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Dolphin Echolocation Algorithm for Solving Optimal Reactive Power Dispatch Problem

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Abstract

This paper proposes Dolphin echolocation Algorithm (DEA) for solving the multi-objective reactive power dispatch problem. Echolocation is the genetic sonar used by dolphins and more than a few kinds of other animals for direction-finding and hunting in different environments. This aptitude of dolphins is mimicked in this paper to develop a new process for solving optimal reactive power dispatch problem. A detailed study has shown that meta-heuristic algorithms have certain overriding rules. These rules will facilitate to get enhanced results. Dolphin echolocation algorithm takes reward of these rules and outperforms many active optimization methods. The new approach DEA leads to outstanding results with little computational efforts. In order to evaluate the efficiency of the proposed algorithm, it has been tested on IEEE 30 bus system and compared to other specified algorithms. Simulation results show that DEA is superior to other algorithms in tumbling the real power loss and enhancing the voltage stability.

Keywords: Dolphin echolocation Algorithm, optimization, metaheuristics, optimal reactive power, Transmission loss.

1. Introduction

Power system trustworthiness is associated with security, and it refers to continuity of service, constancy in frequency and specified voltage limits. Key duty is to uphold the voltage profiles within the limits while boosting and deduction of reactive power. The perfect regulation of reactive power resources is one of the core ways for the secure operation of transmission system. The meagre regulation of reactive power sources precincts the active power transmission, which can be basis for riotous lows of voltage and tension fall down in the load buses. Optimal reactive power dispatch is one among the key issue for the operation and control of power systems, and it should be carried out properly such that system reliability should not get affected.The gradient method [1, 2], Newton method [3] and linear programming [4-7] experience from the intricacy of handling the inequality constraints. In recent times universal Optimization techniques such as genetic algorithms have been proposed to solve the reactive power flow problem [8,9]. In recent years, the difficulty of voltage constancy and voltage fall down has become most important concern in power system development and function. This paper put together the reactive power dispatch problem as multi-objective optimization problem with real power loss minimization and maximization of static voltage stability margin (SVSM) as the objectives. Voltage stability assessment using modal analysis [10] is used as the pointer of voltage stability. The meta-heuristic algorithms have remarkable features that differs them from the gradient based methods. In the field of structural optimization, genetic algorithms (GA) [11-12], particle swarm optimization (PSO) [13-14] and Ant colony optimization (ACO) [15-16] are the trendiest algorithms used to solve a variety of optimization problems. Dolphin echolocation [17] is a new optimization technique which is presented in this paper for solving reactive power dispatch problem. This method mimics strategy used by dolphins for their hunting procedure. Dolphins create a type of voice called sonar to trace the target. By doing this dolphin alter sonar to alter the target and its position. In this paper Dolphin echolocation Algorithm (DEA) is used to solve the optimal reactive power problem. The performance of DEA has been evaluated in standard IEEE 30 bus test system and the simulation outcome shows that our proposed method outperforms all approaches investigated in this paper.

2. Voltage Stability Evaluation

2.1. Modal analysis for voltage stability evaluation

Modal analysis is one among best method for voltage stability development in power systems. The linearized steady state system power flow equations are given by,

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_{p\theta} & J_{pv}\\ J_{q\theta} & J_{QV}\end{bmatrix} \quad (1)$$

Where

ΔP = Incremental change in bus real power.

ΔQ = Incremental change in bus reactive

Power injection

$\Delta\theta$ = incremental change in bus voltage angle.

ΔV = Incremental change in bus voltage Magnitude

$J_{p\theta}$, J_{PV} , $J_{Q\theta}$, J_{QV} jacobian matrix are the sub-matrixes of the System voltage stability is affected by both P and Q. However at each operational point we keep P constant and evaluate voltage stability by considering incremental relationship between Q and V.

To reduce (1), let $\Delta P = 0$, then.

$$\Delta Q = \left[J_{QV} - J_{Q\theta} J_{P\theta^{-1}} J_{PV}\right] \Delta V = J_R \Delta V \quad (2)$$

$$\Delta V = J^{-1} - \Delta Q \quad (3)$$

Where

$$J_R = \left(J_{QV} - J_{Q\theta} J_{P\theta^{-1}} JPV\right) \quad (4)$$

J_R is called the reduced Jacobian matrix of the system.

