Coordination of directional overcurrent relays for distribution system using particle swarm optimization

Deepak Vyas, Praghesh Bhatt, Vipin Shukla
Pandit Deendayal Petroleum University, Raisan, Gandhinagar, Gujarat, India

Abstract
The protection of electrical distribution network with multiple loops and bidirectional power flow needs optimal coordination of directional overcurrent relays (DOCRs). The DOCRs coordination is highly non-linear and largely constrained optimization problem where plug settings (PS) and time dial settings (TDS) of DOCRs are set as control variables. The objective function in this paper is based on minimizing the operating time of all primary DOCRs considering far-end and near-end fault approach. The optimization is performed with particle swarm optimization (PSO) for standard test systems of 3-bus, 4-bus and 6-bus and the results are compared with the existing methods of relay coordination reported in literature. The optimized PS and TDS for DOCRs has resulted in the least value of objective function along with proper coordination time interval for all test systems.

Keywords: Directional overcurrent relay coordination, coordination time interval, optimization, particle swarm optimization

1. Introduction

Directional overcurrent relays (DOCRs) are required for the protection of feeders at sub-transmission and distribution level which carry bidirectional power flow. The relaying system must be selective, sensitive, reliable and fast in its operation to isolate the faulty section of electrical network. Selectivity of relaying systems identifies the primary and backup relays. Backup relays will operate only in case of failure of primary relay with proper coordination time interval. The problem of relay coordination requires the knowledge of maximum possible load and fault current for each possible fault location to cover whole network with primary and backup overcurrent protection. The optimal relay coordination guarantees the correct relay operating sequence with the least fault clearing time for each fault location.

DOCRs coordination has been obtained by various optimization techniques in literature. Linear programming (LP) is one of the popular techniques to solve this problem. LP formulates the problem in linear form and solved with the help of simplex methods [1-3]. In LP technique, PS requires to be assumed while allowing TDS as a linear function which will determine time of operation (TOP) for each relay. In [4], Random Search Technique (RST) is applied to achieve optimal relay settings. To optimize both TDS and PS, Sequential Quadratic Programming was proposed in [5-6]. Relay coordination is formulated by Mixed integer nonlinear programming problem and optimized by different variants of PSO in [7-11]. Various evolutionary methods such as Differential Evolutionary (DE) algorithm and its modified variants [12-15], Seeker algorithm [16], Teaching Learning Based Optimization (TLBO) [17-18], Ant colony algorithm [19], Group search optimization method [20], Chaotic firefly algorithm [21] and real coded genetic algorithm (RGA) with bounded exponential cross over and power mutation [22] have been reported to solve this highly constrained optimization problem of DOCRs coordination. Hybrid methods which are the combination of two or more methods such as GA-LP [23], GA-NLP [24], Gravitational Search Algorithm (GSA)-SQP [25], PSO-GSA [26], Biogeography-Based Optimization...
algorithm-LP [27] have also been reported for this problem.

It is observed through the literature survey that the researchers have applied different optimization techniques to solve the relay coordination problem by using different objective functions. These objective functions are mainly dependent on the minimizing the operating time of primary relays. The ‘near-end fault’ approach [5-6], [21], [24-25] and ‘near-end and far-end fault’ approach [4-5], [12], [16-17], [22] have been implemented for relay coordination. The optimization obtained with ‘near-end fault’ approach sometimes results in mis-coordination of relay operation [5]. In this paper, comparative results for both approaches have been presented. PSO based on constriction factor approach is used for optimal coordination of DOCRs for standard 3 bus, 4 bus and 6 bus test systems. The optimized values of TDS and PS of DOCRs are obtained which meets all required constraints. The obtained results are also compared with the existing methods available for DOCRs coordination. It is shown that even simple PSO is capable to find the optimal set of PS and TDS of DOCRs coordination.

