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Modelling and Simulation of Resistive Superconducting Fault Current Limiter (RSFCL) in Three Phase Transmission and Wind Energy Generation System (WEGS) Applications

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Abstract: In present scenario, electrical networks are desperately integrating with Superconducting Fault Current Limiters (SFCL) because of their capability to improve the stability, fault compensation within milliseconds, auto-transformation from Superconducting state to normal state. Hence, the characterization and performance of RSFCL integration with the power systems should be analyzed for better utilization for Indian scenario. This paper alights, developed simulation model of RSFCL with Coated Conductors (CC's) in MATLAB/SIMULINK. This model is simulated to predict the fault compensation capacity during three phase faults in Three Phase Transmission and isolated WEGS respectively. Based on E-J power law the current density and resistance characteristics of RSFCL are analyzed during fault. Different faults such as LG, LLG, and LLLG are investigated, and it is found that RSFCL is very effective in fault compensation with in very first peak and in fewer times in both Three Phase Transmission and isolated WEGS.

Keywords: RSFCL, Coated Conductors (CC's), MATLAB/SIMULINK, Three Phase Transmission, Wind Energy Generation System (WEGS), Fault current compensation.

1 INTRODUCTION

The demand for the power increasing drastically since few decades due to increase in population, industries etc. Hence, many Distributed Generation systems, Isolated Systems and Integrated Grids are developed to meet the power demand. Due to these systems, short circuits are increased predominantly because of faults and leads to instability in power generation, storage, transmission and distribution [1], [2]. The conventional electrical devices have limited operational limits and during faults these limits may exceed and power devices may be damaged [3]. The self trigging [4], millisecond compensation of fault current densities [5], fail safe and automatic recovery to Superconducting state after fault compensation [6] made SFCL to develop a novel and unique utilized RSFCL technology in power grids. The fault limit will depends on the superconducting material used for manufacturing the HTS tape and its index number [7]. Many SFCL projects are done to know its behaviour [8]. The application of the RSFCL at various positions of grid are investigated [9]–[13]. In recent past, RSFCL design, fabrication and manufacturing done by using CC's [14], [15]. Experimental investigation on RSFCL is done by using Coated conductors (CC's) for Indian medium capacity is Kar et al [16] and simulation is done by Dutta et al [17].

However, the integration of RSFCL in the power grids and WEGS of India are not yet studied. Motivated by this, MATLAB/SIMULINK models similar to the India transmission systems and WEGS are developed to analyze the behaviour of RSFCL integration. Later, fault such as LG, LLG, LLLG are applied on the circuits of Three phase transmission and WEGS. From the investigation, the RSFCL integration in power grids have better potential of application.

2 MATLAB/SIMULINK RSFCL MODEL

Figure 1 shows the MATLAB/SIMULINK model of RFSCL.

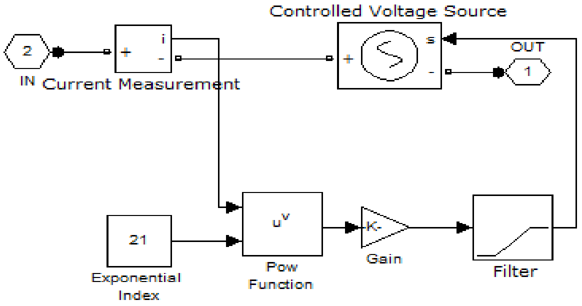

Figure 1 MATLAB/SIMULINK model of RSFCL

This model includes constant exponential index of 21 because to simplify as well as to minimize the computational time.

The E-J characteristic of the Superconductor shows the state on which it operates. During normal operation, RSFCL remains in Superconducting state which means that it has minimum impedance and zero resistance.. However, when the fault occurs, the transition from the Superconducting state i.e., E-J relation follows power law to Normal state i.e., it follows normal conductor V-I relation.

