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Real Power Loss Reductionby Enhanced Imperialist Competitive Algorithm

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Abstract

In this paper, an Enhanced Imperialist Competitive (EIC) Algorithm is proposed for solving reactive power problem. Imperialist Competitive Algorithm (ICA) which was recently introduced has shown its decent performance in optimization problems. This innovative optimization algorithm is inspired by socio-political progression of imperialistic competition in the real world. In the proposed EIC algorithm, the chaotic maps are used to adapt the angle of colonies movement towards imperialist's position to augment the evading capability from a local optima trap. The ICA is candidly stuck into a local optimum when solving numerical optimization problems. To overcome this insufficiency, we use four different chaotic maps combined into ICA to augment the search ability.Proposed Enhanced Imperialist Competitive (EIC) algorithm has been tested on standard IEEE 30 bus test system and simulation results show clearly the decent performance of the proposed algorithm in reducing the real power loss.

***Keywords**: Optimal Reactive Power, transmission loss, Enhanced Imperialist Competitive Algorithm.*

1. Introduction

Optimal reactive power dispatch (ORPD) problem is a multi-objective optimization problem that minimizes the real power loss and bus voltage deviation. Various mathematical techniques like the gradient method [1-2], Newton method [3] and linear programming [4-7] have been adopted to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods have the complexity in managing inequality constraints. If linear programming is applied then the input- output function has to be uttered as a set of linear functions which mostly lead to loss of accuracy. The problem of voltage stability and collapse play a major role in power system planning and operation [8]. Global optimization has received extensive research awareness, and a great number of methods have been applied to solve this problem. Evolutionary algorithms such as genetic algorithm have been already proposed to solve the reactive power flow problem [9, 10]. Evolutionary algorithm is a heuristic approach used for minimization problems by utilizing nonlinear and non-differentiable continuous space functions. In [11], Genetic algorithm has been used to solve optimal reactive power flow problem. In [12], Hybrid differential evolution algorithm is proposed to improve the voltage stability index. In [13] Biogeography Based algorithm is projected to solve the reactive power dispatch problem. In [14], a fuzzy based method is used to solve the optimal reactive power scheduling method. In [15], an improved evolutionary programming is used to solve the optimal reactive power dispatch problem. In [16], the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinear interior point method. In [17], a pattern algorithm is used to solve ac-dc optimal reactive power flow model with the generator capability limits. In [18], F. Capitanescu proposes a two-step approach to evaluate Reactive power reserves with respect to operating constraints and voltage stability. In [19], a programming based approach is used to solve the optimal reactive power dispatch problem. In [20], A. Kargarian et al present a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads. This paper proposes a new Enhanced Imperialist Competitive Algorithm (EIC) to solve the optimal reactive power problem. Recently, a new algorithm known as ICA has been proposed by Atashpaz-Gargari and Lucas [21], which is inspired from a socio-human phenomenon [22]. In this paper, a new-fangled method using the chaos theory is proposed to regulate the angle of colonies movement in the direction of the imperialist's positions. The projected method uses some chaotic maps to produce chaotic movement angle. This chaotic movement angle, will act like the mutation operator in genetic

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algorithm. With the chaos theory the semi-random variation of movement angle causes the planned algorithm escape from the local optimums during the search process. ProposedEIC algorithm has been evaluated in standard IEEE 30 bus test system and the simulation results show that the proposed approach outperforms all the entitled reported algorithms in minimization of real power loss.

2. Problem Formulation

The optimal power flow problem is treated as a general minimization problem with constraints, and can be mathematically written in the following form:

Minimize f(x, u) (1)
subject to g(x,u)=0 (2)
and
$h(x,u) \leq 0$ (3)

where f(x,u) is the objective function. g(x.u) and h(x,u) are respectively the set of equality and inequality constraints. x is the vector of state variables, and u is the vector of control variables.

The state variables are the load buses (PQ buses) voltages, angles, the generator reactive powers and the slack active generator power:

$$x = \left(P_{g1}, \theta_2, .., \theta_N, V_{L1}, ., V_{LNL}, Q_{g1}, .., Q_{gng}\right)^T \quad (4)$$

The control variables are the generator bus voltages, the shunt capacitors/reactors and the transformers tap-settings:

$$u = \left(V_g, T, Q_c\right)^T \quad (5)$$

or

$$u = \left(V_{g1}, ..., V_{gng}, T_1, .., T_{Nt}, Q_{c1}, .., Q_{cNc}\right)^T \quad (6)$$

where ng, nt and nc are the number of generators, number of tap transformers and the number of shunt compensators respectively.

