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Particle Swarm Optimization for Directional Overcurrent Relay Coordination with Distributed Generation

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ABSTRACT

The Directional Overcurrent Relays (DOCRs) Coordination with Distributed Generation (DG) optimization problem is addressed in this study using the optimization method Particle Swarm Optimization (PSO). Changes in fault current, bus voltages, power flow, and reliability may result from DG integration. Thus, it might have an impact on the current protection coordination system. The formulation is built on a Mixed Integer Non-Linear Programming (MINLP) problem to address this DOCR issue. MATLAB was used to validate the technique on the IEEE-14 bus system, and Electrical Test Transient Analyzer Programming (ETAP) version 2021 software was used to model the test system. According to the simulation results, the suggested PSO with DG for Case 2 has reduced power loss by 6.24% and relay operating time by 46.79% when compared to PSO without the presence of DG.

Keywords: particle swarm optimization, directional overcurrent relay, distribution grid

1 INTRODUCTION

Power system network faults are a common occurrence that cannot be discounted. If nothing is done, this situation could lead to a failure of the power system. The existence of distributed generation (DG) is a current trend in power system functioning. This DG installation in a certain spot, with the right kind of equipment, and in the right size could alter the fault current. The distribution network's dependability, power flow, and bus voltage can all fluctuate [1]. If the components are not properly controlled by a system, they could have a negative impact on the networks and the loads. As a result, it may have an impact on protection coordination, coordination time, and damage to electrical equipment, which could cause the electrical grid to go offline.

Directional Overcurrent Relays (DOCRs) are currently used to secure modern interconnected network systems. With multi-source network and DG, the protection strategies have grown more difficult. The introduction of DGs may impact the system's network configuration and power loss by affecting the protection mechanism already in place. According to changes in network distribution, DOCR settings for example Time Multiplier Setting (TMS), Plug Multiplier Setting (PMS) and Pickup Current, I_p will be adjusted [2]. The researcher must therefore use a variety of strategies to address the miscoordination problem of DOCRs in the presence of DG.

Due to the size, complexity, and nonlinearity of the system, DOCRs coordination is seen as an optimization problem [3]. Most optimization strategies resulted in local optima for the solution. When dealing with complicated power systems, several standard analytical procedures, including Linear Programming (LP), Non-Linear Programming (NLP), and Mathematical Based Optimization (MBO) techniques, are proven to be erroneous and excessively time consuming. Additionally, in ring networks and with DG presence, main and backup relay pair miscoordination has occasionally been seen. This could result in incorrect DOCR responses to the same fault location. To address and resolve this issue, a trustworthy Nature Inspired Metaheuristic Algorithm (NIMA) has been developed.

The ideal setting of DOCRs, TMS and PMS or I_p has been suggested for a decade using intelligence NIMA such as swarm families. The DOCR's coordination problem have been addressed using Artificial Bees Colony (ABC), Honey Bee Algorithm (HBA), Firefly Algorithm (FA), and PSO [4]-[7]. Due to its superior performance, speed, and lack of a need that the problem be differentiable, PSO has been employed to tackle this issue extensively. To solve DOCRs with DG, PSO is used.

A comparison between PSO considering a balanced network three phase fault for an IEEE 14-bus system with and without DG penetration was done. According to the findings, the proposed PSO has reduced power loss and relay operation time.

2 FORMULATION OF DOCR

The goal of the study is to establish the best DOCR settings for the test system for symmetrical three phase fault occurrences with and without DG. Prior to choosing the DOCRs configuration, characteristics, and type, it is necessary to satisfy common restrictions like coordination time margin and objective function.

