Performance Analysis of Different Optimization Algorithms on Overcurrent Relay Coordination Problem in Distribution Systems

Nidhi Yashvantrai Savjani, Research Scholar, GTU

Abstract

Optimal coordination of overcurrent relays is essential to ensure reliable and selective fault isolation in distribution systems. This paper evaluates the performance of various optimization algorithms in solving the overcurrent relay coordination problem. Algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), and Differential Evolution (DE) are compared based on their ability to minimize relay operating times while adhering to coordination constraints. The analysis is conducted on a standard distribution system model, considering fault scenarios with and without Distributed Generation (DG). The study provides insights into the suitability of each algorithm for practical implementation in dynamic power systems.

Keywords

Overcurrent Relay Coordination, Optimization Algorithms, Distribution Systems, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Differential Evolution (DE).

1. Introduction

Overcurrent relays are fundamental components of distribution system protection. Their coordination ensures that only the nearest relay to a fault operates, preventing unnecessary outages and preserving system stability. The integration of Distributed Generation (DG) has introduced complexities in relay coordination due to bidirectional fault currents and varying fault levels. This paper investigates the performance of five optimization algorithms in addressing these challenges.

2. Problem Formulation

2.1 Objective Function

The primary objective is to minimize the total relay operating times: where is the operating time of the relay, subject to:

- **Coordination Time Interval (CTI):** Ensuring a sufficient time margin between primary and backup relay operations.
- **Relay Operating Characteristics:** Constraints based on relay settings.

2.2 System Constraints

The optimization must satisfy:

- CTI seconds.
- Relay operating times within manufacturer-defined limits.

2.3 Impact of DG

DG integration alters fault levels and directions, making relay coordination more complex. Algorithms must adapt to these variations for effective fault isolation.

3. Optimization Algorithms

3.1 Genetic Algorithm (GA)

GA is inspired by the principles of natural selection and evolution. It uses operations such as selection, crossover, and mutation to evolve optimal solutions.

- **Strengths:** Handles non-linear and multi-objective problems effectively.
- **Weaknesses:** May require extensive computational effort for large systems.

3.2 Particle Swarm Optimization (PSO)

PSO simulates the social behavior of particles, where each particle adjusts its position based on its own experience and that of its neighbors.

- **Strengths:** Fast convergence and simplicity.
- **Weaknesses:** Prone to premature convergence in complex search spaces.

3.3 Ant Colony Optimization (ACO)

ACO is inspired by the foraging behavior of ants, where pheromone trails guide the search for optimal paths.

- **Strengths:** Suitable for discrete optimization problems.
- **Weaknesses:** Computationally expensive for large-scale systems.

3.4 Artificial Bee Colony (ABC)

ABC mimics the foraging behavior of honeybees, focusing on exploration and exploitation to find optimal solutions.

- **Strengths:** High exploration capability.
- **Weaknesses:** Slower convergence compared to GA and PSO.

3.5 Differential Evolution (DE)

DE is a population-based optimization algorithm that uses differential operators to explore the search space effectively.

- **Strengths:** Robust in handling complex optimization problems.
- **Weaknesses:** Requires careful parameter tuning.

4. Case Studies and Results

4.1 Test System

The optimization algorithms were applied to a standard distribution system model with and without DG. Various fault scenarios were simulated to evaluate relay coordination.

4.2 Performance Metrics

- **Total Relay Operating Time:** Sum of operating times across all relays.
- **Coordination Time Interval Violations:** Instances where CTI constraints were not met.
- **Computational Efficiency:** Time required for the algorithm to converge.

4.3 Results and Analysis

- **Without DG:** All algorithms performed comparably, with GA and PSO achieving minimal relay operating times. DE demonstrated robustness but required longer computational times.
- **With DG:** PSO and DE showed superior adaptability to the dynamic conditions introduced by DG. ACO and ABC were effective but required higher computational resources.

5. Discussion

The integration of DG significantly impacts relay coordination, necessitating adaptive optimization techniques. PSO and DE emerged as the most effective methods for dynamic systems due to their balance of speed and accuracy. While GA remains a reliable choice for smaller systems, ACO and ABC offer robust solutions for discrete optimization problems. The choice of algorithm should consider system complexity, fault scenarios, and computational constraints.

6. Conclusion

This study analyzed the performance of five optimization algorithms for overcurrent relay coordination in distribution systems. PSO and DE demonstrated superior performance in dynamic scenarios, while GA provided competitive results for simpler systems. Future research could explore hybrid optimization techniques and real-time applications for enhanced relay coordination.

References

1. Kennedy, J., & Eberhart, R. (1995). Particle Swarm Optimization. Proceedings of IEEE International Conference on Neural Networks.
2. Dorigo, M., & Gambardella, L. M. (1997). Ant Colony System: A Cooperative Learning Approach to the Traveling Salesman Problem. IEEE Transactions on Evolutionary Computation.
3. Karaboga, D., & Basturk, B. (2007). A Powerful and Efficient Algorithm for Numerical Function Optimization: Artificial Bee Colony (ABC) Algorithm. Journal of Global Optimization.
4. Storn, R., & Price, K. (1997). Differential Evolution – A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces. Journal of Global Optimization.
5. Glover, J. D., Sarma, M. S., & Overbye, T. J. (2016). Power System Analysis and Design. Cengage Learning.