Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings XX (2016) XXX–XXX

www.materialstoday.com/proceedings

PMME 2016

Optimum Placement of Fault Current Limiter in 11 kV Distribution System ☆

P Sridhar[a], V Purna Chandra Rao[b], B P Singh[a,b]*

[a]Department of Electrical and Electronics Engineering, Institute of Aeronautical Engineering, Hyderabad, INDIA
[b]Lords Institute of Technology and Science, Hyderabad, INDIA
[a,b]Department of Electrical and Electronics Engineering, (Rtd. GM, BHEL,) St. Martins Engineering College, Hyderabad, INDIA

Abstract

Presently a number of radial distribution systems are in operation supplying power to utilities. Due to rapid growth of loads in a distribution system and more network connections, high current flows in the event of short circuit faults in the system. In such cases, the relay co-ordination is disturbed and hence the equipment like circuit breakers needs to be replaced with enhanced ratings. So that relay can handle the new operating currents which are often expensive retrofit costs. In order to mitigate the consequences of huge fault currents in a system a Fault Current Limiter (FCL) is proposed and discussed in this paper. FCLs can be fixed in a power system to enable circuit breakers to operate within their operating range. This paper proposes the application of deterministic method of establishing the optimal placement of FCL in a distribution system. An IEEE 6 bus system has been considered for fault analysis and placement of FCL to reduce the impact of fault.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: Fault Current Limiter; IEEE 6 bus system; Optimum location; Distribution system

---

* Corresponding author. Tel.: 99487 50050; fax: +0-000-000-0000 .
E-mail address: Sridharp35@gmail.com

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

1. Introduction

Expeditious development of the power system network has caused the fault levels of the system to increase accordingly. Levels of fault currents in many situations have increased more than the withstand capability of the existing distribution system apparatus. Several connected lines / feeders and loads not only increase the fault current but also increase the rated continuous operating current level of circuit breaker. It causes issues related to stability, reliability, security of power system dynamics. These parameters have negative effect on the system performance. The fault current can be restricted to an acceptable value and hence the voltage dips at PCC of the power system network with effective placement of FCL [1, 2, 3].

The common Power Quality (PQ) issues today are harmonic distortions, low power factor, voltage sags. Voltage sags/dips are the most crucial power quality concern, caused by a fault within the customers' facility or a utility system with a high commercial loss. Thus it causes disturbance to the end user. The utilization of power semiconductor technology (FACTS) has been introduced for enhancing power system dynamics with versatile advanced control methods in transmission / distribution networks [4]. The main demerits of FACTS devices are more expensive to provide smooth outcome, large size and more complex to implement. Implementation of this simple technology discussed is this work is the utilization of principle of FCL. Performance evaluation of power system transient stability improvement with a reliable operation, maximization of the power transfer capability of the power system network while using FCL operating under current and or voltage controlled mode have been discussed in literature [5, 6, 7]. Several topologies are introduced and examined for applicability. It is observed that a single switch voltage controlled FCL has ideal characteristics as listed as follows:

- Normal power loss as FCL offers Zero/Low Impedance in the normal operating region
- Recovery speed is very high hence fast appearance of impedance in a faulty section
- Controllability of FCL is quite good and is well coordinated with the existing protection devices, in terms of timing the current magnitude
- FCL provides economical alternatives to costly upgrades of the conductors and protection devices on a system or distribution power
- Compact in size

Normally, FCLs are employed in the power system network where interrupting devices are not capable of interrupting the fault current at the earliest. The placement of FCL has certain advantages in the system. These are

- Probability of increasing the distribution sources
- Improvement in power capability of the system
- Mitigating the sags at PCC in a system
- Improving the system stability and
- Improving the system reliability and security.

In radial power systems, the placement of FCL is not difficult, but in loop power system, FCL placement becomes much more complex when more than one location that has high fault current problems is involved. In such a system, short-circuit currents could come from many directions and are not easily blocked by a single FCL. Therefore, from distribution system operation and planning point of view, a technique that can choose optimum number and locations for FCL placement becomes necessary. For this purpose, rectifier-type superconducting FCL models are included in short circuit current analysis and a method to find FCL locations suitable for short-circuit current reduction is proposed.

