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OPTIMUM OVERCURRENT RELAY COORDINATION: A REVIEW

*S. A. RAZA, T. MAHMOOD and S.B.A. BUKHARI

Electrical Engineering Department, University of Engineering and Technology, Taxila, Pakistan

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In power system the protective relays are coordinated optimally to ensure that only the faulted zone of the system will be detached when the abnormal operating state will occur. The interconnected system as well as deregulated environment and increase in user demand force the utilities to implement optimally coordinated protection scheme to increase reliability of the system. In this paper an overview of overcurrent relay coordination techniques is presented. Deterministic, heuristic, hybrid and trial and error optimization techniques, have been reviewed to understand their method of implementation, modes of operation, nature of power distribution system, advantages and disadvantages.

Keywords : Distribution system, Relay coordination, Optimization, Plug setting multiplier (PSM).

1. Introduction

The main objective of protective device coordination in a power system is to select their suitable settings so that their protection function is fulfilled with the requirements of sensitivity, selectivity, reliability and speed. Abnormal operating conditions in a power system lead to the power supply interruption and equipment damage. It compels the protection engineers to design a reliable protection scheme for the power systems. To make the system more reliable, secondary protection is also provided with primary protection. The secondary protection acts as backup protection in case of primary protection failure [1].

In coordination, the protection devices are installed in series to achieve a specific operating sequence. The main constraint in coordination is that the relay near to the fault point should operate first and no false tripping will occur. Performing relay coordination in interconnected or meshed network is the main concern of protection engineers [2]. In modern power systems, the directional overcurrent relays cause difficulties in coordination but their main advantage is that they are economical. In transmission systems it is widely used as a secondary protection and as a primary protection in sub transmission and distribution systems [3]. Researchers have made great efforts to solve the protection coordination problem through computational tools, since 1960s. The methods, which are used to perform relay settings, can be divided into three categories: (1) Heuristic optimization method [4-7], (2). Deterministic method [8, 9] and (3) trial and error method [10]. Figure 1, shows the year-wise distribution of paper published in the literature to solve relay coordination problem.

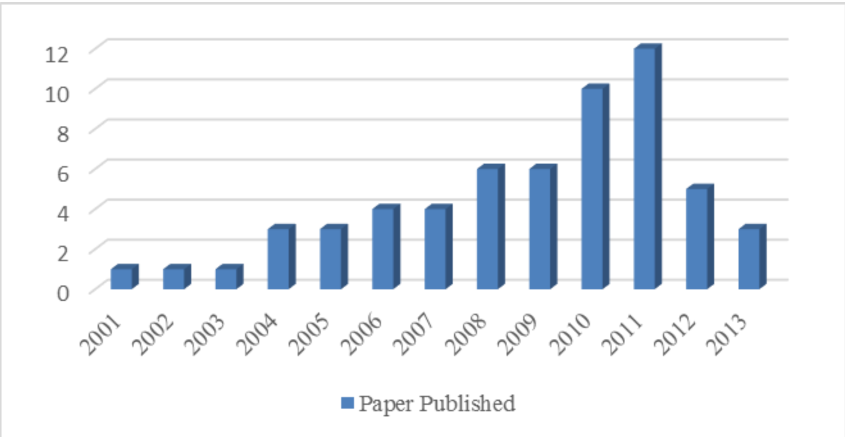

Figure 1. No of papers published each year in literature on relay coordination.

* Corresponding author : syedauonraza@gmail.com

2. Overcurrent Relay Coordination

The overcurrent relay (OCR) is a type of protective relay that sends the tripping signal to the circuit breaker (C.B) when the current exceeds to a specific value. Overcurrent relay usually have current setting multipliers in the range of 50 to 200% in steps of 25% that is called plug setting (PS). The minimum fault current and the maximum load current determine the PS for each relay [11-13]. The fault current calculations are used for the coordination of the relays. Their coordination play a vital role in the design of power system protection to isolate the faulted section with sufficient margin and without unnecessary time delay [14]. Figure 2, shows the maximum employed techniques to solve relay coordination problem.

