論文の内容の要旨

論文題目　Applications of New Types of Rotating Power Apparatus with Advanced Control Systems for Power System Stabilization - Rotary Type Frequency Converter and Superconducting Generator -
（電力系統安定化のための先端的制御システムを備えた新しい回転型電力機器(回転型周波数変換装置と超電導発電機)の適用）

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(本文)

Power system stability is one of the important issues that must be considered and maintained in order to ascertain power system operation. Problems with associated with dynamic performance were noticed in power systems when synchronous machine were first operated in parallel. The rapid development of power systems generated by increased demand for electric energy initially in industrialized countries and subsequently in emerging countries leads to different technical stability problems in the systems, e.g., stability limitations and voltage stability problems. Environment concern is also one of factors leading to difficulty in construction new power plants and transmission lines, which may cause stability problem in the near future. In addition, by the electric power deregulation, power system in several countries has become deregulated facilities; customer can select their own electricity providers, high competition occurs in electric utility industry. One of several important factors to survive in this competition is cost. One who can reduce cost possibly gains the customer purchase. In order to cut off the cost, power system operation near stability limit is the way mostly taken into account and it is risk that power system may become unstable. Furthermore, power system blackout has become too common occurrence recently; in a span of less than two months, August-September of 2003, 4 blackouts affecting a large number of customers happened in US-Canada, London, Sweden-Denmark, and Italy. Those indicate and reflect the stability problems in the power systems. Therefore, it becomes necessary to enhance and improve power system stability in order to assure the operation of power systems even in more severe conditions and increase the robustness of power systems.

Breaking innovations in power electronics technology and superconductor technology can solve problems in power systems. The power electronics technology enables the manufacture of powerful thyristors and, later, of new elements such as the gate turn-off thyristors (GTO) and insulated gate bipolar transistors (IGBT). Development based on those semiconductor devices first established high-voltage DC transmission. HVDC technology, in turn, has provided the basis for the development of flexible AC transmission system (FACTS) equipment such as SVC, STATCOM, UPFC, and IPFC. With FACTS devices, active power and reactive power flowing in transmission line can be controlled and power system dynamics can be improved. The superconductor technology also offers solutions to critical problems facing power systems, including the needs for improved power system stability, higher capacity and a "smart grid" in which power flows can be controlled. After discovery of superconducting materials and the great development in power systems, superconducting power apparatus such as superconducting generator (SCG), transformer, transmission-cable, superVAR dynamic synchronous condenser, superconducting magnetic energy storage (SMES), and superconducting fault current limiter (SCFCL) can ultimately be developed and realized. Their installations in power system lead to improve power system dynamics.

There are a lot of types of power apparatus developed for power systems. They can be mainly divided into 2 types; non-rotating power apparatus and rotating power apparatus. The non-rotating power apparatus or static type power apparatus is the apparatus without moving parts such as SVC and STATCOM. The rotating power apparatus is the apparatus with moving parts such as synchronous condenser, adjustable speed generator/motor and rotary type frequency converter. Although static type power apparatus are mostly used in power systems and highly contribute to improvement of power system stability, rotating power apparatus is also another choice for the objective and they also has some advantages which can not be realized in the static type power apparatus such as transient overload capability and rotating inertia. It will become attractive and useful to study and research in more detail on rotating power apparatus in order to use them more effectively in power systems for improving power system stability.

In this research, two new types of rotating power apparatus are considered for improving power system stability: rotary type frequency converter and superconducting generator; their characteristics, models and behaviors in power systems are examined; advanced control systems of those rotating power apparatus are designed and proposed for power system stabilization. In addition, installation scheme is also proposed to achieve improvement of power system dynamics. This dissertation is mainly divided into two parts and the explanation in detail of each part is given as follows:

The first part of this dissertation is the topic on the rotary type frequency converter

