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Improvement of wind turbine DFIG using Fault Ride through capability technique

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Abstract - *In this paper, the ability of doubly fed induction generator based on wind turbines to remain connected through power system disturbances is discussed. Here a protection system to provide a power system fault ride-through capability for doubly fed induction generator based wind turbines is also described. The dynamic behavior of DFIG wind turbines normal operation and during grid faults are simulated and assessed to verify the recommended method using a Matlab/Simulink developed model.*

Key Words: Conventional crowbar scheme, doubly-fed induction generator (DFIG), fault ride through (FRT), low voltage ride through (LVRT), and wind turbines (WTs) etc.

1. INTRODUCTION

Currently the world is developing towards cleaner and greener environment, leading to the concept of increasing penetration of distributed generation from renewable energy sources (RES). However, integrating them in the main grid is a challenging subject as they may decrease the quality and reliability of the grid. The main reasons to these setbacks are their stochastic nature of power generation and their low or no inertial response capability to dynamics [1, 2].

Today, however, new wind machines are beginning to appear on the landscape, as windy rural areas tap a unique opportunity to benefit from wind power. Modern wind turbine technology now makes it possible to generate cost-effective, clean, renewable electricity on a scale ranging from a single wind turbine for an individual landowner up to large, utility-scale wind farms. Declining costs and improving technology are quickly making electricity generated from wind energy competitive with all types of non-renewable fuels, like new coal-fired generation. The price of wind generated electricity has decreased ten times since the early 1980s, to the point that the American Wind Energy Association estimates that within three to four decades, wind power could realistically supply ten to twenty percent of developed countries need.[3,4]

The dip in the grid voltage will result in an increase of the current in the stator windings of the DFIG. Because of the magnetic coupling between stator and rotor, this current will also flow in the rotor circuit and the power converters. So that it will cause over current in the rotor windings and over voltage in the dc bus of the power converters. When the situation after the fault is not serious enough, improved vector control strategy can provide adequate control of the DFIG\ during voltage dips with much smaller rotor currents and DC bus voltage [5].

This paper proposes an improved control strategy for the crowbar protection. The crowbar is activated as soon as the rotor current exceeds a threshold value and it is disconnected when the rotor currents are reduced to a secure value. So that the controllability of the DFIG will only be lost for a short time and the DFIG can resume normal operation quickly after the clearance of the grid faults. The global model and control system are simulated with the help of Matlab Simulink™, by considering a practical 1.5MW DFIG wind turbine. Simulation results show the effectiveness of the improved crowbar protection scheme against voltage dips.

1.1 DFIG Based Wind Turbine:

Doubly Fed Induction Generator (DFIG) based Wind Turbine (WT) systems are usually required by grid operators to stay connected to the grid during faults. This section discusses the basic configuration of a DFIG and the model of SFCL that is proposed for FRT improvement.

A. DFIG-based Wind Energy Conversion System:

The major components of a DFIG-based Wind Energy Conversion System (WECS) are wind turbine with gearbox, induction generator, GSC, RSC, DC link capacitor, coupling transformer, pitch controller and protection system.

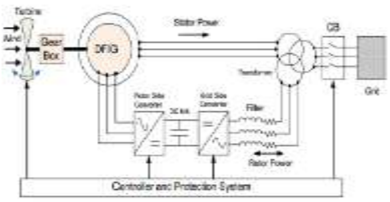

Figure 1: Components of DFIG-based WECS

The stator of DFIG is directly connected to the grid and the rotor to the mains through a partially rated variable frequency ac/dc/ac cascaded converter. The rotor side converters handle only a fraction of rated power, usually 25-30% only. The rotor current is controlled by RSC to vary the machine excitation and electromagnetic torque. During grid faults, GSC and RSC may be damaged due to heavy fault currents so a SFCL is designed to reduce over current stresses.

2. Modeling of the Wind Turbine System:

Figure 2 shows the overall DFIG wind generation system. The stator is directly connected to the grid while the rotor is interfaced through a back-to-back power converter. The grid side converter is connected to the grid via three chokes to filter the current harmonics. A crowbar protection circuit is connected between the rotor circuit and the rotor-side converter. The system is described using Energetic\ Macroscopic Representation (EMR). The EMR is a synthetic graphical tool between connected elements, which has been developed to propose a synthetic and dynamical description of electromechanical conversion systems [6-7].

