Optimization for Placement of FCL in Distribution System by Voltage Controlled Method

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Abstract: 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 enhanced in ratings perspective. So the relay can handle the new operating currents which are often expensive retrofit costs. The line impedance is kept normally low to accommodate more number of loads and distributed generator (DG) units to the existing system. This configuration allows very huge current in the system whenever short circuit takes place. Hence to limit such currents, a technique is required to adopt. The fault current can be reduced to acceptable value in coordination with existing protection system by fault current limiter. In this paper, the operation of Fault Current Limiter (FCL) with voltage sensing scheme is discussed to place it in a typical distribution system to place FCL is very important in connection with the system complexity. Separate program is developed in Electromagnetic Transient Program (EMTP) to place FCL more optimally. An IEEE 6 bus system has been considered for fault analysis and placement of FCL to reduce the impact of fault.

Keywords: Fault Current Limiter, IEEE 6 bus system, Optimum location, PCC Voltage, Distribution system.

Introduction

In many cases, during fault, levels of fault currents increases beyond the withstand capabilities of the protecting apparatus in distribution systems. The short circuit faults are main causes for voltage sags in the system. Voltage quality is one of the major issues observed and the consequences of such, especially in distribution systems cannot be ignored. Voltage sags depends on short circuit current and are proportional to them. So, an effective approach to mitigate voltage sags and hence voltage quality, is limiting the fault current in the feeder connected to common bus bar. 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 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 system performance. The fault current can be restricted to an acceptable value and hence the voltage dips at Point of Common Coupling (PCC) of the power system network with effective placement of FCL [1] – [3].

The voltage sags are recorded at PCC of the network. A typical calculation of PCC is given in equation (1)

$$V_{sag} = \frac{Z_F}{Z_s + Z_F} \qquad (1)$$

Where, Z_s= Source impedance at PCC and Z_F= Impedance between PCC and fault point.

The limitations of FACTS devices are [4]: more expensive to provide smooth outcome, large size devices and more complex to implement. Implementation of a simple technology preferred in this work as, 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. Several topologies [5],[6],[7] are introduced in literatures. Moreover, 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

1. Probability of increasing the distribution sources;
2. Improvement in power capability of the system;
3. Mitigating the sags at PCC in a system;
4. Improving the system stability and
5. Improving the system reliability and security

The fault current can be limited by placing a FCL in the most exposed feeder and hence sag magnitude brought to the accepted range of voltage. The fault current limiter works in coordination with the existing protection devices like CB, relay and other components in the protection system. The semiconductor bridge type of FCL configuration is depicted in Fig.1. It consists of two paths via (a) DC route consists of diodes R_{dc} and dc reacting L_{dc} so IGBT during positive cycle of supply D1 and D3 conducts and D2 and D4 provides a path in negative half cycle of source voltage. (b) Shunt branch consists of L_{sh} and R_{sh}. The basic structure of FCL is as shown in Fig.1.

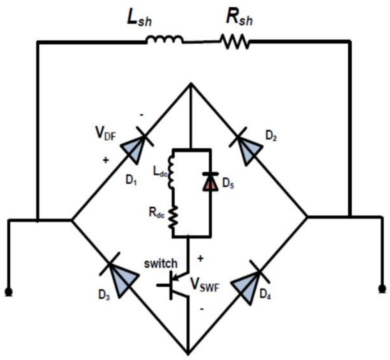

Figure 1. Schematic Diagram of FCL structure

The IGBT in dc path will conduct during healthy operation of system i.e. no-fault conditions. It will remain off whenever it observers the abnormalities in the system i.e. sudden variation in voltage across or current through the bridge. Based on such deviation in certain quantities, the IGBT can be operated in two methods

1 Voltage controlled and
2 Current controlled method

In the present work, the voltage controlled method is used to operate FCL. In this method the IGBT will be triggered based on the voltage magnitudes. The triggering pulses are generates by comparing the voltages during normal and fault conditions. The sensing scheme with the help of relational operation is explained in Fig 2. In this voltage sensing scheme the RMS values are compared to change the states of IGBT switch.