2. Problem Formulation for Relay Coordination

2.1. Formulation of objective function

The problem of relay coordination of DOCRs has been formulated for ‘near-end and far-end fault’ approach as can be viewed from Fig. 1. For Relay $R_{pri,near}$ in Fig. 1, the fault occurs at location $L_{pri,near}$ i.e. very close to primary relay $R_{pri,near}$ is defined as near end fault. Similarly, the fault occurs at location $L_{pri,far}$ is defined as far-end fault for relay $R_{pri,near}$. In Fig. 1, $R_b$ is a backup relay for relay $R_{pri,near}$ for both near-end and far-end fault. Hence, relay $R_b$ must be coordinated with relay $R_{pri,near}$ for both the faults and should operate only after pre-defined coordination time interval in case of failure of $R_{pri,near}$. The objective function for ‘near-end and far-end is given in (1). While optimizing (1), the running sum of coordination constraints violations discussed in Section 2.2.4 is also added to the evaluated objective function.

$$Z_{near\_far} = \sum_{i=1}^{N_{near}} T_{pri,near}^i + \sum_{j=1}^{N_{far}} T_{pri,far}^j$$

where $N_{near} = \text{total primary relays operating for near-end fault}; N_{far} = \text{total primary relays operating for far-end fault}; T_{pri,near}^i = \text{operating time of } i^{th} \text{ primary relay for near-end fault}; T_{pri,far}^j = \text{operating time of } j^{th} \text{ primary relay for far-end fault}.$

$$T_{pri,near}^i = \frac{TDS_{pri,near}^i \times 0.14}{\left(\frac{I_f^i}{PS_{pri,near}^i \times CTR_{pri,near}^i}\right)^{0.02}} - 1$$
2.2. Formulation of constraints

2.2.1. Limits on time dial settings (TDS) of DOCRs

TDS of DOCRs are set as control variables and are bounded in the range given by (4). The upper limit and lower limit for TDS are set as 1.1 and 0.05, respectively.

\[ TDS_{i, lower}^i \leq TDS_i^i \leq TDS_{i, upper}^i, \quad i = 1, 2, ..., N (Total \ relays \ in \ network) \quad (4) \]

2.2.2. Limits on plug setting (PS) of DOCRs

PS of DOCRs are also set as control variables and are bounded in the range given by (5). Lower and upper limits for PS are set as 1.2 and 1.5, respectively.

\[ PS_{i, lower}^i \leq PS_i^i \leq PS_{i, upper}^i, \quad i = 1, 2, ..., N (Total \ relays \ in \ network) \quad (5) \]

2.2.3. Limits on operating time of relays

The operating time of relay in (1) should be limited by the constraints otherwise relays will operate either too fast or too slow. Higher limit of 1 sec and lower limit of 0.05 sec are set for the relay operating time.

2.2.4. Coordination time interval (CTI)

In case of failure of primary relay, backup relay will respond after some time interval. If the backup relay will operate earlier than primary relay, then larger portion of the network will be disconnected. Hence, selectivity constraints as given in (6) are used. In this work, CTI is set as 0.3 sec for 3-bus test system and 0.2 sec for 4-bus and 6-bus test systems.

\[ ToP_{backup} - ToP_{primary} \geq CTI \quad (6) \]

3. Primary-Backup (P/B) Relay Pairs, Fault Current and CT Ratings

In this work, three standard test systems of 3-bus, 4-bus and 6 bus as shown in Figs. 2-4 have been used for the DOCRs coordination. In Figs. 2-4, the DOCRs are also shown along with their assigned direction of operation. The P/B relay pairs are determined using LINKNET structure [28]. Table 1, 2 and 3 list P/B relay pairs, fault current and CT rating for 3-bus, 4-bus and 6 bus test systems, respectively. In Tables 1-3, it can be observed that some of the primary relays don’t get back up protection due to network topology, hence, their corresponding constraints related to coordination time interval are relaxed during optimization. Selectively constraint is further relaxed if the fault current for any relay drops below its pick up current.

