Abstract

The modern wind power sector is predominantly powered by doubly-fed induction generators (DFIGs) due to their inherent advantages; however, several stability issues still exist in the system that need to be investigated and addressed. Therefore, in this thesis, a small and large signal stability analysis of the full-order model of the DFIG-based wind turbine generator (WTG) system has been performed first to investigate the impact of various plant and control parameters on system instability. In general, a single grid-connected DFIG-WTG system is relatively stable compared to a grid-connected wind farm having multiple DFIG-WTG systems due to their complex dynamical interactions. The wind farms tend to get disconnected from the power network during medium/severe grid disturbance scenarios. However, the interconnection standards have made it mandatory for the DFIG-WTG system to comply with the high/low-voltage ride-through (H/LVRT) requirements. As a result, a comprehensive assessment has been carried out to investigate the H/LVRT compliance of these wind farms comprising multiple grid-connected DFIG-WTG systems. Further, it has also been observed that the grid-synchronization instability of the DFIG-WTG system is primarily ignited by the dynamics of the Phase-Locked-Loop (PLL). Studying the large-signal grid-synchronization instability phenomenon from the full-order model (sixteenth-order dynamical model) of the DFIG-WTG system is a cumbersome task. To address and overcome this challenge, a reduced-order quasi-static model of the DFIG-WTG system has been developed by amplifying the dynamics of PLL alone (to extensively focus on the study of synchronization stability of DFIG with the grid). The transient stability analysis of the proposed ROM of the DFIG-WTG system has been done by synthesizing an energy function based on Lyapunov's direct method, which has been found to be an effective tool for the same; however, its applicability gets complicated with the higher-order systems comprising of multiple DFIG-WTG in a wind farm. Therefore, as a countermeasure, a new methodology has been proposed to assess the transient stability by applying the trajectory sensitivity analysis (TSA) of states *w.r.t.* parameters of the system, which is pretty generic and can be applied to higher-order systems. The methodology proposed for transient stability analysis by TSA provides more insight into the system's stability margin and critical values of the influential parameters in contrast to the conventional simulation methods and facilitates ease of computation. Lastly, it has also been identified that a full-order model of the DFIG-WTG system has many states, leading to various possible reduced-order models by combining different states of the system. These may create confusion while selecting a reduced-order model for a particular type of study. Therefore, to overcome this challenge and as a part of the final objective, the final chapter in this thesis investigates the adequacy of synthesizing four different reduced-order DFIG-WTG models for dynamic stability assessment.

The major highlights of the work are summarized as follows:

(a) Time-domain simulations of the grid-connected DFIG-WT system are done for open-loop and closed-loop systems under different sensitive operating conditions. The mathematical model of PLL is developed and applied to the full-order system. The proposed model is used for the dynamic aggregation of multi-machine DFIG-WTG in WPP for the H/LVRT capability study of the same system.

(b) A reduced-order model (ROM) considering only PLL mode has been developed to study grid synchronization stability problems. The proposed ROM is used to develop an analogous second-order equation to find PLL parameters for stable grid synchronization. A new Lyapunov function has been developed for studying large signal stability assessments. The proposed methodology was extended to a wind farm having N numbers of DFIG-WTG systems. Modeling adequacy analysis of four different proposed reduced-order models of the DFIG-WTG system for dynamic stability assessment has been done.

(c) A new methodology has been developed to do transient stability analysis of the DFIG-WTG system using trajectory sensitivity of states of the system *w.r.t.* to parameters. This methodology can also be used to find the system's critical parameters and transient stability margin.

***Key Words*:** DFIG-based wind turbine generator system, Lyapunov's Method, Reduced-order-Model, Small-signal Stability, Transient Synchronization Stability.