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Application of PSO for optimal coordination of directional over-current relays in distribution system with distributed renewable energy sources

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ABSTRACT

The use of distributed renewable energy sources (D-RES) in the electrical network has expanded greatly. However, integration of these resources into distribution systems caused more problems in protection related issues such as mis-coordination and changes the direction and value of fault currents. When connecting new D-RES to electrical power distribution networks, it is required to re-coordinate directional over-current relays (DOCR) to ensure the continuity of the power transmission when the short circuits take place. This work presented a particle swarm optimization (PSO) algorithm to determine two independent variables called pickup current (Ip) and time dial setting (TDS) for optimal setting of relays. From analysis result, the impacts of RES location in the distribution system on DOCRs had been observed on the optimal relays settings.

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1. INTRODUCTION

Distributed renewable energy generation is small power-generating unit clubbed with modern technologies and present diverse challenges while integrating with utility grid Most of the distributed renewable energy sources (D-RESs) shall be located near load centre on distribution grid. D-RES introduces negative effects on system operation. One of the negative impacts is relay coordination [1]. The integration of distributed renewable energy sources (D-RES) on the electrical network contains many advantages.

However, the result of introducing these energies in the network will change the value and direction of energy flow as well as short-circuit current levels in different points. Several factors may lead to the effects of RES energies on protection devices, including the type of technology, capacitance, and the position in the network [2].

Bougouffa and Chaghi [3] proposed a dual simplex method to find the setting of time dial setting (TDS) while keeping constant values of Ip in modified IEEE 33-bus with installing the D-RES. In the present article, a particle swarm optimization is proposed to find out the new setting for both TDS and I_P of relays with respect to various constraints in the presence of two D-RES.

2. DIRECTIONAL OVER-CURRENT RELAYS

For optimal coordination of directional over-current (DOC) relays, it is necessary to determine the optimal values of TDS and IP of each relay in the system, this optimization of TDS and IP for minimize the operating time of the primary relays. The tripping time equation of DOC relay is a non-linear equation, depending on the fault current and both TDS and IP settings. Thus, the relay tripping time equation for DOC relay is given by (1) [4], [5].

$$T_{ot} = TDS \times \frac{0{,}14}{\left(\frac{I_f}{KCT \times I_p}\right)^{0.02} - 1} \tag{1}$$

Where, KCT is the current transformer ratio. The pickup value is the minimum value of the current for which the relay operates. The operating time (T_{ot}) of the relay is defined by the TDS for each current value. The limits on the TDS can be presented as (2).

$$TDS_i^{min} \leq TDS_i \leq TDS_i^{max} \tag{2}$$

The TDS are assumed to vary between 0.05 and 1.2.

$$I_{Pi}^{min} \leq I_{Pi} \leq I_{Pi}^{max} \tag{3}$$

The pickup current setting Ip are assumed to vary between 0.25 and 2.5 with step 0.25.

When a fault occurs, there must be primary protection for isolat as soon as possible to reduce the isolated area as much as possible, and in the case of primary relay, other relay should be protected as backup protection to assure the requirement of selectivity. In order to satisfy selective requirements, you must add the following limitation [6], [7].

$$T_{back-up}^{FI} - T_{primary}^{FI} \leq CTI \tag{4}$$

$$T_j^{FI} - T_i^{FI} \leq CTI \tag{5}$$

Where:
Tj^{F1} is the tripping time of jth backup relay.
Ti^{F1} is the tripping times of ith primary relay.
The CTI is the minimum time gap in operation between the primary and its backup relay, is usually selected between 0.2 s and 0.5 s [4], [7], [8]. The CTI is set to a desired value of 0.3 sec.

