

# Voltage SAG analysis in loop power distribution system with SFCL

VALLALA BABU RAO

M-Tech Student Scholar

Department of Electrical & Electronics Engineering,  
Laqshya Institute of Technology & Sciences,  
Telangana, India.

EMail: baburao243@gmail.com

Mr. K NAVEEN

Assistant Professor

Department of Electrical & Electronics Engineering,  
Laqshya Institute of Technology & Sciences,  
Telangana, India.

EMail:224naveen@gmail.com

**Abstract-** Interruptions to supply and sags of distribution system voltage are the main aspects causing customer complaints. There is a need for analysis of supply reliability and voltage sag to relate system performance with network structure and equipment design parameters. This analysis can also give prediction of voltage dips, as well as relating traditional reliability and momentary outage measures to the properties of protection systems and to network impedances. Existing reliability analysis software often requires substantial training, lacks automated facilities, and suffers from data availability. Thus it requires time-consuming manual intervention for the study of large networks. Distribution system reliability can be divided into two aspects: system adequacy and system security. Adequacy describes the normal state capability of the system to supply customer demands. Security describes the ability of the system to continue to supply the customer in spite of faults in the network. In this paper, the improvement of the voltage sag is analyzed according to the fault location, resistance value of SFCL, and the length of the loop power distribution system. First, a resistor-type SFCL model is used using the MATLAB/SIMULINK. Next, the loop power distribution system is modeled. Finally, when the SFCL is installed in the radial or loop power distribution system with various lengths, voltage sags are evaluated according to various fault locations. The results of voltage sag analysis in the loop system are compared with the voltage sags in radial power distribution system. In extension to the work discussed in paper the system can be tested under different Loading conditions and a study on positioning of super conducting fault current limiter can be analyzed.

**Index Terms**—Loop power distribution system, superconducting fault current limiter (SFCL), voltage sag

## I. INTRODUCTION

Superconducting Fault Current Limiter (SFCL) has been developed in the world and applied to substation of power distribution system in Korea. SFCL can limit the fault current in power system using the increased resistance caused by quenching characteristics of superconducting elements. In addition, SFCL can improve voltage quality not only in faulted phase but in non-faulted phase when a 1 phase to ground fault is occurred. The assessment method of voltage sag using the Information of Technology Industry Council curve is presented in Reference [1] when SFCL is applied to power distribution system. The parallel connection of radial systems via the

SFCL which can make voltage dips less severe is presented in Reference [2]. The improvement of voltage sags caused by decreased fault current is presented in References [3] and [4]. These studies dealt with the voltage sags in the power distribution system with SFCL. However, voltage quality such as voltage sag and overvoltage in faulted and non-faulted phase has been not dealt with. The magnitude of sag, whereas it may worsen the duration of sag because of the delayed trip time of a protective device by the decreased fault current. These effects of SFCL on voltage sags should be evaluated. Also, power distribution system will be changed to loop system such as micro grid or smart grid. Thus, effects of SFCLs should be evaluated and analyzed when SFCLs are installed in radial and loop power distribution system according to the location and impedance of SFCL, the length of feeder, and location of fault. However, the overall effects on voltage sag were not dealt with in the above mentioned studies.

In this paper, we assess the impact of SFCL on voltage sags in radial and loop power distribution system. In Section II, we model a resistor-type SFCL. In Section III, the voltage sag occurred by fault current is explained. In Section IV, we evaluate the voltage sag magnitude according to the fault location and resistance of SFCL in radial and loop power distribution system.

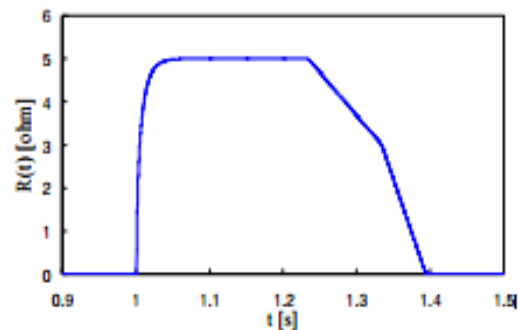


Fig. 1 Quenching and recovery characteristics of SFCL

## II RESISTIVE-TYPESFCL

Many SFCL models have been developed. In this paper, we use resistive-type SFCL based on [1], [5]–[10] which represents the experimental studies for superconducting

elements of SFCL being applied to Korean power distribution systems. The impedance of SFCL according to time  $t$  is given at (1), where  $R_n$  and  $T_F$  represent the impedance being saturated at normal temperature and time constant, respectively. In addition,  $t_0$ ,  $t_1$ , and  $t_2$  represent quench-starting time, the first recovery-starting time, and the secondary recovery-starting time, respectively.

