Design of power control system using SMES and SVC for fusion power plant

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Abstract. A SMES (Superconducting Magnetic Energy Storage System) system with converter composed of self-commutated valve devices such as GTO and IGBT is available to control active and reactive power simultaneously. A SVC (Static Var Compensators) or STATCOM (Static Synchronous Compensator) is widely employed to reduce reactive power in power plants and substations. Owing to progress of power electronics technology using GTO and IGBT devices, power converters in the SMES system and the SVC can easily control power flow in few milliseconds. Moreover, since the valve devices for the SMES are equivalent to those for the SVC, the device cost must be reduced. In this paper the basic control system combined with the SMES and SVC is designed for large pulsed loads of a nuclear fusion power plant. This combined system largely expands the reactive power control region as well as the active one. The simulation results show that the combined system is effective and prospective for the nuclear fusion power plant.

1. Introduction
The fusion power reactor plant is expected to be prospective power plants in middle of 21st century. The construction of ITER (International Thermo-Nuclear Experimental Reactor), leading the fusion power plant, will be started under the cooperation of several international countries. The fusion power plant and the fusion experimental facilities such as ITER need large pulsed power, and hence cause instabilities, such as power fluctuation and frequency deviation in utility power systems, when they are operated to control plasma current inside the reactor. The pulsed power loads supplied through a lot of DC converters consume also large amount of reactive power including higher harmonics. The power factor of the pulsed power is assumed to be very low without compensation of the reactive power, and therefore rapid change of the reactive power in the power system causes large voltage fluctuations and instabilities. In order to reduce the above fluctuations and to stabilize the power instabilities, we propose a power control system using both SMES (Superconducting Magnetic Energy Storage System) and SVC (Static Var Compensators) or STATCOM (Static Synchronous Compensator).

In this paper, the basic control system combined with the SMES and the SVC is designed and simulated for the large pulsed loads.
2. Typical configuration of SMES and SVC

2.1. SMES
The SMES is superior to the other energy storage system in view of rapid charging and discharging, and high efficiency of energy storage. The SMES with converter composed of self-commutated valve devices such as GTO is available to control the active and the reactive power simultaneously [1] [2]. The SMES applied for the large pulsed power loads such as fusion power plant has not been employed yet. The SMES has been developed to manufacture large scale to reduce its installation cost [3]. A typical configuration of the SMES equipped with self-commutated converter is shown in figure 1. This converter is a typical current type of converter controlled by PWM (Pulse Width Modulation). This kind of converter requires snubber circuit to reduce current derivative of the switching device.

![Figure 1. Typical configuration of SMES converter.](image)

Owing to characteristic of the SMES equipped with self-commutated converter, the scheme of quadrant power control for SMES is indicated in figure 2. The active and reactive power control is assumed to be ideal. The available reactive power $Q_s$ Mvar of the SMES is represented as follows. The rated capacity and the active power of SMES are represented as $S_s$ MVA and $P_s$ MW, respectively.

$$Q_s = \sqrt{S_s^2 - P_s^2}$$  \hspace{1cm} (1)

![Figure 2. Power control area of SMES.](image)
2.2. SVC
The SVC is widely employed to reduce reactive power in power plants and substations. The SVC equipped with self-commutated AC/DC converter has features of generating continuous and desirable reactive power in the area from lag to lead suppressing harmonic waves, of increasing power system stability owing to quick response and fine compensation, and of increasing effect of compensating voltage fluctuation caused by load change. The method using PWM control of rapid switching devices is available to output continuous wave and to response fast. It also generates less harmonic waves.

There are two types of self-commutated SVC converters, the current type and the voltage type. Since the current type has a reactance coil in the DC side and is basically equal to the composition of the SMES, we treat the voltage type only. A typical configuration of SVC equipped with self-commutated converter is shown in figure 3.

The converters in the current type of SVC are similar to the one of SMES; there are possibilities to use same specification of device and to reduce manufacturing cost and running cost.

![Figure 3. Typical configuration of voltage type converter for SVC.](image)

3. Control system using SMES and SVC
3.1. System Configuration
The power control system combined with the SMES and the SVC is connected in parallel with the utility power, as shown in figure 4.

![Figure 4. Connection of control system using SMES and SVC.](image)
3.2. Basic rules for load dispatching
The utility power source supplies the active power to the large pulsed load, as long as the load demands low or steady power. When the load requires rapid large power, the SMES supplies the power in cooperation with the utility power source. In the case of steep decreasing load, the SMES can absorb surplus power from the utility power to smooth the rapid change. The SMES absorbs and supplies the active power deviation between the load and the utility by mean of compensating the difference between the present and weighted moving average values of the load. The initial charging of SMES is assumed to be done before the simulation cycle. The SMES cannot be affected by the small power below 10 MW. The storage efficiency of the SMES is assumed to be 90%.

While the utility power source supplies the main part of the reactive power of the large pulsed load, the SVC and the SMES supply 20% of the reactive power of the pulsed load to reduce the utility power. The SMES can supply 10% of its capacity to the reactive power when it hasn’t burden of active compensation and has surplus capacity.

3.3. Simulation conditions
As the simulation model for the large pulsed load, we use a simplified load pattern model of the typical fusion machine, as shown in figures 5 and 6 [4]. One cycle of this model is 1800 seconds, and the simulation step is 1 second.

The peak active power is 275 MW, the maximum positive change rate of the power is 215 MW/s and the maximum negative one is 230 MW/s. The target maximum change rate of the utility power source for the active power fluctuation is restricted within around 30 MW/s.

The peak reactive power is 250 Mvar, the positive and negative change rate of the power is small and negligible. The available energy rates for the SMES are assumed 80%. The output of the SMES and the SVC is assumed to supply ideal response output to the load demand without any delay in this simulation.

4. Simulation results
The simulation results of capacities are listed in table 1. The output power, available energy and stored energy of the SMES are 200 MW, 2.59 GJ and 3.24 GJ, respectively. The figures 5 and 6 show that the active peak power is compensated by the SMES and the reactive power is reduced by the SMES and the SVC.

| SMES output (MW) | SMES available energy (GJ) | SMES stored energy (GJ) | SVC maximum output (MVA) | SVC average output (MVA) | Utility power source |
|------------------|-----------------------------|-------------------------|--------------------------|--------------------------|----------------------|
|                  | 200                         | 2.59                    | 3.24                     | 50                       | 30                   | 225                  | 28                   |

5. Discussion
We propose the power system combined with the SMES and the SVC to reduce the peak loads and to suppress the power fluctuations. We can simulate the additional power dispatches of the SMES and the SVC to the typical pulsed load. The simulation result of the capacities of the SMES and the SVC is indicated in table 1. We can simulate the system to suppress the change rate of the utility power within 28 MW/s. By using the SMES, the utility power for the pulsed load is improved from 275 MW to 225 MW. Utilizing the SMES’s power control area with the SVC, the reactive power of the utility power for the pulsed load is suppressed from 250 Mvar to 200 Mvar. However, the reactive power wave
forms are strongly depending on the fusion operation modes, and therefore the simulation should be further investigated in detail.

6. Conclusion
We propose the power system combined with the SMES and the SVC, and can simulate that the power system suppresses the change rate of the utility power within 28 MW/s, improves its peak from 275 MW to 225 MW, and reduces its reactive power from 250 Mvar to 200 Mvar. The simulation results show that the combination system is effective and prospective for the large pulsed loads such as the nuclear fusion power plant.
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