A subsystem with current measurement and Voltage sources are connected in series to show the E-J characteristic. When fault occurs, the superconductor follow E-J power law to transform into flux flow state. So, power block is connected in series with the constant exponential index i.e., 21. Due to transition from flux flow state to normal state a coefficient will appear to show that a gain block is also attached to the system. The transition of superconductors is shown in Figure 2.

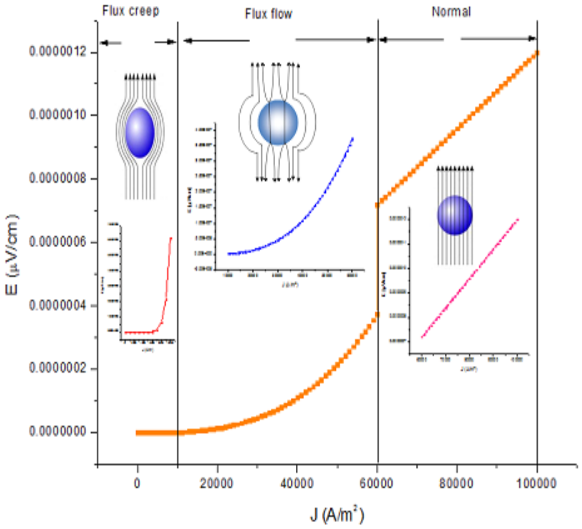

Figure 2 Transition of Superconductor

The mathematical calculations used for fining the E-J characteristics are expressed as [18], [19].

$$E(T,t) = \rho(t) * J(T(t)) \qquad (1)$$

$$E(T,t) = \begin{cases} E_C \left(\dfrac{J(t)}{J_C(T(t))} \right)^{\alpha} \\ for\ E(T,t) < E_0\ and\ T(t) < T_C \\ E_0 \left(\dfrac{E_C}{E_0} \right)^{\frac{\beta}{\alpha}} \left(\dfrac{J_C(T_a)}{J_C(T(t))} \right) \left(\dfrac{J(t)}{J_C(T_a)} \right)^{\beta} \\ for\ E(T,t) > E_0\ and\ T(t) < T \\ \rho(T_C) \dfrac{T(t)}{T_C} J(t) \\ for\ T(t) > T_C \end{cases} \qquad (2)$$

3 ANALYSIS OF SIMULATED MODEL

The integration of RSFCL in real time power system is modeled to simulate the performance of RSFCL in grid. A three phase fault and load is connected to the RSFCL and the source is connected on the other end. Figure 3 shows that simulated model of RSFCL in three phase transmission. Different types of faults such as LG, LLG, LLLG are analyzed. A frequency of 50Hz and triggering time of 0.2 seconds are used for simulation. RSFCL is used to protect power devices from the fault current. Since from few decades the drastic increase in the generation of power from Renewable resources. Hence, WEGS are integrated to the power grids are predominantly increased. Figure 5 shows the simulated model of RSFCL in isolated Wind Energy Generation System.

