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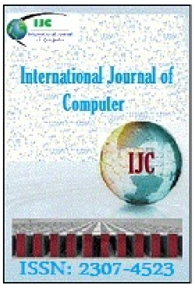
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Voltage Profile Index Enrichment and Dwindling of Real Power Loss by using Acclimatized Imperialist Competitive Algorithm

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Abstract

In this paper, Acclimatized Imperialist Competitive Algorithm (AICA) is proposed for solving reactive power dispatch problem. The Imperialist Competitive Algorithm (ICA) was recently introduced has shown its good performance in optimization problems. This novel optimization algorithm is enthused by socio-political progression of imperialistic competition in the real world .The ICA is straightforwardly stuck into a local optimum when solving numerical optimization problems. In the proposed algorithm, for an effective search, the amalgamation Policy changed dynamically to adapt the angle of colonies movement towards imperialist's position. To overcome this inadequacy we use probabilistic model that make use of the information of colonies positions to balance the exploration and exploitation aptitude of the imperialistic competitive algorithm. Using this mechanism, ICA exploration capability will augmented. The proposed (AICA) algorithm has been tested on standard IEEE 57 bus test system and simulation results shows clearly about the good performance of the proposed algorithm in reducing the real power loss.

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Key words: Optimal Reactive Power, Transmission loss, 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 has 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 accurateness. 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], proposes a two-step approach to evaluate Reactive power reserves with respect to operating constraints and voltage stability. In [19], a programming based proposed approach used to solve the optimal reactive power dispatch problem. In [20], presents a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads. This paper proposes a new Improved Imperialist Competitive Algorithm (IICA) is used to solve the optimal reactive power dispatch problem. Recently, a new algorithm ICA has been proposed by Atashpaz-Gargari and lucas [21], and it is inspired from a socio-human phenomenon. In this paper, we have proposed a new algorithm called Acclimatized Imperialist Competitive Algorithm (AICA) that uses the probability density function to acclimatize the angle of colonies movement in the direction of imperialist's position during iterations energetically. This method, augment the global search capability of the algorithm. This idea increases the performance of the ICA algorithm effectively in solving the optimization problems. The proposed algorithm AICA been evaluated in standard IEEE 57 bus test system & the simulation results shows that our proposed approach outperforms all reported algorithms in minimization of real power loss .

2. Problem Formulation

The OPF problem is measured 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

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

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:

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

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 g_k : is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems. P_d: is the total active power demand, P_{gi}: is the generator active power of unit i, and P_{gsalck}: 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:

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

Where ω_v: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

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

3.3.Equality Constraint

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

$$P_G = P_D + P_L \qquad (11)$$

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:

$$P_{gslack}^{min} \le P_{gslack} \le P_{gslack}^{max} \qquad (12)$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \text{ }, i \in N_g \qquad (13)$$

Upper and lower bounds on the bus voltage magnitudes:

$$V_i^{min} \le V_i \le V_i^{max} \text{ }, i \in N \qquad (14)$$

Upper and lower bounds on the transformers tap ratios:

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in N_T \quad (15)$$

Upper and lower bounds on the compensators reactive powers:

$$Q_c^{min} \leq Q_c \leq Q_C^{max}, i \in N_C \quad (16)$$

Where N is the total number of buses, N_T is the total number of Transformers; N_c is 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

$$country = [p_1, p_2, .., p_N] \quad (17)$$

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

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

The algorithm begins with *N* initial countries and the N_{imp} best of them (countries with minimum cost) selected as the imperialists. The left over countries are colonies that belong to a kingdom. The primary colonies belong to imperialists in convenience with their authority. To allocate the colonies among imperialists proportionally, the standardized cost of an imperialist is defined as follow

$$\mathrm{c_n} = \mathrm{max_i c_i} - \mathrm{c_n} \quad (19)$$

Where, $\mathrm{cost_n}$ is the cost of *n*th imperialist and $\mathrm{c_n}$ 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

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

Where, Nc_n is initial number of colonies of nth empire and N_{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.

$$TC_n = cost(imperialist_n) + \xi mean\{cost(colonies\ of\ Empire_n)\} \qquad (22)$$

Where TC_n is the total cost of the nth empire and ξ is a positive number which is considered to be less than one.

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

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 β is greater than 1 and is near to 2. So, a suitable option can be $\beta = 2$. In our execution γ is $\frac{\pi}{4}(rad)$ respectively.

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

In ICA algorithm, 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.

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

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

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

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.

