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Reduction of real power loss by using Kudu Herd Algorithm

Kanagasabai Lenin, Bhumanapally Ravindhranath Reddy, Munagala Suryakalavathi

Jawaharlal Nehru Technological University Kukatpally, Hyderabad 500 085, India

Email address

gklenin@gmail.com (K. Lenin)

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Abstract

In this paper, a new Bio-inspired algorithm, namely kudu herd algorithm (KHA) is proposed for solving reactive power dispatch problem. A population of candidate solution approach as a herd of kudus carries out a succession of jumps through the search space in order to find the most excellent solution. The logic of this algorithm is quite different from that of most population based algorithms, as the individual solutions are moved collectively in a herd-like approach. The proposed (KHA) algorithm has been tested in standard IEEE 57 bus test system and simulation results show clearly about the good performance of the proposed algorithm in reducing the real power loss.

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 bio-inspired optimization algorithm called kudu herd algorithm is used to solve the optimal reactive power dispatch problem. KHA imitate the behaviour of a herd [21] of kudus that jump their way through a solution space to find the optimal point. The kudu is a species of antelope present in sub-Saharan Africa, which mostly lives in herds and is known for its ability to jump high and far [22]. This algorithm tries to find an optimal point by iteratively changing a population of candidate solutions. However it does not rely on evolutionary principles or swarm intelligence, but rather on herd-like behaviour with centralized decisions. The proposed algorithm KHA has 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

$$f(x, u) \tag{1}$$

Subject to

$$g(x,u)=0 \tag{2}$$

and

$$h(x, u) \le 0 \tag{3}$$

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:

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

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

$$u = \left(V_g, T, Q_c\right)^T \tag{5}$$

or

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

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:

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

or

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

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:

$$F = PL + \omega_v \times VD \tag{9}$$

Where ω_v: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \tag{10}$$

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:

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

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:

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

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. Kudu Herd Algorithm

The behaviour of the kudu is jumping around their habitat in search of the location containing the best food. And a kudu finding itself in any point in space can give it a real-valued mark, indicating food quality shown in Fig .1.

Fig. 1. *Kudu Herd*

Fig. 2. *Kudu Herd Movement*

The kudu leader jumps to a given location, and all the other kudus jump to arbitrary positions around the leader shown in Fig 2. The kudus then report their fresh positions and the related quality to the leader. Based on this information, the leader decides the way of its next jump. The leader's jump distance raise smaller if two successive jumps are in conflicting directions, or else it raise larger. Several jumps are executed in this fashion, and the dimension of the disperse region around the leader can be reduced over time to develop information from narrower regions. The herd remembers the single best location it has been found so far. Properly, we try to find the point that reduces a real valued cost function over a given bounded D-dimensional real valued explore space:

$$\arg min_x \, cost(x), x \in S \quad (17)$$

Where $S = [lb_1, ub_1] \times .. \times [lb_D, ub_D]$

For this reason we use a population of P kudus (D-dimensional vectors representing candidate solutions), of which one is the head or leader.

Let we define ,

$\overrightarrow{leader}$ be an D-dimensional vector containing the leader's position,

A be a P×D matrix whose first row is $\overrightarrow{leader}$ and whose remaining rows contain the other kudus' positions,

$\overrightarrow{rank}$ be a P-dimensional vector containing the cost-ranking of each of the kudus,

$\overrightarrow{jump}$ be an D-dimensional vector giving the direction of the leader's jump,

j length be a scalar value representing the leader's jump's length,

scatter be a scalar value controlling how close to the leader the kudus will be scattered,

η^+ and η^- be scalar values used to automatically lengthen or shorten the jumps,

m length be a scalar value representing the minimal allowed jump length.

