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Modeling and investigation of Gulf El-Zayt wind farm for stability studying during extreme gust wind occurrence

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Abstract This paper investigates the impact of extreme gust wind as a case of wind speed variation on a wind farm interconnected electrical grid. The impact of extreme gust wind speed variation on active and reactive power of the wind farms is studied for variable speed wind farm equipped with Doubly Fed Induction Generators (DFIGs). A simulation model of the under implementation 120 MW wind farm at Gulf El-Zayt region, Red Sea, Egypt, is simulated as a case study. A detailed model of extreme gust wind speed variation is implemented and simulated, using MATLAB/Simulink toolbox, based on International Electrotechnical Commission IEC 61400-1 and climate characteristic of Gulf El-Zayt site. The simulation results show the influence of different extreme gust wind speed variations on the fluctuation of active power and reactive power at the Point of Common Coupling (PCC) of the studied wind farm.

1. Introduction

Wind power generation systems are already popular in the world, and the utilization of this renewable energy source is expanding rapidly. Because of its attractive advantages, including zero-CO_2 emissions and low operation cost, the penetration of wind power generation systems is increasing in spite of the variable characteristics of wind speed. The DFIG concept has become one of the most favorable options in modern wind power market. The DFIG wind turbine consists of wound rotor induction generator, that is connected to the turbine blades via a gearbox. The stator of a wound rotor generator is connected directly to the grid, whereas the rotor is connected to the grid through two back-to-back converters with a common DC link capacitor bank. This arrangement allows for power in the rotor to be at a different frequency than that of the grid frequency, thereby allowing for speed control by adjusting this frequency. There are several advantages of the DFIG system, where the variable speed allows for optimal power to be extracted for a wide range of wind speeds. Both active and reactive power can be controlled independently. Also, reactive power can be supplied by the generator to support grid voltages. The disadvantages of the DFIG are the harmonics generated by the power converter need to be filtered to comply with grid connection specifications [1]. The wind itself

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is a variable source of energy. The ability of a wind turbine to extract power from varying wind is a function of three main factors – the wind power availability, the power curve of the generator, and the ability of the turbine to respond to wind fluctuations. Wind turbines are typically be placed in rows perpendicular to the prevailing wind direction. The distance between the wind turbines in each row and the distance between the rows depend on the rotor diameter. In a uniform wind direction the distance between turbines in rows and columns is approximately equal to 5 times of rotor diameter. In case of predominate wind direction, the recommended turbine spacing is equal to 8–12 times of rotor diameter in rows apart in the windward direction, and equal to 1.5–3 times of rotor diameter a part in the crosswind direction [2]. The wind turbines with tall hub heights can extract large amounts of energy from the atmosphere because they are likely to encounter higher wind speeds, but they face challenges given the complex nature of wind flow and turbulence at these heights in the boundary layer. Depending on whether the boundary layer is stable, neutral, or convective, the mean wind speed, direction, and turbulence properties may vary greatly across the tall turbine swept area (40–120 m above ground level) [3]. This variability can cause tall turbines to produce difference amounts of power during time periods with identical hub height wind speeds. The strategy of New and Renewable Energy Authority of Egypt NREA, which was approved in February 2008, aims to the contribution of renewable energies by 20% of the total electricity generation by the year 2020, including 12% contribution from wind energy, translating about 7200 MW grid-connected wind farms. Gulf El-Zayt site at the Red Sea region, it is classified as an excellent wind speed site which it reaches 10.5 m/s as average wind speed over one-year period at 25 m above ground level and it can host about 3000 MW wind power plants. However, technical considerations suggest that the area cannot absorb more than 2000 MW. The target is to develop the overall area until 2024. One of those projects under implementation is a 120 MW wind farm as a first step (possibly upgraded to 400 MW), and it sited at Gulf El-Zayt site [4]. This project is expected to be completed and operated in the end of 2014. This wind farm will produce approximately 500.000 MW h contributing to partially cover 35% of the Suez cement factory energy needs. In this paper, the effect of extreme gust wind speed variation on the stability of Gulf El-Zayt wind farm is investigated for different operation conditions by monitoring the variations in wind farm active and reactive power. To investigate the impacts of extreme gust wind speed variations on the stability of the studied wind farm, a simulation model of a 120 MW wind farm connected to a grid is investigated. Also, a detailed model of extreme gust wind is investigated and simulated according the recorded average wind speed over one-year period at Gulf El-Zayt site and the standard IEC 61400-1. The impacts of extreme gust wind speed variation on the stability of the simulated wind farm are studied by monitoring the active power and reactive power at the Point of Common Coupling (PCC) bus of the studied system. The complete wind farm connected-grid model, includes the extreme gust wind model, the aerodynamic model of the wind turbine, the model of electrical component namely the DFIG, transmission line model, transformers. All the model components of the wind farm connected-grid are built with standard electrical component models using the MATLAB SimPowerSystems toolbox and 32 bit windows 7 platform.

