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A new hybrid algorithm for optimal reactive power dispatch problem with discrete and continuous control variables

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ABSTRACT

In this paper, a reliable and effective algorithm based on hybrid modified imperialist competitive algorithm (MICA) and invasive weed optimization (IWO) is proposed for solving the optimal reactive power dispatch (ORPD) problem. Without doubt, one of the simple but powerful optimization algorithms in the field of evolutionary optimization is imperialist competitive algorithm (ICA) outperforming many of the already existing stochastic and direct search global optimization techniques. The original ICA method often converges to local optima. In order to avoid this shortcoming, a new method is propose that profits from IWO method to improve local search near the global best and a series of modifications is purposed to the assimilation policy rule of ICA in order to further enhance algorithm's rate of convergence for achieving a better solution quality. The hybrid MICA-IWO method is then offered for handling ORPD problem. The introduced method is applied to ORPD problem on IEEE 30-bus, IEEE 57-bus and IEEE 118-bus power systems for testing and validation purposes. The hybrid MICA-IWO provides better results compared to the original ICA, IWO, and other methods reported in the literature as demonstrated by simulation results.

1. Introduction

One of the main sub problems of optimal power-flow (OPF) calculation is optimal reactive power dispatch problem (ORPD) which can be used to figure out controllable variables such as reactive-power outputs of generators and VAR sources, and to minimize desired objective functions including transmission losses, while simultaneously satisfying a given set of operating and physical constraints. The problem of ORPD for goal of improving economy and security of a power system operation has gained considerable attention. The main idea behind using an ORPD problem in improving a power system operation is to redistribute reactive power in a system in the way that the minimum amount of transmission line losses and also improvement the voltage profiles can be attained [1–3].

In the past, extensive efforts have been done development and utilization of several conventional optimization techniques such as dynamic programming, Newton method, linear programming, quadratic programming and interior point methods [4–8] for the purpose of solving an ORPD problem. However, these techniques generally suffer from algorithmic complexity, insecure convergence, and sensitivity to initial search point [9].

In last years, stochastic search methods have been widely considered and used as a more efficient alternative for the global optimization problem. Examples of this development are Wu's application of an evolutionary programming (EP) for global optimization of a power system in order to achieve optimal reactive power dispatch and voltage control [10]. Lai and Ma [11] also demonstrated higher capability of EP in handling non-continuous and non- smooth functions in comparison to nonlinear programming. In [12], Lee used the mixture of successive linear programming with simple genetic algorithm (SGA) to solve reactive power operational problem. Particle swarm optimization (PSO) was another approach to this problem applied by Yoshida in [13] for reactive power and voltage control with regard to voltage security assessment, Zhao in [14] purposed a multi-agent based PSO for the ORPD problem. In [15], a fuzzy adaptive PSO for reactive power and voltage control is used, and in [16], differential evolutionary algorithm formed the core of the solution applied to the optimal reactive power dispatch problem. In another case, Mahadevan and Kannan [17] also presents another method based on CLPSO for solving ORPD problem. Other approaches for handling the above mentioned problem such as SOA and SARCGA are also presented in

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[18,19] and finally a stochastic reactive power method is solved by GA in [20].

In 2007, Atashpaz-Gargari and Lucas introduce a novel with inspiration from social and political relations [21]. The performance of this evolutionary optimization algorithm has been continuously reinstated by successful utilization in many engineering applications such as control [22], data clustering [23], and industrial engineering [24] in recent years and has demonstrated great effectiveness in both critical factors of convergence rate and capability in achieving global optimal. In [25], a new modified ICA method further improves the performance of ICA method by taking advantage of chaotic maps to determine the movement angle of colonies toward imperialist's position in order to enhance the escaping capability from a local optimal trap. The ICA algorithm can be used for neural network learning based on chaotic imperialist competitive algorithm [26].

The rests of this article are classified in four sections as follows: Section 2 covers formulation of an optimal reactive power dispatch while Section 3 explains the standard structure of the ICA, IWO and hybrid modified ICA and IWO (MICA-IWO) algorithms, Section 4 of the paper is allocated to presenting optimization results and undertaking comparison and analysis of the performance of the mentioned methods used to solve the case studies of optimal reactive power dispatch problem on IEEE 30-bus, IEEE 57-bus and IEEE 118-bus systems and finally, in Section 5, the conclusion of the implementation for the hybrid method is presented.

2. Problem formulation

In general, the goal of a solution of ORPD is to optimize the active power loss in the transmission network through optimal adjustment power system control parameters while satisfying equality and inequality constraints at the same time [14,17].

