

## Passerine swarm optimization algorithm for solving optimal reactive power dispatch problem

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### ABSTRACT

This paper presents Passerine Swarm Optimization Algorithm (PSOA) for solving optimal reactive power dispatch problem. This algorithm is based on behaviour of social communications of Passerine bird. Basically, Passerine bird has three common behaviours: search behaviour, adherence behaviour and expedition behaviour. Through the shared communications Passerine bird will search for the food and also run away from hunters. By using the Passerine bird communications and behaviour, five basic rules have been created in the PSO approach to solve the optimal reactive power dispatch problem. Key aspect is to reduce the real power loss and also to keep the variables within the limits. Proposed Passerine Swarm Optimization Algorithm (PSOA) has been tested in standard IEEE 30 bus test system and simulations results reveal about the better performance of the proposed algorithm in reducing the real power loss and enhancing the static voltage stability margin.

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## 1. INTRODUCTION

Optimal reactive power dispatch problem is subject to number of uncertainties and at least in the best case to uncertainty parameters given in the demand and about the availability equivalent amount of shunt reactive power compensators. Optimal reactive power dispatch plays a major role for the operation of power systems, and it should be carried out in a proper manner, such that system reliability is not got affected. The main objective of the optimal reactive power dispatch is to maintain the level of voltage and reactive power flow within the specified limits under various operating conditions and network configurations. By utilizing a number of control tools such as switching of shunt reactive power sources, changing generator voltages or by adjusting transformer tap-settings the reactive power dispatch can be done. By doing optimal adjustment of these controls in different levels, the redistribution of the reactive power would minimize transmission losses. This procedure forms an optimal reactive power dispatch problem and it has a major influence on secure and economic operation of power systems. Various mathematical techniques like the gradient method Alsac et al . Lee et al and linear programming mangoli et al [1-7] have been adopted to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods has the difficulty in handling inequality constraints. If linear programming is applied then the input- output function has to be expressed as a set of linear functions which mostly lead to loss of accuracy. This paper formulates by combining both the real power loss minimization and maximization of static voltage stability margin (SVSM) as the objectives. Global optimization has received extensive research attention, and a great number

of methods have been applied to solve this problem. Many Evolutionary algorithms Aparajita Mukherjee et al., Hu et al., Mahaletchumi et al., Sulaiman et al., Pandiarajan et al., have been already proposed to solve the reactive power flow problem. This paper presents Passerine Swarm Optimization Algorithm (PSOA) for solving optimal reactive power dispatch problem. This algorithm is based on behaviour of social communications of Passerine bird Anderson et al., Barnard et al., Beauchamp et al., Bednekoff et al., Coolen et al. [8-13]. Basically Passerine bird has three common behaviours: search behaviour, adherence behaviour and expedition behaviour. Through the shared communications Passerine bird will search for the food and also run away from hunters [14-20]. By using the Passerine bird communications and behaviour, five basic rules have been created in the PSO approach to solve the optimal reactive power dispatch problem. Key aspect is to reduce the real power loss and also to keep the variables within the limits. Proposed Passerine Swarm Optimization Algorithm (PSOA) has been tested in standard IEEE 30 bus test system and simulations results reveal about the better performance of the proposed algorithm in reducing the real power loss and enhancing the static voltage stability margin.

## 2. VOLTAGE STABILITY EVALUATION

odal analysis for voltage stability evaluation; Modal analysis is one among best methods for voltage stability enhancement in power systems. The steady state system power flow are given by (1).

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

Where

$\Delta P$  = Incremental change in bus real power.

$\Delta Q$  = Incremental change in bus reactive Power injection

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

$\Delta V$  = 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.

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

$$\Delta Q = [J_{qv} - J_{q\theta}J_{p\theta}^{-1}J_{pv}]\Delta V = J_R\Delta V \quad (2)$$

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

Where

$$J_R = (J_{qv} - J_{q\theta}J_{p\theta}^{-1}J_{pv}) \quad (4)$$

$J_R$  is called the reduced Jacobian matrix of the system.

Modes of Voltage instability:

Voltage Stability characteristics of the system have been identified by computing the Eigen values and Eigen vectors.

