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Technique for the Prevention of Inrush Current in a TCC Reactive Power Compensator

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〈Abstract〉

With the propagation and spread of the new regeneration energy and increase in electricity demand, power systems tend to be decentralized, and accordingly, the use of a power system stabilizer tends to expand for the stabilization of the distribution system. Thus, typical power system stabilizer, Static Var Compensator (SVC) is developed on a variety of topologies. In addition, the trend of technology leads from SVC to Static Synchronous Compensator(STATCOM) technology development. Recently, to overcome STATCOM's conversion losses and economic disadvantages, studies of a hybrid method using STATCOM and SVC in parallel have actively been conducted. This study proposes a new Soft-Step Switching method to limit inrush current problematic in Thyristor Controlled Capacitor (TCC) method in SVC function. In addition, to reduce Statcom's capacity, groups of reactive power compensation reactor and condenser for SVC were designed.

Keywords : SVC(Staic Var Compensator), STATCOM(Static Synchronous Compensator), TCC(Thyristor Controlled Capacitor), Inrush Current

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1. Introduce

With the development of power electronics device technology, various SVC(Static Var Compensator) are developed, and of the static reactive power compensators, the simplest method is to improve the load power factor, inputting or opening a reactor or condenser that can generate leading and lagging reactive power in parallel. This method cannot make successive reactive power compensation, so STATCOM(Static Synchronous Compensator) method using an inverter is found as a solution. However, Statcom method has demerits such as a higher unit cost of system configuration and lower efficiency than SVC. Recently, to reduce the unit cost of the system and improve efficiency, studies of a hybrid method using Statcom method and SVC method in parallel have actively been conducted. In TSC operation of an SVC system, the power condenser connected to the system in parallel is in the form of bank divided into groups, inserted and interrupted in the system, using a Thyristor switch. This method has simple composition and control, so it is much used in places to prevent voltage sag by using it as a reactive power compensator of a system or permanent magnet generator. And yet, in a TSC compensating device, a circuit that limits an inrush current is essential when a Thyristor switch is turned on. To prevent this inrush current, generally, a small reactor or quenching resistor is composed vertically. However, the reactor or quenching resistor added to limit the inrush current has a demerit that it forms resonance or reduces system efficiency. Thus, this paper proposes a new Soft-Step Switching method to limit the inrush current in TSC operation. The proposed method removed a reactor of quenching resistor added to limit the inrush current, does not have any resonance in the inrush current when the switch is turned on or off and can reduce the size less than the condenser's steady-state current. In addition, to verify the validity of the proposed method, a simulation was conducted.[1]-[4]

2. Hybrid Reactive Power Compensator

2.1 Characteristic Analysis of Reactive Power Compensator

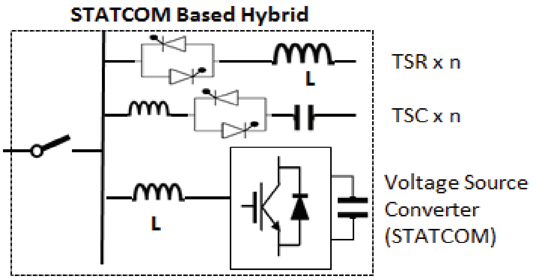
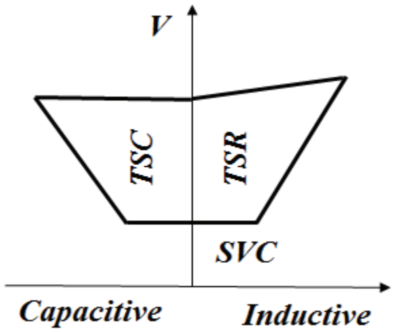


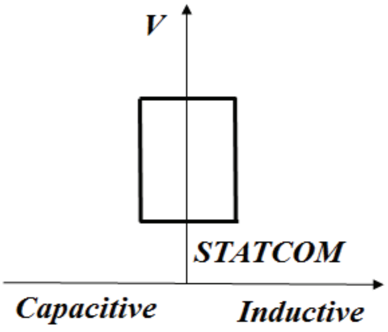
Fig. 1 hybrid reactive power compensator.

