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Providing A New Characteristic for Overcurrent Relays

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Abstract

This with the integration of distributed generation (DG) to meshed distribution systems, the operating time of the protective system becomes a major concern in order to avoid nuisance DG tripping. This paper proposes a new tripping characteristic for directional overcurrent relays (DOCRs) that can achieve a higher possible reduction of overall relays operating time in meshed distribution networks tripping. The proposed tripping characteristic is described in detail. The proposed characteristic is tested on the distribution system is a part of a distribution network, owned by Himmerlands Elforsyning, in Aalborg, Denmark. Also, in this paper using hybrid algorithm GA and LP for solve relay coordination problem. Also, in this paper fault considered is kind of three phase fault. Finally, the results of the proposed characteristic compared with a standard IEC characteristic. The result shown that propose characteristic are better than standard IEC characteristic. Therefore, we can use this characteristic for DOCRs.

Keywords: overcurrent relay; hybrid algorithm; relay characteristic.

1. Introduction

One of the most popular solutions proposed in the literature to solve the protection coordination problem of interconnected systems is the use of optimization methods [1]–[6]. The main objective is to achieve minimum possible tripping times by obtaining the optimal settings of each DOCR. In [6], an MINLP formulation for the protection coordination problem is proposed. Yet, in [7]–[9], the problem is linearized and formulated as a linear-programming (LP) problem. More recently, heuristic techniques, such as particle swarm optimization (PSO), genetic algorithm (GA), and evolutionary methods have been proposed to solve the complex and nonconvex DOCRs protection coordination problem [10]–[13]. Finally, in [2]–[5] and [14], the protection coordination problem is relaxed and formulated as nonlinear programing (NLP) problem.

Usually, DOCRs operate based on the conventional inverse time–current characteristic. According to [15], further reduction of overall tripping time is possible by investigating the tripping time characteristic equation. Since in today's technology overcurrent relays (OCRs)/DOCRs are microprocessor based, the tripping time characteristic equation can be changed by reprogramming the relay. In [15], a new tripping characteristic equation was proposed for OCR based on the logarithmic function. The proposed logarithmic characteristic replaces the conventional inverse time–current characteristic equation of OCRs. The results indicate that the use of the new characteristic equation leads to a noticeable reduction of the tripping time with respect to the conventional characteristic for radial systems using OCR and, more specifically, with inverter-based DG [15].

This paper proposes a new nonstandard relay characteristic that depends not only on current magnitude but also on voltage magnitude for determining the relay operating time. The proposed characteristic, which will be denoted as the time–current–voltage characteristic, can be implemented in microprocessor based DOCRs. The proposed relay characteristic should achieve minimum overall tripping time in the protection coordination problem of meshed distribution networks equipped with directly connected synchronous generator-based DG units as well as inverter-based DG units. In order to test and verify the effectiveness of the proposed approach, the distribution system is a part of a distribution network, owned by Himmerlands Elforsyning, in Aalborg, Denmark. Moreover, the problem with the proposed characteristic is formulated as a constrained LP problem to determine the optimal relay settings for each system. A comparative study is presented that highlights the advantages of the proposed nonstandard characteristic over the conventional time–current relay characteristics.

2. Proposed Relay Characteristic

Most of the conventional DOCRs used up till today utilize a time–current characteristic where the time changes inversely with current magnitude. The characteristic equation varies slightly depending on the type of DOCR used and the standard, which the relay manufacturer follows. In this study, the IEC 255-3 standard inverse characteristic is followed [16]. Since microprocessor-based DOCRs provide an opportunity to develop user-defined characteristics for the DOCR's overcurrent unit [17], [18], this paper proposes a new nonstandard characteristic for the DOCRs.

The proposed DOCR algorithm involves directional sensing and tripping time computation. Usually, DOCR determines the direction of the fault using the phase relationship of the voltage and current. DOCRs are equipped with three voltage transformers (VTs) for three-phase operation in addition to the three existing current transformers (CTs) to measure voltage and current, respectively [19]. Based on the measured quantities, the respective voltages and currents magnitudes and phases are computed. The algorithm used to determine the fault direction varies among different relay manufacturers in terms of how the angular relationships are sensed [19].

The 90 quadrature method is typically used for direction detection. This method involves comparing each current's phase angle with a polarizing quantity which is the line-to-line voltage between the other two phases shifted by an angle commonly referred to as the relay characteristic angle (RCA) for digital and numerical relays [19]–[20].

