Two bio-inspired algorithms for solving optimal reactive power problem

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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.

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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,

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

Voltage deviation magnitudes (VD) is stated as follows,

$$\text{Minimize VD} = \sum_{k=1}^{nl}|V_k - 1.0| \quad (2)$$

Load flow equality constraints:

$$P_{Gi} - P_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \quad (3)$$

$$Q_{Gi} - Q_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \sin\theta_{ij} \\ +B_{ij} & \cos\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \quad (4)$$

Inequality constraints are:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}, i \in ng \quad (5)$$

$$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max}, i \in nl \quad (6)$$

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max}, i \in nc \quad (7)$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i \in ng \quad (8)$$

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in nt \quad (9)$$

$$S_{Li}^{min} \leq S_{Li}^{max}, i \in nl \quad (10)$$

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,

$$Re = \left(\frac{\partial v}{\partial t} + v.\nabla v\right) + \nabla p = \mu\nabla^2 v + f\nabla. v = 0 \; x \in \Omega \quad (11)$$

Simpler form of Stokes written as:

$$\nabla p = \mu\nabla^2 v + f \quad (12)$$

$$\nabla. v = 0, y \in \Omega \quad (13)$$

C singularity velocity solution as follows,

$$v_i(t) = \left(\frac{1}{8\pi u}\right) * \left(\frac{\delta_{ij}}{h} + \frac{h_i h_j}{h^3}\right) * Fl_j = \left(\frac{1}{8\pi u}\right) * s_{ij}(y,\xi) * Fl_{lj}; i,j = 1,2,3.. \quad (14)$$

Due to a force Fl_j concentrated at the point ζ, the flow will be as,

$$h_i = y - \xi \quad (15)$$

$$h^2 = h_1^2 + h_2^2 + h_3^2 \quad (16)$$

It has been updated as,

$$y_{i+1}(t) = y_i(t) + \left(\frac{\delta t}{2}\right) * \left(v_{i+1}(t) + v_i(t)\right) + \alpha(y_i(t) - J^*) \quad (17)$$

Chemo attractant is defined as follows,

$$ca_i(t) = ca_o(t) + ca_1(\|J^* - x_i(t)\|)^{-b} \tag{18}$$

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_0 has been engendered for N sperm with reference to primary position y_0 and velocity v_0 are produced.
Parameters of the motility are described; While (t< 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 ca_i 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 constraints 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 α,β and γ to lead the population toward promising regions of the exploration space in each iteration of wolf optimization. φ is named for the rest of wolves and it will assist α,β and γ 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:

$$\vec{G} = \left|\vec{F}.\vec{Y_P}(t) - \vec{Y}(t)\right|,$$
$$\vec{Y}(t+1) = \vec{Y_P}(t) - \vec{H}.\vec{G} \tag{19}$$

Where t indicates the current iteration, $\vec{H} = 2\vec{b}.\vec{r_1} - \vec{b}$, $\vec{F} = 2.\vec{r_2}$, $\widehat{Y_P}$ 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,

$$\vec{G_\alpha} = \left|\vec{F_1}.\vec{Y_\alpha} - \vec{Y}\right|$$
$$\vec{G_\beta} = \left|\vec{F_2}.\vec{Y_\beta} - \vec{Y}\right| \tag{20}$$

$$\vec{G_\gamma} = \left|\vec{F_3}.\vec{Y_\gamma} - \vec{Y}\right|$$
$$\vec{Y_1} = \vec{Y_\alpha} - \vec{H_1}.\vec{G_\alpha}$$
$$\vec{Y_2} = \vec{Y_\beta} - \vec{H_2}.\vec{G_\beta} \tag{21}$$

$$\vec{Y_3} = \vec{Y_\gamma} - \vec{H_3}.\vec{G_\gamma}$$
$$\vec{Y}(t+1) = \frac{\vec{Y_1}+\vec{Y_2}+\vec{Y_3}}{3} \tag{22}$$

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

$$flag_{i,j} = \begin{cases} 1 & Y_{i,j} > 0.50 \\ 0 & otherwise \end{cases} \tag{23}$$

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.

$$v_{t+1}^{i} = \omega_t . v_t^i + cg_1 . Rm_1 . \left(m_t^i - y_t^i\right) + cg_2 . Rm_2 . \left(m_t^g - y_t^i\right) \tag{24}$$

$$y_{t+1}^{i} = y_t^i + v_{t+1}^i \tag{25}$$

The current position of particle is y_t^i & search velocity is v_t^i . Global best-found position is. m_t^g. In uniformly distributed interval (0, 1) Rm_1 & Rm_2 are arbitrary numbers. Where cg_1 and cg_2 are scaling parameters.ω_t is the particle inertia. The variable ω_t is modernized as

$$\omega_t = (\omega_{max} - \omega_{min}) . \frac{(t_{max} - t)}{t_{max}} + \omega_{min} \tag{26}$$

Maximum and minimum of ω_t is represented by ω_{max} and ω_{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 α,β and γ determine the position of the prey. $\vec{H} = 2\vec{b} . \vec{r_1} - \vec{b}$ 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 "α" position, score & as like second best, third best accumulated as "β" and " γ" position & score.

