Protection Coordination of Over Current Relays in Distribution System with DG and Superconducting Fault Current Limiter

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Abstract— **This paper proposes the use of Superconducting fault current limiter (SFCL), in conjunction with directional over current relays (OCRs) to solve the protection coordination problem in distribution systems equipped with distributed Generator (DG). The SFCL size and optimal directional OCR settings are determined in the grid connected mode. The proposed approach is tested on the IEEE 34 node distribution system in which 26 OCRs are placed. On the occurrence of fault, level of fault current changes which in turn changes the operating time of various OCRs. Therefore, it is important to calculate and suggest method of the relay setting in order to minimize the operating time of relays and also to avoid the mal-operation. SFCL reduces the magnitude of short circuit current on the occurrence of fault and ultimately retains the coordination among various directional over current relays.**

Keywords—Distributed Generator(DG); Over current relays (OCRs); Superconducting Fault current limiter (SFCL), Grid connected mode, Microgrid.

I. INTRODUCTION

Due to rapid growth in load demand, conventional generation units are unable to meet the energy demand and new trends of generating electricity at distribution level by using non-conventional energy resources like wind energy, solar energy, biomass etc. is being introduced. Incorporation of these resources into the distribution network has helped the utility in tackling the power crisis problem. This is known as distributed generation (DG) and resources used for it is known as distributed energy resources (DERs). Due to integration of DG in the utility, several problems which were not present in the traditional grid system arises and among those protection coordination is one of the major issue. The most widely used form of protection in power system is over current protection. Every relay in the power system should be coordinated with another relays protecting the adjacent equipment. If the primary is not able to clear the fault, the backup protection initiates its operation. If relays are not properly coordinated, mal-operation may occur. Thus over-current protection is one of the major concern in power system protection [1].

A strong protection system should be capable enough to isolate minimum part of the power system on the occurrence of fault, in order to avoid the unnecessary interruption of power to areas unaffected by the faults. In the conventional distribution system, power flow is unidirectional i.e. from substation towards the load [2]. The integration of DG to the conventional distribution system has increased the complexity of protection coordination problem. The main changes due to DGs are bidirectional power flow, change in short circuit current level and therefore the existing coordination schemes may not be able to perform its coordination function correctly [3]. The majority of protection schemes used in modern power system are based upon the short circuit current sensing capability [4], [5]. The main protection issues associated with the introduction of DERs to the distribution network includes Blinding of Protection, false sympathetic tripping, reclosure-fuse mis-coordination, lapse of inter fuse coordination and failed auto-reclosing [6], [7].

Superconducting Fault Current Limiters (SFCLs) can be applied to reduce the fault current in a microgrid due to its faster response time to reduce the fault current using its quench properties. Apart from its quench property it also enhances the transient stability of the power system [8]. SFCLs are series connecting devices, which are invisible to the system during normal operation but reduce the short circuit current under faulty condition. Protection coordination of such systems can be achieved by optimally setting the directional over current relay in conjunction with SFCL which is in series with each DG. For mitigating the effect of DGs and fault on protection coordination, fault current limiters have been proposed in conjunction of each DGs and protection coordination of a looped distribution system is achieved by optimally setting directional over current relays [9], [10]. The insertion of SFCL affects the system admittance matrix, which will affect the magnitude of the short circuit current. This will influence the values of Time Delay Setting (TDS) and Pick-up current (I_p), which is required to achieve the relay coordination. Hence it can be observed that the relay operating time response is a function of impedance offered by SFCL.

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II. IMPACT OF DG ON COORDINATION OF OVERCURRENT RELAYS

Microgrids connected to the distribution system include several DG sources; this causes the increase in short circuit capacity. Moreover, due to the limited current rating of silicon devices, the fault current of electronically interfaced DGs must be limited to a maximum of about two times their nominal current [11]. Thus the traditional over-current protection technique remains no longer applicable for the islanded converter-based microgrids [12]. The major protection issues associated with the introduction of distributed generation (DG) to a distribution network includes blinding of protection and false/sympathetic tripping.

A. Blinding of Protection

The fault current in distribution systems observed by an over current relay is lower by an amount negatively contributed by DG connected to the system. The reduction in current results in malfunction of overcurrent relays [13]. This situation may arise when DERs are connected anywhere between the feeding substation and fault location. Due to the contribution of the DER(s), the fault current measured by the feeder relay, which is normally located at the start of the feeder, decreases as compared to the situation when no DER is connected to the network. This may result in malfunction operation of the relay in order to detect the faults.

