Protection coordination of directional over current relay with distributed generation

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ABSTRACT

The present study is focussed on a comparative analysis of different meta-heuristic optimization approaches for directional overcurrent relay (DOCRs) coordination which has been discussed and presented in the literature. Further, to have a comparative analysis of the performance of the optimization methods discussed they have been tested on power system network of different sizes. To overcome such issues, this work proposed a simplex linear programming technique-based overcurrent relay method using general algebraic modelling system (GAMS). The execution of this work is done on the MATLAB 2018 a platform. Based on the obtained result the best meta-heuristic optimization method for mitigating the problem of relay coordination has been identified. Nevertheless, the operating time of the relay is high, so the fault is not corrected at a time. The developed model has been tested on test system of different sizes namely IEEE 9 bus and IEEE 14 bus system. The obtained values through series of simulation are compared with different methods for proving the proposed protection coordination scheme is more effective and efficient than others in terms of operating time and coordination time.

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1. INTRODUCTION

Microgids are formed in order to increase the reliability of supply, reduce losses and greenhouse gas emission. Due to increased distributed generation (DG) penetration fault current magnitude changes and radial nature of power flow is converted to bidirectional flow and increased short circuit level [1]. Thus, the protection system designed for conventional power flow maloperates due to addition of DG. Directional overcurrent relays (DOCRs) clear the fault accurately if the primary and backup relays maintain minimum coordination time but due to incorporation of DG this coordination has become complicated. Overcurrent protection is used to protect the system as it is cost effective and efficient [2]. The protection scheme should be such that the primary relay must operate quickly in order to remove the faulty part of the feeder to maintain reliability of the supply [3]. However, if the primary protection fails to operate then the corresponding back up protection according to the designed zone of protection must operate. This attribute of designed protection scheme for distribution system is necessary as the primary protection removes only smaller portion of the system whereas operation of backup protection leads to unwanted tripping of larger portion of the system [4]. For this reason, the coordination of protection scheme plays a foremost part in the power scheme to protect the electrical component on or after fault current [5]. Normally, protection has been done using the coordination of relying arrangements which is depends upon the analysis of short circuit and load flow [6]. In relay kind of coordination protection, the overcurrent (OC) relay process is extensively utilized. If there is any fault identifies then the OC relay will work and provides guideless for the incorporated circuit breaker towards open [7]. Thus, the electrical components in the power scheme are not impacted via the fault current due to the working of circuit breakers [8]. Consequently, the essential as well as backup based protective components are utilized to enhance the working of power scheme also protection coordinated method is considered for the fault scheme [9]. The protection coordination-based OC relay should be developed based on the conditions such as reliable, selective, rapid isolating region and flexible.

However, if the coordination protection is poor then it tends to create blackouts, fault regions and electrical device damage [10]. The inverse coordination in the OC relay standard is considered as very, normal and extreme based on the International Electro-technical commission reference [11]. There are two settings considered for the validation of directional based OC relay working time such as time multiplier-based setting (TMS) and plug based setting (PS) [12]. Nevertheless, this is not an easy task to estimate the specific setting of OC relay in regulating each state using the power engineer of manual solution or traditional technique [13]. Thus, it required new methods to place the finest setting of relay to diminish the working time of relay.

To resolve these problems, a new optimized method of coordination is essential to safeguard and significantly utilize the distribution generation schemes [14]. In previous, curve fitting technique, trial as well as error technique, analytical technique and graph theoretical based method is utilized for relay setting. However, this method has certain drawbacks such as less convergence, a huge amount of recurrence [15]–[17]. Moreover, the linear form of coordination is solved using the dual-stage simplex, simplex as well as twice simplex methods. The dual simplex method is mainly utilized in the distribution cable, flexible alternating current (AC) transmission systems (FACTS) components as well as overhead line linked with the coordination scheme [18]–[20]. The linear programming method of coordination algorithm is easy and rapid process yet it has to create more hazards to the native solution [21]–[23].

The DOCRs are mainly utilized for transmission and distribution network protection. However, the directional coordination of relay is the foremost problem in the meshed power network system. Thus, Tjahjono *et al.* [24] contributed a new method named as an adaptive based modified FA (AMFA) method for solving the problems in conventional firefly algorithm for OC relay coordination problem. Moreover, the time has been reduced as 40.446% over the normal FA method. Sarwagya *et al.* [25] provided a sine cosine algorithm (SCA) method for the problem of finest coordination in OC Relay of power distribution system. However, an effective solution is not achieved by those techniques. For this reason, Rivas *et al.* [26] projected a new random walk based grey wolf optimizer (RW-GWO) method for the optimal solution for high complex issues in power system. However, the problem-solution accuracy is very low.

