a supplementary controller for the pitch control. This controller detects the deviation of the wind power generation ($\Delta P_{GW}$) and controls the wind power generation to maintain at constant level. The block diagram of isolated wind-micro hydro-diesel hybrid power system with LFC and BPC is shown in Figure 1.2.

Various intelligent controllers are designed to improve the performance of the hybrid system. The dynamic performances of the hybrid system with these designed intelligent controllers have been studied and investigated for various load disturbances and wind input power disturbances.
1.5 OBJECTIVE OF THE THESIS

Objective of the Thesis is to minimize the various performance criteria such as settling time, overshoot and steady state error value for the responses of the wind- micro hydro- diesel hybrid power system by designing a proper control strategy such as Load Frequency Control (LFC) and Blade Pitch Control (BPC). It is achieved through implementation of the intelligently designed controllers for maintaining the system frequency, wind power and hydro power generation of the hybrid system by controlling the generation of diesel power generating unit. This is justified by simulation, analysis and comparison. This thesis presents novel intelligent techniques for the proposed control of the hybrid power system by proceeding with the following steps.
1. Mathematical modelling of isolated wind-micro hydro-diesel hybrid power system for LFC and BPC with conventional PI controller for improving the performance of the existing system.

2. Following intelligent controllers are designed and investigated by simulating the simulink model of the hybrid system.
   1. Fuzzy Logic Controller (FLC)
   2. Self tuning Fuzzy Logic PI Controller (FLPIC)
   3. Adaptive gain scheduling Fuzzy Logic PID Controller (FLPIDC)
   4. Novel intelligent Multi stage Fuzzy Logic PID Controller (Multi stage FLPIDC)
   5. ANFIS based Neuro-Fuzzy Controller (NFC)

3. Tuning the parameters of intelligent FLC, FLPIC, FLPIDC and Multi stage FLPIDC for optimal system operation under various load disturbances and wind input power disturbances for LFC and BPC.

4. Tuning and training the parameters of Neuro-Fuzzy Controller for LFC and BPC of the hybrid system.

5. Comparing and analysing the dynamic responses for basic Fuzzy Logic Controller of the hybrid system with conventional PI Controller.

6. Investigating and comparing the dynamic responses for improved intelligent controllers (FLPIC, FLPIDC, Multi stage FLPIDC and ANFIS based NFC) of the hybrid system with conventional PIC and basic FLC.

1.6 LITERATURE SURVEY

There has been a lot of work in the area of power system quality control and even then there is a great need to improve the frequency/real power and reactive power control strategy. The imbalance between generation and load is the main reason behind the instability of frequency and voltage. A constantly increasing power demand has to be met through an adequately planned electrical power generation programme (Tripathy et al. 1992, Das et al. 1999).
The most challenging application of computational intelligence is the area of power system because of the economic and quality of power to be supplied to consumer.

1.6.1 Isolated Renewable Hybrid Power System

The conventional energy sources are not environmental friendly source of power generation to supply power to all consumers near and far-off places. Moreover, wind power is expected to be economically attractive when the wind speed of the proposed site is considerable for electrical generation and electrical energy is not easily available from the grid (Ackerman 2005). The mismatch between supply and demand can be minimised if some of the locations have isolated/stand-alone power systems to meet local load requirements (Abbey and Joss 2009). Integration of renewable sources with other source of power generation such as diesel etc. is required to obtain a reliable power system (Lipman 1989, Hunter and Elliot 1994, Shaahid 2010, Ross et al. 2009).

1.6.2 Load Frequency Control

The Load Frequency Control (LFC) has been one of the most important subject concerning power system engineers in the last decades. The function of the load frequency is to eliminate the mismatch between real power and load demand. Different control schemes for load frequency control strategies such as conventional, intelligent and optimistic methods are discussed by Shayegi et al. (2009) for researchers. Understanding automatic generation control by Jaleeli et al. (1992) and recent philosophies of automatic generation control strategies by Ibraheem et al. (2005) have created a base for researchers. George Gross and Jeong Woo Lee (2001) analysed the LFC performance criteria to stabilise the system. Among the various types of LFC, PI controller is most widely employed to speed governor systems for

1.6.2.1 Fuzzy logic controller

Based on the experience in implementing LFC schemes, modifications in the design of efficient controllers are suggested from time to time, according to the change in power system environment (Karnavas and Papadopoulos 2002). Ibraheem et al. (2005) explained that a supplementary controller is needed along with the governor. The investigation carried out on the conventional approaches resulted in relatively large overshoots and frequency deviation. The advent of AI techniques such as Fuzzy logic, ANN and GA has gained increasing interest for application in LFC of power system (Vinod Kumar 1998, Zeynelgil et al. 2002, Mathur 2006).