2.1 Relay Characteristic and Type

Relay typically has two types of features: linear characteristics and non-linear characteristics. In this investigation, the non-linear relay characteristic based on Europe standard, IEC 60255-4 was selected [8]. The relay can be visualized as an equation and is an ordinary Inverse Definite Minimum Time (IDMT) microprocessor as in equation (1). Because of their quick response times, precision over time, and significantly lower cost when compared to electromechanical relay, microprocessors are widely used nowadays.

$$t_i = \left[\frac{K}{\left({I_{f_i}}/{I_{p_i}} \right)^{\alpha} - 1} + L \right] TMS_i \quad (1)$$

where t_i is the i[th] relay's fault's relay operation time, I_{fi} is its fault current and I_{pi} is its pickup current setting. The i^{th} relay's TMS_i values of the range from 0.05 to 1 and its I_{pi} values have discrete range between 100 to 500 with a step size of 1. Based on the IDMT microprocessor type, the fixed is K = 0.14, L = 0, and α = 0.02 [9].

2.2 Constraint for Main and Backup DOCR

The value of the main and backup relay operation time needs to be established initially to prevent improper coordination between the main and backup DOCR. One of the primary factors needed to determine if the main relay is functioning properly is the Coordination Time Interval (CTI) or Coordination Time Margin (CTM). In terms of equation (2) below, it can be made simpler.

$$\Delta t_{mb} = t_b - t_m - CTM \quad (2)$$

where t_m is the main relay's operation time and t_b is the backup relay's operation time. CTM fluctuates between 0.2 and 0.5 seconds depending on the situation [10].

2.3 Objective Function

The goal of this study is to reduce the test system's DOCR's operation time. In terms of total relay operating time, the formulation is shown as equation (3).

$$OF = min\left(\left(\frac{K}{\left({I_{f_1}}/{I_{p_1}}\right)^{\alpha}-1} + L\right)TMS_i + \cdots \left(\frac{K}{\left({I_{f_i}}/{I_{p_i}}\right)^{\alpha}-1} + L\right)TMS_i\right) \quad (3)$$

3 PARTICLE SWARM OPTIMIZATION

Rusel C. Eberhat, an engineer, and James Kennedy, an American social psychologist, created the Particle Swarm Optimization (PSO) swarm in 1005 [11]. It is often motivated by human behaviour and occasionally by the parallel of swarming fish and birds. Based on specific amount of knowledge, each particle or group of agents moves about the n-dimensional search space in pursuit of the best solution. The swarm particle then adjusts its orientation to move in the direction of both its individual best positions (pbest) and the overall best position (gbest), while also exhibiting a tendency to wander randomly. The particles adjust their position and speed in accordance with equation (4).

$$v_i^{k+1} = \omega v_i^k + c_1 rand \times (pbest_i - x_i^k) + c_2 rand \times (gbest_i - x_i^k) \quad (4)$$

where *c1, c2* are two positive acceleration constants, v_i^k is particle *i's* prior velocity, *rand* is a random variable with values between 0 and 1, and ω is the inertia weight.

Normal values for c1, c2, which determine how the particle flows during the initial iteration, are 2 and 3. Equation (5) can be used to calculate the particle's new position from equation (4).

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (5)$$

where v_v^{k+1} is the newly updated particle velocity *i* and x_i^k is the earlier position of the particle *I,*

An inertia weight is utilized at the early section of equation (4) to regulate the PSO's convergence. The convenience value of offers a balance between global and local research and exploitation to achieve an ideal solution with fewer iterations. Equation (6) establishes:

$$\omega_i = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{k_{\max}} \times k \qquad (6)$$

where k and k_{max} are the current iteration and maximum iteration and ω_{min} and ω_{max} are the minimum and maximum inertia weight respectively.

The inertia weight typically ranges between 0.9 and 0.4. This parameter was added to the startup procedure to provide additional global searching capability. The pseudo code shown in Figure 1 can be used to summarize the fundamental processes of the PSO approach.

```
PSO algorithm
Create the TMS xi starting population (i=1, 2, … ,N)
Determine maximum inertia weight and velocity
Make iteration 1
For individually particle {
    Determine the fitness function (Ofi) value
    Analyze the individual's best position, pbest
    Analyze the group's best position, gbest
    Whenever the fitness function value exceeds pbest
    {Set pbest to the current fitness value}
    {set gbest=pbest} if superior to gbest}
For each particle {
The previous position and velocity are utilized to update particle position by using (5) to determine its velocity value by using (4)}
Iteration = Iteration+1
Until Iteration equal to maximum
```

Figure 1: Pseudo code of the PSO

Figure 2 depicts the flow diagram used to address the DOCR coordination issues.