2. OPTIMIZATION ALGORITHM USED

The simplex linear programming technique is more efficient process for achieving primary possible consequences. If the result is not finest then this method contributes for achieving a nearby primary possible result that is less than or equal to the progress. The flowchart of the simplex linear programming method is detailed in Figure 1. Assume that the radial distribution system bus is N. Estimate the operation of relay by the way of backup and primary relay on behalf of the loads. Then estimate the utmost fault current as well as load current on behalf of the loads. These rates are achieved from the test bus system is executed in MATLAB/Simulink using general algebraic modelling system (GAMS) theory modeling. The utmost rate of fault current is achieved by the three-phase line (LLL) fault simulation on all loads. Estimate total dissolved solids (TDS), PS and current transformer (CT) ratio. The bus system relays have the boundary of TDS and PS. Each relay has a minimum and maximum limit of TDS and PS has been set.

3. PROPOSED METHOD

The proposed coordination problem of DOCRs in a distribution system has to be minimized and its mathematical model is demonstrated in (1):

$$\min z = \sum_{i=1}^{n} t_{ij} \quad (1)$$

where n is the number of relays, t_{ij} is operating time of i^{th} relay for fault in j^{th} zone. The constraints to solve this optimization problem are divided in three sections [6], [7], [9], [10].

3.1. Limit on time interval between primary and backup relay coordination time interval (CTI)

Coordination time interval (CTI) between backup and primary is the difference between time of operation of backup and primary relays. It acts as a constraint to the optimization problem defined in (1).

$$t_{bi,j} - t_{pi,j} \geq \Delta t \quad (2)$$

Where $t_{bi,j}$ and $t_{i,j}$ are the operating time of the primary relay R_p and the backup relay R_q respectively, for fault at location k. Δt is the CTI taken as 0.2 s.

3.2. Constraint on time multiplier setting (TMS)

The bound on TMS is be given by (3):

$$TMS_{i,j\ min} \leq TMS_{i,j} \leq TMS_{i,jmax} \quad (3)$$

where $TMS_{i,j\ min}$ and $TMS_{\ i,j\ max}$ are minimum and maximum value of *TMS* of relay at ith location and $TMS_{i,j\ max}$ is the maximum range of *TMS* of relay at ith location. In this work the boundary limits of TMS taken is [0.05,1.2].

3.3. Bounds on pickup current

The limit on plug setting can be defined as (4).

$$PS_{\ min} \leq PS \leq PS_{max} \quad (4)$$

PS_{min} and PS_{max} is lower and upper limit of plug settings respectively. In this work the range of PS is [0.5,2.5].

4. RESULTS AND ANALYSIS

The proposed method has been implemented and tested on 9-bus and 14-bus test systems. Further, the relay settings are also computed using the techniques discussed for both the test systems. Function value has been computed and evaluated for reduction in time. Moreover, coordination time interval for each primary backup relay pair is calculated and checked for violations.

4.1. Section I: 9 bus test system

The implementation of this work has been done on the MATLAB platform using GAMS modelling. Initially, design the IEEE 9 Bus Radial Scheme IEEE 14 Bus Radial distributed generation scheme. The structure of bus scheme includes relay, generator, Loads and transformer. The structure of IEEE 9 bus is illustrated in Figure 1. In this Figure R1-R19 are the IDMT based relays incorporated in the distribution system in order to completely protect the feeder. Three Generators G1, G2 and G3 are connected.

– Then, develop the three-phase fault at the middle of the bus lines for validating the performance of the developed model.
– Apply the directional based overcurrent relay to the multi-bus scheme.
– The data of CT ratio, backup rate, primary relay rate, current value and features constant are collected.
– Initialized all the parameters to the proposed linear method.
– Then the developed simplex linear programming method has been applied to the OC relay in the multi-bus scheme for better protective coordination in terms of reduced operating time.

The validation of the developed simplex linear programming method is tested under different buses such as IEEE 9 as well as IEEE 14. For validation, the TDS has been considered as in the range of 0.02 to 6. For analysing the operating time of the relay, the fault has been designed in the bus scheme. The rate of primarily as well as backup relay rate is estimated. The current flow in the bus scheme is measured by the current transducer. The fault current of each relay is measured for validation.