3. IMPLEMENTATION OF PROPOSED PSO ALGORITHM ON THE COORDINATION PROBLEM

The particle swarm optimization (PSO), which has gained rapid popularity as an efficient optimization technique, is relatively a recent heuristic introduced by Eberhart and Kennedy [9]. The various steps involved in the implementation of PSO to the DOCRs problem with 64 decisions variables are:

Step1. Input the data of 33 IEEE distribution test system for calculate the power flow and current
Step2. Define population size (50), no of iteration (=500), assume suitable values of PSO parameters
Step3. Initial searching points and velocities are randomly generated within their limits. Pbest is set to each initial searching point. The best-evaluated values among individual best (P^{best}) are set to global best (g^{best}).
Step4. New velocities are calculated using the equation (9).
Step5. Evaluate the fitness values for new searching point. If evaluated values of each agent is better than previous Pbest then set to Pbest. If the best Pbest is better than best gbest then set to gbest.
Step6. If the maximum iteration is reached stop the process otherwise go to step3.

The summation of tripping times of all primary relays is known as objective function (OF). Conventionally, the optimal coordination problem determines two parameters, that is, the pickup current setting I_P and the time dial setting TDS. The OF is given by (6).

$$OF = min \sum_{i=1}^{N} t_{il} \tag{6}$$

Where: OF is the objective function in sec,

t_{il} is the operating time of the ith relay,
N is the total DOCRs in the system.
The two variables in the objective function are TDS and Ip. By minimizing both the TDS and Ip we can be able to minimize the tripping time of the primary relays and satisfying the CTI.

3.1. Goal of Study

This work presented the PSO algorithm to find the optimal CTI of DOC Relays. The proposed algorithm was evaluated using IEEE 33-bus system in presence of two D-RESs. The main contributions of this paper are using the optimization technique to find optimal relay settings, solve the non-linear coordination problem of DOC Relays with the system changed topology.

4. CASE STUDIES

In this paper IEEE 33-bus radial distribution feeder is considered to optimal pair of DOC Relays in presence of two emplacements of D-RES. The operating voltage is 12.66 kV. DOC Relays are used in the system to protect the feeder in case of three phase faults. The IEEE 33-bus system is presented in Figure 1 [10], [11]. The model is simulated in MATLAB software without and with renewable energy sources to calculate the optimal setting of DOCRs using PSO method under system changes. The program is implemented for two emplacements of renewable energy sources. Three phase faults are generated on each bus.