KHA for solving optimal reactive power dispatch problem

a) Initialization

i) Initialize the leader to a random point in the search space.

ii) Initialize the (P -1) other kudus to random points in a region around the leader, with parameter scatter controlling the size of this region.

iii) Evaluate the cost function at each of the P points.

iv) Rank the costs and store the result in $\overrightarrow{rank}$

v) Store the lowest cost and the associated position.

vi) Compute the jump direction according to the following formula:

$$\forall i \in [1, D], \overrightarrow{jump}_i = cov\left(\overrightarrow{rank}, A_{.i}\right) \quad (18)$$

$\overrightarrow{jump}$i denotes the i-th element of the jump vector and A.i denotes the i-th column of matrix A.

vii) Initialize jump-length variable j length to the maximal distance between the leader and the other kudus.

b) Loop (until stopping criterion is met)

i) Update the leader's position according to the following formula:

$$\overrightarrow{leader^{t+1}} = \overrightarrow{leader^t} - \frac{jlength^t}{\left\|\overrightarrow{jump^t}\right\|} \overrightarrow{jump^t} \quad (19)$$

ii) Update the other kudus' positions by randomly placing them in a region around the leader, the size of which is controlled by parameter scatter.

iii) Evaluate the cost function at each of the P points.

iv) Rank the costs and store the result in $\overrightarrow{rank}$.

v) Store the lowest cost and the associated position if it is lower than the stored best.

vi) Compute the jump direction according to formula (18).

vii) Update the jump-length variable: if the new jump is made a direction opposite to that of the last jump (if $\overrightarrow{jump^{t+1}}, \overrightarrow{jump^t} < 0$) then multiply j length by η^-, else multiply it by η^+ . If this makes j length smaller than m length, set it to m length.

vii) Update the scatter parameter.

The algorithm fundamentally takes three parameters: the population size P, the scatter-range scatter, and the minimal jump-length m length. P is the number of cost-function evaluations in each iteration and the concentration of exploitation of each visited area. The scatter range controls "how local" the search is at each iteration: a lower scatter value will let the random evaluations occur in a narrower region around the leader. The minimum jump-length is used to avoid convergence to local optima. Parameters η^{+} and η^{-} are directly inspired by those of Riedmiller and Braun's RPROP algorithm [23] for the training of feed forward neural networks. The idea, interpret the original article, is that two successive jumps in conflicting directions designate that the last jump was too long and the algorithm has jumped over a local minimum; jump-length is then decreased by factor η^{-}. Otherwise, jump-length is slightly increased by factor η^{+} in order to increase speed of convergence in shallow regions. Although our setting is quite different, we used the original values of both parameters, η^{+} = 0.49 and η^{-} = 1.1. We chose to use the rank of costs instead of costs to compute the jump direction. This makes the algorithm invariant to any increasing transformation of the cost function. Kudus were uniformly distributed inside a hyper parallel piped centred on the leader, according to the following formula:

$$\forall(i,j) \in [2,P] \times [1,D], a_{ij} = \overrightarrow{leader_j} + (r_{ij-}0.5) \times scatter \times (ub_j - ib_j) \quad (20)$$

Where a_{ij} denotes element (i, j) of matrix A, $\overrightarrow{leaderj}$ is the leader-vector's j-th element, scatter is a scalar value chosen in [0,1], ub_j and lb_j are respectively the upper and lower bounds of dimension j, and r_{ij} is a random value uniformly drawn from [0,1]. A better choice might be to generate normal deviates from $\overrightarrow{leader}$.

5. Simulation Results

The proposed KHA algorithm for solving ORPD problem is tested for standard IEEE-57 bus power system. The IEEE 57-bus system 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:

$$P_{load} = 12.412 \text{ p.u. } Q_{load} = 3.345 \text{ p.u.}$$

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

$$\sum P_G = 12.7894 \text{ p.u. } \sum Q_G = 3.4678 \text{ p.u.}$$

$$P_{loss} = 0.28381 \text{ p.u. } Q_{loss} = -1.2399 \text{ p.u.}$$

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

Table 1. *Variables limits*

reactive power generation limits							
bus no	1	2	3	6	8	9	12
Q_{gmin}	-1.4	-.017	-.01	-0.08	-1.4	-0.03	-0.3
q_{gmax}	2	0.5	0.6	0.25	2	0.09	1.55
voltage and tap setting limits							
v_{gmin}	v_{gmax}	v_{pqmin}	v_{pqmax}	t_{kmin}	t_{kmax}		
0.9	1.1	0.94	1.08	0.9	1.1		
shunt capacitor limits							
bus no	18	25	53				
q_{cmin}	0	0	0				
q_{cmax}	10	5.9	6.3				

