Development of an Optimal Coordination Scheme For Dual Relay Setting In Distribution Network Using Smell Agent Optimization Algorithm

[1]Muhammad U Iliyasu; [2]Mohammed R. Ozohu; [3]Safiya Yusuf; [4]Ibrahim Abdulwahab, [5]Agbon. E. Ehime; [6]Abubakar Umar

[1]Federal Polytechnic, Bali Taraba State, Nigeria
[2&3]Department of Electrical and Electronics Engineering, Kaduna Polytechnic, Nigeria
[4]Department of Electrical Engineering, Ahmadu Bello University, Zaria, Nigeria
[5]Department of Electronics and Telecommunications Engineering, Ahmadu Bello University, Zaria, Nigeria
[6]Department of Computer Engineering, Ahmadu Bello University, Zaria, Nigeria
jamilmammailmanjen@yahoo.com; safiyayusuf2010@gmail.com; iabdulwahab@abu.edu.ng

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Abstract

This research work is aimed at developing an optimal coordination scheme for dual relay settings in distribution system. The fault current through a relay in forward direction is usually higher than that in the reverse direction for distribution system. Therefore, it is preferable to have a dual setting directional over-current relay. These relays have the capability to operate in both directions (forward and reverse direction) of fault current with two independent relay settings. Additional fault current contribution to the fault location is present due to the integration of distributed generation to the system. The coordination problem is therefore formulated as a nonlinear optimization problem to help mitigate the operating times of the relays using smell agent optimization (SAO) technique. The developed model was applied on IEEE 14-bus network equipped with synchronous distributed generation. The protection setting comprises of two time dial settings (TDS) and a pick up current setting for each relay. The SAO was used to obtain the TDS with the sole purpose of minimizing it while ensuring that the constraints set were satisfied. In the case of TDS with three cases of faults considered. the results obtained showed that the maximum fault current in all the three cases represent 6.79% while the minimum fault current was reduced to 2.70% when compared with the base case. The developed technique thereby achieved a reduction of time dial settings for which the relay operation of 14.50% and 13.69% reduction for the adopted 14 bus IEEE network.

***Keywords*: Distributed generation, Smell agent optimization, Time dial settings.**

1. Introduction

The continuous growth in population, improved living standards and enhanced industrialization always lead to energy demand growing at faster pace than electricity generation [1]. The major primary sources of generating energy are fossil fuels (gas, oil, coal e.t.c) which are a major cause of greenhouse emissions which in turn degrade the environment [2, 3]. Recently, power stations are frequently employed to feed high voltage network connected to millions of equipment. However, the consequence of occurrence of fault in the network can be devastating [4]. Protective relays are now employed into the system, to enable effective security of the network from such abrupt scenarios [5]. The relay ensures proper security of the system by isolating the faulty section of the network from the system by tripping the circuit [6]. The role of protection relays in ensuring effective operation within the power system cannot be overemphasized. The inverse time over-current relay is the backbone of the protection strategies in distribution system. While, the over-current relays are chosen to achieve coordination in order to guarantee reliable, fast and selective relay operation [4]. Directional over-current relays (DORs) has been established to be an economical, attractive and technical choice. It functions by measuring the magnitude of fault current in each phase before issuing a trip signal after specific operating time [7]. The operating time is dependent on the fault current magnitude and the setting values. The recent increasing interest in smart grids, has increased the integration of distributed generations (DGs) into distribution system [8]. These integrations has led to a transformation of distribution system from radial system to mesh and loop structure which increases the short circuit levels of the system. The major trade-off in integrating DGs into a distribution system is the negative effects it brings to the protection system [9]. The impact of the integration on the protection system depends on the nature of the distribution system and the type of DG. Inverter based DGs and synchronous based DGS are the two major types of distributed generations. Of the two types of DGs the impact of the synchronous based distributed generations (SBDG) on the distribution system is more pronounced. The SBDG inject high fault current which results in significant changes to the network [4, 10]. The radial distribution networks are known to be protected by over-current relays, fuses and reclosers. However, for the SBDG, the fuse might operate before the reclosers first operation and this affects the fuse saving strategy [11].

