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学位論文内容の要旨

This thesis deals with the stability enhancement of grid-connected fixed speed wind turbines with squirrel cage induction generators (FSWT-SCIGs) based wind farm (WF) and conventional synchronous generators (SGs) by using variable speed wind generators. The penetration level of grid-connected large-scale WF into the existing grid system has been increasing significantly since the last decade. This increasing rate of wind power impacts on the power system transient stability, for example, the power system can be unstable during severe network fault. During network disturbance situation, voltage stability of WF and frequency stability of entire power system are the important concerns. The modern grid codes demand that the WF should stay online during network disturbances and support the power system in the same way as conventional units. New studies must be performed in order to maintain the stable and reliable operation of WF and the entire power system. Therefore, from the view point of transient and dynamic characteristics, interaction of large-scale WF with the existing power system is an important issue to be analyzed in order to enhance the stability of WF and power system.

High penetration of wind power into an existing grid can be attributed largely to the FSWT-SCIG due to its robust construction, low cost, and operational simplicity. However, SCIG based WF is sensitive in nature to the grid faults, and thus, big concern has created for their mass integration into the existing power system. WF grid codes require wind generators to have the low voltage ride-through (LVRT) capability, which means that normal power production should be resumed quickly once the nominal grid voltage has been recovered and they are also supposed to participate in voltage build up process. But SCIG based WF has failed to fulfil the LVRT requirements, which has great impact on the power system stability.

On the other hand, variable speed wind turbine with permanent magnet synchronous generator (VSWT-PMSG) has suitable LVRT capability. In addition, the PMSG system can control the active and reactive power injected to the power system independently. The only drawback of this system is expensive cost because it requires full rating of power converter.

By taking the advantage of reactive power control capability of PMSG, it is possible to stabilize the large-scale SCIGs. Thus, combined installation of large-scale FSWT-SCIGs along with smaller rating of VSWT-PMSGs in a WF can decrease the overall installation cost and also ensure LVRT capability. The power converter of PMSG consists of machine side converter (MSC) and gird side converter (GSC). The GSC is responsible for injecting reactive power during voltage dip situations. Normally, conventional cascaded proportional-integral (PI) controller is used to design the GSC controller. But conventional PI controller is not sufficient to ensure LVRT capability of large-scale SCIGs. In this thesis, a novel fuzzy logic controller (FLC) in the GSC controller of VSWT-PMSG is proposed to improve the LVRT capability of WF during voltage dip situation due to severe network fault. The simulation results in this thesis show that the proposed control strategy is more effective to enhance the transient stability of WF during fault condition compared to conventional PI based controller.

Also, variable speed wind turbines with doubly fed induction generators (VSWT-DFIGs) have sufficient LVRT augmentation capability and can control the active and reactive power delivered to the grid independently. However, in the same way as PMSG, the DFIG is more expensive than the SCIG due to its partial rating of AC/DC/AC converter. Therefore, the combined use of SCIGs and DFIGs in a WF also could be an effective solution. The design of the rotor side converter (RSC) controller of DFIG is crucial because the RSC controller contributes to the system stability. The cascaded control strategy based on four conventional PI controllers is widely used to control the RSC of the DFIG, which can inject only a small amount of reactive power during fault conditions. Therefore, the conventional strategy can stabilize only the lower rating of the SCIG. Therefore, in this thesis, a new control strategy based on fuzzy logic is proposed in the RSC controller of the DFIG in order to enhance the LVRT capability of the SCIG in a WF. The proposed FLC is used to control the reactive power delivered to the grid during fault conditions. Moreover, reactive power injection can be increased in the proposed control strategy. Extensive simulations analyses for both the proposed and conventional PI controllers of the RSC of the DFIG reveal that the proposed control strategy can stabilize the higher rating of the SCIG.

Another salient feature of this thesis is the development of virtual inertia controller (VIC) for DFIG to enhance the transient stability of hybrid power system. Large integration of renewable energy sources (RESs), such as WF and solar photovoltaic (PV) plant, into the power systems, impacts on the system frequency stability. Normally, a WF and PV system do not provide frequency support because of the uncontrollability of the input energy. Moreover, overall system inertia will be reduced due to massive integration of RES, because conventional generation units that provide reserve power need to be decreased. To overcome the problems of frequency stability as well as power system transient stability resulting from the insufficient inertia response, this thesis proposes a new method to enhance the transient stability of the power system with RESs introduced, in which VSWT-DFIG supplies its kinetic energy (KE) during generation outage to stabilize conventional SGs. A suitable fuzzy logic based VIC is proposed to release the KE efficiently during transient period. This FLC can continuously adjust the VIC gain depending upon the incoming wind speed. To verify the effectiveness of the proposed VIC, simulation analyses are performed on a multi-machine hybrid power system model.

Simulations are carried out by PSCAD/EMTDC software. Real wind-speed data measured in Hokkaido Island, Japan are used in the dynamic analysis. Three-line-to-ground (3LG) fault is considered as network disturbance in this study. The standard IEEE nine-bus model is used to evaluate the performance of the proposed control strategies.

Considering all the aspects, it is concluded that the stability of the WF and power system can be ensured by the control strategies for PMSG and DFIG proposed in this thesis.

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、その結果通常の同期発電機の容量が相対的に低下している。太陽光発電や風力発電に代表される再生可能電源は、多くの場合に慣性エネルギーを持たないので、この結果、系統全体の慣性エネルギーが低下し、系統故障時等における安定度の低下が問題となっている。このような状況下において、本論文では可変速風力発電機を用いた新しいウィンドファームや系統全体の安定化制御法を提案している。

これを要するに、申請者は可変速風力発電機による安定化制御システムの構築を目的として、固定速風力発電機の安定化制御法、仮想慣性制御による系統全体の過渡安定度改善法を提案し、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。