Case1: IEEE 9 bus network

The validation of PS shows that the optimized value is obtained under the directional OC relay connection to the bus scheme. The plug setting and coordination time interval for the 9-bus system has been illustrated in Figure 2. The observation shows that the overall operating time for the developed simplex method in the OC relay coordination is attained as 0.3 s. From Figure 2(a) it can be inferred that the Plug setting values computed follows the lower and upper limits in (4) and from Figure 2(b) it can be pointed out that the CTI values computed for each primary backup relay pair follows the constraint in (2).

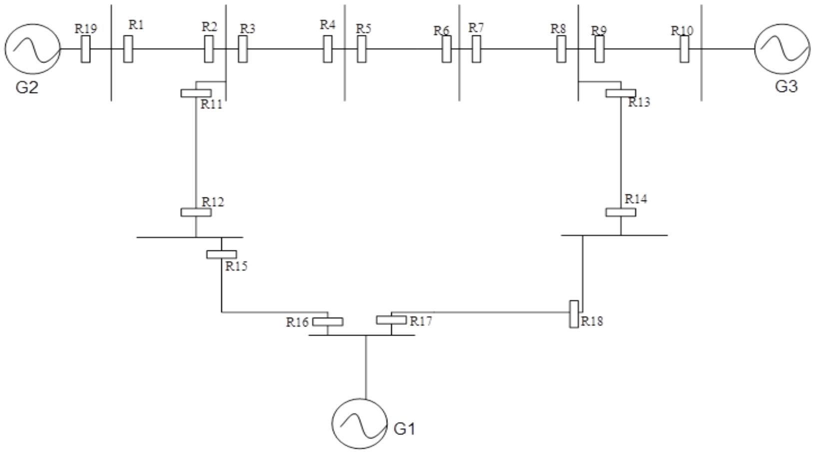
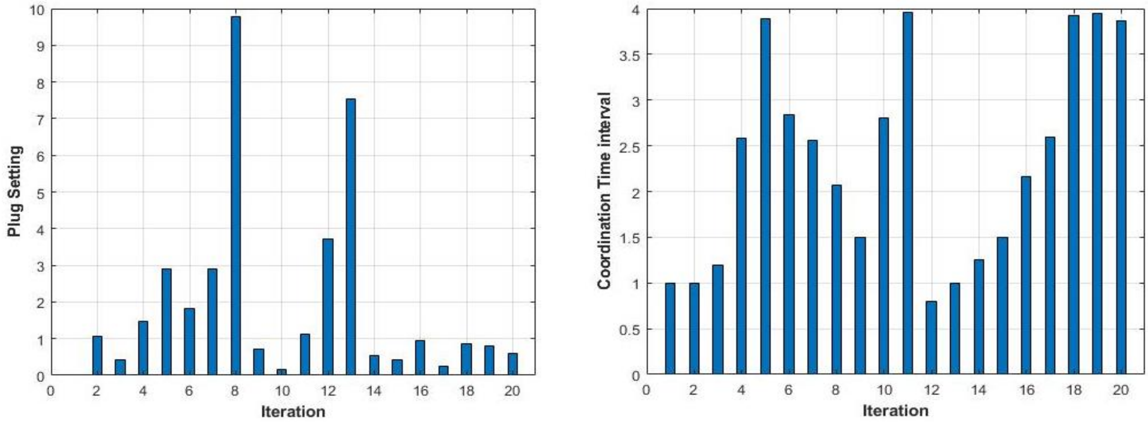


Figure 1. Structure of IEEE 9 bus radial scheme



(a) (b)

Figure 2. Comparison of plug setting and CTI for each iteration for 9 bus of (a) plug setting and (b) CTI

In Figure 3 optimized value of total operating time has been listed. From Figure 3 it can be inferred that total operating time at each iteration for the relays in a 9 bus system is minimum. Plot at different population size has been shown. The overall estimated parameters for the objective function for IEEE 9 bus network is detailed in Table 1. The tabulation demonstrates that the method has overall 20 iterations for the process. It can be observed from Table 1 that every primary and backup relay pair follows the coordination time interval constraint.

