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Full Length Article

A bio-inspired novel optimization technique for reactive power flow

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ABSTRACT

In the arena of power system operation and planning, the optimal reactive power flow (ORPF) plays a pivotal role, wherein the application of classical techniques poses issues in obtaining the optimal solutions and hence is usually employed with the meta-heuristic and/or bio-inspired techniques, with a view to converge swiftly towards an optimal solution. Usually, ORPF can have uneven, intermittent objectives and multi-constraint functions; and such intricacies of ORPF can best be suppressed by employing a combination of nature-inspired algorithms as a process of hybridization. Thus, in this paper, an approach has been endeavoured to hybridize the Biogeography based optimization (BBO) with that of the predator-prey optimization (PPO), so as to be rightfully termed as "adaptive biogeography based predator-prey optimization" (ABPPO). In such a way, this paper elucidates a novel hybrid technique that includes adaptive mutation combined with predator-prey pattern for attaining the global optimal point. In adaptive mutation scheme, the diversity measure of distance-to-average point is the predominant feature that dodges the supremacy of extremely feasible solutions throughout enhancing the population diversity. The predators explore around the elite prey in a determined way, whereas the preys search the solution space so as to evade from the predators. This tool improves the utilization and searching abilities of the BBO exploration procedure, thereby offers a mean of evading from the suboptimal point and imposes the populace to attain at the global best point. The efficacy of this hybrid scheme is validated against the standard test cases of IEEE-30 and IEEE-57 bus systems. The results show the efficiency and vitality of the proposed method.

1. Introduction

Optimal reactive power flow (ORPF) is a very significant phenomenon in the field of power system operation, modeling and control, which is a sub-problem of optimal power flow and helps to effectively utilize the existing reactive power sources. The main objective of ORPF is minimization of real power loss with the aid of the optimal adjustment of the power system control variables. The power flow or load flow balance equations are taken as equality constraints. Independent variables with its limit and power system state variables with its operating limits are considered as inequality constraints. The problem control variables include the voltage magnitude of generator, tap settings of transformer, and the injected values of shunt capacitor. The problem dependent variables, on the other hand, include the specified magnitude of load bus, the generator reactive powers, and the line flows. Generally, the ORPF problem is a huge scale, heavily constrained, nonlinear, non-convex and multimodal optimization problem [1,2]. The further growth in energy demands, reduction of the prevailing generation and transmission resources originate a different type of problem, named as the phenomenon of voltage instability or voltage collapse in power systems. The phenomenon of voltage instability, described by a monotonic voltage drop, is lower at first and suddenly increases after some duration. It is mainly caused by variation in the operating conditions that create an increased demand for reactive power. Various indices that provide an indirect relative measure of proximity to voltage instability for assessing the voltage stability (VS) are suggested by the researchers [3,4]. The ORPF problem can be modified to enhance VS and improve voltage profile (VP) in addition to reducing the loss.

