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Optimal Protective Coordination of Overcurrent Relays in Electrical Distribution System with the Presence of Distributed Generation

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Abstract

In the current scenario, the principle of penetration of electric grid delivery generation technologies is being rigorously applied. With the inclusion of distributed generation sources within the network, the short circuit MVA capacity of the electrical distribution network increases. The variation in short circuit current levels would depend on the network layout, DG sizing, and the DG placement. The discrimination time period associated with the pair of main and backup relays is breached because of the variation in short-circuit current levels. Thus, with the presence of distributed generation, coordination between main and back up relay's malfunctions. The relay settings should therefore be properly updated in every region of the power system. By choosing the Optimum time dial setting (TDS) and pickup current or plug setting, an optimum setting of Overcurrent Relay coordination (OCR) coordination can be achieved. The Elephant herding algorithm (EHA) is suggested to overcome the optimum overcurrent relay coordination without sacrificing the characteristics. The impact of penetration of various Distributed Generation sources on Over-Current Relays in the 33-test bus distribution system has been observed from the simulation outcome and analysis, and the optimal relay settings as well as the usefulness of the proposed algorithm in locating optimal coordination of over-current relays.

Keywords: Distributed generation, Elephant hearding algorithm, Relay coordination, optimal setting, Time Dial Setting, Plug Setting

1. Introduction

Distributed generation (DG) means small to medium scale environmental-friendly electrical power generation units. DGs are used to increase generation of utility, to decrease the transmission losses, to increase the quality of power, reliability, and supply load to remote area. However, the connection of DGs may disrupt the function of the distribution network and result in a loss of coordination of the protection system [1].Thus, protecting of distribution network with including of DG is a major problem in power systems. Once DG is injected in a system, causes change in level of the fault current and disturb radial power flow nature in the system.[2][3]. This results in loss of relay coordination. And this influence of DG on protection system coordination is depends upon type, size, as well as location of DG.

It is therefore essential to change the relay settings, i.e., the plug setting (PS) and the time dial setting (TDS) of each relay. To operate any power system in stable condition, the protection devices need to be reliable, sensitive, quick as well as selective in case of faults on the distribution network. Over-current relays are usually used as protective devices, as its cost is low and no need of costly communication devices for operation. Two types of settings are to be determined for relays are current settings and time settings. Therefore, unnecessary effects of faults are protected by Optimal Overcurrent relay settings. Plug Setting (PS) and Time Dial Setting (TDS) are two factors for over-current relays to be properly designed. [3][4]

There are many techniques for the over-current relay coordination. These are classified into three types those are topological analysis, trial & error and optimization methods. However, first two methods will not provide optimal solutions in any strict sense [5]. Then, different types of optimization algorithms are used for relay coordination applications. For determining optimized PS and TDS concurrently, algorithms with non-linear-based have been effectively useful. This paper uses MATLAB to organise relay settings using the Elephant herding optimization algorithm.[7][8]

1.1 Directional Over Current Relay Protection

Overcurrent relay is the simple and cheap and it is easy to quickly readjust or can be replaced with system changes. And it is usually used in protection of phase faults and ground faults in stations and distribution circuits and industrial electrical systems and on certain sub-transmission systems in such a condition where distance relay is not economical. This is utilised for primary earth fault safety in maximum transmission systems in which distance relays utilized for protection of phase faults.[9][10][11] In general, two to three OCRs are used to secure inter-phase faults and in the event of 1-phase to ground faults, separate overcurrent relays are used and distinct ground fault relays are usually favored because, in the case of 1-phase ground fault relays, they are accustomed to obtaining faster and extremely fragile protection than phase relays. For all other types of defects, however, only phase relays are always trusted for protection. In the case of a zero-phase sequence portion of the earth fault current, other side phase relays should be configured to function in inoperative condition. Overcurrent relays are suitable for protection of distribution system for numerous reasons [12][13]. They are mainly simple as well as economical and these benefits are recognized in the highest degree in most of the distribution circuits. The greatest advantage in the safety of the electricity distribution circuit is the inverse time characteristics as shown in **Figure 1**, since the extent of the fault current is dictated by the location of the fault and not necessarily by the difference in power generation or variation in high voltage transmission lines.

