PSCAD/EMTDC를 이용한 저항형 초전도한류기의 계통적용분석 연구

A Study on the Application Analysis of the Resistive type Superconducting Fault Current Limiters using PSCAD/EMTDC

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Abstract: Since the discovery of the high temperature superconductors many researches have been performed for the practical applications of superconductivity technologies in various fields. As results, significant progress has been achieved. Especially, Superconducting Fault Current Limiter (SFCL) offers an attractive means to limit fault current in power systems. HTS resistive type SFCL is based on the ultra fast transition from the superconducting (non resistive) state to the normal (resistive) state by overstepping the critical current density. In this study, the simulation method of resistive type superconducting fault current limiter using EMTDC is proposed and the developed EMTDC model of SFCL is applied to the modeled power network using the parameters of real system.

Keywords: SFCL, EMTDC, Modeling, Superconducting Power Devices.

1. Introduction

Recently, increases in the installed electrical power and the interconnection of the transport networks lead to very high short-circuit currents.Fault currents are usually momentary and originate from equipment failures, lightning, tree branches, or animals shorting out circuits. Under certain conditions faults can destabilize a regional power grid producing blackouts extending over several regions. It is very important to protect the electric power system from the high short-circuit current.[1-5].

Conventional alternative methods for current limiting include replacing the existing circuit breakers and other equipment with more expensive components with higher short circuit ratings, splitting and reconfiguring the system. Consequently it reduces the operational flexibility and system stability. There are a lot of alternative methods as follows; 1) using cost ineffective transformers with higher short circuit impedance, 2) using series reactors which incur losses during the normalsystem operation, 3) using single operation devices, such as fuses and pyrotechnic current limiters, which have to be replaced after each operation.

The present techniques use circuit breakers, but since it is to cut the current at its zero crossing, all the components related with the fault have to withstand the destructive effects of the short-circuit currents for a period of at least 3cycles and for about 5cycles[1].

A much more attractive device is a SFCL.Basically, there are threedifferent concepts of SFCLs; the resistive type, the shielded core type and the diode bridge type. The most developed superconducting limiter is the resistive type. Based on the ultra-fast transition from the superconducting state to the normal resistive state by overstepping the critical current density, the resistive type superconducting limiter should guarantee the absence of a current excursion higher than a predetermined value without the need for detection systems or order givers. So, resistive type SFCL has many benefits and advantages[6,7].

In this study, the EMTDC model component of SFCL is introduced to the modeled transmission and distribution system using the real system parameters for the analysis of the fault current and the voltage stability assessment. Through this study, the advantage of SFCL application is shown, and the effective parameter values of SFCL are also recommended.

2.Theoretical Background

2.1. Basic principle of resistive type SFCL

Fig. 1 shows a simplified phase diagram of superconducting state. It is divided into three regions namely, the "superconducting regime" ($\rho = 0$), the "flux-flow regime" ($\rho = \rho(j)$), and the "normal conducting regime" (ρ = constant). The most straightforward concept of an SFCL is the resistive one, in which the superconductor is directly connected in series to the line. The cross-section of the superconductor is so determined that the superconductor is operated inside the

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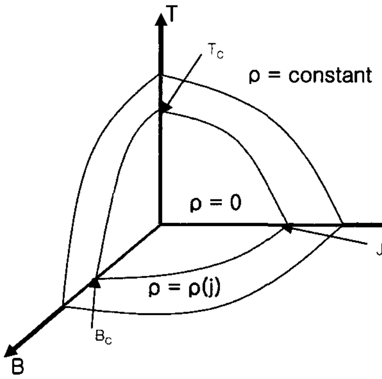

Fig. 1. Simplified phase diagram of superconducting state.

superconducting state, where its interference with the electrical network is negligible. Even though, for ac applications the superconductor has a certain reactance and exhibits ac - losses. Both depend very strongly on the geometry of the superconductor, and can be minimized by optimal conductor-architecture.

2.2. Parameterizationof I-Vcharacteristics

The E(j)characteristics can be practically described by subdividing it into three regions. In each of the three regions E(j) is approximated by a power law.