Figure 1 shows the system diagram of a hybrid reactive power compensator. As shown in Figure 1 the hybrid reactive power compensator is in the form in which three types of reactive power controller, including STATCOM, TSR, and TSC are mixed, the loss of the system in the reactive power compensator is reduced by the parallel use of TSR and TSC, and it can be made smaller by the combination of TSR with TSC, which are smaller than Statcom.

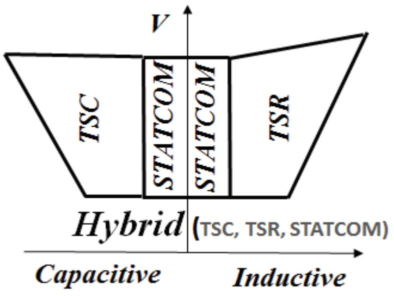
Figure 2 shows the compensation area, according to each reactive power compensator. Fig. 2(a) shows SVC, which has a low rapid response with the use of SCR but has merits such as a stable system and excellent efficiency.



(a)



(b)



(c)

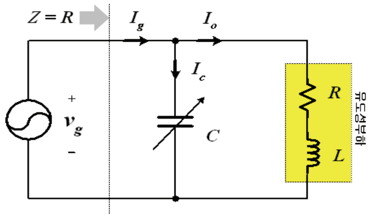
Fig. 2 Comparison of compensation area.

Figure 2(b) shows STATCOM method, which has an excellent rapid response using a high-speed switch device but has a demerit of low efficiency. Fig. 2(c) shows a hybrid type, which cannot make a rapid response to the overall reactive power variation but can maintain a rapid response to reactive power variation within STATCOM area.

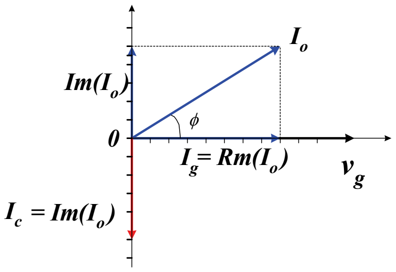
2.2 Characteristic Analysis of TSC

In the SVC system, by TSC operation, the reactive power compensator's equivalent circuit and its compensation principle can be expressed like Figure 3.

In Figure 3, Vg shows the terminal voltage while Io shows the general load, that is, inductive load and load current. As for the load current, there is the effective current part in the same phase as the terminal voltage and there is a 90° lagging reactive current component by the power factor angle of the load. The image phase component of



(a) Equivalent circuit



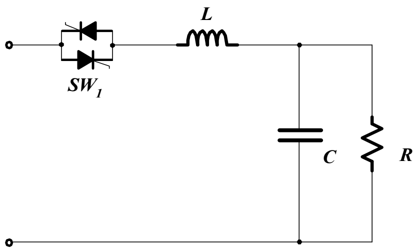
(b) phasor diagram

Fig. 3 Reactive power compensation of TSC.

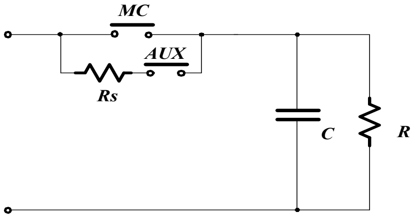
the load current generates 90° leading reactive current to the generator terminal voltage in the condenser and uses the condenser capacity so that the sum of the two reactive currents becomes zero.[5]-[11]

Figure 4 shows a typical inrush current prevention circuit. In the Series reactor insertion type in Figure 4(a), generally, to limit the inrush current, the reactor, about 6% of the condenser capacity is connected vertically, and for condenser discharging resistance, the resistance value is selected so that 75% is discharged three minutes later.