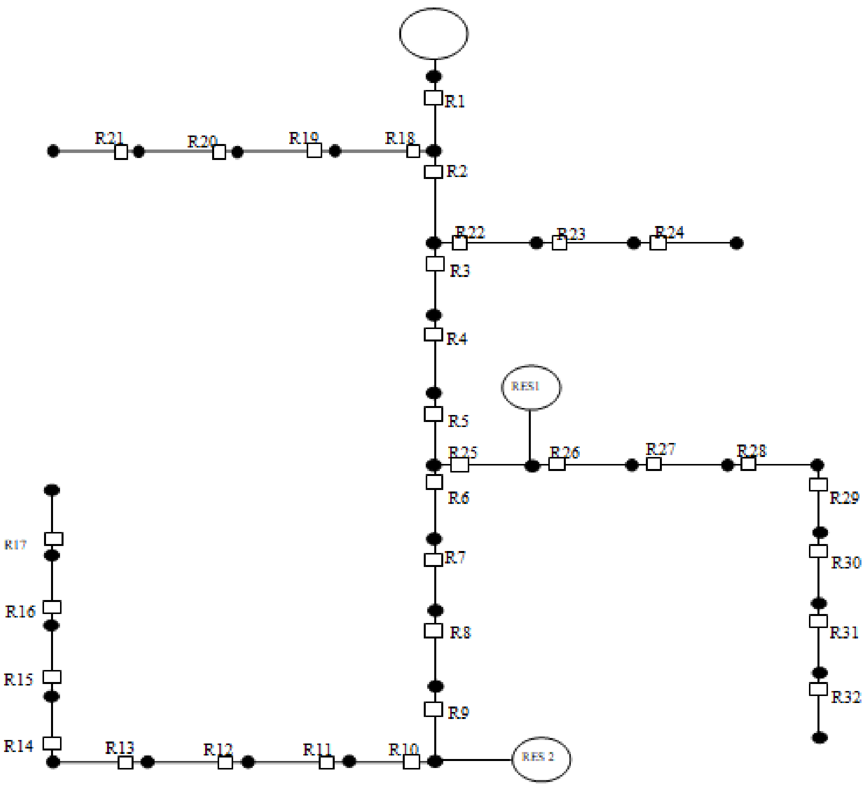

Figure 1. Power distribution system of the IEEE 33-bus system under study

4.1. Impact of the D-RES on the short circuit level

From a power perspective, the integration of a new D-RES into the distribution networks will increase the power of the network. Thus, the new source will be modeled in such a way as to take only its current contribution in the event of a short circuit. The electrical network, of which we will determine the different short circuit currents without (and with) D-RES, has a radial architecture Figure 1, and we take a part of this network for the calculations of short circuit currents, as show in Figure 2.

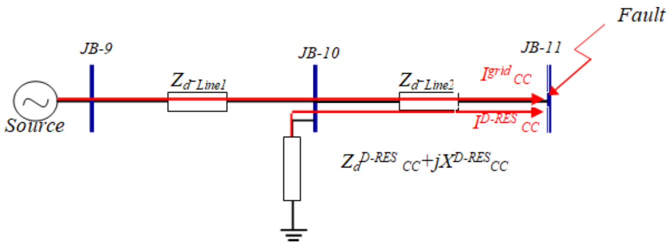

Figure. 2. Simple distribution network with RES

The current in the fault point will be the sum of the short circuit current without D-RES and the short circuit current injected into the network only by the D-RES, is given by (7).

$$I_{cc} = I^{grid}{}_{cc} + I^{D-RES}{}_{cc} \tag{7}$$

The direct impedance seen between the bar (11) and the earth is (8).

$$z^{D-RES}{}_{d} = z^{D-RES}{}_{d-cc} + jX^{D-RES}_{cc} + Z_{d-Line2} \tag{8}$$

Implies that (9), (10), (11).

$$I_a^{D-RES} = \frac{V_d^p}{z^{D-RES}{}_{d-cc}+jX^{D-RES}_{cc}+Z_{d-Line2}} \tag{9}$$

$$I_b^{D-RES} = a^2.\frac{V_d^p}{z^{D-RES}{}_{d-cc}+jX^{D-RES}_{cc}+Z_{d-Line2}} \tag{10}$$

$$I_c^{D-RES} = a.\frac{V_d^p}{z^{D-RES}{}_{d-cc}+jX^{D-RES}_{cc}+Z_{d-Line2}} \tag{11}$$

We find the fault current is (12), (13), and (14).

$$I_a = \frac{V_d^P}{Z_{d-cc}+Z_{d-Line1}+Z_{d-Line2}} + \frac{V_d^p}{z^{D-RES}{}_{d-cc}+jX^{D-RES}_{cc}+Z_{d-Line2}} \tag{12}$$

$$I_a = a^2.\left[\frac{V_d^P}{Z_{d-cc}+Z_{d-Line1}+Z_{d-Line2}} + \frac{V_d^p}{z^{D-RES}{}_{d-cc}+jX^{D-RES}_{cc}+Z_{d-Line2}}\right] \tag{13}$$

$$I_c = a.\left[\frac{V_d^P}{Z_{d-cc}+Z_{d-Line1}+Z_{d-Line2}} + \frac{V_d^p}{z^{D-RES}{}_{d-cc}+jX^{D-RES}_{cc}+Z_{d-Line2}}\right] \tag{14}$$

5. RESULTS AND DISCUSSION

Two locations are chosen for installing the D-RES in the distribution system; to illustrate the effects of D-RES insertions on the setting of Relays. A minimum relay tripping time is the main goal of setting of relays. Also, the CTI is satisfied (i.e., CTI≥0.3). Table 1 shows the optimal results of TDSs in presence of D-RES installation in the 33-bus distribution system. Table 2 shows the optimal results of Ips in presence of D-RES.