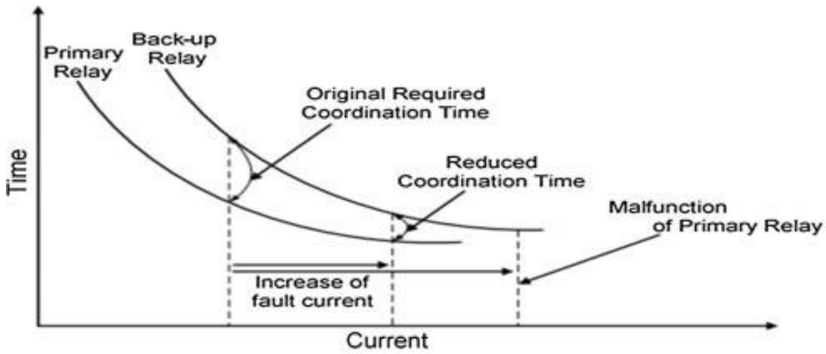


Figure 1 Inverse time characteristics of overcurrent relay.

However, if the magnitude of the ground fault current is strictly limited by neutral grounding impedance, there may be little to no value to be added by the inverse function of a ground relay.

1.2 Overcurrent Relay Coordination

An overcurrent relay (OCR) is a form of protective relay that activates when the load current exceeds a pre-determined set value. When the fault occurs, the faulted part is detected by primary protection as well as backup protection. Since the primary scheme has less operating time than the backup relay operating time, so the primary scheme acts first.[14][15]. Design of over current relay coordination decides the operating sequence of relays for each and every possible location of the fault so that affected part is separated. In the overcurrent relays coordination, the main function is to calculate the TDS (time dial setting) and PSM (plug setting multiplier) of each relay, to minimize the primary relays total operating time accurately with considering maximum fault current at the relay location. Relay co-ordination could be accomplished by choosing appropriate plug setting and time dial setting of the overcurrent relay, taking into of maximum fault current in the relay locality**. Figure 2** shows the primary and secondary zone setting of the relays.

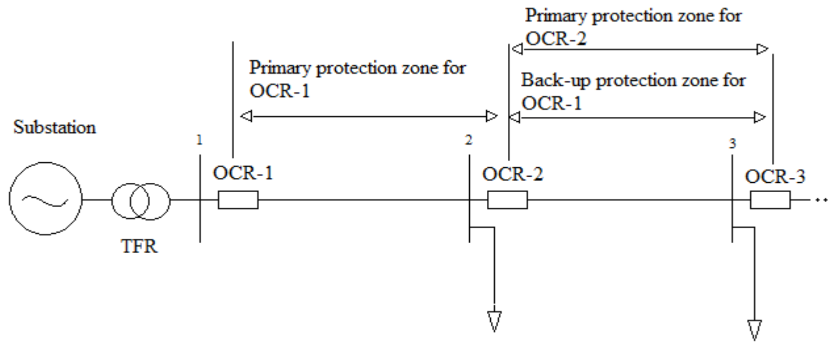


Figure 2: Over Current relays to protection of radial distribution system

Whenever a minimal fault occurs in the system, the main relay should be enabled first, based on the direction of the fault. and if the primary relays fail to operate within a given period, backup relays should be enabled..[16][17][18] As presented in **Figure 2,** suppose a fault arises in the region between the buses 2 and 3, the OCR-2 need work first. before OCR-1 and OCR-1 must operate suppose OCR-2 fails to work. The suitable time wait or interval between the primary and backup relay is the coordination time interval (CTI). CTI refers to coordination time interval between main and backup relay. So the limit for coordination of secondary relay with primary relay will be:

$$t_{backup} - t_{primary} \geq CTI \qquad (1)$$

Therefore, to avoid inconsistency in functioning of OCRs in the protection system coordination between them is primary factor and hence mal operation can be circumvented.

