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A Hybrid Shuffled Frog Leaping Algorithm to Solve Optimal Directional Over Current Relay Coordination Problem for Power Delivery System with DGs

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Abstract: This study presents a new approach for simultaneous coordinated tuning of over current relay for a Power Delivery System (PDS) including Distribution Generations (DGs). In the proposed scheme, instead of changing in protection system structure or using new elements, solving of relay coordination problem is done with revising of relays setting in presence of DGs. For this, the relay coordination problem is formulated as the optimization problem by considering two strategies: minimizing the relays operation time and minimizing the number of changes in relays setting. Also, an efficient hybrid algorithm based on Shuffled Frog Leaping (SFL) algorithm and Linear Programming (LP) is introduced for solving complex and non-convex optimization problem. To investigate the ability of the proposed method, a 30-bus IEEE test system is considered. Three scenarios are examined to evaluate the effectiveness of the proposed approach to solve the directional overcurrent relay coordination problem for a PDS with DGs. Simulation result show the efficiency of proposed method.

Keywords: Directional over current relay coordination, Distributed Generation (DG), linear Programming, Looped Power Delivery System (PDS), short-circuit analysis, shuffled frog leaping algorithm

INTRODUCTION

Directional Over Current Relays (DOCRs) are good technical and economic alternative for the protection of interconnected sub transmission systems and back-up protection of transmission systems. These relays are coordinated to provide a reliable redundant protection scheme while minimizing load interruption. DOCRs have two types of settings: pickup current setting and Time Multiplier Setting (TMS). Basically, to determine these settings, two different approaches are used; conventional approach, and optimization techniques. Several optimization techniques have been proposed to solve the over current relay coordination problem. For example in (Birla *et al*., 2006), Genetic Algorithm (GA), Evolutionary Algorithm (EA), and Particle Swarm Optimization (PSO) algorithms are used to calculate the optimal solution for relay settings. In (Noghabi *et al*., 2009) a novel hybrid GA method is developed. The hybrid GA method is designed to improve the convergence of conventional GA using a local LP optimizer.

Introducing DG into the PDS has both positive and negative impacts on system design and operation. One of the negative effects of DGs is system protection, especially the disturbance caused to the existing relay coordination (Barker and de-Mello, 2000; Kauhaniemi and Kumpulainen, 2004; Tailor and Osman, 2008). This disturbance is caused by the change in value and direction of both the system's power flow under normal operation and short-circuits current under fault conditions due to DG implementation. Solving the identified relay coordination problem for PDS with DG is still under development. In (University Washington Seattle, http://www.ee.washington.edu/research/pstca/, 2006) disconnecting of DGs in fault duration is recommended, so that before operation of relays in the event of fault the source of change in current and disturbance of the relay coordination's is removed. But disconnecting of DGs confines their benefits and on the other hand the problem of synchronization must be considered. In (Tailor and Osman, 2008) authors suggested the implementation of a Fault Current Limiter (FCL) to locally limit the DG fault current and thus restore the original relay coordination. This approach requires FCL design. Implementation of an advanced protection scheme based on automation and communication channels is another approach. This approach has many advantages but is costly (El-Khattam and Sidhu, 2008).

In this study, solving of relay coordination problem for PDS with DGs is done with revising of relays setting. Actually instead of changing in protection system relays

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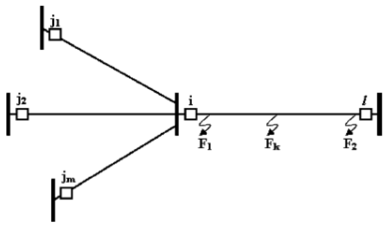

Fig. 1: The concepts of near-end and far-end faults for relay (Noghabi *et al*., 2009)

structure or using new elements, setting of current is changed. In this work, the revising relays setting in presence of DGs is performed using the optimization framework suggested in (Noghabi *et al*., 2009). For this aim, the relay coordination problem is formulated as the optimization problem and two strategies are recommended. Firstly, optimization the relays operation time and secondly, minimizing the number of changes in relays setting. Also, an efficient hybrid algorithm based on Shuffled Frog Leaping (SFL) algorithm and Linear Programming (LP), which is called SFL-LP algorithm, is used for solving complex and non-convex optimization problem. SFLA is a population-based optimization algorithm inspired from the memetic evolution of a group of frogs when searching for food and proven its superior capabilities, such as faster convergence and better global minimum achievement (Brahma and Girgis, 2004).

This study deals with a design method for relay coordination. This coordination is formulated as the optimization problem by considering two strategies: minimizing the relays operation time and minimizing the number of changes in relays setting. Also, an efficient hybrid algorithm based on Shuffled Frog Leaping (SFL) algorithm and Linear Programming (LP) is introduced for solving complex and non-convex optimization problem.

