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Doubly Fed Induction Generator's (DFIG) Contribution to Improve Voltage Stability in Grid using Rotor Side Converter and Grid Side Converter

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Abstract

Nowadays wind energy has become one of the most important and promising sources of renewable energy, which gives additional transmission capacity and better means of maintaining system reliability. Variable speed wind turbines that present gives many advantages compared to the fixed speed wind turbines due to growth of technology related to wind systems. These wind energy conversion systems are connected to the grid through Voltage Source Converters (VSC) to make variable speed operation possible. The stator of the generator is directly connected to the grid while the rotor is connected through a back-to-back converter which is dimensioned to stand only a fraction of the generator rated power. Grid connected Doubly Fed Induction Generator (DFIG) gives more efficient to the wind power with the most reliable system in the present era. The DFIG brings the advantage of utilizing the turns ratio of the machine, so the converter does not need to be rated for the machine's full rated power. The rotor side converter (RSC) usually provides active and reactive power control of the machine but the grid-side converter (GSC) keeps the voltage of the DC-link constant. The additional advantages of reactive power generation by the GSC are usually due to the fact that it is more preferable to do so using the RSC. However, within the available current capacity the GSC can be controlled to participate in reactive power generation in steady state as well as during low voltage periods. The GSC can supply the required reactive current very quickly whereas the RSC passes the current through the machine resulting in a delay. Both converters can be temporarily overloaded, but at that time, the DFIG is able to provide a considerable contribution to grid voltage support during short circuit periods. In this paper we focus on analysing a wind turbine system using MATLAB Sim Power Systems. The machine used was a doubly fed induction generator (DFIG). A fault ride through situation was investigated. As protection against short circuit transients, the crowbar protection was modelled.

Keywords: Wind Power, Voltage Source Converter, Doubly Fed Induction Generator (DFIG), Crowbar.
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Introduction

A wound rotor induction motor may also act as a generator when driven above the synchronous speed. Since there are connections to both the stator and rotor, such a machine is known as a doubly-fed induction generator (DFIG). The singly-fed induction generator only had a useable slip range of 1% when driven by troublesome wind torque. Since the speed of a wound rotor induction motor may be controlled over a range of 50-100% by inserting resistance in the rotor, we may expect the same of the doubly-fed induction generator. Not only can we slow the rotor by 50%, we can also over speed it by 50%. That is, we can vary the speed of a doubly fed induction generator by ±50% from the synchronous speed. In actual practice, ±30% is more practical.

If the generator over-speeds, resistance placed in the rotor circuit will absorb excess energy while the stator feeds constant 60 Hz to the power line (Figure. 1). In the case of under-speed, negative resistance inserted into the rotor circuit can make up the energy deficit, still allowing the stator to feed the power line with 60 Hz power [6].

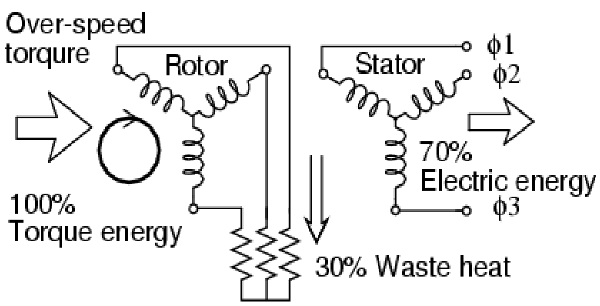

Figure 1: Rotor resistance allows over-speed of doubly-fed induction generator

In actual practice, the rotor resistance may be replaced by a converter (Figure.2) absorbing power from the rotor, and feeding power into the power line instead

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of dissipating it. This improves the efficiency of the generator.

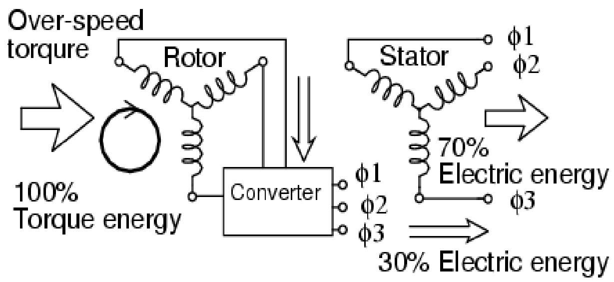

Figure 2: Converter recovers energy from rotor of doubly-fed induction generator

The converter may "borrow" power from the line for the under-speed rotor, which passes it on to the stator. (Figure.3) The borrowed power, along with the larger shaft energy, passes to the stator which is connected to the power line. The stator appears to be supplying 130% of power to the line. Keep in mind that the rotor "borrows" 30%, leaving the line with 100% for the theoretical lossless DFIG.