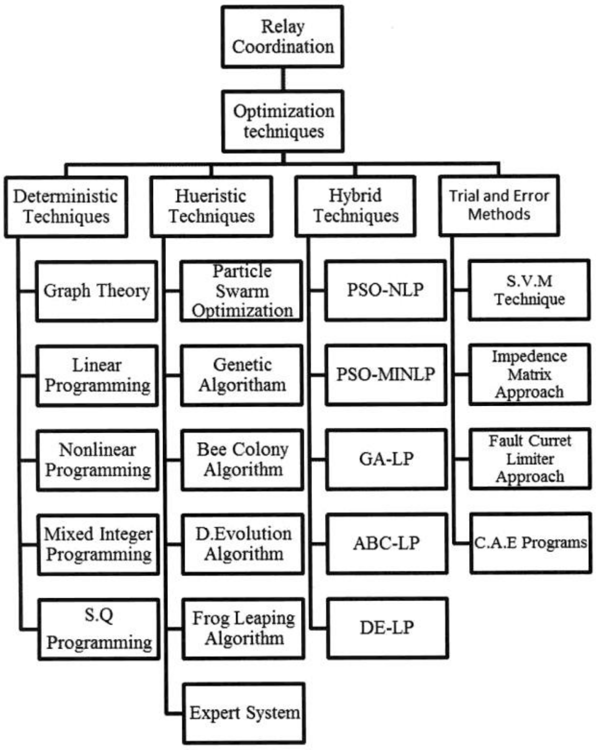

Figure 2. Classification of relay coordination techniques.

3. Problem Formulation

Relay coordination problem can be solved optimally by using heuristic and meta heuristic optimization techniques [15]. It can also be solved by trial and error optimization techniques [10]. The optimization techniques define the objective function for relay coordination by the following equation.

$$\min z = \sum_{i=1}^{m} W_i \times t_{i,k} \quad (1)$$

Where,

"m" is the no of relays.

"$t_{i,k}$" is the operating time of relay "R_i" for the fault in zone "k".

"W_i" is the weight assigned for operating time of the relay.

4. Constraints

4.1 Coordination Criteria

$$t_{i,k} - t_{j,k} \geq \Delta t \quad (2)$$

4.2. Bound on Relay Setting and Operating Time

$$TMS_{i,\min} \leq TMS_i \leq TMS_{i,\max} \quad (3)$$

&

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

Here, $t_{i,min}$ and $t_{i,max}$ are the minimum and maximum operating time of relay R_i for any fault

&

$TMS_{i,min}$ and $TMS_{i,max}$ are minimum and maximum time multiplier setting for relay R_i

4.3 Relay Characteristic

$$t_{op} = \frac{\lambda \times TMS}{(PSM)^{\gamma} - 1} \quad (5)$$

Where, t_{op} is the relay operating time and PMS is the Plug Setting Multiplier.

5. Mathematical Modelling of Different Optimization Techniques:

5.1 Particle Swarm Optimization

Particle swarm optimization (PSO) is a stochastic population based optimization technique. In PSO, the particles (feasible solutions) fly through the search space and follow the current optimum particle [16]. The particles modify their new position according to their own experience and the experience of the neighbour particles. The position of the n^{th} particle in a *D* dimensional space is represented in (6). The *x* and *v* denote the particle's position and its velocity in the search space.

$$x_n = x_{n1} + x_{n2} + x_{n3}, \ldots\ldots\ldots\ldots\ldots, x_{nd} \quad (6)$$

$$v_i = (v_{i1}, v_{i2}, \ldots. v_{iD}) \quad (7)$$

The previous best position discovered by the n^{th} particle is logged and denoted as p_{bestn}. In the population the best value obtained by any particle is also recorded and known as gbest. Then each particle modifies its velocity and position according to its distance from p_{best} and g_{best}. This modification is given by the following formulas.

$$v_{nd}^{i+1} = w.v_{nd}^{i} + c_1.rand1().(p_{best_{nd}} - x_{nd}^{i}) + c_2.rand2().(g_{best} - x_{nd}^{i}) \quad (8)$$

$$x_{nd}^{i+1} = x_{nd}^{i} + v_{nd}^{i} \quad (9)$$

$$\left| v_{nd}^{i+1} \right| \le kv_{\max} \quad (10)$$

The inertia of the particles is represented by the first term in (8), while the second and third terms represent the memory and the cooperation between particles, respectively. The parameter v_{max} denotes the upper bound for v_{id}. The constants c_1 and c_2 represent the acceleration of each particle towards p_{best} and g_{best} positions. The inertia weight ω governs how much of the previous velocity should be retained from the previous time step. Inertial weight can be calculated as follows:

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{itr_{\max}} \times itr \quad (11)$$

ω_{max} and ω_{min} are the maximum and minimum weight values and itr is the iteration number.