In the proposed hybrid approach, the SFLA and LP are used as global and local optimizers, respectively. These cause a decrease in the search space which results in time consuming and computational efficiency in finding the optimum solutions. To investigate the ability of the proposed method, the numerical results are presented on a 30-bus IEEE test system. Three scenarios are examined to evaluate the effectiveness of the proposed approach to solve the directional over current relay coordination problem for a PDS with DGs. Moreover, to validate the results obtained by SFL-LP algorithm, the hybrid approach based on Genetic Algorithm (GA) and LP algorithm (GA-LP) is adopted from (Noghabi *et al*., 2009) and applied for comparison. Simulation results show the efficiency and superiority of the SFL-LP algorithm over the GA-LP algorithm.

RELAY COORDINATION PROBLEM

The coordination problem of DOCRs is one of the most important problems to be solved in the operation and protection of a power system. The primary objective of the relay coordination problem is to determine the time multiplier setting and pickup current setting of each relay which would minimize the time of operation of the primary relays, while satisfying certain coordination constraints.

The optimal coordination problem of OCRs, can be formulated as an optimization problem, where consists of minimizing an objective function (performance function) subject to limits on problem variables and certain coordination constraints. In (Eusuff *et al*., 2006), an overview on the objective functions formed by researchers to solve the relay coordination problem has been presented recently. In this work, the total time objective function, for primary relay near-end-fault, is considered as (1) by including the constraints aiming to avoid the sympathy trips. These constraints are relay setting constraints and backup-primary relay constraints that presented in the next subsections:

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

In (1), n is the number of relays. Also, t_i is the operation time of i^{th} relay for near-end fault and w_i is the correspondent weighting factor and depends upon the probability of a given fault occurring in each protection zone. Commonly these weighting factors set to one. Figure 1 shows the concepts of near-end fault (F_1) and far-end fault (F_2).

Relay characteristics: There are various linear and nonlinear over current relay characteristics reported in the literature. In this study, relays were assumed identical and with characteristic functions approximated by the following nonlinear characteristics function based on IEC standard:

$$t_i = TDS_i \left\{ \frac{A}{M_i^c} + B \right\}, \qquad M_i = \frac{I_{fi}}{I_{pi}} \tag{2}$$

where TDS_i stand for the time multiplier setting, and also, l_{pi} and l_{fi} are pickup current setting of the i^{th} relay the fault current passing through i^{th} relay, respectively.

Primary-backup relay constraints: In the relay coordination problem, to ensure the relay coordination, it is necessary that the operating time of the backup relay be greater than that of the primary relay for the same fault location by a Coordination Time Interval (CTI) . For this, the coordination constraints between the primary i[th] relay and its/their backup relay(s) for the near-end and the far-end faults are considered as follows:

$$t_j^{F1} - t_i^{F1} \geq CTI$$
$$t_j^{F2} - t_j^{F2} \geq CTI \qquad (3)$$

where t^{F1}_i is the operating time of i[th] primary relay for the near-end fault. Also, t^{F1}_i is defined in the j[th] backup relay. Moreover, CTI is the minimum interval that permits the backup relay to clear a fault in its operating zone. In the other words, the CTI is the time lag in operation between the primary and its backup relay. It includes many factors, such as the breaker operating time and a safety margin. The value of CTI is usually chosen between 0.2 and 0.5 s.

Bounds on the relay settings: The limits on the relay parameters can be written as following inequalities:

$$TDS^k_{\min} < TDS^k < TDS^k_{\max} \qquad (4)$$

$$Ip^k_{\min} < Ip^k < Ip^k_{\max} \qquad (5)$$

SFLA overview: Over the last decades there has been a growing concern in algorithms inspired by the observation of natural phenomenon. It has been shown by many researches that these algorithms are good alternative tools to solve complex computational problems.

The SFLA is a meta-heuristic optimization method inspired from the memetic evolution of a group of frogs when searching for food (Eusuff *et al*., 2006). SFLA, originally developed in determining the optimal discrete pipe sizes for new pipe networks and for existing network expansions. Due to the advantages of the SFLA, it is being researched and utilized in different subjects by researchers around the world, since 2003 (Elbeltagi, 2007; Huynh, 2008; Bijami *et al*., 2010; Ebrahimi *et al*., 2011).

The SFL algorithm is a memetic meta-heuristic method that is derived from a virtual population of frogs in which individual frogs represent a set of possible solutions. Each frog is distributed to a different subset of the whole population described as memeplexes. The different memeplexes are considered as different culture of frogs that are located at different places in the solution space (i.e. global search). Each culture of frogs performs simultaneously an independent deep local search using a particle swarm optimization like method. To ensure global exploration, after a defined number of memeplex evolution steps (i.e. local search iterations), information is passed between memeplexes in a shuffling process. Shuffling improves frog ideas quality after being infected by the frogs from different memeplexes, ensure that the cultural evolution towards any particular interest is free from bias. In addition, to improved information, random virtual frogs are generated and substituted in the population if the local search cannot find better solutions. After this, local search and shuffling processes (global relocation) continue until defined convergence criteria are satisfied. The flowchart of the SFLA is illustrated in Fig. 2.

