Chapter 8

Conclusion and Future Work

8.1 Conclusion

In this work, the three aspects of stability; voltage stability, harmonic stability and small signal stability are analysed. The different cases are studied and results are evaluated in depth. The gist of all results and conclusion are given here.

The steady state voltage stability is an important aspects of power system with renewable energy sources. The probabilistic approach should be followed, during the planning stage and also during routine unit commitment, to put check on the voltage instability. As the renewable energy will contribute more and more in future, the voltage instability is likely to creep in to the system and may affect the whole power system. In this work, from simple approach for single system to complex approach using statistical estimation methods are given. Different statistical approaches are compared and the balanced approach has been suggested for practical use. The point estimation is used to reduce the computational burden and still holding accuracy. This approach is sampling based and applied before core analysis. The problem with point estimation is that, it requires large data to compute the cummulants and moments. Also, this method doesn't guarantee the stability with increased number of variables. Also, with multipoint estimation, the accuracy should get improved, but it is found that accuracy is negatively affected. In this regard, the Latin Hypercube Sampling approach is very balance. This method gives very accurate first moment (μ) and very consistent second moment (σ). The error in calculation in second moment is on the higher side as compared to point estimation, but it is still satisfying as the result shows consistency of 12 % to 15 % in error. The important point, which should be kept in mind is that, the data points required for point estimation is 1000, whereas the LHS requires very few samples (10 samples). In probability estimation, various methods like Gram - Charlier expansion, exact series expansion and several approximation is examined for accuracy. It is found that second approximation works well and gives good consistency. The Gram - Charlier expansion is very conservation and overlooks the accuracy to uphold the stability or series convergence. The estimation and series expansion method can be used in combination to achieve the best result. The LHS and Second Approximation (SA) is good combination, which can estimate non-normal variable accurately with small sample size.

The variability of wind power definitely induce the variability in voltages at various buses. The higher the share of uncertain sources, larger will be the variability. Also, it is found that the variability in voltage gets affected by the correlation between different wind sources. Negatively correlated wind sources helps in maintaining the voltage stability. Also, the system strength (short circuit capacity) affects the voltage stability. The placement of wind sources also plays important role in determining the voltage stability. The wind sources shall be placed in the system, where the system strength is high.

The second important aspect, which studied in this work, is harmonic stability. The harmonic stability is a derived word and it is not found in any literature so far studied. The reason behind using this word is to imply that the stability of power system gets affected by harmonic level in the power system. The new technologies of wind turbines are mostly based on power electronic converters. The power electronic converters generate harmonics. As the number of WTGs in power system is increasing, the harmonic level definitely get affected. And first, it will affect the individual WTG and consequentially the entire power system will get affected. Traditionally, harmonic problems are related with the power quality. But, in this work, it is related with stability.

To study the harmonic stability and find optimal solution, different methods are studied and modal analysis is selected based on merits, mainly considering its simplicity and effectiveness. Till now, the modal analysis has been applied for determination of harmonic resonance only. However, in this work, it is taken further for determining the root cause of harmonic resonance and designing the optimal solution.

Different WTGs have, different harmonic spectrum. So, any WTG cannot be connected at any location in the power system. The system strength and harmonic spectrum of WTG shall be checked before placement of any WTG. Using actual spectrum of two different WTG, it is explained that, how one WTG is suitable and another is not for connecting to a given location.

The harmonic level also gets affected by the controller structure of WTG. It is explained that WTG with different output filter, different Phase Lock Loop and different gains, will have different output impedance characteristics. The controller parameter can be used to reshape the converter impedance and achieve stability. It is also shown that how capacitive reactance is achieved using gain parameter.

The third and important aspect studied in this work is small signal stability. The small signal stability of WTG gets affected by different parameters of power system and it is studied using probabilistic approach. The single point small signal stability of WTG is not useful with uncertain wind and many other variables in power system. On the other side, multipoint small signal stability requires many computation and hence will be time consuming and shall not be appropriate for many optimization techniques. The balance can be achieved by using probabilistic analysis. The proposed method based on LHS is less computational intensive and can be used for fast evaluation of stability. It is demonstrated that the variation in different parameters may affect the small signal stability of WTG. It is difficult to predict the stability with single point calculation. Here, the simple and effective way of analysis has been given to carry out probabilistic small signal stability analysis.

Finally, the simulation is carried out using EMTP to show the compliance to grid code related to LVRT. In this simulation it is shown that, the decoupled control is effective in successful in riding through of fault.

8.2 Future Work

In this work, the probabilistic analysis of DFIG is restricted to power circuit of DFIG only and controller dynamics are not included. It has been done intentionally to check the effect of uncertain variables of the small signal stability of DFIG. This approach can be taken further and shall be used to design the effective controller, which ensure stability under all operating conditions.