(RFC). RFC using two sets of adjustable speed generators/motors is expected to be applied at the interconnections between 50Hz and 60 Hz power systems in Japan. RFC can work not only as a power interchanger but also as a power system stabilizer by effectively utilizing energy stored in rotors, so-called rotational energy. This research investigates how the RFC affects power system dynamics and since shaft torsional oscillation and slow response due to mechanical connection are inevitable and may lead to instability in power system, it also presents some countermeasures or control schemes to handle such inherent problems and to improve power system dynamics. Three different control methods (parameter optimization techniques) are employed for the controller designs; eigenvalue sensitivity based parameter optimization technique, energy function based control method, and feedback linearizing control method. The control performances and participations in performance improvement of power system dynamics are examined in the test model system. Each designed control system has its own characteristic and influences power system dynamics differently. RFC with the designed control systems can improve performance of power system dynamics by more effectively utilizing rotational energy. Shaft torsional oscillation can be suppressed well by the designed control systems. The designed control systems are effective to solve the inherent problems of RFC and to improve power system dynamics.

The second part of this dissertation is the topic on superconducting generator (SCG). SCG with superconducting field winding has many advantages such as small size, light weight, and high generation efficiency. In particular, the property of low synchronous reactances, which is not realized in the conventional generators, is able to improve the power system stability. The high response excitation type SCG has a rotor having thermal radiation shield without damping effect; it can enables excitation power in self-excited operation of the generator to change rapidly enough to affect the conditions of power system. The effect is called “SMES Effect”. In this research, control system designs of SCG with high response excitation in consideration of SMES effect for improving the power system dynamics are proposed. Three different control methods (parameter optimization techniques) are employed for the controller designs; eigenvalue sensitivity based parameter optimization technique, energy function based control method, and feedback linearizing control method. The SMES effect is modeled and put into consideration in the controller designs. Control system designs of reactive power of SMES effect are also proposed. The effectiveness of the designed controllers of SCG with high response excitation are verified in two different test model systems, IEEJ east 10-machine system and west 10-machine system, by showing that they can improve power system stability; however, they contribute to improve the stability differently due to the control concepts. The SMES effect can be utilized effectively to compensate the output variation of SCG, in turn, to improve overall stability. The designed controllers of reactive power of SMES effect contribute to improve voltage regulation. The designed controllers are effective to improve power system dynamics; however, locations of SCGs influence the performances of those controllers.

In addition, installation schemes of SCGs in multi-machine power systems are also discussed, Firstly, examinations of SCG installation in power systems in consideration of dominant mode are done to search for possible locations and some specific parameters. Two new methods for installation schemes of SCG with low response excitation are proposed. The method type 1 employs the observation of global inter-area mode and approximated eigenvalue sensitivity to evaluate installation indices used for the SCG location. Synchronous reactance Xd (Xq) and transient open-circuit time constant T'do are also determined later by eigenvalue sensitivity based parameter optimization technique. The method type 2 employs hierarchical genetic algorithm (HGA) to simultaneously determine SCG location and both parameters. Tuning of control parameters such as gains of AVR and speed governors is also taken into account in both methods. It is verified in the test model system that both methods are effective to improve stability of power system.

RFC and SCG with the designed control systems can improve power system dynamics and appropriate installation schemes of SCGs can also contribute to the improvement of power system dynamics. These results show the effective applications of rotating power apparatus to power system stabilization.

Furthermore, the following research subjects should be further studied.

1) Coordination control between RFC and generators should be studied in order to extend the performance of RFC to improve power system dynamics.

2) Control Systems of Multiple SCGs: In the near future, when SCGs are commercialized, multiple SCGs in power systems can then be realized. How to control multiple of SCGs becomes attractive to study in order to obtain more robust and stable power systems.

3) Installation schemes of SCGs with high response excitation in power systems: SMES effect which is expected to improve power system stability need to be taken into account in selection process of SCG location and some specific parameters.

4) Other types of rotating power apparatus: Applications of other types of rotating power apparatus such as SuperVAR dynamic synchronous condenser for power system stabilization can be studied based on this research.