Table 1. Setting values of relais TDS

Relays	Setting of TDS	
	Without D-RES	With D-RES
TDS_1	0.5000	0.5000
TDS_2	0.3500	0.3500
TDS_3	0.3400	0.3400
TDS_4	0.3300	0.3300
TDS_5	0.3400	0.3000
TDS_6	0.3500	0.3500
TDS_7	0.2700	0.2700
TDS_8	0.2400	0.2000
TDS_9	0.3100	0.3800
TDS_{10}	0.4600	0.5700
TDS_{11}	0.4200	0.5200
TDS_{12}	0.3000	0.4000
TDS_{13}	0.3400	0.4500

Table 2. Setting values of relais Ip

Relays	Setting of Ip	
	Without D-RES	With D-RES
Ip_1	0.7300	0.7300
Ip_2	0.7500	0.7500
Ip_3	1.0400	1.0400
Ip_4	0.8100	0.8100
Ip_5	0.3500	0.5000
Ip_6	0.3500	0.3500
Ip_7	1.0700	1.0700
Ip_8	1.0100	1.2000
Ip_9	0.3600	0.3600
Ip_{10}	0.5200	0.5200
Ip_{11}	0.5600	0.5300
Ip_{12}	0.5400	0.5100
Ip_{13}	0.5600	0.5500

Table 1. Setting values of relais TDS *(continued)*

Relays	Setting of TDS	
	Without D-RES	With D-RES
TDS_{14}	0.3700	0.4100
TDS_{15}	0.3600	0.4500
TDS_{16}	0.3000	0.3900
TDS_{17}	0.3200	0.4500
TDS_{18}	0.4000	0.0700
TDS_{19}	0.2600	0.1700
TDS_{20}	0.3500	0.3700
TDS_{21}	0.3200	0.3300
TDS_{22}	0.3300	0.0900
TDS_{23}	0.2900	0.0500
TDS_{24}	0.2800	0.3200
TDS_{25}	0.4300	0.4000
TDS_{26}	0.4400	0.3800
TDS_{27}	0.3200	0.2600
TDS_{28}	0.3300	0.2700
TDS_{29}	0.3400	0.3700
TDS_{30}	0.2600	0.2800
TDS_{31}	0.3300	0.3500
TDS_{32}	0.4200	0.4400

Table 2. Setting values of relais Ip *(continued)*

Relays	Setting of Ip	
	Without D-RES	With D-RES
Ip_{14}	0.5200	1.0500
Ip_{15}	0.5300	0.5000
Ip_{16}	0.5000	0.5300
Ip_{17}	0.8300	0.5300
Ip_{18}	1.2200	1.2300
Ip_{19}	1.0300	1.0000
Ip_{20}	0.5000	0.5200
Ip_{21}	0.5500	0.5100
Ip_{22}	0.9800	1.0300
Ip_{23}	1.0200	1.0200
Ip_{24}	1.0100	0.9800
Ip_{25}	0.5200	0.7500
Ip_{26}	0.5500	0.5200
Ip_{27}	0.5700	0.5100
Ip_{28}	0.5200	0.5600
Ip_{29}	0.7200	0.7400
Ip_{30}	1.5600	1.6000
Ip_{31}	1.0900	1.1300
Ip_{32}	0.5100	0.5200

The results obtained after the study from the proposed PSO algorithm of the impact of D-RES on the DOC-Relays settings are displayed in Tables 1 and 2. By examining the results obtained, it can be said that D-RES increased the values of short circuit currents at the fault point. This increase will be reflected in the reduced operating time for protection before damage to the equipment that makes up the electrical network.

6. CONCLUSION

In this paper the authors presented the particle swarm optimization method to explain and visualize the influence of D-RES on the protection settings of DOC Relays in the test system. The result of using PSO algorithm on an IEEE 33-bus is compared in two cases with and without D-RES. From analysis result, the impacts of D-RES location in the distribution system had been observed on the optimal relays settings. The results show the optimal settings of DOC-relays for eliminate the three fault currents.

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