



Science

## **ACTIVE POWER LOSS DIMINUTION & VOLTAGE STABILITY ENHANCEMENT BY RED WOLF OPTIMIZATION ALGORITHM**

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### **Abstract**

In this paper optimal reactive power dispatch problem (ORPD), has been solved by Enriched Red Wolf Optimization (ERWO) algorithm. Projected ERWO algorithm hybridizes the wolf optimization (WO) algorithm with swarm based algorithm called as particle swarm optimization (PSO) algorithm. In the approach each Red wolf has a flag vector, and length is equivalent to the whole sum of numbers which features in the dataset of the wolf optimization (WO). Exploration capability of the projected Red wolf optimization algorithm has been enriched by hybridization of both WO with PSO. Efficiency of the projected Enriched Red wolf optimization (ERWO) evaluated in standard IEEE 30 bus test system. Simulation study indicates Enriched Red wolf optimization (ERWO) algorithm performs well in tumbling the actual power losses & particularly voltage stability has been enriched.

**Keywords:** Reactive Power; Dispatch; Loss; Red Wolf Optimization; Swarm Optimization.

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### **1. Introduction**

Reactive power problem plays major role in improving secure & economic of power system operation & control. A variety of methodologies [1-6] have been implemented to solve the problem, but difficulty found in handling the constraints. Now days various types of Evolutionary algorithms implemented to solve problem [7-15]. For last twenty years various types of programming and probabilistic based approach [16-20] has been used to solve the problem. In this work Enriched Red wolf optimization (ERWO) algorithm has been implemented to work out the problem. Both Exploration & Exploitation has been improved. In basic Wolf optimization algorithm (WO) [21], exploration spaces are missing the diversity and the high-quality diversity is needed to upgrade the performance of the algorithm to find an optimal solution. Particle swarm optimization (PSO) [22] has good feature of exploration ability and it has been hybridized with Wolf optimization algorithm (WO) to produce an Enriched version called as Enriched Red wolf

optimization (ERWO). PSO will aid to form better preliminary population to WO. In standard IEEE 30 bus test system efficiency of Enriched Red wolf optimization (ERWO) algorithm has been evaluated. Results indicate that Enriched Red wolf optimization (ERWO) algorithm performs well in tumbling the actual power losses & particularly margin index value of voltage stability has been improved.

## 2. Voltage Stability Evaluation

### 2.1. Modal Analysis for Voltage Stability Evaluation

Power flow equations of the steady state system is 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

$\Delta P$  = bus real power change incrementally.

$\Delta Q$  = bus reactive Power injection change incrementally.

$\Delta\theta$  = bus voltage angle change incrementally.

$\Delta V$  = bus voltage Magnitude change incrementally.

$J_{p\theta}$ ,  $J_{pv}$ ,  $J_{q\theta}$ ,  $J_{qv}$  are sub-matrixes of the System voltage stability in jacobian matrix and both P and Q get affected by this.

Presume  $\Delta P = 0$ , then equation (1) can be written as,

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

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

Where

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

$J_R$  Denote the reduced Jacobian matrix of the system.

### 2.2. Modes of Voltage Instability

Voltage Stability characteristics of the system have been identified through computation of the Eigen values and Eigen vectors.

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

Where,

$\xi$  denote the right eigenvector matrix of  $J_R$ ,  $\eta$  denote the left eigenvector matrix of  $J_R$ ,  $\Lambda$  denote the diagonal eigenvalue matrix of  $J_R$ .

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

From the equations (5) and (6),

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

or

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

$\xi_i$  denote the  $i$ th column right eigenvector &  $\eta$  is the  $i$ th row left eigenvector of JR.  
 $\lambda_i$  indicate the  $i$ th Eigen value of JR.

reactive power variation of the  $i$ th modal is given by,

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

where,

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

Where  $\xi_{ji}$  is the  $j$ th element of  $\xi_i$   
 $i$ th modal voltage variation is mathematically given by,

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

When the value of  $|\lambda_i| = 0$  then the  $i$ th modal voltage will get collapsed.