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Nomenclature

ABPPO	Adaptive biogeography based predator-prey optimization
BBO	biogeography based optimization
DE	differential evolution
$D(t)$	diversity measure at generation-t
d	euclide an distance between predator and prey
E^{max}	maximum emigration rate
GA	genetic algorithm
G_{ij} *and jBij*	real and imaginary terms of bus admittance matrix corresponding to k-th row and j-th column
g_{ij}	conductance of the transmission line connected between buses -i and j
$g(x_1,u_1)$	equality constraint
HSI	Habitat Suitability Index
$h(x_1,u_1)$	inequality constraint
h_i	habitat-i
$\bar{h}_j$	population mean point of the j-th*SIV*
h_{ij}	jth*SIV*of i-th habitat
$h_{predator}(t)$	a possible solution that represents a predator at generation-t
$h_{worst}(t)$	the worst solution in the population at generation-t
I^{max}	maximum immigration rate
$J(x_1,u_1)$	objective function
L_j	Voltage stability index at load bus-j
ns	number of shunt reactive power compensators
nd	number of decision variables
nh	number of habitats
ng	number of generators
nt	number of transformers
n	maximum number of species in the population
neh	number of elite habitats
NET	Net Execution Time
ORPF	Optimal Reactive Power Flow
PSO	Particle Swarm Optimization
P^{mod}	modification probability of the habitat
P_m	rate of mutation
P_m^0	initial mutation rate
Q_{Gi}	reactive power generation at bus-i
Q_{Ci}	reactive power injection by i-th shunt compensator
Q_{Gi}^{limit}	limit violated reactive power generation at i-th PV bus
SIV	Suitability Index Variable
TTS	tap settings of the transformer
t_{max}	maximum number of generations
VDS	deviations of the voltage
VPE	voltage profile
VSY	voltage stability
VSI	voltage stability index
V_i	voltage at i-th bus
V_{Li}^{limit}	limit violated voltage magnitude at i-th load bus
V_{Gi}	voltage magnitude at i-th generator bus
V_{Li}	voltage magnitude at i-th load bus
w	weight values
ρ	rate of hunting
λ and μ	rate of immigration and emigration
λ_V and λ_Q	limit violation factors (penalty)
δ_{ij}	voltage angle between buses-i and j
$\mathscr{R}$	a set of load buses, whose voltages violate either the lower or upper limits.
Z	a set of generator buses, whose Q_G violate either the lower or upper limits
$\mathfrak{I}$	a set of transmission lines
Φ	a set of load buses
Ω	a set of generator buses
Ψ	augmented objective function to be minimized
χ	length of the longest diagonal in the search space

superscript min and maxlower and upper limits respectively

Traditional mathematical programming techniques such as Gradient method [1,2], Newton method [5], Linear Programming [6–9], interior point method [10] and non-linear programming [11] have been used in order to solve the ORPF problem. A modified objective function, derived from a local voltage stability index for ORPF problem, has been built and solved using an iterative algorithm with a view of improving VS margin in [12]. The multi-period ORPF with security constraints has been formulated as a mixed-integer nonlinear programming problem and solved using generalized benders decomposition in [13]. The ORPF with discrete control variables has been solved using interior-point filter line search algorithm, which assumes all variables as continuous and rounds off the original discrete variables to the nearest discrete value in [14]. An elegant LP based solution method for ORPF has been suggested for hybrid AC-DC power systems with FACTS devices in [15], where in the formulation of the problem involves additional control variables representing the DC links and FACTS devices. Unfortunately, classical methods so mentioned have severe limitations in handling non-linear and discontinuous objectives and constraints. The gradient and Newton methods, for instance, suffer from difficulty in handling inequality constraints. The linear programming, on the other hand, requires the objective and constraint functions to be linearized during optimization, which may lead to the loss of accuracy. Thus it is a need for evolving simple and effective methods for obtaining the global optimal solution for the ORPF problem. Heuristic methods such as Genetic Algorithm (GA) [16–18], Evolutionary Programming (EP) [19], Particle Swarm Optimization (PSO) [20], Differential Evolution (DE) [21–23] and Seeker Optimization Algorithm (SOA) [24] were suggested for validating ORPF-oriented hybrid approaches involving variable scaling, mutation and probabilistic state transition rule used in the ant system, with an aspect of achieving towards the optimum operating point, which was presented in [25]. A modified teaching learning based optimization algorithm involving quasi-opposition based learning concept with a view to accelerate the convergence, speed and improve solution quality for solving multi-objective ORPF problem has been suggested in [26]. A method involving Gravitational search algorithm and opposition-based learning with a view of obtaining better quality solution for ORPF problem has been notified in [27]. A hybrid multi-agent based PSO method, which allows searching in different zones of the solution space, for ORPF problem has been suggested with a view of avoiding local optima traps in [28]. The novelties of AGA for validating ORPF problem has been outlined [29]. The approach handles different objectives and treats specified voltage of the generators, transformer tap settings values, and shunt compensators as variables. It adjusts the population size during the solution process. A DE based solution algorithm with random localization technique for ORPF problem has been outlined with a view of improving the convergence in [30]. A gravitational search technique has been suggested for validating optimal reactive power flow problem with multiple objectives of minimizing the loss and maximizing the VS margin in [31,44]. These heuristic approaches have been found to be extensive applications in solving complex optimization