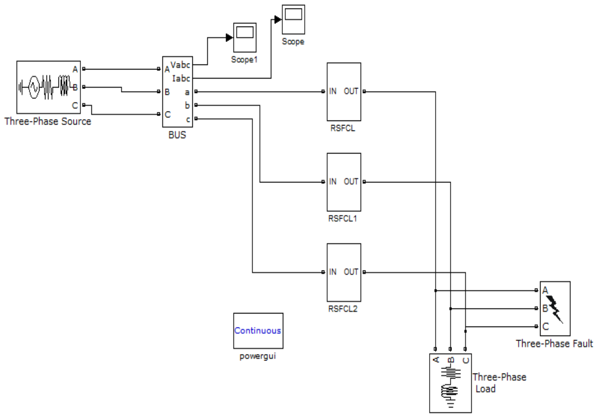

Figure 3 Simulated model of RSFCL in Three Phase Transmission

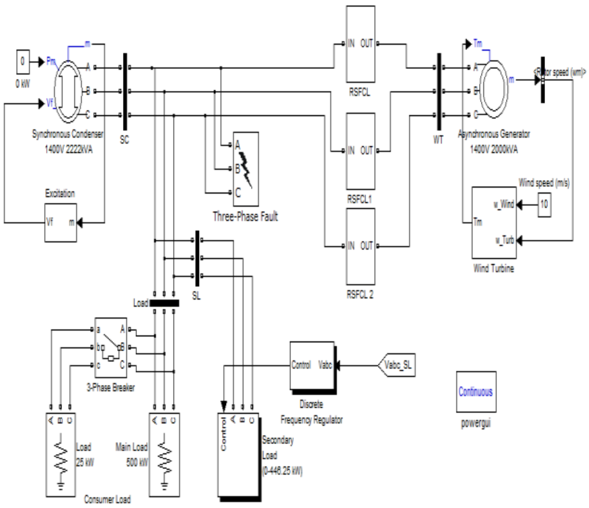

Figure 4 Simulated model of RSFCL in isolated Wind Energy Generation System

4 RESULTS AND DISCUSSION

The Three phase transmission and WEGS simulated models are parametrically initialized. LG, LLG, LLLG faults are analyzed under load with fault and R-SFCL.

Figure 5 shows the normal operation of Three phase transmission current Time waveforms without fault and RSFCL. These models are simulated with the triggering time of 0.2 seconds.

4.1 Three Phase Transmission System

Figure 6, Figure 7, Figure 8 shows the LG, LLG and LLLG fault of Three phase transmission current waveforms without RSFCL. Figure 9, Figure 10 and Figure 11 shows the LG, LLG and LLLG fault compensation of Three phase transmission current waveforms with RSFCL. During normal operation the peak current is 580A without fault and RSFCL. The peak values of LG, LLG, LLLG of Phase A, Phase B and Phase C with fault, with fault and RSFCL as well as the percentage of the limiting current are shown in Table 1. It is observed that 51% of the fault current is limited within the very first peak by integrating with RSFCL and fault limiting time is 60ms.

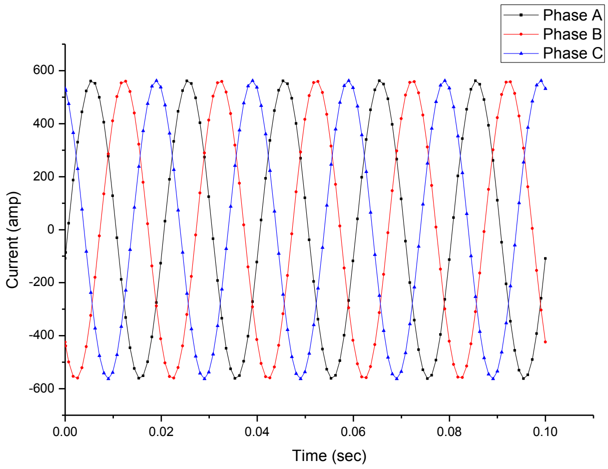

Figure 5 Normal operation of Three phase transmission current Time waveforms without fault and RSFCL

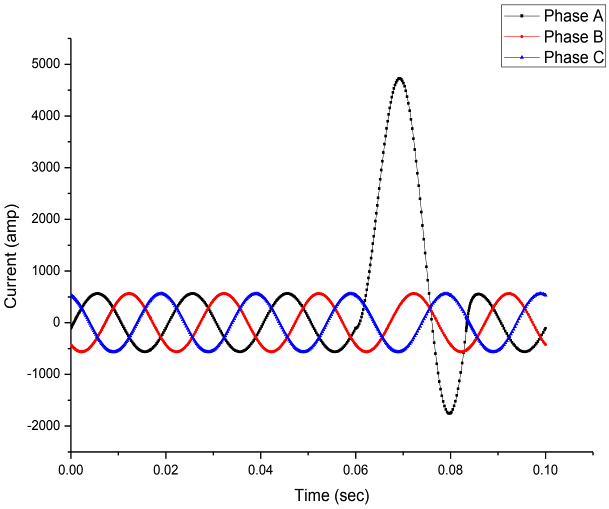

Figure 6 LG fault of three phase transmission current Time waveforms without RSFCL

