International Journal of Railway Research, (2015), Vol.2, No1, pp 10-14 ISSN: 236153768187

Iran University of Science and Technology

International Journal of

Railway Research

Study of Superconducting Fault Current Limiter Device in a AC Railway System

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ABSTRACT

Development of the electric networks led to more interconnection in this system, therefore high level of short circuit faults flows in the networks. Many destructive damages such as instability, insulation problems and voltage mitigation can highly play unwanted influences on the system’s equipment. Using appropriate protection devices like high voltage fuses, fast switches, and such devices reduce these destructive effects. Superconducting Fault Currents Limiter (SFCL) as one of developing method of fault current reduction is able to be used for the mentioned goal. In this paper SFCL is studied in an AC electric railway system.

Keywords: Current limiter, Superconducting fault current limiter, AC railway system

1. Introduction

The expansion of the railway transportation system needs to more and more power supply on the mono phase 25KV-50 HZ power system. Due to the high level of importance and reliability issue’s for railway system, the design of electrical supply for railway system always includes tow transformer, one is operating and the other one is back up, so back up transformer feeds the line power during maintenance period and fault occurrence.

Traffic increasing requires to expand the power supply for more power generation and lots of costs imposed to the manufactures [1][2]. First mind for more power generation is to connect parallel transformers to each other. This method leads to increase the level of fault current in the circuit [3][4][5]. These increasing in fault current level may exceed switchgears rating and harm protection devices and even cause loss of reliability, consequently. The fault current limiter is the effective device that reduce short circuit current level to the acceptable range for circuit breakers, relays, and other protection devices so it is not necessary to upgrade and renew existent equipment [6].

Circuit breakers and switchgears are not fast enough to eliminate the fault current in the circuit so almost two or three cycle of short circuit fault passes through the network and may cause destructive effects on network after long time [7]. Despite of conventional protection devices like fuses, circuit breakers and high impedance transformers fault currents limiters are much faster and limit the short circuit fault current in a few milliseconds [8].Fault current limiters are divided in two major groups including superconducting fault current limiter and solid state fault current limiter [9]. Solid state fault current limiter is older that the first one and includes power electronic devises like capacitor, inductance and diodes or other semiconductors. After inventing superconductor material and with the laws

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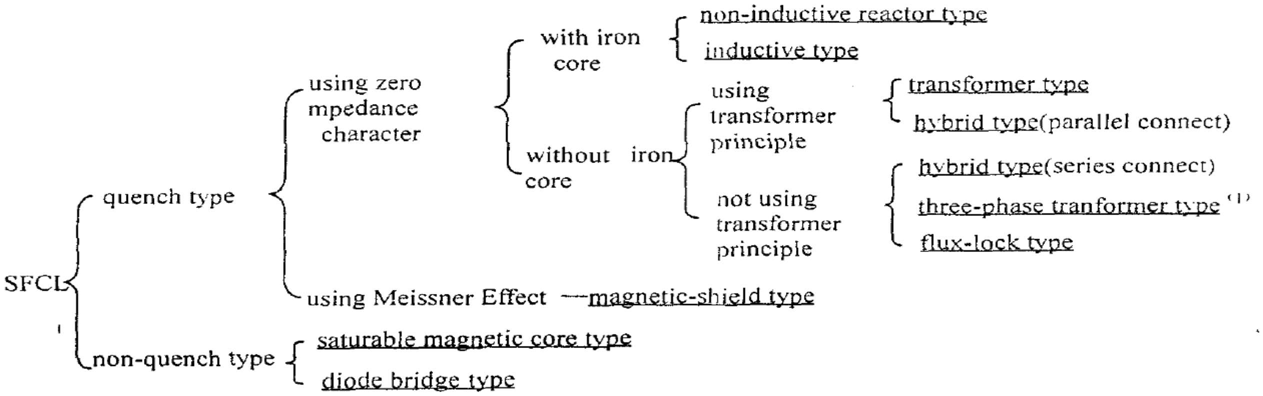
proposed like Meissner effect (electromagnetic field is zero in superconductors if they be kept in their superconducting temperature) superconducting fault current limiters have been noticed and utilized in power systems [10].

FCLs are placed series in circuit and they have no impedance in their normal mode after fault occurrence the insert high level of impedance in the circuit and limit the fault current level. Figure 1 shows the simple system of railway track which is connected to two transformers.