5.2 Artificial Bee Colony Algorithm

In first step of the algorithm solution sets are randomly generated within the constraints [17]. Each employed bee identifies a new food source in her food source site and exploits the better source. A new source is produced by (12) and the index of the solution chosen randomly from the colony is given by (13).

$$v_{ij} = x_{ij} + \varnothing_{ij}(x_{ij} - x_{kj}) \quad (12)$$

$$k = \text{int}(rand \times SN) + 1 \quad (13)$$

Where $\varnothing_{ij}$ is a uniformly distributed real random number, j = 1, D and D is the dimension of the problem and SN is the number of the food sources. Then an onlooker bee selects a food source with the probability (14).

$$P_i = \frac{fit_i}{\sum_{j=1}^{SN} fit_j} \quad (14)$$

Where fit_i is the fitness of the solution x_i .When all onlookers are sent to their sources, then sources are checked whether they are to be abandoned or not. If a food source position cannot be improved further with in preset number of cycle, then that food source is assumed to be exhausted. The employed bee associated with the exhausted source becomes a scout and makes a random search to look for another source in the problem domain by:

$$x_{ij} = x_j^{\min} + (x_j^{\max} - x_j^{\min}) \times rand \quad (15)$$

5.3 Genetic Algorithm

GA has been used to solve the coordination problem. Two constraints are considered. One is that the CTI should be equal to or larger than 0.30 s and the CSM constraint is fulfilled by adding an appropriate weight factor in the objective function (OF) to yield applicable setting [18]. Then the OF is redefined as:

$$O.F = \left[\frac{1}{N} \sum_{n=1}^{N} \sum_{l=l_{\min}}^{l_{\max}} t(n,l) \right] + w.(tap - 1.0)^2 \quad (16)$$

The constant N denotes the number of all concerned $\sum_{n=1}^{N} \sum_{l=l_{\min}}^{l_{\max}} t(n,l)$ for averaging the operating time of each relay pair and total relay operation time, w is the weighting factor for the contribution of current taps.

5.4 Differential Evolution

The process starts with the generation of random population. Crossover between the two individuals is carried out to generate two new ones [19]. Mutation is applied based upon standard deviation associated with each gene by the following formula.

$$\sigma_k^t = \sigma_k^{t-1} e^{(z_o^t - z_i^t)} \quad (17)$$

Here, z_o^t is a random value of normal distribution and z_i^t is a random value of normal distribution with zero average such that,

$$z_o^t \sim N(0, \tau_i^t) \; z_i^t \sim N(0, \tau_i^2) \quad (18)$$

With the obtained value of σ_i^t, v_i^t is calculated using the expression below:

$$v_i^t \sim N(0, (\sigma_i^t)^2) \quad (19)$$

5.5 Frog Leaping Algorithm

The Frog Leaping (F.L) algorithm is a memetic meta-heuristic optimization method in which a virtual population of frogs is generated randomly and individual frogs represent a set of possible solution. The population is divided into different subsets and are named as memeplexes. Each memeplex performs simultaneously as an independent deep local search and after a defined number of memeplex evolution steps, information is passed between memeplexes in a shuffling process. This local search and shuffling processes continue until the convergence criteria is satisfied [20].

In F.L during memeplex evolution, the position of i^{th} (D_i) frog is modified according to the difference between the worst fit (X_w) frog and the best fit (X_b) frog by (20). Then, the worst frog X jumps toward the best frog X_{band} and the location of the worst frog is updated based on the leaping rule shown in (21).

$$D_i = rand() \times (X_b - X_w) \tag{20}$$

$$X_w(new) = X_w + D, (\|D\| < D_{max}) \tag{21}$$

Where *rand ()* is a random number in the range [0, 1] and D_{max} is the maximum allowable change in frog's position for one jump.

5.6 Mixed Integer Nonlinear Programming

Digital overcurrent relays have current setting multipliers (CSM) ranging from 50 to 200% in step of 1% and a time dial setting ranging from 0.01 to 1 in steps of 0.01. The problem is a MINLP problem. The coordination problem was formulated [21] as follows:

$$\begin{aligned} O.F &= \Psi \times \sum relay\ operating\ time + \beta \times \sum (relay\ TDS - user\ preferred\ TDS)^2 \\ &\alpha \times \sum (relay\ CSM - user\ preferred\ CSM)^2 \\ &+ \delta \times \sum (T_{nk} - T_{ik} - \Delta T)^2 \end{aligned} \tag{22}$$

It can be seen that the constraints are added in the objective function by squaring and multiplying to a weighting factor. Ψ, β, α, and δ are the weight factors for each constraint.

6. Deterministic Techniques

Deterministic methods have a problem of high dimensionality [22-24]. Large computational time and memory are needed to solve the relay coordination problem by these techniques. Therefore different heuristic approaches [25-27] have been introduced to reduce the computational time and increase the search space.