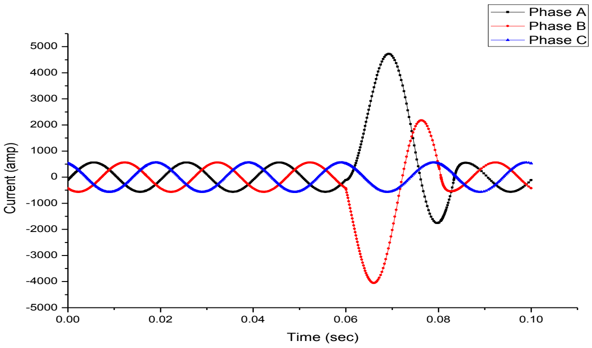

Figure 7 LLG fault of Three phase transmission current Time waveforms without RSFCL

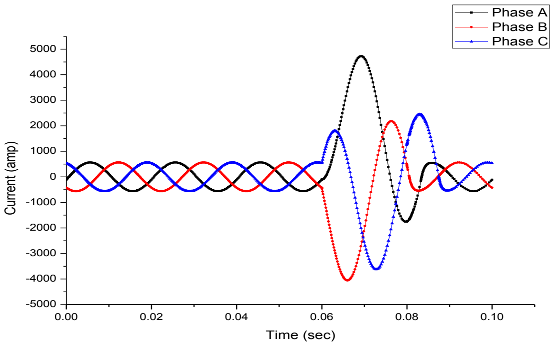

Figure 8 LLLG fault of Three phase transmission current Time waveforms without RSFCL

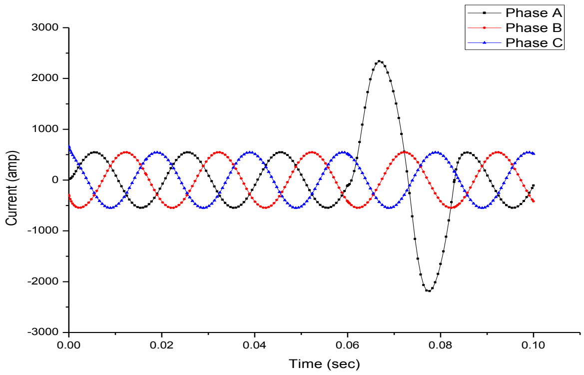

Figure 9 LG fault compensation of Three phase transmission current Time waveforms with RSFCL

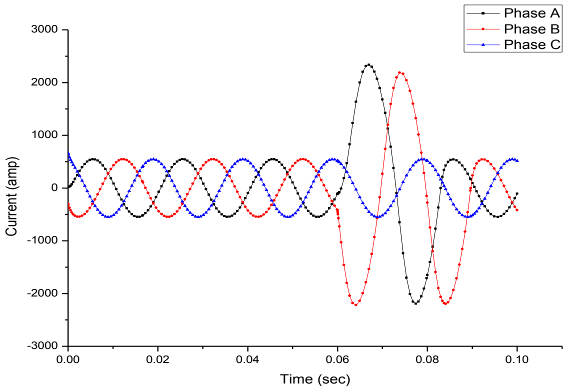

Figure 10 LLG fault compensation of Three phase transmission current Time waveforms with RSFCL