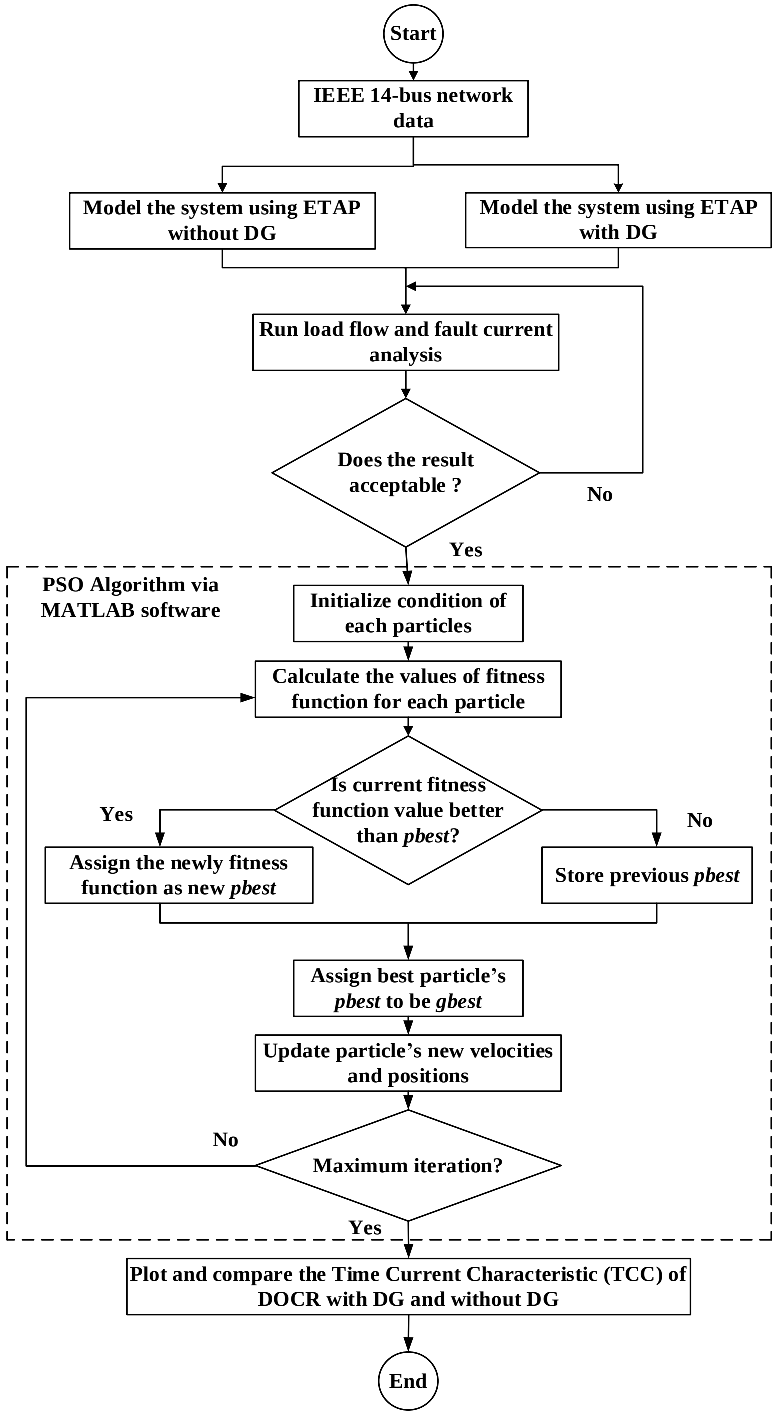

Figure 2: Flowchart of DOCR Coordination Process for PSO with and without DG

4 RESULTS AND DISCUSSION

The PSO technique was used to conduct this investigation on the IEEE 14-bus system. The system consists of 40 DOCRs, five generators, two transformers, twenty transmission lines, and fourteen buses [12]. Two basic cases have been taken into consideration: Case 1 without DG and Case 2 with DG presence. The ideal size of the DG at bus 5 and bus 7 is 5 MVA, according to [13]. So, this DG's ideal value is considered. 138kV and 100 MVA are used in ETAP software to calculate the fault current value. 50 runs of the PSO performance have been done in the MATLAB software to get the shortest relay operation time. The control parameters are indicated in Table 1.

