Journal of the Korea Institute of Applied Superconductivity and Cryogenics
Vol.7, No.2, (2005), pp.35~38

R-type HTS-FCL Model considering transient characteristics

Jae Young Yoon, Seung Ryul Lee, and Jong Yul Kim

Korea Electrotechnology Research Institute

jyyoon@keri.re.kr

Abst ract- **One of the most serious problems in KEPCO system operation is higher fault current than the SCC(Short Circuit Capacity) of circuit breaker. There are many alternatives to reduce the increased fault current such as isolations of bus ties, enhancement of SCC of circuit breaker, applications of HVDC-BTB(Back to Back) and FCL(fault current limiter). But, these alternatives have some drawbacks in viewpoints of system stability and cost. As the superconductivity technology has been developed, the resistance type HTS-FCL(High Temperature Superconductor Fault Current Limiter) can be one of the most attractive alternatives to solve the fault current problem. To evaluate the accurate transient performance of resistance type HTS-FCL, it is needed that the dynamic simulation model considering transient characteristics during quenching and recovery state. Under this background, this paper presents the EMTDC model for resistance type HTS-FCL considering the nonlinear characteristic of final resistance value when quenching and recovery phenomena by fault current injection and clearing occurs.**

1. INTRODUCTION

If the fault occurs in power system, circuit breaker separates the fault location with other system area promptly. To perform this action successfully, the capacity of circuit breaker has to be bigger than fault current magnitude. But, owing to the enlargement of power system scale, the fault current is bigger and it exceeds the breaking capacity. In this case, fault current magnitude should be controlled to foster stable operation of power system. There are many alternatives to reduce the increased fault current such as isolations of bus ties, enhancement of SCC of circuit breaker, applications of HVDC-BTB(Back to Back) and FCL(fault current limiter), but these alternatives have the problems of enormous expenses growth or system stability degrade [1-3].

The development of HTS-FCL(High Temperature Superconductor-Fault Current Limiter) is recently under way worldwide through HTS technology and attempt to power system application is going on. Resistance type HTS-FCL has a large reduction effect without degrade of system stability compared with other alternatives. Also, it costs relatively lower than HVDC BTB or breaking capacity increasing [4-5]. Dynamic behavior and its control effect have to be confirmed under the various operating condition for the application of R-type HTS-FCL.

To evaluate the accurate transient performance of resistance type HTS-FCL, it is needed that the dynamic simulation model considering transient characteristics during quenching and recovery state. Under this background, this paper presents the EMTDC model for resistance type HTS-FCL considering the nonlinear characteristic of final resistance value when quenching and recovery phenomena by fault current injection and clearing occurs. Thus, it is developed the EMTDC dynamic model to simulate quenching phenomena of R-type HTS-FCL and confirmed the effectiveness by applying this to simulated system similar to real power system conditions.

2. DYNAMIC MODEL OF R-TYPE HTS-FCL

The power In normal operation state, HTS-FCL resistance can maintain nearly zero because of superconducting characteristics. But, if the fault current over critical quenching current flows, HTS-FCL resistance will increase by the quenching resistance. This means that the HTS-FCL can control the fault current below the specific values by inserting quenching resistance.

Basically, whether or not reaching quenching status is dependent upon current magnitude and temperature. In practical concept, the status variation of HTS-FCL resistance is co-related to several factors such as fault current peak magnitude, integration of fault current, fault current per second and temperature of HTS-FCL. This paper introduces the generic model to simulate the superconducting, quenching and recovery state for R-type HTS-FCL. Fig. 1 represents the dynamic characteristics of

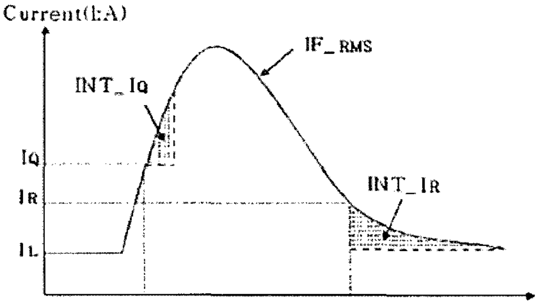


Fig. 1. Dynamic characteristics of HTS-FCL resistance.

HTS-FCL resistance depending on fault current(IF_RMS) and other factors. The overview of mathematical modeling is as follows.