1.3 Effect of DG on Shortcircuit current

The level of network fault current is affected by the inclusion of DG in a system, as DG is infiltrated into the distributed network, the level of fault current increases. The effect of the fault from a single smaller DG is not immense, but it will raise the current of the fault, then the rise in short circuit level will be sufficient to cause damage to protective equipment coordination, such as fuses, protective relays in the case of several small units, or some bulk power units. The effect of DG depends on variables such as DG sort, generation power, distance from and point of fault between DG. This could change the efficiency of the electrical distribution system and affect its safety. If a small DG is penetrated into the circuit, the magnitude of short circuit currents increases by a small amount. On the other hand, if there is a greater number of small capacity units or any large capacity units connected to the system, the short circuit levels of the system can be increased enough to allow the protective relays to fail to coordinate or function.[19][20].This malfunction affects the reliability of the distribution system as well as its safety. The **Figure 3** shows Over Current relays for protection of radial distribution system

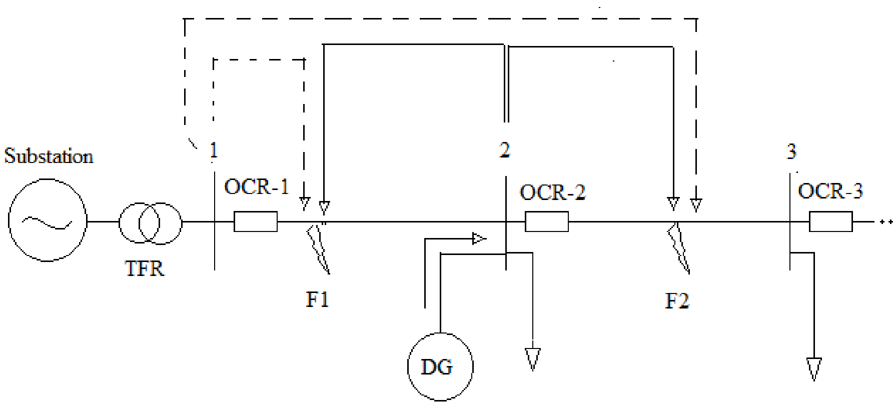


Figure 3: Increase in fault current and reverse power flow Change of coordination of relay

Consider **Figure 4**. Before installing DG-1, OCR-2 can operate before OCR-3 when a fault occurs at point 1. The fault current (If3) flows from DG-1 to fault point 1 when DG1 is linked to sub feeder-3 and OCR-3 works before OCR-2 depending on the selected margin between I_{f2} and $I_{f3.}$

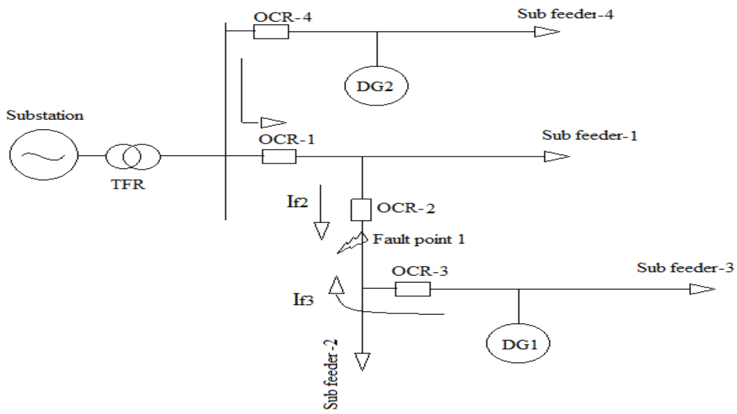


Figure 4: Change of coordination of relays and nuisance trip

2.Problem Formulation

The current relay coordination problem can be modelled as a restricted optimization problem. The aim is to keep all the overcurrent relays present in the distribution network is overall operating time. The main function is to reduce the operating time of each relay and the system's reliability should be kept to minimum.[20][21]. The objective function is denoted by the letter "s" in this case.

$$\boldsymbol{min\, s = \sum_{i=1}^{n} t_{i,k}} \quad (2)$$

Where 'n' - the total number overcurrent relays in the network, $t_{i,k}$ is the individual operating time of i^{th} relay in the network for fault in k^{th} zone

