Optimal Coordination of Directional Overcurrent Relays in a Microgrid System Using a Hybrid Particle Swarm Optimization

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Abstract: Recently, microgrid operation increased significantly with increasing distributed renewable energy resources in the power system. Microgrids can operate with and without utility. Fault currents are significantly different in island and utility connected operation modes. Therefore, microgrid protection is one of the important subjects in microgrid operation. In this paper, a hybrid particle swarm optimization (HPSO) approach has been developed for coordination of directional overcurrent relays (DOCRs) in a microgrid system. The coordination constraints include the utility connected and an autonomous condition of the microgrid operation. In the optimization procedure, the current setting (I_{set}) of relays is considered as discrete parameters and time multiplier settings (TMS) is assumed as continues parameter. The proposed algorithm has two parts, in the first part, PSO is used to calculate the I_{set} and in the second part, linear programming is applied to calculate the TMS of each relay. In the case study, loads connected to the network are divided into critical and noncritical ones. In normal operation of the system, distributed generators (DGs) operate in parallel with the utility. When a fault occurs on the utility side, noncritical loads are disconnected from the network and DGs are operated in microgrid as islanded mode. Regarding to simulation results, DOCRs have a suitable and reliable operation in both conditions of microgrid operations. In addition, overall operating time of the primary relays is properly minimized.

Keyword: **HPSO, microgrid, linear programming, overcurrent relay, relay coordination**

1 Introduction

Microgrids have been proposed as a way of integrating large numbers of distributed generation (DG) renewable energy sources with distribution systems [1]. Microgrid can operate in both the grid-connected mode and the islanded mode [1]-[3]. A microgrid, it is seen as a single aggregate load or source when it is connected to the system. Reliable supply to customers is one of the benefits of microgrid because it could operate in island mode when the event of a major disturbance occurs in the system [1]. However, microgrid system has many challenges in the power system. Microgrid protection is one of these challenges [4] because fault currents are different in both of microgrid operation circumstances. Therefore, overcurrent relays should be coordinated properly so that they have an appropriate operation in grid-connected and the islanded modes for microgrid operation.

(DOCRs) coordination problem is a mixed integer nonlinear programming (MINLP) because TMS and I_{set} parameters are continuous and integer variables, respectively [5]. Several algorithms have been proposed to coordinate DOCRs in the power system. In [6], a modified PSO algorithm is proposed to calculate relay settings of DOCRs in power system. In [5] optimal time coordination of over current relays considering different network topologies was performed using a hybrid genetic algorithm (GA). In [7] DOCRs coordination problem solved using an approach based on the interval analysis considering the uncertainty in the network topology. In [8], a new hybrid particle swarm optimization has been proposed for DOCRs coordination problem. In [4] DOCRs was coordinated for microgrid in both of microgrid operation modes as separately using PSO. A modified particle swarm optimization in [9] has been used DOCRs coordination problem solving for microgrid system only in islanded mode.

In this paper, DOCRs coordination problem in microgrid has been performed using a hybrid PSO algorithm. Proposed algorithm will coordinate DOCRs properly so that protection system has an appropriate operation with satisfying coordination constraints for both of microgrid operation modes. Both TMS and I_{set} parameters take into a count in optimization procedure.

2 Overcurrent relay coordination

The aim of DOCRs coordination problem is to determine the TMS and I_{set} of each relay, so that the overall operating time of the primary relays is minimized [5]. Therefore, Equation 1 can define as the objective function. In this equation, t_i and n are the operating time of the *i*th relay for

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near-end fault and number of relays, respectively. Also, the weight W_i shows the probability of fault occurring in each protection zone. This weight is usually set to one.

$$\min J = \sum_{i=1}^{n} W_i t_i \tag{1}$$

In this paper, characteristic functions of all relay were supposed identical and approximated by the Equation 2. In Equation 2 TMS_i is time multiplier setting i_{th} overcurrent relay, I_i and I_{set_i} is the fault current and pick-up current of this relay, respectively.

$$T_i = \frac{0.14 \times TMS_i}{\left(\frac{I_i}{I_{set_i}}\right)^{0.02} - 1} \tag{2}$$

DOCRs coordination problem has several constraints that are described as follows:

- There are coordination constraints between the primary relay and its/their backup relay for near-end and far-end faults. These constraints are defined with regarding Figure 1 by Equation 3 Where $t_i^{F_1}$ and $t_i^{F_2}$ are the operating time of ith primary relay for the near-end and far-end faults, respectively. Also, $t_j^{F_1}$ and $t_j^{F_2}$ are defined in the same way as the jth back-up relay. Also, CTI is the coordination time interval between primary and back-up relay.

$$\begin{aligned} t_j^{F_1} - t_i^{F_1} &\geq CTI \\ t_j^{F_2} - t_i^{F_2} &\geq CTI \end{aligned} \tag{3}$$

- TMS is one of the coordination constraints of each relay that is between lower and upper bounds, which is defined as follows.

