Electric Power Systems Research 128 (2015) 39–52

Contents lists available at ScienceDirect

Electric Power Systems Research

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

A comparative study of metaheuristic optimization approaches for directional overcurrent relays coordination

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ARTICLE INFO

Article history:
Received 5 March 2015
Received in revised form 27 May 2015
Accepted 22 June 2015

Keywords:
Directional overcurrent relays
Meta-heuristic optimization approach
Power system protection
Protective relaying

ABSTRACT

In this paper, a comparative study of different meta-heuristic optimization approaches, which had been proposed in the literature for directional overcurrent relay coordination (DOCRs), is presented. Towards this goal, five most effective meta-heuristic optimization approaches such as genetic algorithm (GA), particle swarm optimization (PSO), differential evolution (DE), harmony search (HS) and seeker optimization algorithm (SOA) have been considered. The performances of these optmization methods have been investigated on several power system networks of different sizes. The comparative performances of these methods have been studied by executing each method 100 times with the same initial conditions and based on the obtained results, the best meta-heuristic optimization method for solving the coordination problem of directional overcurrent relays is identified.

1. Introduction

A properly coordinated protection scheme is one of the inherent requirements to operate a power system with highest reliability. A good protection scheme removes only the least possible portion of the system whenever a fault occurs so as to maintain supply to the rest of the healthy system unaffected by the fault. Each equipment of a power system is protected with two lines of defence, which are known as primary protection and backup protection. For reliable operation of the system, primary protection must react for a fault as quickly as possible to isolate the faulty parts from the healthy parts, but if primary protection fails to operate, the backup protection should operate. This condition is the most desired feature of any protection scheme as primary protection removes only faulted part whereas, whenever backup protection operates, a larger portion of the system has to suffer from outage unnecessarily. For ensuring that only the faulted portion of the network is disconnected thereby reducing the possibility of unwanted power outage, proper co-ordination among the protective devices is necessary.

An economic and effective protection scheme for meshed or multi-sourced power systems requires directional overcurrent relays (DOCRs). The operation of DOCRs depends on its two parameters, namely time multiplier setting (TMS) and plug setting (PS). Through co-ordination, the proper TMS and PS of the relays are determined such that any fault is cleared by the corresponding primary relay as soon as possible. Also, both these settings of any relay should be properly coordinated with the relays protecting the adjacent equipments which, in turn, makes the co-ordination problem quite complex.

To solve this complex problem, several methods have been developed in the literature. These methods include curve intersection approach [1], application of a graphical selection procedure for selecting the settings of the relays [2], identification of minimum break point set (MBPS) using expert system [3], linear graph theory [4], simplex method [5,6], Gauss–Seidel iterative procedure [7], and sequential quadratic programming (SQP) [8], etc. Recently, meta-heuristic optimization approaches have shown great potential to solve protection coordination problems. Application of various meta-heuristic optimization approaches such as particle swarm optimization (PSO) [9,10], genetic algorithm (GA) [11–13], differential evolution (DE) [14], harmony search (HS) [15], seeker optimization algorithm (SOA) [16], etc., have also been proposed in the literature. The applications of these algorithms have been demonstrated on several small to medium sized systems in all these works. Although these approaches are somewhat time-consuming but they provide quite high quality solutions.

Now, because of the availability of several meta-heuristic optimization methods for co-ordination of DOCRs, it is a natural curiosity to find the most effective meta-heuristic optimization method for practical implementation. However, in the literature,

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http://dx.doi.org/10.1016/j.epsr.2015.06.018
0378-7796/