In equation (8), when  $\Delta Q = e_k$  is assumed, then  $e_k$  has all its elements zero except the  $k$ th one being 1. Then  $\Delta V$  can be formulated as follows,

$$\Delta V = \sum_i \frac{\eta_{1k} \xi_{i1}}{\lambda_i} \quad (12)$$

$\eta_{1k}$  is  $k$ th element of  $\eta_1$   
 At bus  $k$  V-Q sensitivity is given by,

$$\frac{\partial V_k}{\partial Q_k} = \sum_i \frac{\eta_{1k} \xi_{i1}}{\lambda_i} = \sum_i \frac{P_{ki}}{\lambda_i} \quad (13)$$

### 3. Problem Formulation

Minimization of actual power loss and augmentation of static voltage stability margin index (SVSM) is main key to solve optimal reactive power dispatch problem. Voltage stability evaluation has been done through modal analysis method.

#### 3.1. Minimization of Real Power Loss

Real power loss (Ploss) minimization is given as,

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

Where n is the number of transmission lines,  $g_k$  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.

### 3.2. Minimization of Voltage Deviation

Formula for reducing the voltage deviation magnitudes (VD) is derived as follows,

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

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

### 3.3. System Constraints

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,  $P_G$  and  $Q_G$  are the real and reactive power of the generator,  $P_D$  and  $Q_D$  are the real and reactive load of the generator, and  $G_{ij}$  and  $B_{ij}$  are the mutual conductance and susceptance between bus i and bus j.

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

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

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

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

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

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

## 4. Red Wolf Optimization

Red wolf optimization mimics the communal management and hunt deeds of Red wolves in nature. There are three fittest candidate solutions assumed as  $\alpha, \beta$  and  $\gamma$  to lead the population toward

promising regions of the exploration space in each iteration of red wolf optimization.  $\varphi$  is named for the rest of Red wolves and it will assist  $\alpha, \beta$  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:

$$\begin{aligned} \vec{G} &= |\vec{F} \cdot \vec{Y}_p(t) - \vec{Y}(t)|, \\ \vec{Y}(t+1) &= \vec{Y}_p(t) - \vec{H} \cdot \vec{G} \end{aligned} \quad (24)$$

Where  $t$  indicates the current iteration,  $\vec{H} = 2\vec{b} \cdot \vec{r}_1 - \vec{b}$ ,  $\vec{F} = 2 \cdot \vec{r}_2$ ,  $\widehat{Y}_p$  the position vector of the prey,  $\vec{Y}$  is the position vector of a Red 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 Red wolves are mathematically simulated by following equations,

$$\begin{aligned} \vec{G}_\alpha &= |\vec{F}_1 \cdot \vec{Y}_\alpha - \vec{Y}| \\ \vec{G}_\beta &= |\vec{F}_2 \cdot \vec{Y}_\beta - \vec{Y}| \end{aligned} \quad (25)$$

$$\begin{aligned} \vec{G}_\gamma &= |\vec{F}_3 \cdot \vec{Y}_\gamma - \vec{Y}| \\ \vec{Y}_1 &= \vec{Y}_\alpha - \vec{H}_1 \cdot \vec{G}_\alpha \\ \vec{Y}_2 &= \vec{Y}_\beta - \vec{H}_2 \cdot \vec{G}_\beta \end{aligned} \quad (26)$$

$$\begin{aligned} \vec{Y}_3 &= \vec{Y}_\gamma - \vec{H}_3 \cdot \vec{G}_\gamma \\ \vec{Y}(t+1) &= \frac{\vec{Y}_1 + \vec{Y}_2 + \vec{Y}_3}{3} \end{aligned} \quad (27)$$

In this work, a new Enriched Red wolf optimization (ERWO) algorithm is proposed to solve reactive power dispatch problem & the position of a Red wolf was updated by equation (27) & the following equation is used to discrete the position.

$$flag_{i,j} = \begin{cases} 1 & Y_{i,j} > 0.50 \\ 0 & otherwise \end{cases} \quad (28)$$

Where  $i$ , indicates the  $j$ th position of the  $i$ th Red wolf,  $flag_{i,j}$  is features of the wolf.