2.1. Equations of temperature dependence for basic parameter

$$T_{PU} = \frac{T}{T_0} \quad (1)$$

$$I_L \ or \ I_Q \ or \ I_R = I_{L0} f(T_{PU}) \ or \ I_{Q0} f(T_{PU}) \ or \ I_{R0} f(T_{PU}) \quad (2)$$

$$\text{ex)} \ I_L = I_{L0} f(Tpu)$$

$$VINT_{IQ} = VINT_{IQ0} \times f(T_{PU}) \quad (3)$$

$$VINT_{IR} = VINT_{IR0} \times f(T_{PU}) \quad (4)$$

$$VPT_{IQ} = VPT_{IQ0} \times f(T_{PU}) \quad (5)$$

$$VPT_{IR} = VPT_{IR0} \times f(T_{PU}) \quad (6)$$

Where, T_0, T: Base and operational temperature
I_L, I_Q, I_R : Steady state, quenching and recovery current
I_{L0}, I_{Q0}, I_{R0} : Base steady state, quenching and recovery current
$VINT_{IQ}$, $VINT_{IR}$: Integration value of fault current for quenching and recovery (kA-sec)
VPT_{IQ}, VPT_{IR} : Integration value of fault current per second for quenching and recovery (kA-sec/sec)

2.2. Superconducting state and resistance

If Eq. (7) is satisfied, the superconducting status will be maintained and the resistance value is nearly zero.

$$I_{RMS} \leqq I_{L,MAX} \quad (7)$$

$$FCL_R \cong 0.0 \quad (8)$$

2.3. Quenching state and resistance value

If all Eqs. (9)-(11) are satisfied, the HTS-FCL should be quenched and the resistance value will be a quenching design value. The quenching resistance will increase with the specific characteristics, for example exponential function, from zero(superconducting resistance) to quenching resistance.

$$I_{RMS} \geq I_Q \quad (9)$$

$$\int_{t_Q}^{t} I_{RMS}\, dt \geq VINT_{IQ} \quad \text{for } t_Q \leq t \leq t_R \quad (10)$$

$$\frac{\int_{t_Q}^{t} I_{RMS}\, dt}{t - t_Q} \geq VPT_{IQ} \quad \text{for } t_Q \leq t \leq t_R \quad (11)$$

$$HTS_R = f(I_F, t) \quad \text{ex)} \ HTS_R = (t - t_Q) \times I_{RMS} \times \exp(-kt)$$

Where, HTS_R: HTS-FCL resistance during quenching state.

2.4. Recovery state

If Eqs. (12)-(13) are satisfied, the HTS-FCL must be recovered after quenching state is finished, and the resistance value will be back to a superconducting value, nearly zero. The recovery resistance will decrease with the specific characteristics, for example exponential function, from quenching resistance to zero(superconducting resistance).

$$I_L \leq I_{RMS} < I_Q \quad (12)$$

$$\frac{K_Q \times \int_{t_Q}^{t_R} I_{RMS}\, dt + K_R \times \int_{t_R}^{t} I_{RMS}\, dt}{t - t_Q} \leq VPT_{IR} \quad (13)$$

$$\text{for } t \geq t_Q$$

$$HTS_R = f(I_F, t) \quad (14)$$

$$\text{ex)} \ HTS_R = (t_R - t_Q - t + t_R) \times I_{RMS} \times \exp(-kt)$$

Where, HTS_R: HTS-FCL resistance during/after recovery state.

This paper develops the EMTDC dynamic model of HTS-FCL resistance depending on the above Equations, and Fig. 2 describes this model. Also, main parameters which influences the dynamic behaviors of HTS-FCL controlling the fault current is presented at Fig. 2.

For the EMTDC model of Fig. 2, if necessary, non-linear characteristic as Eq. (15) could be structured to change HTS-FCL resistance with fault current, temperature and other factors during quenching and recovery process. Also, it can be designed to add alteration of function and input factors. This means that we can change the detail transit function for the dynamic behavior of each HTS-FCL resistance because the actual transient characteristics of HTS-FCL resistance during quenching and recovery phenomena is not clear until now and the dynamic performance is not same for different type of HTS-FCL.

$$y = f(I_F, \ Temperature, \ Other \ Factors) \quad (15)$$

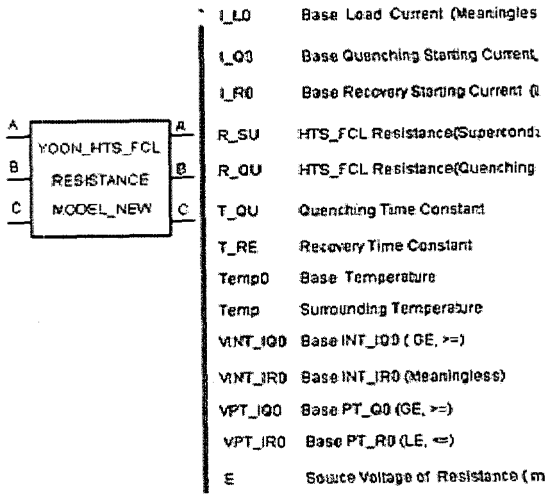


Fig. 2. Dynamic model of HTS-FCL resistance.

