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Coordination of directional overcurrent relay using evolutionary algorithm and linear programming

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ABSTRACT

In this article, we present a new method to coordinate the directional overcurrent relay (DOCR) installed in a meshed electricity network. Using evolutionary algorithms and linear programming we solve the problem that allows the calculation of the adjustment intensity (relay setting current, *J*) and the time multiplier factor, *K*, such that, in the light of any triphasic or biphasic failure that may occur in the network, the relays may act in the least time possible and in a coordinated manner. We are considering the problem without taking into account the intensity variations that occur when a switch is opened. It may happen that the problem at hand does not have a solution, in that case we determine the constraints that should be removed in order to achieve at least a partial coordination of the relays.

1. Introduction

Directional overcurrent relays (DOCR) are often used as primary protection in distribution networks (normally radial) and as secondary protection in Transmission networks (normally meshed).

The determination of the DOCR adjustment parameters, in such a way that the primary relay and backup relay coordinate correctly, is relatively easy when it is a radial network. On the other hand, when the network is made up of several meshes, the determination of said parameters is a more complicated task.

The methods employed up till now can be classified into the following blocks:

☐ Topological analysis
☐ Linear programming
☐ Non-linear programming
☐ Genetic algorithms

The first ones are heuristic methods that determine the relays that open the highest number of loops. The *K* parameter of all the DOCR of the network is calculated from those relays, in a sequential and recurrent manner. *J* is considered constant in those methods [1–5].

Methods based on linear programming consider *J* as constant and suggest a simplified [6] and [7] linear model. Some authors suggest the use of Gauss–Seidel for calculating said *K*.

Methods based on [12] and [13] non-linear programming determine both *K* and *J* of each DOCR of the network. And the problem set out in [6] and [7] is solved using non-linear programming techniques.

The non-linear problem set out in [6] and [7] is solved with genetic algorithms through a genetic algorithm in which both *J* and *K* are codified [8–10].

Ref. [11] is an analysis of the different methodologies employed to solve the problem of the coordination of the DOCR of the system, up to the date of publication of the paper.

In this paper, *J*s and *K*s of the DOCR of the system are determined through evolutionary algorithms, in which *J*s become part of the codification of individuals and *K*s are obtained through linear programming as an optimal solution for that *J* group, based on the optimization criterion. An improvement of this method, as against that suggested by other authors, is that should the problem of optimization not have an overall solution, a systematic method of eliminating restrictions is proposed. The elimination of restrictions means that a linear stretch, protected by the relays implicated in the restriction that has been eliminated, would not have backup protection, even though it would have primary protection. Therefore, the solution to the problem must be found eliminating the least possible number of restrictions.

The advantage that this method has over the one proposed in [10] is that, for each combination of *J*s obtained with the evolutionary algorithm, the combination of optimum *K* is obtained by

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applying linear programming. Thus the search parameters are reduced by half.

2. Statement of the problem

2.1. Relay operating-time (t)

The operation time of a DOCR with inverse characteristic is given by [14]:

$$t = \frac{a \cdot K}{\left(\frac{I}{J}\right)^{b} - 1} \quad (1)$$

where t is the operation time, when I is constant; a, b is the are relay constants; K is the time multiplier setting; I is the relay current; J is the relay setting current.

The a and b constants depend on the type of characteristics selected: Standard Inverse (SI), Very Inverse (VI) or Extremely Inverse (EI).

2.2. Coordination of a pair of relays

Fig. 1 shows a stretch of network in default.

The group of (i,j) relay pairs are designated by R where i is j's relay backup when an f_j fault occurs in the line protected by j.

In order for the j and i relays to coordinate when an f_j fault occurs, the operation time of the i relay, $t_{ij1}^{f_j}$, must have a time-delay, $r_{(i,j)}^{f_j}$, on the operation time of the j relay, $t_{jj1}^{f_j}$. Mathematically speaking:

$$t_{ij1}^{f_j} - t_{jj1}^{f_j} \geqslant r'_{(i,j)} \quad \forall (i,j) \in R, \quad \forall f_j \quad (2)$$

where f_j is the fault in the line protected by the main relay, j; $t_{jj1}^{f_j}$ is the operation time of j relay when an f_j fault occurs in the line protected by the j relay while the switch for another main relay of said line, k, is closed (1); $t_{ij1}^{f_j}$ is the operation time of i relay when an f_j fault occurs in the line protected by the j relay while the switch for another main relay of said line, k, is closed (1); $r'_{(i,j)}$ is the time-delay between the i and the j relays.