Table 1. P/B relay pairs, fault currents and CT ratings for 3-bus test system

| Primary relay | CT ratings | If (near) | If (far) | Backup relay | CT ratings | If (near) | If (far) |
|---------------|------------|-----------|---------|--------------|------------|-----------|---------|
| R1            | 2.06       | 9.46      | 14.08   | R5           | 0.8        | 9.46      | 14.08   |
| R2            | 2.06       | 26.91     | 100.63  | -            | -          | -         | -       |
| R3            | 2.23       | 8.81      | 12.07   | R6           | 0.8        | 8.81      | 12.07   |
| R4            | 2.23       | 37.68     | 136.23  | -            | -          | -         | -       |
| R5            | 0.8        | 17.93     | 25.9    | R2           | 2.06       | 17.93     | 25.9    |
| R6            | 0.8        | 14.35     | 19.2    | R4           | 2.23       | 14.35     | 19.2    |
Fig. 2. IEEE test bus system: (a) 3-bus system (b) 4-bus system and (c) 6-bus system

Table 2. P/B relay pairs, fault currents and CT ratings for 4-bus test system

| Primary relay | CT ratings | $I_f$ (near) | $I_f$ (far) | Backup relay | CT ratings | $I_f$ (near) | $I_f$ (far) |
|---------------|------------|--------------|-------------|--------------|------------|--------------|-------------|
| R1            | 0.48       | 20.32        | 12.48       | R5           | 1.5259     | 20.32        | 12.48       |
| R2            | 0.48       | 88.85        | 23.75       | -            | -          | -            | -           |
| R3            | 1.1789     | 1.789        | 10.38       | R7           | 1.2018     | 1.789        | 10.38       |
| R4            | 1.1789     | 116.81       | 31.92       | R1           | 0.48       | 116.81       | 31.92       |
| R5            | 1.5259     | 116.79       | 31.92       | -            | -          | -            | -           |
| R6            | 1.5259     | 16.67        | 12.07       | R2           | 0.48       | 16.67        | 12.07       |
| R7            | 1.2018     | 71.7         | 18.91       | -            | -          | -            | -           |
| R8            | 1.2018     | 19.27        | 11          | R4           | 1.1789     | 19.27        | 11          |

Table 3. P/B relay pairs, fault currents and CT ratings for 6-bus test system

| Primary relay | CT ratings | $I_f$ (near) | $I_f$ (far) | Backup relay | CT ratings | $I_f$ (near) | $I_f$ (far) | Backup relay | CT ratings | $I_f$ (near) | $I_f$ (far) |
|---------------|------------|--------------|-------------|--------------|------------|--------------|-------------|--------------|------------|--------------|-------------|
| R1            | 0.258      | 2.531        | 5.375       | R8           | 1.746      | 2.932        | 4.090       | R11          | 0.772      | 1.288        | -           |
| R2            | 0.258      | 2.737        | 5.949       | R3           | 0.486      | 0.621        | 1.665       | -            | -          | -            | -           |
| R3            | 0.486      | 2.972        | 4.589       | R10          | 1.042      | 2.561        | -           | R13          | 0.587      | -            | 1.499       |
| R4            | 0.486      | 4.147        | 6.664       | R1           | 0.258      | 0.886        | 1.524       | -            | -          | -            | -           |
| R5            | 0.713      | 1.954        | 4.257       | R12          | 0.772      | 1.454        | 2.544       | R14          | 0.587      | -            | 1.714       |
| R6            | 0.713      | 2.767        | 6.234       | R1           | 0.258      | 1.465        | 1.123       | R3           | 0.486      | -            | -           |
| R7            | 1.746      | 3.842        | 4.178       | R11          | 0.772      | 1.971        | 2.143       | R2           | 0.258      | 1.871        | 2.035       |
| R8            | 1.746      | 5.618        | 6.369       | -            | -          | -            | -           | -            | -          | -            | -           |
| R9            | 1.042      | 4.653        | 5.269       | R4           | 0.486      | 3.036        | 3.438       | R13          | 0.587      | 1.61         | 1.832       |
| R10           | 1.042     | 3.526        | 3.87        | -            | -          | -            | -           | -            | -          | -            | -           |
| R11           | 0.772      | 2.584        | 3.900       | R6           | 0.713      | 1.109        | 1.813       | R14          | 0.587      | 1.474        | 2.087       |
| R12           | 0.772      | 3.800        | 6.114       | R2           | 0.258      | 0.473        | 1.543       | R8           | 1.746      | 3.322        | 4.573       |
| R13           | 0.587      | 2.414        | 4.335       | R6           | 0.713      | 1.836        | 1.608       | R12          | 0.772      | -            | 1.608       |
| R14           | 0.587      | 5.354        | 2.901       | R10          | 1.042      | 2.778        | 2.026       | R4           | 0.486      | 2.582        | 0.845       |
4. Particle Swarm Optimization (PSO)

