Sperm Movement Algorithm for Solving Optimal Reactive Power Dispatch Problem

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Abstract Sperm Movement (SM) algorithm has been proposed in this paper for solving the multi-objective optimal reactive power dispatch problem. Sperm Movement (SM) algorithm is inspired by movement of the sperm, fertilization process in human and it replicated to solve the problem. There are some standard regulations during the exploration progression. (a) All sperms are fascinated towards the ovum as the species chemo attractant. (b) Attractiveness is proportionate to Chemo attractant concentration and both will augment whenever the sperm is close to the ovum. (c) To the subsequent generation the highest quality of sperm will be passed over & termed as -Type W; the remaining low quality sperms – named types X, Y and Z are discarded with a probability $P_a \in [0, 1]$. Proposed Sperm Movement (SM) algorithm is tested in standard IEEE 30 bus test system. Simulation results reveal about the high-quality performance in reduction of actual power loss, static voltage stability margin enhanced when compared to other standard reported algorithms.

Keywords - Modal analysis, optimal reactive power, Transmission loss, Sperm Movement.

I. INTRODUCTION

Key objective of the reactive power dispatch problem is to operate the system in safe & economic mode. Gradient method [1, 2] Newton method [3] and linear programming [4-8] like different mathematical methods have been implemented to solve the optimal reactive power dispatch problem. But several techniques have intricacy in managing inequality constraints. Various types of Evolutionary algorithms have been solved the reactive power dispatch problem [9-20]. Almost all algorithms have their own constancy in search of global solution for reactive power problem. Generally if one algorithm good in exploration, it may lack in exploitation & vice versa. This research paper proposes a new Sperm Movement (SM) algorithm for solving the multi-objective optimal reactive power dispatch problem in which both the exploration & exploitation has been improved to reach an optimal solution. Sperm Movement (SM) algorithm is stimulated by fertilization process in human [21] and this technique has been imitated to solve the optimal reactive power dispatch problem. Proposed Sperm Movement (SM) algorithm has been evaluated in standard IEEE 30 bus test system. Simulation results reveal about the high-quality performance in reduction of actual power loss, static voltage stability margin enhanced when compared to other standard reported algorithms.

II. VOLTAGE STABILITY EVALUATION

A. *Voltage stability evaluation by Modal analysis*

For voltage stability enhancement in power systems Modal analysis methodology [25] has been used. The steady state system power flow equations are given by.

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

Where

ΔP = change in bus real power incrementally.

ΔQ = change in bus reactive Power injection incrementally.

Δθ = change in bus voltage angle incrementally.

ΔV = change in bus voltage Magnitude incrementally.

sub-matrixes of the System voltage stability are Jpθ , JPV , JQθ , JQV jacobian matrix and it affected by both P and Q.

Assume ΔP = 0 , to reduce equation (1) 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.

B. *Modes of Voltage instability*

By computing the Eigen values and Eigen vectors voltage Stability characteristics of the system have been identified.

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

Where,

ξ = right eigenvector matrix of JR

η = left eigenvector matrix of JR

$\wedge$ = diagonal eigenvalue matrix of JR and

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

From the equations (5) and (8), we can write,

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

or

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

Where ξi is the ith column right eigenvector and η the ith row left eigenvector of JR.

λi is the ith Eigen value of JR.

The ith modal reactive power variation is given by,

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

where,

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

Where

ξji is the jth element of ξi

The corresponding ith modal voltage variation is mathematically given by,

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

When | λi | =0 then the ith modal voltage will get collapsed.

In equation (8), assume ΔQ = ek where ek 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 is given by,

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

III. Problem Formulation

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

a. *Minimization of Real Power Loss*

real power loss (Ploss) Minimization in transmission lines is mathematically given as,

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

Where n is the number of transmission lines, gk is the conductance of branch k, Vi and Vj are voltage magnitude at bus i and bus j, and θij is the voltage angle difference between bus i and bus j.

b. *Minimization of Voltage Deviation*

At load buses minimization of the voltage deviation magnitudes (VD) is stated as follows,

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

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

c. *System Constraints*

These are the following constraints subjected to objective function as given below,

Load flow equality constraints:

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

(16)

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

(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.

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

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

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

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

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

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

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

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

Transformers tap setting (T_i) inequality constraint:

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

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

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

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

IV. Sperm Movement Algorithm

Fertilization procedure in human beings has been inspired by the Sperm Movement (SM) algorithm. There are some standard regulations [21] during the exploration progression. (a) All sperms are fascinated towards the ovum as the species chemo attractant. (b) Attractiveness is proportionate to Chemo attractant concentration and both will augment whenever the sperm is close to the ovum. (c) To the subsequent generation the premier class sperm will be passed to next stage & termed as -Type W; the remaining low quality sperms – named types X, Y and Z are discarded with a probability $P_a \in [0,1]$. (d) Rule has been customized as there is possibility of more than one egg as one sperm penetrates the ovum, to suit the multi-objective reactive power optimization problem (e) Over 270 million sperms swim arbitrarily towards the ovum with velocity v_i at position x_i, & the movement can be described by the Stokes equations [21] & given by,

$$Re = \left(\frac{\partial v}{\partial t} + v.\nabla v\right) + \nabla p = \mu \nabla^2 v + f \nabla . v = 0 \; x \in \Omega$$
(24)