3. CASE STUDY FOR POWER SYSTEM APPLICATION

3.1. Analysis overview

We analyzed the dynamic performance of EMTDC model developed in this paper and verified the effectiveness of this model. The overview of test system, basic data and analysis case is specified. We constructed the test system as Fig. 3 which has a basic characteristic of KEPCO system to verify the effectiveness of EMTDC dynamic model developed in this paper. This test system reflects exactly on actual system state for 154kV overhead transmission line, 154kV/22.9kV conventional/ superconducting cable with HTS-FCL resistance to reduce fault current and other power equipments which represents the whole power system. It can be simulated under the various operation states for test power system by changing the basic data.

3.2. Analysis results

The basic data of HTS-FCL resistance is described in Table I, Table 2 shows the difference of analysis result for the base case whether HTS-FCL applies to 154kV bus or not. Base case means that the 3-ph. fault occurs on the 154kV bus in the case of HTS-FCL is applied at the 154kV bus. We can see that the analysis result for base case with HTS-FCL, the peak and steady-state RMS fault current is quite smaller than for base case without HTS-FCL. When comparing the analysis result, the peak fault current reduces from 151.3(kA_peak) to 46.4(kA_peak) in case of having HTS-FCL with basic data.

TABLE I
BASIC DATA OF HTS-FCL RESISTANCE.

Data	Base Data	Remark
I_LO	0.5 [kA]	Base Load Current
I_QO	8.0 [kA]	Base Quenching Starting Current
I_RO	0.5 [kA]	Base Recovery Starting Current
R_SU	0.001	HTS_FCL Superconducting Resistance
R_QU	10.0	HTS_FCL Quenching Resistance
T_QU	0.01	Quenching Time Constant
T_RE	100	Recovery Time Constant
Temp0	20.0	Base Temperature
Temp	20.0	Surrounding Temperature
VINT_IQ0	0.001	Base INT_IQ0
VINT_IR0	100	Base INT_IR0
VPT_IQ0	5.0 [kA]	Base PT_IQ0
VPT_IQ0	100 [kA]	Base PT_IR0

TABLE II
ANALYSIS RESULT FOR BASE CASE.

CASE	IFCL_peak(kA)	IFCL_rms
Base case with HTS-FCL	46.4(kA_peak)	8.4(kA_rms)
Base case without HTS-FCL	151.3(kA_peak)	62.1(kA_rms)

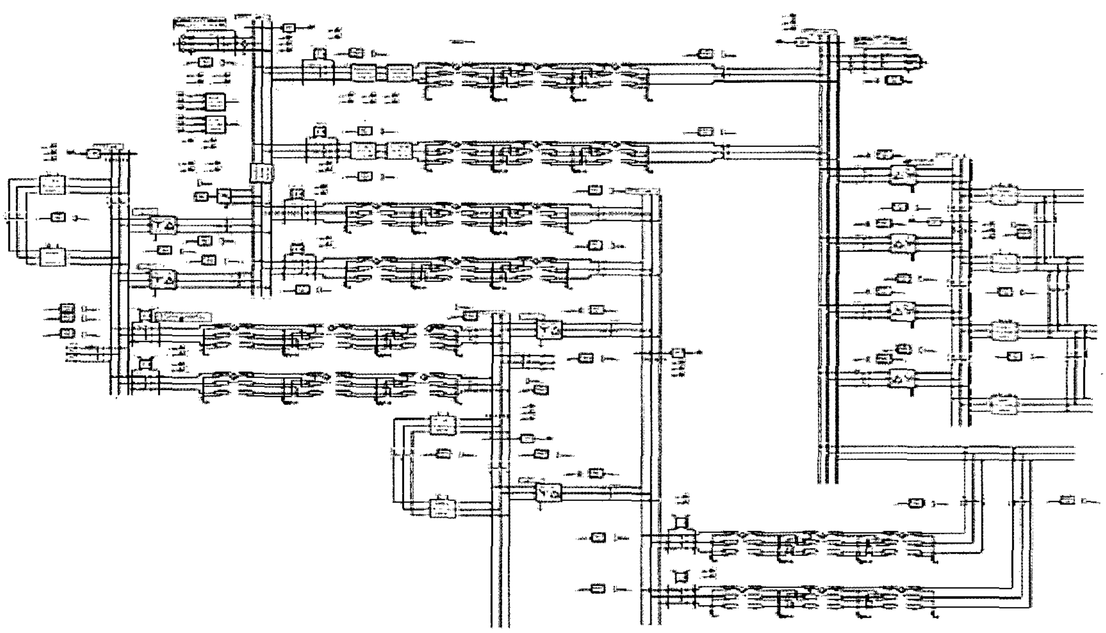
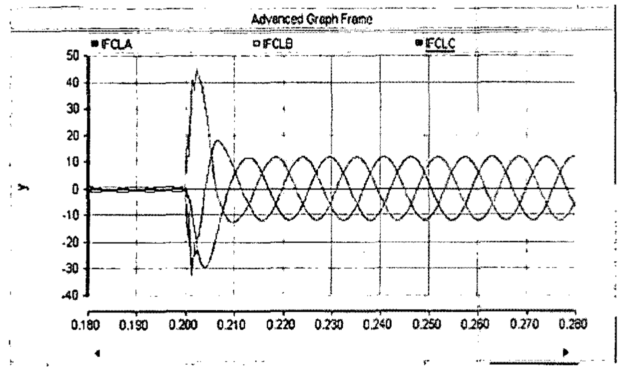
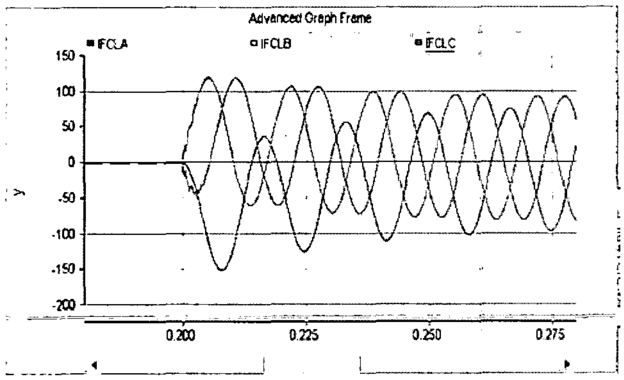