Nomenclature

i	individuals of population $i \in \{1, 2, \ldots, N\}$
j	components of an individual $j \in \{1, 2, \ldots, D\}$
k	iteration counter ($k \in \{1, 2, \ldots, Maxite\}$)
CF	crossover factor
MF	mutation factor for genetic algorithm
CR	crossover rate
F	mutation factor for differential evolution
N	population size
D	component of each individual of population
$Maxite$	maximum number of iterations
b	index of the best individual in population
c	index of the worst individual in population
w	inertia factor
$w_{\min}$	minimum value of inertia factor
$w_{\max}$	maximum value of inertia factor
BW	bandwidth for harmony search
BW_{min}	minimum value of bandwidth
BW_{max}	maximum value of bandwidth
PAR	pitch adjustment rate of harmony
PAR_{min}	minimum value of pitch adjustment rate
PAR_{max}	maximum value of pitch adjustment rate
$HMCR$	harmony memory consideration rate
μ_{min}	minimum value of membership degree
μ_{max}	maximum value of membership degree
c_1 and c_2	acceleration factor
bc	$bc \in \{bc_1, bc_2, bc_3\}$ is an index of best seeker of first, second and third 1/3rd of population
$abs(\cdot)$	return an absolute value of an input number
$f(\cdot)$	objective function to be evaluated
$sign(\cdot)$	signum function on each variable of the input vector
$rand()$	uniformly generated random number in the range [0, 1]
$rand_j$	uniformly generated random numbers in [0, 1] for jth component of an individual
$randi(N)$	return a uniformly generated random integer such that $randi(N) \in \{1, 2, \ldots, N\}$
$RAND(\mu_i^k, 1)$	uniformly generate random number in the range $[\mu_i^k, 1]$
$\mathbf{X}$	population of N individuals each having D components (variables)
$\mathbf{V}$	initial velocity of N individuals each having D components
$\mathbf{X}_i^k$	ith individual of population $\mathbf{X}$ at iteration k, i.e., $\mathbf{X}_i^k = [X_{i,1}^k, X_{i,2}^k, \ldots, X_{i,D}^k]$
$X_{i,j}^k$	jth component of ith individual of population at iteration k
$V_{i,j}^k$	velocity of jth component of ith individual of population at iteration k
F_i^k	value of objective function for ith individual of population at iteration k
TF_i	value of objective function for trial solution i at iteration k
$TX_{i,j}$	jth component of ith individual of trial solution
$U_{i,j}$	jth component of ith individual of trial solution obtained after crossover operation
$\mathbf{Pbest}_i^k$	personal best of ith individual of population up to iteration k
$Pbest_{i,j}^k$	personal best jth component of ith individual of population up to iteration k
$\mathbf{Gbest}^k$	the global best individual of population up to iteration k
$Gbest_j^k$	jth component of the best individual of population up to iteration k
NHV_j	jth component of new harmony vector
$X_{min,j}$	minimum value of jth component of an individual of population
$X_{max,j}$	maximum value of jth component of an individual of population
δ_j^k	step length of jth component of a seeker at iteration k
μ_i^k	membership degree of ith seeker at iteration k
$\mathbf{Lbest}^k$	the local best seeker of population at iteration k
$Lbest_j^k$	jth component of local best seeker of population at iteration k
$Xbest_{bc,j}^k$	jth component of the best seeker of a subpopulation $bc \in \{bc_1, bc_2, bc_3\}$ at iteration k
$d_{i,j,ego}$	jth component of egotistic direction of ith seeker
$d_{i,j,alt1}$	jth component of global altruistic direction of ith seeker
$d_{i,j,alt2}$	jth component of local altruistic direction of ith seeker
$d_{i,j,pro}$	jth component of proactiveness direction of ith seeker
$\alpha_{i,j}^k$	jth component of step size of ith seeker at iteration k

no such comprehensive comparative study is available. Motivated by this fact, this paper endeavours to conduct this study for finding out the most effective method.

This paper is organized as follows. In Section 2, the co-ordination problem of the DOCRs is described. In Section 3, the detailed algorithms of different meta-heuristic methods investigated in this work are described. Lastly, Section 4 gives the main results of this work and recommends the most effective method.

2. Problem formulation of protection coordination

The protection coordination problem can be formulated as an optimization problem where the objective is to minimize the sum of the operating times of all the numerical DOCRs for the near-end three phase fault current [5,17]. Therefore, the objective function (OF) is expressed as,

$$\min \sum_{l=1}^{n} t_{op,l} \tag{1}$$

In Eq. (1), n is the number of relays in the system and $t_{op,l}$ is the operating time of the relay R_l. The operating times of the relays are obtained from their characteristic curves which are defined by IEC/IEEE [18] as,

$$t_{op} = \frac{\lambda \times TMS}{(I_F/PS)^{\eta} - 1} + L \tag{2}$$

In Eq. (2), λ, η and L are the characteristic constants of the relays while I_F is the fault current through the relay operating coil. For standard inverse definite minimum time (IDMT) relays $\lambda = 0.14$, $\eta = 0.02$, and $L = 0$ [18]. Whereas, for other types of relays like very inverse (VI) relays $\lambda = 13.5$, $\eta = 1$, and $L = 0$ and for extremely inverse (EI) relays $\lambda = 80$, $\eta = 2$, and $L = 0$ [18].

The objective function defined above is subjected to the following sets of constraints [5,6]: