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Application of Optimization Techniques in Overcurrent Relay Coordination-A Review

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Abstract: In power system properly coordinated protection scheme is designed to make sure that only the faulty part of the system will be isolated when abnormal operating condition of the system will reach. The complexity of the system as well as the increased user demand and the deregulated environment enforce the utilities to improve system reliability by using a properly coordinated protection scheme.This paper presents overview of overcurrent relay coordination techniques. Different techniques such as Deterministic Techniques, Meta Heuristic Optimization techniques, Hybrid Optimization Techniques and Trial and Error Optimization Techniques, have been reviewed in terms of method of theirimplementation, operation modes, nature of distribution system and finally their advantages as well asthe disadvantages.

Key words: Distribution System · Relay Coordination · Optimization · Plug Setting Multiplier (PSM)

INTRODUCTION

The main objective of protective device coordination in power system is to select their suitable setting so that their vital and most essential protection function is fulfilled along with requirements of sensitivity, selectivity, reliability and speed. Abnormal conditions in power system lead to the power supply interruption and equipment damage. It compels the protection engineers to design a reliable protection scheme for power system. In order to make the system more reliable, secondary protection is also provided along with primary protection. The secondary protection acts as back up 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 concern in coordination is that the relay near to the fault would operate first and no false tripping will occur. Performing relay coordination in interconnected or meshed network is of main concern to the protection engineers [2].

In modern power system, the directional overcurrent relay causes difficulties in coordination but the main advantage is that the directional overcurrent relaying is simple and economical. In transmission systems it is widely used as a secondary protection and as a primary protection in distribution and sub-transmission systems [3]. Researchers have made great efforts to solve the protection coordination problem through computational tools, since 1960s.The methods, which are used for performing relay settings, can be divided into three categories:1 Heuristic optimization method [4-7], 2. Deterministic method [8, 9] and 3 trial and errormethod [10]. Figure 1, shows the year wise distribution of paper

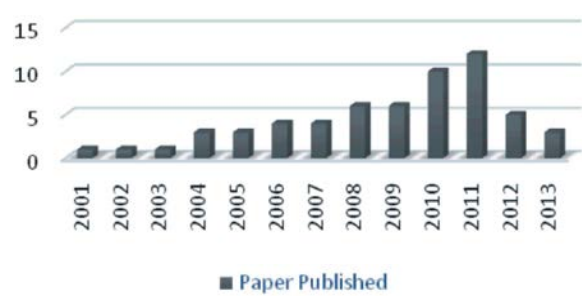

Fig. 1: Number of papers published each year

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Overcurrent Relay Coordination: The overcurrent relay (OCR) is a type of protective relay which sends tripping signal to the circuit breaker (C.B) when the current exceeds to a specified value. Overcurrent relays 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. Each protective relay has to coordinate with other protective relays located at all adjacent buses to clear faults properly within a definite time. Their coordination plays a vital role in the design of power system protection to isolate the faulted section with sufficient margins and without excessive time delays [14].

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.

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

where, "m" is the number of relays, "$t_{i,k}$" is the operating time of relay "R_i" for the faultin zone "k" and "W_i" is the weight assigned for operating time of relay.

Constraints

Coordination Criteria:

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

Bound on Relay Setting and Operating Time:

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

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

where, $t_{i,min}$ and $t_{i,max}$are the minimum and maximum operating time of relay R_i for any fault while $TMS_{i,min}$and $TMS_{i,max}$are minimum and maximum time multiplier setting for relay "R_i".

Relay Characteristic:

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

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

Deterministic Techniques: Deterministic methods such as Linear Programming (LP). Non-linear Programming (NLP), Mixed Integer Programming (MIP) Mixed Integer Non-linear programming (MINLP), Dynamic programming (DP), Branch and Bound method have been widely used to optimally solve relay coordination problem. The main drawback of these methods is their high dimensionality [16-18]. High computational time and large computer memory are needed to solve the relay coordination problem by these techniques. Therefore different heuristic approaches such asmodified DP, Langrangian relaxation [19, 20] and Adaptive Dynamic programming [21] have been introduced in relay coordination problem solution to reduce the computational time as well as the search space. X. Yan, *et al*.[22] presented new graphical algorithm for minimum or near to minimum break point search (BPS) and proposes back track iteration strategy to rapidly reach towards minimum BPS.In [23] a new algorithm based on the combination of graph theory and expert system is proposed. As a rule of expert system it uses reduced graph theory.S. Mks, presented a simple and effective method based on network topology to solve coordination problem even in complex networks in [24]. The articles [25-27] formulate the directional overcurrent relay coordination problem as Mixed Integer Programming (MIP) problem. The chances of getting struck in local optimaare minimized by updating the values of global best (gbest) and position vector (Pbest) after each iteration [28]. On-line risk assessment is used to find out the regions of vulnerability for miscoordination and condition probability for relay miscoordination is computed by event tree method [29]. S. Jamali, *et al*. in [30] used LP to optimally coordinate overcurrent relays. Pathfollowing method is used as solving method in linear programming. D. Birla, *et al*. [31] implemented and Sequential Quadratic Programming (SQP) and investigated that the solution of coordination problem of directional overcurrent relay based on only near-end faults approach does not lose the optimality. The additional near-end selectivity constraints and far-end selectivity constraints are added to avoid sympathy trips in [32]. This complex problem is solved in two stages. In 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.

