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ORIGINAL RESEARCH ARTICLE

Benefits and weak points of various control strategies in enhancing variable speed wind turbine transient performance

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It is important to keep grid connected wind farms in operation during disturbances in the power network. This paper investigates various control techniques of wind farm composed of Doubly Fed Induction Generator (DFIG) and fixed speed induction generator. Several enhancement schemes were considered with the aim of stabilizing the mixed wind farm. Some schemes were used to enhance the performance of other schemes. The schemes considered were subjected to the same transient condition at the rated wind speed of the wind turbines. The simulation results in Power System Computer Aided Design and Electromagnetic Transient Including DC (PSCAD/EMTDC) platform show the improved performance of the wind turbines and the wind farm for the various cases. In addition, a comparison of the benefits and weak points in terms of economic costs and performance of the various approaches to enhance the stability of the variable speed wind turbines were analyzed.

1. Introduction

The demand for wind power is on the rise daily, thus, it is imperative to take into account the stability of wind farms in order to ensure safe and good power delivering. According to the recent grid requirements, wind farms must attend to transient disturbances as quickly as possible. Various Flexible AC Transmission Systems (FACTS) have been proposed in the literature to enhance wind turbine stability, ranging from the use of Static Var Compensator (SVC), Static and Unified Power Flow Controller (UPFC), Dynamic Voltage Restorer (DVC), Solid State Transfer Switch (SSTS), Energy Capacitor System (ECS), and SMES [1–6]. A comparative study of the transient stability improvement of fixed speed based grid connected wind farm with the help of SVC and a STATCOM was presented in [7], while the improvement of power quality considering voltage stability in grid connected system by FACTS devices was discussed in [8]. The transient stability improvement with electrical braking and reactive compensation of large scale wind power generation was carried out in [9], where it was concluded that the combination of braking resistors and reactive power compensation could significantly improve the stability of wind turbines.

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A comparative study using FACTS devices and variable speed drive to stabilize wind farms was presented in [10], where it was established that the variable speed drive is more favourable because no external reactive power compensation is required. In [11], a comparative stability analysis of DFIG-based wind farms and conventional synchronous generators was analyzed, with the conclusion that the oscillatory behaviour of the synchronous generators was improved by the DFIG system when connected. The tunning method for parameter optimization to achieve effective stability and tune damping controller considering eigenvalues were carried out for the DFIG system in [12,13]. The effects of the increase stability margins and penetration effects for including a DFIG based system at point of coupling connection at transmission lines were presented in [14–17] respectively. According to these papers, the voltage control capabilities of the wind farm based on DFIG, improves the voltage stability margin at distribution and transmission stages. In [18,19], the study of using trajectories eigenvalues of the DFIG were calculated and a four generator system was used to know the effect of replacing synchronous generators by wind turbines, with the aim of improving the stability of the wind farms when they are grid connected.

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Since DFIGs are becoming more popular, the idea is shifting from using external reactive compensation devices for wind farm stability [20,21] to the use of the DFIG systems. Although, an alternative use of variable speed wind turbine for wind farm stability is the implementation of the Permanent Magnet Synchronous Generator (PMSG) [22]. The major drawback of the PMSG system is the full power converter rating as compared to DFIG that has only 20–30% power converter rating. Based on this fact, many Fault Ride Through (FRT) methods on DFIG system have been proposed. In [23,24], the use of a crowbar switch was proposed to improve the FRT of DFIG system during transient, while in [25,26], a DC-chopper voltage was implemented. The combination of the crowbar system and the DC-chopper system was investigated in [27], while a study comparing the operation of the DC-link chopper with the crowbar protection mechanisms was presented in [28]. The effective use of a Static Series Compensator (SSC) and a Dynamic Voltage Restorer (DVR) was reported in references [29–31] and the use of STATCOM device to boost and support DFIG was presented in [32]. The use of a series dynamic braking resistor (SDBR) to boost the FRT of large wind farms made up of only induction generators was reported in [33]. The connection of SDBR switch to the rotor side converter of the DFIG and the stator side were presented in [34] and [35] respectively. Superconducting Fault Current Limiter (SFCL) [36], Passive Resistance Network (PRN) [37], and connections involving series antiparellel thyristors [38] to the stator side of a variable speed DFIG system, already exist in the literature. A study of low voltage ride through for DFIG considering rotor current dynamics was analyzed in [39]. In this paper, the rotor transient analysis and differential equations were derived in a bid to improve the ability of the DFIG during grid fault. The use of hybrid current controllers to enhance DFIG reactive power and capability to withstand low and high voltage ride through was reported in [40]. In [41–44], the authors discussed the problems and possible solutions to improve the performance of DFIG during transient by proposing active voltage control and fast coordinated control strategy based on the characteristics of the DFIG. Enhanced field oriented control technique (EFOC) [45,46] was proposed for the rotor side converter of the DFIG system to facilitate the power flow transfer and also enhance the dynamic and transient stability of the wind generator. The analysis of asymmetric faults considering stability [47,48] of the DFIG system already exists in the literature. Also, analyses of DFIG connected wind farms and a review of the impact of the DFIG wind farm on transient stability of power systems were reported in [49] and [50] respectively.

