

Polar wolf optimization algorithm for solving optimal reactive power problem

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ABSTRACT

This paper proposes polar wolf optimization (PWO) algorithm to solve the optimal reactive power problem. Proposed algorithm enthused from actions of polar wolves. Leader's wolves which denoted as x_α are accountable for taking judgment on hunting, resting place, time to awaken etc. second level is x_β those acts when there is need of substitute in first case. Then x_γ be as final level of the wolves. In the modeling social hierarchy is developed to discover the most excellent solutions acquired so far. Then the encircling method is used to describe circle-shaped vicinity around every candidate solutions. In order to agents work in a binary space, the position modernized accordingly. Proposed PWO algorithm has been tested in standard IEEE 14, 30, 57, 118, 300 bus test systems and simulation results show the projected algorithms reduced the real power loss considerably.

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1. INTRODUCTION

Reactive power problem plays an important role in secure and economic operations of power system. Numerous types of methods [1-6] have been utilized to solve the optimal reactive power problem. However many scientific difficulties are found while solving problem due to an assortment of constraints. Evolutionary techniques [7-16] are applied to solve the reactive power problem. This paper proposes polar wolf optimization (PWO) algorithm to solve the optimal reactive power problem. PWO enthused from actions of polar wolves. In the modeling social hierarchy is developed to discover the most excellent solutions acquired so far.

Then the encircling method is used to describe circle-shaped vicinity around every candidate solutions. The hunting technique assists candidate solutions to trace the prey [17]. Leaders of a pack are defined as Alpha and it makes all vital decisions in the group about day to day activity. Alpha will be supported by Beta in all aspects and particularly performing actions. Delta executes its duty as scouts, guard, concierge. Exploration and exploitation are balanced in iterations. Modernizing mechanism of wolves is function of three vectors position; X_1, X_2, X_3 which endorse every wolf to reach three most excellent solutions. For that the agents will work in a binary space. Proposed PWO algorithm has been tested in standard IEEE 14, 30, 57, 118, 300 bus test systems and simulation results shows that active power loss has been reduced.

2. PROBLEM FORMULATION

Objective of the problem is to reduce the true power loss:

$$F = P_L = \sum_{k \in \text{Nbr}} g_k (V_i^2 + V_j^2 - 2V_i V_j \cos \theta_{ij}) \quad (1)$$

Voltage deviation given as follows:

$$F = P_L + \omega_v \times \text{Voltage Deviation} \quad (2)$$

Voltage deviation given by:

$$\text{Voltage Deviation} = \sum_{i=1}^{\text{Npq}} |V_i - 1| \quad (3)$$

Constraint (equality)

$$P_G = P_D + P_L \quad (4)$$

Constraints (inequality)

$$P_{\text{gslack}}^{\min} \leq P_{\text{gslack}} \leq P_{\text{gslack}}^{\max} \quad (5)$$

$$Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max}, i \in N_g \quad (6)$$

$$V_i^{\min} \leq V_i \leq V_i^{\max}, i \in N \quad (7)$$

$$T_i^{\min} \leq T_i \leq T_i^{\max}, i \in N_T \quad (8)$$

$$Q_c^{\min} \leq Q_c \leq Q_c^{\max}, i \in N_C \quad (9)$$

3. POLAR WOLF OPTIMIZATION

PWO algorithm enthused from actions of polar wolves. Leader's wolves which denoted as x_α are accountable for taking judgment on hunting, resting place, time to awaken etc. second level is x_β those acts when there is need of substitute in first case. Then x_γ be as final level of the wolves. In the modeling social hierarchy is developed to discover the most excellent solutions acquired so far. Then the encircling method is used to describe circle-shaped vicinity around every candidate solutions. The hunting technique assists candidate solutions to trace the prey. Exploration and exploitation are balanced in each iteration. Modernizing mechanism of wolves is function of three vectors position - X_1, X_2, X_3 which endorse every wolf to reach three most excellent solutions. For that the agents will work in a binary space.

$$\bar{D} = |\bar{C}\bar{X}_p(t) - \bar{X}(t)| \quad (10)$$

$$\bar{X}(t+1) = \bar{X}_p(t) - \vec{A} \cdot \bar{D} \quad (11)$$

$$\vec{A} = 2\vec{a} \cdot \vec{r}_1 - \vec{a} \quad (12)$$

$$\vec{C} = 2 \cdot \vec{r}_2 \quad (13)$$

$$\vec{a} = 2 - t * \frac{2}{\text{max iteration}} \quad (14)$$

The state of wolves are adjusted by,

$$\vec{D}_\alpha = |\vec{C}_1, \vec{X}_\alpha - \vec{X}| \quad (15)$$

$$\vec{D}_\beta = |\vec{C}_2, \vec{X}_\beta - \vec{X}| \quad (16)$$

$$\vec{D}_\gamma = |\vec{C}_3, \vec{X}_\delta - \vec{X}| \quad (17)$$

where $\vec{X}_\alpha, \vec{X}_\beta, \vec{X}_\gamma$ symbolize the locations of α, β, δ ,