The SFLA begins with an initial population of "*P*" frogs $F = \{X_1, X_2, ..., X_n\}$ created randomly within the feasible space ?. For S-dimensional problems (S variables), the position of the i[th] frog is represented as $X_i = [x_{i1}, x_{i2}, ..., x_{is}]^T$. A fitness function is defined to evaluate the frog's position. Afterward the performance of each frog is computed based on its position. The frogs are sorted in a descending order according to their fitness. Then, the entire population is divided into *m* memeplexes, each of which consisting of *n* frogs (i.e., P = n×m). The division is done with the first frog goes to the first memeplex, the second frog goes to the second memeplex, frog *m* goes to the m^{th} memeplex, and the $(m + 1)^{th}$ frog back to the first memeplex, and so on. The local search block of Fig. 2 is shown in Fig. 3.

According to Fig. 3, during memeplex evolution, the position of frog i^{th} (D_i) is adjusted according to the different between the frog with the worst fitness (X_w) and the frog with the best fitness (X_b) as shown in (6). Then, the worst frog x leaps toward the best frog $x_b$and the position of the worst frog is updated based on the leaping rule, as shown in (7).

$$Position\,change(D_i) = rand() \times (X_b - X_w) \qquad (6)$$

$$X_w(new) = X_w + D, (\|D\| < D_{\max}) \qquad (7)$$

where *rand ()* is a random number in the rang [0,1] and D_{max} is the maximum allowed change of frog's position in one jump. If this repositioning process produces a frog with better fitness, it replaces the worst frog, otherwise, the calculation in (6) and (7) are repeated with respect to the global best frog (X_g), (i.e., X_g replaces X_b). If no improvement becomes possible in this case, then a new frog within the feasible space is randomly generated to replace the worst frog. Based on Fig. 2, the evolution process is continued until the termination criterion is met. The termination criterion could be the number of

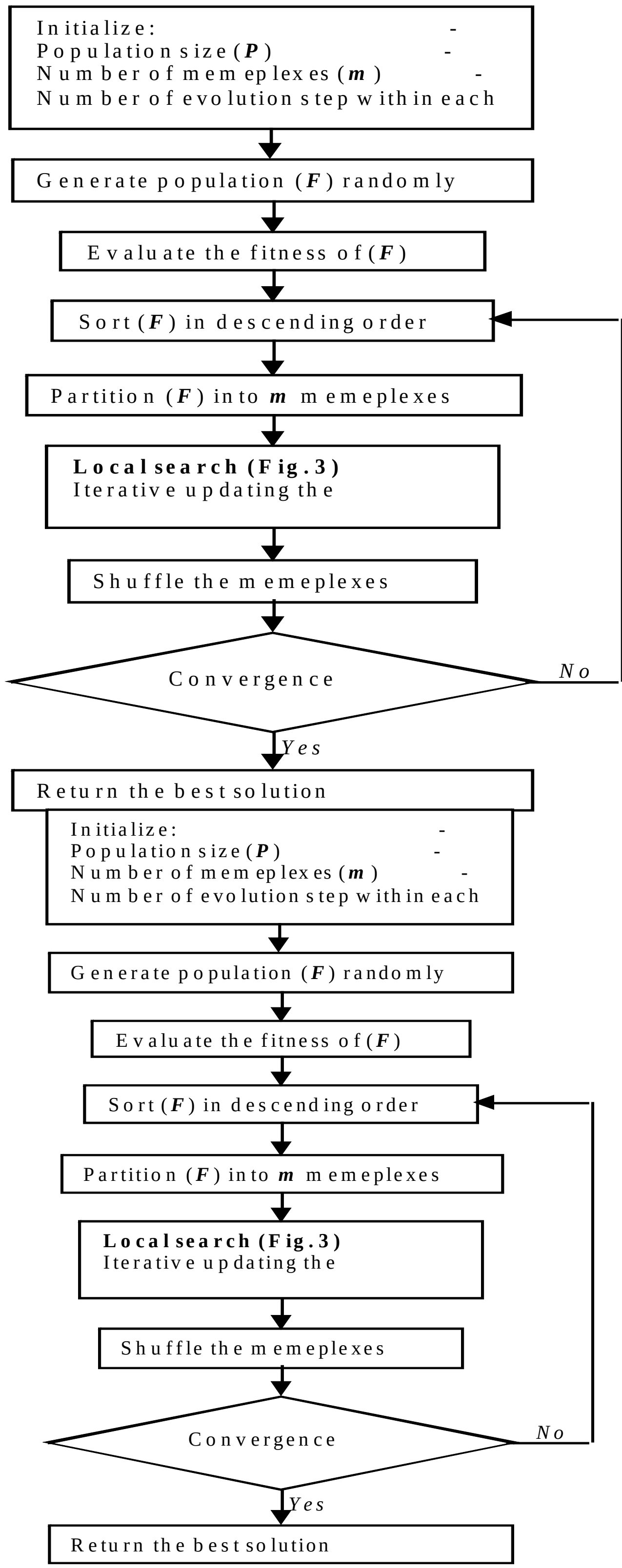

Fig. 2: General principle of SFLA (Huynh, 2008)

