学位論文内容の要旨

This thesis deals with the stabilization of grid connected wind farms by doubly fed induction generators (DFIGs). The fast growth of wind generation has led to concern about the effect of wind power on the transient stability of the electric grid. As the amount of wind power is drastically increasing in years to come, maintaining power system stability during, for example, a short circuit fault will be more important in order to ensure power supply reliability and other important issues. New studies must be performed in order to evaluate the behavior of the wind farms after severe faults and improve the design of the wind farms in an efficient and economical way. Under such circumstances, the most demanding requisite for wind farm is the Fault Ride-Through (FRT) capability. Wind farms connected to high voltage transmission system must stay connected when a voltage dip occurs in the grid, otherwise, the sudden disconnection of great amount of wind power may contribute to the voltage dip, with terrible consequences. Therefore, the dynamic and transient analyses of wind generators are necessary.

Recently, wind farm grid codes require wind generators to have sufficient FRT capability, which means that normal power production should be re-initiated once the nominal grid voltage is recovered. The fixed speed wind turbine (FSWT) system with squirrel cage induction generator has limited ability to provide voltage and frequency control, and thus requires expensive external reactive power compensation during a grid fault in order to have sufficient FRT capability. It is therefore imperative to use the DFIG variable speed wind turbine (VSWT) to stabilize the FSWT during a grid disturbance. Simulation analyses in this thesis show that the DFIGs can effectively stabilize the IGs and hence the entire wind farm through the proposed control scheme by providing sufficient reactive power to the system without additional cost.

Thus, wind farms composed of both FSWTs and VSWTs could be promising.

Since the DFIGs will be stressed or overloaded in the process of stabilizing the wind farm during a grid fault, it is paramount to consider a protection scheme for the DFIG, in order to protect its power converters. Two schemes, the DC-link chopper-controlled braking resistor with the supplementary rotor current (SRC) control of the rotor side converter and series dynamic braking resistor (SDBR) connected to the stator of the DFIG, are proposed and compared to each other in this study. It is found from the simulation results in this thesis that the two proposed schemes can eliminate the need for an expensive crowbar switch in the rotor circuit, because both can limit the rotor current of the DFIG within its nominal value during a grid fault. However, the latter scheme offers more advantages as per FRT capability requirement of the DFIG system, and hence it is recommended in this thesis.

During a grid fault, the DFIG experiences over currents which lead to increasing DC-link voltage in the power converters. Thus, the power converters are vulnerable and can easily get damaged during a grid fault. A crowbar protection switch is normally considered to protect the power converter of DFIG during a grid fault, in order to enhance FRT capability. However, the crowbar protection has some adverse effects on the operation of DFIG as it deteriorates the independent controllability of real and reactive powers. The effect on the participation of FACTS (Flexible AC Transmission System) device such as a STATCOM (Static Synchronous Compensator) connected to the point of common coupling (PCC) of a wind farm is investigated in this thesis. Simulation results show that a FACTS device can effectively enhance the performance of the DFIG when its crowbar switch is activated during a grid fault, by providing additional reactive power to the system, thus improving the voltage stability performance of the DFIG and the wind farm as well. A comparative study using the proposed DFIG control and FACTS approaches in wind farm stabilization is also carried out. The DFIG system seems to be more advantageous because, in addition to generating electric power at steady state, it can also stabilize the wind farm during dynamic and transient conditions.

A new current controlled voltage source converter (CC-VSC) scheme is proposed in this thesis for a DFIG system. Results obtained using the proposed scheme is then compared with those of two other DFIG control schemes that uses voltage controlled voltage source converter (VC-VS) and SDBR, to show the effectiveness of the proposed controller. Different types of symmetrical and unsymmetrical faults in the multi-machine power system model are analyzed using the proposed scheme considering wind farm recent grid codes. Though all of the schemes are able to stabilize the wind farms during transient conditions, the proposed CC-VSC scheme offers the advantages of less intricacy of controller design, reduced number of PI controllers at the rotor side converter of the DFIG system, and better performance during a grid fault. The transient stability index of the system is also improved for different fault type in different fault location in the considered model system by using the proposed CC-VSC scheme for DFIG. The terminal voltage of the wind farm can also be stable during wind speed change in the dynamic condition by using the proposed CC-VSC based DFIG scheme.

Simulations are carried out by using the digital simulation software package PSCAD/EMTDC (power system computer aided design and electromagnetic transient including DC). For wind power fluctuation analysis, the real wind speed data is used, which is measured at Hokkaido Island of Japan. Different types of symmetrical and unsymmetrical faults are considered for the transient stability analyses of wind turbine generator systems. It is concluded that the various proposed DFIG VSWT approaches with their control strategy can be very effective to stabilize a grid connected wind farm.

論文審査結果の要旨

近年、世界中で風力発電が増加しているが、種々の風力発電機の中でも2次励磁形誘導発電機を用いたDFIG (Doubly Fed Induction Generator) 方式が世界的に普及している。これは、DFIGが2次回転子側に励磁用インバータを有し、その制御により発電機有効・無効電力を自在に調整できるからである。しかしながら、系統側での故障発生時等における風力発電機の安定性が近年問題となっており、安定度改善に関する研究が急務となっている。このような状況下において、本論文ではDFIG形風力発電機の新しい安定化制御法を提案している。

これを要するに、申請者はDFIG形風力発電機の安定度改善を目的として、2次回転子回路に挿入されるインバータ/コンバータとして電流制御型変換器を提案し、その有効性を確認したものであり、電力工学、特に自然エネルギーの分野に対して貢献するところ大である。

よって、申請者は北見工業大学博士(工学)の学位を授与される資格があるものと認める。