B. False/Sympathetic tripping

This tripping refers to a situation in which tripping occurring due to fault outside the zone of protection for a feeder embedded with DER. In this case, the DERs contribute to the fault via its feeder, and the fault current flows upwards on the feeder. Thus, the non-directional relay of the healthy feeder may falsely detect a fault and may isolate the feeder, which is undesirable. The higher the short-circuit capacity; more is its effect on relay performance [14]. *Fig. 1* shows that for a fault F_1 circuit breaker CB_3 should operate but due to contribution of current I_{DG} from DG, circuit breaker CB_4 will operate which may lead towards unnecessary interruption of healthy feeders.

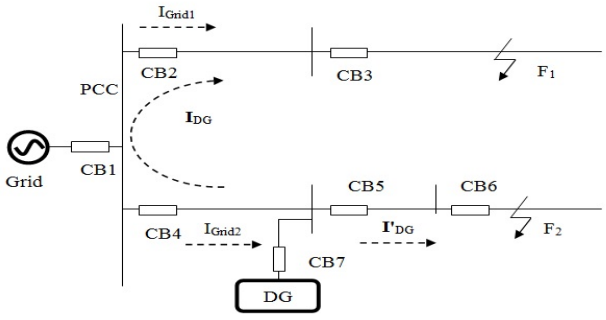


Fig. 1. Maloperation of Relays at different fault location

III. PROBLEM FORMULATION FOR PROTECTION COORDINATION OF OCR

The operating time of an OCR is inversely proportional to the short circuit current passing through it. The two parameters involved in the operating characteristics are relay pick-up current (I_p) and time delay setting (TMS).

$$t = A \frac{TDS}{\left(\frac{Isc}{Ip}\right)^{B} - 1} \quad (1)$$

where I_{sc} is the short circuit current. The value of A and B depends upon the type of OCR. In this paper it is assumed that inverse definite OCRs are used and thus the values of A and B are taken to be 0.14 and 0.02 respectively [15], [16]. Therefore, the operating time of OCRs can be expressed as shown in equation 2.

$$t = A \frac{TDS}{(PSM)^{B} - 1} \quad (2)$$

where, PSM is known as plug setting multiplier which can be determined for a known configuration after calculating the values of I_{sc} and I_p. The objective function denoted by T is the summation of coordination times of all relays, which is to be minimised and is expressed as following:

$$\min T = \sum_{i=1}^{m} t_{i,i} \quad (3)$$

where, t_{ii} indicates the operating time of primary relay i, for near end fault. Therefore equation 2 becomes,

$$t = C\,(TDS) \quad (4)$$

$$\text{where, } C = \frac{A}{(PSM)^{B} - 1} \quad (5)$$

Therefore equation 3 becomes,

$$\min T = \sum_{i=1}^{m} C_i\,(TDS)_i \quad (6)$$

where, C_i is the constant and for i_{th} relay whose value for different fault location is to be determined. The main objective is to calculate the value of $(TDS)_i$. The calculation of fault current and TDS is presented in "Section V" of this paper.

IV. SYSTEM DETAILS AND SIMULATION SETUP

A. IEEE 34 Node Test System

In this paper, IEEE 34 node test bed, which is taken as distribution network for studying the effect of DG on coordination of overcurrent relay is described. All the line and load data has been taken keeping Indian distribution system voltage level in mind. Simulation of the given system is done in SimPowerSystem of MATLAB software. The supply voltage source is of 66 kV to the distribution network which is further stepped down to 33 kV, 11 kV and 410 V according to the requirement of local consumers. Over current relay is employed at each node as shown in *"Fig. 2"*.

In this system twenty six relays are connected, as on the remaining part due to no load condition the values of current are very small even under the influence of fault and in presence of DG. Three phase fault is introduced in the system to study the effect of fault on coordination of overcurrent relay i.e. Blinding of Protection and False/Sympathetic Tripping. All the studies as mentioned above, related to the coordination problem of the over current relay are performed by connecting the DG at node 864 and introducing fault at node 842 and 810 separately. one of the important parameter on which the level of short circuit current depends is the penetration level of DG, which is assumed to be fixed in all related studies. The results obtained are justified, as the time of operation of OCRs decreases with the increase in level of fault current.