Coordination Criteria

$$\boldsymbol{t_{bi,k} - t_{i,k} \geq \Delta t} \quad (3)$$

Where $t_{bi,k}$ is the operating time of primary relay for the fault in zone k at i^{th} bus and $t_{bi,k}$ is the operating time of backup for the fault in the same zone, and t is the coordination time interval(CTI)

$$\boldsymbol{t_{i,k}\, min \leq t_{i,k} \leq t_{i,k}\, max} \quad (4)$$

Here, $t_{i,k}$ min is the minimum relay operating time and $t_{i,k}$ max is the maximum relay operating time , Consequently, TDS will be bound to

$$\boldsymbol{TDS_{i,k}\, min \leq TDS_{i,k} \leq TDS_{i,k},} \quad (5)$$

3. Elephant herding Optimization

In this work, a swarm-based metaheuristic hunt technique is discussed for getting optimization is called Elephant Herding Optimization (EHO). The EHO approach is developed based on the herding behaviour of elephant's community. Of course, under the leadership of a mother elephant, the elephants of the different the clans live in a group meaning matriarch and as long as they age, the male elephants move away from their group. These two actions could therefore illustrated in two operators one is clan updating operator and another is separating operator. In this method, the elephants of each clan are updated by its present location and matriarch by clan updating operator. This is a new metaheuristic, EHO but it is effectively applied to many problems like multilevel thresholding, scheduling problem, etc. Normally all such type algorithms include global search and local search. In smaller, optimistic areas of the search room, and local search, attempts to find better results. Using this definition, the conduct of elephant herding was termed as the population of one elephant divided into several clans. Grandma is followed by every clan, Clans imply native search in this algorithm, and global search is implemented by male elephants. Matriarch represents the response in the clan that is the largest suitability feature result. And the alternatives to the worst suitability values are male elephants who abandon the community. As explained below, the EHO algorithm. The elephant population is divided by the K clans. In the hunting universe with less bound x_{min} and higher bound x_{max}, D dimensional results are primarily generated arbitrarily by the following equation:

$$\boldsymbol{x = x_{min} + (x_{max} - x_{min} + 1)rand} \quad (6)$$

Here 'rand' is the arbitrary figure form uniform distribution in [0, 1] range. In every generation, results are varying in the below manner. The member j of clan i travel or move predisposed by the result $x_{best,ci}$ with the greatest suitability function result in clan ci:

$$\boldsymbol{x_{new,ci,j} = x_{ci,j} + \alpha(x_{best,ci} - x_{ci,j})rand} \quad (7)$$

Here $x_{new,ci,j}$ is the new solution j in clan ci and $x_{ci,j}$ characterizes the result in preceding generation, and algorithm factor α ∈ [0, 1] that desires to be fixed according to the predefined problem, whereas random number rand ∈ [0, 1] in uniform distribution. Then α is a scale factor that concludes the effect of finest result. Position of finest result in every clan is modernised according to the below mentioned equation:

$$\boldsymbol{x_{new,ci} = \beta xcenter, ci} \quad (8)$$

Here β ∈ [0, 1] means the second algorithm factor and it regulates the effect of clan center xcenter, ci. It is defined as:

$$\boldsymbol{xcenter, ci, d = \frac{1}{nci}\sum_{l=1}^{nci} xci, l, d} \quad (9)$$

Here 1 ≤ d ≤ D denotes the dth length and nci is number of results in ci clan. And in all generation, investigation is done as given below. In every clan, mci solutions along with the worst suitability results of clan ci are preferred to be substituted by the below equation:

$$\boldsymbol{x_{worst,ci} = x_{min} + (x_{min} - x_{min} + 1)rand} \quad (10)$$

Here x_{min} denotes lower bound and x_{max} denotes upper bounds of the examination cosmos. Factor rand ∈ [0, 1] denotes a arbitrary figure form uniform distribution. Elephant Herding Optimization algorithm is described in Algorithm.

4. Results and Discussion

In this work a radial distribution system of IEEE 33 test system is analyzed which has 33 DOCRs located as shown in **Figure 5.** This scheme has 33 buses and 32 lines, with the source at bus 1. The standard inverse relay curves with the constants 0.14, and 0.02 for α, β are considered to be equal for all OCRs [24]. **The data from the IEEE 33-bus test method is available in a report. [25].** A 4 MW synchronous DG with a 0.9 lagging power factor is penetrated to bus 10 to provide local loads. For each backup-primary OCR pair, CTI is assumed to be 0.3 seconds.