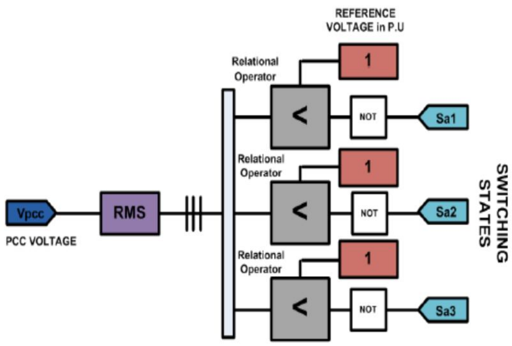

Figure 2. Generation of Switching states by using voltage sensing scheme

The placement of FCL is also important to control the consequences of SC faults at the earliest in the distribution systems. 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 have high fault current problems. 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 became 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 was proposed.

Network Simulation and Data preparation

In order to obtain location for FCL placement, an algorithm is developed and programmed by using Electro Magnetic Transient Program (EMTP).

An IEEE 6 bus system is modeled in EMTP software. The IEEE 6 bus system considered in this work is as shown in Fig.3. The generators are modeled 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. Fig.4 shows the flow chart of location optimization. The optimum placement of location for placement of FCL is necessary to make the system simple and cost effective.

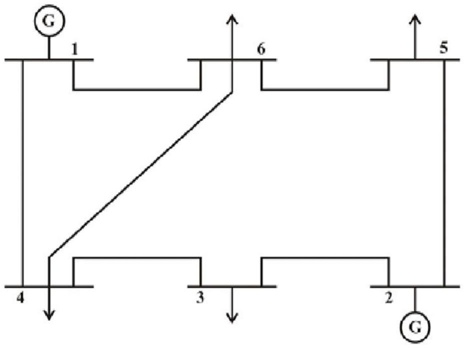

Fig.3. IEEE 6 bus system

Optimal Placement Of FCL in IEEE 6 Bus System

In this work, IEEE 6 bus distribution network is considered for optimal location of FCL as discussed above. 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 normal 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.

a) Fault analysis without fault and without FCL i.e. healthy behaviour of the system
b) Fault analysis with fault and without FCL
c) Fault analysis with fault and with FCL

The flow chart for determining the appropriate placement of FCL is given in Fig.4.

Results and Discussions

The impact of the FCL is analysed after insertion it into the system during fault conditions. FCL is placed at each line. Fault current deviation after inserting FCL is calculated. It is also essential to identify the optimal location of placement in the system. 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 circuit breaker can be assumed as per available data sheet from manufacturers of 11 kV circuit breaker. The rating of 11 kV SF6 or vaccum circuit breaker is assumed to be 4000 amps maximum allowable for circuit breaker. 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.

As seen in Table 1, since bus 1 & 2 are the fault currents at these buses are large in amplitude. These faults currents are relatively very large as compared to 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, such faults may be permanent in the nature. This causes the connected network to be isolated for maintenance or restoration.

Table 1: Fault currents at different buses without FCL

Fault Bus No	Magnitudes of Fault currents					
	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

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 time lag is large in magnitude. 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 busses. The respective fault current magnitudes are as shown in Table 2.

From the Table 2, it is clear that by placing FCL at bus 1, the fault current at bus 2 is larger than the CB capacity. If the fault is simulated at bus 6 and FCL is placed at bus 6, all the bus currents are within the acceptable limits where as other bus currents are larger than the existing limit. Based on such results, it is difficult to develop an algorithm to identify the optimal location. Therefore, the 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 FCLs instead of single FCL. The typical results are shown in Table 3. In the Table 3, FCLs are placed bus 1 and 3 and the fault is simulated at bus 2. The resultant fault currents are not in the acceptable limit.

Table 2: Fault currents at different buses with single FCL

Fault Position	FCL Locations	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

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

Figure 4. Algorithm for optimal placement of FCL

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

Since, the bus current limit exceeds the desirable level in the case of single FCL mode and even in multiple placement mode 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.

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

Conclusion

The location of FCL is very important to simplify the system. The location of FCL is necessary to reduce the fault current more effectively by a limiter, FCL 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 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 for optimal location of FCL. A computer based program is developed for this purpose yields the combination of FCL location for desired result.

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.