$$R(t) = \begin{cases} 0 & (t < t_0) \\ R_n [1 - \exp(-(t - t_0)/T_F)]^{1/2} & (t_0 \leq t < t_1) \\ a_1(t - t_1) + b_1 & (t_1 \leq t < t_2) \\ a_2(t - t_2) + b_2 & (t \geq t_2) \end{cases} \quad (1)$$

Fig. 1 represents quenching and recovery characteristics of the SFCL shown. When a reclosing scheme is 2 Fast 1 Delay (2F1D). When a fault is occurs in a power distribution system, the resistance of SFCL increases.

TABLE I  
PARAMETERS OF MODELED SFCL

Parameter	$R_n$ [ $\Omega$ ]	$T_F$	$a_1$ [1/s]	$a_2$ [1/s]	$b_1$ [ $\Omega$ ]	$b_2$ [ $\Omega$ ]
Value	variable	0.01	-80	-160	$R_n$	$R_n/2$

If a reclose is tripped, SFCL is recovered. The scheme is repeated two times more. The used values for parameters are shown in Table I. The recovery time of SFCL is set to the value less than 0.5 s based on [9], because the reclosing time of power distribution system in Korea is 0.5 s.

### III. VOLTAGE SAGS IN POWER DISTRIBUTION SYSTEM

When faults occur in power distribution system, the automatic recloser or circuit breaker with over-current relay (OCR) and reclosing relay will open to clear the fault and automatically reclose after a time delay. This reclosing behavior can take place several times in an effort to establish a continuous service when a temporary fault occurs [11].

The voltage sag generally happens from fault. In case 1 in Fig. 2(a), if a temporary fault occurs between CB and recloser, the reclosing operation of the OCR of breaker will be successful and the momentary interruption will occur. In this case, the customers at feeder 1 (faulted feeder) will experience voltage sag and a momentary interruption. The customers at feeder 2 (neighbor feeder) will experience the voltage sag during the fast-trip time of the OCR and this is shown in Fig. 2(b).

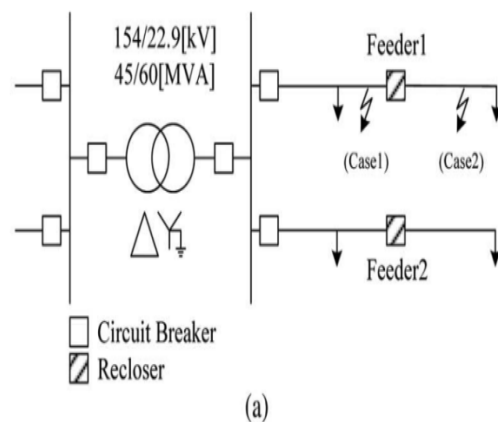
However, if a permanent fault is occurs, the reclosing operations will be failed and the reclosing operation will be finally locked out. In this case, the customers in feeder 1 will experience three voltage sags, two momentary interruptions and a sustained interruption. The customers in feeder 2 will experience two voltage sags during the

fast-trip time of OCR and one voltage sag during the delay-trip time of OCR when reclosing scheme of OCR is 1F1D; this is shown in Fig. 2(c) during a fault.

