EXPERT SYSTEM FOR PROTECTIVE DEVICE ADJUSTMENTS ON DISTRIBUTION SYSTEMS WITH DG

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ABSTRACT

Due to the high competitiveness of the power market along with cost reduction of new technologies, currently there exists a worldwide tendency for using novel electric power generation resources. In this way, according to technical and economic analyses, the insertion of such generation can be suitable not only within transmission networks, but also at medium and low voltage levels, within the distribution networks. However, this Distributed Generation (DG) makes some parts of the feeder lose its radiality. It has direct influence on the protective devices coordination installed on the feeder. DG placed on the distribution feeders affects the voltage profile and short-circuit current levels, system stability, and may result in islanding of some network areas. Thus, an expert computational system for performing protection projects for overhead distribution feeders that present -or not- distributed generation (DG) is proposed. In order to assess the computational system efficiency a real-life distribution feeder is used.

INTRODUCTION

Insertion of Distributed Generation (DG) in distribution systems may bring socio-economic benefits to the government and electric utilities, and, mainly, to consumers. Use of DG could assist reducing investment costs related to new large plants, which, in most cases, present more environmental impacts.

For electric utilities, DG could improve voltage profiles, reduce losses, increase transmission and distribution capacity, and improve system's reliability [1]. On the other hand, DG sited in aerial distribution feeders requires changes on the traditional philosophy of aerial system's protection, in terms of allocation, coordination and selectivity of overcurrent protective devices. These changes imply the development of new concepts and methodologies for analyzing protection strategies suitable for this new scenario.

Typical aerial distribution systems present radial topology whereas protection schemes are basically restricted to the usage of relays, reclosers and fuses, all being coordinated and selective to each other. In radial networks the power flow is unidirectional; consequently, a fault at a given feeder will be detected by the closest protective device, isolating the faulting area, thus minimizing the number of consumers switched off from the grid.

After the connection of a generator, part of the feeder losses its radiality, directly impacting on the coordination of its protective devices. Other effects may include increased voltage and short-circuit levels, system's stability, and islanding. In this new scenario, during a fault, protective devices may face fault currents coming from both upstream (e.g. substation) and downstream (e.g. generation units), leading to the unnecessary or incorrect actuation of such devices.

In this work, a computation algorithm that allows designing protection schemes for aerial distribution systems considering DG is proposed and implemented. Technical and economic aspects of allocation, re-allocation, specification and coordination of protective devices are taken into account in a fully integrated manner.

DG IMPACT ON PROTECTION SCHEMES

A typical radial distribution feeder is presented in Figure 1. When a fault occurs, as indicated, the fault current source will solely be the substation. With an adequate coordination of the overcurrent protective devices, the closest device to the fault will actuate, and the minimum number of consumers will be disconnected.

When sitting a distributed generator, as shown in Figure 2, for the same fault there will be fault currents coming upstream (substation) and downstream (generator) the protective devices. In case these devices have no directional capabilities -as it occurs with fuses and non-modern reclosers- they will not be able to actuate, or will operate in a non-coordinated and non-selective way for most of the faults.

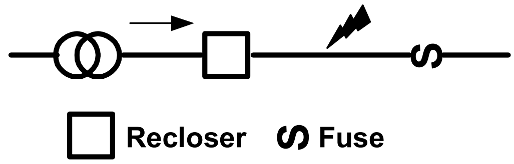


Fig. 1.: Fault current in a radial distribution feeder.

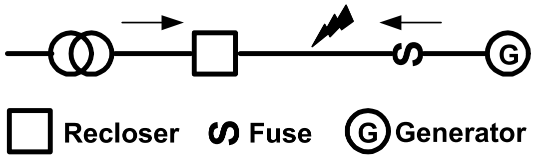


Fig. 2.: Fault current in a distribution feeder with DG.

The load currents share of the generator also may lead to setting problems of protective devices. It might happen some cases where settings corresponding to a configuration without DG have to be changed due to the increased currents produced by the DG.
Other problems include the short-circuit level and the fault current share of each source (substation and generators). Depending on the DG location and capacity, there may be an increase or reduction of the short-circuit current whose value is required for setting the protective device. Therefore, severe setting modifications could occur leading to the reduction of short-circuit ranges utilized for coordinating and making selective protective devices.