In Figure 4(a), the reactor comes to have a resistance component in addition to an inductance component, and the circuit equation considering the resistance component is like Equation (1).



(a) Series reactor insertion type



(b) Suppression resistor insertion type

Fig. 4 A typical inrush current prevention circuit.

$$V(S)=\left(R+LS+\frac{1}{CS}\right)I(S)+\frac{V_{CO}}{S} \tag{1}$$

If the input voltage, $v=Vsin(\omega_0 t+\theta)$, the value of the current is like the below formula.

$$\begin{aligned} i=&I_m\sin(\omega_0 t+\theta-\phi) \\ &+I_m\frac{1}{\omega_n\sqrt{LC}}e^{-at}[\sin(\theta-\phi)\sin(\omega_n t-\phi) \\ &-\frac{1}{\omega_0}cos(\theta-\phi)\sin(\omega_n t)] \end{aligned} \tag{2}$$

$$단,\ I_m=\frac{V}{Z},\ Z=\sqrt{R^2+\left(\omega_L-\frac{1}{\omega_C}\right)^2}, \tag{3}$$

$$\alpha=\frac{R}{2L},\ \omega_n=\sqrt{\frac{1}{LC}-\left(\frac{R}{2L}\right)^2}, \tag{4}$$

$$\tan\phi=\frac{\sqrt{\frac{1}{LC}-\left(\frac{R}{2L}\right)^2}}{R} \tag{5}$$

As shown in Equation (2), for the condenser current, the value of the current in the fundamental frequency component is I_{ac}, and Items 2 and 3 in Equation (2) decrease while they vibrate at an angular velocity, ω_n.

The Suppression resistor insertion type in Figure 4 (b) has a method in which, first, in the insertion of a condenser, auxiliary switch AUX is input, and then, MC switch is input after a delay for a certain time. The maximum value of the primary inrush current by the insertion of AUX is expressed like the following formula approximately for R, where $R < 2\sqrt{L} < C$.

$$\frac{I_{Im}}{I_{Nm}} = \frac{1}{\sqrt{K_R^2 + (K_L - 1)^2}} \times \left\{ 1 + \frac{1}{\sqrt{KL}} exp\left(-H \tan^{-1} \frac{1}{H} \right) \right\} \qquad (6)$$

if,

I_m: Maximum inrush current peak value due to input

I_{Nm}: Capacitor normal current wave height value

$$H = \frac{K_R}{\sqrt{4K_L - K_R^2}}$$

$$K_R = R / X_c$$

$$K_L = X_L / X_C$$

$$X_C = 1/\omega C$$

$$X_L = \omega L$$

Next, if the excess current of the primary inrush current is ignored, and attenuation effect by the insertion of MC is ignored to calculate the size of the secondary inrush current occurring by the short-circuit of the inserting resistance, the maximum value of the secondary inrush current is expressed like the following Equation [3].

$$\frac{I_{2m}}{I_{Nm}} = \frac{1}{1 - K_L} \left(1 + \frac{K_R}{\sqrt{K_R^2 + (K_L - 1)^2}} \sqrt{\frac{1}{K_L}} \right) \qquad (7)$$

I_{2m}: The maximum value of the secondary inrush current.

2.3 The Proposed TSC Composition and Switching Method

Figure 5 proposes a new topology that can add a small reactor vertically to limit the current in a condenser bank-type reactive power compensation device, or input and remove a power condenser safely without adding an inrush current quenching resistor.

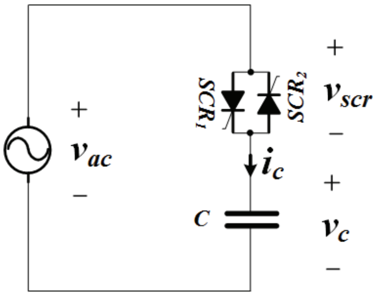


Fig. 5 TSC configuration for phase compensation.