In case 2 in Fig. 2(a), all sequences and phenomena is equal to that of case 1 such as the number of voltage sags, momentary interruptions, and sustained interruption except the fault clearing time of recloser instead of OCR. In other words, if a temporary fault is occurs, the customers at feeder 2 will experience the voltage sag during the fast-trip time of recloser instead of OCR, so on. As presented above, the automatic reclosing scheme in power distribution systems can produce various voltage sags to the customers on the neighbor feeder. Moreover, the number of neighbor feeder is about 6 to 10 while the number of faulted feeder is only one. Generally, a voltage magnitude at bus of secondary-side of main transformer (MTr.) during fault can be represented as equation (2) if fault impedance is ignored, a type of fault is 3-phase fault, and source voltage is 1.0 p.u.

$$V_{bus} = \frac{Z_{line}}{Z_{source} + Z_{MTr} + Z_{line}} \quad (2)$$

Where  $Z_{source}$ ,  $Z_{MTr}$ , and  $Z_{line}$  are source impedance, transformer impedance, and line impedance from source to faulted location, respectively. Equation (2), also, can approximately represent the voltage magnitude at customers on all neighbor feeders. In this paper, the voltage magnitude is focused than sag duration.



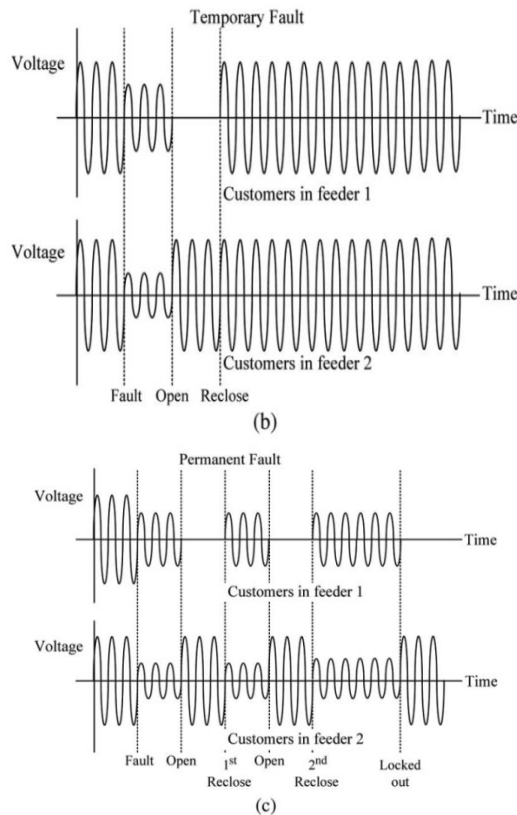


Fig. 2 Voltage sag in power distribution system d. (a) Power system configuration, (b) voltage sags of customers (temporary fault), and (c) voltage sags of customers (permanent fault).

#### IV ASSESSMENT OF IMPACT OF SFCL ON VOLTAGE SAGS

If SFCL is installed at the starting point of feeder, (2) is changed to equation (3) during fault.

$$V_{bus} = \frac{Z_{SFCL} + Z_{line}}{Z_{source} + Z_{MTr} + Z_{SFCL} + Z_{line}} \quad (3)$$

The voltage sag is improved more than the case without SFCL. To evaluate the improvement of voltage sag, the radial and loop power distribution system is modeled and the various cases are studied.

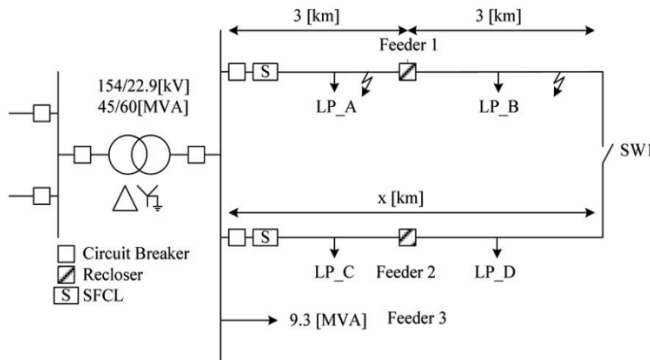


Fig. 3. Power distribution system model

TABLE II  
POWER DISTRIBUTION SYSTEM DATA

	Data
Source	154 kV, 100 MVA, $j4 \Omega$
M. Tr	154/22.9 kV, 45 MVA, $j15 \%$
Line impedance	$Z_0=10.8+j23.6 \%/km$
	$Z_1=3.48+j7.44 \%/km$
Line length	F1 : 3 km, 3 km
	F2 : x km (variable)
Load	F1 : LP_A=3 MVA, LP_B=4 MVA
	F2 : LP_C=5 MVA, LP_D=5 MVA
	F3 : 9.3 MVA

