ABSTRACT

Growing environmental concerns and attempts to reduce dependency on fossil fuel resources are bringing renewable energy resources to the mainstream of the electric power sector. Among the various renewable resources, wind power is assumed to have the most favourable technical and economical prospects. Wind generation technologies can be classified as-

(1) Fixed speed wind energy conversion system (FSWECS).

(2) Partially variable speed wind energy conversion system (PVSWECS).

(3) Variable speed wind energy conversion system (VSWECS).

Among the several wind generation technologies, VSWECS with power electronic interface has attracted interest due to its efficient and stable utilization of wind energy than FSWECS systems. On the other hand, PVWECS provides advantages such as- simplicity, robustness, reliability and low cost in comparison to variable speed wind turbines which require a larger number of power electronic devices, leading to more losses and complexity. In addition, it is possible to obtain a much faster output power response to wind speed variations by means of adjusting an external rotor resistance than FSWECS. However PVWECS have some drawbacks such as requiring reactive power compensation system and a narrow speed range regulation (typically limited to 10% slip above synchronous speed) due to the excessive power that is dissipated in the external resistor.

The main objective of this thesis is to study and analyze the small signal stability of the power system connected with fixed, partially variable and variable speed wind generators. Conventional squirrel cage induction

generator (SCIG) based FSWECS, wound rotor induction generator (WRIG) with rotor external resistance controller based PVWECS and permanent magnet synchronous generator (PMSG) based VSWECS are considered for the analysis.

PMSG is connected to the grid using AC-DC-AC link power electronic interface with machine side and grid side controllers. In order to maximize the power extracted from wind, (speeds between the cut-in and cut-off speed) wind turbines operate continuously at the optimum tip-speed ratio by changing the generator speed in proportion to the wind speed.This is achieved by the machine side converter (MSC). The grid side converter (GSC) controls the power flow between the DC-link and the grid to maintain the DC-link capacitor voltage at a constant value. Hence performance of a PMSG is largely dependent on its converter and associated controls.

Due to the stochastic nature of wind speed, generator speed varies continuously to track the maximum power point. These speed variations are translated into generator output power variations and in turn into DC link voltage fluctuations. Hence there arises a need for coordinated tuning of MSC and GSC controllers. However, coordinated tuning of these controllers using the traditional trial and error method is a cumbersome and challenging task. Therefore optimization techniques are being utilized for the coordinated tuning of controllers.

This thesis proposes an optimum design procedure for the coordinated tuning of MSC and GSC controllers of PMSG based WECS. The MSC and GSC controller parameters are determined by using three different approaches. Three approaches are posed as optimization problems with the following objective functions-

(a) Maximization of the overall system damping
(b) Minimization of time domain performance indices
(c) Simultaneously optimizing time domain performance indices and system damping (leads to a multi-objective problem).

The system damping is obtained through eigenvalue analysis and performance indices are calculated from transient stability analysis of the test system. The performance indices considered are maximum peak overshoot and settling time of the generator speed and the maximum peak overshoot, maximum peak undershoot and settling time of DC link voltage and grid voltage.

The first two (single objective) optimization problems (approaches 1and 2) are solved by using Genetic Algorithm (GA) whereas the third (multi objective) optimization problem (approach 3) is solved by the proposed RSM (response surface methodology)-NSGA II (non-dominated sorting genetic algorithm II) technique. The coordinated controller design is carried out in two steps in this technique. First step is to arrive at the analytical expression that relates the system damping and performance indices with the controller parameters. This is achieved using response surface methodology. In the second step the determination of controller parameters is posed as a constrained multi-objective optimization problem. The constrained multi-objective optimization problem is solved using NSGAII.

The proposed methodologies are tested on a SMIB (Single machine infinite bus bar) system with PMSG based WECS and results are compared. Transient stability analysis of SMIB system is performed with tuned controller parameters obtained by solving the above said optimization problems. The analysis is conducted for step change in wind velocity, variable wind speed under partial load operation, variable wind speed near rated speed, a load change and a fault. Simulation results demonstrate that the third approach is superior compared to first and second approaches with respect to its performace and also in terms of execution time.

Later, stability analysis is extended for a multi-machine system (Anderson 3 machine 9 bus system). The effect of fixed and variable speed wind generators location and penetration on stability of the system is studied. Stability analysis is applied to the test system with following combinations of fixed speed, partially variable speed and variable speed wind farms (FSWF/PVSWF/VSWF).

(1) Base case (No wind farms connected).

System with FSWECS/VSWECS

(2) SG2 is replaced with FSWF/VSWF.

(3) SG3 is replaced with FSWF/VSWF.

(4) Both SG2 & SG3 are replaced by FSWF/VSWF.

System with FSWECS/PVWECS

(5) SG2 is replaced with PVSWF and
SG3 are replaced by FSWF.

System with both FSWECS and VSWECS

(6) SG2 is replaced with FSWF and
SG3 is replaced with VSWF.

Tuning of controllers of PMSG based WECS are performed as explained in the SMIB system. With optimized controller parameters, small signal stability analysis is performed against step change in wind velocity, change in wind turbines and a load change. Also, by varying the controller parameters their influence on the eigenvalues are studied. The result shows that the system stability can be improved by proper tuning of both generator side and grid side converter controller parameters. Eigenvalue analysis is also verified with results of time domain analysis.

Then, small signal stability analysis is performed for a 156 bus Indian utility grid system with 10 synchronous generators and 40 fixed speed wind farms. Eigenvalues are analyzed at different wind velocities and stability conditions are verified in time domain analysis. Finally, a study is made on the 156 bus practical system by replacing the conventional FSWF with the provision of variable rotor resistance control (ie, PVSWF). This structure presents power-wind velocity characteristics comparable with VSWF.

Time domain analysis is also performed against step change in wind velocity and three phase fault and compared with 156 bus system with only FSWFs. The overall effect of wind generators on power system stability depends on several structural factors and a general statement as to whether it improves or deteriorates the oscillatory stability of a system cannot be made.