Commence
Initialize the parameters
Initialize b, $\vec{H}$ and $\vec{F}$; beginning positions of wolves has been stimulated.
i = 1: 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 “α”
Second maximum fitness of the wolf is designated as “β”
Third maximum fitness of the wolf is designated as “γ”
While k < maximum iteration
For i = 1: population size
Exact Location of the existing wolf has been revised periodically
End for
For i = 1: population size
For i=1:n;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 "α","β" and " γ" has to be revised
k=k+1;
End while
Re-examine the value of” α “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.

Table 1. Generator data

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 OGSA [24]	Method SOA [22]	Method QODE [23]	Method CSA [25]	SM	WO
PLOSS (MW)	24.5152	16.7857	23.4611	23.43	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.

Table 3. Limitation of reactive power sources

Bus number	5	34	37	44	45	46	48
Maximum value of QC	0.000	14.000	0.000	10.000	10.000	10.000	15.000
Minimum value of QC	-40.000	0.000	-25.000	0.000	0.000	0.000	0.000
Bus number	74	79	82	83	105	107	110
Maximum value of QC	12.000	20.000	20.000	10.000	20.000	6.000	6.000
Minimum value of QC	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4. Evaluation of results

Active power loss – Minimum & Maximum values	Methodology - BBO [27]	Methodology - ILSBBO/ strategy1 [27]	Methodology ILSBBO/ strategy1 [27]	SM	WO
Minimum value	128.770	126.980	124.780	126.540	125.172
Maximum value	132.640	137.340	132.390	132.860	131.248
Average value	130.210	130.370	129.220	129.120	128.864

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.

Table 5 comparison of real power loss

Parameter	Method EGA [28]	Method EEA [28]	Method CSA [25]	SM	WO
PLOSS (MW)	646.2998	650.6027	635.8942	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.

REFERENCES

[1] K. Y. Lee, "Fuel-cost minimisation for both real and reactive-power dispatches," *Proceedings Generation, Transmission and Distribution Conference*, vol. 131, no. 3, pp. 85-93, 1984.