$$TMS_i^{\min} < TMS_i < TMS_i^{\max} \tag{4}$$

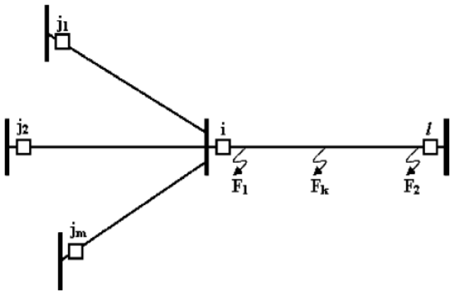

Figure 1 Schematic diagram of Primary and backup relays

- Lower and upper bounds for pickup current for each relay are other coordination constraints that are defined by Equation 5. In this equation $I_{load_i}^{\max}$ is maximum load current and $I_{fault_i}^{\min}$ is minimum fault current. α and β are constant parameters.

$$\max(\alpha . I_{load_i}^{\max}, I_{set_i}^{\min}) < I_{set_i} < \min(\beta . I_{fault_i}^{\min}, I_{set_i}^{\max}) \tag{5}$$

3 Hybrid particle swarm optimization

Particle Swarm Optimization (PSO) is one of the as optimization algorithm. In this algorithm, the best previous position explored by the nth particle is recorded and denoted as p_{best}. g_{best} is Another value in PSO that is the best value obtained so far by any particle in the population. This best value is a global best. Each particle tries to modify its position using the current velocity and its distance from p_{best} and g_{best}. The modification can be represented by the concept of velocity and can be calculated as shown in the equation (6) and (7) [8]. In these equations, *x* and *v* show, the particle's position and its velocity in the search space, respectively. Also the constant parmeters c_1 and c_2 are the learning rate or the acceleration term that pulls each particle towards p_{best} and g_{best} positions. The inertia weight governs how much of the previous velocity should be retained from the previous time step. In this work, a linearly decreasing inertia weight is used [8].

$$\begin{aligned} v_{i+1} &= \omega v_i + c_1 rand\,(p_{best} - x_i) \\ &+ c_2 rand\,(g_{best} - x_i) \end{aligned} \tag{6}$$

$$x_{i+1} = x_i + v_{i+1} \tag{7}$$

In this paper, an algorithm base on hybrid of modified PSO and linear programming is used to overcurrent coordination relays. In this modified PSO, then updating process are done with equation (8) if the constraints are not satisfied. Then the constraints are checked again, and if the constraints are not satisfied, updating is done by equation (9) [8].

$$\begin{aligned} v_{i+1} &= c_2 rand(g_{best} - x_i) \\ x_{i+1} &= x_i + v_{i+1} \end{aligned} \tag{8}$$

$$\begin{aligned} v_{i+1} &= 0 \\ x_{i+1} &= p_{best} - x_i \end{aligned} \tag{9}$$

In our problem, a random set of I_{set} which one available in the relays are selected for creating the first population at the beginning and then for improving the convergence of PSO the TMS is computed with linear programming. Then the position of each particle (I_{set}) is updated using 6, and then the constraints should be checked and If the constraints are not satisfied, updating process will do regarding to Equations 8. and 9. The TMS can be calculated using linear programing method at the end of each iteration of PSO method when updating process of the I_{set} is finished and quantizing to available setting. In this work, both near-end and far-end faults for both operation modes of microgrid are taken into account in the DOCRs constraints.

3 Simulation results

In this paper, microgrid system in Figure 2 is used for DOCRs coordination problem. This system consists of two synchronous based DGs connected to the utility. Loads connected to the network are divided into critical and noncritical ones. Circuit breaker B_s opens when any fault or abnormal condition occurs on the utility side. Also, noncritical loads are disconnected by central protection unit operation, and the DGs are operated in an islanded mode. Therefore, load currents and fault currents passing through the relays change due to the change of the system configuration. The system data for generators, loads and lines are presented in Table 1, 2 and 3 [4]. Also, it is noncable that frequency, S_{base} and V_{base} are assumed 60 (HZ), 10 (MVA) and 13.8 (kV), respectively for microgrid system. Also, CTI is assumed to be 0.3 seconds and TMS is a continues parameter which can set in [0.1 1.1], while the I_{set} is a discrete value which can set between 0.5 to 2.5 with step 0.25. and the parameters of PSO algorithm C_1, C_2, iteration and population is considered 1.7, 1.2, 75 and 15, respectively.

