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Allocation of fault indicators in distribution feeders containing distributed generation

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ABSTRACT

As distribution systems are typically radial and branched, different branches have the same accumulated impedance from substation. Consequently, the impedance-based distance estimation techniques may identify multiple suspected locations for the same fault. The allocation of fault indicators reduces this problem. However, with distributed generation in distribution systems, the fault current, previously fed only by the substation, is now also fed by distributed generators. This may cause an incorrect operation of conventional fault indicators, requiring directional ones. In this context, an approach for allocation of conventional and directional fault indicators in distribution feeders, taking into account the distributed generation, is proposed in this paper. To represent the distance traveled by the maintenance teams during faults location, the proposed approach uses actual paths between the suspected fault locations, making the method realistic. Furthermore, using a NSGA-II algorithm, the best set of conventional and directional fault indicators required is determined. Results show that conventional fault indicators work accurately in the presence of low power distributed generators (less than 20% of the substation power) and, in the presence of high power generators, few directional fault indicators are needed.

1. Introduction

Electrical distributions systems are very susceptible to faults, especially the overhead ones. These faults are caused by equipment failure, animals, trees, lightning, etc. [1,2], and the incapability of quickly locate and eliminate them leads to social and economic problems. Moreover, bad reliability indexes blacken the utilities' image and may cause legal and contractual penalties. In order to solve this issue, researchers have been developing improvements in fault location techniques [3].

Depending on the available monitoring devices, different fault location approaches can be applied. The most recent ones use neural networks [4], wavelets [5] and S-transform [6], but the impedance-based methods are better adapted for current distribution systems [7], being the main class of approaches adopted by utilities. To obtain the fault location, these methods estimate the fault impedance from substation using voltage e current measurements. Based on that estimate, the fault location can be determined. However, as the distribution feeders are typically radial with many laterals, more than one suspected fault location for the same impedance estimated at substation may exist. This problem is known as the multiple fault location problem [8]. In order to reduce or even eliminate it, utilities frequently use Fault Indicators (FIs).

FIs are installed along the feeder to help the maintenance teams on identifying fault locations, providing visual and remote indications [9]. They have an acceptable level of reliability, greater than 98% correct indication [10]. In conventional feeders, where there is no distributed generation (DG), FIs trip only for downstream faults since there is only one source contribution, the substation. For instance, given a feeder containing one lateral, installing one FI at the beginning of the lateral is enough to eliminate the multiple fault location problem. If the fault is on the lateral, the FI trips; otherwise, if the fault is on the main feeder, the FI does not trip. In this example, choosing the adequate location for the FI is trivial. However, this is not the case for feeders containing several laterals.

Literature presents different approaches to allocate FIs. For instance, in Ref. [11] the Fuzzy logic is used to identify the best branches for FIs allocation to reduce the fault location time. Other approaches assume the availability of impedance-based methods providing the impedance (or the distance) from substation up to the fault, while FIs are allocated in order to reduce or eliminate the multiple fault location problem. In Ref. [12], the optimal allocation of the FIs is obtained by a genetic

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algorithm (GA) using an objective function that considers the loads, the number of customers and the distance between FIs. In Ref. [13] a study of fault location based on the distance estimation with and without FIs is presented; the results show that the use of FIs associated with distance estimation reduces the SAIDI (System Average Interruption Duration Index) when compared with the distance estimation sole. In Ref. [14] it is shown the importance of considering the patrolling speed in FIs allocation procedure. Some different patrolling speeds along lines were used to calculate their impact on the FIs allocation. The Ref. [15] describes the application of FIs associated with fault analyzers for distance estimation in compensated networks. The number and the location of the FIs were chosen by an agreement between the manufacturer and the utility; that is, based on their experience.

When admitting the availability of fault distance estimation, the distance between the suspected fault locations is a very important information and, instead of the actual distances, approximated distances (simplified calculations) are commonly adopted. In Ref. [8], the FIs allocation is obtained by a Chu–Beasley based GA with two possible objective functions. The first one uses the number of suspected fault locations, while the second one provides an approximated distance between them. The adoption of a simplified approach to estimate the distances to be run by maintenance teams may mask the effort to find the faults. Thus, one contribution of this paper is the use of the actual distances between the suspect fault locations. These directions through streets are calculated using Dijkstra algorithm [16]. For that, the actual map (streets, corners, etc.) of the feeder is modelled as a graph and constraints, such as one-way streets and closed streets for vehicles, may be considered, which makes the method realistic.

Furthermore, traditionally the methods used for the FIs allocation do not consider DG. In this case, power flows are unidirectional, from substation to loads or faults. However, depending on the fault location, DGs may unwantedly trip the FIs, which makes the FIs innocuous for the fault location purpose [17]. In order to solve this problem, there are some developments to adapt FIs, such as the directional FIs for systems with high grounding impedance [18], but this functionality is not available for solidly grounded systems. Also, despite relays being more expensive than conventional FIs, devices already installed along the feeder may provide the directional function, as reclosers with ANSI 67 relays.