2.3. Posing of the Problem

When there is a fault in one of the lines of the network, it is convenient that: (a) the operation time of the relays be as little as possible, (b) the main relays be the first to operate and (c) only the main relays operate. Therefore, for the f_j fault depicted in Fig. 1, the j and k relays must be the first and only ones to operate, and their operation time, t_j and t_k, must be as little as possible. The problem would be expressed as such:

$$\begin{aligned} &\psi = \sum_{j=1}^{n}\sum_{f_j=1}^{n_{ccj}} t_{jj1}^{f_j} \\ &Sujeto \quad a: \\ &t_{ij1}^{f_j} - t_{jj1}^{f_j} \geqslant r'_{(i,j)} \quad \forall (i,j) \in R, \quad \forall f_j \end{aligned} \quad (3)$$

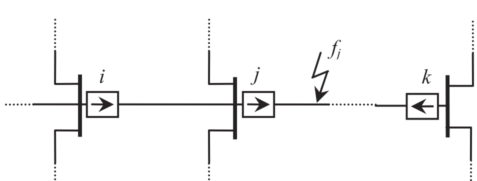

Fig. 1. Pair of directional relays. For the f_j fault the j relay is the main relay and the i is its backup.

where n is the number of relays in the network and n_{ccj} is the number of faults in the line protected by main relay j.

The operation time of each DOCR is determined with the understanding that the I intensity is constant, from the moment the fault occurs until it is isolated.

The adjustment limits of J, J_{min} and J_{max}, depend on the nominal intensity of the line that contains the relay, the adjustment range of said parameter in the relay, the winding ratio of the intensity of the transformer that interconnects the relay with the line and the percentage of the adjacent line that we wish to cover with the relay when it operates as backup. The J limits are those outlined in (4).

$$J_{min} > I_n$$

$$J_{max} = \begin{cases} J_{min} \quad si \quad \exists \quad I_{cc}^{f} < J_{min} \\ min\{I_{cc}^{f}\} \quad \forall f \in F \quad si \quad I_{cc}^{f} > J_{min} \end{cases} \quad (4)$$

where I_{cc}^{f} is the intensity that runs through the backup relay when an f fault occurs.

Substituting (1) in (3) and adding the restrictions of K, [K_{min}, K_{max}], and of J, [J_{min},J_{max}] margins, we have:

$$\psi = \sum_{j=1}^{n}\sum_{f_j=1}^{n_{ccj}} \frac{a \cdot K_j}{\left(\frac{I_{jj1}^{f_j}}{J_j}\right)^{b} - 1}$$

$$Sujeto \quad a:$$

$$\begin{cases} \frac{a \cdot K_i}{\left(\frac{I_{ij1}^{f_j}}{J_i}\right)^{b} - 1} - \frac{a \cdot K_j}{\left(\frac{I_{jj1}^{f_j}}{J_j}\right)^{b} - 1} \geqslant r'_{(i,j)} \quad \forall (i,j) \in R, \quad \forall f_j \\ K_{imin} \leqslant K_i \leqslant K_{imax} \quad \forall i \\ K_{jmin} \leqslant K_j \leqslant K_{jmax} \quad \forall j \\ J_{imin} \leqslant J_i \leqslant J_{imax} \quad \forall i \\ J_{jmin} \leqslant J_j \leqslant J_{jmax} \quad \forall i \end{cases} \quad (5)$$

where $I_{jj1}^{f_j}$ is the intensity that runs through the j relay when an f_j fault occurs in the line protected by the j relay while the switch for the other main relay of said line, k, is closed (1) and $I_{ij1}^{f_j}$ is the intensity that runs through the i relay when an f_j fault occurs in the line protected by the j relay while the switch for the other main relay of said line, k, is closed (1).

When the intensity that runs through the i relay at the time of the f_j fault $I_{ij1}^{f_j}$ is less than or equal to the lower limit of the adjustment intensity, J_i, said relay does not operate (infinite operation time). In such cases, the first restriction of (5) is not included for said faults.

Since the objective function, ψ, and the first restriction are non-linear, the problem is difficult to solve. Its settlement may be tackled with non-linear programming techniques, but their application would be limited by the dimension of the network. To work out any network, it is proposed that an evolutionary algorithm be used to determine the adjustment intensities, J, and to calculate Ks as part of the cost function through linear programming.

The genetic algorithm employed to work out the problem in (5) is based on an evolution strategy ($\lambda + \mu$)-EE, in which only the adjustment intensities, J, of each network relay are codified.

The evolutionary algorithm undergoes an evolution in each repetition, from an initial randomly selected J population, and obtaining, through the use of crossing, mutation and selection operators, better individuals than those of the previous repetition.

Below is a description of elements and operators of the proposed algorithm.