Meta Heuristic & Hybrid Optimization Technique: The solution obtained from Deterministic techniques is far away from global optimal solution. Meta-heuristic techniques therefore have been developed to obtain a global optimal solution in reasonable computational time and most widely used in relay coordination. Particle Swarm optimization (PSO), Artificial Bee Colony (ABC) Algorithm, Evolutionary Programming (EP), Tabu search and Genetic algorithm (GA) are random search technique that produce more feasible and near-optimal solutions [33-37]. Hybrid techniques that are the combination of deterministic and meta-heuristic approaches and are also extensively used to solve relay coordination problem [36, 38-40]. These techniques use advantages of both approaches.

The relay coordination problem is solved by using Particle Swarm Optimization (PSO) [41, 42]. The algorithm checks the fitness of the new calculated value with the previous one and updates particle position only when the new value is better than the previous one The gradient approach is used in [43] to find the optimal solution by the obtained feasible solution. The pickup current values are initialized randomly and TDS values are found by applying the interior point method [44].H. Qu, *et al*. solved Micro grid relay coordination problem [45]. Premature convergence problem is avoided and particle position in the algorithm is updated based on feasibility, fitness and acceptance ratio. The authors used Simplified Velocity-Modified PSO with cut down approach is used in[46]. M. Bashir, *et al*. used hybrid PSO Algorithm for optimal coordination of overcurrent relay [47]. Near-end faults and far-end faults are taken into account in the constraints of optimal coordination

L. Yinhong, *et al*. in [48] proposed GA to optimally coordinate overcurrent relay and used constraint interval coding technique to enhance the efficiency and precision of GA. The researchers practically implemented Genetic Algorithm to coordinate the IDMT overcurrent relays in an industrial plant radial distribution system and IEEE test system [49-52]. To control the time delay to optimally coordinate IDMT and distance relay Fuzzy GA is proposed [53]. The sets of primary and back up relays are chosen by Graph Theory[54].Continuous Genetic Algorithm (CGA) technique is also implemented to optimally coordinate the overcurrent relay in ring fed distribution system in [15]. Penalty method is used to incorporate constraints in fitness function.

Artificial Bee Colony (ABC) Algorithm for optimal relay coordination is proposed [55, 56]. Onlooker bees are placed onto the food source sites by using roulette wheel selection method. Abandonment criteria is used to classify the scout bees.The Enhanced Discrete Differential Evolution algorithm is also implemented to perform overcurrent relay coordination to protect the meshed distribution system [57-60]. Three improved Differential Evolution algorithms Laplace Mutated Differential Evolution (LMDE)**,** Cauchy Mutated Differential Evolution(CMDE)andGaussian Mutated Differential Evolution (GMDE) based on "Local Neighborhood Search" (LNS) are used to improve convergence and enhance search space [61]. The authors in [62, 63]used Frog Leaping algorithm and linear programming to optimally solve the relay coordination problemby just revising the relay settings.

Trial and Error Methods: The computer aided coordination technique is used to solve relay coordination problem in complex power system with graphical user interface [64, 65]. These papers further propose that if intelligence technology is applied to the software then it can make illation and finish all the work autonomously without human interruption and improves the efficiency of relay coordination. The "Power System SimulatorSiemens Network Calculation (PSS SINCAL®)" software is also used to carry out coordination studies [66]. The authors carryout Coordination studies by means of "Computer Aided Protection Engineering (CAPE)" [67]. Thereforring network, is easilyimplemented and different types of faults such as single line to ground fault, line to line fault and double line to ground fault are inserted on feeder.

A. Saran, *et al*. in [68] used "Real Time Digital Simulator (RTDS)" to perform closed loop relay coordination. The paper at [69] proposed a relay coordination software based on user-defined principles to meet different desires of different electrical power companies. In [70, 71] the Multiagent technology is presented to coordinate protective relays in the power system. The suggested agent model uses agents that are geographically distributed and located in numerous Intelligent Electronic Devices.

The effects of Superconducting Fault Current Limiter (SFCL) on the optimal sizing of the renewable energy resources and relay coordination are described in [72]. The impedance type FCL is used with the DG connected to the distribution system [73]. The both papers conclude that relay coordination scheme remains unchanged by using appropriate rating of the FCL.

CONCLUSION

A comprehensive review of Overcurrent relay coordination techniques is presented in this paper. In literature many methods and techniques are proposed and implemented to solve relay coordination problem. It has been observed that the proper selection of primary and back up protection and maintaining a small time delay between primary and backup relays operation reduces the mal-operation of relays. It is also noticed that the Meta-heuristic optimization techniques especially GA with multipoint cross over yields the best fit results.

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