3. Objective Function

3.1. Active Power Loss

The objective of the reactive power dispatch is to minimize the active power loss in the transmission network, which can be described as follows:

$$F = PL = \sum_{k \in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}\right) \quad (7)$$

or

$$F = PL = \sum_{i \in Ng} P_{gi} - P_d = P_{gslack} + \sum_{i \neq slack}^{Ng} P_{gi} - P_d \quad (8)$$

where gk: is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems. Pd: is the total active power demand, Pgi: is the generator active power of unit i, and Pgsalck: is the generator active power of slack bus.

3.2. Voltage profile improvement

For minimizing the voltage deviation in PQ buses, the objective function becomes:

$$F = PL + \omega_v \times VD \quad (9)$$

where ωv: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \quad (10)$$

yy

3.3. Equality Constraint

The equality constraint g(x,u) of the Optimal reactive power problem is represented by the power balance equation, where the total power generation must cover the total power demand and the power losses:

$$P_G = P_D + P_L \tag{11}$$

This equation is solved by running Newton Raphson load flow method, by calculating the active power of slack bus to determine active power loss.

3.4. Inequality Constraints

The inequality constraints h(x,u) reflect the limits on components in the power system as well as the limits created to ensure system security. Upper and lower bounds on the active power of slack bus, and reactive power of generators:

$$P_{gslack}^{min} \le P_{gslack} \le P_{gslack}^{max} \tag{12}$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max}, i \in N_g \tag{13}$$

Upper and lower bounds on the bus voltage magnitudes:

$$V_i^{min} \le V_i \le V_i^{max}, i \in N \tag{14}$$

Upper and lower bounds on the transformers tap ratios:

$$T_i^{min} \le T_i \le T_i^{max}, i \in N_T \tag{15}$$

Upper and lower bounds on the compensators reactive powers:

$$Q_c^{min} \le Q_c \le Q_C^{max}, i \in N_C \tag{16}$$

where N is the total number of buses, NT is the total number of Transformers; Ncis the total number of shunt reactive compensators.

4. Imperialist Competitive Algorithm

Imperialist Competitive Algorithm (ICA) is a new-fangled evolutionary algorithm in the Evolutionary Computation ground based on the human's socio-political progression. The algorithm starts with a primary random population called countries. Some of the paramount countries in the population selected to be the imperialists and the rest form the colonies of these imperialists. In an N dimensional optimization problem, a country is $1 \times N$array. This array defined as below

$$country = [p_1, p_2, .., p_N] \tag{17}$$

The cost of a country is found by calculating the cost function f at the variables $(p_1, p_2, .., p_N)$. Then

$$c_i = f(country_i) = f(p_{i1}, p_{i2}, .., p_{iN}) \tag{18}$$

The algorithm begins with N initial countries and the Nimpbest of them (countries with minimum cost) selected as theimperialists. The left over countries are colonies that belong to a kingdom. The primary colonies belong toimperialists in convenience with their authority. To allocatethe colonies among imperialists proportionally, thestandardized cost of an imperialist is defined as follow

$$c_n = \max_i c_i - c_n \tag{19}$$

where, costnis the cost of nth imperialist and $c_n$is its standardized cost. Every imperialist that has more cost value, will have less standardized cost value. Having the standardized cost, the authority of each imperialist is computed as below and based on that the colonies spread among the imperialist countries.

$$p_n = \left|\frac{c_n}{\sum_{i=1}^{N_{imp}} c_i}\right| \quad (20)$$

On the other hand, the standardized power of an imperialist is weighed up by its colonies. Then, the primary number of colonies of an empire will be

$$Nc_n = \text{rand}\{p_n \cdot (N_{col})\} \quad (21)$$

where, $Nc_n$is initial number of colonies of nth empire andN_{col} is the number of all colonies.

To allocate the colonies among imperialist, $Nc_n$of the colonies is selected arbitrarily and allocated to their imperialist. The imperialist countries absorb the colonies towards themselves using the absorption policy. The imperialists take in these colonies towards themselves with respect to their power that described in (22). The entire power of each imperialist is determined by the power of its both parts, the empire power with addition of its average colonies power.

$$TC_n = \text{cost}(\text{imperialist}_n) + \xi \text{mean}\{\text{cost}(\text{colonies of Empire}_n)\} \quad (22)$$

where $TC_n$is the total cost of the nth empire and$\xi$is a positive number which is considered to be less than one.

$$x \sim U(0, \beta \times d) \quad (23)$$

In the amalgamation strategy, the colony moves in the direction of the imperialist by x unit. The direction of movement is the vector from colony to imperialist. The distance between the imperialist and colony shown by d and x is a random variable with uniform distribution. Where $\beta$is greater than 1 and is near to 2. So, a suitable option can be β =2. In our execution $\gamma$is $\frac{\pi}{4}$(rad)respectively.

