Design of Fault Current Limiters in Distribution System in Presence of Distributed Generation

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***Abstract*—The integration of renewable energy resources into the existing distribution network poses several challenges to the protection of the distributed system. One such challenge is the increase in the fault current which is more than the breaking capacity of existing circuit breakers and fuses. Since, the share of such resources is rising day by day, the ratings of protective devices cannot be changed every time with the addition of such generations in the system. Thus, a fault current limiter (FCL) application is proposed to solve this problem. This work also aims at making the FCL adaptive in nature to the changing system conditions so that it can act effectively even when the share of DGs increases. The working of the FCL has been tested and examined on a radial distribution test system.**

***Index Terms*—distribution system protection, fault current limiter, real-time simulation, RTDS,**

I. Introduction

The protection schemes associated with the existing distribution systems face challenges in the form of integration of distributed generators (DGs) including renewable energy sources (RES). One of the main challenges is the increase in the fault current level to a level higher than the breaking capacity of existing breakers and fuses [1], [2]. This demand resetting of relays, circuit breakers and related protective devices with every new integration of RES. This problem can be addressed with the application of fault current limiter (FCL) [3]–[5]. The FCL should be adaptive in nature so that the system is protected even with variations in the share of RES.

The working and effectiveness of the adaptive FCL is demonstrated on a radial distribution test system. The simulations are performed in Real Time Digital Simulator (RTDS).

II. Fault current limiter and its design

The FCL is designed by placing a gate turn-off thyristor (GTO) in parallel with an inductor. The GTO is used as it is fast and can be turned off by passing a negative pulse. Thus, the load current is intercepted instantly when the GTO receives a negative gate pulse. A metal oxide varistor (MOV) voltage limiting element is also connected in parallel to prevent overvoltage spikes caused by sudden interruption of current [6] (Fig. 1).

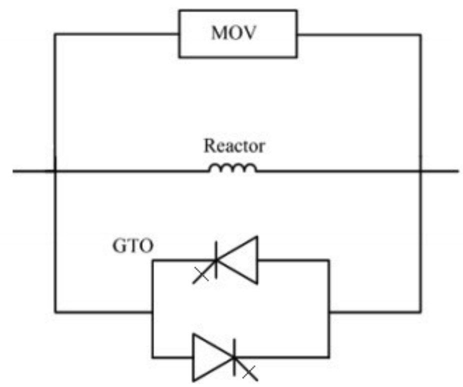

Fig. 1. Basic configuration of fault current limiter

III. Control circuit of FCL

An overcurrent detector along with a power factor comparator are used to detect fault conditions and produce signals for turning on and off the GTO. The basic control schematic diagram is presented in Fig. 2.

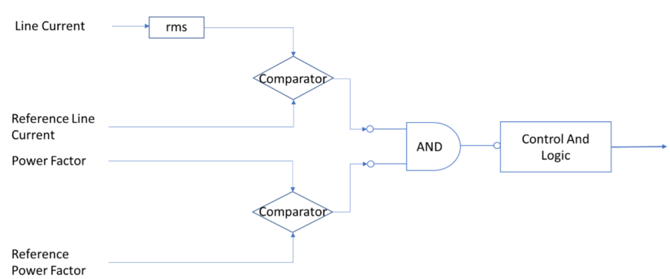

Fig. 2. Basic schematic of control circuit of FCL

The default position of GTO for normal operation is ON. The fault is detected by comparing the line current with reference current. However, only current comparison may lead to erroneous operation as a high load condition may get wrongly recognized as fault condition. Leading to undesirable operation.

Such an operation of FCL can be averted by comparing current power factor with a reference power factor. The typical power factor of the system varies from 0.75 lagging to 0.75 leading. Whereas a fault is a high current with highly lagging and low power factor phenomenon. Thus, by comparing both current and power factor, the control circuit will ascertain that the FCL only operates when a fault exists in a network.

The proper functioning of FCL requires continuous monitoring of current and power factor. Once a fault is detected, the control circuit will issue gating signal to the GTO switching it to OFF position. The FCL will continue to limit the current if the fault exists and will automatically return to the normal condition once the fault is cleared.

When the control circuit recognizes the current is restored within the normal operating levels and stays there for few cycles, then turn on signal is given to GTO restoring the normal operation.

IV. Adaptive fault current limiter

The constant impedance FCL may be unable to function to the best of its abilities in the changing or varying operating conditions. Therefore, a variable impedance FCL is required to satisfy the requirements of limiting the fault current under fault conditions in a distribution with RES integrated in the form of DGs. The impedance of the FCL is varied in accordance with the change in operating condition. This is done by varying the firing angle of the GTO pair. Thus, the system is protected, and all relays and circuit breakers may work without the need of changing the devices.