PSO was proposed by Eberhart and Kennedy in [29] and has been widely reported in literature for handling constrained optimization problems due to its superiority over other evolutionary techniques. It relies on simple computational steps and requires less memory and shorter solution time. The PSO equations modified with constriction factor approach is followed from [30] and explained in brief. The velocity and position update are as per (7) and (8), respectively.

\[ v_{j}^{p+1} = CF \times v_{j}^{p} + \left( c_{1} \times r_{1} \times P_{\text{best},j} - x_{j}^{p} \right) + \left( c_{2} \times r_{2} \times g_{\text{best},j} - x_{j}^{p} \right) \]  
\[ x_{j}^{p+1} = x_{j}^{p} + v_{j}^{p+1} \]

\[ CF = \frac{2 \times K}{2 - \varphi - \sqrt{\varphi^{2} - 4\varphi}} \quad \varphi = \varphi_{1} + \varphi_{2} \quad \varphi_{1} = \varphi_{2} = 2.05, K = 1 \]

\[ c_{1} = CF \times \varphi_{1} \quad \text{and} \quad c_{2} = CF \times \varphi_{2} \]

where \( v_{j}^{p} \) = velocity of \( j^{th} \) particle at iteration \( p \); \( r_{1} \) and \( r_{2} \) are random numbers in range of 0-1; \( x_{j}^{p} \) = position of \( j^{th} \) particle at iteration \( p \); \( c_{1} \) and \( c_{2} \) are acceleration co-efficient; \( P_{\text{best},j} \) and \( g_{\text{best},j} \) are personal and global best of particle.

5. Simulation Results

The PSO algorithm is applied for DOCRs coordination for standard 3, 4 and 6 bus systems. The fault currents are determined by creating three phase solid fault on each bus ends. Occurrence of fault near a bus and gets clearance by the relay placed on the same bus is treated as near-end fault. If the same fault gets clearance by the relay placed on other end of line, then it is treated as far end fault. The objectives are to minimize (1) and (2) subjected to the constraints satisfaction listed in Section 2. In each line of test systems, two DOCRs are placed. For each DOCR, there are two control variables, namely PS and TDS. Thus, there are 12, 16 and 28 control variables to be optimized for 3-bus, 4-bus and 6-bus test systems, respectively. Total constraints related to coordination time interval for the 3-bus, 4-bus and 6-bus were 8, 9 and 48, respectively. Depending upon the assumptions of fault current less than pick up current of the relay, these constraints are reduced to 38 for 6-bus test system. The coordination constraints for 3-bus and 4-bus test system remain unchanged.