5. Acclimatized Imperialist Competitive Algorithm

The ICA algorithm like many Evolutionary Algorithms experience deficient in ability to global search properly in the problem space. During the search process, the algorithm may trap into local optima and it is possible to get far away from the global optima. This is root for the premature convergence. In this paper, a novel method suggested that balance the exploration and exploitation capability of the proposed algorithm, using colonies location information. In the ICA algorithm amalgamation policy that mentioned in the previous section, the colonies move in the direction of imperialists with an angle, which is a arbitrary variable. The colonies movement because of the constant θ parameter has a monotonic nature, so the colonies movement could not be tailored with the search process. Therefore, if the algorithm traps in the local optima, it cannot leave it and move in the direction of the global optima. For solving this problem, and to make equilibrium between the explorative and exploitative search, we define the θ parameter to acclimatize, and dynamically adjust the movement of colonies to the imperialists during the search process.

5.1.Acclimatize movement angle in the amalgamation policy

As mentioned before in ICA algorithm the colonies move in the direction of the imperialist by an arbitrary amount of variation. The □ constraint is this deviation. In this paper, we extort the statistical information regarding the search space from the current population of solutions to provide an acclimatize movement angle. We projected a probabilistic model, to modify the ICA global search ability. The probabilistic model P(x) that we use here is a Gaussian distribution model [22,23,24,25]. The combined probability distribution of all the countries, is given by the product of the marginal probabilities of the countries:

$$p(country) = \Pi_{i=1}^{n} N(country_i; \mu_i, \sigma_i) \qquad (27)$$

Where

$$N(country_i; \mu_i, \sigma_i) = \frac{1}{\sqrt{2\pi\sigma_i}} \frac{1}{2} \left(\frac{country\ _i - \mu_i}{\sigma_i}\right)^2 \qquad (28)$$

The average, μ, and the standard deviation, σ, for the colony countries of each empire is approximated as below:

$$\hat{\mu}_l = \overline{country_i} = \frac{1}{M} \sum_{t=1}^{M} country_{t,i} \qquad (29)$$

$$\hat{\sigma}_l = \sqrt{\frac{1}{M} \sum_{t=1}^{M} \left(country_{t,i} - \overline{country_l}\right)^2} \qquad (30)$$

In every iteration, the country densities calculate using the probabilistic model in Eq(27). If the countries concentration in the current iteration is more than the previous iteration, then with 85% the previous angle of the movement of the countries towards their kingdom will be shrunk and with

15% the mentioned angle will be prolonged.

$$\theta_{iter} = 0.85(\theta_{iter-1} + \alpha) + 0.15(\theta_{iter-1} - \alpha) \quad (31)$$

θ_{iter}, is the current angle of movement. θ_{iter-1} , is the previous angle and α is the step size of shrinking and escalating the angle of movement. The value of this step size is varying between 0.0001 and 0.1. Otherwise, if the countries concentration in the current iteration is less than the previous iteration, then with 85% the previous angle of the movement of the countries in the direction of their empires will be prolonged and with 15% the mentioned angle will be shrunk.

$$\theta_{iter} = 0.25(\theta_{iter-1} + \alpha) + 0.75(\theta_{iter-1} - \alpha) \quad (32)$$

If the countries concentration in the current iteration is more than the previous iteration, it means that may be the countries are converging to an optimum point. So, in Eq. (31), depending on the concentration of the countries distribution, we set the angle of movement so that each country can flee from the opaque area with 15% and with 85% the country will move in the direction of its empire with a shrinking angle. In the cases that the countries converge to a local optima, this method will help to flee from falling into the local optima's trap with possibility of 15% . In this way, we add explorative search ability to the ICA algorithm. In Eq. (32), if the countries concentration in the current iteration is less than the preceding iteration, every country with possibility of 15% will move in the direction of its empire with a shrinking angle and with 85% the country will move in the direction of its empire with a mounting angle. This way, endow with a more efficient search in all over the search space of the problem.

AICA for solving optimal reactive power problem

(i) Initialize the kingdoms and their colonies positions arbitrarily.

(ii) Calculate the acclimatize θ using the probabilistic model.

(iii) Calculate the total cost of all kingdoms

(iv) Select the weakest colony from the weakest empire and provide it to the kingdom that has the most likelihood to acquire it.

(v) Eradicate the powerless kingdoms.

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

(vii) Check the stop conditions.

6. Simulation Results

The proposed AICA algorithm for solving ORPD problem is tested for standard IEEE-57 bus power system. The IEEE 57-bus system data consists of 80 branches, seven generator-buses and 17 branches under load tap setting transformer branches. The possible reactive power compensation buses are 18, 25 and 53. Bus 2, 3, 6, 8, 9 and 12 are PV buses and bus 1 is selected as slack-bus. In this case, the search space has 27 dimensions, i.e., the seven generator voltages, 17 transformer taps, and three capacitor banks. The system variable limits are given in Table 1. The initial conditions for the IEEE-57 bus power system are given as follows:

$P_{load} = 12.471$ p.u. $Q_{load} = 3.363$ p.u.