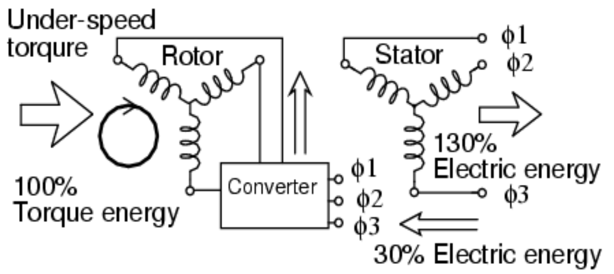

Figure 3: Converter borrows energy from power line for rotor of doubly fed induction generator, allowing it to function well under synchronous speed

Withstanding grid faults becomes an obligation for the bulk wind generation units connected to the transmission network and it is highly desired for distribution wind generators. Doubly-Fed Induction by Generator (DFIG) technology is widely used in large and the modern wind turbines since it permits variable speed operation at reasonable cost and provides a reactive power control. With the increasing penetration of wind turbines employing DFIG, it becomes a necessity to investigate their behavior during transient disturbances and support them with fault ride through capabilities. A bypass resistor-set known as crowbar that is connected in the event of fault to the rotor terminals in order to improve the DFIG fault ride through capabilities were analyzed.

Advantages of Variable Speed Wind Turbine

Seen from the wind turbine point of view, the most important advantages of the variable speed operation compared to the conventional fixed speed operation are:

- The Mechanical stress is Reduced on the mechanical components such as shaft and gear-box – the high inertia of the wind turbine is used as a flywheel during gusts, i.e. the power fluctuations are absorbed in the mechanical inertia of the wind turbine.
- Power capture Increases – because of the variable speed feature, it is possible to continuously adapt (accelerate or decelerate) the rotational speed of the wind turbine to the wind speed, in such a way that the power coefficient is kept at its maximum value.
- Reducing in acoustical noise – low speed operation is possible at low power conditions (lower wind speeds).

Additionally, the presence of power converters in wind turbines also provide high potential control capabilities for both large modern wind turbines and wind farms to fulfil the high technical demands imposed by the grid operator, such as:

- controllable active and reactive power (frequency and voltage control)
- quick response under transient and dynamic power system situations
- influence on network stability
- improved power quality (reduced flicker level, low harmonics filtered out and limited in-rush and short circuit currents)

Block Diagram of DFIG

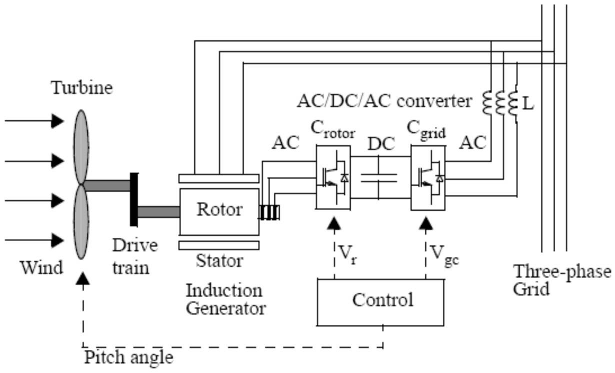

Figure 4: The wind turbine and the doubly-fed induction generator system

The mechanical power and the stator electrical power output are computed as follows:

$$P_m = T_m \omega_r$$

$$P_s = T_{em} \omega_s$$

For a lossless generator the mechanical equation is:

$$J(d\omega_r/dt) = T_m - T_{em}$$

In steady-state at fixed speed for a lossless generator

$$T_m = T_{em} \text{ and } P_m = P_s + P_r$$

It follows that:

$$P_r = P_m - P_s = T_m \omega_r - T_{em} \omega_s = -sP_s$$

Where,

s =(ωs- ωr) / ωs is defined as the slip of the generator.

Generally the absolute value of slip is much lower than 1 and, consequently, P_r is only a fraction of P_s. Since Tm is positive for power generation and since ω_s is positive and constant for a constant frequency grid voltage, the sign of P_r is a function of the slip sign. P_r is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed).

For super-synchronous speed operation, P_r is transmitted to DC bus capacitor and tends to rise the DC voltage. For sub-synchronous speed operation, P_r is taken out of DC bus capacitor and tends to decrease the DC voltage. C_{grid} is used to generate or absorb the power P_{gc} in order to keep the DC voltage constant. In steady-state for a lossless AC/DC/AC converter P_{gc} is equal to P_r and the speed of the wind turbine is determined by the power P_r absorbed or generated by C_{rotor}. The power control will be explained below.

The phase-sequence of the AC voltage generated by C_{rotor} is positive for sub-synchronous speed and negative for super-synchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip. C_{rotor} and C_{grid} have the capability for generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.

Where,

P_m = Mechanical power captured by the wind turbine and transmitted to the rotor.

P_s, Q_s = Stator active and reactive power output.