In order to mitigate the problems highlighted (ensuring coordination between the relays and mitigating the operating time of the over-current relays) due to the integration of the SBDG into the distribution system, several literatures have used trial and error techniques for selecting the settings of the relays. However, the technique involves a lot of computational time. Metaheuristic techniques such as bat algorithm, particle swarm optimization and genetic algorithm .... have also been used. However, due to the no free lunch theorem, other recent algorithms can also be used to optimize the relay settings to ensure a reduction in the operating time of the relays to guarantee proper functioning of the equipment connected to the distribution system [4]. [12] developed a scheme for ensuring coordination of the relays by taken into account all the short circuit types. A linear programming method was used in optimizing the objective function. However the coordination problem between the relays is a non-linear problem which cannot be effectively solved with the proposed model. [13] developed an optimal dual characteristics to enhance coordination index in protecting forward and reverse fault currents. However, the coordination process is tedious due to the stages of logic systems used. [14] introduce a fast protection scheme for secure micro-grid operation in both islanded and grid connected modes. However, the proposed method reduces the total operating time for all fault location by fifty seven percent which can still be further reduced. It is evident from the reviewed literature that, the relay coordination plays a vital role in the operation and protection of the distribution power system. Also, the installation of the DG into the network increased the complication in the operation and coordination of the relay in the network. Thus, this work used a smell agent algorithm to optimize the relay settings considering fault analysis in the distribution system. The technique is chosen due to its inherent favourable characteristics (ability to ensure balance between exploitation and exploration process to avoid getting stuck in local minima). This will ensure an effective coordination between the relay and the back-up relay and also mitigate the operation time of the relays.

2 PROBLEM DEFINITION

Integration of these DGs in a distribution network creates an adverse effects on the power flow, voltage profile, fault level (short circuit) and also, the protection scheme of the power system and this could be due to the reverse flow of current from the DG or current produce by the DG which depend on the type of DG use. Relay coordination (overcurrent relay) are mostly employed in the distribution network for the protection of the power system equipment. In this work, smell agent algorithm was used to find the optimal DG placement and relay settings (determination of pick up current and time dial setting) of directional overcurrent relay while the dual relay settings was used to address the problem of forward and reverse direction of Fault Current. This ensures proper coordination between the primary and backup relays and at the same time minimize the total operating time of the relays.

METHODOLOGY

IEEE 14 bus test system was used in implementing the developed technique. Figure 1 shows the standard IEEE 14 bus network.

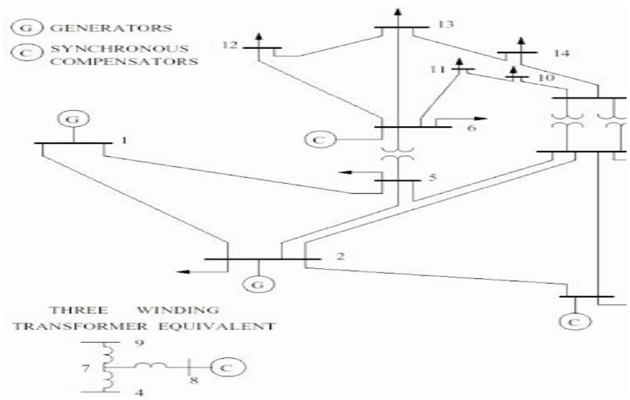

Figure 1: IEEE 14 Bus System

2.1 Standard IEEE 14 Bus Network

The standard IEEE 14-bus test system is also referred to as the Washington network consisting of a meshed sub-transmission system. It comprises mainly of five generators, three transformers, fifteen lines and hence thirty dual-setting relays. Nominal frequency of this system is 60 Hz.

2.1.1 Load Flow analysis

Load Flow Analysis which also termed as power flow analysis is an important tool in power system analysis that helps to determine the steady state behavior of a system. A number of load flow analysis algorithms has been developed over the years to help in solving load flow problems for both balanced and unbalanced distribution networks. Some of the algorithms were capable of finding solution even after inclusion of DG sources in the network.

2.1.2 Short Circuit Analysis

The most common faults in distributed power system are asymmetrical fault. Thus an unbalanced three phase was used in this work in analyzing the asymmetrical fault. The direct solution to handling such systems are very difficult. These techniques provide excellent results for the balanced electric power systems. However, the micro-grid configuration is unbalanced, but with the method of symmetrical components application to fault analysis, it was transform arbitrarily and then, computation of the system response is carried out by straightforward circuit analysis. Then, the results obtained are transform back to the original phase variables.

2.2 Development of dual Relay Coordination system using smell agent optimization

The smell agent optimization (SAO) was used for relay setting by formulating its parameter modification with respect to the dual relay settings. This was carried out by initializing the smell agent population.

