氏　　名	LINDA SARTIKA
授与学位	博士（工学）
学位記番号	博乙第34号
学位授与年月日	平成30年3月16日
学位授与の要件	学位規則第4条第2項
学位論文題目	Operation and Control of VSC based Grid Connected Wind Farm （電圧源コンバーターに基づいた系統連系ウィンドファームの運転及び制御）
論文審査委員	主査　教授　田村　淳二 教授　小原　伸哉 教授　黒河　賢二 准教授　川村　武 准教授　髙橋　理音

学位論文内容の要旨

This thesis deals with the operation and control of VSC (Voltage Source Converter) based grid connected wind farm. The fast growth of wind generation has led to concern about the effect of wind power on the stability of the electric grid. Therefore, it is essential to analyze the effect of wind farm penetration into power system on its frequency and other characteristics, especially frequency drop when unexpected generation loss due to a fault in the grid system or load increase occurs. During severe network disturbance such as a short circuit fault, the terminal voltage of wind farm decreases significantly and active power from wind farm cannot be supplied to the grid system. 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. Therefore, the interaction between wind farm and grid system from points of view of transient and steady state characteristics has become a very important issue to be analyzed.

The Fixed Speed Wind Turbines with Squire Cage Induction Generators (FSWT-SCIGs) are widely used in wind farm due to their advantages of mechanical simplicity, robust construction, and lower cost. However, the FSWT-SCIG directly connected to the grid does not have any LVRT (Low Voltage Ride Through) capability when a short circuit occurs in the system. Moreover, under steady state condition its reactive power consumption cannot be controlled and hence terminal voltage of the wind generator leads to large fluctuation. Combined installation of PMSG (Permanent Magnet Synchronous Generator) and SCIG in a wind farm can be considered a good solution, because the PMSG can provide the required reactive power of SCIG during fault condition. Therefore, in this thesis new control system for cooperated stabilizing control of PMSG based grid connected wind farm is proposed and it is shown that the proposed control system can stabilize the wind farms effectively.

Currently, most of studies about PMSG system consider normal operation, for example, realization of maximum power point tracking. Studying on the PMSG system protection is not so much, meanwhile, enhancement of FRT (Fault Ride-Through) capability is required for operating of wind farm. The wind farm should stay online during and after a network disturbance. When a fault occurs in the grid, a voltage dip appears at the terminal of wind generator and then the active

power delivered to the grid is also reduced. As the generator side converter is decoupled with the grid, generator continues to generate the active power and thus the DC-link voltage increases due to the energy unbalance between the generator side converter and the grid side converter. Usually, a simple DC chopper with a braking resistance is inserted into the DC-link circuit to dissipate the active power produced by PMSG in such a way that the active power balance in the DC-link circuit is maintained. However, it can have a problem if the active power coming from the PMSG is not balanced against the capacity of braking resistor. This is because the capacity of resistor in the protection system with a simple DC chopper is constant (uncontrolled). In order to solve the problem new topology of DC-link protection of PMSG by using buck converter is proposed in this thesis. From the simulation results, it is shown that the proposed method can control well the DC-link voltage as well as other dynamic responses of PMSG such as rotor speed and active power output. Therefore it is concluded that the dynamic performance of PMSG can be enhanced by the proposed DC-link protection system.

Offshore wind farm can be connected to onshore power system using HVAC (High Voltage AC) transmission technology if the wind power plant is near the onshore. But HVDC (High Voltage DC) technology may be more attractive for the transmission of bulk power over long distances. HVDC becomes a more economical solution than HVAC in the case of transmission over a certain distance called "break-even". The break-even distance is between 500-800 km for overhead lines and around 50 km for submarine cables.

In this thesis, Fixed Speed Wind Turbine-Squirrel Cage Induction Generator (SCIG) based wind farm which is connected to onshore power system through the VSC-HVDC transmission system is also considered. This is because, in comparison with DFIG and PMSG, SCIG has some superior characteristics such as a simple design with high reliability, brushless and rugged construction, low investment and maintenance cost, and operational simplicity. In addition, the SCIG needs no individual power converter in its operation. Although SCIGs have almost no Low Voltage Ride Through (LVRT) capability, the LVRT capability of the SCIG based wind farm can be enhanced if the wind farm is connected to onshore main grid through VSC-HVDC line and controlled by the proposed cluster VSC converter system. It is shown that the proposed system based on the SCIG wind turbines controlled by the new cluster converters with VSC-HVDC system can enhance the performance and stability of the SCIG based wind farm under both transient and steady state conditions.

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、風速変動に伴う出力変動に加え、通常の同期発電機に比較して同期化力を持たないことに起因して系統事故等に対する安定性が低い点が問題となっている。

このような状況下において、本論文では永久磁石型同期発電機(PMSG)による可変速風力発電機並びにかご形誘導発電機(SCIG)による固定速風力発電機を対象として、電圧源形コンバータ(VSC)の新しい制御方式を構築し、系統事故時の安定度を向上するための抑制法を提案している。具体的には、PMSGにおけるVSCのDCリンク回路における新しい保護回路システムを構築し、またSCIGから構成されるオフショアウインドファームにVSCを基本とするクラスター回路システムを提案している。

これを要するに、申請者は可変速風力発電機・固定速風力発電機の両者を対象として、VSCの新しい制御方法並びにVSCの新しい回路構成を構築することにより、系統故障時における風力発電システムの安定度向上を達成できるシステムを提案し、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。