Let

$$J_R = \xi \Lambda \eta \quad (5)$$

Where,

$\xi$  = right eigenvector matrix of  $J_R$

$\eta$  = left eigenvector matrix of  $J_R$

$\Lambda$  = diagonal eigenvalue matrix of  $J_R$  and

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

From (5) and (8), we have

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

Or

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

Where  $\xi_i$  is the  $i$ th column right eigenvector and  $\eta$  the  $i$ th row left eigenvector of JR.  $\lambda_i$  is the  $i$ th Eigen value of JR. The  $i$ th 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

$\xi_{ji}$  is the  $j$ th element of  $\xi_i$

The corresponding  $i$ th modal voltage variation is

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

If  $|\lambda_i| = 0$  then the  $i$ th modal voltage will collapse .

In (10), let  $\Delta Q = ek$  where  $ek$  has all its elements zero except the  $k$ th one being 1. Then,

$$\Delta V = \sum_i \frac{\eta_{1k} \xi_i}{\lambda_i} \quad (12)$$

$\eta_{1k}$   $k$  th element of  $\eta_1$

V -Q sensitivity at bus  $k$

$$\frac{\partial V_k}{\partial Q_k} = \sum_i \frac{\eta_{1k} \xi_i}{\lambda_i} = \sum_i \frac{P_{ki}}{\lambda_i} \quad (13)$$

### 3. PROBLEM FORMULATION

The objectives of the reactive power dispatch problem is to minimize the system real power loss and maximize the static voltage stability margins (SVSM).

#### 3.1. Minimization of real power loss

Minimization of the real power loss (Ploss) in transmission lines is mathematically stated as (14).

$$P_{\text{loss}} = \sum_{k=1}^n g_k (V_i^2 + V_j^2 - 2V_i V_j \cos \theta_{ij}) \quad (14)$$

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  $\theta_{ij}$  is the voltage angle difference between bus  $i$  and bus  $j$ .

Minimization of Voltage Deviation. Minimization of the voltage deviation magnitudes (VD) at load buses is mathematically stated as (15).

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

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

#### 3.2. System constraints

The following is an objective function that experiences constraints.

a. Load flow equality constraints:

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

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{nb} V_j \begin{bmatrix} G_{ij} & \sin \theta_{ij} \\ +B_{ij} & \cos \theta_{ij} \end{bmatrix} = 0, i = 1, 2, \dots, nb \quad (17)$$

where, nb is the number of buses, PG and QG are the real and reactive power of the generator, PD and QD are the real and reactive load of the generator, and Gij and Bij are the mutual conductance and susceptance between bus i and bus j.

b. Generator bus voltage (VGi) inequality constraint:

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

c. Load bus voltage (VLi) inequality constraint:

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

d. Switchable reactive power compensations (QCi) inequality constraint:

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

e. Reactive power generation (QGi) inequality constraint:

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

f. Transformers tap setting (Ti) inequality constraint:

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

g. Transmission line flow (SLi) inequality constraint:

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

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

#### 4. PASSERINE BIRD SWARM HYPOTHESIS

The Passerine bird Figure 1 social behavior's can be written as follows:

- a) Rule 1. Every Passerine bird has choice to alter between the adherence behaviour and search behaviour. Whether the Passerine bird searches or in observance, it is molded as a stochastic decision.
- b) Rule 2. While search, each Passerine bird can promptly record and renovate its previous most outstanding experience and the swarms' previous most outstanding experience about food area. This information has been used to discover food. Social information is shared rapidly among the whole swarm.
- c) Rule 3. During adherence, every Passerine will attempt to move near to the centre of the swarm. This behaviour can be embroidered by the interference tempted by the rivalry among swarm. The Passerine with the uppermost reserves would be more prone to lie nearer to the centre of the swarm.
- d) Rule 4. While flying Passerine may often change between generating and sponging. The Passerine with the uppermost reserves would be a creator, while the one with the bottom most reserves would be a sponger. Passerine have reserves between the uppermost and bottom most reserves would randomly choose to be creator and sponger.
- e) Rule 5. Creators with desire search for food. Spongers would randomly follow a creator to search for food.