2. Network Simulation and Data preparation

In order to obtain location for FCL placement, an algorithm is developed and is used in association with Electro Magnetic Transient Program (EMTP). The basic structure of FCL is as shown in Fig.1. L_{sh} and R_{sh} is the shunt branch elements, D1 to D4 are the diodes, D5 is a freewheeling diode. L_{dc} and R_{dc} are the DC reactor impedance and IGBT switch.

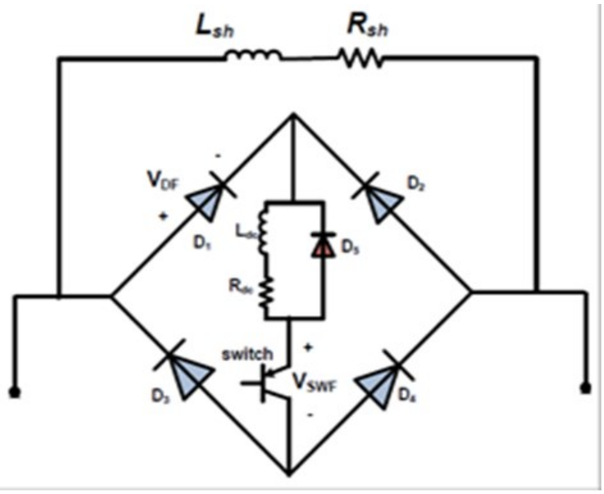

Fig.1 Schematic Diagram of FCL structure

An IEEE 6 bus system is modelled in EMTP software. The IEEE 6 bus system considered in this work is as shown in figure 2. The generators are modelled with its sub transient reactance. The faults are simulated at various buses with ground resistance. The fault currents and associated bus voltages are recorded for further analysis. To reduce the consequences of short circuit faults in the distribution system, FCL is intended to place at appropriate locations. The FCL can be added in the system like an element to the existing power system network. The fault analysis is carried out by keeping FCL in lines of the network sequentially. The fault is assumed to be asymmetrical. The change in currents after the placement of FCL is calculated. The optimum placement of location for placement of FCL is necessary to make the system simple and cost effective.

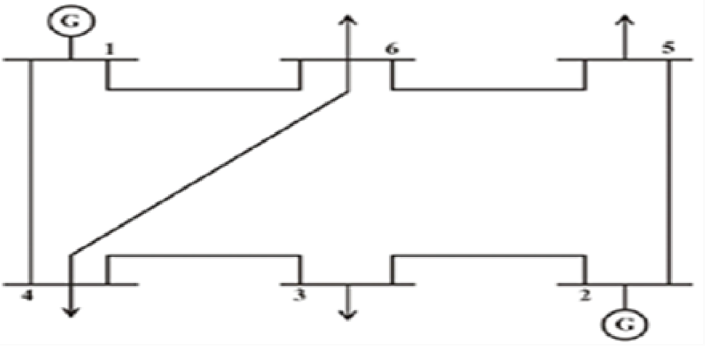

Figure 2 IEEE 6 bus system

3. OPTIMAL PLACEMENT OF FCL IN IEEE 6 BUS SYSTEM

In the present work, the Impedance matrix is formed by using the building algorithm. As a case study, single line to ground fault is assumed and the fault analysis is carried out. The faults are simulated at different buses in the considered system. From the fault analysis, it is observed that the fault current increased beyond the rated continuous capacity of circuit breaker and that current must be brought to lower level by using a suitable device. In the present case, the FCL have been used as shown in Fig. 1. In the analysis, the variations in the currents before and after the occurrence of the fault are determined. The analysis is done in three ways.

- Fault analysis without fault and without FCL i.e. healthy behaviour of the system
- Fault analysis with fault and without FCL
- Fault analysis with fault and with FCL

The flow chart for determining the appropriate placement of FCL is given in Fig.3.