TABLE III  
CASES FOR VOLTAGE SAG SIMULATION

Cases	SFCL $\Omega$	Fault location	x km	Fault type	
SW1 open	Case1-0	No			
	Case1-1	0.5			
	Case1-2	1	1, 2, 3, 4,	6	
	Case1-3	1.5	5, 6 km		
	Case1-4	2			3phase fault
SW1 Closed	Case2-0	No			
	Case2-1	0.5			
	Case2-2	1	1, 3, 6 km	2, 4, 6	
	Case2-3	1.5			
	Case2-4	2			

#### A. Power Distribution System Model

Fig.3 represents the power distribution system model with SFCL and interconnecting switch to simulate voltage sags. Table II shows the data of Fig. 3.

#### B. Case Studies

Total 10 cases of contingency analysis are studied as shown in Table III. Case 1-x is for radial distribution system and Case 2-x is for loop distribution system. The resistance of SFCL ranges from 0 to  $2\Omega$  and the fault location is 1 to 6 km. The length of feeder 2 varies 1 to 6 km at loop distribution system.

#### V. MATLAB/SIMULINK RESULTS

Here the simulation is carried out by different cases they are 1) Radial distribution system Fault location without and with SFCL 2) loop distribution system Fault location without and with SFCL 3) radial distribution system Fault location without and with SFCL of R and RLC loading conditions 4) loop distribution system Fault location without and with SFCL of R and RLC loading conditions  
**Case-1 radial distribution system Fault location without and with SFCL**

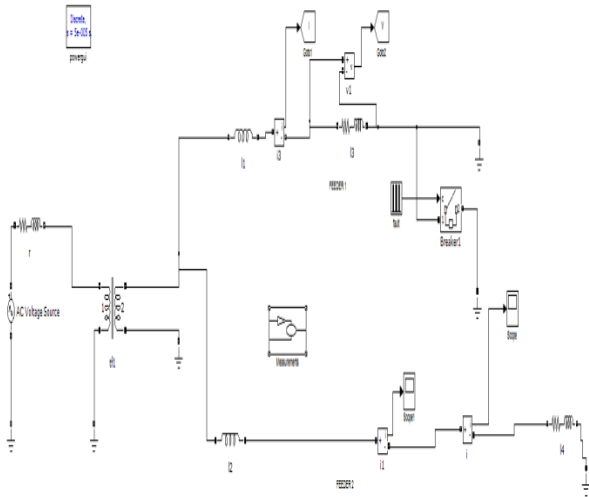


Fig.4 Matlab/simulink model of radial distribution system Fault at 3 km location without SFCL

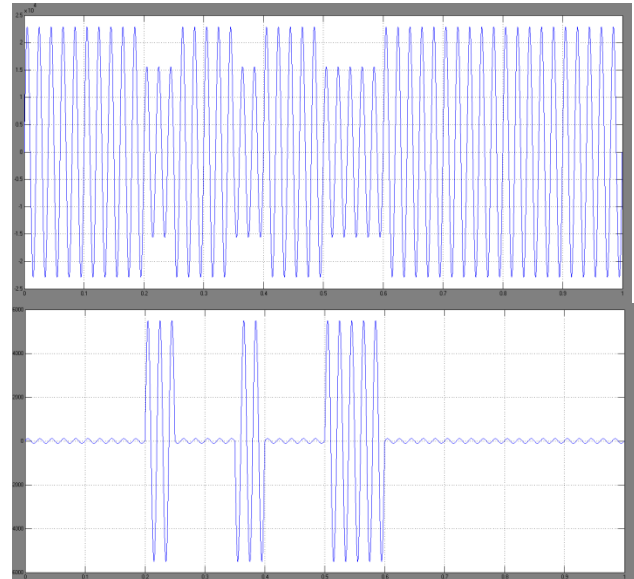


Fig. 7 Voltage and current wave in radial distribution system fault at 3 km location with SFCL