Authors in paper [28] presented a new graphical algorithm for minimum or near to minimum break point search (BPS). It decreases the calculation scale and proposes back track iteration strategy to overcome the difficulty in definite access to the minimum BPS. To decrease the calculation scale it simplifies the graph by breaking it into numerous sub graphs and increases the possibility to obtain a minimum BPS.

In [29] a new algorithm based on the combination of graph theory and expert system is proposed. The reduced graph theory is used as a rule of expert system. The proposed algorithm yields satisfactory results on the network that includes 6 busses and 12 transmission lines.

S. Mks in [30] presented a simple and effective method based on network topology to solve coordination problems in complex networks. Although the previous methods give the results but they give no assurance that the break point relays will be placed on one bus or in groups. The algorithm is very fast. It avoid complex calculations and matrix building.

The reference in [21] formulates the directional overcurrent relay coordination problem as a Mixed Integer Programming (MIP) problem. The non-linearity is avoided by the addition of new constraints and variables. To eliminate the chances of getting stuck in local optima the proposed algorithm uses the discrete pickup current values.

MINLP is used to solve the PSO based coordination problem in [31]. The optimal values of Time Multiplier Setting and Relay pickup current are obtained. The values of global best (gbest) and position vector (Pbest) are updated after each iteration to get the best solution. The obtained results show the robustness of the proposed method in order to optimize the relay settings.

The relay coordination problem is formulated as MIP problem and taken into account the discrete pickup current setting in [32]. The relay coordination problem is solved using General Algebraic Modelling System (GAMS) software. The authors conclude that if we solve coordination problems as a nonlinear programming problem and then rounding the pickup current, it will lead to infeasible solution.

An optimization method is discussed to solve the directional overcurrent relays coordination problem in complex power system in [33]. A new algorithm for directional overcurrent relay coordination is proposed. In this algorithm, the primary relay coordinates with two secondary (backup) relays. One backup relay senses the clockwise current and the other relay senses the anti-clockwise current. Hence whenever the fault occur one of the backup relays will operate at a time. The optimization toolbox of Matlab is used to solve the nonlinear programming problem for continuous value of TDS & Ip.

The authors in [34] discussed on-line risk assessment to find out the regions of vulnerability for miscoordination. The condition probability for relay miscoordination is computed by event tree method. Linear integer programming (LIP) is used to solve minimum break point set. The relays that have a major impact on power system are identified and to improve their performance a method of online relay settings is used.

S. Jamali, *et al.* in [35] used LP to optimally coordinate the distance relay's zone 2 and overcurrent relay. Path following method is used as a solving method in linear programming. Further, to identify the set of primary and backup relays topological analysis is carried out.

D. Birla, *et al*. investigated that the weight factors and far end fault considerations do not disturb the optimality of the solution [36]. For small systems the approach based on near end faults is acceptable and for the large interconnected systems the approach based on near-end faults and far-end faults is a better approach. For simulation Matlab tool is used and Sequential Quadratic Programming (SQP) is employed.

The reference at [37] introduces additional near-end selectivity constraints and far-end selectivity constraints to avoid sympathy trips. The problem is solved by nonlinear SQP in two stages. In the first stage normal coordination procedure is used to identify the sympathy trips. In the second stage proposed additional constraints are included only for the sympathy trips obtained from previous stage.

7. Heuristic & Hybrid Optimization Technique

The solution obtained from deterministic optimization techniques is far away from the global optimal solution. Meta- heuristic techniques therefore have been developed to obtain a global optimal solution in a reasonable computational time and most widely used in relay coordination. These techniques are random search techniques and yield optimal solutions [38-42].

Hybrid techniques are the combination of deterministic and meta-heuristic approaches and are extensively used to solve relay coordination problem [41, 43-45].

Relay coordination problem is formulated as MINLP. For the coordination problem the variables are continuous (TDS). Therefore to transform the particle position values between 0 and 1 sigmoid function is used. This is done by the following formula:

$$sig(v_{nd}^{i+1}) = \frac{1}{1+e^{-v_{nd}^{i+1}}} \quad (23)$$

In order to set the particle's position either 0 or 1, the overall change in the particle's position is governed by the following rule.

if

$$(rand() > sig(v_{nd}^{i+1}))\ then\ x_{nd}^{i+1} = 1 \quad (24)$$

else,

$$x_{nd}^{i+1} = 0 \quad (25)$$

Modified Particle Swarm Optimization (MPSO) is also used and simplex method is employed to calculate the discrete pick up current values. The MPSO updates each dimension of the particle one an after the other and checks the feasibility of this move. It also compares the new calculated fitness value with the previous one and updates particle position only when the new value is better than the previous one. Therefore the improved computation time and convergence rate is obtained [46].