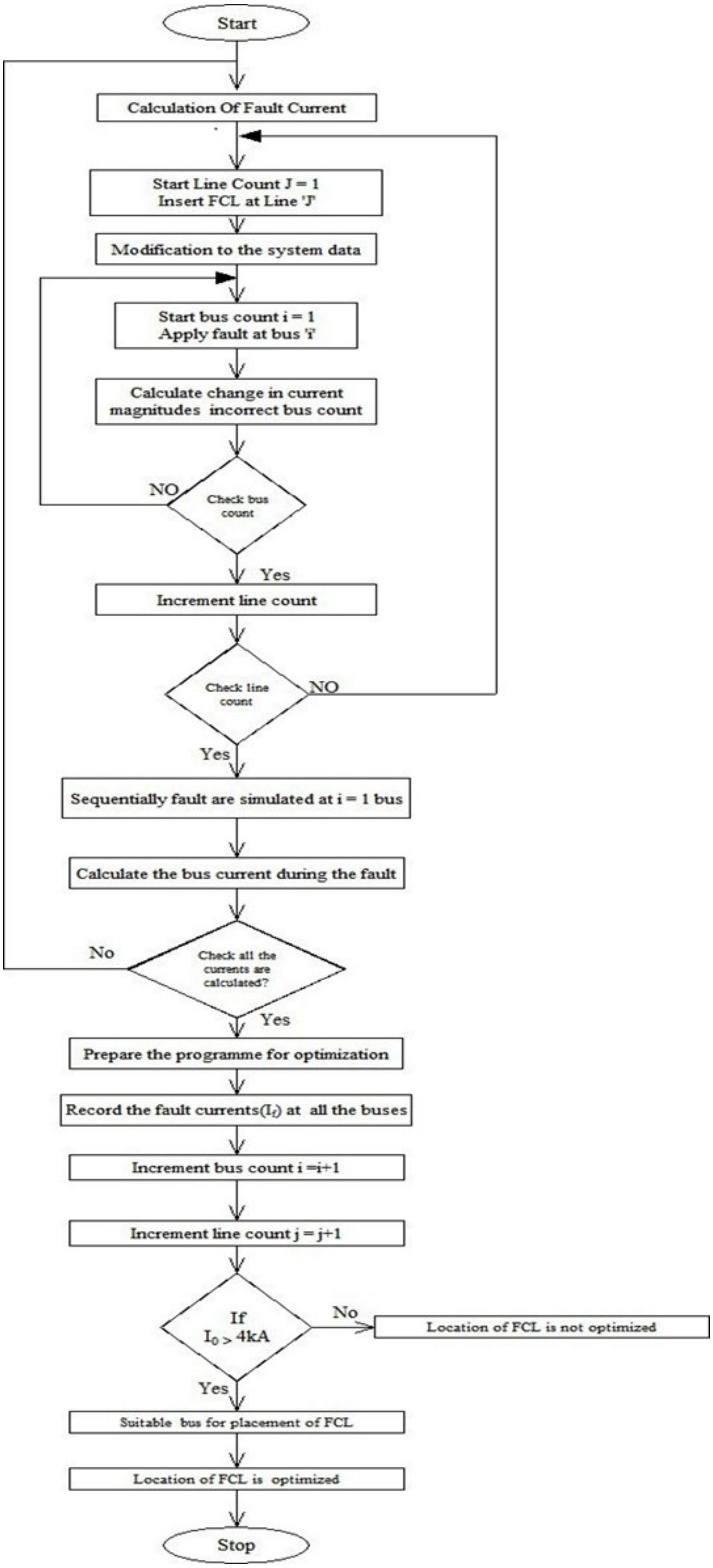

Figure 3 Algorithm for optimal placement of FCL

4. Results and Discussions

The impact of the FCL is analyzed after insertion it into the system during fault conditions. FCL is placed at each line. Fault current deviation after inserting FCL is calculated. Optimal location of FCL can be found out using developed algorithm. The data pertaining to distribution system parameters, switches, FCL locations etc. are entered in EMTP software. The maximum rating of 11kV circuit breaker is assumed as per available data sheet from manufacturer. The maximum rating of 11 kV SF6 or vaccum circuit breaker is assumed to be 4000 amps as allowable rated continuous current. Firstly, the faults are simulated at various buses in the network of IEEE 6 bus system. The magnitudes of fault currents are as shown in Table 1.