## 5. Particle Swarm Optimization

In Particle swarm optimization (PSO) algorithm [22] the positions and velocities of the Particles are modernized as follows:

$$v_{t+1}^i = \omega_t \cdot v_t^i + cg_1 \cdot Rm_1 \cdot (m_t^i - y_t^i) + cg_2 \cdot Rm_2 \cdot (m_t^g - y_t^i) \quad (29)$$

$$y_{t+1}^i = y_t^i + v_{t+1}^i \quad (30)$$

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.  $\omega_t$  is the particle inertia. The variable  $\omega_t$  is modernized as

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

Maximum and minimum of  $\omega_t$  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.

## 6. Enriched Red Wolf Optimization (ERWO) Algorithm for Solving Optimal Reactive Power Dispatch Problem

In this approach red wolves  $\alpha, \beta$  and  $\gamma$  determine the position of the prey.  $\vec{H} = 2\vec{b} \cdot \vec{r}_1 - \vec{b}$  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 " $\alpha$ " 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 Red 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 Red wolves as follows,

Primary maximum fitness of the Red wolf is designated as " $\alpha$ "

Second maximum fitness of the Red wolf is designated as " $\beta$ "

Third maximum fitness of the Red wolf is designated as " $\gamma$ "

While  $k < \text{maximum iteration}$

For  $i = 1$ : population size

Exact Location of the existing Red wolf has been revised periodically

End for

For  $i = 1$ : population size

For  $i=1$ :  $n$ ; If  $(i, j) > 0.500$

$(j) = 1$ ;

Else

$(j) = 0$ ;

End if

End for

Sporadically revise the values of  $b$ ,  $\vec{H}$  and  $\vec{F}$ ;  
 At this stage Fitness of Red wolves has been calculated  
 The assessment of red 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

## 7. Simulated Outcomes

The efficiency of the proposed Enriched Red Wolf Optimization (ERWO) algorithm is demonstrated by testing it on standard IEEE-30 bus system, it has 41 transmission lines of which four branches are (6-9), (6-10), (4-12), 6 generator buses, 24 load buses, (28-27) - are with the tap setting transformers. Optimal values of the control variables are given and are given in Table 1.

Table 1: Results of ERWO – ORPD optimal control variables

| List of Control variables | Variable setting values |
|---------------------------|-------------------------|
| V1                        | 1.04120                 |
| V2                        | 1.04020                 |
| V5                        | 1.04000                 |
| V8                        | 1.03020                 |
| V11                       | 1.00260                 |
| V13                       | 1.03020                 |
| T11                       | 1.0000                  |
| T12                       | 1.0000                  |
| T15                       | 1.0100                  |
| T36                       | 1.0100                  |
| Qc10                      | 2                       |
| Qc12                      | 3                       |
| Qc15                      | 2                       |
| Qc17                      | 0                       |
| Qc20                      | 2                       |
| Qc23                      | 2                       |
| Qc24                      | 3                       |
| Qc29                      | 2                       |
| Real power loss           | 4.2096                  |
| SVSM                      | 0.2484                  |

Table 2 indicates the optimal values of the control variables & there is no limit violations in state variables. Static voltage stability margin (SVSM) has increased from 0.2484 to 0.2496. contingency analysis was conducted using the control variable setting obtained in case 1 and case 2 to determine the voltage security of the system. In Table 3 the Eigen values equivalent to contingencies are given. In Table 4 Eigen value has been improved for all contingencies. Limit Violation Checking Of State Variables. Comparisons of results are shown in Table 5.

Table 2: Results of ERWO -Voltage Stability Control Reactive Power Dispatch Optimal Control Variables

| List of Control Variables | Variable Setting values |
|---------------------------|-------------------------|
| V1                        | 1.04420                 |
| V2                        | 1.04040                 |
| V5                        | 1.04120                 |
| V8                        | 1.03040                 |
| V11                       | 1.00320                 |
| V13                       | 1.03200                 |
| T11                       | 0.0900                  |
| T12                       | 0.0900                  |
| T15                       | 0.0900                  |
| T36                       | 0.0900                  |
| Qc10                      | 3                       |
| Qc12                      | 3                       |
| Qc15                      | 3                       |
| Qc17                      | 3                       |
| Qc20                      | 0                       |
| Qc23                      | 2                       |
| Qc24                      | 2                       |
| Qc29                      | 3                       |
| Real power loss           | 4.9890                  |
| SVSM                      | 0.2496                  |