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1 \cdot (\vec{D}_\alpha) \quad (18)$$

$$\vec{X}_2 = \vec{X}_\beta - \vec{A}_2 \cdot (\vec{D}_\beta) \quad (19)$$

$$\vec{X}_3 = \vec{X}_\delta - \vec{A}_3 \cdot (\vec{D}_\delta) \quad (20)$$

$$\bar{X}(t+1) = \frac{x_1+x_2+x_3}{3} \quad (21)$$

In order to agents work in a binary space, the position modernizing can be customized by,

$$x_d^{t+1} = \begin{cases} 1 & \text{if } \text{sigmoid}\left(\frac{x_1+x_2+x_3}{3}\right) \geq \text{random} \\ 0 & \text{otherwise} \end{cases} \quad (22)$$

$$\text{sigmoid}(a) = \frac{1}{1+e^{-10(x-0.5)}} \quad (23)$$

X_1, X_2, X_3 are updated by,

$$x_1^d = \begin{cases} 1 & \text{if } (x_\alpha^d + bstep_\alpha^d) \geq 1 \\ 0 & \text{otherwise} \end{cases} \quad (24)$$

$$x_2^d = \begin{cases} 1 & \text{if } (x_\beta^d + bstep_\beta^d) \geq 1 \\ 0 & \text{otherwise} \end{cases} \quad (25)$$

$$x_3^d = \begin{cases} 1 & \text{if } (x_\delta^d + bstep_\delta^d) \geq 1 \\ 0 & \text{otherwise} \end{cases} \quad (26)$$

where

$$bstep_{\alpha,\beta,\delta}^d = \begin{cases} 1 & \text{if } cstep_{\alpha,\beta,\delta}^d \geq \text{random} \\ 0 & \text{otherwise} \end{cases} \quad (27)$$

$$cstep_{\alpha,\beta,\delta}^d = \frac{1}{1+e^{-10(A_1^d D_{\alpha,\beta,\delta}^d - 0.5)}} \quad (28)$$

Positions and velocities are modernized to improve the performance of the exploration and exploitation in the projected algorithm.

$$v_i^{k+1} = \omega * v_i^k + c_1 \cdot r_1 \cdot (x_1 - x_i^k) + c_2 \cdot r_2 \cdot (x_2 - x_i^k) + c_3 \cdot r_3 \cdot (x_3 - x_i^k) \quad (29)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (30)$$

$$\omega = (\omega_{\max} - \omega_{\min}) \cdot \frac{(t_{\max}-t)}{t_{\max}} + \omega_{\min} \quad (31)$$

Exploration and exploitation has been controlled by the inertia weight " ω ";

$$\vec{D}_\alpha = |\vec{C}_1, \vec{X}_\alpha - \omega * \vec{X}| \quad (32)$$

$$\vec{D}_\beta = |\vec{C}_2, \vec{X}_\beta - \omega * \vec{X}| \quad (33)$$

$$\vec{D}_\gamma = |\vec{C}_3, \vec{X}_\delta - \omega * \vec{X}| \quad (34)$$

Initialization of parameters

n wolves positions are initialized arbitrarily $\in [1,0]$

α, β, δ Solutions are attained by the fitness function value

Agent's fitness values are calculated by (35):

$$\vec{D}_\alpha = |\vec{C}_1, \vec{X}_\alpha - \omega * \vec{X}| ; \vec{D}_\beta = |\vec{C}_2, \vec{X}_\beta - \omega * \vec{X}| ; \vec{D}_\gamma = |\vec{C}_3, \vec{X}_\delta - \omega * \vec{X}| \quad (35)$$

while ($t < \text{Maximum_iterations}$). For each population modernize the velocity by:

$$v_i^{k+1} = \omega * v_i^k + c_1 \cdot r_1 \cdot (x_1 - x_i^k) + c_2 \cdot r_2 \cdot (x_2 - x_i^k) + c_3 \cdot r_3 \cdot (x_3 - x_i^k)$$

Modernize the agent's position into a binary position by:

$$x_i^{k+1} = x_d^{t+1} + v_i^{k+1}$$

End

Modernize A, a, C and w

Through objective function assess all particles

Modernize the positions of α, β, δ ; $t=t+1$

End while

4. SIMULATION RESULTS

At first in standard IEEE 14 bus system [18] the validity of the proposed PWO algorithm has been tested. Table 1 shows the constraints of control variables. Table 2 shows the limits of reactive power generators, and comparison results are presented in Table 3.

