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Transient Stability Improvement in DFIG based Wind Energy System using Series Compensating Device

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Abstract:The Doubly Fed Induction Generator (DFIG) is getting wider popularity due to its ability to adapt with variable wind speed and to capture more wind energy. Though DFIG has a salient feature of the fault ride through capability, this is not sufficient to preserve the necessity of the grid code when the DFIG system is connected with the grid. To accomplish this goal, a DC resistive superconducting fault current limiter (SFCL) is proposed, as it reduces the system power losses during stable operation of the network with improved system efficiency, in comparison with the conventional SFCL. To verify the performance of the transient stability of the DFIG based wind power system with the DC resistive SFCL, both the symmetrical and asymmetrical faults are considered. The performance of the DC resistive SFCL is compared with that of the series dynamic braking resistor (SDBR) and the crowbar system. Simulations are carried out by using the Matlab/Simulink software.

Introduction:

The Wind Energy Conversion System (WECS), although there are lots of fixed-speed wind generators available in the world, the Doubly Fed Induction Generator (DFIG) and Permanent Magnet Synchronous Generator (PMSG) are getting wider acceptance due to their abilities to capture much more energy by running as variable speed wind generator systems. Using DFIG is an attractive solution over the PMSG, as it requires lower rated power electronic converters than the PMSG. Besides, the DFIG provides better speed control with reduced flicker , the WECS should have the feature of transient stability, that is, the ability to maintain synchronism when subjected to a severe disturbance, such as a short circuit or a fault on a transmission line. The wind generator should also have the low and high voltage ride through capability. The wind generator should remain connected with the grid if the voltage is lower and higher than the rated voltage, respectively due to any problem of the system. The series and shunt compensating Flexible AC Transmission System (FACTS) devices support the wecs to maintain the Fault Ride Through (FRT) ability.Most of the dfigs are equipped with the crowbar system to maintain the transient stability. The crowbar operation helps protect the rotor circuit during faults. Among the adopted series compensating facts devices, the thyristor controlled series compensator, gate controlled series capacitor, and Superconducting Fault Current Limiter (SFCL) are also considered to improve the performance of the DFIG system.

One of the most promising technologies to minimise the fault current, and to improve the transient stability. The SFCL introduces significant system losses during normal operation of the system, and reduces the overall system efficiency. To overcome this problem, a novel dc resistive SFCL is reported and explained in detail in which is based on the combined use of the 'resistive' and the 'rectifier' fault current limiter concepts. The effective application of the DC resistive SFCL in the power network. However, this new technology has not been applied for enhancing the transient stability of the DFIG based WECS. Moreover, the necessity of auxiliary devices to improve the transient stability of the DFIG wind power system cannot be ignored. Besides, maintaining the system efficiency is also very important, as it will reduce the per unit power cost.

Wind Turbine Modelling:

Most of the wind turbines use induction generators because of their advantageously characteristics. Induction machines are simple and rugged in construction, offer impressive efficiency under varying operating conditions, relatively inexpensive and require minimum maintenance and care. Characteristics of these generators like the over speed capability make them suitable for the wind turbine application. The wind power captured by the turbine rotor and converted to mechanical power is dependent on the average wind speed over the rotor surface and the rotational speed of the rotor. Therefore maximum wind energy capture can be achieved only if the rotor speed is varied tracking the changes of the wind. Variable speed operation of the wind turbines is necessary to gain high efficiency in the generating systems. Additional advantages of the variable speed operation are the reduction of the drive train mechanical stresses which permits the use of lighter transmissions, the improvement of the output power quality and the reduction of the noise emitted from the wind turbines. The induction generators that are used in the wind turbine are usually squirrel cage induction generators (SCIG) and in nowadays doubly fed induction generators (DFIG). Doubly fed induction generators have windings on stator and rotor where both of the windings transfer significant power between the shaft and the electrical system.

Doubly Fed Induction Generator Model:

Doubly-fed electric machines are basically three-phase wound-rotor induction machines Fig 1, where ac currents are fed into both the stator and the rotor windings. The stator of the machine is directly connected with the grid through a transformer, and the wound rotor is also connected to the grid with the help of AC–DC and DC–AC converters. Two three-phase pulse width modulated (PWM) voltage source converters, that is, the rotor side converter (RSC) and grid side converter (GSC) are coupled to a common DC link.