2.2.1 Methodology

In the distribution network, the primary relays ensure proper clearing of the fault to prevent mal-operation of the equipment connected to the system. These faults are cleared by optimizing the plug settings and the time dial settings. This work uses the summation of the operating times of all the primary and backup relays responding to clear close-in and far bus faults as the objective function.

For the DORs, the relay time current characteristics is depicted as:

$$t_{ij} = TDS \frac{A}{\left(\frac{I_{sc_{ij}}}{I_{pi}}\right)^{B} - 1} \qquad (1)$$

Where the parameters A and B are constants that changes based on the type of overcurrent relay (OCR). These OCR's are normally set at 0.14 and 0.02 respectively, i is the relay identifier and j is the fault location identifier. The term $I_{sc_{ij}}$ represents the relay Fault Current and I_{p_i} represents the relay pickup current. Each DOCR has one pair of setting for both primary and backup operation. The optimization objective is to minimize the times of all the relays (primary and backup) while maintaining the conditions of protection coordination.

The objective function is therefore expressed as:

$$T = \sum_{j=1}^{M}\left(\sum_{i=1}^{N} t_{fw_{ij}} + \sum_{k=1}^{N} t_{rv_{kj}}\right) \ \forall (i,k) \in \Omega \qquad (2)$$

Where Ω represents set of primary/backup pairs of the relays, N depicts the total number of relays, and M is the total number of fault locations across all feeders. $t_{fw_{ij}}$ and $t_{rv_{kj}}$ represent the operation times for the forward/primary and reverse/backup relays, respectively. The variables $t_{fw_{ij}}$ and $t_{rv_{kj}}$ are the time of operation of relay *i*, and *k* for a fault at location *j* during forward (primary) and reverse (backup) operation, respectively.

Fault Current, due to a fault at location *j*, passing through relay *k* in the reverse direction. The coordination constraints must be satisfied while solving the protection coordination problem which can be represented as follows:

$$t_{rv_{kj}} - t_{fw_{ij}} \geq CTI \;\; \forall i, k, j \tag{3}$$

In addition, there are upper and lower bounds on the relay settings which can be expressed as:

$$TDS_{i\_\min} \leq TDS_{fwi}, \; TDS_{rvi} \leq TDS_{i\_\max} \tag{4}$$

$$I_{pi\_\min} \leq I_{pfwi}, \; I_{prvi} \geq I_{pi\_\max} \tag{5}$$

Where coordination time interval (CTI) indicates the minimum time between the primary and the backup relay. The CTI value was set to 0.3 s. Where I_{pi_min} and I_{pi_max} represent the lower and upper bounds on relay *i* pickup current setting. The parameters TDS_{i_min} and TDS_{i_max} represent the lower and upper bounds on the TDS for relay *i*. The main variables, to be optimized, for the protection coordination problem, are the TDS and *Ip* in both forward and reverse directions. The short circuit current is considered a parameter within the optimization but the DG location and size will have an effect on FCL. For each study, prior to optimizing the relay settings, fault analysis is conducted to determine the Fault Currents passing through each relay [15]. As can be seen from (4) and (5), the relationship between the relay operating time and the pickup current setting is nonlinear. Thus, the model is formulated as a constrained NLP problem, integrated with a primary/backup pair scheme such that the relays closest to the fault are consider.

3 Smell Agent Optimization Algorithm

Optimization techniques are now frequently used for solving complex engineering optimization problems. The behaviors of various natural systems are used in developing metaheuristics optimization algorithms [16]. Smell agent optimization (SAO) algorithm is developed using the interaction between a smell agent, smell molecules and smell source. The general framework of this algorithm is governed by three different modes. The sniffing mode, trailing mode and random mode. The framework of SAO shown in figure 2 is done such that the agent is represented as a man while a circle is used to depict the smell source. The smell molecules represented with dotted lines, and the black thick line denotes the path of smell molecules with highest concentration. x_{fe} are all feasible path leading to the smell source. However, the agent always tries to maintain its position on the path with the highest concentration of smell molecule. The agent takes note of its position at all stage in the searching process.