"Superconducting"regime:

$$E^{(1)}(j,T) = E_c\left(\frac{j}{j_c(T)}\right)^{\alpha(T)} \tag{1}$$

with jcthe critical current density defined at EC = 1μV/cm.jc(T) is fitted to experimental data. The exponent (T) is given by:

$$\alpha(T) = \max[\beta, \alpha'(T)], with$$

$$\alpha'(T) = \frac{\log(E_o / E_c)}{\log\left[\left(\frac{j_c(77K)}{j_c(T)}\right)^{(1-1/\beta)}\left(\frac{E_o}{E_c}\right)^{1/\alpha(77K)}\right]} \tag{2}$$

"Flux flow"regime:

$$E^{(2)}(j,T) = E_0\left(\frac{E_c}{E_0}\right)^{\beta/\alpha(77K)} \frac{j_c(77K)}{j_c(T)}\left(\frac{j}{j_c(77K)}\right)^{\beta} \tag{3}$$

"Normal conducting"regime:

$$E^{(3)}(j,T) = \rho(T_c)\square\frac{T}{T_c}j \tag{4}$$

where ρ is the normal resistivity and TC is the critical temperature of the HTS.

2.3. HTS composite

The HTS composite is modeled as a parallel connection of the HTS material and the normal conducting bypass. The composite was assumed to be homogeneous along its length. Therefore, heat dissipated in the superconductor (and normal conducting bypass) will be transferred to the liquid nitrogen bath (and/or the substrate) in the direction perpendicular to the current direction only. The heat diffusion can thus be described with the one dimensional differential equation:

$$c\frac{\partial T}{\partial t} = \frac{\partial}{\partial_x}\left(k\frac{\partial T}{\partial_x}\right) + E\square j \tag{5}$$

2.4. Different design possibilities

The SFCL can be tailored to different specifications, such as: limitation behavior (e.g. limitation factor, which is the ratio between the first peak of the limited current and $\sqrt{2} * I_n$) 1)maximum "limitation time" before the short circuit has to be interrupted, 2)minimum "recovery time" before a possible re-close, 3) losses and 4)overload capability.

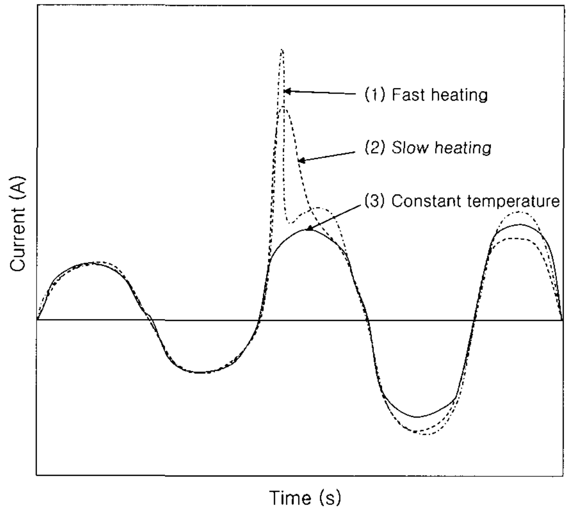

Fig. 2. Different limiting behaviors realized by mainly varying the conductor length.

2.5. Limitation time

During the fault the HTS-composite will heat up and in order to avoid thermal damage, the short circuit has to be cleared after a certain time. This maximum limitation time,which is given by the maximum accepted HTS temperature, depends on the total thermal mass of the composite (mainly the length of the conductor) and on the cooling-rate. If thecurrent is limited to e.g. 3 times In, the HTS-composite will be heated with the enormous power of 3 times the rated power. A temperature increase of up to about 100 K can be accepted. Thus limitation times between several 10 ms and a few seconds can be realized.

2.6. Recovery time

Another important feature of the SFCL is "Recovery time". Recoverytime depends on the thermal mass of the composite, the resistance of the bypass and the limitation time. Usually the recovery time will be in the other of a few seconds. However, the SFCL can be designed so that it can operate again immediately after the limitation action, i.e. zero recovery time. There are two approaches:

First, the so-called constant temperature design, where the HTS during limitation stays essentially at constant temperature and thus in the superconducting state. As second approach, the so-called "operation recovery" can be realized, if the warmed HTS-component can recover to its superconducting state under nominal current, In (or partial In, if sufficient for operation). The former approach needs a very large thermal mass (e.g. realized via very long conductor). For the latter a very good bypass system and an optimized heat transfer away from the SFCL-component plays a crucial role.

2.7. Transient behavior - inrush current

In case of transient overloads, the behavior of the SFCL depends very much on the time of the transient and again on the design, e.g. the bypass system.