Tables 4-5 list the optimized values of PS and TDS for DOCRs obtained with PSO for all test systems along with the minimized value of objective functions. Similarly, Tables 6-7 list the time of operation of P/B relay pairs and their corresponding CTI for all three systems under consideration. Table 8 compares the optimized values of objective function obtained with PSO to other methods reported in literature. For 3-bus and 4-bus test system, only RST [4], TLBO and modified TLBO [15], BEX-PM [22] and PSO-CFA can produce feasible solution. BEX-PM [22] reported recently is far better compared to RST [4] and TLBO [15] but PSO-CFA has resulted slightly better result than BEX-PM method. The results obtained with DE and its variants reported in [13], [15] are comparable, but they did not satisfy all valid constraints. For 6-bus test system, except BEX-PM and proposed PSO-CFA, all methods result in infeasible solution. TLBO not only result in infeasible solution, its optimized values is very high as compared to BEX-PM and PSO-CFA. For relatively larger test system of 6-bus, PSO-CFA gives better result compared to BEX-PM.
Table 4. list the optimized values of PS and TDS for DOCRs obtained with PSO for 3 and 4 bus test system

| Relay | TDS | PS | Relay | TDS | PS |
|-------|-----|----|-------|-----|----|
| R1    | 0.05| 1.2| R1    | 0.05| 1.2|
| R2    | 0.2097| 1.3267| R2    | 0.1766| 1.2111|
| R3    | 0.05| 1.2| R3    | 0.05| 1.2984|
| R4    | 0.2158| 1.4045| R4    | 0.1202| 1.3766|
| R5    | 0.1885| 1.3293| R5    | 0.104| 1.2003|
| R6    | 0.1786| 1.4987| R6    | 0.05| 1.2195|
| R7    | 0.1165| 1.2114| R7    | 0.1165| 1.2114|
| R8    | 0.05| 1.2026| R8    | 0.05| 1.2026|

Table 5. list the optimized values of PS and TDS for DOCRs obtained with PSO for 6 bus test system

| Relay | TDS | PS | Relay | TDS | PS |
|-------|-----|----|-------|-----|----|
| R1    | 0.1028| 1.5| R8    | 0.05| 1.2|
| R2    | 0.1768| 1.5| R9    | 0.05| 1.2|
| R3    | 0.097| 1.2| R10   | 0.0513| 1.5|
| R4    | 0.1135| 1.2| R11   | 0.0622| 1.5|
| R5    | 0.05| 1.2| R12   | 0.0557| 1.4335|
| R6    | 0.05| 1.2| R13   | 0.0605| 1.2|
| R7    | 0.05| 1.2| R14   | 0.0727| 1.4292|

Table 6. list the time of operation of P/B relay pairs and their corresponding CTI for 3 and 4bus test system

| Primary Relay | Backup relay | TOB | TOP | CTI | Primary Relay | Backup relay | TOB | TOP | CTI |
|---------------|--------------|-----|-----|-----|---------------|--------------|-----|-----|-----|
| 1             | 5            | 0.4977| 0.1977| 0.3  | 1             | 5            | 0.2952| 0.0948| 0.2004|
| 1             | 5            | 0.5906| 0.2573| 0.3333| 1             | 5            | 0.372| 0.1103| 0.2617|
| 3             | 6            | 0.5289| 0.2289| 0.3  | 3             | 7            | 0.3567| 0.1567| 0.2|
| 3             | 6            | 0.6143| 0.2902| 0.324 | 3             | 7            | 0.407| 0.1794| 0.2276|
| 5             | 4            | 0.7002| 0.4002| 0.3  | 4             | 1            | 0.4965| 0.1885| 0.308|
| 5             | 4            | 0.851| 0.454| 0.397 | 6             | 2            | 0.3954| 0.1837| 0.2117|
| 6             | 2            | 0.8705| 0.4911| 0.3793| 6             | 2            | 0.3562| 0.1562| 0.2|
| 6             | 2            | 0.7383| 0.4383| 0.3  | 8             | 4            | 0.4313| 0.169| 0.2624|
| 8             | 4            | 0.3317| 0.1317| 0.2001|