Fuzzy logic is an innovative technology that enhances conventional system design with engineering expertise (Kaimal et al. 1997). As in many different areas, the use of fuzzy logic controller (FLC) has been increased rapidly in power systems, such as in LFC, voltage regulation, Stability, Load estimation, power flow analysis and many other fields. El-hawary (1998) has given a detailed survey on the applications of FL in power systems. The applications of fuzzy set theory to power systems and the basic procedures for fuzzy set band methods to solve specific power system problems are explained briefly by Momoh et al. (1995). This paper presents a comprehensive set of references classified according to the power system areas mainly published in archival journals on the fuzzy set theory.
applications in power systems (1994-2001) as shown in Figure 1.3 (Bansal 2003a). Chown and Hartman (1998) discussed the experience of fuzzy logic controller design for AGC.

![Figure 1.3](image)

**Figure 1.3** Classification of papers on Fuzzy set theory applications in power systems

1.6.2.2 Fuzzy logic PI and PID controller

Self tuning fuzzy logic PI and PID controllers are designed and explained by Sheikh et al. (2009) and Zulfatman and Rahmat (2009). These papers discussed about tuning the parameters of PID controllers by fuzzy logic technique. The gain scheduling FLPI and FLPID controllers for LFC are presented by Chang and Fu (1997), Masila et al. (2004), Kumar and Chanana (2010). Multi stage FLPID controllers for LFC are designed and performance is compared with conventional controllers by Shayeghi et al. (2006, 2007).
1.6.2.3 Neuro-fuzzy controller

This newly developed control strategy combines the advantages of Neural network and Fuzzy Inference System and has simple structure that is easy to implement. In order to keep system performance near its optimum, it is desirable to track the operating conditions and use the updated parameters to control the system (Lin and Lee 1996, Cirstea et al. 2002, Jang et al. 2005). Adaptive Neuro-Fuzzy Inference System (ANFIS) is an artificial intelligent technique which creates a fuzzy inference system based on the input output model data pairs of the system (Jang et al. 2005). Ashok Kusagur et al. (2010) presented the modelling and design of an Adaptive Neuro-Fuzzy Inference System (ANFIS) for Speed Control of Induction Motor.

Hybrid Neuro-fuzzy approach for Automatic Generation Control (AGC) of two area power system was presented and the improved performance is analysed by Gayadhar et al. (2009). Srinivasa Rao (2010) discussed the frequency regulation of hydro thermal system under deregulated environment by using Adaptive Neuro Fuzzy based inference system for LFC.

1.6.3 Regulation of Frequency and Power of the Hybrid System

The works reported in the literature survey are for LFC of thermal and hydro thermal system with conventional and intelligent controllers (Chang and Fu 1997, Mathur and Manjunatth 2006, Cam 2007).

My work concentrates on the investigations in the regulation of frequency and generated power of an isolated renewable hybrid power system for LFC and BPC using intelligent techniques.
1.6.3.1 Wind-diesel hybrid power system


Different strategies can be adopted to reduce a mismatch between generation and load and thereby control system frequency deviations. The Strategies are dump load control (Woodward and Boys 1980), priority switched load control (Lipman 1989), flywheel (Davies et al. 1988, Dettmer 1990), superconducting magnetic energy storage (SMES) (Mitani et al. 1998, Mufti et al. 2002, Ngamroo 2009) and battery energy storage (BES) systems (Nayar et al. 1993, Raja et al. 2010, Mohamed Thameem Ansari and Velusami 2010). By these strategies, they showed their improved performance by comparing with other control schemes. These schemes have their own limitations and are maintenance-intensive and expensive.
Kamva (1990) suggested to achieve the power balance by controlling the generation and termed it as Load Frequency Control.

The wind power generation of the hybrid system maintained at constant level with blade pitch controller using conventional PI controller was explained by Bhatti et al. (1997a, 1997b). Cuk Supriyadi et al. (2008a) and Cuk Supriyadi (2008b) focussed on the parameter optimization of pitch controller for robust frequency control in an isolated wind-diesel hybrid system by monitoring the wind turbine speed continuously.

Reactive power control of renewable hybrid power system was proposed by Bansal et al. (2007), Pawan Sharma et al. (2010a, 2010b) and maintained the reactive power and voltage at an acceptable range. Load frequency control on wind-diesel hybrid system was explained by Bhatti et al. (1997a) using conventional PI controller. Hu and Chen (2005) presented a study about the frequency and power control in an autonomous power system consisting of wind turbines, diesel generation units and energy storage devices. Mairaj et al. (1998) presented a new scheme for smoothing out the voltage and frequency fluctuations simultaneously in a hybrid wind-diesel system using a SMES unit. Robust frequency control of wind-diesel hybrid system using SMES was discussed by Ngamroo (2009). Raja et al. (2010) presented a PSO based robust frequency control of wind-diesel power plant using BES. Simulation result of BES controller confirms its robustness for load disturbances.