ISLANDING

When a distributed generator is sited at a radial or weakly-meshed feeder the number and duration of blackouts faced by costumers can be reduced. After the isolation of a fault by the protective devices and considering that a generator is outside the faulted region, part of the system can be operated in island mode (disconnected from the grid) through a suitable procedure of network restoration. This can reduce the impact a fault has on consumers and improve reliability indices. Here, it is necessary to take into account issues such as stability and operating sequence of directional reclosers and/or line section fuses. The use of such equipment is out of scope of this work.
Figure 3 illustrates an islanding situation where it is possible to keep supplying energy to a largest number of consumers than when DG should be disconnected immediately in case of permanent fault.

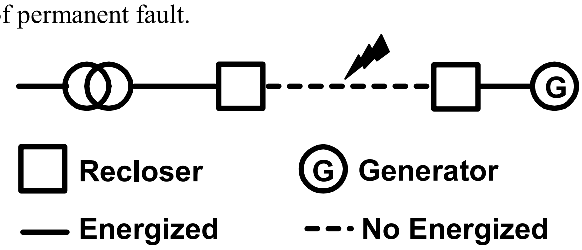


Fig. 3.: Distribution feeder with DG that may operate in island mode

SOFTWARE STRUCTURE

This paper proposes a user integrated and interactive computational system for developing protection system projects on overhead distribution feeders with and without DG.
This system consists of information stored in databases and knowledge-base that are used in the implementation of efficient algorithms for protection system projects, and that are reflected in rules applied for the placement, selection and coordination of protective devices on distribution feeders.
The software is structured as follows: Power Flow and Short-Circuit calculations according to the system's topology (radial or with DG); and, allocation, specification and coordination of protective devices.

In this dedicated system, an artificial intelligence (*if-then*) programming model is used to represent the knowledge-base in order to specify the protection system in a selective and coordinated manner. The developed system is composed by four parts: *Database, knowledge-base, inference engine and user interface*.

Database

The database is divided into protective device data and feeder data. Protective devices data are represented by tables that contain information such as: type (whether device is relay, recloser, or fuse, and phase or ground), operational voltage range, interrupting rating, trip coil for electromechanical reclosers, settings for each type of overcurrent that are used for specification, coordination and selectivity in protection projects. Each overcurrent protective device, i.e., fuse, overcurrent relay and recloser, should have its time-current actuation characteristics stored, so they can be used during the coordination and selectivity project.

Knowledge-base

Rules for specification, coordination and selectivity of sets of protective devices compose the knowledge-base [2-5]. This knowledge-base is shared for formulating protection system projects for aerial distribution networks considering both radial topology and with DG.

Inference Engine

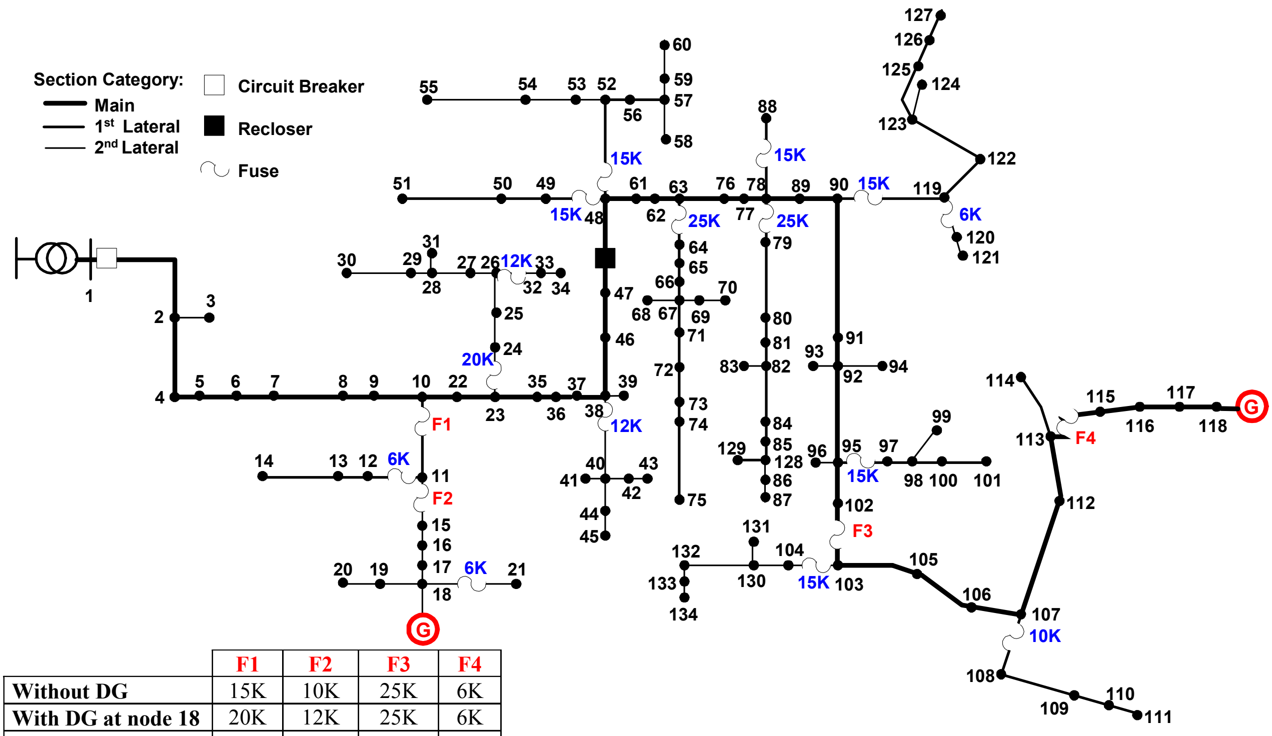
The placement, selection and coordination of various protective devices are processed by inference engine. The inference engine represents the means by which the knowledge is handled, using information stored in the knowledge and data bases and the user-system interaction through the user interface for developing the protection project of the feeder.