By the above Rules the mathematical model for the problem has been developed,

All N virtual Passerine bird, portrayed by their position  $Z_t^i$  ( $i \in [1, \dots, N]$ ) at time step t, search for food and fly in an organized space.



Figure 1. Passerine bird

#### 4.1. Search behaviour

Every Passerine will search for food according to its experience. Rule 2 can be written in (24) as follows,

$$Z_{i,j}^{t+1} = Z_{i,j}^t + (k_{i,j} - Z_{i,j}^t) \times M \times \text{rand}(0,1) + (l_j - Z_{i,j}^t) \times N \times \text{rand}(0,1) \quad (24)$$

Where  $j \in [1, \dots, C]$ ,  $\text{rand}(0, 1)$  denotes independent uniformly distributed numbers in  $(0, 1)$ .

$M$  and  $N$  are two positive numbers, which can be respectively called as cognitive and social accelerated coefficients.  $k_{i,j}$  is the best preceding position of the  $i$ th passerine and  $l_j$  is the most excellent preceding position shared by the swarm.

The Rule 1 can be defined as a stochastic decision. If a uniform arbitrary number in  $(0, 1)$  is smaller than,  $K$  ( $K \in (0,1)$ ) a constant value, the Passerine would search for food. Otherwise, the passerine would carry on observance.

#### 4.2. Adherence behaviour

Rule 3 indicates that passerine would try to move near the Centre of the swarm, and they would inevitably contend with each other. Thus, each Passerine cannot directly move towards the Centre of the swarm. This drive can be written as follows:

$$Z_{i,j}^{t+1} = Z + F1(\text{mean}_v - Z_{i,j}^t) \times \text{rand}(0,1) + F2(K_{k,j} - Z_{i,j}^t) \times \text{rand}(-1,1) \quad (25)$$

$$F1 = f1 \times \exp\left(-\frac{k\text{Fit}_i}{\text{sumFit} + \varepsilon} \times N\right) \quad (26)$$

$$F2 = f2 \times \exp\left(\left(\frac{k\text{Fit}_i - k\text{Fit}_r}{|k\text{Fit}_r - k\text{Fit}_i| + \varepsilon}\right) \frac{N \times k\text{Fit}_r}{\text{sumFit} + \varepsilon}\right) \quad (27)$$

Where  $k$  ( $k \neq 1$ ) is a positive integer, which is illogically chosen between 1 and  $N$ .  $f1$  and  $f2$  are two positive constants in  $[0, 2]$ ,  $k\text{Fit}_i$  denotes the  $i$ th passerine best fitness value and  $\text{sumFit}$  represents the sum of the swarms' best fitness value. 1, which is used to keep away from zero-division error,  $\text{mean}_v$  denotes the  $j$ th element of the average position of the whole swarm. When a Passerine move near the Centre of the swarm, it will unavoidably compete with each other. The average fitness value of the swarm is measured by the surrounding swarm when a Passerine move to the Centre of the swarm. Each Passerine always wants to position at the Centre of swarm, the product of  $F1$  and  $\text{rand}(0, 1)$  should not be more than 1. Here,  $F2$  is used to create the direct effect persuaded by interference when a Passerine move to the Centre of the swarm. If the most outstanding fitness value of a random  $k$ th Passerine ( $k - i$ ) is greater than that of the  $i$ th Passerine, then  $F2$ ,  $f2$  which means that the  $i$ th may bear Passerine a greater interference than the  $k$ th Passerine. The  $k$ th Passerine would be move near the centre of the swarm than the  $i$ th passerine.