The reference at [47] presented the use of MPSO to overcome the problem of generation of infeasible particles in relay coordination problem. The gradient approach is used to find the optimal solution by the obtained feasible solution.

In [48] Relay coordination problem is formulated as NLP. In MPSO the pickup current values are initialized randomly and TDS values are found by applying the interior point method to overcome the above mentioned problem. If a particle violates the constraint then according to its objective function we fix it to its minimum value.

$$x_i^k = \begin{cases} x_i^k\ if\ satisfies\ all\ constraints \\ x_{i,\min}^k\ if\ constraints\ not\ satisfy\ (\min\ problem) \\ x_{i,\max}^k\ if\ constraints\ not\ satisfy\ (\max\ problem) \end{cases} \quad (26)$$

The velocity update in MPSO is calculated by the following if-else statement.

If

$$iter_{\max} \le iter \quad (27)$$

then

$$\omega = \frac{\omega_{\min} - \omega_{\max}}{iter_{\max} - 1} \times (iter - 1) + \omega_{\max} \quad (28)$$

else

$$\omega = \omega_{\min} \tag{29}$$

Simplified velocity-modified PSO with cut down approach is used in [16]. Authors modify velocity equations for better convergence. These modified equations are given below.

$$v_{ij}^{t+1} = \omega \times v_{ij}^{(t)} + c_1 \times rand1()[gbest_{ij}^{(t)} - x_{ij}^{(t)}] \tag{30}$$

H. Qu, *et al*. solved Micro grid relay coordination problem by using MPSO in [49]. The premature convergence problem is quashed. Particle position in this system is updated based on feasibility, fitness and acceptance ratio.

The researchers in [50] used hybrid PSO Algorithm for optimal coordination of overcurrent relays. It calculates the particle position of the swarm with a linear approach. The position of each particle is updated and the constraints are checked. If the constraints are not satisfied, then updating process is carried out by (31). Again the constraints are checked. If the constraints are not satisfied, updating process is done by (32). Thus we have:

If constraints are not met for the first time.

$$\begin{Bmatrix} v_{nd}^{i+1} = c_2.rand2().(g_{best} - x_{nd}^{i}) \\ x_{set}^{i+1} = x_{set}^{i} + v_{nd}^{i+1} \end{Bmatrix} \tag{31}$$

If constraints are not met for the second time

$$\begin{Bmatrix} v_{nd}^{i+1} = 0 \\ x_{set}^{i+1} = p_{best_{nd}} \end{Bmatrix} \tag{32}$$

A 33 bus radial distribution test system with distributed generation is formulated as an NLP Problem in [51]. The PSO algorithm is modified to obtain fast computation speed and convergence rate in relay coordination problem.

L. Yinhong, *et al*. in [52] used constraint interval coding technique to enhance the efficiency and precision of GA and implemented it to optimally coordinate the definite time overcurrent relays. In the proposed technique the solution space of natural variables is divided into a fixed number of constraint intervals according to the defined constraints.

The reference at [53] introduced Genetic Algorithm to optimally coordinate the IDMT overcurrent relays in an industrial plant and radial distribution system. This paper shows that it is possible to use GA to implement the overcurrent relay coordination by considering different types of relay curves and equipment curves.

The reference at [54] proposed Fuzzy GA to optimally coordinate IDMT and distance relays. The time delay of overcurrent relay is obtained by a fuzzy logic controller. The system is simulated for both fuzzy logic OCR and IDMT relay and it has been depicted that fuzzy logic OCR gives better results than IDMT relay.

Hybrid GA is used to optimally solve the relay coordination problem in [55]. The search space of GA is significantly increased by reducing the size of the genetic string. The increased search space of HGA and the use of LP increase the computation efficiency of the algorithm.

In [56] the coordination of digital overcurrent relays is performed by GA. The technique is implemented on 6-bus test system and the obtained results are better than those from Quasi-Newton (Q.N) method.

To find out the optimal solution of relay coordination problem in loop distribution system GA is proposed in [57]. The sets of primary and backup relays are chosen by graph theory.

The researchers used Continuous Genetic Algorithm (CGA) technique to optimally coordinate the overcurrent relay in the ring fed distribution system in [15]. Penalty method is used to incorporate constraints in the fitness function. CGA is faster than ordinary GA as no binary conversion is required. Matlab code is developed to find the optimal time coordination of relay for any combination of primary and backup relays.

