Fault ride through study of doubly fed induction generator wind turbine in real-time simulation environment

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Topic and sub-topic numbers: 14c and 14a (dialogue presentation)

Abstract

In this paper, the fault ride through of doubly fed induction generator wind turbine is studied. The study is done by using a novel real-time simulation environment consisting of Real-Time Digital Simulator and dSPACE. Simulation results show that voltage support can be maximized if transient flux compensation control is used.

Introduction

The behaviour of doubly fed induction generator (DFIG) wind turbine concept is considered to be problematic since the induction generator generates high voltages and currents to the rotor circuit as a result of a voltage dip. The maximum attainable voltage of the rotor side converter (RSC) is limited by the dc-link voltage. A deep network voltage dip induces higher voltages to the rotor circuit than the RSC can generate from the dc-link voltage. [1] Thus, the RSC control system saturates. In other words, RSC cannot control the rotor current anymore and the currents can't be limited. Typically, the RSC is disconnected from the rotor circuit and the crowbar, i.e. a set of resistors, is used to decrease the rotor currents.

Xiang *et. al.* [2] proposes a method where RSC generates rotor currents that oppose zero and negative sequence components of the stator flux linkage during a fault. The purpose is to cancel the transient flux in order to avoid rotor overvoltage and RSC saturation. Lopez *et. al.* [3] uses also currents that oppose zero and negative sequence components of the stator flux linkage. They define these currents as demagnetizing currents. However, they also point out that the amount of demagnetizing current needed to cancel the transient flux is very high. Thus, the RSC should be overdimensioned to have large current capacity. This fact, however, is against of the advantage of a DFIG which is small converters.

In this paper, the fault ride through (FRT) process relies on combination of crowbar protection and transient flux compensation control. The aim is to investigate the effects of transient flux compensation control, i.e. demagnetizing current injection, during a fault. First, the FRT relies only on active crowbar. Then, the transient flux compensation is applied on FRT process and results are compared. Simulation results indicate that control system variables show much steadier behaviour when transient flux is compensated. This leads to better power quality and improved utilization of the current capacity of the RSC. Thus, it is possible to maximize the reactive power injection of the wind turbine during a fault.

Practical Implementation

The combination of the powerful power system simulator (RTDS) and efficient control system simulator (dSPACE) provides excellent environment for wind turbine and network interactions studies. The simulation environment used makes it possible to develop control strategies for wind turbines to qualify more demanding grid codes in the future. Minimization of simulation time is additional benefit.

Figure 1 shows the block diagram of the RTDS/dSPACE implementation. The DFIG is modelled in Simulink and based on the model dSPACE makes the simulation in real time. Program ControlDesk is used to control and observe the simulation. Power system model is created in RSCAD Draft mode. RSCAD Runtime mode is used to control the real time simulation that is performed by RTDS.

Data transmission between real time simulators is done through analog signals. In other words, first digital signals of the simulator is converted to analog signals which are converted back to digital signals when fed to other simulator. dSPACE receives connection point voltages $u_{s(a,b,c)}$ and interruption signal from RTDS and gives the connection point current $i_{grid(\alpha,\beta)}$ back. From the RTDS viewpoint, the wind turbine is modelled as a current source. The interruption signal *int* is used to synchronize the calculations of dSPACE and RTDS. The hardware arrangement of the environment is shown in Fig. 2.