During grid faults the DFIG experiences overcurrents which lead also to increasing DC-voltage on the converter side. The behaviour of the DFIG during grid fault is described as follows. If there is no protection system, the DFIG can suffer from large transient currents in the stator during a grid fault since its stator circuit is directly connected to the grid. Because of the magnetic coupling between the stator and the rotor, large currents and high voltages appear also in the rotor circuit. Furthermore, the surge following the fault includes a rush of power from the rotor terminals towards the rotor side converter. Therefore, there can be a possibility that the desired rotor voltage cannot be maintained and thus the rotor currents cannot be controlled. This means that the rotor side converter can reach to its operating limit and as a consequence it may lose the independent control of real and reactive powers during the grid fault. On the other hand, as the grid voltage drops in the fault moment, the grid side converter is not able to transfer the power supplied from the Rotor Side Converter (RSC) to the grid, and therefore, the excess energy is stored in the DC-link capacitor, resulting in rapid increase of the DC-bus voltage [51–53]. It is therefore necessary to protect the power converters against over-currents and the DC-link against overvoltage.

This paper focuses on the Fault Ride Through (FRT) methods of a wind farm composed of DFIG and Induction Generator (IG). Eight scenarios were considered in this study. In the first case, the DFIG based wind turbine is operated using a Voltage Controlled Voltage Source Converter (VC-VSC) system including a DC-link chopper protection scheme. The second case considers a crowbar active switch having different crowbar resistances with the DFIG VC-VSC system. A STATCOM was considered to further enhance the DFIG based system during grid fault in case 3, since the crowbar switch in case 2 would disconnect the RSC of the DFIG thereby loosing controllability of active and reactive power control. In case 4, an SDBR is connected at the rotor side of the VC-VSC DFIG based wind turbine. The performance of the SDBR system was also investigated in case 5, when it was connected to the stator of the DFIG and the grid side converter instead of the rotor side of the wind generator. A proper sizing, best time of insertion and duration of operation of the SDBR was considered in this case. Case 6 considers when the DFIG-based wind turbine converter system is operated using a Current Controlled Voltage Source Converter (CC-VSC) system with no protection mechanism circuitry. In case 7, a hybrid approach of controlling the variable speed wind generator power converters using VC-VSC and CC-VSC were considered respectively. Case 8 uses a parallel interleaved configuration of the DFIG power converters. Simulations were run in PSCAD/EMTDC [54] environment. Furthermore, a comparison was carried out with regards to some of the benefits and weak points of the schemes used in this study.

2. Wind turbine modelling

The parameters of the wind turbines used in this study are given in Table 1. Basically the primary components required in the modelling of a wind turbine system are the turbine rotor or prime mover, a shaft and a gearbox unit. The wind generators ratings are 2 MW for the DFIG and IG respectively. The aerodynamic torque and the mechanical power of a wind turbine are given by [26,35]:

$$T_M = 0.5\rho C_t(\lambda)\pi R^3 V_w^2[\mathrm{NM}] \tag{1}$$

$$P_{wt} = 0.5\rho C_p(\lambda,\beta)\pi R^2 V_w^3[W] \tag{2}$$

TABLE 1

Generator parameters.

Generator type	IG	DFIG
Rated voltage	690 V	690 V
Stator resistance	0.01 pu	0.01 pu
Stator leakage reactance	0.07 pu	0.15 pu
Magnetizing reactance	4.1 pu	3.5 pu
Rotor resistance	0.007 pu	0.01 pu
Rotor leakage reactance	0.07 pu	0.15 pu
Inertia constant	1.5 s	1.5 s