Generally it can be said, that the SFCL will not react to currents less than 2 times In, if this transient overload lasts less than a second. Currents above 3 times Inwill be limited. Whether the device will immediately go back to the normal operation depends on the duration of the transient and on the design of the by pass system. If the duration is above 100 [ms], the SFCL will essentially behave as under a fault as described above. When designed for "operational recovery", the device will go back to normal operation without opening the circuit, as long as the transient does not exceed several seconds[8-11].

2.8. Model development of SFCL in EMTDC

Fig. 3 depicts the EMTDC component of resistive type SFCL[7], for which the characteristic equation of limiting resistance (6) is used.

$$R(t) = R_{sc}\left\{1 - \exp(1 - \frac{t - t_0}{\tau})\right\} \tag{6}$$

Fig. 4 (a) shows the characteristic curve, and Fig. 4 (b) shows the fault current restricted by the impedance component of SFCL. When the fault current is occurred in the system, the fault current is restricted by the high impedance in the SFCL, as it is the characteristic of the superconducting element within a few milliseconds. As the circuit breaker opens, the fault current is eliminated and SFCL quickly recovers its superconducting state.

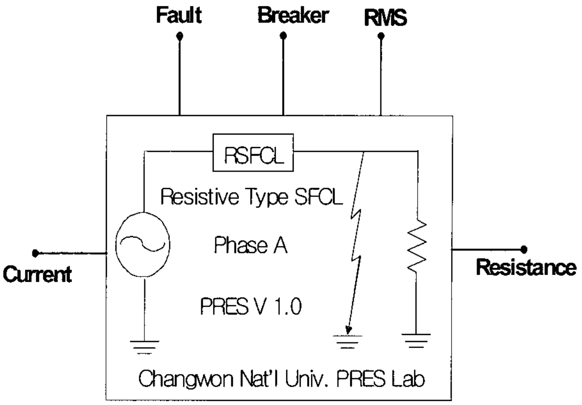

Fig. 3. EMTDC component of resistive type SFCL developed.

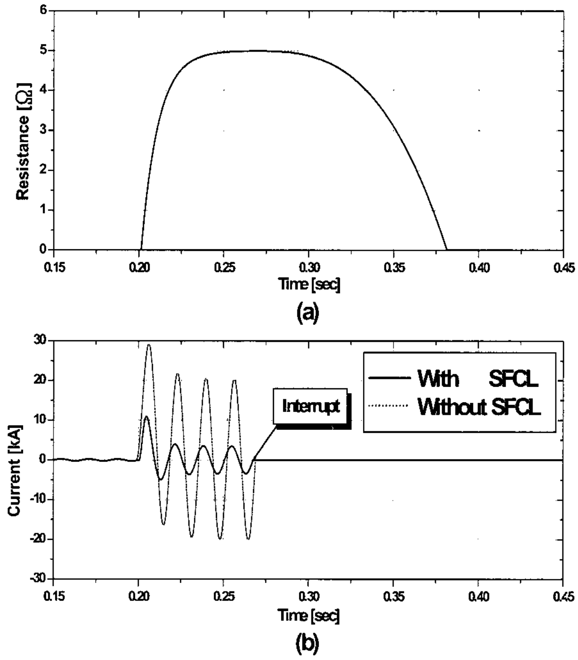

Fig. 4. Characteristic curves of SFCL and current limiting effects.

3. Simulation results of resistive type SFCL

3.1. Simulation of 22.9 [kV] system

Fig. 5 shows a simplifiedpractical distribution system associated with a SFCL. The model system consists of a 154[kV] system bus, three banks of 154/22.9[kV], 60[MVA] conventional transformers and the SFCLs.

In this study, three cases: single line to ground fault, two lines to ground fault and three phase short-circuit, are simulated and the results are given.

The resistance curve, fault current of D/L(A) and the voltage shape of D/L(B) with 1[Ω] of maximum SFCL resistance are given in Fig. 6The peak of fault current reaches 21.0[kA], and the voltage drop of D/L(B) is 49[%] in this case.

Fig. 7 shows the simulation results with 5[Ω] of maximum SFCL resistance. The peak of prospective fault current is suppressed to 11.0[kA], which is 40[%] of the fault current without a SFCL, and the voltage drop of D/L(B) is only 4[%] in this case.