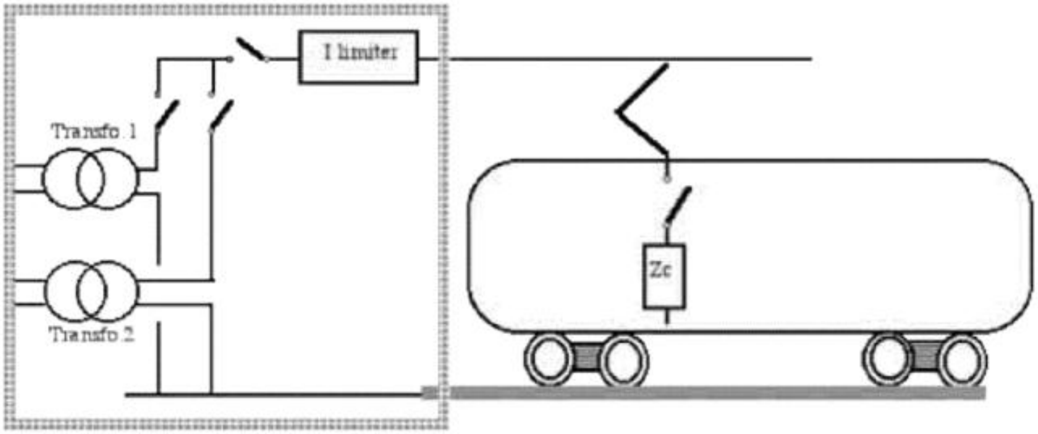


Figure 1. 25kV-5OHz railway power electrical substation equipped with 2 redundant transformers, current limiter is inserted in the overhead line.

At the first time low temperature superconductors have been invented. They had high costs issues because their cryogenic environment. After invention of High Temperature Superconductors, LTS materials vanished in constructing of superconducting fault current limiters. HTS materials have the higher temperature for their cooling system. Liquid helium used for LTS which has lower temperature than liquid nitrogen used for HTS cooling unit, thus using HTS could be high cost-effective for assembling of superconductor fault current limiter[11]. Different models of SFCL introduced and developed that have different operation mechanism. Here some models of superconducting fault current limiters are classified [9].

2. Modeling of SFCL

Some companies like Zenergy, superpower and nexans have done several researches and experimental tests of applying superconducting fault current limiter in different projects. Most of the projects focus on resistive type and saturated type fault current limiters. They used SFCL in different places such as generation coupling, bus tie, transmission sides and reaches useful conclusion after using different type SFCL which is shown in table1. Resistive type SFCL uses thin YBCO films that make the smaller and cheaper than other kind of SFCLs. SFCL operation is shown by Figure 2 and Figure 3.

Table 1. General characteristic of FCL technologies

Technology	Losses	Triggering	Recovery	Size/Weight	Distortion
Purely Resistive SFCL	Hysteretic (amount depends on HTS materials).	Passive	HTS conductor must be re-cooled.	Potential to be small, because HTS performs limiting action.	Only during first cycle.
Hybrid Resistive SFCL	Hysteretic (amount depends on HTS materials).	Passive or Active[2]	Much faster than the purely resistive because less energy is deposited in the HTS.	Potential to be small, but additional components may increase size.	Only during first cycle.
Saturable-Core SFCL	DC power required to saturate the iron core and Joule heating in conventional conductors.	Passive	Immediate.	Large and heavy due to iron core and conventional windings.	Some; caused by nonlinear magnetic characteristic.
Shielded-Core SFCL	Hysteretic (amount depends on HTS materials).	Passive	Faster than purely resistive, but re-cooling required.	Large and heavy due to iron core and windings.	Only during first cycle.
Solid-State (SSFCL-CB)	Similar to resistive type SFCLs.	Active	Immediate.	Similar to purely resistive.	Switching electronics introduce harmonics.
Fuses	Negligible.	Passive	Never; requires replacement.	The smallest of the technologies summarized.	None.

