Two bio-inspired algorithms for solving optimal reactive power problem

Lenin Kanagasabai
Department of EEE, Prasad V. Potluri Siddhartha Institute of Technology, India

ABSTRACT

In this work two ground-breaking algorithms called: Sperm Motility (SM) algorithm & Wolf Optimization (WO) algorithm is used for solving reactive power problem. In sperm motility approach spontaneous movement of the sperm is imitated & species chemo attractant, sperms are enthralled in the direction of the ovum. In wolf optimization algorithm the deeds of wolf is imitated in the formulation & it has a flag vector also length is equivalent to the whole sum of numbers in the dataset the optimization. Both the projected algorithms have been tested in standard IEEE 57,118, 300 bus test systems. Simulated outcomes reveal about the reduction of real power loss & with variables are in the standard limits. Almost both algorithms solved the problem efficiently, yet wolf optimization has slight edge over the sperm motility algorithm in reducing the real power loss.

Keywords:
Optimal reactive power
Sperm motility
Transmission loss
Wolf algorithm

1. INTRODUCTION

Optimal reactive power problem has been key problem in power system, since it plays major role in secure & economic operation of the power system. Many conventional methods [1-8] have been applied for solving optimal reactive power problem. But many drawbacks have been found in the conventional methods and mainly difficulty in handling the inequality constraints. Last two decades many evolutionary algorithms [9-18] continuously applied to solve the problem. This paper proposes a new Sperm Motility (SM) algorithm for solving optimal reactive power problem. Sperm Motility (SM) algorithm is stimulated by fertilization process in human beings [19]. Wolf optimization (WO) algorithm has been formulated on the basis of basic deeds of wolf search for the prey. The formulation has been enhanced by utilizing the velocity & movement properties of particle swarm optimization algorithm. Both the projected algorithms have been tested in standard IEEE 57,118, 300 bus test systems. Simulated outcomes reveal about the reduction of real power loss & with variables are in the standard limits. Almost both algorithms solved the problem efficiently, yet wolf optimization has slight edge over the sperm motility algorithm in reducing the real power loss.

2. PROBLEM FORMULATION

The key objective of the reactive power problem is to minimize the system real power loss & given as,
\[ P_{\text{loss}} = \sum_{k=1}^{n} g_k(V_i^2 + V_j^2 - 2V_i V_j \cos \theta_{ij}) \]  

Voltage deviation magnitudes (VD) is stated as follows,

Minimize VD = \[ \sum_{k=1}^{n} |V_k - 1.0| \]  

Load flow equality constraints:

\[ P_{Gi} - P_{Di} - V_i \sum_{j=1}^{nb} V_j \left[ G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij} \right] = 0, i = 1, 2, ..., nb \]

\[ Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{nb} V_j \left[ G_{ij} \sin \theta_{ij} + B_{ij} \cos \theta_{ij} \right] = 0, i = 1, 2, ..., nb \]

Inequality constraints are:

\[ V^\text{min}_{Gi} \leq V_i \leq V^\text{max}_{Gi}, i \in \text{ng} \]  

\[ V^\text{min}_{li} \leq V_i \leq V^\text{max}_{li}, i \in \text{nl} \]  

\[ Q^\text{min}_{Gi} \leq Q_i \leq Q^\text{max}_{Gi}, i \in \text{nc} \]  

\[ Q^\text{min}_{Gi} \leq Q_i \leq Q^\text{max}_{Gi}, i \in \text{ng} \]  

\[ T^\text{min}_i \leq T_i \leq T^\text{max}_i, i \in \text{nt} \]  

\[ S^\text{min}_i \leq S_i \leq S^\text{max}_i, i \in \text{nl} \]