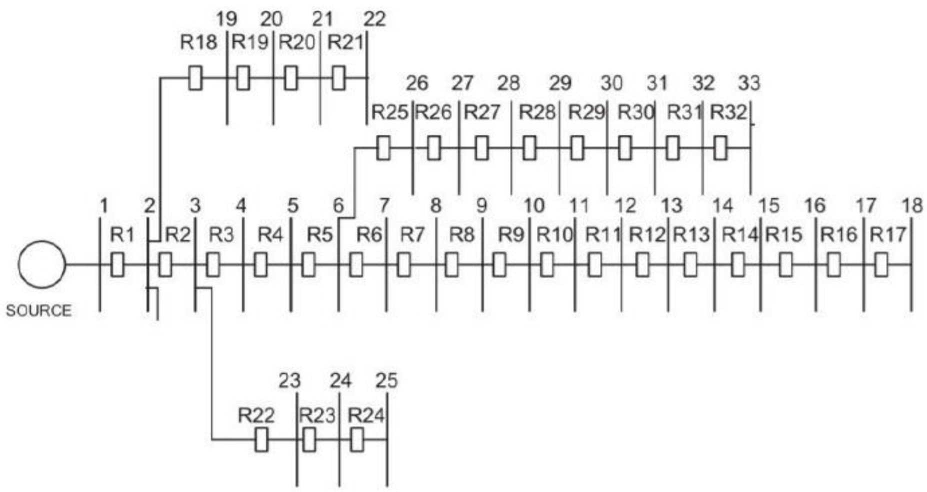
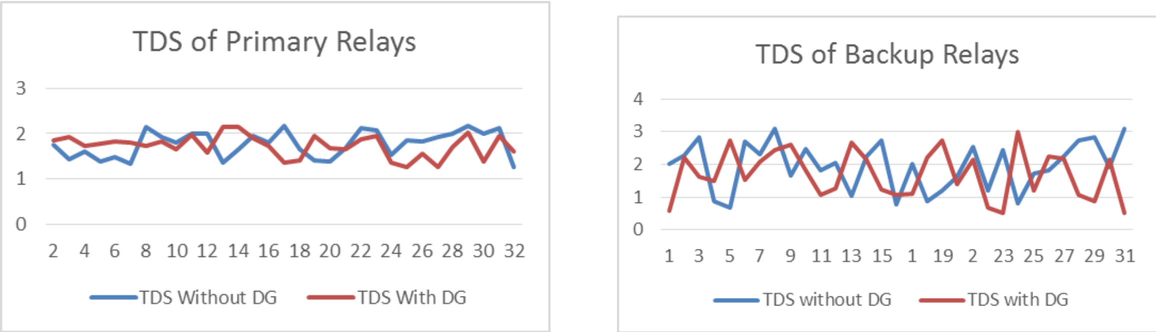
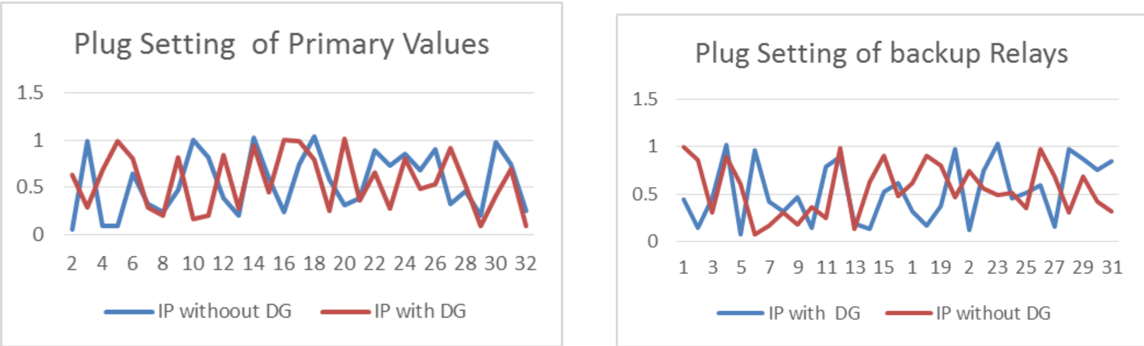


Figure 5 The 33-bus radial distribution network



(a) TDS values of Primary Relays (b)TDS values of Backup

Figure 6 TDS values of Primary and Backup overcurrent relays with and without DG



(a) Plug setting of Primary Relays (b) Plug setting values of Backup Relays

Figure 7 Plug setting values of Primary and Backup overcurrent relays with and without DG

The **Figure 6** shows the optimum TDS Values of relays with and without DG by applying EHA algorithm to the sample network for primary and Backup relay, respectively. The **Figure 7** shows the optimum plug setting values of relays with and without DG by applying EHA algorithm to the sample network for primary and Backup relay respectively.