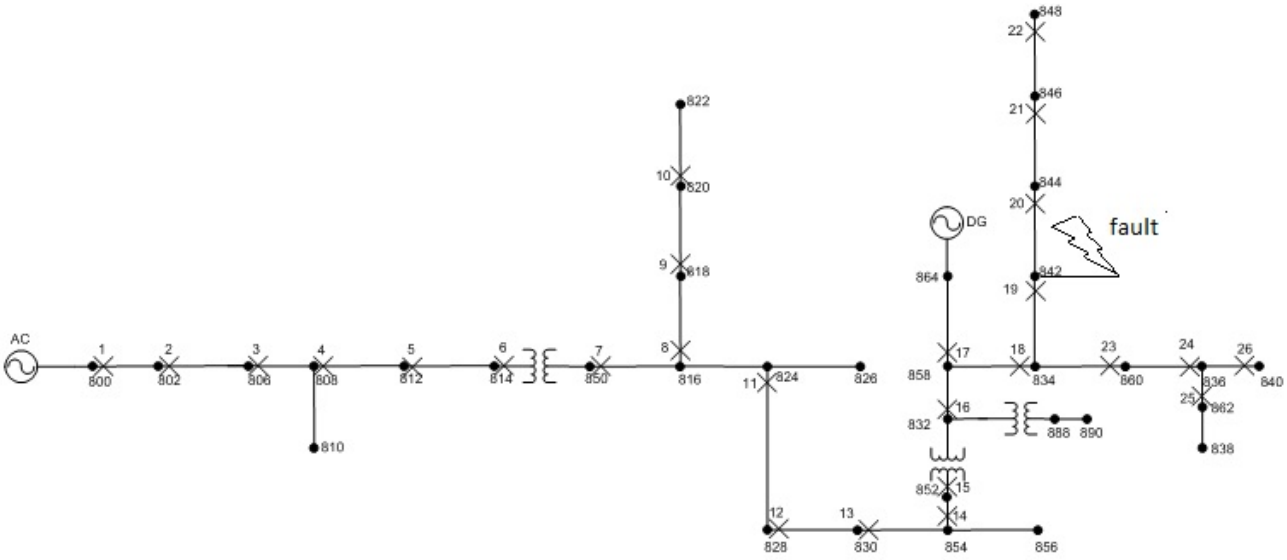


Fig. 2. IEEE-34 node test system

B. *Superconducting Fault Current Limiter (SFCL)*

SFCL is an electrical device with the property to reduce the fault current in the first cycle of fault current. Its current limiting features depend on the nonlinear reaction of SFCL to temperature, current and magnetic field variation. Change in any of the three parameters may cause a transition between the superconducting and the normal conducting characteristics. The increased current can cause a part of superconductor to become highly resistive such that the heat generated cannot be dissipated locally. This additional heat is transferred along the conductor, leading the temperature of adjacent sections to increase.

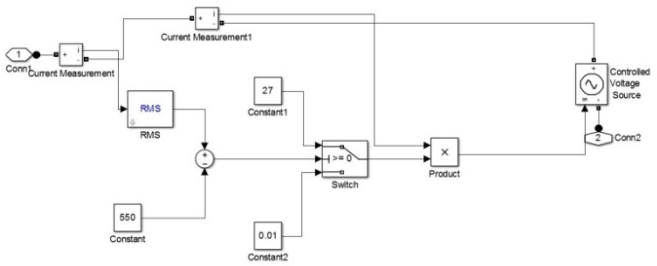


Fig. 3. SFCL modeling

In this paper the resistive type SFCL was modeled, considering four fundamental parameters of SFCL. These parameters and their selected values are:

TABLE I . FUNDAMENTAL PARAMETERS OF SFCL [17]

S. No.	SFCL Parameters	Values
1.	Transition/Response Time	2 msec
2.	Minimum Impedance	0.01 Ω
3.	Maximum Impedance	20-27 Ω
4.	Triggering Current	550 A
5.	Recovery Time	10 msec

The SFCL working voltage is 22.9 kV. The SFCL model developed in Simulink/SimPowerSystem is shown in *"Fig.3"*.

First step is to calculate the RMS value of the passing current and then it is compared with the characteristic table. Second, if a passing current is larger than the triggering current level, the resistance of SFCL is increased to maximum impedance level in a pre-defined response time. Finally, when the current level falls below the triggering current level, the system waits. The current limiting resistance value is calculated and this value is implemented in the developed simulation model.

V. SIMULATION RESULTS AND ANALYSIS

This section presents the results of relay coordination problem in the presence and absence of DG where three phase fault is introduced in the system to study the effect of fault on coordination of overcurrent relay i.e. blinding of protection and false/sympathetic tripping with and without SFCL. The simulation is conducted by connecting the DG at node 864 and introducing fault at node 842 and 810 separately to solve the coordination problem of the over current relay.

The fault current sensed by each relay is measured in the presence of three phase fault and the value of TDS for each relay is calculated. "TABLE II" shows the simulation results of fault current and TDS calculation at 26 important nodes in IEEE 34 node distribution system. In this case fault location is on node 842 and DG is not present in the system. Out of 34 nodes, relays are connected at only 26 location as the current on the remaining nodes are not considerable even in the presence of fault.

"Table III" shows the results of blinding of protection, with three phase fault at node 842 and DG connected at node 864. DG is connected to node number 864 looking at the voltage profile of the entire node of the distribution network. Simulation results shows that DG reduces the contribution of fault current from grid i.e. maximum contribution of fault

current if from DG. Also with the decrease in fault current, TDS of corresponding relays decreases. But at nodes 16, 17, 18, 19 and 20 current increases abruptly and TDS is almost unaffected compared to the case when there is no DG in the system. In this context, the simulation result of relays from 1 to 7 and from 14 to 20 is presented in this paper. This case study represents the blinding of protection.