For wind-diesel system, Chaiyatham et al. (2009) developed Fuzzy logic PID controller using Bee-Colony Optimisation (BCO) and the performance analysed only to control the frequency of the system for 1% load disturbance. Chokpanyasuwan et al. (2008) designed robust FLPID controller using Particle Swarm Optimisation (PSO) for frequency control of wind-diesel system and resulted with better performance only for 1% load
disturbance. Most of the works were reported to control the frequency and voltage of the wind-diesel hybrid system.

1.6.3.2 Wind-micro hydro-diesel hybrid power system

Only one or two works were reported on power quality control of wind-micro hydro-diesel hybrid power system. Bansal (2003b) presented the analysis on reactive power control of wind-diesel-micro hydro hybrid system. Bhatti et al. (1997b) analysed the performance of the wind-diesel-micro hydro hybrid power system for LFC using conventional PI controller. In their work, they have analysed the transient responses for different load disturbances and the frequency deviations are damped out with some steady state error value.

1.6.4 Summary

The works reported in the Literature survey for LFC using conventional and intelligent controllers were based mainly on Thermal and hydro thermal systems. Some works were reported in the wind-diesel hybrid system. It is clear from the literature survey that intelligent control techniques find wide application in the areas of stability enhancement, frequency control and voltage of the power system. Only two works were reported in wind-diesel-micro hydro hybrid system, one in reactive power control using Artificial Neural Network (ANN) and one in LFC using conventional PI controller.

1.7 ORGANIZATION OF THE THESIS

The details of the research are organized in seven chapters. The contents of these chapters are briefly outlined as follows.

Chapter 1 gives the introduction of power quality of the renewable hybrid power system. It also provides general introduction about the
importance of LFC and BPC in hybrid power system. This chapter presents the objective of the thesis and literature survey in the related areas.

Chapter 2 presents the mathematical modelling of an isolated wind-micro hydro-diesel hybrid power system. The system model is developed with conventional PI controller for LFC and BPC, which is used for comparison with the proposed intelligent controllers designed in further chapters. The parameters of the conventional controller are optimized using Integral Square Error (ISE) technique.

Chapter 3 presents the introduction of different intelligent control schemes. Background and applications of fuzzy set theory are outlined. It proposes intelligent controller to the considered hybrid system with fuzzy logic technique. Structure and design of Fuzzy Logic Controller for LFC and BPC of the hybrid system is explained in detail. The simulation results are compared and analysed with conventional PI Controller. Significant improvement in system performance has been observed for FLC through the obtained results.

Chapter 4 presents the introduction of Self tuning Fuzzy Logic PI Controller and Adaptive gain scheduling Fuzzy Logic PID Controller for further improvement in system performance. The structure, simulink model, design and implementation of Self tuning FLPIC and Adaptive gain scheduling FLPIDC for LFC and BPC of the hybrid system are explained in detail. The simulation results are compared and analysed with FLC and conventional PIC. The observed results show that the FLPIC and FLPIDC are more effective than FLC and conventional PIC.

Chapter 5 presents a novel intelligent Multi stage FLPID Controller for LFC and BPC of the wind-micro hydro-diesel hybrid power system. A different approach of fuzzy logic structure is used as Multi stage FLPIDC to
enhance capability of PID Controller. The structure, simulink model and design of Multi stage FLPIDC are explained in detail. The simulation results are compared and analysed with previously designed FLC, FLPIC and FLPIDC. The observed results show that Multi stage FLPIDC is robust and effective than previously designed other Fuzzy Logic Controllers.

Chapter 6 presents an ANFIS based Neuro-Fuzzy Controller for LFC and BPC of the wind-micro hydro-diesel hybrid power system. Background and application of Neuro-Fuzzy system is explained by combining the merits of Neural networks and Fuzzy logic. Adaptive Neuro-Fuzzy Inference System (ANFIS) architecture is explained in detail. This chapter presents the design steps of ANFIS based NFC and its implementation for LFC and BPC of the hybrid system. Simulation results are compared and analysed with FLC and conventional PI Controller. Improvement in system performance are investigated with the hybrid learning method of ANFIS based NFC.

The Conclusion of the investigations is summarized in Chapter 7. Scope of future work has been suggested in this chapter.