The proposed topology is a method of limiting the inrush current, controlling the gate signals of SCR1 and SCR2 independently according to the polarity of the condenser voltage, and this method is not limited by the switch-on time, does not have resonance in the inrush current and can form a smooth current.

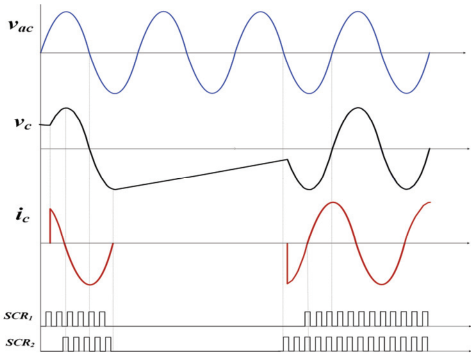
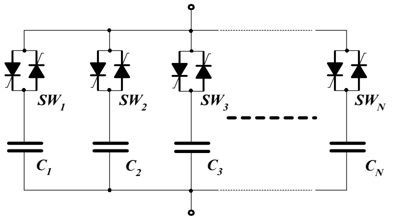


Fig. 6 The proposed switching method.

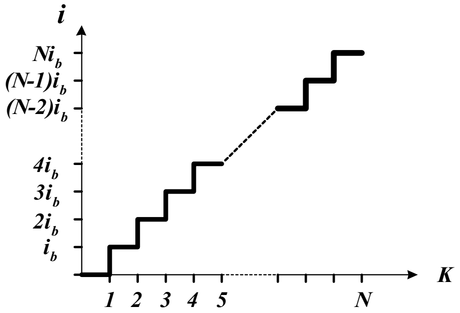
Figure 6 is the principle of the generation of a switch to make the Soft-Step Switching in the condenser bank-type reactive power compensation device in Figure 5.

If a condenser bank is inserted, the voltage polarity of the condenser is judged, and if the voltage is positive, from the starting point of the section in which the source voltage is positive, the gate signal of SCR1 is triggered, and SCR2 is triggered after 90° delay. For the negative voltage, from the starting point of the section in which the source voltage is negative, the gate signal of SCR2 is triggered, and SCR1 is triggered after 90° delay. By this trigger signal, the continuity of the condenser can limit the inrush current in the SCR ignition as SCR is ignited at the same time for the source voltage and the condenser voltage.

In Fig. 7, to compensate reactive currents in various sizes, various condenser capacities are needed, but it is difficult to implement them in reality, so several condenser groups are formed and used. Fig. 7 connects several condensers in parallel, so in the connection of N condensers in parallel, the input capacitance is the same as the individual condenser capacitance of 0, 1, 2 ...N times. In other words, it can be changed to N steps, the reactive power can be controlled.



(a) Variable Capacitor Configuration

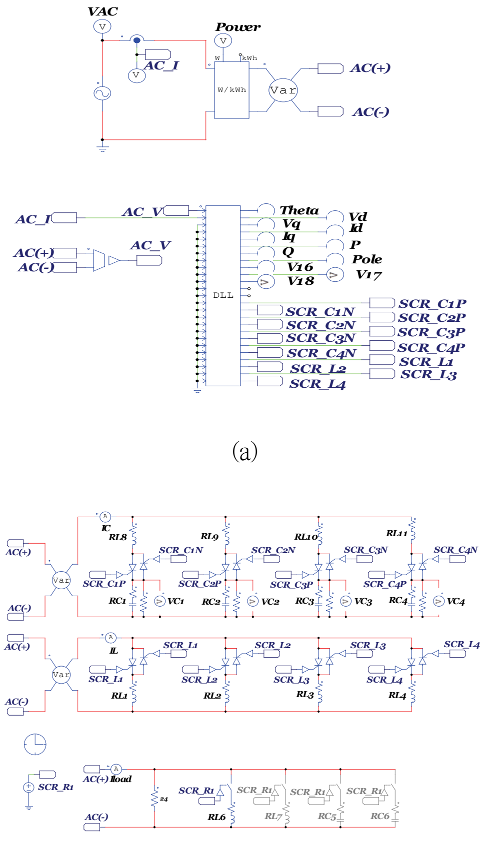


(b) Capacity characteristics according to coupling of condenser group

Fig. 7 Variable capacitor configuration for reactive power compensation.