Table 3: Voltage Stability under Contingency State

| Sl.No | Contingency | Optimal Reactive Power Dispatch Setting values | Voltage Stability Control Reactive Power Dispatch Setting values |
|-------|-------------|--|--|
| 1     | 28-27       | 0.1412   | 0.1423   |
| 2     | 4-12        | 0.1644   | 0.1652   |
| 3     | 1-3         | 0.1762   | 0.1765   |
| 4     | 2-4         | 0.2021   | 0.2054   |

Table 4: Limit Violation Checking of State Variables

| State variables | limits |        | Optimal Reactive Power Dispatch Setting values | Voltage Stability Control Reactive Power Dispatch Setting values |
|-----------------|--------|--------|--|--|
|                 | Lower  | Upper  |  |  |
| Q1              | -20.00 | 152.00 | 1.34220  | -1.32690   |
| Q2              | -20.00 | 61.00  | 8.99000  | 9.82320  |
| Q5              | -15.00 | 49.920 | 25.9200  | 26.0010  |
| Q8              | -10.00 | 63.520 | 38.8200  | 40.8020  |
| Q11             | -15.00 | 42.00  | 2.93000  | 5.0020   |
| Q13             | -15.00 | 48.00  | 8.10250  | 6.0330   |
| V3              | 0.950  | 1.050  | 1.03720  | 1.03920  |



|     |       |       |         |         |
|-----|-------|-------|---------|---------|
| V4  | 0.950 | 1.050 | 1.03070 | 1.03280 |
| V6  | 0.950 | 1.050 | 1.02820 | 1.02980 |
| V7  | 0.950 | 1.050 | 1.01010 | 1.01520 |
| V9  | 0.950 | 1.050 | 1.04620 | 1.04120 |
| V10 | 0.950 | 1.050 | 1.04820 | 1.04980 |
| V12 | 0.950 | 1.050 | 1.04000 | 1.04660 |
| V14 | 0.950 | 1.050 | 1.04740 | 1.04430 |
| V15 | 0.950 | 1.050 | 1.04570 | 1.04130 |
| V16 | 0.950 | 1.050 | 1.04260 | 1.04050 |
| V17 | 0.950 | 1.050 | 1.03820 | 1.03960 |
| V18 | 0.950 | 1.050 | 1.03920 | 1.04000 |
| V19 | 0.950 | 1.050 | 1.03810 | 1.03940 |
| V20 | 0.950 | 1.050 | 1.01120 | 1.01940 |
| V21 | 0.950 | 1.050 | 1.04350 | 1.02430 |
| V22 | 0.950 | 1.050 | 1.04480 | 1.03960 |
| V23 | 0.950 | 1.050 | 1.04720 | 1.03720 |
| V24 | 0.950 | 1.050 | 1.04840 | 1.03720 |
| V25 | 0.950 | 1.050 | 1.01420 | 1.01920 |
| V26 | 0.950 | 1.050 | 1.04940 | 1.04220 |
| V27 | 0.950 | 1.050 | 1.04720 | 1.04520 |
| V28 | 0.950 | 1.050 | 1.02430 | 1.02830 |
| V29 | 0.950 | 1.050 | 1.04390 | 1.04190 |
| V30 | 0.950 | 1.050 | 1.04180 | 1.03970 |

Table 5: Comparison of Real Power Loss

| Method                                | Minimum loss |
|---------------------------------------|--------------|
| Evolutionary programming [23]         | 5.0159       |
| Genetic algorithm [24]                | 4.665        |
| Real coded GA with Lindex as SVSM[25] | 4.568        |
| Real coded genetic algorithm [26]     | 4.5015       |
| projected ERWO                        | 4.2096       |

## 8. Conclusion

Enriched Red wolf optimization (ERWO) approach effectively solved the problem. Exploration & Exploitation has been considerably improved through the proposed methodology. In standard IEEE 30 bus test system proposed technique has been tested, , comparison of the real power loss has been done & proposed methodology reduced the actual power loss considerably with augmentation of static voltage stability margin index.

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