Table 1: Fault currents at different buses without FCL

Fault Bus No	**Magnitudes of Fault currents (Amps)**					
	I1	**I2**	**I3**	**I4**	**I5**	**I6**
1	16730	7105	5.123	3.995	5.123	3.995
2	7105	7088	3.995	5.123	3.995	5.123
3	6684	8824	15470	4.969	5.656	5.668
4	10060	7618	4.473	17640	5.267	4.456
5	6684	8824	5.656	5.668	15470	4.969
6	10060	7618	5.267	4.456	4.473	17640

As seen in Table 1, the fault currents at bus 1 & 2 are large in amplitude. These faults currents are relatively very huge as compared to the allowable continuous current rating of a typical 11 kV circuit breaker. The fault currents approximately vary from 2 to 4 times the circuit breaker capacity. Due to these fault currents, there appears voltage sags at PCC in the network. If these voltage sags persists in the system at PCC for a considerable duration, the faults may be permanent in the nature.

Table 2: Fault currents at different buses with single FCL

Fault Position	**FCL Locations**	**Magnitudes of Fault currents (Amps)**					
		I1	**I2**	**I3**	**I4**	**I5**	**I6**
Bus-1	1	33.98	7159	5.059	3.929	5.059	3.929
	2	16870	33.95	2.821	2.871	2.821	2.817
	3	16730	7105	4.396	3.995	5.123	3.995
	4	16730	7105	5.123	3.428	5.123	3.995
	5	16730	7105	5.123	3.995	4.396	3.995
	6	16730	7105	5.123	3.995	5.123	3.428
Bus-3	1	28.67	9974	9992	3.481	4.591	3.924
	2	7824	29.71	7840	4.564	4.214	4.918
	3	6684	8824	15470	4.969	5.656	5.668
	4	6684	8824	15470	4.263	5.656	5.668
	5	6684	8823	15470	4.969	4.853	5.668
	6	6684	8824	15470	4.969	5.656	4.863
Bus-6	1	31.68	8342	4.679	3.557	4.304	8361
	2	10810	31.07	3.534	3.771	3.059	10830
	3	10060	7618	4.519	4.456	4.473	17640
	4	10060	7618	5.267	3.824	4.473	17640
	5	10060	7618	5.267	4.456	3.838	17640
	6	28.02	25.46	8.284	8.283	8.283	34.24

In such cases, the connected load is to be disconnected from the system by operating the suitable interrupting devices like CBs. The operating time of CB is half cycle to one cycle. This duration is relatively high. During this time, sags may appear and may cause the connected sensitive apparatus to mal operate. During this transient time period, sensitive equipment must have to be isolated from a portion of network. However, it will depend on the type and severity of the fault. The duration of the fault persistence on the network also plays vital role. Hence, a device is required to minimize the interruption time and mitigate the voltage sag at PCC. These can be achieved by connecting FCL at an appropriate location in the network. The semiconductor type FCLs are positioned at different buses. The respective fault current magnitudes are shown in Table 2.

Table 2 shows that with FCL at bus 1, the fault current at bus 2 is larger than the CB continuous current capacity. If the fault is simulated at bus 6 and FCL is placed at bus 6. Current in bus 6 is low; however the other bus currents are larger than the existing limit. Based on such results, an algorithm has been developed for optimal location. From the result, it is observed that a single FCL is not sufficient to limit the fault current at all the buses and in all the lines.

To mitigate the voltage sag, it is decided to place two FLCs instead of single FLC. The typical results are shown in Table 3. If, FLCs are placed bus 1 & 3 and the fault is simulated at bus 2. The resultant fault currents are not in the acceptable limit.

Table 3: Fault currents at different buses with FCLs at bus 1 & 3

Fault locations	**Fault Currents**					
Bus No.	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**
Bus 2	7158	7143	3.929	5.059	3.372	5.059

Similarly, FCLs are placed at two buses i.e. at bus 1 & 2 and the results of fault currents are given in Table 4. The currents are within acceptable limits.