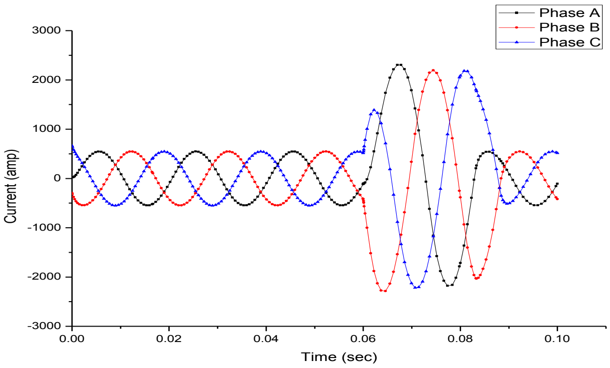

Figure 11 LLLG fault compensation of Three phase transmission current Time waveforms with RSFCL

Table 1 Three phase transmission system fault limiting percentage with RSFCL

Type of Operation		Phase A in Amps	Phase B in Amps	Phase C in Amps
Normal		580	580	580
With Fault	LG	5000	800	800
	LLG	4900	4500	800
	LLLG	5000	4200	3900
With Fault, RSFCL	LG	2500	400	400
	LLG	2300	2200	400
	LLLG	2300	2000	1900
% of peak limited	LG	50%	50%	50%
	LLG	52%	51%	50%
	LLLG	52%	51%	51%