2.2 Modes of Voltage instability:

Voltage Stability characteristics of the system can be known by compute the Eigen values and Eigen vectors

Let

$$J_R = \xi \wedge \quad (5)$$

Where,

ξ = right eigenvector matrix of J_R

η = left eigenvector matrix of J_R

$\wedge$ = diagonal Eigen value matrix of J_R and

$$J_{R^{-1}} = \xi \wedge^{1} \eta \quad (6)$$

From (3) and (6), we have

$$\Delta V = \xi \wedge^{1} \eta \Delta Q \quad (7)$$

or

$$\Delta V = \sum_{I} \frac{\xi_i \eta_i}{\lambda_i} \Delta Q \quad (8)$$

Where ξ_i is the ith column right Eigen vector and η the ith row left eigenvector of J_R.

λ_i is the ith eigen value of J_R.

The ith modal reactive power variation is,

$$\Delta Q_{mi} = K_i \xi_i \quad (9)$$

where,

$$K_i = \sum_j \xi_{ij^2} - 1 \quad (10)$$

Where

ξ_{ji} is the jth element of ξ_i

The corresponding ith modal voltage variation is

$$\Delta V_{mi} = [1/\lambda_i] \Delta Q_{mi} \quad (11)$$

In (8), let $\Delta Q = e_k$ where e_k has all its elements zero except the kth one being 1. Then,

$$\Delta V = \sum_i \frac{\eta_{1k} \; \xi_1}{\lambda_1} \quad (12)$$

η_{1k} k th element of η_1

V –Q sensitivity at bus k

$$\frac{\partial V_K}{\partial Q_K} = \sum_i \frac{\eta_{1k} \; \xi_1}{\lambda_1} = \sum_i \frac{P_{ki}}{\lambda_1} \quad (13)$$

3. Problem Formulation

The objective of the reactive power dispatch problem is to curtail the real power loss and maximize the static voltage stability margins (SVSM) index.

3.1. Minimization of Real Power Loss

Minimization of real power loss (Ploss) in transmission lines is mathematically stated as follows.

$$P_{loss} = \sum_{\substack{k=1 \\ k=(i,j)}}^{n} g_{k}(V_i^2+V_j^2-2V_i V_j \cos\theta_{ij}) \qquad (14)$$

Where n is the number of transmission lines, g_k is the conductance of branch k, V_i and V_j are voltage magnitude at bus i and bus j, and θ_{ij} is the voltage angle difference between bus i and bus j.

3.2 Minimization of Voltage Deviation

Minimization of Deviations in voltage magnitudes (VD) at load buses is mathematically stated as follows.

$$\text{Minimize } VD = \sum_{k=1}^{nl} |V_k - 1.0| \qquad (15)$$

Where nl is the number of load busses and V_k is the voltage magnitude at bus k.

3.3 System Constraints

Objective functions are subjected to the following constraints ,

Load flow equality constraints:

$$P_{Gi} - P_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \dots., nb \qquad (16)$$

$$Q_{Gi} - Q_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \dots., nb$$

(17)

where, *nb* is the number of buses, P_G and Q_G are the real and reactive power of the generator, P_D and Q_D are the real and reactive load of the generator, and G_{ij} and B_{ij} are the mutual conductance and susceptance between bus *i* and bus *j*.

Generator bus voltage (V_{Gi}) inequality constraint:

$$V_{Gi}^{min} \le V_{Gi} \le V_{Gi}^{max}, i \in ng \qquad (18)$$

Load bus voltage (V_{Li}) inequality constraint:

$$V_{Li}^{min} \le V_{Li} \le V_{Li}^{max}, i \in nl \quad (19)$$

Switchable reactive power compensations (Q_{Ci}) inequality constraint:

$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max}, i \in nc$ (20)

Reactive power generation (Q_{Gi}) inequality constraint:

$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i \in ng$ (21)

Transformers tap setting (T_i) inequality constraint:

$T_i^{min} \leq T_i \leq T_i^{max}, i \in nt$ (22)

Transmission line flow (S_{Li}) inequality constraint:

$S_{Li}^{min} \leq S_{Li}^{max}, i \in nl$ (23)

Where, nc, ng and nt are numbers of the switchable reactive power sources, generators and transformers.