Table 1: PSO control parameters

Parameters	Value
Total number of particles	100
Inertia weight maximum limitation, ωmax	0.9
Inertia weight minimum limitation, ωmin	0.4
c_1 & c_2	2.0
Total number of iterations	100

4.1 Power Loss Analysis

The parameter of synchronous generators, synchronous compensators, and bus data can be referred to [12] while doing the power loss analysis with ETAP. Comparing the overall power loss of the system with and without DG is the goal of the power loss analysis for both systems. A comparison has been made between the overall losses with and without DG, which are 13.38 MW and 12.55 MW respectively. This results in a 6.20 percent reduction in power loss. Table 2 provides the specifics of this analysis.

Table 2: IEEE 14 Bus System Power Losses for both cases

From Bus	To Bus	Without DG		With DG	
		MW Loss	MVAR Loss	MW Loss	MVAR Loss
1	2	4.30	7.27	3.92	6.11
1	5	2.76	6.08	2.58	5.22
2	3	2.32	5.16	2.22	4.71
2	4	1.68	1.47	1.53	0.99
2	5	0.9	-0.93	0.83	-1.21
3	4	0.37	-0.36	0.41	-0.28
4	5	0.51	1.62	0.49	1.54
4	7	0.00	1.70	0	1.19
4	9	0.00	1.30	0	1.21
5	6	0.00	4.42	0	4.82
6	11	0.06	0.12	0.07	0.15
6	12	0.07	0.15	0.07	0.15
6	13	0.21	0.42	0.22	0.44

From Bus	To Bus	Without DG	With DG	From Bus	To Bus
		MW Loss	MVAR Loss	MW Loss	MVAR Loss
7	8	0.00	0.46	0	0.86
7	9	0.00	0.8	0	0.86
9	10	0.01	0.03	0.01	0.03
9	14	0.12	0.25	0.11	0.23
10	11	0.01	0.03	0.02	0.05
12	13	0.01	0.01	0.01	0.01
13	14	0.05	0.11	0.06	0.13
Total Power Loss		**13.38**	30.11	**12.55**	27.21

4.2 Fault Current Analysis

For both circumstances, ETAP is used to analyze the fault current. The three-phase symmetrical balanced fault is the fault under consideration. The references to the values are in [14].

4.3 Relay Operation Time

The importance of TMS and PMS is crucial for the conservation of DOCR. Using the right calculation, the output of DOCRs, the relay operation time can likewise be calculated. Equation (1) can be used to reference the formula, and Standard Inverse (SI) with the parameters $\alpha = 0.02$ and $K = 0.14$ has been chosen as the relay characteristic. The values in Table 3 show the best relay operating times for each DOCRs for both situations after 50 simulation runs. Case 2 is superior to Case 1 in terms of overall computation time and relay operation time, with a difference of 46.79% and 0.8267s. The 40 DOCRs for Case 2 were reduced, demonstrating the viability of implementing PSO in a bigger system.