Where, p is the pressure that includes the gravitational potential. μ is kinematic viscosity and f is the force density. v is the velocity vector field in the domain Ω. Sperm such as micro swimmer, Re is approximately rated as 0.01. Stokes equation in linear form & Navier–Stokes equations is in the limit of small Reynolds number. To achieve the simpler form of Stokes equation inertial terms in Navier–Stokes equation [21] have been removed:

$$\nabla p = \mu \nabla^2 v + f \qquad (25)$$

$$\nabla . v = 0 \;\; x \in \Omega \qquad (26)$$

Corresponding to the fundamental singularity velocity solution [21] is given by:

$$v_i(t) = \left(\frac{1}{8\pi u}\right) * \left(\frac{\delta_{ij}}{h} + \frac{h_i h_j}{h^3}\right) * Fl_j = \left(\frac{1}{8\pi u}\right) * s_{ij}(x,\xi) * Fl_{lj}; i,j = 1,2,3.. \qquad (27)$$

Stokes tensor is $s_{ij}(x,\xi)$, at centre ζ, Dirac delta distribution is δ . Owing to a force Fl_j intense at the point ζ, the flow will be and it has been written as,

$$h_i = x - \xi \qquad (28)$$

$$h^2 = h_1^2 + h_2^2 + h_3^2 \qquad (29)$$

Modernized position [21] can be written as follows,

$$x_{i+1}(t) = x_i(t) + \left(\frac{\delta t}{2}\right) * \left(v_{i+1}(t) + v_i(t)\right) + \alpha(x_i(t) - J^*) \qquad (30)$$

Concentration gradient field for Non-linear spatial [21] chemo attractant is written as follows,

$$ca_i(t) = ca_o(t) + ca_1(\|J^* - x_i(t)\|)^{-b} \qquad (31)$$

Where the concentration is, $ca_i(t)$, the position indicated by $x_i(t)$,the proportional coefficient are ca_1 and power of the most important term position is b . Other terms are represented by ca_o. In present iteration J^* is the existing most excellent solution.

Sperm Movement (SM) algorithm for solving the multi-objective reactive power dispatch problem

Begin
Population size of N sperm is initialised
For N sperm, preliminary position x_0 and velocity v_0 are produced & preliminary attentiveness c_0 has been generated
Movement parameters are defined; While (t< Maximum Generation)
For i=1: N do
By equation (27) Velocity v_i is computed from the data at t = t_i;
By equation (30) Position x_i has been modernized for sperm i
Each sperm individual value is calculated according to its position
Modernize the population when fresh solution found to be superior.
From equation (31) value of ca_i has been computed.
Abandon poorer sperm with help of (Pa), when $ca_i \le ca_{i-1}$
Constraints has been checked with respective to objective function
End for
From finest to poorest and present most excellent Population has been sorted out
End while
End

V. Simulation Results

The efficiency of the proposed Sperm Movement (SM) algorithm has been tested in standard IEEE-30 bus system. The system has 6 generator buses, 24 load buses and 41 transmission lines. four branches are (6-9), (6-10) , (4-12) and (28-27) - are with the tap setting transformers.
Table 5 shows the performance of the proposed Sperm Movement (SM) algorithm in reducing real power loss.
In Table 1 minimum loss & optimal values of control variables are given & no limit violations in any of the state variables with corresponding to this control variables.

Table 1. Results of SM – Optimal Reactive Power control variables

List of Control variables	Values of Variable setting
V1	1.0400
V2	1.0410
V5	1.0400
V8	1.0310
V11	1.0010
V13	1.0320
T11	1.0000
T12	1.0000

T15	1.0100
T36	1.0100
Qc10	2
Qc12	2
Qc15	3
Qc17	0
Qc20	2
Qc23	3
Qc24	3
Qc29	2
Real power loss	4.2962
SVSM	0.2472

Table 2 gives the optimal values of the control variables & no limit violations in state variables has been found. Static voltage stability margin (SVSM) has been increased from 0.2472 to 0.2482.

To determine the voltage security of the system contingency analysis has done by using the control variable setting obtained in case 1 and case 2.

In Table 3 equivalent to the four critical contingencies, Eigen values are given & improved considerably for all contingencies in the second case.

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

List of Control Variables	Values of Variable setting
V1	1.0440
V2	1.0430
V5	1.0420
V8	1.0360
V11	1.0030
V13	1.0300
T11	0.0900
T12	0.0900
T15	0.0900
T36	0.0900
Qc10	3
Qc12	3
Qc15	2
Qc17	3
Qc20	0
Qc23	2
Qc24	2
Qc29	3
Real power loss	4.9872
SVSM	0.2482

Table 3. Voltage Stability under Contingency State

Sl.No	Contingency	Optimal Reactive Power Dispatch Setting	Voltage Stability Control Reactive Power Dispatch Setting
1	28-27	0.1416	0.1416
2	4-12	0.1637	0.1642
3	1-3	0.1752	0.1764
4	2-4	0.2014	0.2039

Table 4. Limit Violation Checking Of State Variables

State variables	limits		Optimal Reactive Power Dispatch Setting	Voltage Stability Control Reactive Power Dispatch Setting
	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

Methods	Minimum Real power loss (MW)
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 SM method	4.2962

VI. Conclusion

In this paper, proposed Sperm Movement (SM) algorithm solved optimal reactive power dispatch problem in efficient mode. Fertilization process in human has been imitated to solve the multi-objective optimal reactive power dispatch problem. Both the exploration & exploitation has been improved through this technique in the search procedure. Standard IEEE 30 bus test system has been utilized to show the efficiency of the Proposed Sperm Movement (SM) algorithm. Simulation results shows that proposed algorithm reduced the real power loss & voltage stability margin value has been improved.

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