TABLE II . THREE PHASE FAULT AT NODE 842 WITHOUT DG

Relay No.	TDS	I_p(fault current)	Relay No.	TDS	I_p (fault current)
1	8.9085	36.30	14	3.7274	82.68
2	8.5600	36.40	15	3.8152	82.50
3	8.2605	36.50	16	2.4793	83.00
4	7.9612	38.24	17	1.8425	228.00
5	7.6186	40.60	18	1.2234	260.00
6	7.3168	42.25	19	0.9000	261.10
7	6.9896	82.50	20	1.5418	264.70

TABLE III . RESULT FOR BLINDING OF PROTECTION, THREE PHASE FAULT AT NODE 842 WITH DG AT NODE 864

Relay No.	TDS	Ip (fault current)	Relay No.	TDS	Ip(fault current)
1	9.0452	33.50	14	2.3184	88.80
2	9.0138	33.64	15	2.1062	88.30
3	9.0024	33.74	16	1.4775	214.00
4	8.1427	35.50	17	1.0706	241.00
5	8.1404	37.69	18	0.2243	2657.00
6	4.5410	39.30	19	0.9069	2661.00
7	4.2172	76.50	20	1.5418	680.00

The simulation results for fault current and TDS calculation on IEEE 34 node test system with three phase fault at node 810 is shown in "TABLE IV". Whereas "TABLE V" demonstrates the result for fault current and TDS on same system with three phase fault at node 810 and DG placed at node number 864.

TABLE IV . THREE PHASE FAULT AT NODE 810 WITHOUT DG

Relay No.	TDS	I_p(fault current)	Relay No.	TDS	I_p(fault current)
1	0.3564	7877.00	14	9.4310	27.15
2	0.3562	7877.00	15	9.4312	27.00
3	0.3559	7877.00	16	8.3910	30.00
4	0.3541	7877.00	17	2.3186	88.00
5	9.0021	34.00	18	4.2151	77.50
6	9.0139	33.60	19	4.2250	77.00
7	8.1429	35.00	20	4.2174	76.20

TABLE V . RESULT FOR FALSE/SYMPATHETIC TRIPPING, THREE PHASE FAULT AT NODE 810 WITH DG AT NODE 864

Relay No.	TDS	I_p(fault current)	Relay No.	TDS	I_p(fault current)
1	0.3563	7877.00	14	9.4310	27.00
2	0.3560	7877.00	15	8.3881	30.00
3	0.3540	7877.00	16	2.3181	88.00
4	0.3543	8000.00	17	2.0112	92.50
5	8.1221	36.00	18	2.8536	71.50
6	8.1431	34.90	19	2.8540	71.20
7	8.1024	37.00	20	2.9001	70.10

TABLE IV and TABLE V shows the simulation results for IEEE 34 node test feeder with fault at node number 810, in presence and absence of DG. The DG is connected at the same location i.e. at node number 864. This case study deals the False/Sympathetic tripping.

TABLE VI . RESULT FOR RELAY COORDINATION WITH THREE PHASE FAULT AT NODE 842, DG AT 864 AND SFCL AT PCC

Relay No.	TDS	I_p(fault current)	Relay No.	TDS	I_p(fault current)
1	9.13	30.12	14	3.74	70.12
2	8.8	30.14	15	3.08	80.24
3	8.5	30.24	16	2.45	114.56
4	8.2	32.04	17	1.84	141.67
5	7.9	34.95	18	1.22	458.00
6	7.6	36.58	19	0.90	459.00
7	7.3	72.43	20	1.54	151.34

"TABLE VI" shows the results for relay coordination problem, with three phase fault at node 842 along with DG and SFCL connected to node 864 and PCC respectively. From the comparison of "TABLE III" and "TABLE VI", it has been observed that insertion of SFCL reduces the value fault current and simultaneously maintain the value of TDS to desired level. From the various case studies it has been observed that higher the value of fault current, smaller the operating time, due the inverse time characteristics of OCRs.

VI. CONCLUSION

A comparative study of OCR coordination is presented for different fault location in presence and absence of DG. The effect of penetration of DG on the two main protection coordination problems i.e. blinding of protection and False/Sympathetic tripping is discussed in this paper which is supported with the simulation results. The impact of SFCL on the coordination of OCR is also discussed and presented in this paper and it has been observed that how coordination is maintained even in the presence of fault. From the various case studies it can be concluded that SFCL retains the

coordination of OCRs even in the presence of fault as it has an inherent property to reduce the magnitude of current under abnormal condition.

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