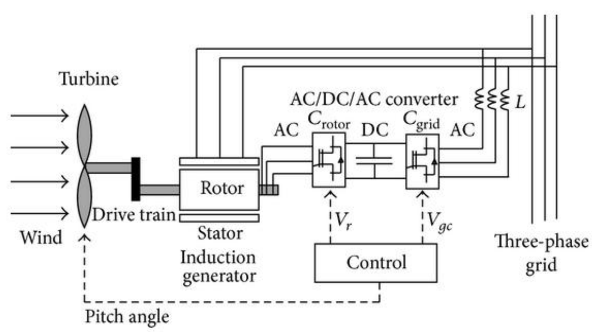

Fig 1 :DFIG Based Wind Energy System Block Diagram

Doubly Fed Induction Generator (DFIG) is a wound rotor induction machine which is included stator and rotor winding.The d-q 5th order of the DFIG,

The d-q stator voltage (V_{ds}, V_{qs}) are described by,

$$u_{ds} = R_s i_{ds} + \frac{d\varphi_{ds}}{\omega_b dt} - \omega_s \varphi_{qs}$$

$$u_{qs} = R_s i_{qs} + \frac{d\varphi_{qs}}{\omega_b dt} + \omega_s \varphi_{ds}$$

The d-q rotor voltage (u_{dr}, u_{qr}) are written by,

$$u_{dr} = R_r i_{dr} + \frac{d\varphi_{dr}}{\omega_b dt} - (\omega_s - \omega_r)\varphi_{qr}$$

$$u_{qr} = R_r i_{qr} + \frac{d\varphi_{dt}}{\omega_b dt} + (\omega_s - \omega_r)\varphi_{dr}$$

Where i_{ds}, i_{qs} are direct and quadrature axis stator current. R_s, R_r are stator and rotor resistance. ω_s and ω_r are Synchronous and DFIG speed.
The d-q stator flux ($\varphi_{ds}, \varphi_{qs}$) include self and mutual flux linkage are written by

$$\varphi_{ds} = L_s i_{ds} + L_m i_{dr}$$

$$\varphi_{qs} = L_s i_{qs} + L_m i_{qr}$$

The d-q rotor fux ($\varphi_{dr}, \varphi_{dr}$) include self and mutual flux linkage are expressed as

$$\varphi_{dr} = L_r i_{dr} + L_m i_{ds}$$

$$\varphi_{qr} = L_r i_{qr} + L_m i_{qs}$$

Where L_s, L_r *and* L_m are stator, rotor and mutual inductance respectively.The electromagnetic torque T_e is expressed as

$$T_e = (\varphi_{ds} i_{ds} - \varphi_{qs} i_{ds})$$

Converter Model:

DFIG converter system is a back-to-back VSC converter connected via a dc link capacitor. It consists of Rotor Side Converter (RSC) and Grid Side Converter (GSC) .The RSC is controlled voltage source as it injects an AC voltage at slip frequency to the rotor. The GSC is controlled voltage source as generates an AC voltage. It maintains the dc link voltage to be constant value. The converter is expressed as,

$$P_{r=}P_g + P_{dc}$$

Where P_r, P_g and P_{dc} are RSC, GSC and DC link real power, expressed by following.

$$P_r = V_{dr}\, i_{dr} + V_{qr}\, i_{qr}$$

$$P_g = V_{dg}\, i_{dg} + V_{qg}\, i_{qg}$$

$$P_{dc} = V_{dc}\, i_{dc} = C_{V_{dc\_nom}} \frac{dv_{dc}}{dt}$$

Crowbar System:

The Crowbar system short-circuits the rotor winding of the DFIG through resistors, therefore limiting the rotor voltage and providing an additional path for the rotor current during network disturbance. The crowbar system helps avoid damaging the RSC by isolating it from the rotor. The crowbar is connected within the rotor and the RSC. The traditional crowbar, modelled by a resistor and a power electronics switch for each phase of the rotor has been considered and its performance is compared with that of the DC resistive SFCL and the SDBR

Control of crowbar: The crowbar is activated by connecting all three phases of the rotor through the crowbar resistors to ground, when either the rotor current or the DC-link voltage exceeds the reference value due to the occurrence of any anomalous situation. At this time, the RSC is kept isolated from the rotor of the DFIG. As soon as the DC link voltage reaches its normal range, the crowbar becomes deactivated and the RSC is reconnected with the DFIG. Moreover, the reactive current component of the generator is increased to support the grid.The crowbar system also can be activated again, immediately after the post fault conditions.

Dc Resistive Superconducting Fault Current Limiter

The DC resistive SFCL Fig 2: is a combination of the rectifier and resistive type SFCL where a low inductance superconducting coil is designed to quench when the current flows over the rated value, thus minimising excessive fault current. The quench resistor of the superconducting coil is represented by R_{SC}, which varies with the current intensity. During normal operation of the system, the resistance of R_{SC} is negligible. The rectifier with the combinations of the four diodes (D1–D4) in each phase, allows the superconductor to operate in nearly DC current conditions. This helps reduce the AC losses in the superconductor, and hence improves the efficiency of the system.