P_r, Q_r = Rotor active and reactive power output.

P_{gc}, Q_{gc} = C_{grid} active and reactive power output.

T_m = Mechanical torque applied to rotor.

T_{em} = Electromagnetic torque applied to the rotor by the generator

ω_r = Rotational speed of rotor.

ω_s = Rotational speed of the magnetic flux in the airgap of the generator. This synchronous speed is proportional to the frequency of the grid voltage and to the number of generator poles.

J = Combined rotor and wind turbine moment of inertia.

Crow-Bar Protection

Crowbar circuits may be anti-parallel thyristor crowbar, diode bridge crowbar or other more unusual configurations.For converter protection reasons, as a part of any fault ride through system, a crow bar is connected between the rotor and the rotor-side converter. If the rotor voltage exceeds a certain threshold, current thyristors in the crow bar will be activated and the current will pass through resistors, which are grounded on the downside. This action will prevent to high rotor currents and excessive DC-link voltage. The resulting voltage amplitude in the rotor circuit is determined by the crow bar resistors [7].

Low fault currents are wanted, but high resistor values that effectively limit the current will at the same time cause high converter voltage. The choice is therefore a trade-off between high rotor currents or high voltage at the converter terminals and the most important of these factors for fast regain of controlled operation, is the current.

The crow bar resistors also act as an active power sink, burning off active power to mitigate rotor over-speeding. During the time the crow bar is activated, the generator works as a conventional induction generator with high rotor resistance. Several different chains of events can follow a crow bar action, and those are effectively the different Low Voltage Ride Through (LVRT)-strategies. One possibility is to overrate the IGBT modules in the converter to allow for an extended, voltage tolerance of the DC-link, another is the possibility to disconnect the rotor side converter but not the grid side converter and a third is to disconnect the stator and continue the active operation of both converters and the DC link. The main goal of the LVRT-systems regardless is instantaneous resumed active operation for the wind turbine after grid fault clearance.

Wind Electric Energy Simulation with Crow-Bar Protection

A simplified power system model of wind turbine crow-bar protection is shown in Figure 5. The SimPower Systems toolbox in MATLAB/SIMULINK is used to conduct the simulation. The Asynchronous Machine Block in the SimPower System toolbox is developed in the graphical SIMULINK environment of the general purpose MATLAB software. The machine is connected to a subsystem block of crow-bar.

The wind speed is considered as a variable function with time; as a result, generated power from the wind turbine is also a variable function with time.

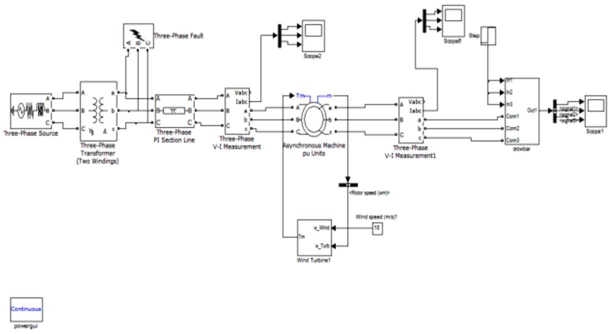

Figure 5: SIMULINK model of wind turbine crow-bar protection

Simulation Result

When the fault occurs at some point during the grid operation, the crow bar protection is activated via ideal switches driven by a step signal. This is followed by a transient state which exists for a short period. Now the fault gets cleared. The crow bar then gets disabled and the power flow in the grid returns back to normal.

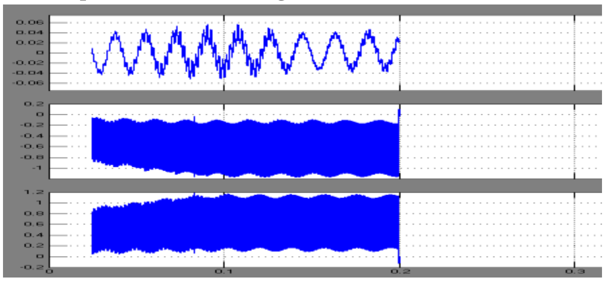

Figure 6: SIMULINK result of wind turbine crow-bar protection.

Conclusion

Careful consideration of the interaction between wind turbines and the grid is now, and will continue to be, an important area of technical design. It must be carefully sustained and is set to play a major role in future technology development. The FRT (Fault Ride Through) assigns a crowbar resistance to be connected across the rotor terminals during the fault. The rotor-side converter is employed along with the grid-side converter to fed reactive current to the grid during the fault. The crowbar limits the generator currents to their rated values and completely protects the DC link and the converters by separating from rotor terminals. The voltage performance is enhanced and the recovery becomes faster. This is reliable and is considered as an adequate solution to keep the DFIG on during sharp voltage dip disturbances occurred outside its protection zone.

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