The total initial generations and power losses are obtained as follows:

$\sum P_G$ = 12.7834 p.u. $\sum Q_G$ = 3.4768 p.u.

$P_{loss} = 0.27582$ p.u. $Q_{loss} = -1.2358$ p.u.

Table 2 shows the various system control variables i.e. generator bus voltages, shunt capacitances and transformer tap settings obtained after AICA based optimization which are within their acceptable limits. In Table 3, a comparison of optimum results obtained from proposed AICA with other optimization techniques for ORPD mentioned in literature for IEEE-57 bus power system is given. These results indicate the robustness of proposed AICA approach for providing better optimal solution in case of IEEE-57 bus system.

Table 1: Variables limits for ieee-57 bus power system (p.u.)

<table>
<tr><td colspan="8">reactive power generation limits</td></tr>
<tr><td>bus no</td><td>1</td><td>2</td><td>3</td><td>6</td><td>8</td><td>9</td><td>12</td></tr>
<tr><td>Q_{gmin}</td><td>-1.4</td><td>-.017</td><td>-.02</td><td>-0.08</td><td>-1.2</td><td>-0.01</td><td>-0.3</td></tr>
<tr><td>q_{gmax}</td><td>2</td><td>0.3</td><td>0.6</td><td>0.27</td><td>3</td><td>0.09</td><td>1.58</td></tr>
<tr><td colspan="8">voltage and tap setting limits</td></tr>
<tr><td colspan="8"><table>
<tr><td>v_{gmin}</td><td>v_{gmax}</td><td>v_{pqmin}</td><td>v_{pqmax}</td><td>t_{kmin}</td><td>t_{kmax}</td></tr>
<tr><td>0.7</td><td>1.3</td><td>0.94</td><td>1.08</td><td>0.7</td><td>1.2</td></tr>
</table></td></tr>
<tr><td colspan="8"><table>
<tr><td colspan="4">shunt capacitor limits</td></tr>
<tr><td>bus no</td><td>18</td><td>25</td><td>53</td></tr>
<tr><td>q_{cmin}</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>q_{cmax}</td><td>10</td><td>5.5</td><td>6.4</td></tr>
</table></td></tr>
</table>

Table 2: control variables obtained after optimization by AICA method for ieee-57 bus system (p.u.).

Control Variables	AICA
V1	1.2
V2	1.087
V3	1.076
V6	1.057
V8	1.075
V9	1.054
V12	1.062
Qc18	0.0843
Qc25	0.335
Qc53	0.0628
T4-18	1.018
T21-20	1.072
T24-25	0.977
T24-26	0.948
T7-29	1.092
T34-32	0.959
T11-41	1.015
T15-45	1.074
T14-46	0.943
T10-51	1.056
T13-49	1.073
T11-43	0.922
T40-56	0.911
T39-57	0.975
T9-55	0.984

Table 3: comparative optimization results for ieee-57 bus power system (p.u.)

S.No.	Optimization Algorithm	Best Solution	Worst Solution	Average Solution
1	NLP [26]	0.25902	0.30854	0.27858
2	CGA [26]	0.25244	0.27507	0.26293

3	AGA [26]	0.24564	0.26671	0.25127
4	PSO-w [26]	0.24270	0.26152	0.24725
5	PSO-cf [26]	0.24280	0.26032	0.24698
6	CLPSO [26]	0.24515	0.24780	0.24673
7	SPSO-07 [26]	0.24430	0.25457	0.24752
8	L-DE [26]	0.27812	0.41909	0.33177
9	L-SACP-DE [26]	0.27915	0.36978	0.31032
10	L-SaDE [26]	0.24267	0.24391	0.24311
11	SOA [26]	0.24265	0.24280	0.24270
12	LM [27]	0.2484	0.2922	0.2641
13	MBEP1 [27]	0.2474	0.2848	0.2643
14	MBEP2 [27]	0.2482	0.283	0.2592
15	BES100 [27]	0.2438	0.263	0.2541
16	BES200 [27]	0.3417	0.2486	0.2443
17	Proposed AICA	0.22488	0.23855	0.23301

7. Conclusion

AICA has been successfully applied for ORPD problem. The AICA based ORPD is tested in standard IEEE-57 bus system. Performance comparisons with well-known population-based algorithms give positive results. AICA come out to find good solutions when compare to that of other algorithms. The simulation results presented in previous section prove the capability of AICA approach to arrive at near global optimal solution.

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