The ORPD problem can be mathematically formulated as follows:

$$Min\, P_{loss} = J(x,u) = \sum_{k \in NTL} g_k(V_i^2 + V_j^2 - 2V_iV_j\cos\delta_{ij}) \quad (1)$$

$$\text{Subject to}: \; g(x,u) = 0 \quad (2)$$

$$h(x,u) \le 0 \quad (3)$$

In the above equation, $J(x,u)$ is the active power loss function of the transmission network, g_k is the conductance of branch k, V_i and V_j are the voltages of ith and jth bus, respectively, NTL depict the number of transmission lines, δ_{ij} phase difference of voltages between bus i and bus j and x is the vector of dependent variables (state vector) consisting of:

1. Load bus voltage V_L.
2. Generator reactive power output Q_G.
3. Transmission line loading (or line flow) S_l.

Accordingly, the x vector can be illustrated as the following:

$$x^T = [V_{L1}\ldots V_{LNPQ}, Q_{G1}\ldots Q_{GNG}, S_{l1}\ldots S_{lNTL}] \quad (4)$$

where NG defines the number of generators; NPQ depict the number of PQ buses.

u is the vector of independent variables (control variables) consisting of:

1. Generation bus voltages V_G (continuous control variable).
2. Transformer taps settings T (discrete control variable).
3. Shunt VAR compensation Q_C (discrete control variable).

Therefore, u can be expressed as:

$$u^T = [V_{G1}\ldots V_{GNG}, Q_{C1}\ldots Q_{CNC}, T_1\ldots T_{NT}] \quad (5)$$

where NT and NC represent the number of tap regulating transformers and number of shunt VAR compensators, respectively.

2.1. Constraints

2.1.1. Equality constraints

In the below terms, g is the equality constraints, illustrating typical load flow equations [1–3]:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NB} V_j[G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})] = 0 \quad (6)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{NB} V_j[G_{ij}\sin(\delta_{ij}) - B_{ij}\cos(\delta_{ij})] = 0 \quad (7)$$

where NB is the number of buses, P_{Gi} is the active power generation, Q_{Gi} is the reactive power generation, P_{Di} is the active load demand, Q_{Di} is the reactive load demand, G_{ij} and B_{ij} are the conductance and susceptance, respectively.

2.1.2. Inequality constraints

h is the inequality constraints that include:

i. Generator related constraints: the active power generation at slack bus, generation bus voltages, and reactive power outputs are restricted by their lower and upper limits as:

$$\begin{aligned} &P_{G,slack}^{\min} \le P_{G,slack} \le P_{G,slack}^{\max} \\ &V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max}, \; i = 1,\ldots,NG \\ &Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, \; i = 1,\ldots,NG \end{aligned} \quad (8)$$

where $V_{Gi}^{\min}$ and $V_{Gi}^{\max}$ are the minimum and maximum generator voltage of ith generating unit; $P_{Gi}^{\min}$ and $P_{Gi}^{\max}$ the minimum and maximum active power output of ith generating unit, and, $Q_{Gi}^{\min}$ and $Q_{Gi}^{\max}$ are the minimum and maximum reactive power output of ith generating unit.

ii. Transformer limitations: transformer tap settings are restricted by their lower and upper limits as:

$$T_i^{\min} \le T_i \le T_i^{\max}, \quad i = 1,\ldots,NT \quad (9)$$

where $T_i^{\min}$ and $T_i^{\max}$ define minimum and maximum tap settings limits of ith transformer.

iii. Shunt VAR compensator constraints: shunt VAR compensations are restricted by their limits as:

$$Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max}, \quad i = 1,\ldots,NC \quad (10)$$

where $Q_{Ci}^{\min}$ and $Q_{Ci}^{\max}$ define minimum and maximum VAR injection limits of ith shunt compensator.

iv. Security constraints: include the constraints of voltages at load buses and transmission line loading as:

$$V_{Li}^{\min} \le V_{Li} \le V_{Li}^{\max}, \quad i = 1,\ldots,NPQ \quad (11)$$

$$S_{li} \le S_{li}^{\max}, \quad i = 1,\ldots,NTL \quad (12)$$

where $V_{Li}^{\min}$ and $V_{Li}^{\max}$ are the minimum and maximum load voltage of ith unit. S_{li} defines apparent power flow of ith branch. $S_{li}^{\max}$ defines maximum apparent power flow limit of ith branch.

Dependent variables are constrained using penalty terms to the objective function. Therefore, Eq. (1) is changed to the following form: