Electrical Power and Energy Systems 78 (2016) 336–342

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

An application of a tent map initiated Chaotic Firefly algorithm for optimal overcurrent relay coordination

S.S. Gokhale *, V.S. Kale

Department of Electrical Engineering, Visvesvaraya National Institute of Technology (VNIT), Nagpur, India

ARTICLE INFO

Article history:
Received 2 December 2014
Received in revised form 19 November 2015
Accepted 25 November 2015
Available online 21 December 2015

Keywords:
Power system protection
Over-current relay coordination
Optimization
Firefly algorithm
Chaos theory
Tent maps

ABSTRACT

Over-current relays provide primary as well as backup protection to electrical distribution systems. These relays should be coordinated and set at the optimum values, to minimize the total operating time and hence ensure that least damage is caused when a fault occurs. While they provide backup protection, it is also imperative to ensure that their settings should not cause their inadvertent operation and subsequent sympathy trips.

This paper describes a Chaotic Firefly algorithm (CFA) for optimal time coordination of these relays. The algorithm has been implemented in MATLAB and tested on several systems, out of which two have been illustrated in this paper. The results obtained by the Chaotic Firefly algorithm are compared with those obtained by the conventional Firefly algorithm (FA). The novel feature of this paper is the application of the Chaotic Firefly algorithm to the problem of over-current relay coordination.

Introduction

Electric power distribution systems are provided primary and back up protection by over current relays. Sometimes they are also used for providing back-up protection to transmission systems, which employ distance protection as the primary protection. These relays while meeting the requirements of sensitivity, selectivity and reliability have to operate fast enough without maloperating, so that the faulty section is isolated immediately by the circuit breaker. This makes coordination of these relays important [1].

The relay coordination problem is often stated as:

> If the magnitude of the load and fault current at every bus are known, how to set the relays at the different buses, so that the entire system gets primary as well as backup over-current protection?

Correct coordination is necessary to ensure that the relays do not operate out of turn. Optimal coordination is necessary so that the system has the lowest possible fault clearing time. As the size and complexity of the system goes on increasing it becomes more and more difficult to coordinate the relays. Therefore, the optimal coordination of relays is formulated as a relay operating time minimization problem under selectivity and other constraints [2,3].

A good review of time-overcurrent relay coordination has been presented in [4]. Usage of digital relays has made possible the setting of the Time Multiplier Setting (TMS) at any non-integral value.

This problem has been dealt with by several optimization methods in the past. In [5] a linear programming technique for adaptive protection has been applied. A random search technique has been employed in [6]. With the advent of meta-heuristic algorithms, researchers began applying these to the relay coordination problem. Evolutionary algorithms were the first to appear [7]. Genetic algorithm (GA) were applied successfully for relay coordination [8–13]. The Particle Swarm Optimization algorithm (PSO) was applied in [14]. The Artificial Bee colony algorithm by [15], a hybrid evolutionary algorithm based on Tabu search by [16], and a Seeker algorithm [17] were used to solve the relay coordination problem. Recently the authors applied the Firefly algorithm (FA) for the same and compared it with Genetic Algorithms and Linear Programming [18].

This paper proposes the Chaotic Firefly algorithm using tent maps for optimally coordinating the relays. The chaos theory is well established and dealt in with details in [19]. In FA, the quality of solutions mainly depends on the randomization parameters α and attractiveness β between the fireflies. If these values are not properly selected it leads to premature convergence. To improve the quality of solutions, in this paper, chaos theory is incorporated

* Corresponding author. Tel.: +91 712 2241175; fax: +91 7104 232376.
E-mail addresses: sanjeev_gokhale@rediffmail.com (S.S. Gokhale), tovijay_kale@rediffmail.com (V.S. Kale).

http://dx.doi.org/10.1016/j.ijepes.2015.11.087

to prevent the search process from being trapped in local minima. Chaos theory is introduced by modifying the concept of random movement factor variable α.

Two relay coordination cases have been investigated by applying the conventional Firefly algorithm as well as the Chaotic Firefly algorithm on them. Detailed calculations have been shown.

Principle of over-current relay coordination

As an example, in the two section radial system shown in Fig. 1, for a fault beyond bus P (zone k), the relay R_P at bus P, operates first. The relay R_Q at bus Q, serves the purpose of back-up protection. As an example if the operating time of relay R_P, is set at 0.1 s, the relay R_Q is set such that it should operate at 0.1 s. Plus the operating time of circuit breaker at bus P, plus the overshoot time of relay R_Q. Overshoot occurs only for analog relays and not for digital relays.