Table 1: Results of 33 bus system applying EHO algorithm without Distributed Generation.

Faulted Bus	**Relay number**	**Backup Relay**	**Main ISC in A**	**Backup ISC in A**	**TDS main**	**PS main**	**TDS Backup**	**PS Backup**	**Relay opert time**	**Backup relay time**
1	2	1	1538.94	1534.37	1.75	0.06	2.03	1.00	1.628532	1.928532
2	3	2	279.08	275.13	1.43	0.99	2.28	0.86	2.007936	2.307936
3	4	3	373.87	371.03	1.61	0.10	2.83	0.30	2.456625	2.756625
4	5	4	356.03	353.33	1.38	0.10	0.87	0.89	0.291888	0.591888
5	6	5	135.52	132.95	1.48	0.64	0.67	0.60	0.143305	0.443305
6	7	6	232.62	231.77	1.34	0.33	2.71	0.07	2.202138	2.502138
7	8	7	192.52	191.54	2.14	0.24	2.31	0.17	1.716440	2.016440
8	9	8	110.72	109.98	1.93	0.47	3.10	0.31	3.026107	3.326107
9	10	9	108.89	108.21	1.81	1.00	1.65	0.18	1.746484	2.046484
10	11	10	709.12	708.47	1.99	0.82	2.46	0.36	2.094320	2.394320

11	12	11	365.87	365.27	1.99	0.39	1.83	0.25	1.357058	1.657058
12	13	12	71.80	71.32	1.35	0.20	2.04	0.99	2.098695	2.398695
13	14	13	158.91	158.52	1.65	1.02	1.05	0.13	0.319114	0.619114
14	15	14	178.66	178.39	1.94	0.60	2.24	0.63	2.757516	3.057516
15	16	15	151.05	150.82	1.79	0.24	2.72	0.91	2.204918	2.504918
16	17	16	62.74	62.60	2.16	0.75	0.76	0.48	0.872767	1.172767
17	18	1	149.66	149.56	1.66	1.04	2.03	0.62	0.151787	0.451787
18	19	18	697.03	696.67	1.40	0.58	0.87	0.91	0.503138	0.803138
19	20	19	71.11	70.86	1.39	0.31	1.19	0.80	0.092797	0.392797
20	21	20	245.75	245.58	1.68	0.39	1.63	0.47	0.617900	0.917900
21	22	2	129.03	128.95	2.12	0.89	2.54	0.74	2.073365	2.373365
22	23	22	279.40	278.38	2.07	0.73	1.19	0.56	0.160101	0.460101
23	24	23	128.90	128.02	1.54	0.85	2.44	0.49	1.798811	2.098811
24	25	5	128.37	127.93	1.86	0.68	0.81	0.51	1.670372	1.970372
25	26	25	658.56	657.22	1.82	0.90	1.72	0.35	2.428294	2.728294
26	27	26	467.03	465.76	1.93	0.33	1.82	0.97	2.444008	2.744008
27	28	27	99.74	98.53	1.99	0.46	2.24	0.68	2.884344	3.184344
28	29	28	132.73	131.56	2.18	0.20	2.74	0.30	2.275931	2.575931
29	30	29	251.46	250.49	2.01	0.98	2.83	0.68	2.358722	2.658722
30	31	30	100.90	100.44	2.12	0.74	1.92	0.42	1.395202	1.695202
31	32	31	302.01	301.70	1.26	0.25	3.08	0.32	2.729324	3.029324

Table 2 Results of 33 bus system applying EHO algorithm with Distributed Generation.