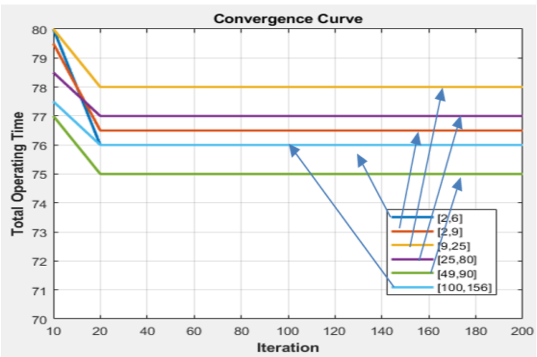


Figure 3. Optimal total operating time for 9 bus schemes

Table 1. Estimated parameters for the objective function for IEEE 9 bus

Iteration	PS	TDS	Overall operating time (s)	Coordination time
2	1	0.02	2	0.3
4	1.5	1	2.7	0.3
6	1.9	1.4	2.8	0.3
8	9.4	2.2	2.2	0.3
10	0.4	2.8	2.8	0.3
12	3.8	3.2	0.8	0.3
14	0.35	4	1.3	0.32
16	0.9	4.2	2.3	0.3
18	0.8	5.3	2.2	0.3
20	0.6	6.1	3.8	0.4

– IEEE 14 bus test system

The directional OC relay coordination is conducted for IEEE 14 bus system which is shown in Figure 4. In this Figure 4, six DGs are connected at buses 1,2,3,5,7,10. A total of 33 IDMT based DOCRs are incorporated in the distribution system.

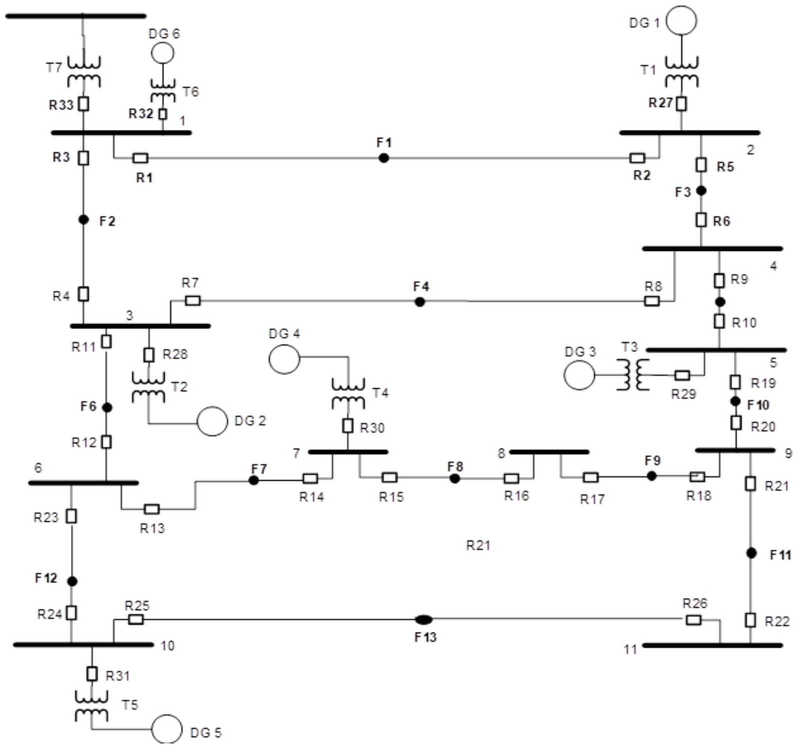
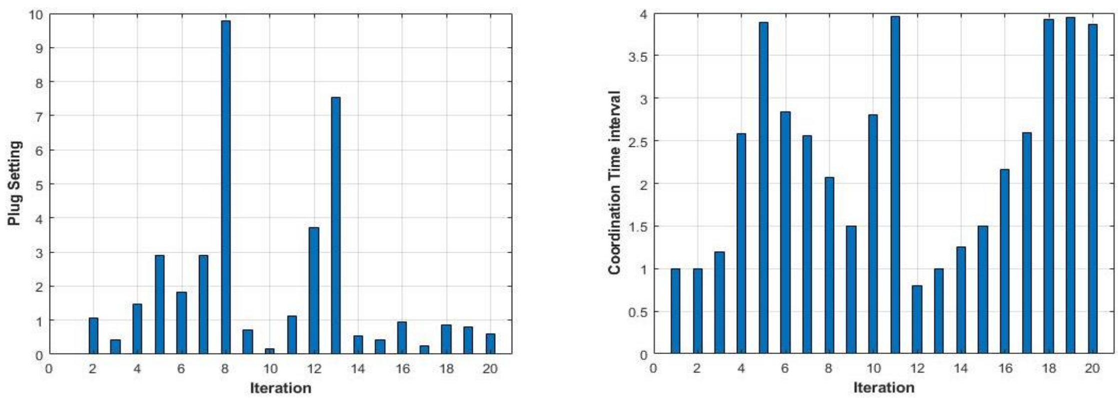