Table 2. *Control variables obtained after optimization by KHA method*

Control Variables	**KHA**
V1	1.2
V2	1.087
V3	1.070
V6	1.055
V8	1.077
V9	1.051
V12	1.061
Qc18	0.0843
Qc25	0.335
Qc53	0.0628
T4-18	1.018
T21-20	1.072
T24-25	0.975
T24-26	0.948
T7-29	1.092
T34-32	0.959
T11-41	1.017
T15-45	1.076
T14-46	0.945
T10-51	1.054
T13-49	1.077
T11-43	0.921
T40-56	0.912
T39-57	0.975
T9-55	0.984

Table 3. *Comparison of real power loss*

S. No.	Optimization Algorithm	Best Solution	Worst Solution	Average Solution
1	NLP [24]	0.25902	0.30854	0.27858
2	CGA [24]	0.25244	0.27507	0.26293
3	AGA [24]	0.24564	0.26671	0.25127
4	PSO-w [24]	0.24270	0.26152	0.24725
5	PSO-cf [24]	0.24280	0.26032	0.24698
6	CLPSO [24]	0.24515	0.24780	0.24673
7	SPSO-07 [24]	0.24430	0.25457	0.24752
8	L-DE [24]	0.27812	0.41909	0.33177
9	L-SACP-DE [24]	0.27915	0.36978	0.31032
10	L-SaDE [24]	0.24267	0.24391	0.24311
11	SOA [24]	0.24265	0.24280	0.24270
12	LM [25]	0.2484	0.2922	0.2641
13	MBEP1 [25]	0.2474	0.2848	0.2643
14	MBEP2 [25]	0.2482	0.283	0.2592
15	BES100 [25]	0.2438	0.263	0.2541
16	BES200 [25]	0.3417	0.2486	0.2443
17	Proposed KHA	0.22445	0.23898	0.23135

6. Conclusion

Kudu Herd Algorithm has been successfully applied for solving Optimal Reactive Power Dispatch problem. The KHA based Optimal Reactive Power Dispatch is successfully tested in standard IEEE-57 bus system. Performance comparisons with well-known population-based algorithms give boosting results. KHA succeeded in reducing real power loss, when compare to other specified algorithms. The simulation results presented in previous section prove the capability of KHA approach to arrive at near global optimal solution.

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Biography

K. Lenin has received his B.E., Degree, electrical and electronics engineering in 1999 from university of madras, Chennai, India and M.E., Degree in power systems in 2000 from Annamalai University, TamilNadu, India. At present pursuing Ph.D., degree at JNTU, Hyderabad, India.

Bhumanapally. RavindhranathReddy, Born on 3rd September,1969. Got his B.Tech in Electrical & Electronics Engineering from the J.N.T.U. College of Engg., Anantapur in the year 1991. Completed his M.Tech in Energy Systems in IPGSR of J.N.T.University Hyderabad in the year 1997. Obtained his doctoral degree from JNTUA,Anantapur University in the field of Electrical Power Systems. Published 12 Research Papers and presently guiding 6 Ph.D. Scholars. He was specialized in Power Systems, High Voltage Engineering and Control Systems. His research interests include Simulation studies on Transients of different power system equipment.

M. Surya Kalavathi has received her B.Tech. Electrical and Electronics Engineering from SVU, Andhra Pradesh, India and M.Tech, power system operation and control from SVU, Andhra Pradesh, India. she received her Phd. Degree from JNTU, hyderabad and Post doc. From CMU – USA. Currently she is Professor and Head of the electrical and electronics engineering department in JNTU, Hyderabad, India and she has Published 16 Research Papers and presently guiding 5 Ph.D. Scholars. She has specialised in Power Systems, High Voltage Engineering and Control Systems. Her research interests include Simulation studies on Transients of different power system equipment. She has 18 years of experience. She has invited for various lectures in institutes.