Fig. 3. Test power system representing KEPCO system.



(a) Fault current with HTS-FCL (Base case)



(b) Fault current without HTS-FCL (Base case)

Fig. 4. Fault current comparison with/without HTS-FCL for base case.

As a case study, quenching resistance(R_QU) and quenching starting current can be varied within limited range. Table III describes the analysis results when the quenching resistance and quenching starting current is changed. It is showed that the higher the quenching resistance and the smaller the fault current.

TABLE III

ANALYSIS RESULT WHEN QUENCHING RESISTANCE CHANGES.

CASE	IFCL_peak(kA)	IFCL_rms
Base case with HTS-FCL R=0(Ω)	151.3(kA_peak)	62.1(kA_rms)
Base case with HTS-FCL R=1(Ω)	100.5(kA_peak)	47.8(kA_rms)
Base case with HTS-FCL R=5(Ω)	59.9(kA_peak)	16.1(kA_rms)
Base case with HTS-FCL R=10(Ω)	46.4(kA_peak)	8.4(kA_rms)
Base case with HTS-FCL R=20(Ω)	34.3(kA_peak)	4.3(kA_rms)
Base case with HTS-FCL R=50(Ω)	21.4(kA_peak)	1.7(kA_rms)

4. CONCLUSION

This paper develops the EMTDC dynamic model of HTS-FCL resistance and evaluates the analysis result by applying to test power system representing the similar characteristics with KEPCO system. Here are the overall research results.

- ○ We analyzed the dynamic behavior of HTS–FCL resistance and developed the generic EMTDC dynamic model. Also, we verify the effectiveness of developed model by applying to test power system.
- ○ As the analysis result of basic case with having HTS-FCL or not, the fault current could be reduced below the breaking capacity if the HTS-FCL is applied.
- ○ This paper simulates the nonlinear characteristic of HTS-FCL, but the accurate equation describing actual nonlinear characteristic is not clear until now. Therefore, it is needed to study about the nonlinear characteristic itself.
- ○ Furthermore, the research on the optimism setting of HTS-FCL parameter such as quenching resistance and critical quenching current for practical power system application should be necessary.

ACKNOWLED GMENT

The authors would like to express their gratitude with special thanks to the Center for Applied Superconductivity Technology in Korea for their financial support and cooperation.

REFERENCES

[1] KEPCO, “Feasibility study for enhancement of power system performance", 2000. 11.
[2] KERI, “A feasibility study for HVDC system”, 1996. 12..
[3] KERI, “A comparison on HTS-FCL characteristics”, 2002.
[4] M. Noe, B. R. Oswald, "Technical and economical benefits of superconducting fault current limiters in power systems" IEEE Transactions on applied superconductivity, June 1999.
[5] J. N. Nielsen, J. J. Ostergaard, "Applications of HTS fault current limiters in the danish utility network".
[6] Hanbat University, “A basic study for HTS-FCL parameter”, 2002. 6.
[7] H. Kameda, "Setting method of specific parameters of a superconducting fault current limiter considering the operation of power system protection" IEEE Transactions on applied superconductivity, June 1999.
[8] Charles A. Gross, "Power System Analysis", 1986.
[9] KERI, “Development of HTS-FCL EMTDC dynamic model”, 2004. 5.
[10] EMTDC Manual, Custum Model, 2001.