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An enhanced cuckoo search algorithm based contingency constrained economic load dispatch for security enhancement

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ABSTRACT

This paper propose a meta-heuristic algorithm known as the enhanced cuckoo search (ECS) algorithm for contingency constrained economic load dispatch (CCELD) in order to relieve transmission line overloading. The power system security assessment deals with finding out the secure and the insecure operating states, whereas the security enhancement deals with the necessary control action against overloads under contingency scenario. By generation rescheduling the overloaded lines can be relieved from the severity. In the proposed ECS algorithm, in order to improve the solution vectors, dynamically variable parameters namely the step size and the probability are incorporated instead of the fixed values of the parameters. The CCELD problem includes scheduling of generators to minimize the severity index with minimum fuel cost. A standard IEEE-30 bus system is considered to study the effectiveness of the proposed ECS algorithm for CCELD problem. Numerical results reveals that, for 100 iterations the proposed ECS algorithm out performs the other state-of-the-art algorithms, namely cuckoo search (CS), Bat algorithm (BA) and particle swarm optimization (PSO) algorithm in obtaining the minimum fuel cost and the minimum severity index in minimum time. Thus, the proposed ECS algorithm is found to be efficient to obtain the solution of contingency constrained economic load dispatch problem.

Introduction

The power system is a complex network, where there is a continuous increase in power demand. In this context, the power system operation has gained importance in security assessment and its control. The security assessment is the task of ascertaining whether the system operating under normal condition can withstand the contingencies (outage of transmission lines, generators, etc.) or not without violating the operating limits. If the current operating state is found insecure under contingency, then necessary control steps must be taken in order to avoid limit violation. In such a case, re-routing of power flows will relieve the transmission lines from overload. The authors in [1] have used the linearized relationship between power flows in the overloaded transmission lines and the generated power to reschedule the power generation. An efficient straight forward algorithm has been modeled in [2] for real time security control. In order to relieve the overload, the authors in [3] have proposed the concept of fuzzy-set-theory-based approach through active power generation rescheduling. Further, the classical optimization techniques have been developed to obtain the optimal power flow (OPF) problem, such as the gradient method [4], Newton method [5], decoupling technique [6] and the interior point method [7]. However, the gradient method has poor convergence characteristics, whereas the Newton method is bounded to continuity of the problem definition and constraints. The interior point method is time consuming and converges to local optima. Thus, the classical methods suffers from several drawbacks to obtain the OPF solution.

In view of the drawbacks of the classical methods, the research has focused on the application of evolutionary programming (EP) [8], genetic algorithm (GA) [9,10], particle swarm optimization (PSO) [11], differential evolution (DE) [12] and many other meta-heuristic algorithms to solve the OPF problem. From these literatures, it can be the observed that the heuristic search algorithms are well-suited to solve the OPF problem. However, research has also revealed the premature convergence of some of these algorithms, which reduces the performance of these algorithms. To improve the performance, modification of some parameters of these existing algorithms were implemented. However, several new heuristic search algorithms are developed to solve the drawbacks. Thus, the heuristic search algorithms are well-suited for solving the OPF problem and can also be extended for the application under contingency scenario for security enhancement.

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Nomenclature

a_i, b_i, c_i	fuel cost coefficients of generator i
D	dimension of the problem
gn	generation number
k	number of overloaded transmission lines
L_o	set of overloaded transmission lines
N_g	number of generators
N_b	number of buses in the system
N_l	number of transmission lines
NP	number of population
NI	maximum number of iterations
P_{gi}	active power output of the generator i
P_D	total load demand
P_L	system losses
P_i, Q_i	computed real and reactive powers for bus i
P_i^{net}, Q_i^{net}	specified real and reactive powers for bus i
P_{gi}^{min}	minimum limit of the active power of generator i
P_{gi}^{max}	maximum limit of the active power of generator i
$P_{a\,min}$	minimum value of the probability
$P_{a\,max}$	maximum value of the probability
P_s	slack bus power
S_l	apparent Power flow in transmission line
S_l^{max}	rating of line l (MVA)
V_i	voltage magnitude of the bus i
V_i^{min}	minimum voltage limit at the load bus i
V_i^{max}	maximum voltage limit at the load bus i
$X_{i\,min}$	minimum value of the problem parameter i
$X_{i\,max}$	maximum value of the problem parameter i
X_{best}	current best solution
α	step size based on the problem of interest
α_{min}	minimum value of the step size
α_{max}	maximum value of the step size

