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Control Strategy of a Dc-Link Brake Chopper for Low-Voltage-Ride-Through in Doubly Fed Induction Generator

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ABSTRACT

Due to proliferation of wind turbines, the performance of DFIG during grid fault is attracting much interest. During a fault, the international grid codes specify that the generator must exhibit a fault ride through (FRT) capability by remaining connected and contributing to network stability. To protect the rotor converter during a fault, many DFIG systems employ a rotor circuit crowbar. It can be also used to protect the generator but it does not provide favorable grid support behavior. To ensure the dc-link voltage under control during a fault, this paper describes an alternative method FRT approach using a brake chopper circuit across the converter dc link.

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INTRODUCTION

The large-scale development of wind power is an effective way to solve the global problems such as the environmental pollution and energy shortage. Wind power is usually extracted by wind turbines using either fixed speed or variable speed regimes. For reasons of improved efficiency of energy transfer from the wind and optimize the operation of wind turbine, the latter is distinctive with getting more energy for a specific wind speed, better aerodynamic efficiency, less mechanical stresses and reduced noise levels. The variable speed operation of wind turbines can be realized by driving DFIGs, Wound Rotor Synchronous Generator (WRSG) or Permanent Magnet Synchronous Generator (PMSG). Among of these types, DFIG represents the most popular one due to its overall lower cost. DFIGs are, therefore, emerging nowadays as the most preferred topology for recent wind farms.

The DFIG is equipped with a back-to-back power electronic converter, which can adjust the generator speed with the variety of wind speed. The converter is connected to the rotor windings, which acts as AC excitation system. The converter is much cheaper, as the rating is typically 25% of total system power, while the speed range of the generator is 33% around the synchronous speed. The major advantage of this design is the fact that the converter does not have to be rated for the machine's full power, but only for about a third of it. Owing to the new policies of recent grid codes, wind farms are required to remain grid- connected during grid faults for a certain time so that they can directly contribute with active and reactive power to the grid. This leads to support the overall system stability. Different problems arise, however, for the associated generator converter protection and control issues. During these voltage dips, the delivered active power to the grid by the farm is remarkably reduced. Consequently, the mechanical power exceeds the delivered active power resulting in increasing the rotor speed. Then, the control scheme of the DFIG variable-speed wind turbines embraces the wind turbine control for preventing over speeding of the wind turbine and the control and protection of the power converter during and after the grid faults. As a result, relay miss-coordination or miss-operation may occur due to the changes in fault current profile.

Existing Methodology:

Doubly fed induction generator (DFIG) technology is presently dominant in the growing global market for variable speed wind power generation, due to its cost-effective, partially rated power electronic converters. However, the DFIG is sensitive to dips in supply voltage because the internal machine flux is exposed directly

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to the electrical grid. The induction generator very quickly loses internal magnetization in proportion to the lost voltage producing large outrush currents on both stator and rotor circuits. Without specific measures to protect against "ride through" grid faults, a DFIG risks damage to its power electronic devices and dc-link capacitors due to the resulting over currents and/or over voltages. Conventional converter protection is via a sustained period of rotor–crowbar application (Seman, S., 2006) that protects the power converter while allowing the converter to resume control at the earliest possible opportunity Fig. 1 shows a schematic diagram of a wind turbine DFIG with conventional IGBT based crowbar protection.

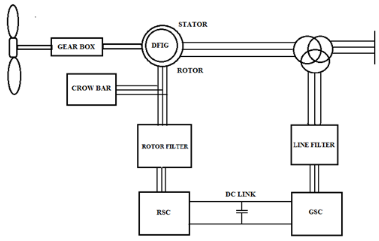

Fig.1: Wind Turbine with conventional IGBT based crowbar protection.

The crowbar was developed as a standard rotor circuit protection device long before the advent of wind turbine grid code regulations (Morren, S.W.H de Haan, 2007). It involves connecting the rotor phases together through a designated resistance, diverting current from the rotor side converter and rapidly de-energizing the rotor. The crowbar absorbs the initial energy outflow from the machine, while the resistance shortens the effective decay timescale of the rotor flux decay, hence hastening the demagnetization process. Conventionally, the crowbar is applied for an extended duration to fully demagnetize the rotor. Unfortunately, vector control is lost while the crowbar is applied and the induction machine must draw its magnetization from the stator side, producing a high-slip reactive power demand leading to poor power and reactive power outputs and sustained suppression of the stator voltages. The FRT performance of wind turbine DFIGs has therefore received much attention in the literature in recent years. Many schemes have been proposed to ensure DFIG compliance with grid code requirements including the use of a brake resistors (Causebrook, A., 2007), the application of a controlled resistance crowbar (Yang, J., 2010), control of the timing of crowbar application (Yan, X., 2011), the application of a dynamic voltage restorer to compensate the faulty line voltage, and the use of novel controller designs to improve the transient response of the grid-connected DFIG under supply fault conditions.

3. Proposed methodology:

An alternative protection technique obtained by using a dc-link brake chopper to contain the dc-link voltage while accepting transient rotor over currents has also been proposed in the literature. This method has been demonstrated successfully in simulation, when used together with a rotor crowbar (Ren, Y. and W. Zhang, 2011), a series dynamic brake resistor (Pannell, G., 2010), and even in conjunction with a superconducting magnet. The use of the dc brake chopper alone as a DFIG protection device has also been proposed and its performance compared with that of a crowbar circuit in a simulation study although no experimental investigation of the application of the dc-link brake chopper as a grid FRT protection device has previously been published.

This paper presents the use of the dc-link brake chopper as a sole protection device for DFIG grid FRT management. Two different control methods are investigated. The first is a relatively simple control strategy in which rotor current control is resumed after a short time delay initiated once rotor currents have returned to a level compatible with effective current control. A schematic diagram of a wind turbine DFIG with a dc brake chopper is shown in Fig. 2. The crowbar circuit is dispensed with and the six anti parallel diodes in the DFIG's rotor-side converter are up-rated to handle short-circuit currents. A power resistor and series switch are placed in parallel with the dc-link delay initiated once rotor currents have returned to a level compatible with effective current control.

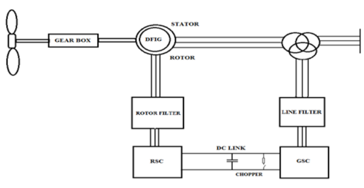

Fig. 2: Wind turbine DFIG with dc brake chopper protection.

A second, more advanced control method was also examined where the application of the dc chopper is released and pulse width modulated (PWM) control restored once rotor current had fallen below a given threshold in order to optimize the resumption of power control. Control of the brake chopper and the FRT performance characteristics of the dc brake chopper based schemes are investigated.

A schematic diagram of a wind turbine DFIG with a dc brake chopper is shown in Fig. 2. The crowbar circuit is dispensed with and the six anti parallel diodes in the DFIG's rotor-side converter are up-rated to handle short-circuit currents. A power resistor and series switch are placed in parallel with the dc-link capacitance to sink power when the dc-link voltage exceeds a fixed predefined threshold.

4. Dc link chopper:

The dc-link brake chopper is a simple protection device that shorts the dc-link through a power resistor when the dc-link voltage exceeds a fixed threshold. The brake is used to contain the dc-link voltage while accepting transient rotor over currents. The dc-link brake appears somewhat similar to the rectifier insulated gate bipolar transistor (IGBT) crowbar configuration. Instead of a separate rectifier, the six anti parallel diodes in the DFIG's rotor-side converter are up-rated to handle short-circuit currents. A power resistor and series switch are placed in parallel with the dc-link capacitance to sink power as required.

A DFIG dc-link brake chopper is shown schematically in Fig. 3. Only the rotor-side converter is pictured, as this is the focus of DFIG fault response. An IGBT chopper circuit is used to rapidly engage and disengage the resistor. The chopper works on a hysteresis band, i.e., the turn-OFF voltage is set below the turn-ON threshold. The anti parallel diode connected across the brake resistor is needed to allow for the stray inductance effects when the chopper IGBT is switched off.

In case of transient over currents as a result of a grid fault, the rotor-side converter PWM control may be disabled and all of the rotor converter's IGBTs are switched off. Without an alternative circuit path, the transient rotor currents are forced to conduct through the rotor converter diodes. Rotor demagnetization energy is dumped into the converter's dc link, causing the dc-link voltage to rise rapidly. The resulting dc-link voltage rise will trigger the brake, sinking power through the brake resistor and helping to prevent a dangerous overvoltage event on the dc link. When the rotor transients have sufficiently decayed, rotor-side PWM and rotor current control may be reengaged.

If the rotor converter switches are held off for long enough for the unsupported rotor flux to decay, then the dc-link voltage will reverse block the converter's diodes. The diodes will cease conducting from the next current zero; the rotor currents are then held at zero until IGBT switching is resumed.