Figure 4. Structure of IEEE 14 bus radial scheme

Case: 2 IEEE 14 bus scheme

Optimal plug setting time as shown Figure 5 for 14 bus system is demonstrated in Figure 5(a). The validation of PS shows that the optimized value is obtained as 9 under the directional OC relay connection to the 14-bus scheme The Optimal coordination time interval for 14 bus system is represented in Figure 5(b). The optimal total operating time for 14 bus scheme is illustrated in Figure 6. The observation shows that the overall operating time for the developed simplex method in the OC relay coordination is attained as 0.29 s for IEEE 14 bus network.



(a) (b)

Figure 5. Comparison of Plug setting and CTI for each iteration for 14 bus of (a) plug setting (b) CTI

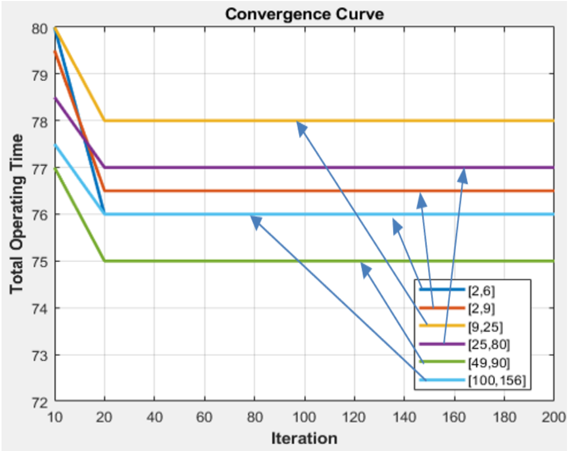


Figure 6. Optimal total operating time for 14 bus system

The Estimated parameters for the objective function for IEEE 14 bus is demonstrated in Table 2. The demonstration shows that the method has overall 20 iterations for the process. Furthermore, it is evident from Table 2 that all the relay follows the minimum CTI limit.

Table 2. Estimated parameters for the objective function for IEEE14 bus

Iteration	PS	TDS	Overall operating time (s)	Coordination time
2	0.9	0.021	2.01	0.29
4	1.3	1.02	2.62	0.29
6	1.82	1.451	2.71	0.29
8	9	2.23	2.14	0.29
10	0.412	2.812	1.9	0.3
12	3.812	3.27	0.2	0.29
14	0.351	4.1	1.3	0.37
16	0.92	4	2.341	0.3
18	0.79	5.02	2.210	0.29
20	0.59	5.9	3.813	0.4

The Comparison of the developed method over conventional methods is detailed in Table 3. Here, the parameters of TDS, PS, coordination time and overall operating time are compared with the conventional RW-GWO [21], mixed nonlinear programming (MINLP) [26], and convexified linear programming (CLP) [5] methods. The comparison shows that the proposed method has highly diminished the overall operating interval than other old methods.

Table 3 Comparison of developed method over conventional methods

Methods		TDS	PS (A)	Coordination time (s)	Overall operational time (s)
RW-GWO [21]		0.0848	157.5032	0.4	0.6416
MINLP [26]		1.0715	13.5	0.775	10.03
CLP [5]		0.1	2.89	0.3	0.77
Proposed	IEEE 9 bus	0.048	10	0.3	0.3
	IEEE 14 bus	0.035	8	0.2	0.29

5. CONCLUSION

The objective of this study was to mitigate the relay coordination issue arising in a low voltage microgrid. In the present study, relay settings have been obtained for the operation of microgrid in grid connected mode for IEEE 9 and 14 bus test system. In addition to this, series of simulation results is carried out, followed by the computation of operating time of all the relays and coordination time interval between primary and backup relays. In this context suitable optimization algorithm using GAMS has been utilized in order to validate the effectiveness of the proper coordination in grid connected mode.

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