Since DOCRs have VTs already installed, this paper proposes a modified DOCR characteristic for the tripping time computation that utilizes, in addition to the current, the fault voltage magnitude at the DOCR. The proposed time–current-voltage DOCR characteristic can be expressed as follows:

$$t_i = \left(\frac{1}{e^{1-v_{fi}}}\right)^k \left(\frac{A\ TMS}{\left(\frac{I}{(V_{fi})^k I_{seti}}\right)^B - 1}\right) \quad (1)$$

Where t_i is the tripping time (in seconds) of relay i due to a three phase fault. K is a constant parameter and set to 2. It is the short-circuit current measured at the secondary winding of the current transformer of relay i for a three phase fault while the pickup current I_{set} is the minimum value of current above which the relay starts to operate. TMS is the time multiplier setting of relay i. The constants A and B are set to 0.14 and 0.02, respectively.

3. Protection Coordination Problem Formulation

In the optimal coordination problem, the objective is to minimize the operating time of overcurrent relays for faults at their primary protection zone. Therefore, the OF may be defined as follows:

$$Obj\_fun \ : \ J(X) = Min\sum_{i=1}^{N} t_i \quad (2)$$

where t_i is the operating time of relay i, for a fault occurring exactly in front of the relay. N is the number of network relays, which should be coordinated.

The coordination, or second group, constraints are related to adjustment of operating time of primary and backup relays. The operating time of primary relay should be less than backup relay to satisfy the selectivity of protection scheme. A delay, known as the coordination time interval, is assumed between the operating time of primary and backup relays. In other words, the backup relay gives the chance to primary protection to clear the fault by disconnecting minimum possible part of network. The coordination constraint is presented as follows:

$$t_j^m - t_i^m \geq CTI \longrightarrow \forall \quad m \in M, \qquad M = 2^h \quad (3)$$

Where M is the number of combinations DGs in system test, and h is the number of DG in system test. T_i^m is the operating time of ith relay for mth State from "M" number of combinations DGs available in network, as primary protection and T_j^m is the operating time of jth relay for mth State from "M" number of combinations DGs available in network, as backup protection. The value of CTI varies from 0.2 to 0.5s under different conditions.

In the coordination problem, there are two groups of constraints. The first group is related to the restrictions of relay setting parameters, whereas the second group is related to the coordination constraints. The boundaries of TMS and I_{set}, form the first group, which is due to the limits in the feasible values of relay settings. Coordination of primary and backup relays forms the second group of constraints. The boundary constraints of TDS and I_{set} are presented as follows:

$$\begin{cases} TMS_i^{min} \le TMS_i \le TMS_i^{max} \\ I_{set_i}^{min} \le I_{set_i} \le I_{set_i}^{max} \end{cases} \quad (4)$$

The I_{seti} should be less than the minimum short-circuit current and, at the same time, greater than the maximum possible peak load current. Selection of I_{set} includes a compromise between security and dependability of protection scheme. In some previous research works, the boundaries of I_{set} are assumed only based on the load values [21].

This is generally a non-linear optimization problem, with many constraints. If known, I_{set} is a linear optimization problem becomes. Given the I_{set} and fault current (I), time relay operation is made linear by equation (5).

$$t = a * TMS \quad (5)$$

$$a = \left(\frac{1}{e^{1-V_{fi}}}\right)^2 \left(\frac{0.14}{\left(\frac{I}{(V_{fi})^2 I_{seti}}\right)^{0.02} - 1}\right) \quad (6)$$

Also, the objective function and constraints are been linear by equation (7) and (8).

$$J = \sum_{i=1}^{n} a * TMS \quad (7)$$

$$\begin{cases} a_j.TMS_j - a_i.TMS_i \ge CTI \\ TMS_i^{min} \le TMS_i \le TMS_i^{max} \end{cases} \quad (8)$$

To solve the problem of coordination of hybrid approach GA and LP suggested in [22] is used. In each chromosome in the genetic population presents only the variables as shown in Fig. 2. By extracting the chromosome information, the DOCRs coordination problem is converted to a Linear Programming problem. Therefore, to evaluate the fitness value for each chromosome, the standard LP is solved to determine the corresponding TMS variables [22].

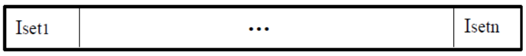

Fig. 1. Structure of chromosome in the hybrid algorithm GA and LP [22].

Each of the chromosome in hybrid algorithm GA and LP divide to "n" home as Fig. 1. In each of these houses, set setting one of the overcurrent relay network is stored. "n" the number of relays on the network.

The flowchart of the hybrid GA and LP is shown in Fig. 2. At first, for each network topology the Primary/Backup (P/B) relay pairs are identified using graph theory. After that, for each P/B relay pairs corresponding to the studied topology, the short circuit currents passing through the relays for near- and far-end faults are calculated.

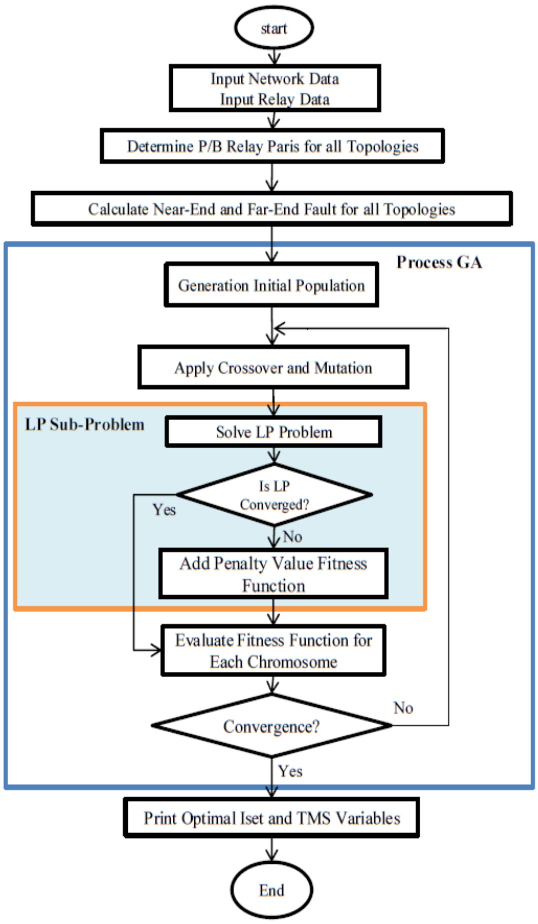

Fig. 2. Structure of chromosome in the hybrid GA method.

The main part of this flowchart which is related to the optimization procedure is explained in two blocks as follows:

Genetic Algorithm Process: In the first step of GA, the initial population is created randomly. The initial I_{set} variable corresponding to each relay is randomly selected based on the mentioned interval that introduced in (4). The next step is evaluation of fitness value for each chromosome in the current generation. The fitness value is defined based on the objective function in (2) which is the overall operating time of primary relays. To evolve the current population and reach to optimal solution, proportional to fitness value, the GA selects some chromosome and uses them for producing the next generation. In order to generate new individuals in the decision space, the crossover and mutation operators are applied to the pair of selected chromosomes. The process will be terminated after a fixed number of generations. The required number of generations varies from system to system and it depends on the system complexity and size of the genetic population.

LP Subproblem: As Fig. 2 shows, the LP subproblem is the main part of fitness function evaluation which is called several times by the GA process. To compute the fitness value for each chromosome, at first the values of the I_{set} variables are extracted by decoding the chromosome information. Based on the fixed values of the I_{set} variables, the nonlinear DOCRS coordination problem is converted to a LP problem. After that, by solving this LP problem the corresponding fitness value and the TMS variables are computed. For some individuals according to the values of the I_{set} variables, the LP subproblem is not converged. In these cases, some of the inequality coordination constraints are violated. To decrease the chance of these chromosomes in the selection process, their fitness values are penalized. The amount of penalty is composed of a fixed value and a variable value in proportion to the number of violated constraints.

4. System Details and Simulation Setup

A) Model of Distribution System

Fig. 3 shows a model of the distribution system in which the proposed new characteristic for overcurrent relays is tested. The distribution system is a part of a distribution network, owned by Himmerlands Elforsyning, in Aalborg, Denmark [23]. Originally, the distribution system, in Aalborg, consists of 3 fixed speed WTGs and a CHP plant with 3 gas turbine generators (GTGs). The fixed speed WTGs are 630 kW machines.

The line data for the test system is given in Table 1. The GTG data are given in [24] and wind turbine data are given in [23]. The modeling of the GTG, its control strategy, and its governor and exciter data are presented in [25]. Relays are represented by “R” in Fig. 3. The transmission grid is represented by GRID and its data is also given in [24]. The voltage of the test distribution system is 20 KV.

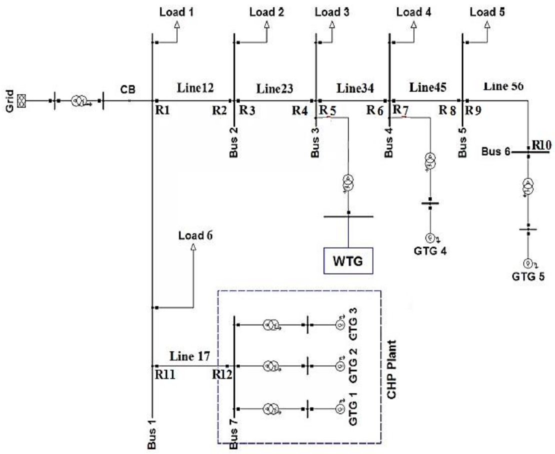

Fig. 3. Test distribution system [23].