3. SPERM MOTILITY ALGORITHM

Sperm Motility (SM) algorithm has been inspired by the fertilization procedure in human beings. Throughout the exploration sequence as the species chemo attractant, sperms are fascinated towards the ovum. Also Chemo attractant & concentration will induce the sperm when is moving closer to ovum. Utmost eminence sperm will be moved over & expressed as - Type A. With probability \( P_a \in [0,1] \) low quality sperms are discarded; specified as type B, C and D. Towards the ovum more than 220 million sperms swim capriciously with velocity \( v_i \) at position \( x_i \), & by the Stokes equations motility can be described as,

\[ \text{Re} = \left( \frac{\partial v}{\partial t} + v \cdot \nabla v \right) + \nabla p = \mu \nabla^2 v + f \nabla v = 0 \quad x \in \Omega \]  

Simpler form of Stokes written as:

\[ \nabla p = \mu \nabla^2 v + f \]  

\[ \nabla v = 0, \quad y \in \Omega \]  

C singularity velocity solution as follows,

\[ v_i(t) = \left( \frac{1}{\mu \nu} \right) \ast \left( \delta_{ij} \ast \frac{h h_j}{h^3} \right) \ast F_{ij} = \left( \frac{1}{\mu \nu} \right) \ast s_{ij}(y, \xi) \ast F_{ij}; i, j = 1, 2, 3... \]

Due to a force \( F_{ij} \) concentrated at the point \( \xi \), the flow will be as,

\[ h_i = y - \xi \]  

\[ h^2 = h_1^2 + h_2^2 + h_3^2 \]

It has been updated as,

\[ y_{i+1}(t) = y_i(t) + \left( \frac{\delta t}{2} \right) \ast \left( v_{i+1}(t) + v_i(t) \right) + \alpha(y_i(t) - f) \]
Chemo attractant is defined as follows,

\[ ca_i(t) = ca_o(t) + ca_\gamma (\| \bar{Y} - x_i(t) \|)^{-b} \]  \quad (18)

In current iteration \( J^* \) is the outstanding solution exist.

Sperm Motility(SM) algorithm for solving reactive power problem

Commence

Based on the problem objective function is defined.

N sperm Population size is initialised

Primary attentiveness \( c_o \) has been engendered for N sperm with respect to primary position \( y_0 \) and velocity \( v_0 \) are produced.

Parameters of the motility are described; While \((t< \text{Maximum Generation})\)

For \( i=1: N \) do

Velocity \( v_i \) is computed from By equation (14) using the data at \( t = t_i \);

Position \( x_i \) has been modernized for sperm \( i \), by equation (17)

Calculate the each sperm individual value, according to its position

When new solution is available & superior then modernize the population.

Value of \( c_o \) from equation (18) has been calculated.

When \( ca_i \leq ca_{i-1} \), poorer sperm with help of (Pa), will be abandon

Checking of the constrains with respective to objective function

End for

Existing outstanding population has been sorted out

End

4. WOLF OPTIMIZATION

Wolf optimization mimics the communal management and hunt deeds of wolf in nature [20]. There are three fittest candidate solutions assumed as \( a, b \) and \( \gamma \) to lead the population toward promising regions of the exploration space in each iteration of wolf optimization. \( \varphi \) is named for the replicates of wolves and it will assist \( a, b \) and \( \gamma \) to encircle, hunt, and attack prey, that is, to find Enriched solutions. In order to scientifically replicate the encompassing behavior of Red wolves, the following equations are proposed:

\[
\begin{align*}
\vec{Y}(t + 1) &= \vec{Y}(t) - H \vec{G} \\
\vec{G} &= |\vec{F}_b \vec{Y}_b(t) - \vec{Y}(t)|
\end{align*}
\]  \quad (19)