Table 7. list the time of operation of P/B relay pairs and their corresponding CTI for 6 bus test system

| Primary relay | Backup relay | TOB | TOP | CTI | Primary relay | Backup relay | TOB | TOP | CTI |
|---------------|--------------|-----|-----|-----|---------------|--------------|-----|-----|-----|
| 1             | 8            | 0.5196| 0.2664| 0.2531| 9             | 13           | 0.4399| 0.2399| 0.2|
| 1             | 11           | 4.1121| 0.2664| 3.8457| 9             | 4            | 0.4399| 0.2399| 0.2|
| 1             | 8            | 1.0377| 0.3763| 0.6615| 9             | 13           | 0.5064| 0.2629| 0.2435|
| 2             | 3            | 10.8334| 0.6208| 10.2126| 9             | 4            | 0.4736| 0.2629| 0.2107|
| 2             | 3            | 0.6409| 0.4409| 0.2  | 11           | 14           | 0.5543| 0.3543| 0.2|
| 3             | 10           | 0.5227| 0.3226| 0.2  | 11           | 6            | 0.5991| 0.3543| 0.2448|
| 3             | 10           | 0.7237| 0.4105| 0.3132| 11           | 14           | 0.9 | 0.5385| 0.3615|
| 3             | 13           | 0.5579| 0.3226| 0.2353| 11           | 6            | 3.899| 0.5385| 3.3605|
Table 8. Comparison of optimized objective function with other optimization techniques

| Optimization Technique | 3-bus | 4-bus | 6-bus |
|------------------------|-------|-------|-------|
| RST [4]                | 4.8354| 3.7050| -     |
| Basic DE [13]          | 4.8422*| 3.6774*| 10.6272*|
| MDE1 [13]              | 4.8070*| 3.6694*| 10.5067*|
| MDE2 [13]              | 4.7873*| 3.6734*| 10.6238*|
| MDE3 [13]              | 4.7822*| 3.6692*| 10.4370*|
| MDE4 [13]              | 4.7806*| 3.6674*| 10.3812*|
| MDE5 [13]              | 4.7806*| 3.6694*| 10.3514*|
| OCDE1 [15]             | 4.7806*| 3.6674*| 10.3479*|
| OCDE2 [15]             | 4.4806*| 3.6674*| 10.3286*|
| TLBO [17]              | 5.3349| 5.5890| 23.7878*|
| TLBO-MOF [17]          | 6.9720*| 8.7088| 24.3900*|
| BEX-PM [22]            | 4.7899| 3.6957| 10.4056|
| PSO-CFA                | 4.7555| 3.2973| 10.0707|

6. Conclusion

The problem of coordination of DOCRs has been solved using PSO based on constriction factor approach. The objective function is based on minimizing the operating time of primary relay for both near-end and far-end fault. The objective function is also modified by adding the running sum of coordination constraints violations in order to satisfy all valid constraints. For all three systems, the obtained optimized values of PS and TDS of DOCRs produced much better results with all valid constraints satisfied as compared to other methods reported in literature. The better solution of objective function leads to faster operation of primary relay and satisfaction of all valid constraints achieves the selectivity of protective relaying.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Mr. Deepak Vyas and Dr. Praghnessh Bhatt conducted the research; Dr. Praghnessh Bhatt and Mr. Vipin Shukla analysed the data; Mr. Deepak Vyas wrote the paper. All authors have approved the final version.

References

[1] Chattopadhyay B, Sachdev M, Sidhu T. An on-line relay coordination algorithm for adaptive protection using linear programming technique. IEEE Transactions on Power Delivery. 1996;11(1):165-173.
Bhatt P, Roy R, Ghoshal S. GA/particle swarm intelligence based optimization of two specific varieties of controller

Oza B, Bhalja B, Shah P. Coordination of over-current relays for cascaded parallel feeder. Presented at 2006: 1

Albasri F, Alroomi A, Talalq J. Optimal coordination of directional overcurrent relays using biogeography-based optimization. IEEE Transactions on Power Delivery. 2007;22(2):851-858.