Fig. 8 and Fig. 9 depict the relationship between fault current, voltage drop and resistance of SFCL for the two different cases (A & B), respectively.

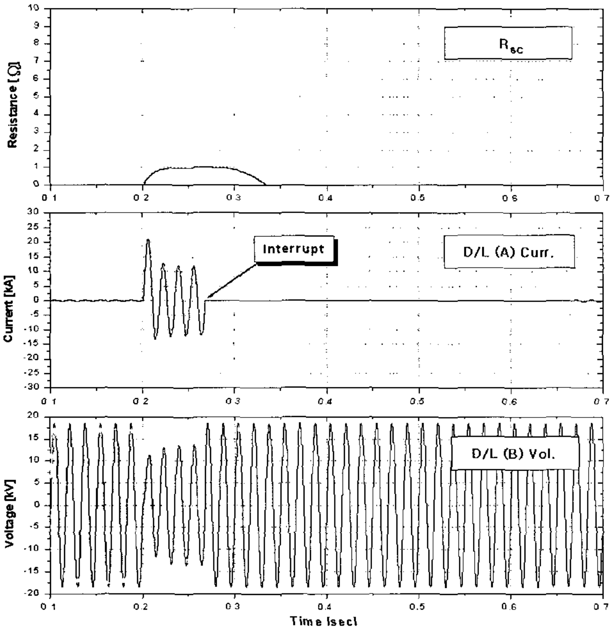

Fig. 6. Fault current of D/L (A) and voltage of D/L (B) with a SFCL(1[Ω]).

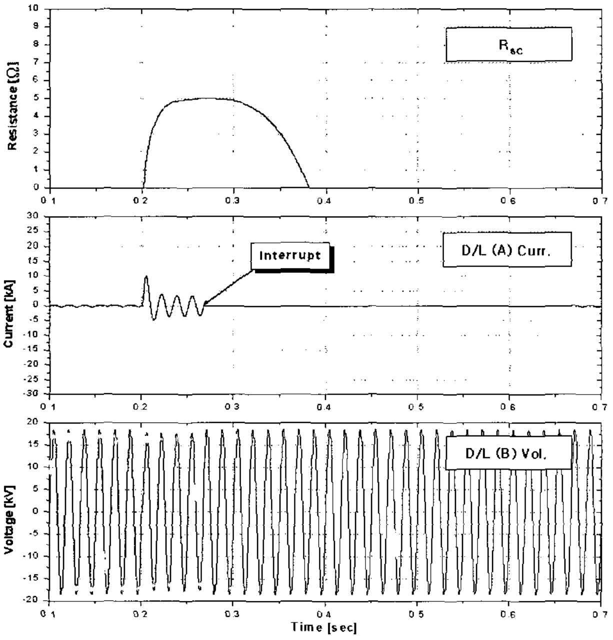

Fig. 7. Fault current of D/L (A) and voltage of D/L (B)with a SFCL(5[Ω]).

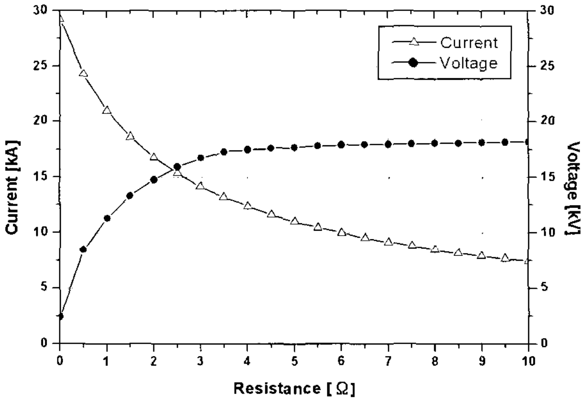

Fig. 8. Fault current and voltage vs. resistance for D/L(A).

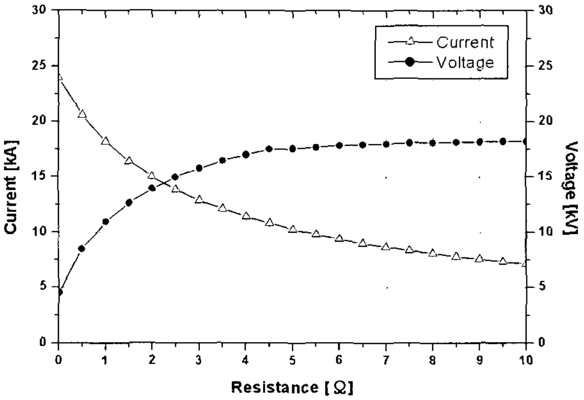

Fig. 9. Fault current and voltage vs. resistance for D/L(B).