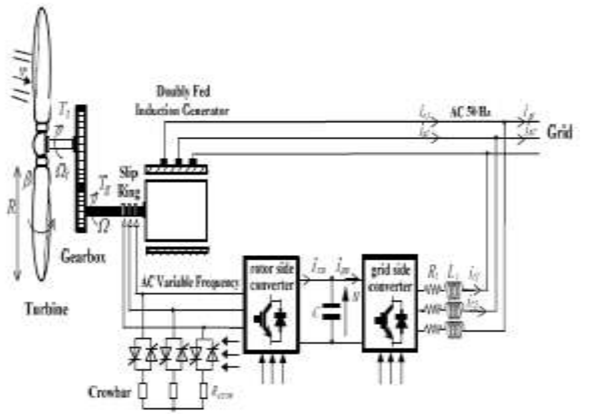

Figure 2: DFIG based wind turbine with crowbar protection.

Most of the low-power wind turbines built to-date were constructed according to the "Danish concept", in which wind energy is transformed into electrical energy using a simple squirrel-cage induction machine directly connected to a three-phase power grid. The generator shaft and the rotor of the wind turbine are coupled with a fixed-ratio gearbox. In some cases, induction generators use pole-adjustable winding configurations to enable operation at different synchronous speeds. However, at any given operating point, this Danish turbine has to operate at a constant speed. The construction and performance of fixed-speed wind turbines mainly depends on the characteristics of mechanical sub circuits, such as, pitch control time constants, main breaker maximum switching rate and etc. The response time of the mechanical circuits is may be in the range of tens of milliseconds. As a result, each time a gust of wind hits the turbine, a fast and strong variation of electrical output power can be observed. Due to these loads variations, it requires a stiff power grid to enable stable operation and a sturdy mechanical design to absorb high mechanical stresses. Overall, this construction strategy results in expensive mechanical construction, especially at high-rated power [8].

Key advantages of adjustable speed generator compared to fixed speed generators:

1. They are cost effective and provide simple pitch control; the controlling speed of the generator (frequency) allows the pitch control time constants to become longer, reducing pitch control complexity and peak power requirements. At lower wind speed, the pitch angle is usually fixed. Pitch angle control is performed only to limit maximum output power at high wind speed.
2. They reduce mechanical stresses; gusts of wind can be absorbed, i.e., energy is stored in mechanical inertia of the turbine, creating an "elasticity" that reduces torque pulsations.
3. They have ability to dynamically compensate for torque and power pulsations caused by back pressure of the tower. This back pressure causes noticeable torque pulsations at a rate equal to the turbine rotor speed times the number of rotor wings.
4. They improve power quality; torque pulsations can be reduced due to the elasticity of the wind turbine system. This eliminates electrical power variations, i.e., fewer flickers.
5. They improve the system frequency; turbine speed is adjusted as a function of wind speed to maximize output power. Operation at a maximum power point can be realized over a wide power range. As a result, energy efficiency can be improved by up to 10%.
6. They reduce acoustic noise, because low speed operation is possible at lower conditions.

3. Fault Analysis of DFIG:

Due to the double fed induction generator's (DFIG) advantage of controlling active and reactive power independently and partial power converter, DFIG is becoming a popular type of wind power generation system. Nowadays, the grid code demands that the wind power generator possesses the ability of riding through the grid voltage sags, only when the grid voltage drops below the specific curve, the wind turbine is allowed to disconnect. DFIG wind power system has serious problems with the corresponding voltage sag as its partly power converter: depending on the depth and the conditions at the start of the sag, current, power and reactive power peaks may exceed rated values and may lead to a system shut down. [9]

In general these grid codes represent the fundamental guidelines for wind turbine manufacturers and wind farm planners. Basically, the North America, grid code follows their European counterpart categorizing wind turbine capabilities as follows:

(i) Low voltage Ride-through (LVRT) requirement to keep wind turbines on the grid during faults by introducing new technologies.
(ii) When tripping, wind turbines have to guarantee reconnection and continuation of power generation in the shortest possible time.
(iii) The establishment of mechanisms for ascertaining and continuous monitoring of the fulfilment of grid requirements.
(iv) Establishing intelligent system protection devices to ensure a minimum loss of wind power and to guarantee fast recovery of normal operation.

The new grid codes requirements includes voltage level, Total Harmonic Distortion (THD) levels in the point of common coupling (PCC) as well as the ride through capabilities during fault events in the grid. Also, the new wind turbines/farms should contribute to regulation if active and reactive power and thereby contribute to the frequency and voltage control [10].

4. Fault Detection and Protection:

Grid codes require wind farms to stay connected and continue generation in the main system low voltage emergency conditions. Due to the limited capacity of converters, DFIG wind turbines may suffer from over rotor currents or over voltages in the DC-links. As a result, appropriate control and protection schemes must be applied. Modelling the fault current behaviour of DFIG will help to determine its dynamic performance and its possible impact on the power system. Different approaches have been taken by many software tools to model DFIG protection scheme and wind farms.