M. N. S. Maurya, *et al*. used GA to optimally coordinate the IDMT relays in an industrial plant radial power distribution system in [58]. The optimal values of time dial settings and current setting multipliers are obtained. Code is developed in Matlab to solve optimization problem.

The optimum TSM and overcurrent relay characteristic values are obtained by applying GA to the simple test system in [59]. TSM and relay characteristics are taken as genomes of chromosomes in GA. Therefore the initial value of characteristics set and TSM is selected randomly.

The authors in [18] implemented GA to optimize the OCR coordination in the power system including transformer protection. It uses GA to implement OCR coordination not only by considering different relay curves but also the curves of other equipments like transformers.

An algorithm based on bee colony for optimal relay coordination in the presence of DG is proposed in [17]. The authors used linear programming with ABC to solve relay coordination optimization problems. The obtained results are compared with the hybrid GA (LP-

GA). Three different scenarios are considered to investigate the proposed method.

- The system is studied under well-established relay coordination, in which no DG is installed on the power distribution system.
- DG is installed as a power source on the distribution system.
- Revising relays setting in the existence of DG.

The reference at [60] uses Artificial Bee Colony (ABC) Algorithm to optimally done overcurrent relay coordination. Onlooker bees are placed onto the food source sites by using roulette wheel selection method. In [61] the authors presented the Enhanced Discrete Differential algorithm to perform overcurrent relay coordination to protect the meshed distribution system. The enhanced discrete differential evolutionary algorithm produces “quantized vectors” and “time varying Scaling Factors” for improved operation.

M. Singh, *et al*. in [62] used Differential Algorithm with hybrid mutation technique to optimally coordinate distance and overcurrent relays for multi-source and multi-loop system. CTI between the zone 2 setting of distance relay and the overcurrent relay is set optimally.

The paper at [19] presents the Differential Evolution Algorithm and LP to optimally coordinate the directional overcurrent relays installed in the meshed network. LP is used to obtain the time multiplier factors. The main advantage of the method is that the LP and the DE algorithm yield fast convergence rate.

Three improved DE algorithms Laplace Mutated Differential Evolution (LMDE)**,** Cauchy Mutated Differential Evolution (CMDE) and Gaussian Mutated Differential Evolution (GMDE) based on “Local Neighbourhood Search” (LNS) is used to optimally coordinate the directional overcurrent relays in electrical systems in [63]. LNS uses mutation operators based on different probability distributions i.e. Laplace, Cauchy and Gaussian. The LMDE, GMDE and CMDE help in improving the search capability of DE. As compared to ODE these modified algorithms yield better results.

C. R. Chen, *et al*. at reference [64] presented partial differentiation approach to optimally solve the relay coordination problem. Industrial power plant is used and a computer program is developed to verify algorithm results.

The authors in [65] used Frog Leaping algorithm and LP to solve the relay coordination problem for power distribution system with DG. Instead of changing the whole protection system layout or use a new relay element the relay coordination problem is solved optimally by just revising the relay setting in the presence of DG.

In reference [20] this paper presents Shuffled Frog Leaping (SFL) algorithm and LP for optimal coordination of overcurrent relays in a power distribution system (PDS). The proposed algorithm is tested on the IEEE 30-bus test system.

8. Trial and Error Methods

Researchers in [66] proposed computer aided coordination technique for relay coordination in power system with graphical user interface. The authors suggested that if we apply an intelligent technology in the software then it can make illation and finish all the work autonomously without human interruption and the efficiency of relay coordination can be improved.

The analysis of overcurrent relay operation is complex as compared to other protective relays because their operating time depends on the fault current. In reference [67] a computational tool is presented for analyzing the dynamic operation of overcurrent relays.

In reference at [68] the coordination of digital protective relays of large scale industrial power plant is done efficiently. Power System Simulator Siemens Network Calculation (PSS SINCAL®) software is used to carry out coordination studies. This software includes its own libraries for all International Electrotechnical Commission (IEC) 255-3, American National Standards Institute (ANSI) relays and breakers of the plant.

The coordination study of the IDMT relays on the test system is carried out in the paper [69]. Coordination studies were carried out by mean of a computer based tool, Computer Aided Protection Engineering (CAPE). The main advantage of CAPE is that different feeder configurations such as ring network, can easily be implemented and different types of faults such as single line to ground fault, line to line fault, and double line to ground fault can be inserted on the feeder.

A. Saran, *et al*. presented a comprehensive overview of the overcurrent relay model and techniques used to perform closed loop relay coordination testing using a Real Time Digital Simulator (RTDS) [70]. RTDS is an effective tool of RSCAD to simulate small as well as large power systems. The shipboard power system is simulated in RTDS and coordination of protective relays is done efficiently.