As shown in the above figures, the prospective fault current and voltage drop rate are decreased with the resistance of SFCL. The impact obtained by the SFCL application is saturated at around 5[Ω] in this study case, which means that the parameter assessment of SFCL is very important and necessary for the proper operation of power systems. Furthermore, the subsequent fault current can be reduced into the load current level with higher values of the SFCL resistance. However, the recovery time of superconductor may exceeds the reclosing time of the protective system and can causes serious voltage stability problems consequently.

3.2. Simulation of 154[kV] system

In this chapter, the resistive type SFCL component is applied to 154[kV] Power Transmission Systems, modeled with Shin-Ma-San substation by PSCAD/EMTDC.

Fig. 10 shows the circuit diagram of the simulated area (Shin-Ma-San substation). There is a transformer bank with the capacity of 345/154[kV], 500[MVA]. The voltage class is downed from 345[kV] class to 154[kV] class and the power is delivered to each 154[kV] substation thru 1 circuit and 2 circuits transmission line.

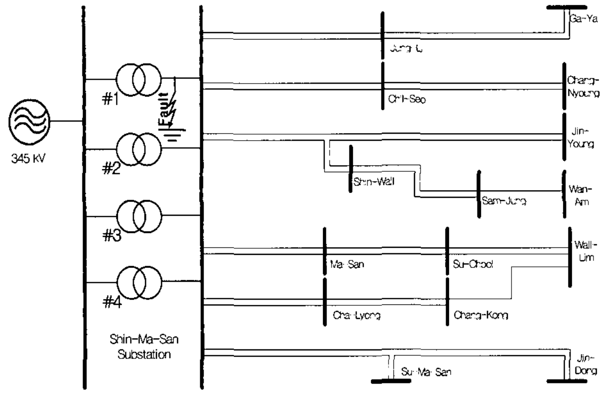

Fig. 10. Circuit diagram of the simulated area (Shin-Ma-San substation).

Fig. 11 shows the result of which the final resistance value of the SFCL is 5[Ω]. In the case of the line-to-ground fault, the moment maximum of 38.16[kA] and the average of 18.5[kA] fault current are shown. It is reduced 45% of fault current according to the final resistance of 5[Ω] of SFCL.

Fig. 12 shows the fault current waveforms of which the final resistance value is 10[Ω]. It is reduced 58% of fault current according to the final resistance of 10[Ω] of SFCL.

Fig. 13 shows the case of 50[Ω]. The average of fault current is 2.6[kA] at line-to-ground fault. In the case of 3 phase line-to-line fault, the limited current shows the same level of the normal condition.

Fig. 14 shows the fault current level according to the various final resistances of SFCL. The simulation results showed that the maximum and average value of fault current decreases in an exponential functional way according to the various resistance values of all SFCL.

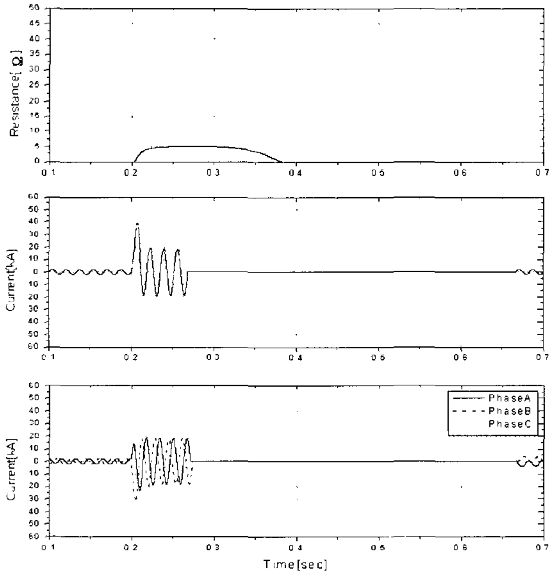

Fig. 11. Resistance level of 5[Ω] after quench of SFCL and the fault current waveforms of line-to-ground and 3 phase line-to-line.

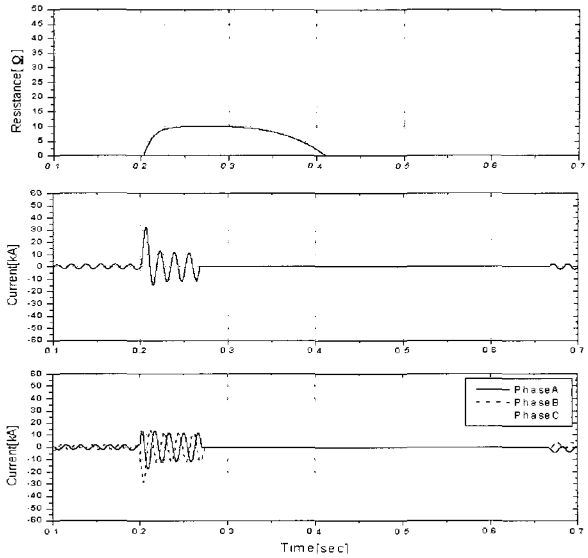

Fig. 12. Resistance level of 10[Ω] after quench of SFCL and the fault current waveforms of line-to-ground and 3 phase line-to-line.

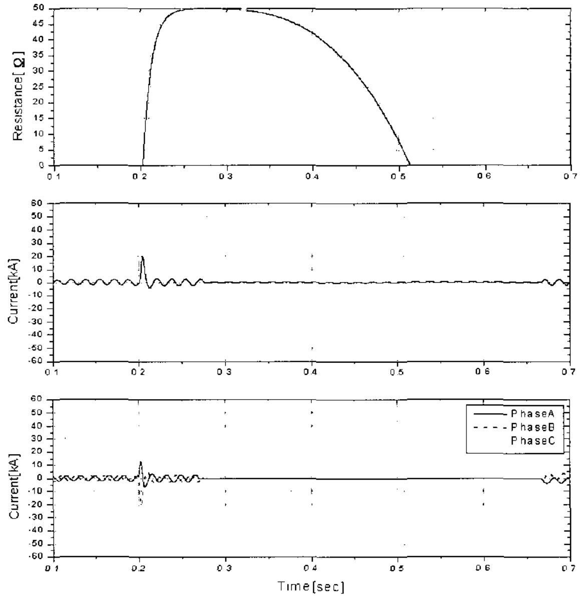

Fig. 13. Resistance level of 50[Ω] after quench of SFCL and the fault current waveforms of line-to-ground and 3 phase line-to-line.

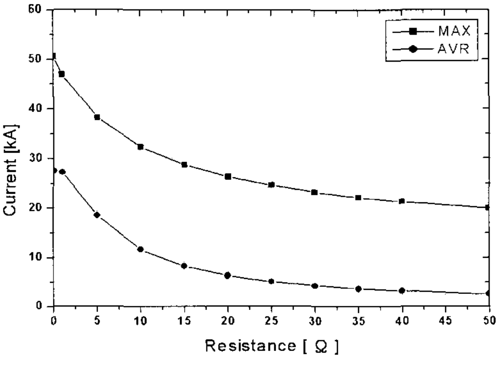

Fig. 14. Fault current level according to the various final resistances of SFCL.

In addition, due to the superconducting element characteristics, the recovering time of SFCL exceeds the generally required time due to the re-closure of the circuit breaker if the final resistance value is comparatively large.

Thus, even after the fault is eliminated and the circuit breaker is re-closed, the resistance component of the SFCL causes continuously the voltage drop of the system.

4.Conclusion

In this study, the effect of SFCL application to the real distribution and transmission system was evaluated by using EMTDC simulation technique. The simulation results showed that the maximum and average value of fault current decreases in an exponential functional way according to the various resistance values of SFCL.

It can be seen that not only the short circuit current level is strongly influenced by the resistance value of conducting state but also the recovery time must be considered while applying the resistive type SFCL to the system. In the future, a more diversely viewed analysis of the effects on introducing the system using the EMTDC model applied in this study shall take place.

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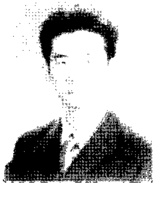
저자소개



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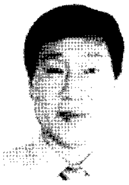

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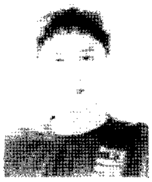

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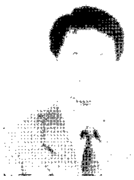

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