4. Dolphin echolocation in natural world

The word ‘‘echolocation’’ was initiated by Griffin [18] to explain the capability of flying bats to locate obstacles and preys by listening to echoes recurring from high-frequency clicks that they emitted. The finest studied echolocation in nautical mammals is the bottlenose dolphins [19]. A dolphin is gifted to generate sounds in the form of clicks. Rate of recurrence of these clicks is superior to that of the sounds used for communication and it differs between species. As soon as the sound strikes an object, some of the power of the sound-wave is reflected back towards the dolphin. Instantaneously an echo is received; the dolphin generates one more click. The time fall between click and echo enables the dolphin to appraise the distance from the object. The altering power of the signal as it is received on the two sides of the dolphin’s head enable to evaluate the way. By incessantly emitting clicks and receiving echoes in this technique, the dolphin can follow objects and home in on them [20, 21]. The clicks are directional. For echolocation, frequently happening in a short sequence called a click rate. The click rate increases when close to an object concentration [19]. Although bats also utilize echolocation, however, they differ from dolphins in their sonar scheme. Bats use their sonar scheme at little ranges around 3–4 m, where as dolphins can sense their targets at ranges varying more than a hundred meters. A lot of bats hunt for insects that dash rapidly to and fro and making it very dissimilar from the runaway behaviour of a fish chased by dolphin. The pace of sound in air is about one fifth of that of water, thus the information transmit rate for the period of sonar transmission of bats is much shorter than that of the dolphins.

5. Dolphin echolocation process

Dolphins primarily investigate all around the search space to discover the prey. The moment a dolphin approaches the target, the animal confine its search, and incrementally increases its clicks in order to concentrate on the location. The method simulates dolphin echolocation by restraining its exploration relative to the distance from the target. Prior to starting, search space should be sorted out by using the following regulation:

Search space order: For every variable to be optimized during the procedure, sort alternatives of the search space in an uphill or downhill order. If alternatives take account of more than one characteristic, then carry out ordering according to the most significant one. Using this technique, for variable j, vector A_j of length LA_j is shaped which contains all probable alternatives for the jth variable putting these vectors subsequently to each other, as the columns of a matrix, the Matrix $\text{Alternatives}_{MA+NV}$ is produced, in which MA is $\max(LA_j)_{j=1:NV}$, with NV being the number of variables. Furthermore, a curve according to which the convergence factor must change during the optimization procedure should be assigned. Here, the change of convergence (CF) is considered as

$$PP(LOOP_i) = PP_i + (1 - PP_1)\frac{LOOP_i^{power} - 1}{(LOOPSNumber)^{power} - 1} \quad (24)$$

PP is the predefined probability, PP_1 the convergence factor of the first loop in which the answers are selected randomly, $Loop_i$ the number of the current loop.

The detailed procedure of dolphin echolocation algorithm (DEA) as follows,

i. Start NL locations for a dolphin arbitrarily. This step enclose creating L_{NL+NV} matrix, in which NL is the number of locations and NV is the number of variables.
ii. Compute the PP of the loop using Eq. (24).
iii. Calculate the fitness of each location.
iv. Calculate the accumulative fitness according to dolphin rules as follows.

- for i = 1 to the number of locations
- for j = 1 to the number of variables
- find the position of L(i,j) in jth column of the Alternatives matrix and name it as A. for k = $-R_e$ to R_e

$$AF_{(A+K)j} = \frac{1}{R_e} * (R_e - |k|)Fitness\ i + AF_{(A+K)j} \quad (25)$$

Where $AF_{(A+k)j}$ is the accumulative fitness of the (A + k)th alternative to be chosen for the jth variable, R_e is the effective radius in which accumulative fitness of the alternative A's neighbours are affected from its fitness. Fitness (i) is the fitness of location i. It should be added that for alternatives close to edges (where A + k is not a valid; A + k < 0 or A + k > LA_j), the AF is calculated using a reflective characteristic.

In order to hand out the option much evenly in the search space, a small value of ε is added to all the arrays as AF = AF + ε. Here, e should be selected according to the method the fitness is defined. It is superior to be less than the minimum value achieved for the fitness.