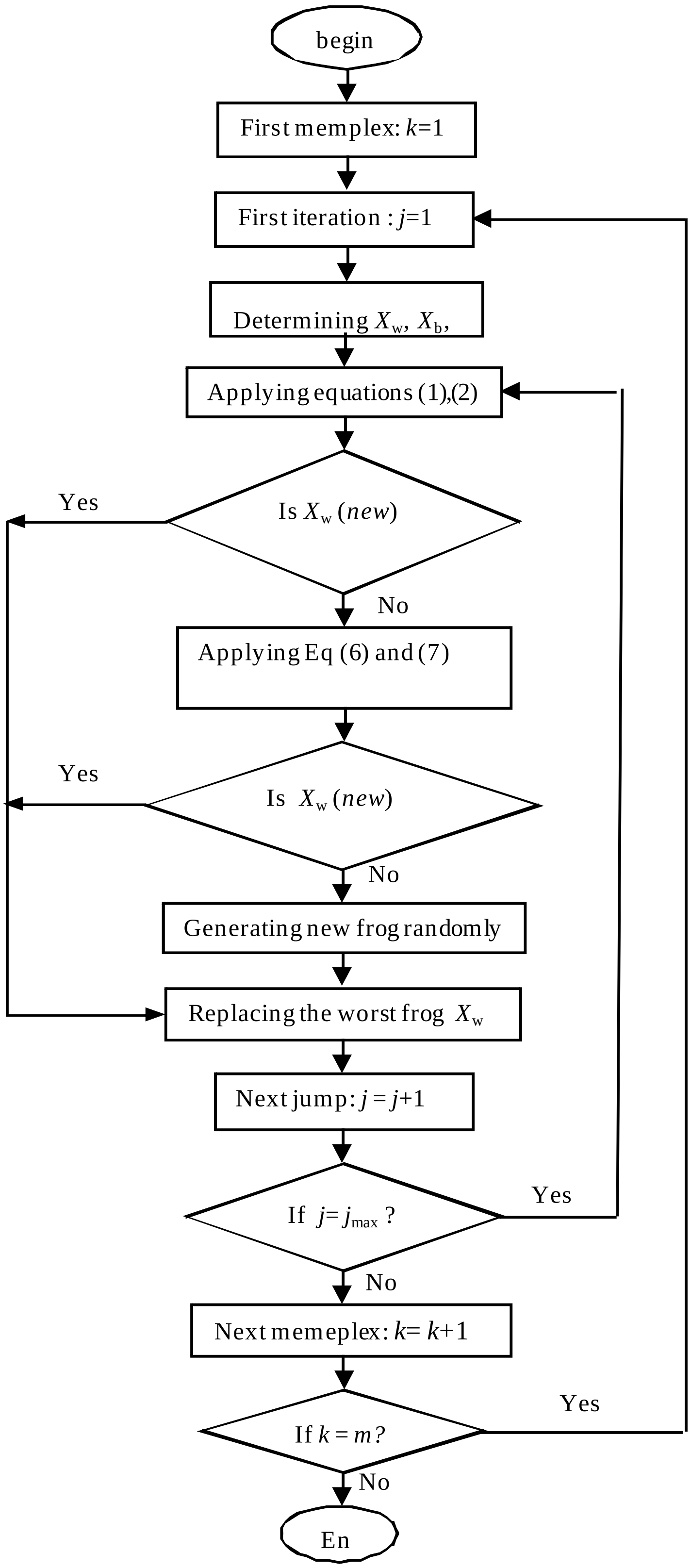

Fig. 3: Local search block of Fig. 2 (Huynh, 2008).