Table 3: Relay Operation Time for bus system for Case 1 and Case 2

DOCRs	Relay operation time (s)	
	Case 1 - Without DG	Case 2 - With DG
1	0.1238	0.0061
2	0.1372	0.0067
3	0.0063	0.0108
4	0.0070	0.1364
5	0.0084	0.0077
6	0.0305	0.0223
7	0.1269	0.0124
8	0.0070	0.0067
9	0.0074	0.0281
10	0.0075	0.0407
11	0.1272	0.0063
12	0.0075	0.0355
13	0.0074	0.0070
14	0.1391	0.0067
15	0.0067	0.0198
16	0.0125	0.0105
17	0.0125	0.0105
18	0.0334	0.0121

DOCRs	Relay operation time (s)	DOCRs
	Case 1 - Without DG	Case 2 - With DG
19	0.4343	0.0118
20	0.0143	0.0084
21	0.0518	0.0099
22	0.0099	0.0070
23	0.0159	0.1687
24	0.0101	0.0079
25	0.0130	0.0118
26	0.0067	0.0065
27	0.0095	0.0087
28	0.0067	0.0186
29	0.1226	0.0096
30	0.0094	0.0324
31	0.0548	0.0117
32	0.0295	0.0233
33	0.0134	0.0086
34	0.0126	0.0096
35	0.0296	0.0173
36	0.0505	0.0121
37	0.0083	0.0074
38	0.0085	0.1401
39	0.0398	0.0156
40	0.1372	0.0061
Total operation time of relay (s)	1.76	0.9333
Computational time (s)	62.522542	27.364711

The convergence of PSO with DG and PSO without DG to the ideal solution is shown in Figure 3. The global optimum of PSO with DG is reached after 27 iterations, but the global optimum of PSO without DG is reached after 37 iterations.

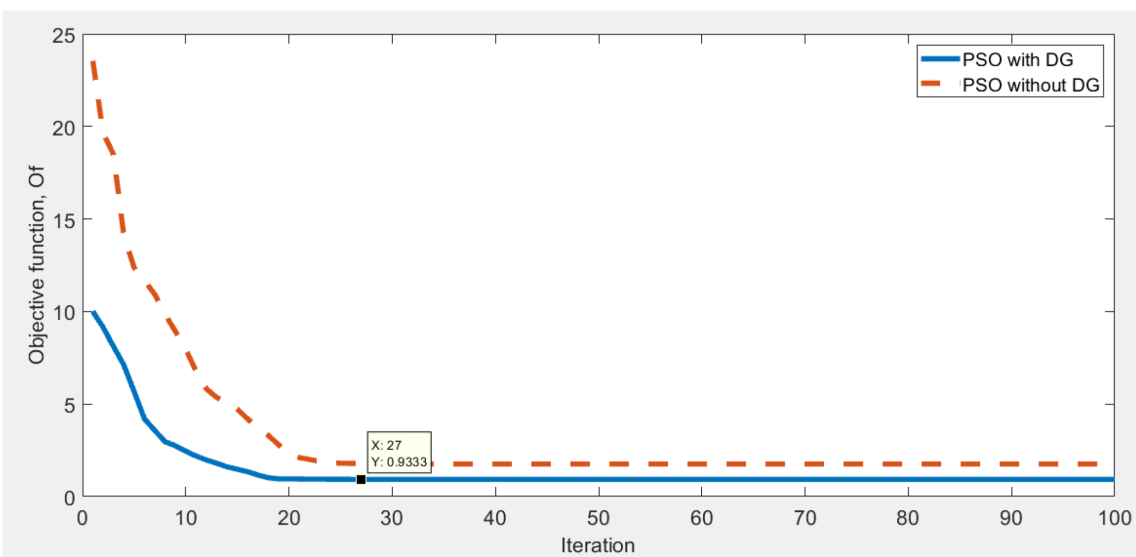

Figure 3: Convergence of PSO with and PSO without DG to the Optimal Solution

5 CONCLUSION

By optimizing parameters, the TMS and PMS and reducing relay operation time for a single objective function, the suggested method addresses the DOCRs problem. The use of the PSO approach was examined in both instances using the IEEE 14-Bus system. To determine the PSO's optimal performance, the analysis considered the total power loss, minimal iteration, computing time, and fitness function. The findings of the simulation show that the addition of DG decreases overall power losses and relay operation time while increasing fault currents. For DOCR to operate, a trip coil in a circuit breaker must be energized where the circuit breaker is open and perform other necessary functions. Thus, the results of relay operation time obtained in this study are significant essential.

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