Table 4: Fault currents at different buses with FCLs at bus 1 & 2

Fault locations	**Fault Currents**					
Bus No.	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**
1	34.26	34.19	2.504	2.5	2.504	2.5
2	34.19	28	2.5	2.504	2.5	2.504
3	34.18	34.2	63.28	2.504	2.506	2.506
4	34.22	34.19	2.502	63.32	2.504	2.501
5	34.18	34.2	2.506	2.506	63.28	2.504
6	34.22	34.19	2.504	2.501	2.502	63.32

With the above results, it is found that the bus current limit exceeds the desirable level in the case of single FCL mode and even in multiple placement modes until a suitable combination is achieved. Software is developed to automatically identify the optimum placement of FCL. On the basis of the output, it is found that optimum location of FCL is at BUS 1 and BUS 2 as depicted by the optimization program. It is generalized to be applicable for any number of bus systems.

Conclusions

The location of FLC is very important for successful operation of distribution system. The location of FLC is necessary to reduce the fault current more effectively by a limiter in the network. The recorded fault currents at all the buses are compared with the limiting rated continuous current level of CB. If the fault current at any bus is greater than the threshold value, FCL is required. A deterministic method of optimization is proposed in this paper to identify the location. In IEEE 6 bus loop system, single FCL is not sufficient to limit the fault current and hence the voltage sags. The result shows two FCLs are suitable to optimize the location. MATLAB is used to calculate the fault currents with and without FCL. EMTP is used in consultation with specially developed software for optimal location of FCL. A computer based program is developed for this purpose yields the combination of FCL location for desired result.

Acknowledgements

The authors would like to acknowledge the support of the Management, Principal and staff of Institute of Aeronautical Engineering and St. Martins Engineering College, Hyderabad in successful completion of this paper.

References

[1]. P. Sridhar, Dr. V Purna Chandra Rao and Dr. B P Singh, "Mitigation of fault in 5 bus system with switch type voltage controlled FCL", Lecture notes in Electrical Engineering, Springer Publications, Pg. No. 291-304, December 2016.

[2]. P. Sridhar, Dr. V Purna Chandra Rao and Dr. B P Singh, "Integration of Unique Switch Type Fault Current Limiter to mitigate the Power Quality problems in Distribution system", International Conference on Smart Structures and Systems (ICSSS), IEEE - 2014, Pg. No. 75 - 80.

[3].P. Sridhar, Dr. V Purna Chandra Rao and Dr. B P Singh, "Mitigation of Multiple Fault Conditions using Unique Switch Type Voltage Controlled FCL" 2015 Conference on Power, Control, Communication and Computational Technologies for Sustainable Growth (PCCCTSG), IEEE- 2015.

[4]. Steven M. Blair, Campbell D. Booth, Nand K. Singh, and Graeme M. Burt, "Analysis of Energy Dissipation in Resistive Superconducting Fault-Current Limiters for Optimal Power System Performance," IEEE Trans. Appl. Supercond , vol. 21, no. 4, August 2011.

[5].M. Brenna, R. Faranda, and E. Tironi, "A new proposal for power quality and custom power improvement: Open UPQC," IEEE Trans. Power Del., vol. 24, no. 4, pp. 2107–2116, Oct. 2009.

[6]. W. M. Fei, Y. Zhang, and Z. Lü, "Novel bridge-type FCL based on self-turnoff devices for three-phase power systems," IEEE Trans. Power Del., vol. 23, no. 4, pp. 2068–2078, Oct. 2008.

[7]. E. Babaei, M. F. Kangarlu, and M. Sabahi, "Mitigation of voltage disturbances using dynamic voltage restorer based on direct converters," IEEE Trans. Power Del., vol. 25, no. 4, pp. 2676–2683, Oct. 2010.

[8]. Diju R Arikkat and Dr.P. Reji, "Location Optimization of Fault Current Limiter", Proceedings of International Conference on Materials for the Future - Innovative Materials, Processes, Products and Applications – ICMF 2013, Pp No: 484-487