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学位論文内容の要旨

This thesis deals with the coordinated frequency control method of hybrid onshore power system by using variable speed wind turbines with permanent magnet synchronous generators (VSWT-PMSGs) based offshore wind farm (OWF), which is connected to the main onshore grid through voltage source converter (VSC) based high voltage DC (HVDC) transmission system. Penetration of large-scale WF into the power grid has increased significantly and it inevitably leads to the retirements of conventional synchronous generators (SGs). Thus, the frequency fluctuations of the power system due to the high penetration of WF is a major concern. Therefore, to maintain the frequency stability of the power system, WF is required to operate like conventional unit. They need not only supply power to the grid, but also need to damp frequency fluctuations. Therefore, the interaction of large-scale WF along with the existing power system is an important issue to be analyzed in order to minimize the frequency fluctuations.

Normally, VSWT-PMSG is preferable for OWF due to its gear-less feature, brushless operation, and lower losses compared to doubly fed induction generator (DFIG). Additionally, to integrate large-scale OWF into the onshore grid, VSC-HVDC transmission system is attractive and more preferable than high voltage AC (HVAC) transmission system from an economic and technical point of view. Normally, detailed model of VSC-HVDC is used in the simulation analysis, which requires, however, large computational time due to the switching phenomena of the power converters. Therefore, detailed model of the VSC-HVDC should be simplified in the analysis in order to diminish complexity and long simulation time. In this thesis, a simplified model of VSC-HVDC transmission system is developed for fast dynamic simulation analysis. Comparative analysis between the proposed simplified and detailed models of VSC-HVDC is also performed and presented. The simulation results show that the proposed simplified model of VSC-HVDC has sufficient accuracy for analyzing dynamic characteristics.

Usually, the characteristics of VSWT-PMSG based OWFs are different from that of the conventional power plants. To contribute to the primary frequency regulation in a similar way to conventional SGs, the VSWT-PMSG based OWF requires additional active power control loop and primary reserve. In this case, power reserve is possible by operating the VSWT-PMSGs at a reduced power level instead of maximum power point tracking (MPPT) mode which is called deloaded operation. Therefore, this thesis proposes firstly a primary frequency regulation method of hybrid power system by fixed deloaded

operation of PMSG-based OWF. A new centralized droop control technique is also embedded for VSWT-PMSGs based OWF connected through VSC-HVDC transmission system to damp frequency oscillation of the main power grid in which a large-scale of WF composed of fixed speed wind turbines with squirrel cage induction generators (FSWT-SCIGs) and photovoltaic (PV) power station are installed. The centralized droop control technique is implemented with the dead band to limit the frequency variation within the permissible limit. Thus, better frequency regulation performance can be achieved.

The active power injected to the grid system from OWF is reduced by a fixed ratio at all times in the fixed deloaded operation, and hence, the energy loss becomes large. Therefore, this thesis also proposes secondly a centralized frequency control scheme with a novel variable deloaded operation for VSWT-PMSGs based OWF connected to the onshore grid through VSC-HVDC transmission system. This is one of the salient features of this thesis. A centralized droop controller with dead band is designed for VSWT-PMSGs to utilize this reserve power to suppress the frequency fluctuations of the onshore grid due to the installations of large-scale FSWT-SCIGs based WF and PV power station. The combination of variable deloaded operation and centralized droop controller can give better frequency regulation and decrease energy loss. To verify the effectiveness of the proposed control system, simulation analyses are performed on a multi-machine hybrid power system model. The simulation results reveal that the variable deloaded operation can decrease the energy loss compared to the fixed deloaded operation as well as suppress the frequency fluctuations in the same level as the fixed deloaded operation.

Simulations are carried out by PSCAD/EMTDC software. Real wind speed data and solar irradiance data measured in Hokkaido Island, Japan, are used in the simulation analyses to obtain the realistic responses. The standard IEEE nine-bus model is used to evaluate the performance of the proposed control strategies.

Considering all the features, it is concluded that the frequency oscillation can be decreased effectively by the proposed control strategies of PMSG.

論文審査結果の要旨

近年、電力系統において再生可能エネルギー電源が増加している。太陽光発電や風力発電に代表される再生可能エネルギー電源は、基本的に日射強度や風速の変動に応じて出力が時々刻々変動するため、連系されている電力系統に周波数変動等の悪影響を及ぼす点が問題視されている。一方、風力発電に目を向けると、陸上での適地が減少し、最近では海上に風車を設置するオフショアウィンドファームが世界的に増加している。このような状況下において、本論文では可変速風力発電機から成るオフショアウィンドファームによる陸上連系系統の周波数変動を抑制する新しい制御法を提案している。

これを要するに、申請者は再生可能エネルギー電源が導入されている陸上電力系統における周波数変動の抑制を目的として、オフショアウィンドファームの出力低減運転を基礎とした周波数制御システムを提案・構築し、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。