Where \( t \) indicates the current iteration, \( \vec{H} = 2\vec{b}, \vec{r}_1 - \vec{b} \), \( \vec{F} = 2, \vec{F}_1, \vec{F}_2 \) the position vector of the prey, \( \vec{Y} \) is the position vector of a wolf, \( \vec{b} \) is linearly decreased from 2.0 to 0, and \( \vec{r}_1 \) and \( \vec{r}_2 \) are arbitrary vectors in [0, 1]. Hunting behavior of wolves are mathematically simulated by following equations,

\[
\begin{align*}
\vec{G}_a &= |\vec{F}_1 \vec{Y}_a - \vec{Y}(t)| \\
\vec{G}_b &= |\vec{F}_2 \vec{Y}_b - \vec{Y}(t)| \\
\vec{G}_\gamma &= |\vec{F}_3 \vec{Y}_\gamma - \vec{Y}(t)| \\
\vec{Y}_1' &= \vec{Y}_a - H_1 \vec{G}_a \\
\vec{Y}_2' &= \vec{Y}_b - H_2 \vec{G}_b \\
\vec{Y}_3' &= \vec{Y}_\gamma - H_3 \vec{G}_\gamma \\
\vec{Y}(t + 1) &= \frac{\vec{Y}_1' + \vec{Y}_2' + \vec{Y}_3'}{3}
\end{align*}
\]  \quad (20)

Position of wolf was updated by (19) & the following equation is used to discrete the position.

\[
flag_{i,j} = \begin{cases} 
1 & Y_{i,j} > 0.50 \\
0 & \text{otherwise}
\end{cases}
\]  \quad (23)
Where \( i \), indicates the jth position of the ith wolf, \( flag_{i,j} \) is features of the wolf.

To enhance the search velocity & position updating equations form particle swarm optimization has been incorporated in this approach.

\[
v_{i+1} = \omega_i v_i + c_{g1} Rm_{1}.(m_i^j - y_i^j) + c_{g2} Rm_{2}.(m_i^g - y_i^j)
\]

(24)

\[
y_{i+1} = y_i^j + v_{i+1}
\]

(25)

The current position of particle is \( y_i^j \) & search velocity is \( v_i^j \). Global best-found position is \( m_i^g \). In uniformly distributed interval \((0, 1)\) \( Rm_1 \) & \( Rm_2 \) are arbitrary numbers. Where \( c_{g1} \) and \( c_{g2} \) are scaling parameters. \( \omega_i \) is the particle inertia. The variable \( \omega_i \) is modernized as

\[
\omega_i = (\omega_{max} - \omega_{min}) \frac{(t_{max} - t)}{t_{max}} + \omega_{min}
\]

(26)

Maximum and minimum of \( \omega_i \) is represented by \( \omega_{max} \) and \( \omega_{min} \): maximum number of iterations is given by \( t_{max} \). Until termination conditions are met this process will be repeated. In this approach wolves categorized as \( \alpha, \beta \) and \( \gamma \) determine the position of the prey. \( \vec{H} = 2\vec{b}.\vec{r} - \vec{b} \) directs the exploration & exploitation process by reducing the value from 2 to 0. When \(|\vec{H}| < 1 \) it converged towards the prey & If \(|\vec{H}| > 1 \) diverged away. The first best Minimum loss and variables are accumulated as "\( \alpha \)" position, score & as like second best, third best accumulated as "\( \beta \)" and "\( \gamma \)" position & score.

Commence

Initialize the parameters

Initialize \( b, \vec{H} \) and \( \vec{F} \); beginning positions of wolves has been stimulated.

\[ i = 1: \text{population size} \]

\[ j = 1: n \]

When \((i, j) > 0.500\)

\[ (i) = 1; \]

Else

\[ (j) = 0; \]

End if

End for

Work out the maximum fitness of wolves as follows,

Primary maximum fitness of the wolf is designated as "\( \alpha \)"

Second maximum fitness of the wolf is designated as "\( \beta \)"

Third maximum fitness of the wolf is designated as "\( \gamma \)"

While \( k < \text{maximum iteration} \)

For \( i = 1: \text{population size} \)

Exact Location of the existing wolf has been revised periodically

End for

For \( i = 1: \text{population size} \)