### 4.3. Expedition behaviour

Passerine may fly to other areas due to countless reasons. When the Passerine arrived at an innovative site, they would again search for food. Some Passerine as creators would search for food patches, while other Passerine try to feed from the food patch found by the creators. By the Rule 4 the creators and spongers can be detached from the swarm. The behaviors of the creators and spongers can be written as follows:

$$Z_{i,j}^{t+1} = Z_{i,j}^t + randn(0,1) \times Z_{i,j}^t \quad (28)$$

$$Z_{i,j}^{t+1} = Z_{i,j}^t + (Z_{k,j}^t - Z_{i,j}^t) \times GH \times rand(0,1) \quad (29)$$

Where  $randn(0,1)$  denotes Gaussian distributed arbitrary number with mean zero and standard deviation 1,  $k \in [1,2,3,\dots,N], k \neq i$ .  $GH(GH \in [0,2])$  means that the sponger would follow the creator to search for food. We assume that each Passerine fly to alternative place every GH (positive integer) unit interval.

### 4.4. Passerine bird Swarm optimization Algorithm for optimal reactive power dispatch problem

Enter: P: the number of individuals (passerine) bounded in the population, Q: the utmost number of iterations, GH: the rate of repetition of Passerine expedition behaviors', K: the probability of searching for food, M, N, f1, f2, GH: are five constant parameters,  $t = 0$  ; Initialize the population

Assessment of the N individuals' fitness value, and find the most outstanding solution

```

While (t < Q)
  If (t%GH ≠ 0)
    For Forr = 1:N
      If rand(0,1) < K
        At that juncture Passerine searches for food (24)
      Else
        The Passerine keep surveillance (25)
      End if
    End for
  Else
    Classifying swarms as creators and spongers.
    For i = 1:N
      If i is a creator
        Then Create (28)
      Else
        It will be Sponger (29)
      End if
    End for
  End if

```

Calculate innovative solutions. If the innovative solutions are greater to their previous ones, renovate them. Find the current most outstanding solution

```

t=t+1;
End while
Output:
The individual with the finest objective function value in the population

```

## 5. SIMULATION RESULTS

The efficiency of the proposed Passerine Swarm Optimization Algorithm (PSOA) method is demonstrated by testing it on standard 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, Table 2, Table 3 & Table 4. The Table 5 shows the proposed algorithm powerfully reduces 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. Corresponding to this control variable setting, it was found that there are no limit violations in any of the state variables.

Optimal Reactive Power Dispatch problem together with 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 simultaneously. 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 0.2452 to 0.2466, 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 1. Results of PSOA – ORPD optimal control variables

Control variables	Variable setting
V1	1.032
V2	1.030
V5	1.033
V8	1.031
V11	1.000
V13	1.029
T11	1.00
T12	1.00
T15	1.00
T36	1.01
Qc10	2
Qc12	2
Qc15	3
Qc17	0
Qc20	2
Qc23	3
Qc24	3
Qc29	2
Real power loss	4.2502
SVSM	0.2452

Table 2. Results of PSOA -voltage stability control reactive power dispatch optimal control variables

Control Variables	Variable Setting
V1	1.040
V2	1.039
V5	1.040
V8	1.029
V11	1.000
V13	1.030
T11	0.090
T12	0.090
T15	0.090
T36	0.090
Qc10	3
Qc12	3
Qc15	2
Qc17	3
Qc20	0
Qc23	2
Qc24	2
Qc29	3
Real power loss	4.9860
SVSM	0.2466

Table 3. Voltage stability under contingency state

Sl.No	Contingency	ORPD Setting	VSCRPD Setting
1	28-27	0.1409	0.1424
2	4-12	0.1649	0.1652
3	1-3	0.1769	0.1779
4	2-4	0.2029	0.2041

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 (MW)
Evolutionary programming [21]	5.0159
Genetic algorithm [22]	4.665
Real coded GA with Lindex as SVSM [23]	4.568
Real coded genetic algorithm [24]	4.5015
Proposed PSO method	4.2502

## 6. CONCLUSION

In this paper, Passerine bird Swarm Optimization (PSOA) algorithm has been successfully implemented to solve optimal reactive power dispatch problem. By using the Passerine bird communications and behaviour, five basic rules have been created in the PSO method to solve the optimal reactive power dispatch problem. Key aspect is to reduce the real power loss and also to keep the variables within the limits. Proposed Passerine Swarm Optimization Algorithm (PSOA) has been tested in standard IEEE 30 bus test system and simulation results reveal about the better performance of the proposed algorithm in reducing the real power loss and enhancing the static voltage stability margin.

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