9. Conclusions and Future Scope

9.1 Conclusions

Wind Power, load, and direction are three important aspects for the assessment of wind resources. The accurate assessment of wind resources enables in (i) efficient conversion of kinetic energy of the wind into useful power generation, (ii) estimation of design wind speed of the structures that lead safe design of structures against forced ruptures, (iii) predicting the most probable zone for the installation of the wind farm, and overhead transmission lines. Although the utilization of wind for practical purpose is from primitive time, continuously increasing the demand for clean and sustainable power has led the researchers to explore new locations for the installation of wind farms, exploring new heights for capturing maximum amount of kinetic energy of the wind, developing new and sophisticated equipment to harness maximum energy, and determination of favourable wind direction to install wind farm that can capture most frequent wind speed encounter in nature, etc. Wind resources can accurately be Modelled using wind statistics. In this thesis, wind resources have been assessed using various statistical models. The sites selected for statistical modelling are three onshore corners of India namely, Trivandrum, Ahmedabad, and Calcutta. The brief conclusions of the present work are discussed below.

The wind data obtained from IMD, Pune are in the distorted form as it contains sampling error. Therefore, the cause of sampling error and technique for its eradication has been adopted so that accurate modelling of wind speed data can be carried out. In this scope of study, it has been observed that the sampling error has significant biasing effect when shape parameter of Weibull distribution (*W.pdf*) is less than unity.

However, the biasing effect decreases as shape parameter approaches towards 2 and beyond it the biasing effect completely disappears.

The methods employed to estimate the Weibull parameter also play a dominant role in estimating unbiased Weibull parameters. The method should be robust, accurate, efficient in calculations, free from binning problems, as well as it does not require any iterative technique for its solution. Therefore, in this section, new proposed modified energy pattern factor method has been used to estimate the parameters of the *W.pdf*. This new method possesses all the characteristics as mentioned above. This method has been compared with six other methods based on simulated data as well as real wind speed data and found that the performance of this method is viable (or even better) than other methods for the estimation of Weibull parameters.

The estimated parameters have further been utilized for wind energy harnessed at particular sites. In this section, the estimated parameters at 10 *m* height are extrapolated upwards to 30 and 60 *m* hub heights of the turbine. The extrapolated parameters have further been utilized to calculate the wind turbine characteristics, viz., Capacity Factor (*CF*) and Power Coefficient (C_p). It has been observed that both these characteristics have a maximum value at different speed parameters, namely, cut-in (V_c), rated (V_r), and furling or cut-out (V_f) speed of the turbine. Therefore, for simultaneous optimization of these two turbine characteristics a novel turbine performance index (*TPI*) has been proposed. The proposed *TPI* takes into account monthly average of the wind speed data and enables in evaluating the optimum rated turbine speed ($V_{r,opt}$) for a given site. At 30 *m* height, the rated wind speed (V_r) of around 11-12 *m/s* and at 60 *m* height, the V_r of around 13-14 *m/s* are the optimum design rated wind speeds ($V_{r,opt}$). Comparative study of commercially available wind turbine reveals that the E-29/300 (V_r = 12 *m/s*) and K-62/1300 (V_r = 14 *m/s*) for 30 and 60 *m* hub heights respectively, are the most suitable for three selected stations (Ahmedabad, Trivandrum and Calcutta) in India, showing higher *TPI* and output wind power density.

Certain wind speed data are heterogeneous, i.e., they show bimodal and bi-tangential characteristics. These wind speed data are difficult to model using *W.pdf*. To model, such types of wind speed data mixture distributions came into existence. In this section, several mixture distributions, as well as distribution derived from maximum entropy principle have been compared with 2-parameter *W.pdf*. It is concluded that the proposed Gamma-Gamma distribution (*GG.pdf*) shows the lowest Akaike Information Criteria (*AIC*) value and is the most suitable distribution to model wind speed data. This distribution performs equally well in estimating the wind power density. Thus, proposed *GG.pdf* can be proved to be a suitable alternative to conventional 2-parameter *W.pdf* to assess the wind speed data for Indian climatology.

Wind load is an equally important aspect as wind power for wind resources assessment. The accurate calculation of design wind speed (V_d) enables in safe design of structures against forced rupture. In this section, for estimation of design wind speed, a new approach has been used that take advantages of both conventional block maxima, and peaks over threshold and avoid their limitations. This new approach is a most suitable for the region of varied wind climate. The wind speed data have been classified into the block of months and each month has separately been taken for extreme value analysis. The threshold value has been selected using quantile function of the *W.pdf*. The data over threshold have been fitted into three types of extreme value distributions as well as Generalized Pareto Distribution. It has been found that Fréchet distribution is the most suitable distribution to model extreme data and March shows the highest V_d of 50.189 *m/s* for Trivandrum, and for both Ahmedabad and Calcutta the highest V_d have been found to be September, i.e., 31.69 and 64.55 *m/s* respectively.

For complete harnessing of wind energy potential, the wind direction assessment is also of utmost importance. In this section, wind directions have been analyzed using 2-von Mises (*vM.pdf*), new 4-Kato-Jones (*K-J.pdf*), and 5-mixture von Mises (*mvM.pdf*) distribution. It has been found that for wind direction analysis the new *K-J.pdf* is a viable (and often better) alternative to the classical *vM.pdf* for describing the wind direction. The southwest monsoon plays a dominant role in deciding the installation of the wind farm in India for generating electricity. The leading path for installation of the wind farm has been found to be the southwest direction for Ahmedabad; northwest direction for Trivandrum, and the south direction for Calcutta. Among these three stations, taken as a reference at three onshore corners of India, Ahmedabad appeared as the most suitable site for installation of the wind farm followed by Trivandrum and Calcutta. Both wind rose and wind direction histogram, confirm the same conclusion about the most suitable direction, thereby, parameterizing the wind direction data can turn out to be a fruitful option for wind directional analysis.

9.2 Future Scope

So far, the study has not addressed the following points and can be considered as a future scope of work:

1. Study of vertical wind shear should be considered. Therefore, wind speed data at two altitudes, and the model suitable to define the vertical wind profile need to be studied.
2. The structural performance of wind turbine blades and poles against wind load needs to be studied, especially, during strong storm conditions like cyclones.
3. The generation of wind power from an offshore wind turbine needs to be studied. The formation of marine boundary layer and wind load on an offshore wind turbine are of prime interest. The study would be different because of the fact that the wind and wave loads are dynamically coupled with each other.