The paper [71] proposed a relay coordination software based on user-defined principles to meet different desires of different electric power companies. The software develops the relay coordination scheme based on user-defined principles. The proposed flexible relay coordination software has several advantages such as (1) large number of combinations of different operating conditions, (2) the flexibility of step relay setting calculations, (3) the flexibility of protective relay setting calculations, (4) the flexibility of report generation of relay settings.

The coordination multiagent system is presented in [72]. In this system communication plays an important role and provides more information for the relay coordination. Java agent development framework platform is used for communication simulation. Relay agents coordinate with themselves as well as with the Distributed Generation (DG) agents and Equipment agents to obtain successful coordination. The Multiagent based relay coordination has the capability to self-check, self-correct and rapidly act in order to achieve selectivity and sensitivity.

Q. Chen, *et al*. proposed a new effective signalling mechanism for relay coordination in long term evolution-advanced to reduce the need of synchronization among numerous relays. It has benefit of practicality and extraordinary spectral efficiency. The simulations are carried out for optimal relaying schemes using Open Data Application Framework (ODAF) and Network Data Administration Facility (NDAF) protocols but the results reveal that NDAF is superior to ODAF protocol [73].

In reference [74] the multiagent technology is presented to coordinate protective relays in the power system. The suggested agent model consists of agents that are geographically distributed and located in numerous Intelligent Electronic Devices (IED). Agents for relays, DG and equipments incorporate to achieve proper selectivity and sensitivity for optimal relay coordination. Java Agent Development Framework Platform is used to carry out simulations.

The authors in [75] proposed the method that first identifies the disturbance field area. In the identified area it reselects the operation mode and resets the protective relays that increase the precision of relay setting calculations.

The reference at [76] utilizes topological information of impedance matrix to solve the relay coordination problem. The effects of Superconducting Fault Current Limiter (SFCL) on the optimal sizing of the renewable energy resources i.e. Wind Turbine Generator System (WTGS) in radial distribution system is studied in [77]. The relay coordination remains unchanged by using an appropriate rating of the FCL for the WTGS that is being connected to the system.

Reference [78] proposed the use of impedance type FCL with the DG connected to the distribution system. Matlab code is developed and used to find the fault current limiter's optimal values for the given DG size. The relay coordination scheme is restored without modification in the original protection scheme. The simulation results are carried out for different DG and fault position in the system.

Z. Yu Sheng *et al*. [79] presented the use of voltage compensation SFCL. The coordination of the voltage compensation SFCL and current relay is done by just resetting the action current of the relays. The simulations are carried out on 10kv isolated neutral distribution system.

In reference [80] Support Vector Machines (SVM) are used as a pattern classifier for distance relay coordination. Transient stability simulations are carried out on 246 bus Indian Southern region practical system. It has been shown the relay settings for zone-3 backup protection are sensitive to line flow changes and the fault resistance will have effect on zone-1 settings of a conventional relay. Further a secure coordinated scheme of the distance relay in the transmission line is made with the SVM.

B. Ravi Kumar, *et al*. proposed methodology [81] that categorizes the zones based on the line connectivity. The method of multiclass SVM is presented to efficiently use in distance relay coordination. SVMs are used as zone classifiers of distance relay coordination. A comparison between three methods (one against one, one against all, and one step) of multiclass SVM classification is evaluated for their effective use in distance relay coordination. The 526-bus system is used and the results reveal the classification accuracy of the one-step approach is the highest and it maintains less time to classify all of the testing data.

9. Discussion

Deterministic, heuristic, hybrid and trial and error methods are used to solve the relay coordination problem. Figure 1, shows complete list of techniques which have been developed to solve relay coordination problem. In trial and error method we predict a solution for our problem and check the results if it does not work fine then we look for another possible solution and so on. For large complicated systems this method is very time consuming and less optimal. Therefore, the researchers looked forward towards the other optimization methods to solve the relay coordination problem.

Deterministic methods have a problem of high dimensionality. Large computational time and memory is necessary to solve the relay coordination problem by such techniques. Therefore, different heuristic approaches have been introduced to solve relay coordination problem solution and to reduce the computational time and the search space but the solution obtained from these techniques is far away from the global optimal solution.

Heuristic and meta-heuristic techniques have been developed to obtain a global optimal solution in a reasonable computational time, and most widely used in relay coordination. These techniques yield optimal solutions. The results of different optimization techniques for IEEE 8-bus 14 relay test system [50] are shown in Tables 1 and 2. The comparison between different optimization techniques is shown in Figure 3. Therefore based upon the results it is suggested to use the heuristic and Meta-heuristic technique to solve relay coordination problem efficiently.