A proper value of FCL inductance should be selected to minimize the peak and rms values of the fault current for varied operational range. The first step is thus, to decide the range of impedance (inductance) that would work in a given system. The maximum FCL impedance would limit the current for the worst-case fault conditions (such as a metallic three phase fault) when the maximum available fault current would flow if not limited. The minimum FCL impedance will be based on the maximum fault impedance that would appear on the fault path in the distribution system. Ideally, the minimum FCL impedance should be zero. Hence, the FCL impedance will be continuously varied over a range of zero to maximum impedance so as to limit the fault current to the desired value even under varying system operating conditions. The working of the adaptive FCL can be understood from the flow chart as shown in Fig. 3.

V. Simulation results

The use of FCL to limit the fault current in distribution systems in presence of DGs and the algorithm for its adaptability to varying system operating conditions have been tested and validated through simulations done in RSCAD/RTDS environment [7]. This section discusses these simulation results.

A typical 5-bus radial distribution network is considered for simulations as shown in Fig. 4. The distribution system parameters are shown in Appendix. Since, 3-phase fault is the most severe fault, the protection scheme is tested for the same. Then, the effect of DG integration on the same system is examined. The parameters of the DG integrated in the distribution system are shown in Table 1. As the fault current level increases with the addition of DG, the FCL is introduced. Integrating FCL in the system limits the fault to the previous level, which was without DG. The simulation results of non-adaptive/ constant impedance FCL are discussed next.

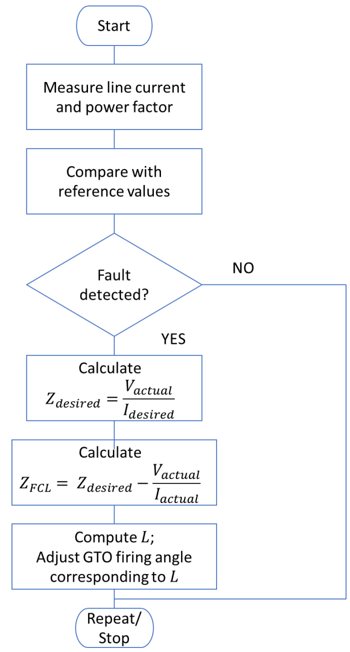

Fig. 3. Flowchart showing the working of adaptive FCL

TABLE I
DISTRIBUTION GENERATION PARAMETERS

Parameter	Value
Rated turbine power (MW)	2.2
Rated generator power (MVA)	2.0

A. Results of non-adaptive fault current limiter

The DG is modeled as a wind farm of capacity presented in Table I. The nonadaptive FCL is installed between bus 3 and 4 for minimizing the impact of DG on the distribution protection system.

Initially the study is considered without DG. Loads are connected at bus 3 and 5. Fig. 7 presents currents of all the three phases under normal operating conditions. Under normal operating conditions the peak current in each phase is observed to be $0.12\mathrm{kA}$.

A 3-phase fault is simulated in the system at bus 4. The fault currents observed at bus 4 are shown in Fig 8. The peak fault current value is observed to be $2.48\mathrm{kA}$.

A DG is then added at bus 4 as shown in Fig. 5. A 3-phase fault is simulated at bus 4 as earlier. Fig. 9 presents the fault currents observed. It is observed that the fault current increases with the addition of DG which may lead to maloperation of protective devices. It is observed that the peak fault current increased from $2.48\mathrm{kA}$ to $3.38\mathrm{kA}$.

A non-adaptive/constant impedance FCL is then introduced between bus 3 and 4 as shown in Fig. 6. As observed in the previous case, the peak fault current rises to $3.38\mathrm{kA}$. The rating of the FCL is determined so as the fault current falls back to the pre-DG installation level. It is determined to be $23.3\mathrm{mH}$. Addition of this FCL brings back the fault current