The second contribution of the proposed approach uses the availability of directional FIs. A new objective function considering the costs of conventional and directional FIs is proposed. Therefore, for feeders with DG, there are two objective functions, one based on the distance between suspected fault locations and another based on the cost of conventional and directional FIs. To solve the multi-objective problem, the NSGA-II (Non-dominated Sorting Genetic Algorithm II) [19] is used, which is one of the most popular multi-objective optimization algorithms [20]. It provides a Pareto optimal front by sorting individuals based on every objective function. The generations are chosen by dominance and crowding-distance criteria.

In summary, this paper proposes an approach to allocate conventional and directional FIs, in the presence of DG or not, admitting that the fault distances from substation are given by impedance-based fault location methods. According to literature, these methods have easy implementation and low deployment costs, however they are not adequate to deal with high impedance faults and their performance depend on the system operation state as well as the faults conditions. A study including a detailed discussion of the pros and cons of the main impedance-based fault location methods are found in Ref. [21].

The paper is organized as follows: in Section 2 the multiple suspected fault location problem is presented. The FIs allocation problem in distribution feeders without DG is then discussed. In Section 4, the impact of DG on the FIs allocation is shown and, in Section 5, the proposed method including DG influence is presented. Complementary studies are in Section 6 and the conclusion in Section 7.

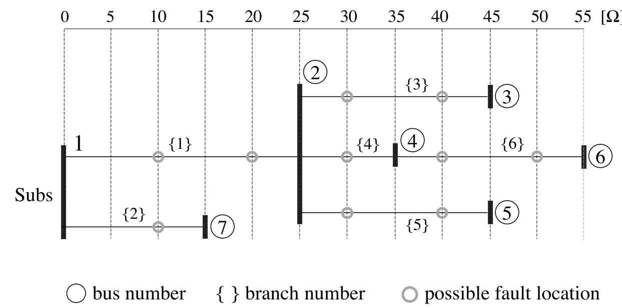

Fig. 1. Feeder containing accumulated impedances and possible fault locations.

2. The multiple suspected fault location problem

Admitting that when there is a fault, an impedance-based method gives its distance from substation, multiple suspected fault locations may exist, since distribution feeders usually have many laterals. The proper allocation of FIs reduces or even eliminates the multiple suspected fault locations. The following example, based on the feeder shown in Fig. 1, clarifies how FIs can be applied. The impedances measured from the substation are indicated by dashed vertical lines. For instance, bus 6 is 55 Ω way from substation. Assuming a 10 Ω impedance step, all possible fault locations are indicated by gray circles. For a fault 30 Ω way from the substation, there are three suspected fault location, on branches {3}, {4} and {5}, and the maintenance team needs to patrol these three branches to find the fault. However, by allocating one FI at the beginning of branch {3}, one suspected fault location is eliminated, once the FI trips for faults on branch {3}. Therefore, by reducing the number of suspect locations, the distance to be traveled by the maintenance team also reduces. Note that, for instance, the allocation of FIs at the beginning of branches {3} and {5} completely eliminates the multiple fault location problem for the 30 Ω fault. Ultimately, for instance, the allocation of FIs at the beginning of branches {2}, {3} and {5} completely eliminates the multiple fault location problem for any fault on this feeder, which means that all faults would be uniquely identified. On the other hand, given less than three FIs, there are many possible allocation proposals, each one associated with a distance to be travelled by the maintenance teams during faults location, and these distances can be used to qualify the proposals. In summary, the best allocation proposal results in the shortest distance to be travelled by maintenance teams.

The quantity of possible allocation proposals $P_{C,FI}$, given by (1), depends on the number of candidate branches, n_C, and the amount of available FIs, n_{FI}. Given a number of FIs, the objective is to define the branches where FIs are allocated resulting in the shortest distance to be travelled during faults location. Assuming no investment limitation, the trivial solution is to allocate FIs on every lateral branch.

$$P_{C,FI} = \frac{n_C!}{n_{FI}!(n_C - n_{FI})!} \tag{1}$$

3. Optimal FIs allocation without DG

In order to model the proposed method, a matrix containing the possible fault locations and the FIs statuses is adopted, as proposed in Ref. [8]. The amount of FIs and the impedance step are given parameters. The number of rows in the matrix is equal to the possible combinations of the FIs statuses (p), given by $p = 2^{n_{FI}}$, where n_{FI} is the number of FIs to be allocated. The number of columns (m) is equal to the highest accumulated impedance divided by the given step. For instance, in Fig. 1, the highest accumulated impedance is 55 Ω (on bus 6). Assuming an impedance step of 10 Ω, m = 5 columns. In general, the impedance step should be lower than the shortest branch impedance, ensuring that every branch has at least one possible fault location.