Table 1. Results of different heuristic optimization techniques

Relay no.	MPSO [50]	PSO [2]	DE [63]	MDE [63]	GA [55]
R_1	0.30	0.10	0.11	0.10	0.30
R_2	0.14	0.34	0.20	0.18	0.29
R_3	0.1	0.33	0.09	0.09	0.25
R_4	0.1	0.19	0.11	0.10	0.18
R_5	0.1	0.10	0.05	0.05	0.17
R_6	0.20	0.27	0.05	0.05	0.27
R_7	0.22	0.23	0.05	0.05	0.53
R_8	0.12	0.28	0.05	0.05	0.23
R9	0.31	0.1	0.05	0.05	0.18
R_{10}	0.18	0.28	0.07	0.05	0.18
R_{11}	0.12	0.35	0.06	0.06	0.20
R_{12}	0.28	0.48	0.06	0.06	0.28
R_{13}	0.16	0.116	0.05	0.05	0.22
R14	0.18	0.18	0.08	0.07	0.52
Obj_Fun	10.42	20.79	10.62	10.35	10.94

Table 2. Results of different deterministic optimization techniques.

Relay TMS values	MIP [20]	MINLP [20]	LP [50]	SQP [36]	GAMS [2]
R_1	0.11	0.11	0.23	0.10	0.10
R_2	0.24	0.21	0.21	0.17	0.24
R_3	0.18	0.18	0.14	0.07	0.20
R_4	0.14	0.14	0.10	0.10	0.14
R_5	0.10	0.10	0.10	0.05	0.10
R_6	0.21	0.21	0.40	0.05	0.22
R_7	0.17	0.17	0.23	0.05	0.19
R_8	0.20	0.20	0.16	0.05	0.21
R9	0.10	0.10	0.26	0.05	0.10
R_{10}	0.19	0.19	0.17	0.05	0.21
R_{11}	0.19	0.19	0.22	0.06	0.21
R_{12}	0.32	0.32	0.39	0.05	0.35
R_{13}	0.10	0.1	0.10	0.05	0.10
R14	0.14	0.14	0.31	0.07	0.15
Obj_Fun	16.5	16.5	11.14	10.04	17.1418

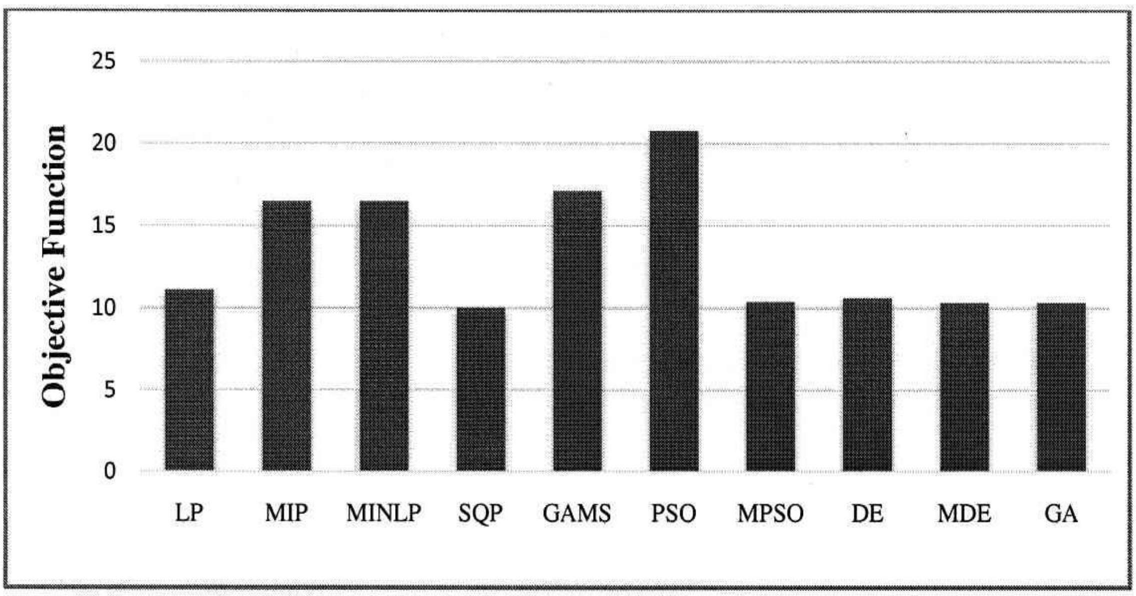

Figure 3. Comparison between different techniques.

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