学位論文内容の要旨

This thesis deals with different approaches to stabilize the grid connected wind farm. Due to the environmental and economical concerns, it is expected that a huge number of wind farms are going to be connected with the existing networks in the near future. Therefore, it is essential to analyze both steady state and transient characteristics of the grid connected wind farms. Both symmetrical and unsymmetrical faults are considered for the transient stability analyses of wind turbine generation system (WTGS). In this study, different types of methods to enhance the stability of fixed-speed WTGSs are discussed, among which, Superconducting Magnetic Energy Storage (SMES) system is the most important one. This is because the SMES has both active and reactive power compensation abilities with high response speed. Therefore, the steady state and transient performance of the wind farm can be enhanced extensively. It is also presented that the capacitor value for compensating reactive power demand of wind farm can be reduced by certain percentage from the rated value, where the rest of the reactive power drawn by the wind farm at steady state will be supplied by SMES.

Wind power fluctuation due to randomly varying wind speed is still a serious problem for power grid companies or transmission system owners (TSO), especially in the case of fixed-speed wind generators. Considering the future energy systems with high wind power penetration, it is essential to emphasize the research on wind power smoothing. But reference power generation is an important problem for wind generator output power smoothing, because more energy storage capacity is needed in the case of constant reference line power. In this study, wind power fluctuation in the time scale of minute range is focused, where STATCOM/SMES system with variable reference line power is proposed to smooth the output power and to maintain the terminal voltage of the wind farm to the rated value. As a result, the energy storage capacity of SMES can be made comparatively small.

Between the two types of trends, the fixed-speed WTGS has inferior fault ride through capability compared to that of variable speed WTGS. Therefore, fixed-speed wind generator that uses the squirrel-cage induction generator needs additional tool to enhance the fault ride through capability. This is because it requires large reactive power to recover the air gap flux when a short circuit fault occurs in the power system. If sufficient reactive power is not supplied, then the electromagnetic torque of wind generator decreases significantly. Then wind generator and turbine speeds increase rapidly due to large difference between mechanical and electromagnetic torques. As a result, the induction generator becomes unstable and it requires to be disconnected from the power system. However, the recent trend is to decrease the shut down operation because a shut down of large wind farm can have a serious effect on power system operation. In this study, a pulse wide modulation (PWM) based voltage source converter (VSC) and two-quadrant DC-DC chopper using insulated gate bipolar transistor is proposed for controlling SMES to enhance the fault ride through capability of fixed-speed WTGS. Comprehensive study is carried out to enhance the transient stability of multi-machine power system including wind farm by using SMES. Two-mass drive train model of WTGS is used in the analysis as the drive train modeling has great influence on the dynamic characteristics of WTGS. Simulation results clearly show that the proposed SMES can enhance the transient stability of wind generators. It is also observed that SMES helps not only in regulating the voltage, but also in mitigating the rotor speed instability, thus can improve the stability of entire power system. Besides these, it is also reported that pitch controller can also enhance the transient stability of wind farm interconnected power system.

Another salient feature of this thesis is the minimization of frequency fluctuation of power system with high wind power penetration. As the output power from wind farm fluctuating due to wind speed variations becomes large, fluctuations of the network frequency and voltage also become large. As the wind turbine dynamics and governor control systems have the significant influence on the system frequency, effects of different governor control system models have been investigated. However, wind turbine pitch controller and governor control system are not sufficient to maintain network frequency of the power system with high wind power penetration to the desired level. Though the pitch control system can maintain the system frequency if the wind power generation is in a few percentage of the total power capacity, but it would be difficult when the wind power penetration becomes 10% or larger. Fluctuation of power system frequency due to large incorporation of wind farm output power to the grid has some adverse effect on power system operation. Therefore, in this study, SMES is proposed to mitigate the power system frequency oscillation caused by wind farm. It is expected that large SMES capacity give better smoothing performance. However, large capacity will definitely increase the system overall cost. Therefore, the optimum size determination of SMES is one of the key points from the viewpoint of cost-effectiveness. So in this study, an evaluation

method of SMES power rating has also been analyzed. Moreover, the minimum energy storage capacity of SMES unit to mitigate the frequency fluctuation is determined. The simulation results show that, using the proposed SMES system, the wind farm output fluctuations can be decreased, and hence the frequency of the grid system can be maintained to within an acceptable range. Wind farm grid voltage can also be maintained to the rated value by the proposed system.

Considering all aspects of proposed SMES system, it is found that the SMES can be the best solution. Therefore, the integration of the proposed SMES system into a wind farm can be an effective means of mitigating the frequency fluctuations of the grid system which consequently improve the stability and reliability of entire power system.

論文審査結果の要旨

要　　旨

近年、世界中で風力発電が増加しているが、風速変動に伴う風力発電機出力変動の問題があり、連系される電力系統に周波数変動や電圧変動などの悪影響を与える点が懸念されている。このような中で本論文では、電力貯蔵装置である超電導エネルギー貯蔵装置(SMES)を用いて、風力発電機の出力変動の平滑化、系統周波数・電圧変動の抑制、更には系統側での故障発生時における風力発電機の安定度改善に関する検討結果が示されている。

これを要するに、申請者は風力発電機の更なる導入を目的として、高品質の発電を行うシステムの構築を目的として電力貯蔵装置の適用、並びにその高度な制御方法を提案し、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。