Impact Analysis of Distributed Generation on Protection Devices Coordination in Power Distribution Systems

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I. Introduction

This document provides additional information concerning the paper "Impact Analysis of Distributed Generation on Protection Devices Coordination in Power Distribution Systems" published in ISGT LA 2021.

II. Characteristics of Protection Devices

Protection devices more common employed in distribution networks are fuses, switchgears and reclosers [1]. Usually, automatic sectionalizing switches include overcurrent relays.

A. Fuses

Fuses are the simpler devices used in protection systems. Fuse's operative characteristics depend on both its dimensions and electrical resistivity. Fuses type K and T are usually employed in distribution network branches, where the first type acts faster than the second. Fuses are still divided into two groups, according to your nominal current:

- Preferential fuses: 6, 10, 15, 25, 40, 65, 100, 140 e 200 A;
- Non-preferential fuses: 8, 12, 20, 30, 50 e 80 A.

Fuse models are differentiated according to their operating characteristics or time vs. current curves, which are used in coordination studies. Its operating curves are determined from a set of samples, obtained through tests performed by the manufacturer. An example of minimum fusion (MM) and maximum interruption (TC) fuse curves are shown in Fig. 1.

Fuses coordination with inverse time characteristic of overcurrent relays must consider the acting time of both

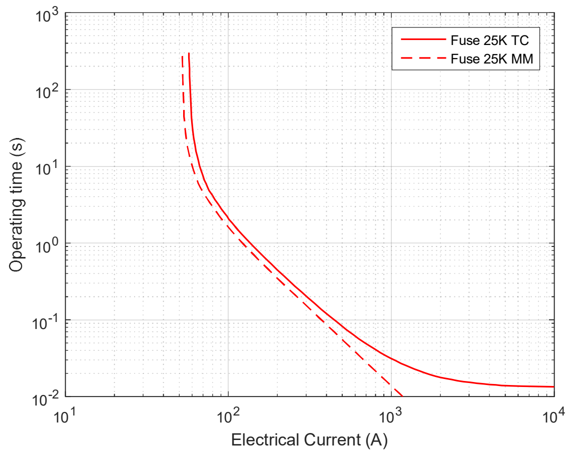

Fig. 1 – Time-current curves of the 25K link fuse

with inverse time (51 function), allowing the adjacent device acts and isolates the smallest part of the distribution network as possible.

Operating curves of overcurrent relays are usually standardized based on IEC 60255 (1989) or IEEE C37.112 (1997). According to IEC 60255, adopted in this work, the operating curve of overcurrent relays is determined using (1).

$$t = TMS \frac{\beta}{\left(\frac{I}{I_p}\right)^{\alpha} - 1} \tag{1}$$

Since TMS is a multiplicative factor for time adjustment, I the current that sensitizes the relay and I_p refers to the device pickup current. Values of α and β are constant and depend on the characteristic of the curve used. Curve types are shown in Table 2.

III. Coordination and Selectivity of Protection Devices

SC currents for different fault types allow determining protection device's sensitivity. Nominal values for fuses must be greater than 1.5 times the load current of their respective branch and less than 25% of the minimum earth fault current with 20 Ω fault impedance, $I_{min}^{1\emptyset}$. Normally, distribution companies generalize the recommended impedance value in their standards to 40 Ω. However, for the test system used, an impedance of 20 Ω adequately represents the overload problems of the tested system. The same fault is used to coordinate fuses with overcurrent relays, in functions 51 and 50 for phase and ground units.

Reclosers are usually composed of two or three overcurrent phase units and one ground. Fig. 2 shows the schematics with secondary relays. One possible configuration is the direct connection of relays to the primary network. However, despite being the most economical option, the scheme with primary relays is technically inferior to the options indicated in Fig. 2 [2]. Schemes with secondary relays allow greater flexibility and precision in the adjustment of protection devices. Both models in Fig. 2 can be used in the

TABLE I. IEC 60255 Constants

Relay operating curve	α	β
Standard inverse (NI)	0,02	0,14
Very inverse (VI)	1	13,5
Extremely inverse (EI)	2	80

a)

b)

Fig. 2 – Usual recloser schemes

The maximum two-phase SC current in the relay branch is used to calculate the operating time in characteristic 51F. The operating time of ground units is calculated considering a single-phase SC current without contact impedance, located in the branch where the relay is installed. Moreover, the operating time for a single-phase high impedance fault is also performed for both units, phase and ground.

The coordination restrictions between reclosers and fuses presented in this section are based on [3].

A. Selectivity Between Fuses

In Fig. 2 (a) there is an example system with two fuses, F1 (protected device) and F2 (protector device). The coordination between fuses is ensured using (2), when the TC fuse time, t_{F2}^{TC}, is less than or equal to 75% of the MM fuse time, t_{F1}^{MM}.

$$0,75t_{F1}^{MM}\left(I_{F2min}^{1\emptyset}\right) \geq t_{F2}^{TC}\left(I_{F2min}^{1\emptyset}\right) \quad (2)$$

B. Coordination and Selectivity Between Recloser and Fuses

In Fig. 2 (b), the coordination and selectivity between overcurrent relay and fuse is guaranteed by expressions (3) and (4) for functions 50F/N and 51, respectively. The coordination factor of characteristic 50, k_{coord}^{50-MM}, considering two operations 50, has a value of 1.35. The coordination time, t_{coord}^{51-TC}, considers a safety margin between devices operating time, normally 0.3s.