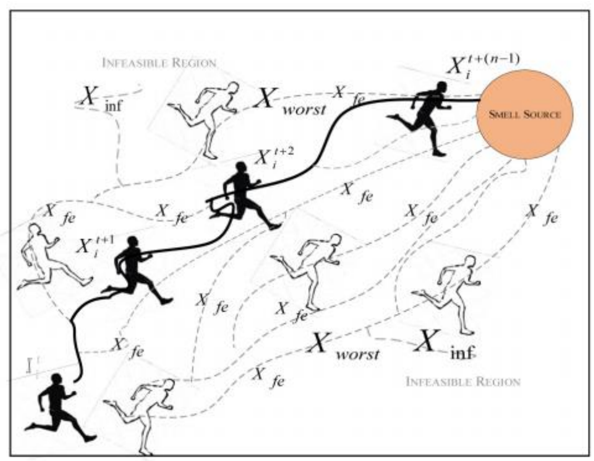

Figure 2: Framework of SAO

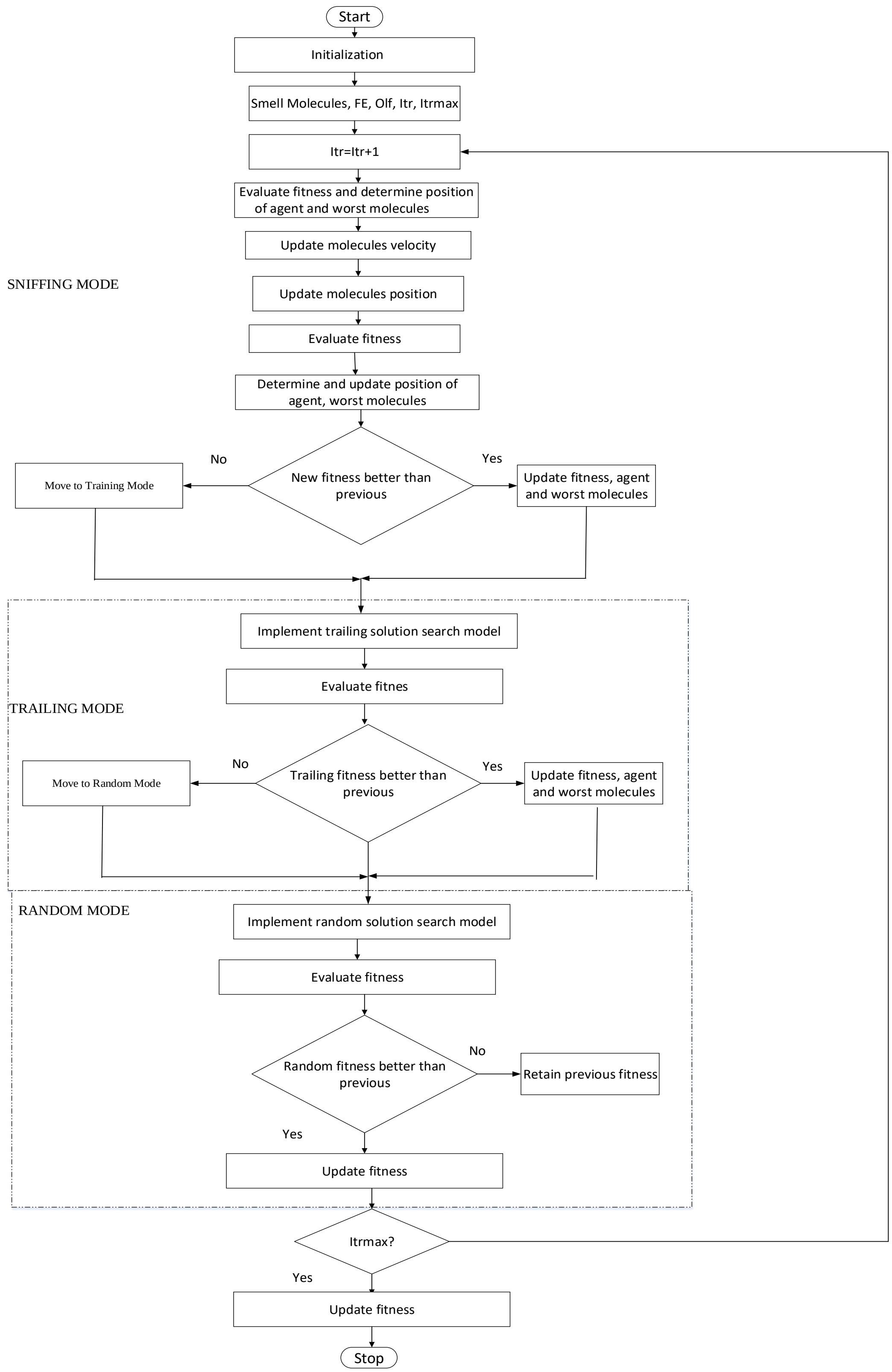

Figure 4: Flow Chart of the Smell Agent Optimization Algorithm

4 RESULTS

The results include the conventional protection coordination and the developed protection method. The implementation of the work is done on IEEE 14-bus test system. The comparison between the developed methods with the work of (Sajjad Dadfar and Majid Gandomkar 2020) are also presented**.** In the analysis, three case scenarios of fault were considered, which involved fault between bus 2 and 3, fault between bus 5 and 6 and also, fault between bus 13 and 14. The fault current, set. I_p, Set. TDS together with the operating time were determined for both without and with DG in the network and the results obtained are shown and discussed.

4.1 Case I: Fault between Bus 2 and 3

For case I scenario, it was assumed that a fault occurred between the mid of bus 2 and 3 which create a virtual bus called bus 15. The buses connected to bus 2 and 3 are: bus 1, bus 4 and bus 5.

Each of these buses have relay connected to them and the results obtained when a fault occurred between the 2 and 3 is shown on Tables 1 and 2. Table 1 shows the fault current and the operating time obtained when the fault occurred for both without and with DG respectively. Table 2 shows the set Ip and set TDS of the relays for without and with DG.

Table 1: Fault Current and Relay Operating Time

S/N	Relay No	Bus No		Fault Current	Operating Time	Fault Current	Operating Time
				Without DG		With DG	
1	215	0.02	P	0.234555313	0.115913948	0.381152383	0.09895673
2	21	0.02	B	0.032820219	0.359096179	0.053332856	0.3000007
3	12	0.01	B	0.032820219	0.359098421	0.053332856	0.30000258
4	215	0.02	P	0.234555313	0.115911646	0.38115238	0.09895817
5	24	0.02	B	0.063005718	0.3000078	0.10238429	0.30000275
6	42	0.04	B	0.063005718	0.300001923	0.10238429	0.30000554
7	215	0.02	P	0.234555313	0.115910417	0.38115238	0.09895597