Table 3 Line data

$R_{line1}=R_{line2}=R_{line3}=R_{line4}$	1.155 (ohm)
$L_{line1}=L_{line2}=L_{line3}=L_{line4}$	0.76 (H)

Table 1 DG_1 and DG_2 Specification

S_{base}	5 (MVA)	V_{base}	13.8 (kV)
R_a	0.0052 (pu)	H	2.9 (sec)
X_d	2.86 (pu)	X_q	2 (pu)
X_d'	0.7 (pu)	X_q'	0.85 (pu)
puX_d''	0.22 (pu)	X_q''	0.2 (pu)
X_p	0.098 (pu)	T_{do}''	0.01 (sec)
T_{do}'	3.4 (sec)	T_{qo}'	0.05 (sec)

Table 2 Load data

Load	Critical load		Load	Noncritical load	
	MW	MVA		MW	MVA
L_1	1.8	0.87	L_3	0.8	0.6
L_2	0.8	0.6	L_4	1.29	0.76
L_5	1.2	0	L_6	0.8	0.6
L_8	1.8	0.87	L_7	1	0
L_{11}	1.8	0.87	L_9	1.29	0.76
L_{12}	1.8	0.87	L_{10}	1.8	0.87
L_{13}	0.8	0.6	L_{14}	0.8	0.6

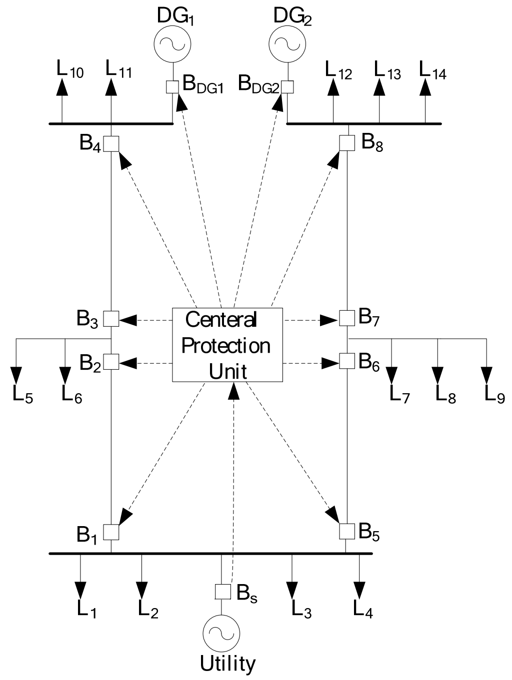

Figure 2 Schematic diagram of case study

The primary and backup relays pairs for both grid connected and micro-grid operation of DGs is presented in Table 4.

Optimal value of setting parameters for overcurrent relays coordination are shown in Table 4 Linear programming and HPSO algorithm calculate these parameters. According to Table 4 overcurrent relay coordination is performed by both algorithms by satisfying all relay coordination constraints in both operation modes of microgrid. However, HPSO algorithm is archived the better solution than LP algorithm. Also, The convergence of the HPSO is shown in Figure 3 Regarding to Figure 3 the algorithm is converged to the global solution.

Table 4 Primary and backup relays

Pairs no.	DG operating in parallel with utility		Microgrid operation of DGs	
	primary	backup	primary	backup
1	6	8	6	8
2	5	2	5	2
3	1	9	-	-
4	1	6	1	6
5	2	4	2	4
6	7	5	7	5
7	8	10	8	10
8	3	1	3	1
9	4	11	4	11

Table 4 Optimal setting of the relays

Relay no.	LP		H PSO	
	TMS	I_{set}	TMS	I_{set}
1	0.1	2.5	0.2276	0.5
2	0.148	1.75	0.124	2
3	0.1	0.5	0.1	0.5
4	0.2074	2	0.1951	2
5	0.1943	0.75	0.2272	0.5
6	0.1733	2	0.1275	2
7	0.1	0.5	0.1	0.5
8	0.2434	2	0.1972	2
9	0.3813	2	0.335	2
10	0.3452	2	0.3329	2
11	0.2539	2	0.2902	1.5
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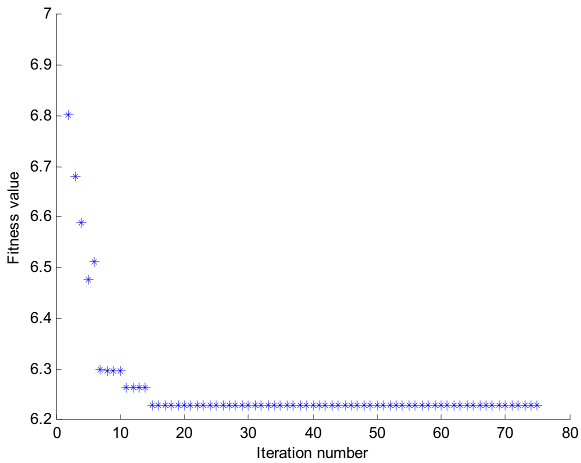

Figure 3 Convergence of the proposed method

4 Conclusion

In this paper, HPSO algorithm is proposed to overcurrent relay coordination in microgrid system.. In DOCRs, the time multiplier settings of relays is considered as continues parameter and current setting of relays is considered as discrete parameters. In our coordination problem, all overcurrent coordination constraints are satisfied when microgied operates in the grid connected mode and islanded mode. Presented results indicate that total operating time of all relays is smaller when HPSO algorithm is used DOCRs.

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