For \( i=1:n; \text{If} \ (i, j) > 0.496 \)

\[ (j) = 1; \]

Else

\[ (j) = 0; \]

End if

End for

Sporadically revise the values of \( b, \vec{H} \) and \( \vec{F} \);

At this stage Fitness of wolves has been calculated

The assessment of wolves "\( \alpha \)," "\( \beta \)" and "\( \gamma \)" has to be revised

\[ k = k+1; \]

End while

Re-examine the value of "\( \alpha \)" as the optimal characteristic division;

End

5. SIMULATED OUTCOME

At first IEEE 57 bus system [21] is used as test system to validate the performance of the proposed algorithms. Total active and reactive power demands in the system are 1240.68 MW and 330.82 MVAR,
respectively. Generator data the system is given in Table 1. The optimum loss comparison is presented in Table 2. Number of iterations taken is 32 & time taken 11.24 sec.

| Generator No | Pgi minimum | Pgi maximum | Qgi minimum | Qgi maximum |
|--------------|-------------|-------------|-------------|-------------|
| 1            | 25.00       | 50.00       | 0.00        | 0.00        |
| 2            | 15.00       | 90.00       | -17.00      | 50.00       |
| 3            | 10.00       | 500.00      | -10.00      | 60.00       |
| 4            | 10.00       | 50.00       | -8.00       | 25.00       |
| 5            | 12.00       | 50.00       | -140.00     | 200.00      |
| 6            | 10.00       | 360.00      | -3.00       | 9.00        |
| 7            | 50.00       | 550.00      | -50.00      | 155.00      |

Table 2 comparison of losses

| Parameter | Method CLPSO [22] | Method DE [23] | Method GSA [23] | Method OGS [24] | Method SOA [22] | Method QODE [23] | Method CSA [25] | SM | WO |
|-----------|-------------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|----|----|
| PLOSS (MW)| 24.5152           | 16.7857        | 23.4611         | 24.2654         | 15.8473         | 15.5149         | 12.1482         | 12.0064        |

Secondly IEEE 118 bus system [26] is used as test system to validate the performance of the proposed algorithms. Table 3 shows limit values and Table 4 show the comparison of results.

| Parameter | Methodology - BBO [27] | Methodology - ILSBBO/strategy1 [27] | Methodology - ILSBBO/strategy1 [27] | SM | WO |
|-----------|-------------------------|-----------------------------------|-----------------------------------|----|----|
| Maximum value of QC | 0.000 | 14.000 | 0.000 | 10.000 | 10.000 | 15.000 |
| Minimum value of QC | -40.000 | 0.000 | -25.000 | 0.000 | 0.000 | 0.000 |
| Bus number | 74 | 79 | 82 | 83 | 105 | 107 |
| Maximum value of QC | 12.000 | 20.000 | 20.000 | 10.000 | 20.000 | 6.000 |
| Minimum value of QC | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Finally IEEE 300 bus system [21] is used as test system to validate the performance of the proposed algorithms. Table 5 shows the comparison of real power loss obtained after optimization.

| Parameter | Methodology - EGA [28] | Methodology - EEA [28] | Methodology - CSA [25] | SM | WO |
|-----------|-------------------------|------------------------|------------------------|----|----|
| PLOSS (MW) | 646.2998 | 650.6027 | 655.8942 | 630.1898 | 629.2824 |

6. CONCLUSION
In this paper both Sperm Motility (SM) algorithm & Wolf Optimization (WO) algorithm solved the problem successfully. Performance of both above said algorithms in solving the problem is outstanding. Both the projected algorithms have been tested in standard IEEE 57, 118, 300 bus test systems. Simulated outcomes reveal about the reduction of real power loss & with variables are in the standard limits. Almost both algorithms solved the problem efficiently, yet wolf optimization has slight edge over the sperm motility algorithm in reducing the real power loss.

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