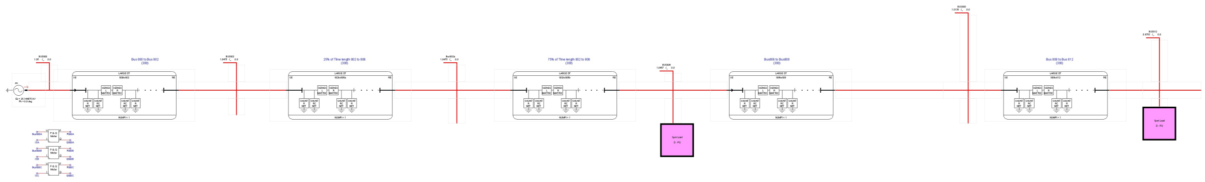

Fig. 4. 5-bus radial distribution test system without DG

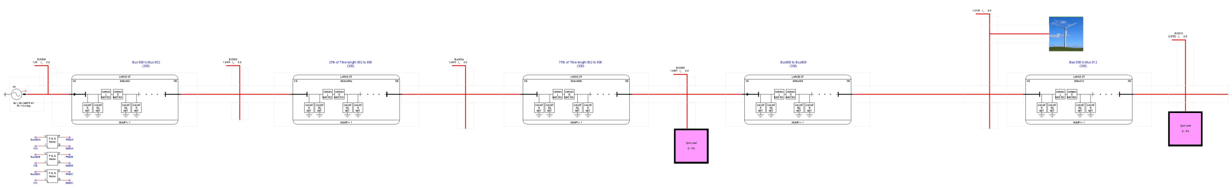

Fig. 5. 5-bus radial distribution test system with DG

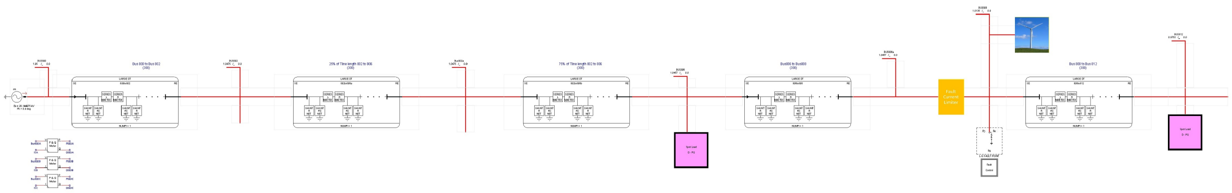

Fig. 6. 5-bus radial distribution test system with DG and FCL

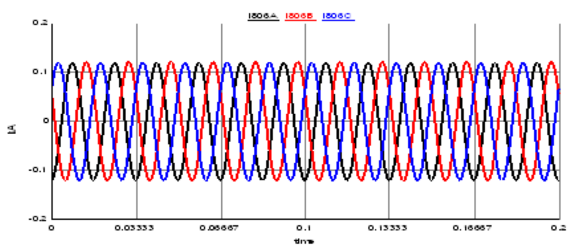

Fig. 7. Currents under normal conditions without the presence of DG

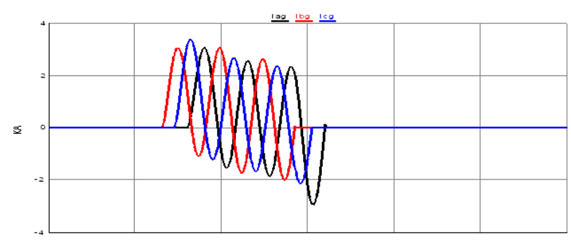

Fig. 9. Fault currents with DG: fault at bus 4

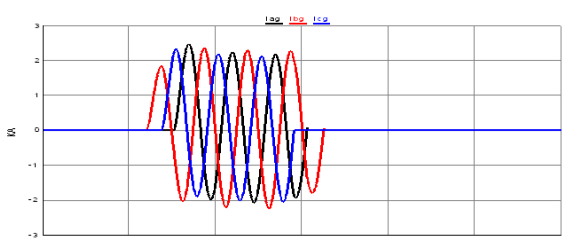

Fig. 8. Currents under 3-phase fault at bus 4

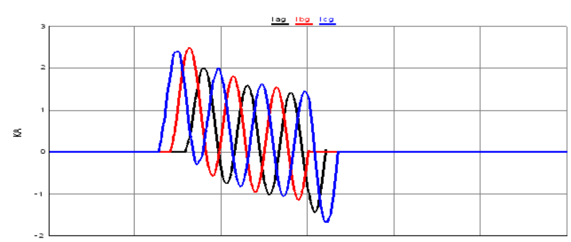

Fig. 10. Fault currents with DG and FCL: fault at bus 4

level to the desired level i.e., 2.48kA as presented in Fig. 10. This eliminates the need for upgrading/recalibrating the protective devices.

In order to simulate a different operating condition for adaptive FCL, changes are made by increasing the wind DG rating to (5 MW) and the associated change in the fault current is studied. The fault current increases to 3.63kA. The modified value of FCL inductor is updated in the adaptive FCL. The updated value of inductor comes out to be $23.48\mathrm{mH}$. The updated value of inductor is manually calculated in this case according to the method described in flowchart, and placed in the circuit in parallel with GTO as in the case of constant FCL.

For both constant and adaptive FCL, reference value of rms current is taken as $0.4\mathrm{kA}$ and reference value of power factor angle is taken as 50^o.

VI. Conclusion

A FCL application is proposed to solve the issues in protection schemes of distribution system due to integration of DGs in existing system. An FCL does not act in the normal condition and therefore does not disrupt the normal operation. However, as soon as a fault is detected, it acts to bring back the fault current to target level, thereby saving on the cost of upgrading the protection devices. The FCL is also made adaptive in nature to the changing system conditions so that it can act effectively even when the share of DGs increases. The working of the FCL has been tested and examined on a 5-bus radial distribution test system. The simulation results demonstrate both the ability of proposed FCL to limit the fault current level and minimizing the impact of DG on protection problems.

Appendix

A. Overhead line configurations [8]

Config.	Phasing	Phase ACSR	Neutral ACSR	Spacing ID
300	BACN	1/0	1/0	500

B. Line segment data [8]

Node A	Node B	Length (ft.)	Config.
800	802	2580	300
802	806	1730	300
806	808	32230	300
808	812	37500	300

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