8	25	0.02	B	0.065640438	0.30000138	0.10666571	0.30000188
9	52	0.05	B	0.065640438	0.300004651	0.10666571	0.30000036
10	315	0.03	P	0.073088937	0.19471765	0.11876952	0.1519838
11	34	0.03	B	0.091964735	0.300023397	0.14944269	0.30001037
12	43	0.04	B	0.091964735	0.300001812	0.14944269	0.30001553

The relay 215 indicate the relay at bus 2 and the relay 315 indicate the relay at bus 3 and they are both taken as the primary relays while relay 12, 21, 24, 42, 25, 52, 34 and 43 serves as the backup relays. From Table 1, it can be seen that the maximum fault current occurred at Bus 2 with fault current of 0.234555313A and 0.381152383A for both without and with DG respectively. The maximum fault current is indicated by the primary relay 215. The minimum fault current occurred at bus 1 and 2 with fault current of 0.032820219A and 0.053332856A for both without and with DG respectively. The maximum and minimum operating time of the relay for without DG are 0.359098421s and 0.115910417s and this occurred at bus 1 and 2 respectively. The maximum and minimum operating time of the relay for with DG are 0.30001553s and 0.09895597s and this occurred at bus 4 and 2 respectively.

From Table 2, the maximum Set Ip for without and with DG both occurred at bus 3 between line 3 and 4 and bus 2 between line 2 and 5 which are indicated by the backup relay 34 and 25 with values of 1.4256082 and 1.43355379 respectively.

The minimum Set Ip for without and with DG occurred at bus 2 which is indicated by the primary relay 215 with value of 1.2500029 and 1.12500221 respectively.

Also, the maximum SET_TDS for without and with DG occurred at bus 4 between line 4 and 3 and bus 3 between line 3 and 4 which are indicated by the backup relay 43 and 34 with values of 0.08160537 and 0.10726447 respectively.

The minimum SET_TDS for without and with DG both occurred at bus 2 which are indicated by the primary relay 215 with values of 0.05000031 and 0.05000016 respectively.