The change in dc-link voltage is chiefly limited by the dc-link capacitance. The voltage across the brake resistor will remain roughly constant. The brake resistor can then be considered as an approximately constant load, sinking power according to the equation:

$$P_{brake} = \frac{V_{dc}^2}{R_{brake}}$$

The presence of the capacitance means that the load is inversely proportional to the brake resistance. A large brake resistor will draw negligible current, while the lower limit of resistance is related to the maximum current rating of the resistor and IGBT pair, which, in turn, is determined by the maximum permissible dc-link voltage:

$$i_{brake} \leq \frac{V_{dc,max}}{R_{brake}}$$

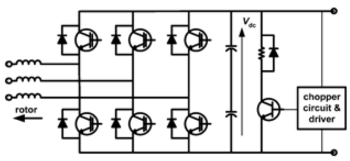

Fig. 3: Rotor Converter with dc link brake chopper.

The Dc Brake Chopper Protection:

Brake chopper operating modes are shown in Fig. 4, with reference to the protection threshold limits used in this investigation.

The brake resistor must be sufficiently rated for to protect the dc link from the worst case of fault induced rotor over currents. The anti parallel diodes in the rotor converter must be capable of handling rotor fault currents of about 5 pu. The dc-link capacitance must be rated to withstand the rectified form of these over currents, for periods where the brake resistor is not engaged. This translates to roughly 7 pu current (on a machine–rotor pu base). The capacitor current rating is unlikely to form an onerous equipment restriction. The key issue is whether the dc brake can prevent the voltage from exceeding the capacitors' maximum voltage capabilities; this can be secured with an appropriate choice of brake resistor.

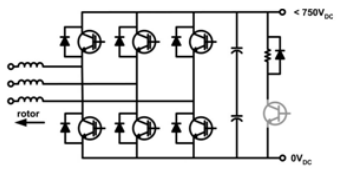

Fig. 4: Normal Operation with the brake OFF, PWM ON.

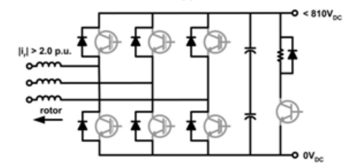

Fig. 5: PWM ON, brake OFF.

In response to a grid fault, transient rotors over currents force the dc-link voltage to rise rapidly. Relying entirely on the dc brake chopper circuit and with no rotor crowbar, the rotor side converter PWM control is disengaged (i.e., all switches are turned "off"), when the measured rotor current magnitude exceeded the threshold value of 2.0 pu, allowing the rotor-side converter anti parallel diodes to carry the transient high rotor currents, as shown in Fig. 5.

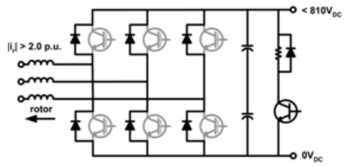

Fig. 6: PWM ON, brake OFF.

The resulting dc-link voltage rise (above 810 V) will trigger the brake, as shown in Fig. 6, and the power dissipation in the brake resistor will halt the increase in dc voltage. The chopper control circuit switches the IGBT device with a duty cycle determined by the magnitude of the overvoltage. The duty cycle of the chopper is increased as the overvoltage increases up to a maximum permanently on state. The brake resistor is disengaged independently when the dc voltage falls below a lower hysteresis threshold level set at 795 V in the test rig.

When the rotor current falls below 2.0 pu, resumption of PWM and rotor current control is delayed by 20 ms to ensure that, at the end of a given rectification period, the rotor flux had sufficiently deteriorated for the vector controller to be able to maintain the rotor current within safe limits. The rotor-side converter power/reactive power proportional–integral (PI) controllers are delayed by a further 20 ms (i.e., 40 ms after the current had exceeded 2.0 pu) to allow the current controllers to settle. During control-off periods, the current control PI integrators are set to deliver values calculated for normal operation. PQ integrators are set to the last measured current to avoid any possible instabilities when power/reactive power control is resumed. As PQ PI control is resumed, the rotor current reference value changes were rate-limited to no more than 1.5 pu/s to ensure current feedback control stability.

A more advanced "minimum threshold" control method was also developed in which the application of the dc chopper brake is released by rotor current threshold (1.9 pu) and feedback control carefully restored to minimize the rectification period and optimize the resumption of power control, exactly as for the minimum threshold crowbar method described in a previous publication (Yan, X., 2011). In this method, the state variables of the rotor current PI controller are suspended with last-good-values to increase stability on the resumption of feedback control. The outer loop power and reactive power PI controllers are suspended and then soft-restarted by means of a 10 ms error signal ramp. When the control is resumed, the PQ PI controllers' integral components are artificially reset to output the most recent measurement of rotor current. As a result, the rotor current PI controllers restart with approximately zero error input, minimizing any kick in current associated with the resumption of feedback control, as detailed in (Yan, X., 2011).