2. Simulation of extreme gust wind

In this paper, the extreme gust wind speed variations are simulated by simulating the extreme wind conditions as specified in IEC 61400-1 [5,6]. The extreme wind conditions include peak wind speeds due to gust and rapid changes in wind speed. The mathematical model of the extreme gust wind depends on the climatic characteristics in the site where the wind farm is located. The wind profile is the average wind speed as a function of height, z, above the ground. The normal wind speed profile is given by

$$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha} \tag{1}$$

where (z) is the average wind speed at height z above the ground (m/s), z_{hub} is the hub height of the wind turbine (m), and V_{hub} is the wind speed at hub height averaged over ten minutes (m/s). The power law exponent, α is assumed to be 0.25 which is the standard value for the Egyptian terrain and wind conditions [7,8]. The wind speed is defined for a recurrence period of N years by the following equation [6]:

$$V(z,t) = \begin{bmatrix} V(z) - 0.37V_{gustN}\left(\sin\left(\frac{3\pi t}{T}\right)\right)\left(1-\cos\left(\frac{2\pi t}{T}\right)\right) & \mathit{for} \rightarrow T_{start} \leqslant t \leqslant T_{final} \\ V(z) & \mathit{for} \rightarrow t < T_{start} \ \mathit{and}\ t > T_{final} \end{bmatrix} \tag{2}$$

where T_{start} is the time of the beginning of the gust, T_{final} is the time of the demise of the gust, and T is the gust characteristics time (s), it equals to 10.5 s for a recurrence period N equal to 1 year and it equals to 14 s for a recurrence period N equal to 50 years. V_{gustN} is the largest extreme gust magnitude with an expected recurrence period of N year and it can be given by

$$V_{gustN} = \beta\left(\frac{\sigma}{1 + 0.1\left(\frac{D}{A}\right)}\right) \tag{3}$$

where β is the parameter for extreme direction change model, it equal to 4.8 for a recurrence period N equal to 1 year, and it equal to 6.4 for a recurrence period N equal to 50 years, D is the rotor diameter (m), and A is the turbulence scale parameter (m) where it can be given by

$$A = \begin{bmatrix} 0.7z_{hub} & \text{for} & z_{hub} < 30\text{ m} \\ 21\text{ m} & \text{for} & z_{hub} \geqslant 30\text{ m} \end{bmatrix} \tag{4}$$

finally σ is the standard deviation of longitudinal wind velocity and it can be given by

$$\sigma = \frac{I_{15}(15 + aV_{hub})}{(a+1)} \tag{5}$$

where I_{15} is the characteristic value of the turbulence intensity at a 10 min average wind speed of 15 m/s, and a is the slop parameter of turbulence intensity.

The wind turbine generator system classes are used to determine the suitable turbine for the normal wind conditions of a particular site [5]. The wind classes are mainly defined by the average annual wind speed which is measured at the turbine hub height, the speed of extreme gusts that could occur over N years, and how much turbulence there is at the wind site. The wind turbine generator system classes are defined by IEC 61400-1 correspond to high, medium and low wind speed as shown in Table 1. It shows that, there are four classes for wind turbine generators. In the case of a wind turbine that is designed for lower wind speeds, the design loads are going to