**Case-2 loop distribution system Fault location without and with SFCL**

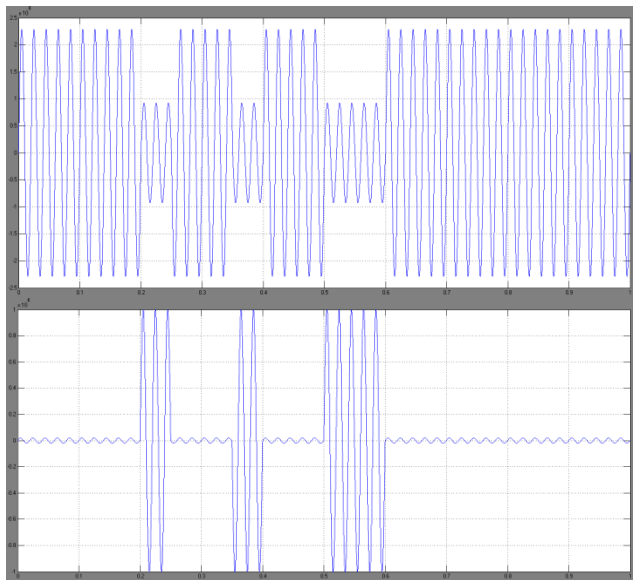


Fig.5 Voltage and current wave in radial distribution system Fault at 3 km location without SFCL

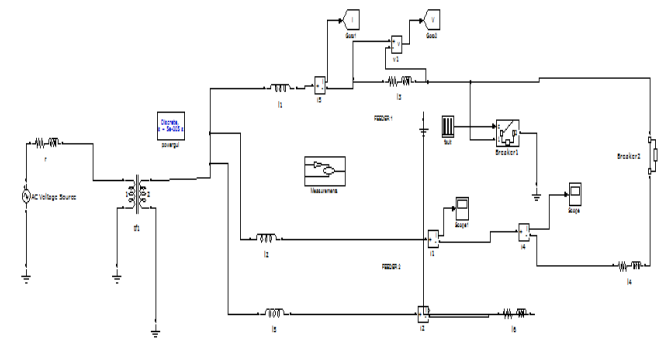


Fig.8 Matlab/simulink model of loop distribution system Fault location without SFCL

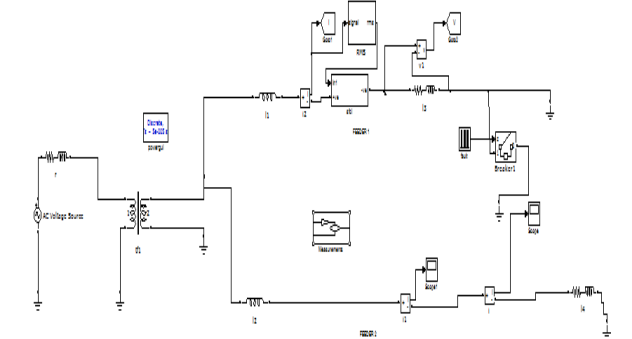
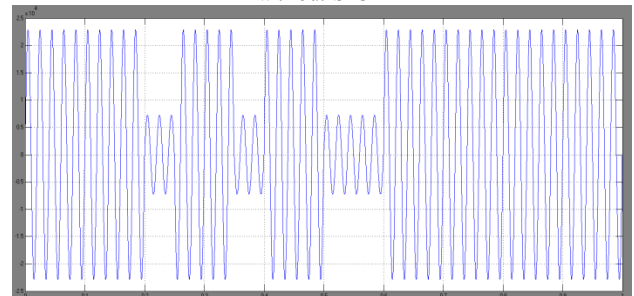


Fig.6 Matlab/simulink model of radial distribution system Fault at 3 km location with SFCL

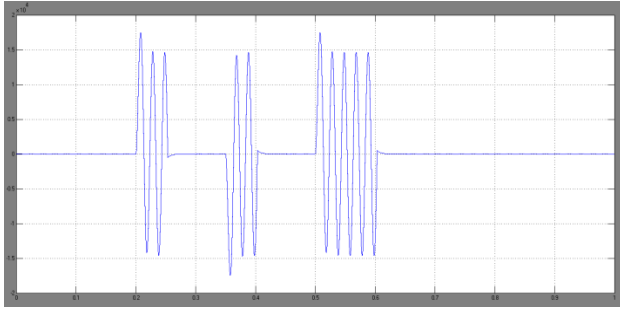


Fig.9 Voltage and current wave in loop distribution system Fault at 3 km location without SFCL