Table.1.
Line Data For The Test System.

From Bus	To Bus	Resistance (Ω)	Reactance (Ω)
1	7	0.1256	0.1404
1	2	0.1344	0.0632
2	3	0.1912	0.0897
3	4	0.4874	0.2287
4	5	0.1346	0.0906
5	6	0.1346	0.0906

The ratios of the current transformers (CTs) are indicated in Table 2 and CTI is assumed to be 0.2 seconds.

Table.2.
CT Ratio.

Relay no	CT ratio
R1	300
R2	300
R3	300
R4	300
R5	200
R6	200
R7	120
R8	120
R9	120
R10	120
R11	300

R12	300

B) *The optimal settings relay attained*

The TMS values can range continuously from 0.1 to 1.1, while seven available discrete pickup tap settings (0.5, 0.6, 0.75, 0.9, 1.05, 1.2, 1.35 and 1.5) are considered. then The settings relays for two modes below to will be obtain.

C) *Using IEC standard characteristic*

Table III shows the optimal settings relays after solving optimization by hybrid algorithm GA and LP, using the IEC standard characteristic.

Table.3.
Optimal Settings Relays Using The IEC Standard Characteristic.

Relay no	Iset (A)	TMS
R1	450	0.337
R2	390	0.054
R3	450	0.255
R4	360	0.092
R5	270	0.204
R6	240	0.165
R7	126	0.140
R8	180	0.214
R9	162	0.05
R10	180	0.250
R11	390	0.05
R12	405	0.120
Fval	-	1.931
Obj_Fun (s)	-	6.612

Fval is sum of TMSs.

D) *Using the Proposed characteristic*

Also, Table 3 shows the optimal settings relays after solving optimization by hybrid algorithm GA and LP, using the proposed characteristic.

Table.4.
Optimal Settings Relays Using The Proposed Characteristic.

Relay no	Iset (A)	TMS
R1	405	0.289
R2	390	0.059
R3	450	0.218
R4	390	0.078
R5	270	0.175
R6	240	0.141
R7	150	0.121
R8	180	0.176
R9	162	0.05
R10	144	0.217
R11	405	0.05
R12	405	0.102
Fval	-	1.676
Obj_Fun (s)	-	5.536

Fig. 4 shows the convergence the objective function for the hybrid algorithm GA and LP with using the proposed characteristic.

Table 5 shows a comparison results between the two modes 1 and 2.

According to Table 5, the relays time for the standard IEC characteristic equals 6.612 (s) and the relays time for the proposed characteristic equals 5.536 (s). Therefore, the results of proposed characteristic are better than the standard IEC characteristic.

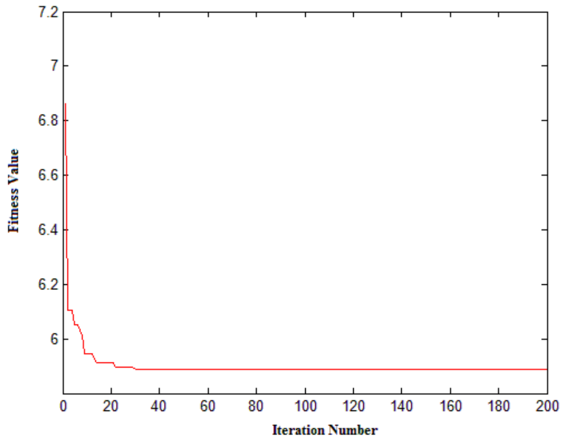

Fig. 4. The convergence the objective function with using the proposed characteristic.

Table.5.
A COMPARISON RESULTS BETWEEN THE TWO MODES 1 AND 2.

Mode	Fval	Obj_Fun (s)
Mode 1 (IEC standard characteristic)	1.931	6.612
Mode 2 (proposed characteristic)	1.676	5.536

5. Conclusion

This paper proposes a new relay characteristic that can be utilized by DOCRs in a meshed distribution network in the presence of DG units. The proposed characteristic relies on utilizing the fault voltage magnitude in addition to the current to determine the operating time of DOCRs. The protection coordination problem is formulated and solved considering the conventional and proposed relay characteristic. The optimal settings attained by solving the hybrid algorithm GA and LP for case study with either a conventional or proposed DOCR characteristic ensure proper coordination of all DCORs under three-phase faults that might occur at near-end, and far-end locations on each line of a system. The results show that the utilization of the proposed characteristic for each DOCR in a meshed distribution network can achieve a significant reduction in the total relay operating time.

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