The following sections will discuss different active crowbar configurations, the fault detection method, the integration of the active crowbar system with the DFIG and the overall system behaviour under various fault conditions. This project report initially addresses the modelling considerations for an induction machine and then identifies the special considerations needed for a DFIG. A 9 MW wind farm with six units of 1.5 MW DFIG wind turbines is studied by creating symmetrical and asymmetrical faults in different zones. Voltage and current waveforms are presented and discussed during fault.

The fault ride-through capability is considered crucial for the system stability. It is commonly demanded from modern wind turbines, that they are not allowed to disconnect in case of faults.

One of the most often used variable speed configurations is to use an active crowbar fault ride through mechanism. Therefore, crowbar circuit is designed enabling the wind turbine to ride through transient faults. With the addition of crowbar the wind turbines can stay connected to the grid, maintain their generation capacity, and resume normal grid operation after the fault is cleared.

The following sections will discuss different active crowbar configurations, the fault detection method, the integration of the active crowbar system with the DFIG and the overall system Behaviour under various fault conditions.

5. Fault Detection Methods

The fault detection methods investigated in this project play an important role in the independent active crowbar system. This active crowbar is connected to the rotor windings providing a bypass path for the rotor current under critical fault conditions. This section will focus on the methods of detection. The detailed model and methods of fault detection are not included in this project as it is above the scope of this project; however, the brief discussion for common methods is included.

Current measurement fault detection methods are used under fault conditions; the rotor current exceeds the converter rating substantially, which can be used for fault detection. The three-phase rotor currents are sensed and feed into detection block, where the currents are converted to the dq reference frame to have a faster response. The magnitude of current vector is compared to a reference value and fault indication is latched based on the equality [11].

The other fault detection method is using voltage RMS value of stator voltage. This method is mostly applied due to the high cost of the rotor current detection method. Fault usually appears as the voltage dip on the stator side. Then the stator voltages can be used to detect the fault. This method segregates the active crowbar independent from the turbine's control system. Also, fault detection using instantaneous pseudo-power detection used as an alternative to detect fault.

Even though, the DFIG can run under single and two phase faults undetected, they do pose a serious problem to the rotor circuit and could possible result in the network disturbance.

Excessive rotor currents under these fault conditions will induce damage to the machine side Vsc.

6. Protection Using Active Crowbar:

In case of grid faults very high short circuit currents arise in the stator. These high transient currents are transferred to the rotor due to the inductive coupling between stator and rotor, implying a high damaging risk for the power electronics of the rotor side converter. Due to this reason a suitable protection of DFIG is necessary.

When the crowbar protection is triggered, the rotor side converter is blocked and the DFIG behaves as a squirrel cage induction generator. This implies that the whole controllability of the DFIG is lost during crowbar coupling.

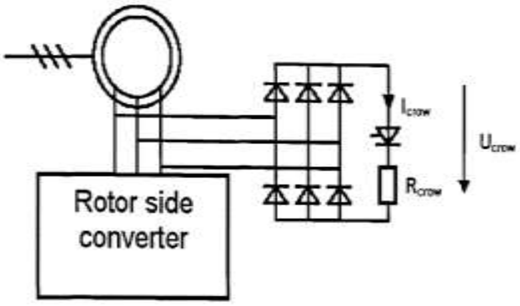

Figure 3: Diode bridge crowbar.

The control strategy adopted during fault for this analysis is described: the RSC is blocked and the crowbar system is activated; the GSC controls the DC-link voltage; the RSC is restarted and crowbar system is removed after the fault elimination. Different R_{crow} are analysed (2, 5 and 10 times the original rotor resistance RR) [12].

This is the most common operation mode during faults for countries with no reactive current injection requirement. Considering the stability of the machine the desired rotor speed should be as closer as possible to the normal operation speed in order to avoid the critical rotor speed, as described in Section 3. The active power injected by the DFIG is also increased for high values of the Rcrow, as explained in [12].

7. Conclusions:

This paper is focused on the control strategy of a DFIG wind turbine system which equips with an active crowbar against severe grid faults. In order to reduce the activated time of the crowbar as much as possible, an improved hysteresis control strategy is proposed. Moreover, a simple demagnetization method is adopted to decrease the oscillations of the transient current both during the voltage dips and after the clearance of the faults. With the cooperation of both control schemes, the DFIG is controllable for most of the time during voltage dips while the crowbar provides sufficient protection. As the crowbar is not required to provide a bypass for the potential high rotor current, the wind turbine can resume normal operation in a few hundred milliseconds after the fault is cleared. For longer time voltage dips, the DFIG can even supply reactive power to the weak grid during voltage dips to assist the voltage recovery. Simulation results show the enhanced low voltage ride-through capability of the generator with the proposed technique. Future work will be done to improve the control strategy of the gird-side converter by limiting the DC-link voltage fluctuation as well as supplying reactive power during grid faults.

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