Table 2: Relay Set Ip and TDS

S/N	**Relay No**	**Bus No**		**Set_Ip**	**Set_TDS**	**Set_Ip**	**Set_TDS**
				Without DG		**With DG**	
1	215	0.02	P	1.2500029	0.05000246	1.2500221	0.05000071
2	21	0.02	B	1.2500202	0.05000046	1.28096572	0.06200984
3	12	0.01	B	1.2500215	0.05000072	1.37234355	0.05897374
4	215	0.02	P	1.2500612	0.05000064	1.25004132	0.05000121
5	24	0.02	B	1.3418991	0.06731838	1.3741348	0.08782379
6	42	0.04	B	1.3137543	0.06825424	1.28188686	0.09092708
7	215	0.02	P	1.2500473	0.05000031	1.25003628	0.05000016
8	25	0.02	B	1.2789701	0.07125444	1.43355379	0.08776261
9	52	0.05	B	1.3281409	0.06958528	1.41786626	0.08825311
10	315	0.03	P	1.2500076	0.05000066	1.25002314	0.05000043
11	34	0.03	B	1.4256082	0.08140967	1.29978607	0.10726447
12	43	0.04	B	1.4191638	0.08160537	1.35460148	0.10540805

4.2 Case II: Fault Between Bus 5 and 6

For the case II scenario, it was assumed that a fault occurred between the mid of bus 5 and 6 which create a virtual bus called bus 15. The buses connected to bus 2 and 3 are: bus 1, bus 2, bus 4, bus 11, bus 12 and bus 13.

Each of these buses have relay connected to them and the results obtained when a fault occurred between the 5 and 6 are shown on table 3 and 4

Table 3 shows the fault current and the operating time obtained as a result of the fault while table 4 shows the set Ip and set TDS of the relays. The simulation was done without and with DG on the network.

For the fault between bus 5 and 6, we have 3 primary relays, which are relay No 515 located at bus 5, 126 located at bus 1 and 612 located at bus 6 connected within the fault zone. The relay No 15,51,25,52,45,54,116,611,615,136,613 serve as the backup relays which are shown with their respective bus on table 3.

From Table 3, the maximum fault current without DG occurred at Bus 5 with fault current of 0.244102504A while the maximum fault current with DG occurred at bus 6 with fault current of 0.396666568A. The maximum fault current for without and with DG are indicated by the relay No 515 both occurring at bus 5. The minimum fault current for both without and with DG is zero (0) indicated by relay No 116 and 126 respectively at bus 1.

The maximum and minimum operating time of the relay for without DG are 1.621429523s and 0.114307027s at bus 6 and 5 indicated by relay No 615 and 515 respectively.

The maximum and minimum operating time of the relay for network with DG are 1.621253141s and 0.097774675s at bus 6 and 5 indicated by relay No 615 and 515 respectively.

Table 3: Fault Current and Relay Operating Time

S/N	Relay No	Bus No		Fault Current Without DG	Operating Time	Fault Current With DG	Operating Time
1	515	0.05	P	0.244102504	0.114310748	0.396666568	0.097775742
2	51	0.05	B	0.030830182	0.384220849	0.050099047	0.300002351
3	15	0.01	B	0.030830182	0.384214887	0.050099047	0.300004521
4	515	0.05	P	0.244102504	0.114313338	0.396666568	0.097774675
5	52	0.05	B	0.061660365	0.300000051	0.100198093	0.300001619
6	25	0.02	B	0.061660365	0.300005009	0.100198093	0.300000141
7	515	0.05	P	0.244102504	0.114307027	0.396666568	0.097776307
8	54	0.05	B	0.080432457	0.300000712	0.130702742	0.300004391
9	45	0.04	B	0.080432457	0.300017338	0.130702742	0.300010654
10	615	0.06	P	0.046515353	0.262889122	0.075587449	0.191019113
11	611	0.06	B	0.048511801	0.300003521	0.078831676	0.300003785
12	116	0.01	B	0	0.300001399	0	0.300010663
13	615	0.06	B	0.015505118	1.621429523	0.015505118	1.621216696
14	612	0.06	P	0.017333298	1.067247592	0.017333298	1.067215466
15	126	0.01	P	0	1.067265981	0	1.067587981
16	615	0.06	B	0.015505118	1.621197275	0.015505118	1.621253141
17	613	0.06	B	0.016620677	1.22507508	0.016620677	1.225063044
18	136	0.13	B	0.016620677	1.225000539	0.016620677	1.224984079