In the hybrid reactive power compensator, if STATCOM with a capacity larger than the discontinuous current level of TSC is installed, continuous reactive power control is made possible.

3. Simulation Result



(a)

(b)

Fig. 8 Simulation Circuits.

Figure 8 is a simulation circuit diagram to check the validity of the proposed method. Figure 8(a) shows the source voltage and the interface part in the dll file to implement the switching algorithm proposed in this study. Figure 8(b) shows the condenser to compensate the reactive power, the reactor bank and load.

Figure 9 shows the result of the simulation of the existing method of inserting a series reactor.

In the simulation, four groups are formed to compensate 2[kVar] with the condenser's capacity 110[uF] and the reactor's capacity 64[mH], and it is designed to compensate the reactor power of 8[kVar] in total. Therefore, the current peak of each group is about 13[A]. For the load condition, effective power was set to 3[kW], and inductive reactive power, to 7[kVar]. In Figure 9, it is noted that, in the insertion of a condenser, the condenser voltage linearly increases from 0[V] to the source voltage 200[V], and accordingly, the peak of the inrush current is about 130[A], which becomes about [10] times of the rated current of the condenser.

Figure 10 shows the result of the simulation of the proposed switching method. The simulation condition was set the same as that of the existing method. For the condenser voltage, it was noted that the capacitor current was generated at the moment when the condenser's voltage was the same as the source voltage as a result of setting to about 200[V] and that there was little voltage variation in the condenser, so the peak of the inrush current was the same as the rated current of the condenser.

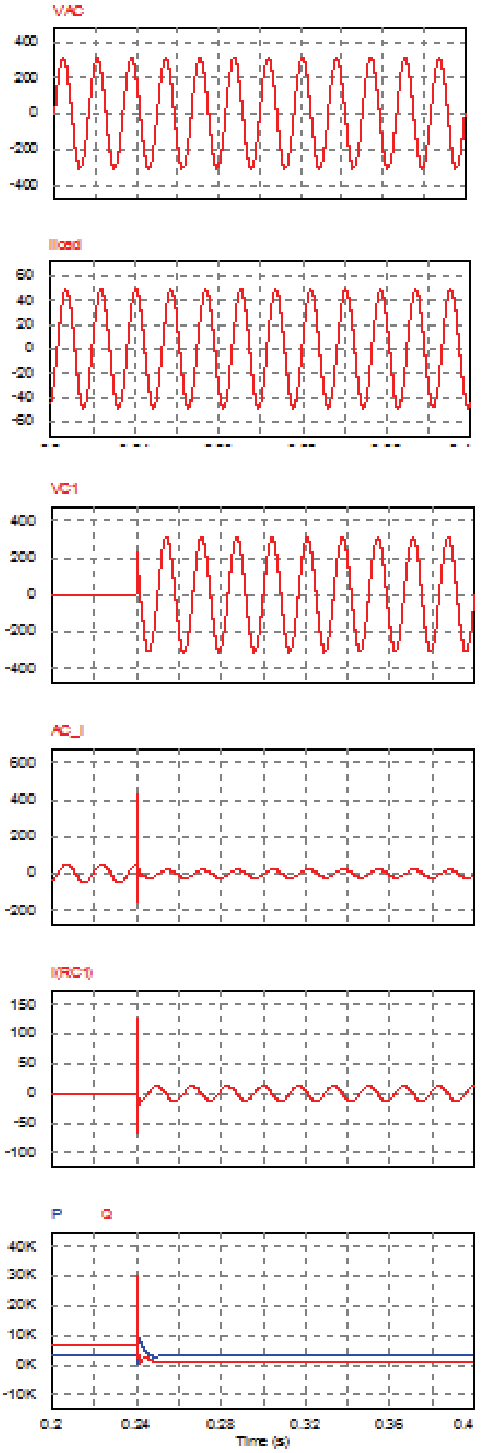


Fig. 9 Simulation results of convensal method.