Table 1. Constraints of control variables

Variables	Minimum (PU)	Maximum (PU)
Generator voltage	0.95	1.1
Transformer tap	0.9	1.1
VAR source	0	0.20

Table 2. Constrains of reactive power generators

Variables	Q Minimum (PU)	Q Maximum (PU)
1	0	10
2	-40	50
3	0	40
6	-6	24
8	-6	24

Table 3. Simulation results of IEEE-14 system

Control variables	Base case	MPSO [19]	PSO [19]	EP [19]	SARVA [19]	PWO
Reduction in PLoss	0	9.2	9.1	1.5	2.5	26.07
Total PLoss (MW)	13.550	12.293	12.315	13.346	13.216	10.1017

Note: NR*-Not reported

Then the proposed PWO algorithm has been tested in IEEE 30 bus system. Table 4 shows the constraints of control variables. Table 5 shows the limits of reactive power generators, and comparison results are presented in Table 6.

Table 4. Constraints of control variables

Variables	Minimum (PU)	Maximum (PU)
Generator voltage	0.95	1.1
Transformer tap	0.9	1.1
VAR source	0	0.20

Table 5. Constrains of reactive power generators

Variables	Q Minimum (PU)	Q Maximum (PU)
1	0	10
2	-40	50
5	-40	40
8	-10	40
11	-6	24
13	-6	24

Table 6. Simulation results of IEEE-30 system

Control variables	Base case	MPSO [19]	PSO [19]	EP [19]	SARGA [19]	PWO
Reduction in PLoss (%)	0	8.4	7.4	6.6	8.3	20.05
Total PLoss (Mw)	17.55	16.07	16.25	16.38	16.09	14.030

Then the proposed PWO algorithm has been tested in IEEE 57 bus system. Table 7 shows the constraints of control variables, Table 8 shows the limits of reactive power generators and comparison results are presented in Table 9. Then the proposed PWO algorithm has been tested in IEEE 118 bus system. Table 10 shows the constraints of control variables and comparison results are presented in Table 11. Then IEEE 300 bus system [18] is used as test system to validate the performance of the proposed PWO algorithm. Table 12 shows the comparison of real power loss obtained after optimization.

Table 7. Constraints of control variables

Variables	Minimum (PU)	Maximum (PU)
Generator voltage	0.95	1.1
Transformer tap	0.9	1.1
VAR source	0	0.20

Table 8. Constrains of reactive power generators

Variables	Q Minimum (PU)	Q Maximum (PU)
1	-140	200
2	-17	50
3	-10	60
6	-8	25
8	-140	200
9	-3	9
12	-150	155

Table 9. Simulation results of IEEE-57 system

Control variables	Base case	MPSO [19]	PSO [19]	CGA [19]	AGA [19]	PWO
Reduction in PLoss	0	15.4	14.1	9.2	11.6	27.41
Total PLoss (MW)	27.8	23.51	23.86	25.24	24.56	20.179

Note: NR*-Not reported.

Table 10. Constraints of control variables

Variables	Minimum (PU)	Maximum (PU)
Generator voltage	0.95	1.1
Transformer tap	0.9	1.1
VAR source	0	0.20

Table 11. Simulation results of IEEE-118 system

Control variables	Base case	MPSO [19]	PSO [19]	PSO [19]	CLPSO [19]	PWO
Reduction in PLoss	0	11.7	10.1	0.6	1.3	13.86
Total PLoss (MW)	132.8	117.19	119.34	131.99	130.96	104.390

Note: NR*-Not reported.

Table 12. Comparison of real power loss

Parameter	Method CSA [20]	Method EGA [21]	Method EEA [21]	PWO
PLOSS (MW)	635.8942	646.2998	650.6027	613.1085

5. CONCLUSION

In this paper PWO algorithm successfully solved the optimal reactive power problem. The hunting technique assists candidate solutions to trace the prey. Exploration and exploitation are balanced in iterations. Modernizing mechanism of wolves is function of three vectors position - X_1, X_2, X_3 which endorse every wolf to reach three most excellent solutions. For that the agents will work in a binary space. Proposed PWO algorithm has been tested in standard IEEE 14, 30, 57, 118, 300 bus test systems and simulation results show the projected algorithm reduced the real power loss. Percentage of real power loss reduction has been enhanced when compared to other reported algorithms.

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