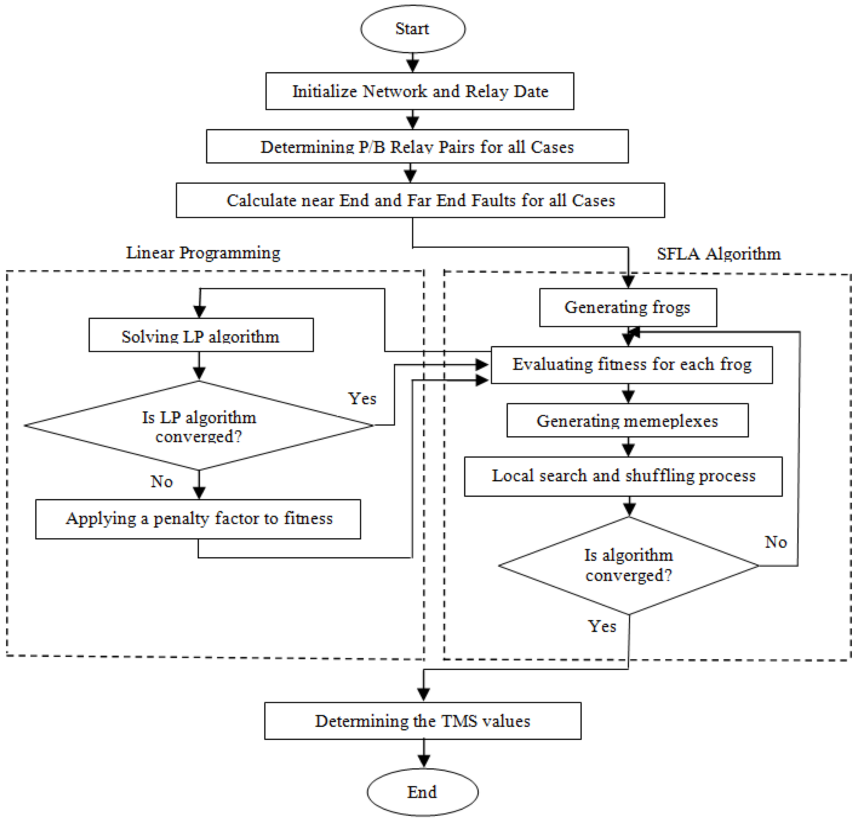

Fig. 4: The principle of Hybrid based SFL and LP algorithms

iterations or when a frog of optimum fitness is found (Eusuff and Lansey, 2003; Eusuff *et al*., 2006).

Proposed approach to solve relay coordination problem: In this section, the problem formulation to solve the DOCRs coordination problem for a PDS with DGs and architecture of proposed hybrid algorithm are described in subsections *A* and *B*, respectively.

Problem formulation: There are two approaches for solving the relay coordination problem in presence of DGs: First, revising the protection system by optimization the relays operation time and second, revising the protection system by minimizing the number of changes in relays setting.

The first approach is explained in section2. In this approach, the fitness value is defined based on the objective function in (1) which is the overall operating time of primary relays.

In the second approach, the fitness function is defined as follow:

$$Fitness = \frac{1}{1+noc} \tag{8}$$

In (8), noc represents the number of relays that their setting is changed. In this paper a hybrid approach based on SFL and LP algorithms is employed to solve the optimization problem.

The proposed hybrid SFL-LP algorithm: Here, the optimization framework suggested in (Noghabi *et al*., 2009) is adopted to develop a hybrid method based on SFL and LP algorithms for solving this complex and nonconvex optimization problem.

In the proposed hybrid approach, the SFLA and LP are used as global and local optimizers, respectively. For this, the LP algorithm is employed as a local optimizer to improve the convergence of SFL algorithm and the SFL algorithm is used to solve the first sub problem [i.e., the nonlinear part of optimization problem (1)] in order to determine the l_{pi} variables.

By extracting the frog information, the DOCRs coordination problem is converted to a Linear Programming problem. Therefore to evaluate the fitness value for each frog, the standard LP is solved to determine the corresponding *TMS* variables. The flowchart of the proposed hybrid method is shown in Fig. 4.

As can be seen from Fig. 4, the LP sub problem is l_{pi} the main part of fitness function evaluation which is

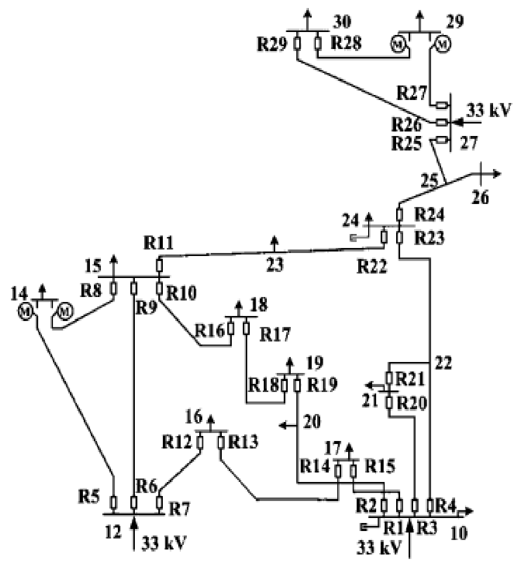

Fig. 5: The 30-bus IEEE test system schematic

called several times by the SFL algorithm. To compute the fitness value for each frog, firstly, the values of the variables are extracted by decoding the frog information. Based on the fixed values of the variables, the nonlinear DOCRS coordination problem is converted to a LP problem.

Then, by solving this LP problem the corresponding fitness value and the TMS variables are computed. This causes a decrease in the search space which results in time consuming and computational efficiency in finding the optimum solutions.

For some individuals according to the values of the variables, the LP sub problem is not converged. In these cases, some of the inequality coordination constraints are violated. To decrease the chance of these frogs in the next 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. Whole approach can be summarizing as following steps:

- Extracting of relays pickup current by decoding each frog.
- Determination of TMS variables by solving LP problem. The objective function in LP sub problem is defined based on (1).
- Comparison between the result of each iteration and current relays setting and calculating fitness value for each frog based on (8).