$$\theta \sim U(-\gamma, \gamma) \quad (24)$$

In ICA to investigate different points in the region of the imperialist, an arbitrary amount of deviation is added to the way of colony movement in the direction of the imperialist. While moving in the direction of the imperialist countries, a colony may reach to a superior position, so the colony position alters according to position of the imperialist. In this algorithm, the imperialistic competition has a significant role. During the imperialistic competition, the weak empires will lose their authority and their colonies. To model this competition, firstly we compute the probability of possessing all the colonies by each empire taking into consideration with the total cost of empire.

$$NTc_n = \max_i\{TC_i\} - TC_n \quad (25)$$

where, $TC_n$is the total cost of nth empire and $NTc_n$is the normalized total cost of nth empire. Having the normalized total cost, the possession probability of each empire is calculated as below

$$p_{pn} = \left|\frac{NTC_n}{\sum_{i=1}^{N_{imp}} NTC_i}\right| \quad (26)$$

After a while all the empires except the most powerful one will fall down and all the colonies will be under the control of this unique kingdom. Figure 1 shows the flow chart of the ICA.

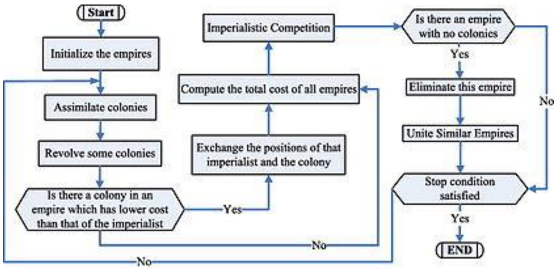

Figure 1. Flowchart of Imperialist Competitive Algorithm (ICA)

Steps of Imperialist Competitive Algorithm
Define objective function

1) Initialization of the algorithm. Generate some random solution in the search space and create initial empires.
2) Assimilation: Colonies move towards imperialist states in different in directions.
3) Revolution: Random changes occur in the characteristics of some countries.
4) Position exchange between a colony and Imperialist. A colony with a better position than the imperialist, has the chance to take the control of empire by replacing the existing imperialist.
5) Imperialistic competition: All imperialists compete to take possession of colonies of each other.
6) Eliminate the powerless empires. Weak empires lose their power gradually and they will finally be eliminated.
7) If the stop condition is satisfied, stop, if not go to 2.
8) End

5. Chaos Theory

In the chaos theory behaviour between unbending regularity and arbitrariness based on unadulterated possibility is called a chaotic system, or chaos. Chaos emerges to be stochastic but it arises in a deterministic non-linear system under deterministic conditions [23]. Chaotic map is very significant for optimization problem. In addition, it has a very susceptible dependence upon its primary condition and parameter. A chaotic map is a discrete-time dynamical system. Since the ICA algorithm experience from being trapped at local optima, chaotic local search has been initiated to conquer the local optima and speed up the convergence.

6. Enhanced Imperialist Competitive (EIC)Algorithm

The primary Imperialist Competitive Algorithm (ICA) utilizes a local search mechanism as like as many evolutionary algorithms. Therefore, the chief ICA may fall into local minimum trap during the search procedure and it is likely to get far from the global optimum. To solve this problem, we augmented the exploration aptitude of the ICA algorithm, using a chaotic behaviour in the colony movement in the direction of the imperialist's position. So it is planned to improve the global convergence of the ICA and to avoid it to stick on a local solution.

In this paper, to augment the universal exploration capability, the chaotic maps are integrated into ICA to augment the ability of absconding from a local optimum. The angle of movement is altered in a chaotic way during the search procedure. Adding this chaotic behaviour in the imperialist algorithm amalgamation policy we make the conditions proper for the algorithm to run away from local peaks. Chaos variables are usually generated by the some well-known chaotic maps [23, 24]. Table 1shows the mentioned chaotic maps for adjusting θparameter (Angle of colonies movement in the direction of the imperialist's position) in the planned algorithm.

Table 1.Chaotic Maps

	Chaotic maps
CM1	$\theta_{n+1} = a\theta_n(1-\theta_n)$
CM2	$\theta_{n+1} = a\theta_n^2 sin(\pi\theta_n)$
CM3	$\theta_{n+1} = \theta_n + b - (a/2\pi)sin(2\pi\theta_n)mod(1)$
CM4	$\theta_{n+1} = \begin{cases} 0 & \theta_n = 0 \\ 1/X_n mod(1) & \theta_n \in (0,1) \end{cases}$

In table I, ais a control parameter. θ is a chaotic variable in kth iteration which belongs to interval of (0,1). During the search process, no value of θis repeated.