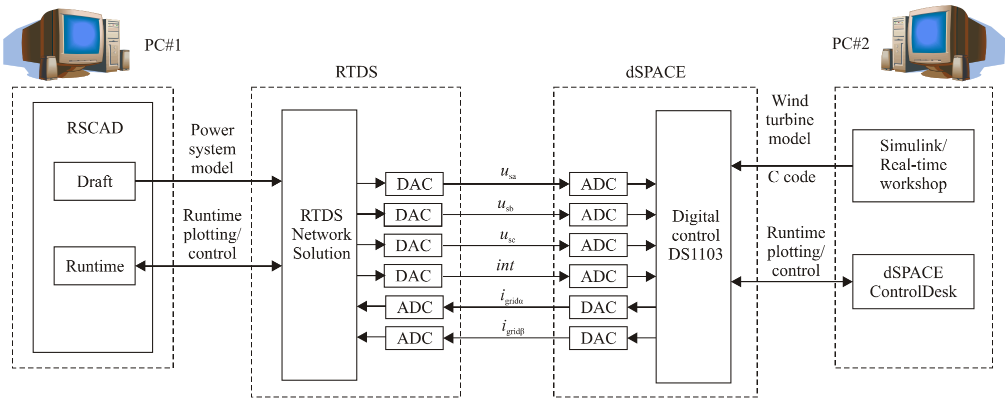

Fig. 1. Block diagram of the RTDS/dSPACE implementation.

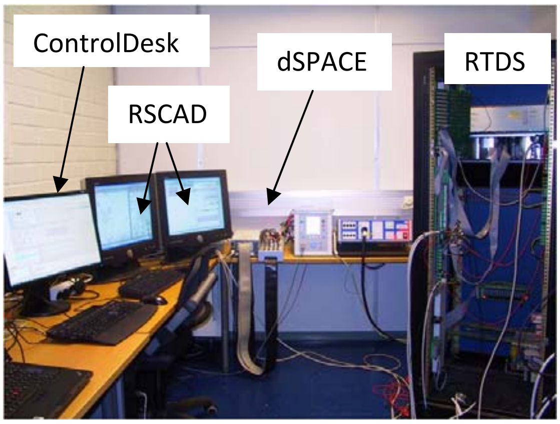

Fig. 2. The hardware arrangement of the real-time simulation environment.

Simulation results

Three-phase network voltage dip of 30% of nominal voltage is simulated. The voltage dip lasts 300ms. The FRT strategy used in first case utilizes active crowbar protection. Crowbar is activated if the measured rotor current, Fig. 3a, increases higher than the current feeding capability of RSC which is sized to be 900 A rms (1270A peak value) in this case. After the currents are decreased so much that the RSC can handle them the crowbar is deactivated and the RSC is connected back in operation. During a voltage dip, the reactive current is prioritized and active current component is set to zero. The rotor reactive current in a stator flux reference frame and its control reference are expressed in Fig. 4a. The measured current doesn't reach the reference exactly since the presence of transient flux causes uncontrolled oscillations to the current around the reference. Due to the oscillations the reference value of the x-component is set to be lower (i.e. 1020 A) than the current capacity of the RSC (i.e. 1270A). If the reference is set to 1270 A, the measured currents would be temporarily higher than the RSC current limit due to the oscillations. That would activate the crowbar protection repetitively which is undesirable. The negative value of reactive power, Fig. 5a, means that the reactive power is fed to the grid.

Next, the same simulation as above is made with transient flux compensation control. The idea behind the FRT concept that uses transient flux compensation control is to first cancel the transient flux and then feed the reactive power to the grid. Thus, the transient flux compensation current is prioritized. After the transient flux is removed the current capacity of RSC can be utilized for reactive power generation. Since the transient flux is removed the current in the rotor circuit is not distorted anymore, as depicted in Fig. 3b. After the crowbar is deactivated the RSC prioritizes transient flux compensation. After the transient flux is decayed the RSC feeds reactive current. Compared to previous case, there are no oscillations in rotor x-component current which is presented in Fig. 4b. This is due to the fact that after the transient flux is cancelled the currents of DFIG are controllable. Hence, the reference for x-component current can be set to 1270 A without a fear of crowbar reactivation. Thus, the reactive power generation is maximized as shown in Fig. 5b.

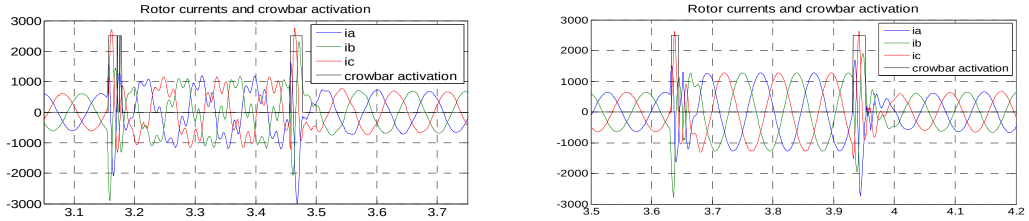

Fig. 3. Rotor currents and crowbar activation: a) Without transient flux compensation, b) with the compensation.

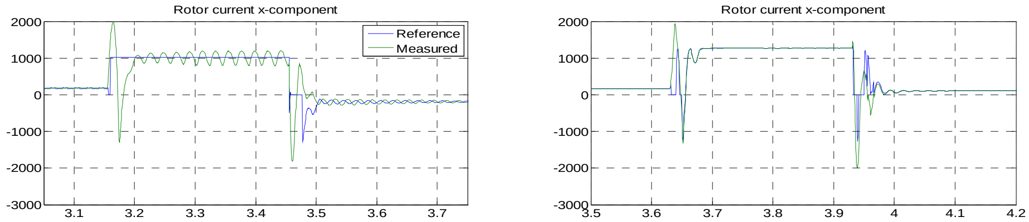

Fig. 4. Rotor reactive current component: a) Without transient flux compensation, b) with the compensation.

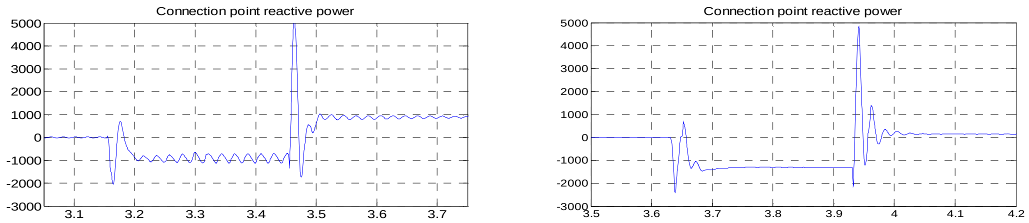

Fig. 5. Connection point reactive power: a) Without transient flux compensation, b) with the compensation.

Conclusion

The fault ride through of doubly fed induction generator is studied. The FRT strategy used in this study utilizes crowbar protection and transient flux compensation control. Simulations are carried out using real-time simulation environment including dSPACE and RTDS. If only active crowbar protection is used the presence of transient flux causes uncontrolled oscillations to the RSC reactive current component around the current reference. Due to the oscillations the reference value of the reactive current component is set to be lower than the current capacity of RSC in order to avoid repetitive activation of crowbar protection. This is undesirable from the reactive power injection viewpoint. However, the simulation results show that if the transient flux is compensated the generator is controllable during a fault. Thus, it is possible to utilize the whole current capacity of RSC for reactive power injection to the grid. This aspect is important since the latest grid codes require reactive power injection to the grid during a grid fault.

In final paper, the wind turbine and the network model as well as control systems of the wind turbine are expressed in detail. Especially the mathematical background related to the transient flux compensation control is introduced. In addition, detailed description of the real-time simulation environment and more simulation results are provided.

References

[1] J. Lopez, P. Sanchis, X. Roboam and L. Marroyo, "Dynamic Behavior of the Doubly Fed Induction Generator During Three-Phase Voltage Dips", IEEE Transactions on Energy Conversion, Vol. 22, No.3, September 2007, pp. 709-717.

[2] D. Xiang, L. Ran, P.J. Tavner and S. Yang, "Control of a Doubly Fed Induction Generator in a Wind Turbine During Grid Fault Ride-Through", IEEE Transactions on Energy Conversion, Vol. 21, No. 3, September 2006, pp. 652-662.

[3] J. Lopez, E. Gubia, E. Olea, J. Ruiz and L. Marroyo, "Ride Through of Wind Turbines With Doubly Fed Induction Generator Under Symmetrical Voltage Dips", IEEE Transactions on Industrial Electronics, Vol. 56, No. 10, October 2009, pp. 4246-4254.