CASE STUDY

PDS under study: In order to show the effectiveness of the proposed method, some numerical results are presented on a 30-bus IEEE test system (El-Khattam and Sidhu, 2008). The considered PDS system is modeled with all of its detailed parameters (synchronous condensers with their generation limits, shunt reactors, distribution transformers taking into consideration their turn's ratio, and aggregated loads represented by constant power models). This study system is illustrated in Fig. 5.

Table 1: The ratios of the current transformers (Cts)

Relay number.	CT	Relay number.	CT
1	200/5	16	200/5
2	300/5	17	100/5
3	600/5	18	100/5
4	300/5	19	200/5
5	300/5	20	600/5
6	600/5	21	100/5
7	300/5	22	100/5
8	500/5	23	200/5
9	600/5	24	100/5
10	200/5	25	200/5
11	200/5	26	200/5
12	300/5	27	200/5
13	100/5	28	100/5
14	100/5	29	300/5
15	200/5		

The considered PDS is fed from three primary distribution substations (132/33 kV) at buses 10, 12, and 27. Each primary distribution feeder is protected by two directional over current relays, one relay at each end. The current relays and the system is originally well coordinated. It is assumed that all relays are identical and have the standard IEEE moderately inverse relay curves with the following constants 0.0515, 0.114,and 0.02 for A, B, and C, respectively (El-Khattam and Sidhu, 2008).

Also, the TMS values can range continuously from 0.1 to 1.3, while seven available discrete pickup tap settings (0.5, 0.6, 0.8, 1.0, 1.5, 2.0 and 2.5) are considered (El-Khattam and Sidhu, 2008).The ratios of the current transformers (CTs) are indicated in Table 1 and the CTI is assumed to be 0.3 s for each backup-primary relay pair.

Moreover, one CDGL is considered which consist: PDS substation bus 19. The selected DG technology is a synchronous type, 10 MVA capacity, operating nominally at 0.9 lagging power factor, and 0.15 p.u. transient reactance based on its capacity. The DG is practically connected to the PDS bus through a transformer which is assumed to have 10 MVA capacity and 0.05 p.u. reactance based on its capacity. The DG is simulated with its required active power and constrained by the minimum and maximum reactive power that can be produced in normal operating conditions. In this work, the maximum individual DG capacity is assumed to be around 10% of the maximum PDS active power loading (115 MVA at 0.9 lagging power factor).

Scenarios under study: Three scenarios are considered to investigate the proposed method.

Table:2 Pickup tap settings and TMS variables

Relay No	SFL		SFL		SFL			GA	
	Pick up tab	TDS	Pick up tab	TDS	Relay No	Pick up tab	TDS	Pick up tab	TDS
1	2/5	0/9197	2/5	0/9507	16	2/5	0/2112	2/5	0/2308
2	2/5	0/5989	2/5	0/6198	17	2	0/5288	2/5	0/6076
3	2/5	0/4412	2/5	0/4667	18	1/5	0/8302	2	0/7690
4	2	0/2367	2/5	0/1711	19	2/5	0/1178	2/5	0/1879
5	2	0/1217	2/5	0/1	20	1/5	0/1	0/8	0/1
6	2/5	0/3267	2/5	0/4031	21	1/5	0/2011	2	0/9469
7	2/5	0/7592	2/5	0/8881	22	2/5	0/6426	2/5	0/7006
8	2	0/1506	2/5	0/4175	23	2/5	0/2997	2/5	0/3485
9	1/5	0/1	2	0/1	24	1	0/6968	2	0/4901
10	2	0/7079	2/5	0/7363	25	1	0/6915	2/5	0/3214
11	2/5	0/3646	2/5	0/4082	26	1/5	0/2606	1/5	0/2505
12	2/5	0/1546	2/5	0/1684	27	1/5	0/2159	2	0/1582
13	1	0/2056	2/5	0/0309	28	1/5	0/1	1	0/1
14	2	0/7217	2/5	0/6927	29	0/6	0/1	0/6	0/1
15	2/5	0/3546	2/5	0/4223					

Table 3: sample of backup-primary relay pair (for SFL results)

Relay unit	Relay current(Amp.)	Operatingtime (sec.)	CTI
R_1	6180	1.0232	-
$R_{19,1}$	627	1.3506	0.3274
$R_{23,1}$	880	1.3916	0.3684

Table 4: primary/backup (P/B) relay pairs in presence of the DG at buse 19

Primary relay		Backup relay		
Relay No.	Realy current (Amp.)	Relay No	Realy current (Amp.)	CTI (see)
1	6754	19	1104	-0.0388
3	7316	19	1104	-0.262
4	7511	19	1104	0.1852
6	6452	12	1256	0.2547
7	6463	91	279	-0.0602
1	1536	31	61368	0.2142

- **Scenario A:** It is considered as the base case with well established relay coordination, in which there is no DG installed on the PDS.
- **Scenario B:** DG as a power source is installed on the PDS territories.
- **Scenario C:** Revising relays setting in presence of DG.