Find the top location of this loop and name it “The best

Location”. Find the alternatives allocated to the variables of the top location, and let their AF be equal to zero. And it can be defined as follows

- for j = 1: Number of variables
- for i = 1: Number of alternatives
- if i = The best location(j)

$$AF_{ij} = 0 \quad (26)$$

v. For variable $j_{(j=1 to NV)}$, compute the probability of choosing alternative $i_{(i=1 to AL j)}$, according to the following relationship:

$$P_{ij} = \frac{AF_{ij}}{\sum_{i=1}^{LAj} AF_{ij}} \quad (27)$$

vi. Allocate a probability equal to PP to all alternatives chosen for all variables of the best location and dedicate rest of the probability to the other alternatives according to the following formula:

- for j = 1: Number of variables
- for i = 1: Number of alternatives
- if i = The best location(j)

$$P_{ij} = PP \quad (28)$$

Else

$$P_{ij} = (1 - PP)P_{ij} \quad (29)$$

vii. Compute the subsequently step locations according to the probabilities assigned to each alternative. Replicate Steps ii–vi as many times as the Loops Number.

6. DEA algorithm for solving optimal reactive power dispatch.

- Step1. Instigate the description of the problem and choose the positions of dolphin randomly.
- Step2. Compute the fitness for every location.
- Step3. Compute the accumulative fitness by devoting the intended fitness to the alternatives chosen for every dimension and its neighbours according to the dolphin regulations and find the best location.
- Step4. Assign the possibility of the most excellent location equal to the predefined possibility value in the current loop and share out rest of the probability between other alternatives according to the premeditated accumulative fitness's.
- Step5. Choose next loop locations according to the designed probability.
- Step6. Is terminating criterion reached- if yes stop or go to step 2.

7. Simulation Results

The soundness of the proposed DEA Algorithm method is demonstrated on IEEE-30 bus system. The IEEE-30 bus system has 6 generator buses, 24 load buses and 41 transmission lines of which four branches are (6-9), (6-10) , (4-12) and (28-27) - are with the tap setting transformers. The lower voltage magnitude limits at all buses are 0.95 p.u. and the upper limits are 1.1 for all the PV buses and 1.05 p.u. for all the PQ buses and the reference bus. The simulation results have been presented in Tables 1, 2, 3 &4. And in the Table 5 shows clearly that proposed algorithm powerfully reduce the real power losses when compared to other given algorithms. The optimal values of the control variables along with the minimum loss obtained are given in Table 1. Equivalent to this control variable setting, it was found that there are no limit violations in any of the state variables.

Table1.Results of DEA – ORPD optimal control variables

Control variables	*Variable setting*
V1	1.043
V2	1.042
V5	1.041
V8	1.033
V11	1.013
V13	1.041
T11	1.08
T12	1.03
T15	1.0
T36	1.0
Qc10	2
Q12	3
Qc1	3
Qc17	0
Qc20	4
Qc23	3
Qc24	2
Qc29	2
Real power loss	4.3945
SVSM	0.2485

ORPD including voltage stability constraint problem was handled in this case as a multi-objective optimization problem where both power loss and maximum voltage stability margin of the system were optimized concurrently. Table 2 indicates the optimal values of these control variables. Also it is found that there are no limit violations of the state variables. It indicates the voltage stability index has increased from 0.2485 to 0.2496, an advance in the system voltage stability. To determine the voltage security of the system, contingency analysis was conducted using the control variable setting obtained in case 1 and case 2. The Eigen values equivalents to the four critical contingencies are given in Table 3. From this result it is observed that the Eigen value has been improved considerably for all contingencies in the second case.