A phase shifter based OPF for the security enhancement by alleviating the line over load is proposed by the authors in [13], by using the rule based method. Devaraj et al. introduced the genetic algorithm (GA) concept for the OPF based security enhancement [14]. In this, approach, the overloaded lines are alleviated by generator rescheduling and regulation of phase shifting transformer. The evolutionary programming (EP) and the PSO algorithms are applied to security constrained economic load dispatch (ELD) in [15,16], without considering the contingency constraints. The authors in [17] have proposed security constrained ELD using PSO under normal conditions and the authors in [18] have proposed improved PSO for the CCELD problem. However, it has several drawbacks as discussed by the authors in [19].

In recent years, the cuckoo search (CS) algorithm gained great importance and applicability in many fields like engineering, Object oriented software (software testing), pattern recognition, networking, data fusion in wireless sensor networks and job scheduling. The authors in [20] have discussed the performance of CS and its application in many fields. The recent literatures focused on the application of CS algorithm in various research areas of electrical engineering [21–28], which shows its usability, importance and performance of the algorithm.

In view of the importance of CS algorithm, this paper has proposed an enhanced cuckoo search (ECS) algorithm to solve contingency constrained economic load dispatch for the security enhancement, by alleviating the overloaded lines through generator rescheduling. In the proposed ECS algorithm, in order to improve the solution vectors, dynamically variable parameters namely the step size and the probability are incorporated instead of the fixed values of the parameters.

The remainder of the paper is organized as follows, The Section "Severity index" deals with the importance of the severity index, Section "Problem formulation" defines the problem formulation along with the system constraints. The Section "Design of CCELD architecture" describes the design of CCELD architecture, whereas the Section "History and overview of cuckoo search algorithm" presents overview of the CS algorithm. The Section "Development of proposed enhanced cuckoo search algorithm" explains the development of the proposed ECS algorithm. In Section "Proposed enhanced cuckoo search algorithm based CCELD", the application of the proposed ECS algorithm to CCELD problem is discussed. The Section "Simulation results and discussion" presents the simulation results and analysis. Finally, the concluding remarks are provided in Section "Conclusion".

Severity index

The contingencies in the power system over load the transmission lines. The severity of such overloaded lines is measured by an index called severity index, which states the post-contingency condition of the power system, as given in (1).

$$\text{Severity index } I_{SI} = \sum_{l \in L_o}^{k} \left(\frac{S_l}{S_l^{\max}} \right)^{2m} \tag{1}$$

The Eq. (1), uses the line flows to compute severity index which are obtained using Newton–Raphson load-flow (NRLF) analysis. Where m is an integer exponent, which is fixed as 1. Higher value of severity index, indicates more insecure nature of the contingency. In this study of security assessment using severity index, over loaded lines alone are taken into consideration to prevent the masking effects.

Problem formulation

The classical optimal power flow problem is to schedule the generators with minimum fuel cost, which is the objective function as given in (2).

$$Min \sum_{i \in N_g} F_T(P_{gi}) \tag{2}$$

$$\text{where,} \quad F_T(P_{gi}) = a_i P_{gi}^2 + b_i P_{gi} + c_i \tag{3}$$

function. The minimization problem is subjected to the following constraints:

(i) Power balance constraint:

$$\sum_{i=1}^{N_g} P_{gi} = P_D + P_L \tag{4}$$

(ii) Power flow equation of the power network:

$$g(|v|, \delta) = 0 \tag{5}$$

where

$$g(|v|, \delta) = \begin{vmatrix} P_i(|v|, \delta) - P_i^{net} \\ Q_i(|v|, \delta) - Q_i^{net} \end{vmatrix} \quad i = 1, \ldots, N_b$$

(iii) Inequality constraints on active power generation P_{gi} of each unit i:

$$P_{gi}^{\min} \leqslant P_{gi} \leqslant P_{gi}^{\max} \quad i = 1, \ldots, N_g \tag{6}$$