4.2 Wind Energy Generation System

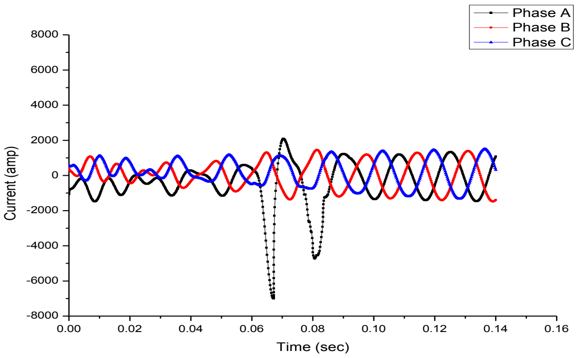

Figure 12 LG fault of WEGS current Time waveforms without RSFCL

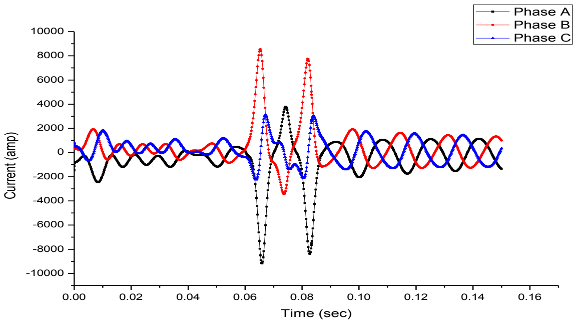

Figure 13 LLG fault of WEGS current Time waveforms without RSFCL

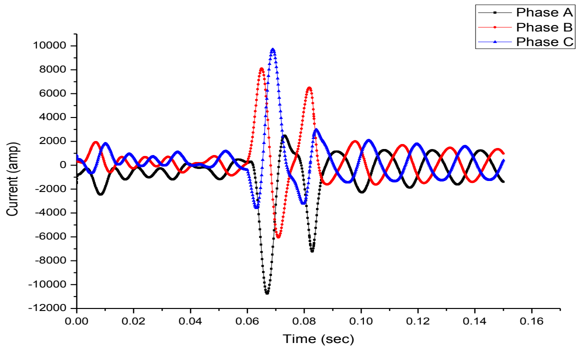

Figure 14 LLLG fault of WEGS current Time waveforms without RSFCL

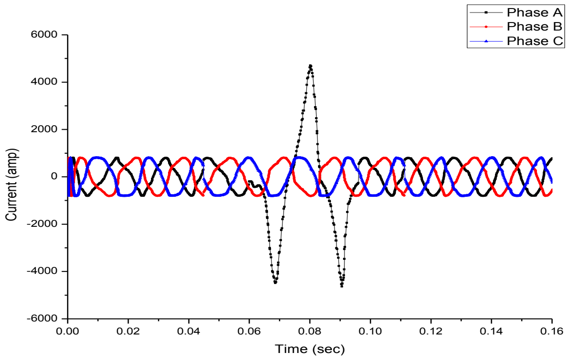

Figure 15 LG fault compensation of WEGS current Time waveforms with RSFCL

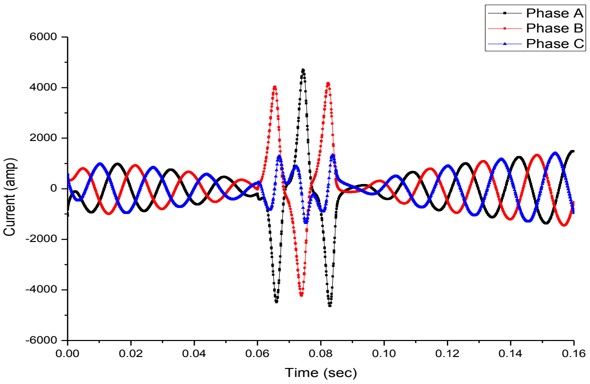

Figure 16 LLG fault compensation of WEGS current Time waveforms with RSFCL

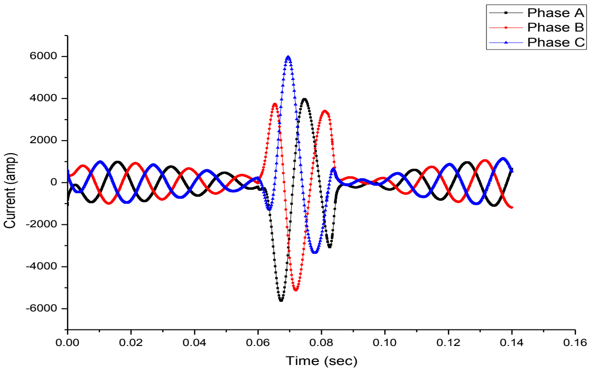

Figure 17 LLLG fault compensation of WEGS current Time waveforms with RSFCL

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Table 2 WEGS fault limiting percentage with RSFCL

Type of Operation		**Phase A in Amps**	**Phase B in Amps**	**Phase C in Amps**
Normal		800	800	800
With Fault	LG	7400	1400	1400
	LLG	9500	9400	1400
	LLLG	9900	9800	8000
With Fault, RSFCL	LG	4200	800	800
	LLG	5000	5000	800
	LLLG	5600	5400	4300
% of Peak Limited	LG	46%	42%	42%
	LLG	47%	46%	42%
	LLLG	43%	44%	45%

Figure 12, Figure 13 and Figure 14 shows the LG, LLG, LLLG fault of WEGS current Time waveforms without RSFCL. Figure 15, Figure 16 and Figure 17 shows the fault compensation of WEGS current Time waveforms with RSFCL. During the normal operation the peak current is 800A without fault and RSFCL. The peak values of LG, LLG, LLLG of Phase A, Phase B and Phase C with fault, with fault and RSFCL as well as the percentage of the limiting current are shown inTable2. It is observed that 43% of the fault current is limited within the very first peak by integrating with RSFCL and fault limiting time is 60ms.

5 CONCLUSION

MATLAB/ SIMULINK models are used to develop the environment friendly RSFCL made up of Coated Conductors (CC's). From the investigation, it is analyzed that RSFCL integration is better to improve the performance and stability of Three phase transmission and WEGS applications. The triggering current is simulated with 0.2 seconds. During normal operation without Fault and RSFCL Transmission system have a peak current value of 580A and the percentage of reduction in the peak during the fault is 51%. During the normal operation without Fault and RSFCL WEGS have a peak current value of 800A and the percentage of reduction in the peak during the fault is 43%. The time for fault recovery is 60ms.

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