In this study, revising relays setting is considered with two explained approaches and the results are compared. Furthermore, in order to validate the results obtained by SFL-LP algorithm, the hybrid approach based on Genetic Algorithm (GA) and LP algorithm (GA-LP) is adopted from (Noghabi *et al*., 2009) and applied for comparison.

RESULTS

Scenario (A) Relay coordination for the original PDS: This scenario is considered as a base PDS case without DGs. To evaluate the optimal tuned relay settings, the DOCRs coordination problem is solved using the proposed hybrid method.

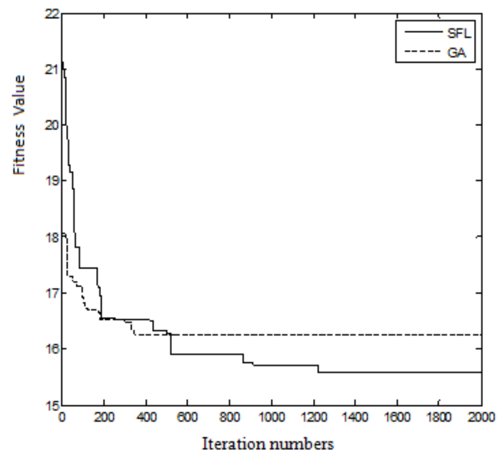

Fig. 6: Convergence characteristics of SFL and GA on the average best-so-far cost function (fitness function is based o Eq. (1))PDS is assumed to have 29 existing directional over

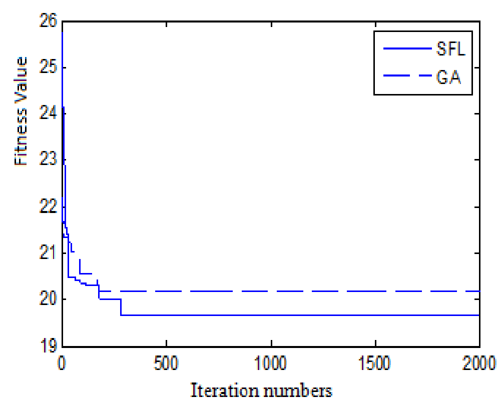

Fig. 7: Convergene characteristics of SFL and GA (approach1-fitness function is based on Eq. (1))

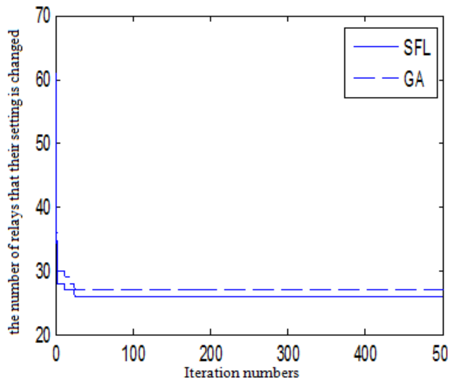

Fig. 8: Cnvergence characteristics of SFL and GA (approach 2)

The first step to implement the SFL is generating the initial population (*N* frogs) where *N* is considered to be 100. The number of memeplex is considered to be 10 and the number of evaluation for local search is set to 10. Also D_{max} is chosen as *inf*.

Based on Fig. 2 the local search and shuffling processes (global relocation) continue until the last iteration is met. In this study, the number of iteration is set to be 2000.

To validate the obtained result by SFL-LP, a GA-LP method is applied. The number of chromosomes in the population is set to be 100. One point crossover is applied with the crossover probability p_c = 0.9 and the mutation probability is selected to be p_m = 0.01. Also, the number of iterations is considered to be 2000, which is the stopping criteria used in SFL.

To find the best value for the solution, the algorithms are run for 10 independent runs under different random seeds. The average best-so-far of each run are recorded and averaged over 10 independent runs. To have a better clarity, the convergence characteristics in finding the best values are given in Fig. 6, where shows SFL performs better than GA.

The optimal values of the decision parameters (i.e., pickup tap settings and TMS variables) are shown in Table 2. Also, the final optimal total time obtained is 15.59s.

Moreover, Table 3 shows a sample of backup-primary relay pair short circuit currents, operating times.

Scenario (B) Relay coordination in presence of DG: The presence of DG will change the normal power flow as well as the short-circuit current all over the PDS, which is not restricted to the DG connected bus.