User Interface

A user-interface is projected in order to facilitate the user-system interaction. In the developed system the user enters easily with data corresponding to the protective device, feeders and rules for the decision processing. This interface also provides settings and specifications, selectivity and coordination of protective devices in a convenient output form through tables and graphs that show coordination diagrams for the feeder under analysis.

RESULTS AND DISCUSSION

The real-life 134-bus feeder presented in Fig. 4 was utilized [6]. Considering the fact that most of fault occurrences in distribution feeders are single phase-to-ground faults, the developed software prioritizes the analysis of coordination and selectivity of the ground protection units, ensuring, at least, selectivity for phase values.
First, the protection analysis for the feeder without DG was performed. Obtained protection scheme was used for



	F1	F2	F3	F4
Without DG	15K	10K	25K	6K
With DG at node 18	20K	12K	25K	6K
With DG at node 118	15K	10K	100K	65K

Fig 4. Real-life, 134 nodes, feeder used to test the proposed methodology.

observing the impact that the insertion of a generator at different points of the network has on the devices.
Fig. 4 shows the results of the protection allocation tests. Setting for the corresponding recloser are presented in Table 1. It is verified that, considering DG, in order to coordinate the 25K fuse with the recloser, it was necessary to specify a slower ground actuation curve for the latter. This new setting is related with the new short-circuit levels due to the presence of generators, modifying coordination ranges between reclosers and fuses.
Coordination range between the recloser and the downstream fuse with the largest capacity is presented in Fig. 5.
When a generator is sited at node 18, it is observed that the specification of those fuses allocated between the substation and the DG suffered alterations. This occurs because. besides the classic analyses for specifying, coordinating and making selective a fuse, it is necessary to guarantee that for any fault within the region among the fuses, the closest device to the DG should actuate first. In Fig. 6 it is illustrated this case, where a fault at node 11 the actuation time of the fuse at line section 11-15 should be smaller than that of line section 10-11. The first one face a short-circuit current whose source is the DG, whereas the latter experiences a short-circuit current produced by the substation. For coordinating these two fuses, it is considered that their actuation time setting for the same short-circuit current value, present a ration of at least 0.75.

Table 1. Settings of Recloser.

	Recloser	
Condition	Without GD	With GD
Scale Factor	1.8	1.8
Fast Curves (phase and ground)	unique	unique
Delayed Curves (phase and ground)	0.1 and 0.5	0.1 and 1.0
Ground Pick-up (A)	20	30
Phase Pick-up (A)	150	150

In case of a fault between the 12K fuse (line section 11-15) and the DG there will not be any coordination problem among the fuses, since the short-circuit current the flows through the devices is the same, i.e., both fuses have to specified considering the short-circuit current produced by the substation.
Another case occur when analyzing DG at node 118. After performing the protection studies, the fuses at line sections 102-103 and 113-115, previously (no DG) specified with 25K and 6K, were upgraded to 100K and 65K, respectively. These values for fuses unable any practical application with the recloser from both specification and coordination points of view. These high values are due to the fact that the current through line section 113-115 was only produced by the loads downstream (approx. 5A). After inserting the generator, it became the supplier of some upstream loads, resulting in a current of approx. 60A through the same line section.