$$t_{F}^{MM}\left(I_{Fmin}^{1\emptyset}\right) \geq k_{coord}^{50-MM} t_{R1}^{50}\left(I_{R1-Fmin}^{1\emptyset}\right) \quad (3)$$

$$t_{R1}^{51}\left(I_{R1-Fmin}^{1\emptyset}\right) \geq t_{F}^{TC}\left(I_{Fmin}^{1\emptyset}\right) + t_{coord}^{51-TC} \quad (4)$$

C. Coordination and Selectivity Between Reclosers

In Fig. 2 (c), there is an example system with two relays/reclosers, R1 and R2. Coordination and selectivity between relays are achieved through expressions (5), (6), and (7). Values defined for t_{coord}^{50-5} , t_{coord}^{51-50}, and t_{coord}^{51-51} are 0.02s, 0.02s and 0.3s, respectively. Neutral units are coordinated considering a phase-to-ground fault. Coordination is also realized using $I_{min}^{1\emptyset}$.

$$t_{R1}^{50}\left(I_{R1-R2}^{2\emptyset}\right) \geq t_{R2}^{50}\left(I_{R2}^{2\emptyset}\right) + t_{coord}^{50-50} \quad (5)$$

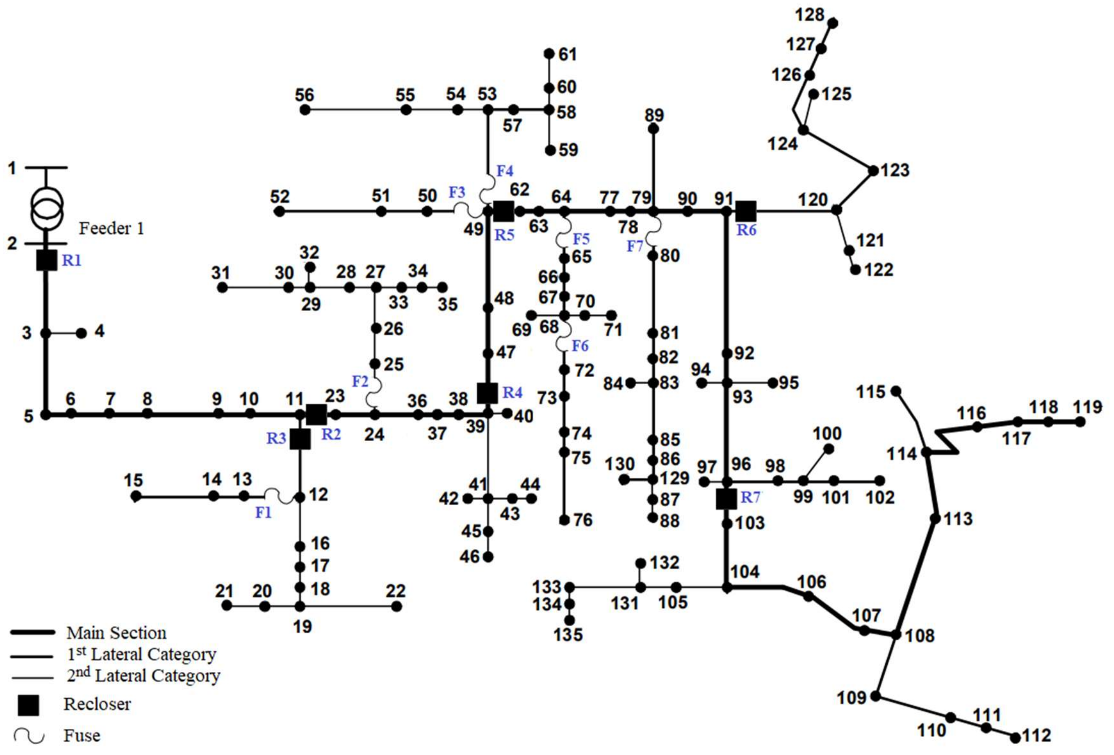

Fig. 4 – Real unbalanced distribution system with 135 buses.

$$t_{R1}^{51}\left(I_{R1-R2}^{2\emptyset}\right) \geq t_{R2}^{50}\left(I_{R2}^{2\emptyset}\right) + t_{coord}^{51-50} \quad (6)$$

$$t_{R1}^{51}\left(I_{R1-R2}^{2\emptyset}\right) \geq t_{R2}^{51}\left(I_{R2}^{2\emptyset}\right) + t_{coord}^{51-51} \quad (7)$$

It is important to highlight that only protection devices with characteristic 79 use the coordination criteria of expressions (5) and (6) with 50TD function. Protection devices composed only by overcurrent relays have no intentional delay, acting only on instantaneous characteristic (50) for three-phase SC currents.

IV. Results

The proposed method was implemented in C ++ programming language for its speed and computational efficiency. Simulations were performed in the real distribution system available in [4]. This three-phase system is aerial and unbalanced, with a nominal voltage of 13.8kV, 7.065kVA of nominal power. The substation transformer (SE) has a grounded wye-delta connection. Distribution network protection includes seven reclosers and seven fuses. Details are shown in Fig. 4.

Simulations were performed on a computer with an Intel® Core ™ i7-8700 CPU @ 3.20GHz and 16GB of memory.

References

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