Faulted Bus	**relay number**	**Backup Relay**	**Main ISC in A**	**Backup ISC in A**	**TDS main**	**IP main**	**TDS Backup**	**IP Backup**	**Relay opert time**	**Backup relay time**
1	2	1	1538.94	1537.79	1.86	0.63	0.59	0.44	0.400980	0.700980
2	3	2	279.70	279.09	1.93	0.29	2.21	0.14	2.105722	2.405722
3	4	3	379.25	379.77	1.72	0.68	1.63	0.46	2.076895	2.376895
4	5	4	364.41	365.08	1.77	0.99	1.49	1.02	1.316165	1.616165
5	6	5	140.03	140.24	1.83	0.81	2.72	0.07	2.739343	3.039343

6	7	6	245.38	245.56	1.80	0.29	1.53	0.96	1.468471	1.768471
7	8	7	203.98	206.49	1.72	0.21	2.09	0.42	2.226333	2.526333
8	9	8	119.37	121.54	1.83	0.82	2.44	0.32	1.955566	2.255566
9	10	9	120.32	122.59	1.66	0.17	2.62	0.47	3.423956	3.723956
10	11	10	803.39	802.82	1.97	0.21	1.83	0.14	2.083027	2.383027
11	12	11	414.59	414.07	1.58	0.84	1.06	0.79	0.884452	1.184452
12	13	12	81.39	80.97	2.14	0.28	1.28	0.89	0.823998	1.123998
13	14	13	180.41	180.06	2.14	0.94	2.66	0.19	3.294686	3.594686
14	15	14	202.95	202.70	1.89	0.45	2.15	0.13	2.804655	3.104655
15	16	15	171.64	171.44	1.74	1.00	1.22	0.53	0.239215	0.539215
16	17	16	71.32	71.19	1.37	0.99	1.07	0.62	0.805126	1.105126
17	18	1	170.20	170.11	1.41	0.79	1.09	0.32	2.124096	2.424096
18	19	18	698.59	698.22	1.94	0.25	2.22	0.17	2.339218	2.639218
19	20	19	71.27	71.02	1.68	1.01	2.75	0.37	2.529083	2.829083
20	21	20	246.31	246.13	1.65	0.36	1.41	0.97	1.738797	2.038797
21	22	2	129.32	129.24	1.87	0.66	2.15	0.12	1.519108	1.819108
22	23	22	283.42	282.41	1.96	0.28	0.69	0.74	0.498713	0.798713
23	24	23	130.77	129.90	1.36	0.81	0.52	1.03	0.081519	0.381519
24	25	5	130.25	129.82	1.26	0.49	2.99	0.45	1.002386	1.302386
25	26	25	694.67	693.41	1.55	0.53	1.21	0.51	0.160748	0.460748
26	27	26	492.74	491.55	1.27	0.91	2.25	0.59	2.252330	2.552330
27	28	27	105.26	104.12	1.71	0.52	2.18	0.16	2.530611	2.830611
28	29	28	140.26	139.15	2.03	0.10	1.07	0.97	0.390009	0.690009
29	30	29	265.97	265.06	1.38	0.41	0.88	0.87	0.425806	0.725806
30	31	30	106.77	106.34	1.96	0.69	2.14	0.76	2.287801	2.587801
31	32	31	319.72	319.44	1.60	0.09	0.52	0.85	0.213064	0.513064

The Table 1 and Table 2 shows the short circuit currents, optimum values of TDS and Plug Setting for the primary relays and backup relays considering without DG and with DG respectively. It has been observed that the fault current increases with inclusion of DG in distribution network and the operating time of over current relays vary according to fault current.

5. Conclusion

This research provides optimized relay settings during variation in distributed generation (DG) performance using two algorithms. Elephant Herding Algorithm is used for optimizing the objective function of the system. IEEE-33 radial bus system is taken as test systems. Results are obtained out in MATLAB software for systems with and without DG and the effectiveness of the proposed algorithms is shown. The pickup current value is determined from the short circuit analysis report, the maximum fault current is calculated, results that are obtained from load flow analysis. The implementation of DG causes the system to increase the fault currents of the buses involved, calculating optimized relay settings for increased system conditions, and calculating the operating times of main and backup relays. It is shown from the results obtained that EHO gives more optimized values.

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