Simulation And Discussion:

A simple simulation of the brake chopper operation was created for consolidating the analytical concepts and FRT ideas before the implementation on the test rig. From simulation tests, two multiples of operational rotor power dissipated from the dc link was sufficient to maintain the dc-link voltage below 1000 V in grid fault situations. Sizing the brake resistor to sink twice the maximum operational converter power with a cut-in dc link voltage of 810 V and brake resistor value of about 0.7 Ω for a 2-MW DFIG drive. The rotor converter's anti parallel diodes were rated sufficiently high to accommodate the maximum rotor over currents. No crowbar was employed in any of the tests. The brake chopper employed on the dc link operated with its own hysteresis controller using a dc-link voltage measurement independent of the voltage recorded by the dSpace controller. In the following discussions, the period for which the rotor PWM was turned off and vector control suspended is referred to as the rectification period, because any rotor currents flowing were rectified by the diodes in the rotor-side converter.

Simulation Results:

Results for fault test are given in Fig. 7, showing a single rectification period following each of fault initiation and clearance during which transient rotor over currents were diverted from the converter IGBTs. The dc-link voltage was well maintained by the brake chopper in this test, scarcely passing 820Von either fault initiation or clearance. Near-dc components of rotor current decayed within the rectification periods, although the stator circuit near-dc decay extends well into the fault and recovery periods. Good rotor current control is exhibited roughly 80 ms after each rectification period. The d component of rotor current was controlled mid fault to 0.67 pu. The q-component was saturated at −0.70 pu.

Prior to fault clearance, the machine delivered 20% active power and 18% reactive power generation. The in-fault stator voltage was steadied at 28 pu. After fault clearance, the reactive power oscillated strongly, while the average value fell from 4 kvar import to zero over roughly 100 ms. This was a disappointing result in terms of local voltage support, which was suppressed by as much as 10% during this period. As a result of the reactivation delay, the first rectification period endured for 27.6ms, starting 1.2 ms after fault initiation, and the second rectification period for 25.6ms, starting 7.8 ms after fault clearance. After the first rectification period, the rotor currents approached zero. During the second period, the rotor currents were "pinched off"; after reaching zero, the diodes became reverse-biased by the dc-link voltage and did not conduct until the rotor PWM was reengaged.

The rotor currents exhibited near-rotor speed oscillations after fault initiation and clearance reflecting the near-dc decay on the stator circuit (54.5 Hz after fault initiation and 5.5 Hz after fault clearance, in accordance with the increased speed). This oscillation extended further into the fault than normal—roughly 140 ms here. Also, the rotor current magnitude during the rectification periods did not exceed 3 pu, well below the maximum current seen when employing crowbar methods. These all point to a slower decay of machine flux and that the dc link inhibited the ac fault current decay.

Unlike a standard crowbar circuit, the dc-link brake does not directly influence the rotor flux decay. Assuming that the internal resistance of the dc-link capacitance is small, the converter appears to the rotor as a short-circuit. This produces a cage-induction-machine-type natural flux decay. When the current is extinguished, the diodes become reverse-biased and will not conduct until the converter's switches are reactivated.

In this manner, the brake resistor behaves very differently from a crowbar resistor. When the rotor current is extinguished, the mutual decay contribution to the stator currents is likewise extinguished. The stator flux can now only decay through its own circuit, and the effective stator time constant is lengthened. This effect is reflected in the fault test results, where the turn-OFF period for the IGBT switches was necessarily elongated in order to be able to resume stable vector control. The slower demagnetization is reflected in the fault test results.

The control-delay method successfully managed the rotor currents and restricted the dc-link voltage to below 850 V in the face of 15% fault voltages, with a single rectification period at fault initiation and at fault clearance. The required rectification periods were 26–29 ms. In each test, the fault clearance rectification period preceded a 50% reactive power import that suppressed the stator voltage by around 11%. The controller required roughly 100 ms in each case to return to unity power factor.

Rectification Of Minimum Threshold:

The simulation results show that the simple control delay method successfully managed the rotor currents and restricted the dc-link voltage to below 850 V in the face of 15% fault voltages, with a single rectification period at fault initiation and at fault clearance. Fig. 8 shows the test results obtained when using the minimum threshold type controller for the dc brake chopper. The results demonstrate how stable control could not be achieved when using this control method. The slower demagnetization process of the machine in this case is reflected in these test results, thus showing that stable vector control could not be established immediately after the first peak of rotor current. Noticeably, the current controllers did not gain good control after the rectification period following fault initiation. Each release led to substantial oscillations that triggered further rectification periods; six instances were recorded after fault initiation before the currents began to settle, two of which lasted only three control cycles (600 μs).