Table 2.Results of DEA -Voltage Stability Control Reactive Power Dispatch Optimal Control Variables

Control Variables	*Variable Setting*
V1	*1.044*
V2	*1.042*
V5	*1.040*
V8	*1.032*
V11	*1.009*
V13	*1.033*
T11	*0.090*
T12	*0.090*
T15	*0.090*
T36	*0.091*
Qc10	*3*
Qc12	*2*
Qc15	*1*
Qc17	*3*
Qc20	*0*
Qc23	*3*
Qc24	*3*
Qc29	*3*
Real power loss	*4.9891*
SVSM	*0.2496*

Table 3. Voltage Stability under Contingency State

Sl.No	*Contingency*	*ORPD Setting*	*VSCRPD Setting*
1	*28-27*	*0.1410*	*0.1440*
2	*4-12*	*0.1658*	*0.1671*
3	*1-3*	*0.1774*	*0.1783*
4	*2-4*	*0.2032*	*0.2051*

Table 4. Limit Violation Checking Of State Variables

State variables	*limits*		*ORPD*	*VSCRPD*
	Lower	*upper*		
Q1	*-20*	*152*	*1.3422*	*-1.3269*
Q2	*-20*	*61*	*8.9900*	*9.8232*
Q5	*-15*	*49.92*	*25.920*	*26.001*
Q8	*-10*	*63.52*	*38.8200*	*40.802*
Q11	*-15*	*42*	*2.9300*	*5.002*

Q13	*-15*	*48*	*8.1025*	*6.033*
V3	*0.95*	*1.05*	*1.0372*	*1.0392*
V4	*0.95*	*1.05*	*1.0307*	*1.0328*
V6	*0.95*	*1.05*	*1.0282*	*1.0298*
V7	*0.95*	*1.05*	*1.0101*	*1.0152*
V9	*0.95*	*1.05*	*1.0462*	*1.0412*
V10	*0.95*	*1.05*	*1.0482*	*1.0498*
V12	*0.95*	*1.05*	*1.0400*	*1.0466*
V14	*0.95*	*1.05*	*1.0474*	*1.0443*
V15	*0.95*	*1.05*	*1.0457*	*1.0413*
V16	*0.95*	*1.05*	*1.0426*	*1.0405*
V17	*0.95*	*1.05*	*1.0382*	*1.0396*
V18	*0.95*	*1.05*	*1.0392*	*1.0400*
V19	*0.95*	*1.05*	*1.0381*	*1.0394*
V20	*0.95*	*1.05*	*1.0112*	*1.0194*
V21	*0.95*	*1.05*	*1.0435*	*1.0243*
V22	*0.95*	*1.05*	*1.0448*	*1.0396*
V23	*0.95*	*1.05*	*1.0472*	*1.0372*
V24	*0.95*	*1.05*	*1.0484*	*1.0372*
V25	*0.95*	*1.05*	*1.0142*	*1.0192*
V26	*0.95*	*1.05*	*1.0494*	*1.0422*
V27	*0.95*	*1.05*	*1.0472*	*1.0452*
V28	*0.95*	*1.05*	*1.0243*	*1.0283*
V29	*0.95*	*1.05*	*1.0439*	*1.0419*
V30	*0.95*	*1.05*	*1.0418*	*1.0397*

Table 5. Comparison of Real Power Loss

Method	*Minimum loss*
Evolutionary programming[22]	*5.0159*
Genetic algorithm[23]	*4.665*
Real coded GA with Lindex as SVSM[24]	*4.568*
Real coded genetic algorithm[25]	*4.5015*
Proposed DEA method	*4.3945*

7. Conclusion

In this DEA algorithm is used to solve optimal reactive power dispatch problem by taking into consideration of various generator constraints. The projected method formulate reactive power dispatch problem as a mixed integer non-linear optimization problem and establish control strategy, with continuous and discrete control variables such as generator bus voltage, reactive power generation of capacitor banks and on load tap changing transformer tap position. The performance of the planned algorithm has been established well through its voltage stability evaluation by modal analysis and is effectual at various instants following system contingencies. The effectiveness of the proposed method has been demonstrated on IEEE 30-bus system. Simulation results shows that Real power loss has been considerably reduced and voltage profile index within the particular limits.

8. Nomenclature:

NB number of buses in the system

N_g number of generating units in the system

t_k tap setting of transformer branch k

P_{sl} real power generation at slack bus

V_i voltage magnitude at bus i

P_i,Q_i real and reactive powers injected at bus i

P_{gi},Q_{gi} real and reactive power generations at bus i

G_{ij},B_{ij} mutual conductance and susceptance between bus i and j

G_{ii},B_{ii} self conductance and susceptance of bus i

θ_{ij} voltage angle difference between bus i and j

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