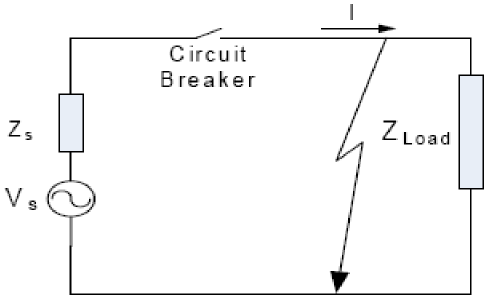


Figure 2. circuit model before using SFCL

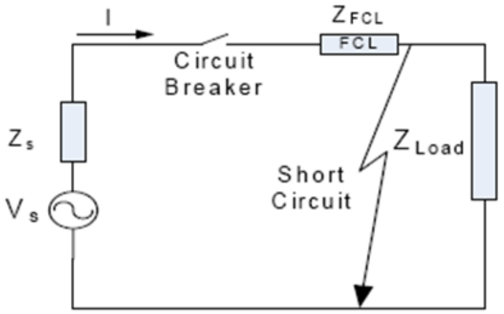


Figure 3. circuit model after using SFCL

Equation (1) and (2) show Some companies like Zenergy, superpower and nexans have done several researches and experimental tests of applying superconducting fault current limiter in different projects. Most of the projects focus on resistive type and saturated type fault current limiters. They used SFCL in different places such as generation coupling, bus tie, transmission sides and reaches useful conclusion after using different type SFCL which is shown in table1.resistive type SFCL uses thin YBCO films that make the smaller and cheaper than other kind of SFCLs. SFCL operation is shown by Figure 2 and Figure 3. Equation (1)and (2) show the SFCL behavior in the normal and superconducting mode.

$$I_{nomind} = \frac{V_S}{Z_S + Z_{LOAD}} \tag{1}$$

$$I_{fualt} = \frac{V_s}{Z_s + Z_{fualt}}, Z_{fualt} \ll Z_{LOAD} \tag{2}$$

$$I = \frac{V_s}{Z_s + Z_{FCL} + Z_{fualt}} \tag{3}$$

According the Table1 and the losses of power and railway system specifications resistive type SFCL is chosen to be used in the 25KV railway system.

Figure 4 shows the V-I waveform of SFCL. As it shows it works with zero impedance in its normal state and after fault quenching (turn superconducting to normal state) happens and SFCL goes to its normal state and impedance rises exponentially .

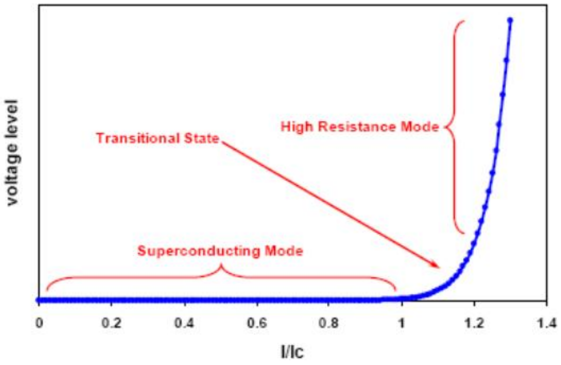


Figure 4. V-I characteristic of resistor type SFCL

The impedance of SFCL according to time t is given as (4):

$$Z(t)=\begin{cases} o & (t<t_0) \\ z_n\left[1-\exp(-\frac{t-t_0}{T_F})\right]^{\frac{1}{2}} & (t_0\le t<t_1) \\ a_1(t-t_1)+b_1 & (t_1\le t<t_2) \\ a_2(t-t_2)+b & (t\ge t_2) \end{cases} \quad (4)$$

Where Z_n is saturated impedance and T_F is time constant, respectively. $a1$, $a2$, $b1$ and, $b2$ are the constant to note exponential behavior of the SFCL. t_0, $t_1$and, t_2 is the quenching time, first recovery time and second recovery time, respectively.

Table 2. General characteristic of FCL technologies

parameter	Z_n	T_F	$a1$	$a2$	$a2$	$b2$
value	12-17	0.02	-54	-100	12-17	5

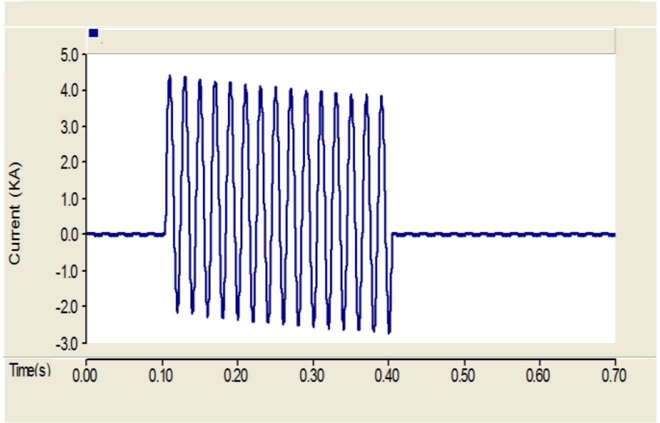


Figure 5. fault current without SFCL

3. Simulation result

SFCL is placed first of the line and limits the fault current level to the acceptable range. Networks parameters is shown as Table 3. Simulation are carried out in 0.7 seconds. Fault occurred at t=0.1s and cleared after 0.3s. Nominal current of the network is 55A and the fault current has the peak of almost 4KA. After fault occurrence SFCL quenches and changes to its normal state mode then high impedance inserts in the power system and suppress the fault current. After utilizing SFCL in the proposed network peak of the fault current reached to 2.6KA for R=17Ω. The peak 0f the fault current with different parameters of SFCL is 2.9KA and 3.2KA for R=12ΩandR=15Ω, respectively. Figure 5 shows the fault current without SFCL and Figure 6-8 show the current limitation with different values of SFCL resistance.

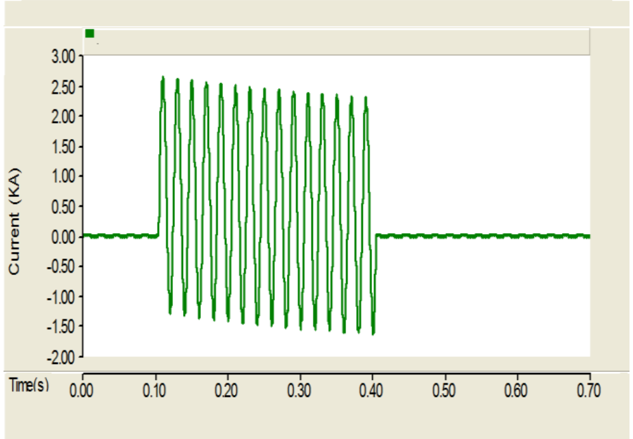


Figure 6. fault current with SFCL (R=17 Ω)

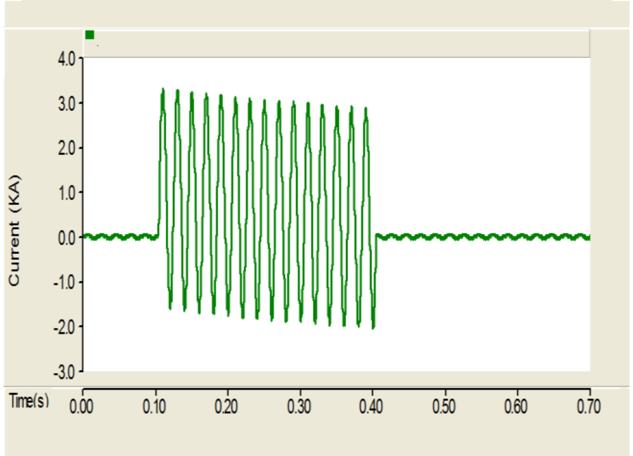


Figure 7. fault current with SFCL (R=12 Ω)

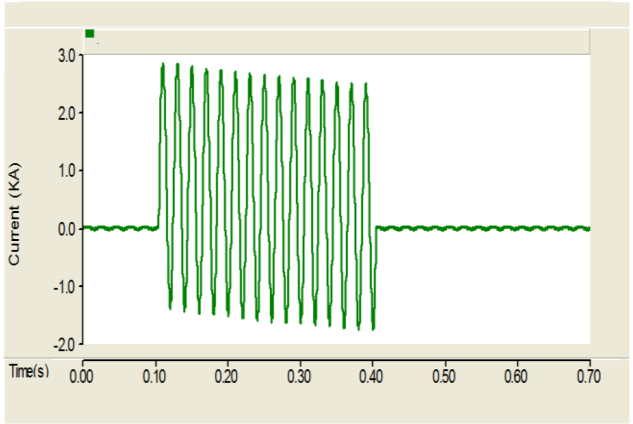


Figure 8. fault current with SFCL (R=15 Ω)

4. Conclusions

In this, we propose a SFCL protection scheme for single phase railway traction system. First different models of FCL are explained. Then a comparison have been done between different type FCLs and then resistor type SFCL selected as the best model for railway system. After modeling of SFCL fault current level limited to 2.6KA. Suppressing the level of short circuit cam greatly increase system reliability. Short circuit level is one of the most parameter in designing system so reducing short circuit level by SFCL can cause significant save of costs.

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