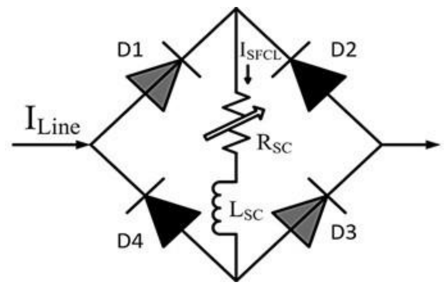

Fig 2: Control of SFCL

DC resistive SFCL operation: In the DC resistive SFCL, one half cycle of the electrical frequency line current (I_{Line}) is carried through the path D1–R_{SC}–L_{SC}–D3, and for another half cycle, this path becomes D2–R_{SC}–L_{SC}–D4. Due to this, the current (I_{SFCL}) flowing through the superconducting coil is unidirectional. This helps minimise the loss across the coil, L_{SC}. Although there are some power losses across the rectifier diodes, it is reported that using the DC resistive SFCL provides better system efficiency, even when considering these losses.

SDBR Configuration And Control

The SDBR Fig 3:is a simple resistor which is dynamically inserted in the circuit in series for a shorter period during the grid faults. During normal operation, the bypass switch is closed and the resistor is deactivated. At the time of network fault, when the voltage at the considered terminal of the network goes lower than the desired threshold value, the controller initiates the bypass switch to be opened to activate the SDBR. As a result, the post fault current flows through the resistor and helps recover the initial post fault condition by reducing the flow of the post fault current, and protects the terminal voltage to become much lower. The SDBR also helps balance the active power during network disturbance through electrical power dissipation.

Control of the SDBR:The operation of the SDBR is controlled by sensing the voltage of the PCC. When this voltage goes below the reference value, the bypass switch is turned off and the resistor is inserted in serieswith the grid. During the simulation, the same value of 0.82 p.u. resistance as the SFCL is also considered for the SDBR to make the comparative study.

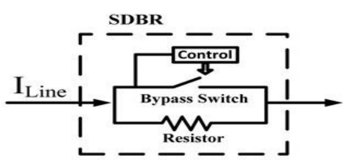

Fig 3: Control of SDBR

LVRT Investigation at PCC

The PCC voltage response for the four cases during the symmetrical fault along with the US grid code is presented. To comply in accordance with the grid code, a larger timeframe of the simulation is considered. It has been clearly realised that, for both the uncompensated system (i.e. using no controller) and condition-IV (i.e. DFIG with the crowbar), the PCC voltage falls closer to zero, which violates the grid code to keep the DFIG system connected with the PCC, although all modern grid codes demand that the wind farms be connected with the power network, even during the faults. The DC resistive SFCL enhances the LVRT performance by maintaining the PCC voltage ±0.1 p.u. of the nominal voltage, which completely follows the grid code. Although SDBR helps maintain the PCC voltage level over 0.77 p.u., the DC resistive SFCL clearly outperforms the SDBR.

Simulation considerations:

Though this study is carried out for a variable wind speed generator system, the wind speed is considered constant (14 m/s), as the duration of the transient stability study is very small for the wind speed to make any considerable influence. The Matlab/Simulink design Fig 4: and run all the simulations for a duration of 2 s. Both the temporary three-phase-to-ground (3LG) and single-phase-to-ground (1LG) faults are considered separately at PCC at 0.1 s, and the fault persists for a duration of 0.42 s. Circuit breakers CB3 and CB4 are opened at 0.1833 s and reclose at 1.0163 s. During the simulation, four different types of situations are considered, such as:.

1. Condition-1: Fault analysis with DC resistive SFCL.
2. Condition-2: Fault analysis with SDBR.
3. Condition-3: Fault analysis with crowbar system.

Simulation Model:

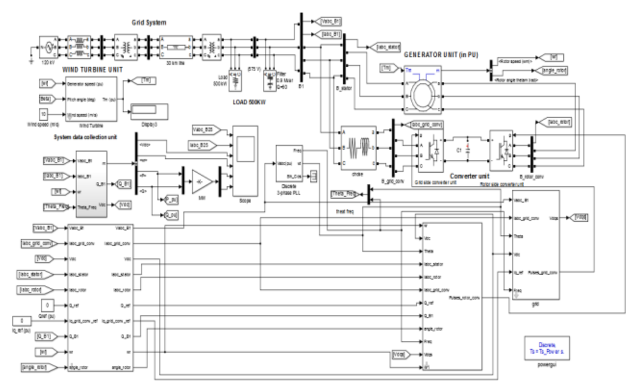

Fig 4: Simulation for transient stability analysis

CONCLUSION

This paper proposes the use of DC resistive SFCL to improve the transient stability of a DFIG based wind power system. From the simulation results, the following assessments can be noted:

- The proposed DC resistive SFCL is able to enhance the transient stability of the DFIG system for both the symmetrical and asymmetrical faults.
- Huge voltage sag and high levels of fault current are significantly supressed by the DC resistive SFCL
- The DC resistive SFCL provides better performance than the SDBR and the crowbar system.

In the WECS, increasing the efficiency is always preferred. Though different studies are reported to improve the DFIG performance with the conventional

SFCL, certainly the DC resistive SFCL is an attractive replacement over them.In the future, the application of DC resistive SFCL can be tested for a large wind farm. Moreover, this can be applied and tested for the PMSG based WECS. As SFCL is a very effective tool to enhance the FRT, its cost minimisation is always an important direction of research as well.

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