In general the coordination of directional over-current relays in power systems can be stated as an optimization problem, where the sum of operating times of the relays 'z' of the system, for a fault is to be minimized. Generally near end faults are considered.

Mathematically it can be stated as:

Minimize :

$$z = \sum_{p=1}^{m} W_p \cdot t_{p,k}. \tag{1}$$

Here m denotes the total number of relays; z is the objective function to be minimized; $t_{p,k}$ is the operating time of the primary relay, for fault in zone k, for near end fault, and W_p is the weight assigned for operating time of the relay R_p.

As in distribution systems the lines are short and are nearly equal in length, the probability of occurrence of the fault is equal for all the lines and hence equal weights are assumed and $W = 1$ is assigned to all the relays [5,20]. This is the general approach.

We have also to take into consideration the constraints in the problem:

A. Coordination constraints

The relays in the system have to be coordinated by the criterion,

$$t_{q,k} - t_{p,k} \geqslant \text{STI}, \tag{2}$$

where $t_{p,k}$ is the operating time of the primary relay at k, for near end fault and $t_{q,k}$ is the operating time of the back-up relay, for the same fault. STI is the Selective Time Interval and is taken between 0.1 and 0.5 s. This depends on the speed with which the circuit breakers operate.

B. Bounds on the relay operating time

Relays take a certain minimum time to operate. However, they should not take too long a time to operate. This puts the constraint,

$$t_{p,k,\min} \leqslant t_{p,k} \leqslant t_{p,k,\max}, \tag{3}$$

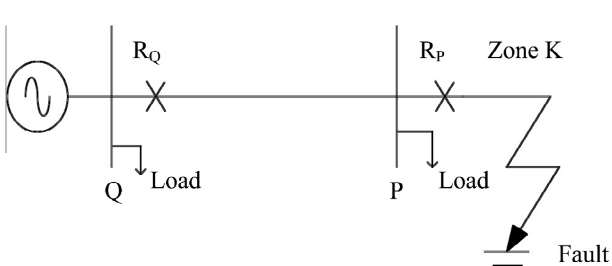

Fig. 1. A radial distribution system.

where $t_{p,k,\min}$ is the minimum operating time and $t_{p,k,\max}$ is the maximum operating time of relay at bus P for near end fault. Similarly, it is also for other relays.

C. Relay characteristics

The relays are assumed identical, having normal Inverse Definite Minimum Time (IDMT) characteristics, which can be described by the equation,

$$t_{op} = \frac{0.14^{*}(\text{TMS})}{\text{PSM}^{(0.02)} - 1}, \tag{4}$$

where t_{op} is the relay operating time. The constants 0.14 and 0.02 are standard for Inverse Definite Minimum Time (IDMT) relay characteristics. TMS is the time multiplier setting and PSM is the plug setting multiplier.

$$\text{PSM} = \frac{I_{relay}}{\text{PS}}. \tag{5}$$

In the above form of Eq. (4), the problem is non-linear in nature. The relay coordination problem can be formulated as a Linear programming problem by considering the Plug Setting (PS) of the relays fixed, and the operating time of the relays, a linear function of the Time Multiplier Setting. (This simplification need not be done always and the problem can be formulated and solved as a non-linear problem [11].)

In the linear problem as PSM is fixed, (4) reduces to

$$t_{op} = a_p(\text{TMS}), \tag{6}$$

where

$$a_p = \frac{0.14}{\text{PSM}^{(0.02)} - 1}. \tag{7}$$

Hence, the objective function can be written as,

Minimize :

$$z = \sum_{p=1}^{m} a_p(\text{TMS})_p, \tag{8}$$

subject to the constraints imposed by (2) and (3).

Coordination of relays in ring fed systems

A typical single end fed ring main feeder used in distribution systems is shown in Fig. 2. It has the advantage that continuity of supply is maintained to all loads even if a fault occurs on any bus. In such arrangements, some of the relays also require a directional feature to implement the protective zones. Relays 2, 4, 6, 8 form one group of relays to be coordinated while 1, 3, 5, 7 form another group. These loops had to be separately coordinated previously but with the use of optimization algorithms, there is no such need [4,21].

Chaos theory and the Firefly algorithm

Firefly algorithm (FA)

The Firefly algorithm (FA) is a meta-heuristic algorithm formulated by Yang in 2007. It is a swarm intelligence type of algorithm inspired by the flashing behavior of fireflies [22].

FA initially produces a swarm of fireflies located randomly in the search space. The position of each firefly in the search space represents a potential solution of the optimization problem. The dimensions of the search space are equal to the number of optimizing parameters. The objective function depends upon the position of the firefly. As positions change every iteration, the objective value also changes. The intensity of brightness of each firefly depends on the objective value of that firefly.