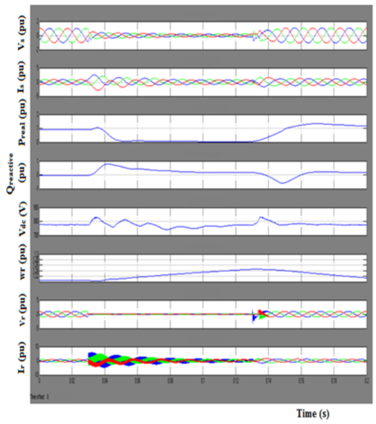

Fig. 7: DC brake chopper; controlled delay method.

Noticeably, after each occasion of PWM control resumption, the rotor currents remained high, thereby rendering the control environment more difficult. Sharp spikes of rotor current were produced as the current references pulled sharply to and from their saturation limits.

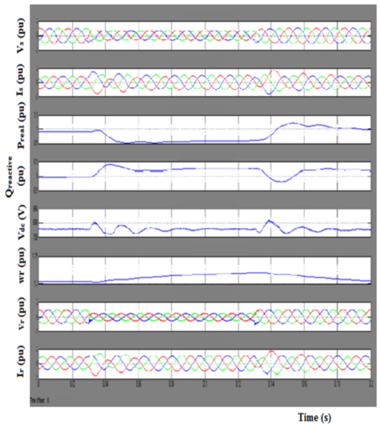

Fig. 8: DC brake chopper rectification of minimum threshold method.

Conclusion:

The use of a dc brake chopper circuit as a DFIG FRT in response to grid faults was simulated in this paper. Using a simple, delayed control method for the resumption of PWM control, the dc-link brake was shown to successfully maintain the dc-link voltage within safe limits, while potentially dangerous rotor over currents were allowed to conduct safely through (overrated) rotor converter diodes. Power control was restored within about 80 ms of each disengagement of the rotor converter's switches, which occurred once for each voltage step of fault initiation and clearance.

However, the periods of converter disengagement and the length of time required to restore power control were each significantly longer than what could be achieved with a rotor crowbar circuit. This is because the dc-link brake chopper fundamentally does not assist the demagnetization process of the machine, whereas the crowbar can shorten the rotor decay timescale. The dc brake fully demagnetizes the rotor before forcing the characteristic slow stator flux decay. The result is a delayed resumption in control.

The dc brake chopper offers inferior electrical characteristics when compared with crowbar based methods; particularly in terms of the rapidity with which full control may be restored. This is because the dc-link brake fundamentally does not assist the demagnetization process of the machine following a fault event, whereas the crowbar can shorten the rotor decay timescales with the appropriate choice of crowbar resistance, thereby leading to much quicker resumption in control.

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REFERENCES

Seman, S., J. Niiranen, S. Kanerva, A. Arkkio, and J. Saitz, 2006. “Performance study of a doubly fed wind-power induction generator under network disturbances,” IEEE Trans. Energy Convers., 21(4): 883-890.

Morren, S.W.H de Haan, 21007. “Short-circuit current of wind turbines with doubly fed induction generator,” IEEE Trans. Energy Convers., 22(1): 174-180.

Causebrook, A., D.J. Atkinson and A.G. Jack, 2007. “Fault ride-through of large wind farms using series dynamic braking resistors,” IEEE Trans. Power Syst., 22(3): 966-975.

Yang, J., J.E. Fletcher and J. O’Reilly, 2010. “A series-dynamic-resistor-based converter protection scheme for doubly-fed induction generator during various fault conditions,” IEEE Trans. Energy Convers., 25(2): 422-432.

Yan, X., G. Venkataramanan, Y. Wang, Q. Dong, and B. Zhang, 2011. “Gridfault tolerant operation of a DFIG wind turbine generator using a passive resistance network,” IEEE Trans. Power Electron., 26(10): 2896-2905.

Ren, Y. and W. Zhang, 2011. “A novel control strategy of an active crowbar for DFIG-based wind turbine during grid faults,” in Proc. IEEE Int. Conf. Electric Machines Drives (IEMDC), Niagara Falls, ON, Canada, 1137-1142.

Pannell, G., D.J. Atkinson, and B. Zahawi, 2010. “Minimum-threshold crowbar for a fault-ride-through grid-code-compliant DFIG wind turbine,” IEEE Trans. Energy Convers., 25(3): 750-759.