[2] N. I. Deeb, “An efficient technique for reactive power dispatch using a revised linear programming approach,” *Electric Power System Research*, vol. 15, no. 2, pp. 121–134, 1988.
[3] M. R. Bjelogrlic, M. S. Calovic, B. S. Babic, et. al., ”Application of Newton’s optimal power flow in voltage/reactive power control,” *IEEE Trans Power System*, vol. 5, no. 4, pp. 1447-1454, 1990.
[4] S. Granville, “Optimal reactive dispatch through interior point methods,” *IEEE Transactions on Power System,* vol. 9, no. 1, pp. 136–146, 1994.
[5] N. Grudinin, “Reactive power optimization using successive quadratic programming method,” *IEEE Transactions on Power System*, vol. 13, no. 4, pp. 1219–1225, 1998.
[6] Wei Yan, J. Yu, D. C. Yu and K. Bhattarai, ”A new optimal reactive power flow model in rectangular form and its solution by predictor corrector primal dual interior point method,” *IEEE Trans. Pwr. Syst*.,vol. 21, no.1, pp. 61-67, 2006.
[7] Aparajita Mukherjee, Vivekananda Mukherjee, “Solution of optimal reactive power dispatch by chaotic krill herd algorithm,” *IET Gener. Transm. Distrib,* , Vol. 9, no. 15, pp. 2351–2362, 2015.
[8] Hu, Z., Wang, X. & Taylor, G. Stochastic optimal reactive power dispatch: Formulation and solution method. *Electr. Power Energy Syst*., vol. 32, pp. 615-621. 2010.
[9] Mahaletchumi A/P Morgan , Nor Rul Hasma Abdullah, Mohd Herwan Sulaiman, Mahfuzah Mustafa and Rosdiyana Samad, “Computational intelligence technique for static VAR compensator (SVC) installation considering multi-contingencies (N-m),” *ARPN Journal of Engineering and Applied Sciences*, vol. 10, no. 22, 2015.
[10] Mohd Herwan Sulaiman, Zuriani Mustaffa, Hamdan Daniyal, Mohd Rusllim Mohamed and Omar Aliman, “Solving Optimal Reactive Power Planning Problem Utilizing Nature Inspired Computing Techniques,” *ARPN Journal of Engineering and Applied Sciences*, vol. 10, no. 21, pp. 9779-9785. 2015.
[11] Mohd Herwan Sulaiman, Wong Lo Ing, Zuriani Mustaffa and Mohd Rusllim Mohamed, “Grey Wolf Optimizer for Solving Economic Dispatch Problem with Valve-Loading Effects,” *ARPN Journal of Engineering and Applied Sciences,* vol. 10, no. 21, pp. 9796-9801, 2015.
[12] Pandiarajan, K. & Babulal, C. K. , “Fuzzy harmony search algorithm based optimal power flow for power system security enhancement,” *International Journal Electric Power Energy Syst.*, vol. 78, pp. 72-79. 2016.
[13] Mustaffa, Z., Sulaiman, M.H., Yusof, Y., Kamarulzaman, S.F., “A novel hybrid metaheuristic algorithm for short term load forecasting”, *International Journal of Simulation: Systems, Science and Technology*, vol. 17, no. 41, pp. 6.1-6.6. 2017.
[14] Sulaiman, M.H., Mustaffa, Z., Mohamed, M.R., Aliman, O., “An application of multi-verse optimizer for optimal reactive power dispatch problems,” *International Journal of Simulation: Systems, Science and Technology*, vol. 17, no. 41, pp, 5.1-5.5. 2017.
[15] Mahaletchumi A/P Morgan, Nor Rul Hasma Abdullah, Mohd Herwan Sulaiman,Mahfuzah Mustafa and Rosdiyana Samad, “Multi-Objective Evolutionary Programming (MOEP) Using Mutation Based on Adaptive Mutation Operator (AMO) Applied For Optimal Reactive Power Dispatch,” *ARPN Journal of Engineering and Applied Sciences*, vol. 11, no. 14, 2016.
[16] Rebecca Ng Shin Mei, Mohd Herwan Sulaiman, Zuriani Mustaffa, “Ant Lion Optimizer for Optimal Reactive Power Dispatch Solution,” *Journal of Electrical Systems,* "Special Issue AMPE2015", pp. 68-74. 2016.
[17] Mahaletchumi Morgan, Nor Rul Hasma Abdullah, Mohd Herwan Sulaiman, Mahfuzah Mustafa, Rosdiyana Samad, “Benchmark Studies on Optimal Reactive Power Dispatch (ORPD) Based Multi-objective Evolutionary Programming (MOEP) Using Mutation Based on Adaptive Mutation Adapter (AMO) and Polynomial Mutation Operator (PMO),” *Journal of Electrical Systems,* 2016.
[18] Rebecca Ng Shin Mei, Mohd Herwan Sulaiman, Zuriani Mustaffa, Hamdan Daniyal,“Optimal Reactive Power Dispatch Solution by Loss Minimization using Moth-Flame Optimization Technique,” *Applied Soft Computing*, vol. 59, pp. 210-222, 2017.
[19] O. A. R. Ibrahim Hezam, “Sperm Motility Algorithm: A Novel Metaheuristic Approach for Global Optimization,” *Int. J. Oper. Res*., vol. 28, no. 2, pp. 143–163, 2017.
[20] A. Kaveh and F. Shokohi, “Application of Grey Wolf Optimizer in design of castellated beams,” *Asian Journal of Civil Engineering,* vol. 17, no. 5, pp. 683–700, 2016.
[21] .[Online] Available: http://www2.ee.washington.edu/research/pstca/
[22] C. Dai, et al., “Seeker optimization algorithm for optimal reactive power dispatch,” IEEE Trans. Power Systems, vol. 24, no. 3, pp. 1218-1231, 2009.
[23] M. Basu, “Quasi-oppositional differential evolution for optimal reactive power dispatch,” Electrical Power and Energy Systems, vol. 78, pp. 29-40, 2016.
[24] B. Shaw, et al., “Solution of reactive power dispatch of power systems by an opposition-based gravitational search algorithm,” *International Journal of Electrical Power Energy Systems*, vol. 55, pp. 29-40, 2014.
[25] S. Surender Reddy, “Optimal Reactive Power Scheduling Using Cuckoo Search Algorithm,” *International Journal of Electrical and Computer Engineering*, Vol. 7, No. 5, pp. 2349-2356. 2017
[26] IEEE, “The IEEE 30-bus test system and the IEEE 118-test system,” 1993, http://www.ee.washington.edu/trsearch/pstca/.
[27] Jiangtao Cao, Fuli Wang and Ping Li, “An Improved Biogeography-based Optimization Algorithm for Optimal Reactive Power Flow,” *International Journal of Control and Automation*, vol.7, no.3, pp. 161-176, 2014.
[28] S.S. Reddy, et al., “Faster evolutionary algorithm based optimal power flow using incremental variables,” *Electrical Power and Energy Systems*, vol. 54, pp. 198-210, 2014.