Enhanced Imperialist Competitive (EIC) Algorithm to solve reactive power problem

(i) Initialize the kingdom and their colonies location arbitrarily.

(ii) Calculate the chaotic θ (colonies movement angle in the direction of the imperialist's location) using the chaotic maps.

(iii) Calculate the sum cost of all kingdom.

(iv) Choose the weakest colony from the weakest kingdom and give it to the empire that has the most likelihood to own it.

(v) Eradicate the powerless empires.

(vi) If there is just one empire then stop else continue.

(vii) Check the stop conditions

7. Simulation Results

Validity of proposed Enhanced Imperialist Competitive (EIC) Algorithm has been verified by testing in IEEE 30-bus, 41 branch system and it has 6 generator-bus voltage magnitudes, 4 transformer-tap settings, and 2 bus shunt reactive compensators. Bus 1 is taken as slack bus and 2, 5, 8, 11 and 13 are considered as PV generator buses and others are PQ load buses. Control variables limits are given in Table 2.

Table 2 Primary Variable Limits (Pu)

Variables	Min.	Max.	category
Generator Bus	0.95	1.1	Continuous
Load Bus	0.95	1.05	Continuous
Transformer-Tap	0.9	1.1	Discrete
Shunt Reactive Compensator	-0.11	0.31	Discrete

In Table 3 the power limits of generators buses are listed.

Table 3. Generators Power Limits

Bus	Pg	Pgmin	Pgmax	Qgmin	Qmax
1	96.00	49	200	0	10
2	79.00	18	79	-40	50
5	49.00	14	49	-40	40
8	21.00	11	31	-10	40
11	21.00	11	28	-6	24
13	21.00	11	39	-6	24

Table 4 shows the proposed EIC approach successfully kept the control variables within limits.Table 5 narrates about the performance of the proposed EIC algorithm. Fig 2 shows about the voltage deviations during the iterations and Table 6 list out the overall comparison of the results of optimal solution obtained by various methods.

Table 4. After optimization values of control variables

Control Variables	EIC
V1	1.0481
V2	1.0401
V5	1.0205
V8	1.0314
V11	1.0701
V13	1.0500
T4,12	0.00
T6,9	0.01
T6,10	0.90
T28,27	0.91
Q10	0.10
Q24	0.10
Real power loss	4.2762
Voltage deviation	0.9092

Table 5. Performance of EIC algorithm

Iterations	30
Time taken (secs)	8.83
Real power loss	4.2762

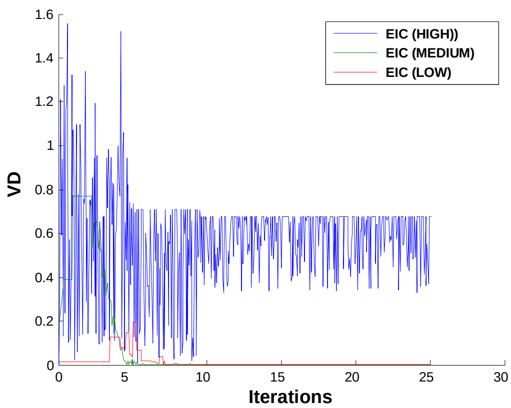

Figure 2. Voltage deviation (VD) characteristics

Table 6 Comparison of results

Techniques	Real power loss (MW)
SGA(Wu et al., 1998) [25]	4.98
PSO(Zhao et al., 2005) [26]	4.9262
LP(Mahadevan et al., 2010) [27]	5.988
EP(Mahadevan et al., 2010) [27]	4.963
CGA(Mahadevan et al., 2010) [27]	4.980
AGA(Mahadevan et al., 2010) [27]	4.926
CLPSO(Mahadevan et al., 2010) [27]	4.7208
HSA (Khazali et al., 2011) [28]	4.7624
BB-BC (Sakthivel et al., 2013) [29]	4.690
MCS(Tejaswini sharma et al.,2016) [30]	4.87231
Proposed EIC	4.2762

8. Conclusion

Enhanced Imperialist Competitive (EIC) Algorithm has been successfully applied for reactive power problem.In the proposed EIC algorithm, the chaotic maps are used to adapt the angle of colonies movement towards imperialist's position to augment the evading capability from a local optima trap. Proposed EIC algorithm has been tested in standard IEEE 30 bus system and simulation results reveal about the better performance of the proposed EIC algorithm in reducing the real power loss when compared to other stated standard algorithms.

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