Table 4: Fault Current and Relay Operating Time

S/N	Relay No	Bus No		Set_Ip Without DG	Set_TDS	Set_Ip With DG	Set_TDS
1	515	0.05	P	1.2501353	0.05000018	1.250028334	0.050000845
2	51	0.05	B	1.2500069	0.05000135	1.364456759	0.056474386
3	15	0.01	B	1.250018	0.05000008	1.429979704	0.054412587
4	515	0.05	P	1.2500517	0.05000247	1.250014524	0.050000464
5	52	0.05	B	1.4944207	0.0616113	1.376758164	0.086775665
6	25	0.02	B	1.3109474	0.06739518	1.303996895	0.089197823
7	515	0.05	P	1.2500076	0.05000032	1.250013017	0.050001317
8	54	0.05	B	1.4115106	0.07589198	1.307905619	0.100961081
9	45	0.04	B	1.3831855	0.07679596	1.299797493	0.101242284
10	615	0.06	P	1.2500509	0.0500027	1.250004712	0.050001544
11	611	0.06	B	1.4118032	0.05355992	1.455950445	0.073626264
12	116	0.01	B	1.3183736	0.05656934	1.310875584	0.078286005
13	615	0.06	B	1.2500481	0.05000203	1.250005414	0.050003412

14	612	0.06	P	1.2500234	0.05000099	1.250010894	0.050001015
15	126	0.01	P	1.2500312	0.05000089	1.250139424	0.050002684
16	615	0.06	B	1.2500031	0.05000324	1.250028414	0.050000256
17	613	0.06	B	1.2500019	0.05000594	1.250012057	0.050004009
18	136	0.13	B	1.2500065	0.05000224	1.25001298	0.050000656

From Table 4, the maximum Set Ip for without and with DG both occurred at bus 5 between line 1 and 5 and bus 6 between line 6 to the point of the fault which are indicated by the backup relay 15 and 615 with values of 1.4944207 and 1.455950445 respectively.

The minimum Set Ip for without and with DG occurred at bus 6 which is indicated by relay No 613 and 615 with value of 1.2500019 and 1.250004712 between line 6 to 13 and line 6 to the point of the fault respectively.

Also, the maximum SET_TDS for without and with DG occurred at bus 4 between line 4 to 5 which is indicated by the backup relay No 45 with values of 0.07679596 and 0.101242284 respectively.

The minimum SET_TDS for without and with DG occurred at bus 1 and 6 which are indicated by relay 15 and 615 with values of 0.05000008 and 0.050000256 between line 1 to 2 and line 6 to the point of the fault respectively.

4.3 Case III: Fault between Bus 13 and 14

For the Case III scenario, it is assumed that a fault occurred between the mid of bus 13 and 14 which create a virtual bus called bus 15. The buses connected to bus 13 and 14 are: bus 6, 9, and 12. Each of these buses have relay connected to them and the results obtained when a fault occurred between the 13 and 14 is shown on Tables 5 and 6. Table 5 shows the fault current and the operating time obtained as a result of the fault while table 6 shows the set Ip and set TDS of the relays. The simulation was done without and with DG on the network.

Table 5: Fault Current and Relay Operating Time

S/N	**Relay No**	**Bus No**		**Fault Current (A)**	**Operating Time**	**Fault Current**	**Operating Time**
				Without DG		**With DG**	
1	1315	0.013	P	0.017358255	0.1295684	0.028207164	0.108848519
2	136	0.013	B	0.009744548	0.30000556	0.01583489	0.30000164
3	613	0.006	B	0.009744548	0.300001947	0.01583489	0.300000886
4	1315	0.013	P	0.017358255	0.129566055	0.028207164	0.108847684
5	1312	0.013	B	0.007613707	0.300037868	0.012372274	0.300007407
6	1213	0.012	B	0.007613707	0.300032271	0.012372274	0.300000364
7	1415	0.014	P	0.001976412	0.760497272	0.003211669	0.367428159
8	149	0.014	B	0.011431192	0.300004305	0.018575687	0.300001051
9	914	0.009	B	0.011431192	0.300007438	0.018575687	0.300007702

For the fault between bus 13 and 14, we have 2 primary relays, which are relay No 1315 located at bus 13, and 1415 located at bus 14 connected within the fault zone. The relay No 136, 613, 1312, 1213, 149 and 914 serves as the backup relays which are shown with their respective bus on table 5.

From table 5, the maximum fault current without and with DG both occurred at Bus 13 which is indicated by relay No 1315 with fault current of 0.017358255A and 0.0282071644A respectively between line13 to 15. The minimum fault current for without and with DG occurred at bus 14 which is indicated by relay No 1415 with fault current of 0.001976412 and 0.003211669 respectively between line 14 to the point of the fault. The maximum operating time of the relay for both without and with DG are 0.760497272s and 0.367428159s respectively at bus 14 indicated by relay No 1415 respectively between line 14 to the point of the fault. The minimum operating time of the relay for both without and with DG are 0.0129566055s and 0.108847684s respectively at bus 13 between line 13 to the point of the fault indicated by relay No 1315.

Table 6: Fault Current and Relay Operating Time

S/N	Relay No	Bus No		Set_Ip Without DG	Set_TDS	Set_Ip With DG	Set_TDS
1	1315	0.013	P	1.2500635	0.0500008	1.250025349	0.05000162
2	136	0.013	B	1.2757131	0.08893484	1.306985914	0.109619093
3	613	0.006	B	1.321396	0.08736387	1.382881206	0.107077402
4	1315	0.013	P	1.2500073	0.05000077	1.250091858	0.050000356
5	1312	0.013	B	1.3694261	0.07480927	1.457317297	0.093656626
6	1213	0.012	B	1.3054139	0.07693238	1.277213879	0.099562869
7	1415	0.014	P	1.2500105	0.05000122	1.250033896	0.050000708
8	149	0.014	B	1.3820432	0.09248947	1.358971347	0.115059935
9	914	0.009	B	1.2928003	0.0954768	1.293988515	0.117276328

From Table 6, the maximum Set Ip for without and with DG occurred at bus 14 between line 14 and 9 and bus 13 between line 13 and 12 indicated by the relay No 149 and 1312 with values of 1.3820432 and 1.457317297 respectively. The minimum Set Ip for without and with DG both occurred at bus 13 which is indicated by relay No 1315 with value of 1.2500073 and 1.250025349 between line 13 to the point of the fault respectively. Also, the maximum SET_TDS for without and with DG occurred at bus 9 between line 9 to 14 which is indicated by relay No 914 with values of 0.0954768 and 0.117276328 respectively. The minimum SET_TDS for without and with DG both occurred at bus 13 which is indicated by relay 1315 with values of 0.05000077 and 0.050000356 respectively between line 13 to the point of the fault. Table 7 shows the summary of bus 14 test system

Table 7: Summary of bus 14 test system

	Maximum Fault Current (A)		Minimum Fault Current (A)	
	Without DG	With DG	Without DG	With DG
	0.234555313	0.381152383	0.032820219	0.053332856
CASE I	1.4256082	1.43355379	1.2500029	1.12500221
	0.244102504	0.396666568		
CASE II	1.4944207	1.455950445	1.2500019	1.250004712
CASE III	0.017358255	0.028207164	0.001976412	0.003211669
	1.3820432	1.457317297	1.2500073	1.250025349
	4.798088172	5.152847647	3.784808731	3.681576796
	6.79%		2.70%	

Ff

Maximum TDS (s)		Minimum TDS (s)	
Without DG	With DG	Without DG	With DG

	0.359098421	0.30001553	0.115910417	0.09895597
CASE I	0.08160537	0.10726447	0.05000031	0.05000016
	1.621429523	1.621253141	0.114307027	0.097774675
CASE II	0.07679596	0.101242284	0.05000008	0.050000256
CASE III	0.760497272	0.367428159	0.012956606	0.108847684
	0.0954768	0.117276328	0.05000077	0.050000356
	2.994903346	2.614479912	0.39317521	0.455579101
	14.50%		13.69%	

From the summary of 14 bus test system, it can be deduced that the maximum fault current in all the three cases represent 6.79% while the minimum fault current was reduced to 2.70% when compared with the base case. Also, the SET_TDS for the three cases at maximum and minimum represent 14.50% and 13.69% reduction for the relay to operate so as to clear out the fault current on the network when compared with the base scenario.

5 Conclusion

This work has presented an optimized Dual Relay Setting Coordination module for Distribution system with Distributed Generation using smell agent algorithm. The smell agent algorithm was applied on a 14 bus IEEE system to obtain optimal protection coordination of DOR in the distribution system. The scheme employed functions by reducing the total operating time of the primary and backup relay while taking into consideration the CTI between the relay pairs. The performance of the presented coordination strategy recorded satisfactory reduction of 14.50% and 13.69% for which the relay operate to clear fault current on the 14 bus network. This showed that the response of the relay was fast in clearing out the fault current in the network.

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