Zeineldin H, El-Saadany E, Salama M. Optimal coordination of directional overcurrent relay coordination. IEEE Power Engineering Society General Meeting. 2005:1101-6.

Manoj Thakur, Anand Kumar “Optimal coordination of directional overcurrent relay settings using modified differential evolution algorithms. Engineering Applications of Artificial Intelligence. 2010;23(5):820-829.

Chelliah T, Thangaraj R, Allamsetty S, Pant M. Coordination of directional overcurrent relays using opposition based chaotic differential evolution algorithm. International Journal of Electrical Power & Energy Systems. 2014;55:341-350.

Amrree T. Coordination of directional overcurrent relays using seeker algorithm. IEEE Transactions on Power Delivery. 2012;27(3):1415-1422.

Singh M, Panigrahi B, Abhyankar A. Optimal coordination of directional over-current relays using Teaching-Learning-Based Optimization (TLBO) algorithm. International Journal of Electrical Power & Energy Systems. 2013; 50, pp. 33-41.

Kelage A, Ghawghawe N. Optimum Coordination of Directional Overcurrent Relays Using Modified Adaptive Teaching Learning Based Optimization Algorithm. Intelligent Industrial Systems. 2016;2(1):55-71.

Shih M, Castillo Salazar C, Conde Enriquez A. Adaptive directional overcurrent relay coordination using ant colony optimisation. IET Generation, Transmission & Distribution. 2015;9(14):2040-2049.

Alipour M, Teimourzadeh S, Seyedi H. Improved group search optimization algorithm for coordination of directional overcurrent relays. Swarm and Evolutionary Computation. 2015;23:40-49.

Gokhale S, Kale V. An application of a tent map initiated Chaotic Firefly algorithm for optimal overcurrent relay coordination. International Journal of Electrical Power & Energy Systems. 2016; 78, pp. 336-342.

Manoj Thakur, Anand Kumar “Optimal coordination of directional over current relays using a modified real coded genetic algorithm: A comparative study”. Electric Power and Energy Systems vol. 82, 2016, pp. 484–495

Noghabi A, Sadeh J, Mashhadi H. Considering different network topologies in optimal overcurrent relay coordination using a hybrid GA. IEEE Transactions on Power Delivery. 2009; 24(4): 1857-1863.

Bedekar P, Bhide S. Optimum coordination of directional overcurrent relays using the hybrid GA-NLP approach. IEEE Transactions on Power Delivery. 2011;26(1):109-119.

Radosavljević J, Jevtić M. Hybrid GSA-SQP algorithm for optimal coordination of directional overcurrent relays. IET Generation, Transmission & Distribution. 2016;10(8):1928-1937.

Srivastava A, Tripathi J, Mohanty S, Panda B. Optimal over-current relay coordination with distributed generation using hybrid particle swarm optimization–gravitational search algorithm. Electric Power Components and Systems. 2016;44(5):506-517.

Albasri F, Alroomi A, Talalq J. Optimal coordination of directional overcurrent relays using biogeography-based optimization algorithms. IEEE Transactions on Power Delivery. 2015;30(4):1810-1820.

Oza B, Bhalja B, Shah P. Coordination of over-current relays for cascaded parallel feeder. Presented at 2006: 7th International Conference On Advances In Power System Control, Operation And Management.

Kennedy J, Eberhart R. Particle Swarm Optimization. Presented at 1995: International Conference On Neural Networks

Bhatt P, Roy R, Ghoshal S. GA/particle swarm intelligence based optimization of two specific varieties of controller devices applied to two-area multi-units automatic generation control. International Journal of Electrical Power & Energy Systems. 2010;32(4):299-310.