Table 5: The results of relays coordination in presence of DG at bus 19

	Approach (1) SFL		Approach(2)GA		Approach (1)SFL		Approach (2)GA	
Relay No	Pick up current	TDS	Pickup up current	TDS	Pick up current	TDS	Pick up current	TDS
1	2.5	1.1208	2.0	1.2556	2.5	1.2655	2.0	1.2910
2	2.0	0.8103	2.0	0.8467	2.5	0.7551	2.5	0.7044
3	2.5	0.5464	2.0	0.6862	2.5	0.6106	2.0	0.7581
4	2.5	0.2232	2.5	0.2256	2.0	0.3700	2.0	0.3885
5	2.0	0.2036	2.5	0.1000	1.5	0.4271	2.5	0.1000
6	2.5	0.4692	2.5	0.47592	0.6	871.00	2.5	0.5143
7	2.5	0.8781	2.0	1.14002	1.1	22800	2.0	1.1993
8	2.5	0.5606	2.0	0.8021	1.5	1.0018	2.0	0.8362
9	2.0	0.1000	2.0	0.1000	2.5	0.1000	2.0	0.1000
10	2.5	1.0072	2.5	1.0252	2 .0	1.2610	2.0	1.2278
11	2.5	0.4349	2.5	0.4442	2.0	0.5659	2.0	0.5484
12	2.5	0.2409	2.5	0.2435	2.5	0.2910	2.5	0.2581
13	2.5	1.0426	2.5	1.1850	2.0	1.2571	2.5	1.2607
14	2.5	0.8579	2.5	0.8636	2.0	1.0779	2.5	0.8967
15	2.5	0.4297	2.0	0.5942	2.5	0.4679	2.0	0.6425
16	2.5	0.3351	2.5	0.3652	2.5	0.4077	2.5	0.3755
17	2.5	0.9456	2.5	0.9670	2.0	1.1442	2.0	1.1068
18	2.0	0.9862	2.0	1.0442	2.0	1.1259	2.5	0.9567
19	2.5	0.4846	2.5	0.4998	2.5	0.5348	2.5	0.5112
20	1.5	0.1000	2.0	0.1000	1.5	0.1000	1.5	0.1000
21	2.5	1.0451	2.5	1.0565	2.0	1.2908	2.5	1.1979
22	2.5	0.9281	2.5	0.9413	2.5	1.0397	2.0	1.1883
23	5/2	0.3828	2.5	0.3947	2.5	0.4223	2.5	0.4037
24	2.0	0.4641	1.5	0.5310	2.5	0.4414	2.0	0.4740
25	2.5	0.3936	2.5	0.3978	2.0	0.5607	1.0	1.0398
26	2.0	0.1975	2.5	0.1724	1.5	0.2628	2.0	0.2070
27	2.0	0.1715	2.0	0.1869	2.0	0.1584	2.0	0.1715
28	1.0	0.1000	2.0	0.1000	1.5	0.1000	1.5	0.1000
29	0.8	0.1000	1.0	0.1000	0.6	0.1000	0.8	0.1000

Table 4 shows the primary/backup (P/B) relay pairs and corresponding fault currents passing through them in presence of the DG at buses 19. Based on the reported results shown in Table 3, the PDS will face relay miss coordination. For the DG at bus 19, three relay pair miss coordinations are reported

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Scenario (C) Revising relays setting in presence of DG: The first stage is solving relays coordination in presence of DG at bus 19. To find the best value for the solution, the algorithms are run for 10 independent runs under different random seeds. The average best-so-far of each run are recorded and averaged over 10 independent runs. To have a better clarity, the convergence characteristics in finding the best values is given in Fig. 7 and 8 for the results of approaches 1 and 2, respectively. As illustrated, SFL performs better than GA in two approaches. Results are shown in the Table 5. As can be seen from the obtained results in revising relays setting, by using the first approach (by SFL), only setting of the relay 20 remains unchanged. While, in the second approach, setting of 3 relays (20, 28 and 29) remains unchanged. The final optimal total time obtained from first approach is 19.6124s, which is increased to 22.7567 in the second approaches. Also, the results show that SFL performs better than GA in two approaches. So, the results of SFL are reliable and effective for using in real systems.

If the first approach is used to solve the problem,almost the settings of all relays are changed. With using the second approach number of relays without changed increases and also the total operation time of relays increased. So, fewer changes in relay settings is equal to upper operation time of relays and vice versa.

CONCLUSION

This study presents a new approach for simultaneous coordinated tuning of overcurrent relay for a power delivery system (PDS) Including Distribution Generations (DGs). In the proposed scheme, solving of relay coordination problem is done with revising of relays setting in presence of DGs. For this aim, two approaches introduced. First, revising the protection system by optimization the relays operation time and second, revising the protection system by minimizing the number of changes in relays setting. For this, the relay coordination problem is formulated as the optimization problem and solved by an efficient hybrid algorithm based on Shuffled Frog Leaping (SFL) algorithm and Linear Programming (LP). To investigate the ability of the proposed method, a 30-bus IEEE test system is considered with three scenarios. Moreover, to validate the results obtained by SFL-LP algorithm, the hybrid approach based on Genetic Algorithm (GA) and LP algorithm (GA-LP) is adopted and applied for comparison. Simulation results show the efficiency of the proposed algorithm.

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