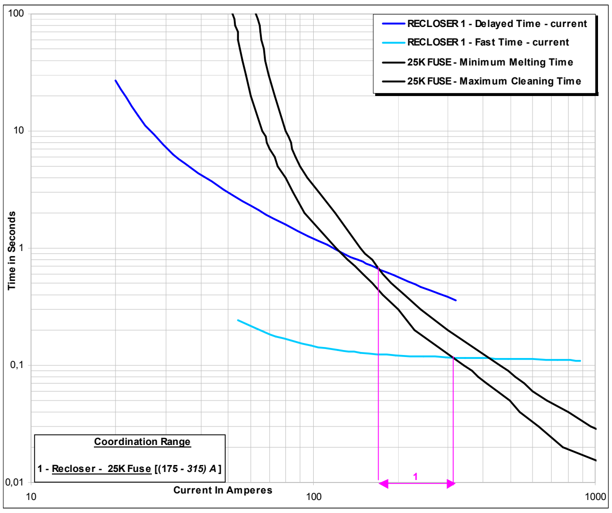


Fig. 5.: Phase-Ground Selective and Coordination Curve – Condition without GD.

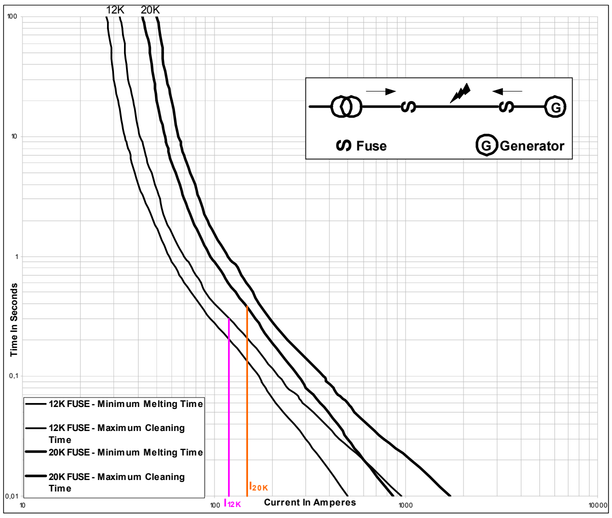


Fig. 6.: Coordination between fuse (10-11) and fuse (11-15) – With GD (node 18).

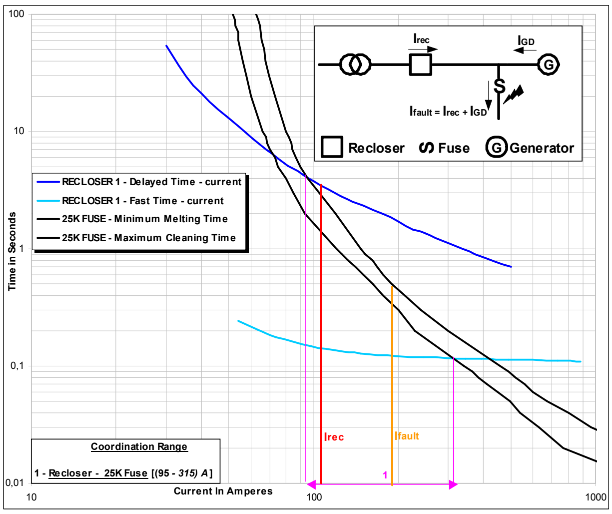


Fig. 7.: Phase-Ground Selective and Coordination Curve –With GD (node 118).

In order to overcome this problem, it was performed a simulation where the fuse of line section 113-115 was removed. The new protection specification presented fuse values equal to those obtained by the non-DG scenario. However, recloser settings differed. To obtain coordination between the recloser and the fuses, it is necessary to observe that for faults within the protection region of a fuse, short-circuit currents that specify each equipment are different. The value of the current flowing through the recloser is just a part of the total current that specifies the fuse. Fig. 7 illustrates this situation.

CONCLUSIONS

Results obtained using the dedicated system for studying and analyzing the protection scheme of a distribution network with DG are reliable and feasible. Specification and conditions of selectivity and coordination were obtained for all analyzed cases. Moreover, this system allows a high level of interactivity with the user.

Placement of distributed generators in distribution systems still requires more attention and studies, mainly regarding the impacts on the equipment already installed in the network.

Use of protective devices without directional capabilities, limits the benefits that DG could bring to the network through islanding. Moreover, communication schemes among those devices should be placed in order to suitably manage islanding mode.

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