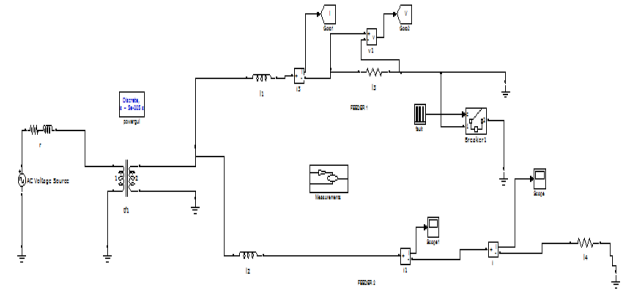


Fig.12 Matlab/simulink model of radial distribution system fault location without SFCL of R load

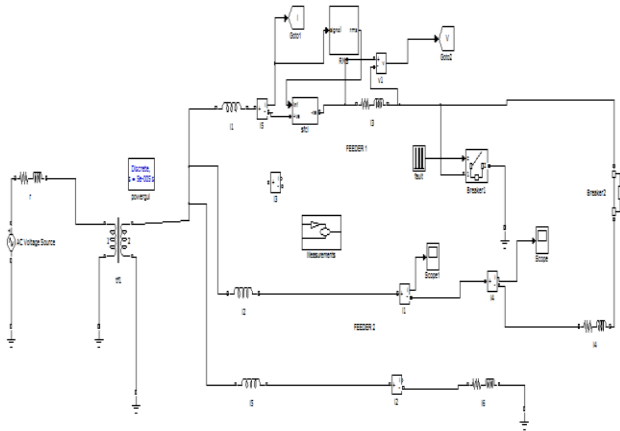


Fig.10 Matlab/simulink model of loop distribution system Fault location with SFCL

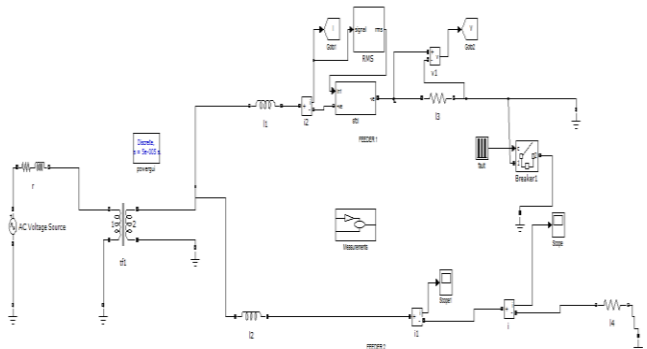


Fig.13 Matlab/simulink model of radial distribution system fault location with SFCL of R load

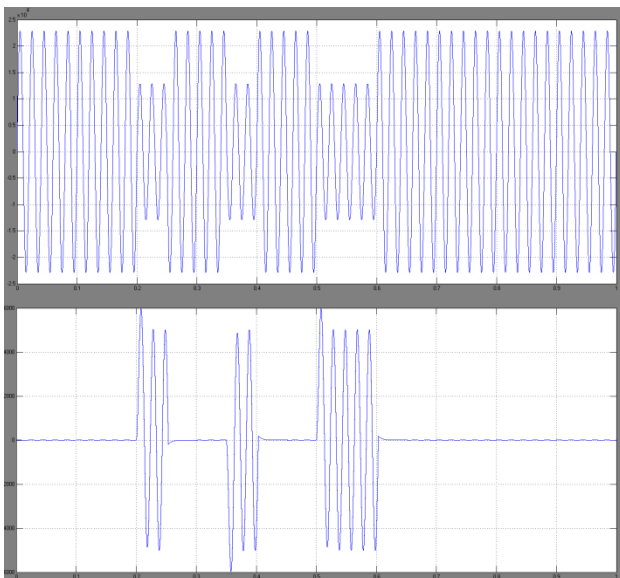


Fig. 11 Voltage and current wave in loop distribution system fault at 3 km location with SFCL