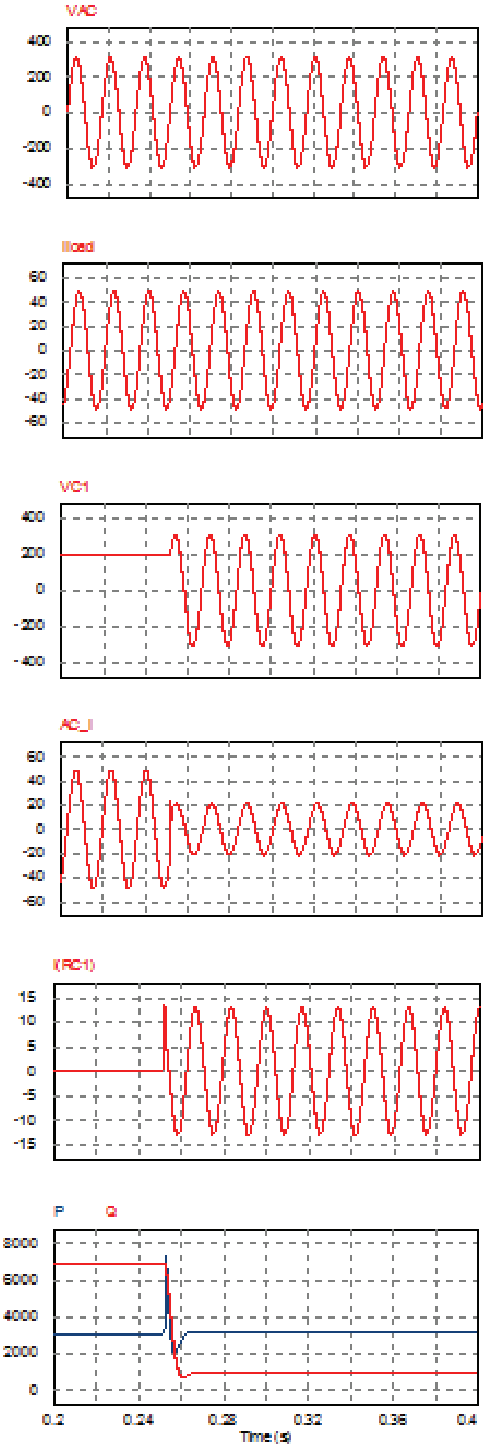


Fig. 10 Simulation results of proposed method.

4. Conclusion

In the modern society, various power sources and loads increase, and to stabilize the voltage of the system in response to these power sources and loads, it is urgently necessary to supply reactive power compensators.

However, there is an insufficient supply of high-performance static reactive power compensator, STATCOM method, because of the constraint conditions, such as installation cost and power conversion efficiency.

To revitalize reactive power compensators, the development of a hybrid reactive power conversion device rapidly emerges as a solution, which can overcome the problems of installation cost and power conversion efficiency.

This paper proposed a new Soft-Step Switching method to prevent inrush current in TSC operation in order to solve the problem of TSC that may have an adverse impact on the system, causing problems such as inrush current and resonance when a hybrid reactive power compensator is constructed.

The proposed method could remove the reactor or quenching resistor for limiting the inrush current.

The switching method proposed as a result of a simulation verified that the inrush current became the rated current in TSC operation.

Acknowledgement

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