**Case-3 radial distribution system Fault location without and with SFCL of R load**

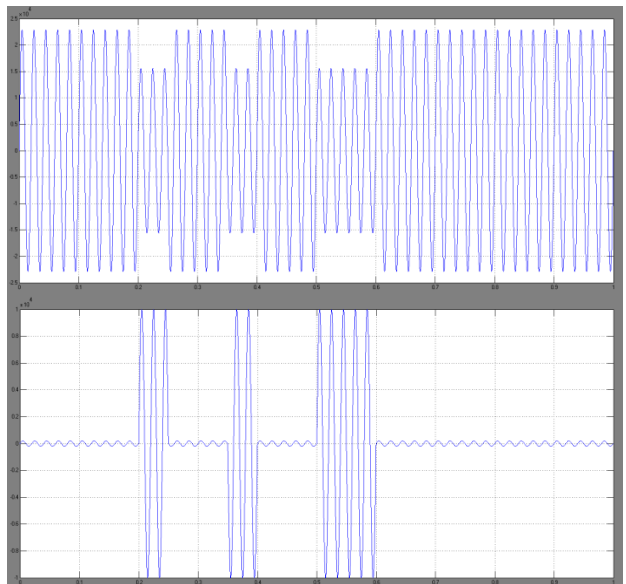


Fig. 14 Voltage and current wave in radial distribution system fault at 3 km location with SFCL of R load

**Case-4 loop distribution system Fault location without SFCL of R and RLC loading conditions**

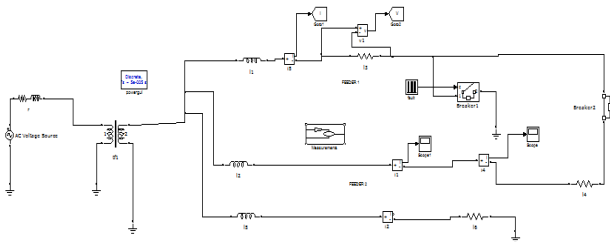


Fig.15 Matlab/simulink model of loop distribution system Fault location without SFCL of R load

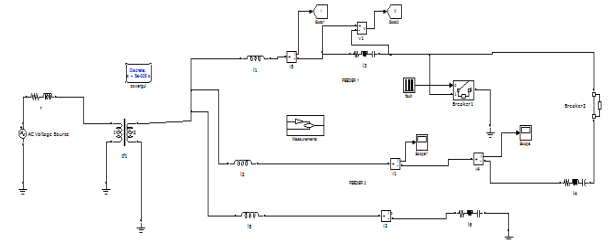


Fig.16 Matlab/simulink model of loop distribution system Fault location without SFCL of RLC load

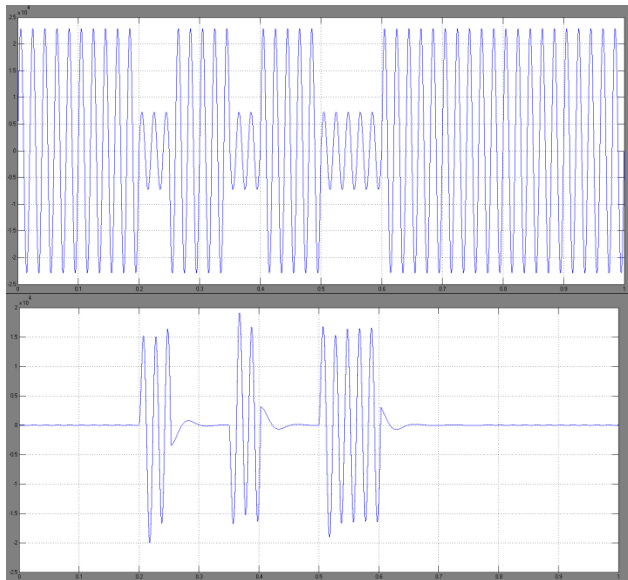


Fig.17 Voltage and current wave in loop distribution system Fault at 3 km location without SFCL of R and RLC loading conditions

## VI. CONCLUSION

The main concept of this proposed converter is simulated at different loading conditions like R and RLC to check the performance of with and without SFCL conditions. Interruptions to supply and sags of distribution system voltage are the main aspects causing customer complaints. There is a need for analysis of supply reliability and voltage sag to relate system performance with network structure and equipment design parameters. The effect of SFCL on voltage sag is analyzed when a SFCL is installed to a radial and loop power distribution system.

Firstly, resistor-type SFCL and radial/loop power distribution system are modeled. The simulation results found that the voltage sags at loop distribution system is more severe than radial distribution system by the increased fault current. The resistance of SFCL ranges from 0 to 2Ω and the fault location is 1 to 6 km. The length of feeder 2 varies 1 to 6 km at loop distribution system. Moreover, the results of simulation represent the SFCL with bigger resistance is needed to improve the voltage sags in loop system. These all results verified through Matlab/simulink software.

## REFERENCES

- [1] J.-F. Moon, S.-H. Lim, J.-C. Kim and S.-Y. Yun, "Assessment of the impact of SFCL on voltage sags in power distribution system," *IEEE Trans. Appl. Supercond.*, vol. 21, no. 3, pp. 2161–2164, Jun. 2011.
- [2] L. Ye, L. Z. Lin, and K.-P. Juengst, "Application studies of superconducting fault current limiters in electric power systems," *IEEE Trans. Appl. Supercond.*, vol. 12, no. 1, pp. 900–903, Mar. 2002.
- [3] J. C. Das, "Limitations of fault-current limiters for expansion of electrical distribution systems," *IEEE Trans. Ind. Appl.*, vol. 33, no. 4, pp. 1073–1082, Jul/Aug. 1997.
- [4] F. Tosato and S. Quiaia, "Reducing voltage sags through fault current limitation," *IEEE Trans. Power Del.*, vol. 16, no. 1, pp. 12–17, Jan. 2001.
- [5] H.-R. Kim, H.-S. Choi, H.-R. Lim, I.-S. Kim and O.-B. Hyun, "Resistance of superconducting fault current limiters based on YBa2Cu3O7 thin films after quench completion," *Phys. C, Supercond.* Vol. 372–376, pp. 1606–1609, Aug. 2002.
- [6] S. H. Lim, S. R. Lee, H. S. Choi, and B. S. Han, "Analysis of operational characteristics of flux-lock type SFCL combined with power compensator," *IEEE Trans. Appl. Supercond.*, vol. 15, no. 2, pp. 131–134, Jun. 2005.
- [7] H. R. Kim, S. W. Yim, S. Y. Oh, and O. B. Hyun, "Recovery in superconducting fault current limiters at low applied voltages," *IEEE Trans. Appl. Supercond.*, vol. 18, no. 2, pp. 656–659, Jun. 2008.
- [8] H.-R. Kim, S.-W. Yim, S.-Y. Oh, and O.-B. Hyun, "Analysis on recovery in Au/YBCO thin film meander lines," *Progr. Supercond.* vol. 9, no. 1, pp. 119–125, 2007.
- [9] J.-S. Kim, S.-H. Lim, J.-F. Moon et al., "Analysis on the protective coordination on neutral line of main transformer in power distribution substation with superconducting fault current limiter," *Trans. Korean Inst. Elect. Eng.*, vol. 58, no. 11, pp. 2089–2094, Nov. 2009.
- [10] H. R. Kim, S. W. Yim, O. B. Hyun et al., "Analysis on recovery characteristics of superconducting fault current limiters," in *Proc. MT-20 Conf. Magn. Technol.*, Philadelphia, PA, Aug. 27–31, 2007.



[11] J. Arrillaga, N. R. Watson, and S. Chen, Power System Quality Assessment. Chichester, U.K.: Wiley, 2000.

#### Author's Profile:



VALLALA BABU RAO M.TECH  
(ELECTRICAL POWER SYSTEMS)  
PURSUING In Laqshya Institute of  
Technology Sciences ,TANIKELLA(V)  
,KHAMMAM(D), TELANGANA,  
INDIA. EMail id: [baburao243@gmail.com](mailto:baburao243@gmail.com)



Mr. K NAVEEN was born in India in the year of 1991. He received B.Tech degree in Electrical and Electronics Engineering in the year of 2012 & M.Tech PG in Electrical power systems in the year of 2015 from JNTUH, Hyderabad. He is expert in Control Systems, Electrical

circuits, Power system and electrical machines Subjects. He is currently working as An Assistant Professor in EEE Department in Laqshya Institute of Technology and Sciences, Khammam, Telangana State ,India. Email id: [224naveen@gmail.com](mailto:224naveen@gmail.com)