Improved canis rufus floridanus optimization algorithm for reduction of real power loss & maximization of static voltage stability margin

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ABSTRACT. *This paper projects Improved Canis Rufus Floridanus (ICRF) Optimization Algorithm for solving optimal reactive power dispatch problem. Projected ICRF algorithm combines the Canis Rufus Floridanus algorithm with particle swarm optimization (PSO) algorithm. When the PSO algorithm has been intermingled with Canis Rufus Floridanus (ICRF) Optimization algorithm, at first exploration will be done and gradually it will be moved to phase of exploitation. Also in this approach social interaction within the swarm also considered with communication diversity. So due the hybridization both Exploration & Exploitation capability of the projected Improved Canis Rufus Floridanus (ICRF) Optimization Algorithm has been improved. Projected algorithm is evaluated in standard IEEE 30 bus test system. Results indicate that proposed algorithm perform well in solving the optimal reactive power dispatch problem. Real power losses are reduced by the proposed algorithm when compared to other standard algorithms & voltage stability index has increased from 0.2462 to 0.2485, which is an improvement in the system voltage stability. To determine the voltage security of the system, contingency analysis was conducted using the control variable setting obtained.*

RÉSUMÉ. *Cet article porte sur l'algorithme d'optimisation améliorée de Canis Rufus Floridanus (ICRF) pour la résolution du problème optimal de répartition de la puissance réactive. L'algorithme ICRF projeté combine l'algorithme Canis Rufus Floridanus avec l'algorithme d'optimisation par essaims particulaires (PSO). Lorsque l'algorithme PSO a été mélangé à l'algorithme d'optimisation Canis Rufus Floridanus (ICRF), l'exploration sera effectuée au début et progressivement, il passera à la phase d'exploitation. Également dans cette approche, l'interaction sociale au sein de l'essaim est également prise en compte avec la diversité de communication. Ainsi, en raison de l'hybridation à la fois l'exploration et l'exploitation, la capacité d'algorithme d'optimisation projeté et améliorée de Canis Rufus Floridanus (ICRF) a été amélioré. L'algorithme projeté est évalué dans le standard IEEE 30 système de test de bus. Les résultats indiquent que l'algorithme proposé fonctionne bien pour résoudre le problème optimal de répartition de la puissance réactive. Les pertes de puissance réelles sont réduites par l'algorithme proposé par rapport à d'autres algorithmes standard. L'indice de stabilité de la tension a augmenté de 0,2462 à 0,2485, ce qui représente une amélioration de la* *stabilité de la tension du système. Pour déterminer la sécurité de tension du système, une analyse de contingence a été réalisée à l'aide du paramètre de variable de contrôle obtenu.*

KEYWORDS: *optimal reactive power, transmission loss, canis rufus floridanus, particle swarm optimization.*

MOTS-CLÈS: *puissance réactive optimale, perte de transmission, canis rufus floridanus, optimisation par essaims particulaires.*

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1. Introduction

The main objective of optimal reactive power problem is to reduce the actual power loss. Various techniques problem (Lee *et al.*, 1984; Deeb and Shahidehpour, 1988; Bjelogrlic *et al*., 1990; Granville, 1994; Grudinin, 1998; Yan *et al.*, 2006) have been utilized but have the complexity in handling constraints. Different types of evolutionary algorithms (Mukherjee and Mukherjee, 2015; Hu *et al.*, 2010; Morgan *et al*., 2015; Sulaiman *et al*., 2015; Pandiarajan and Babulal, 2016; Morgan *et al*., 2016; Mei *et al*., 2016) have been utilized in various stages to solve the problem. Many algorithms may good in Exploration & but very poor in Exploitation, some algorithms will good in Exploitation but lack in Exploration. This paper projects Improved Canis Rufus Floridanus (ICRF) Optimization Algorithm for solving optimal reactive power dispatch problem. Projected ICRF algorithm combines the Canis Rufus Floridanus algorithm with particle swarm optimization (PSO) algorithm. When the PSO algorithm has been intermingled with Canis Rufus Floridanus (ICRF) Optimization algorithm, at first exploration will be done and gradually it will be moved to phase of exploitation. So due the hybridization both Exploration & Exploitation capability of the projected Improved Canis Rufus Floridanus (ICRF) Optimization Algorithm has been improved. Projected algorithm is evaluated in standard IEEE 30 bus test system. Results indicate that proposed algorithm perform well in solving the optimal reactive power dispatch problem. Real power losses are reduced by the proposed algorithm when compared to other standard algorithms & voltage stability index has increased from 0.2462 to 0.2485, which is an improvement in the system voltage stability. To determine the voltage security of the system, contingency analysis was conducted using the control variable setting obtained.

2. Problem formulation

2.1. Modal analysis for voltage stability evaluation

Modal analysis is one among best methods for voltage stability enhancement in power systems. 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=Incremental change in bus real power.

ΔQ=Incremental change in bus reactive Power injection

$\Delta \theta$=incremental change in bus voltage angle.

ΔV=Incremental change in bus voltage Magnitude.

$J_{p\theta}$, J_{PV}, $J_{Q\theta}$, J_{QV} jacobian matrix are the sub-matrixes of the System voltage stability is affected by both P and Q.

To reduce (1), let ΔP=0, then.

$$\Delta Q = [J_{QV} - J_{Q\theta} J_{P\theta^{-1}} J_{PV}]\Delta V = J_R \Delta V \quad (2)$$

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

Where

$$J_R = (J_{QV} - J_{Q\theta} J_{P\theta^{-1}} JPV) \quad (4)$$

J_R is called the reduced Jacobian matrix of the system.

2.2. Modes of voltage instability

Voltage Stability characteristics of the system have been identified by computing the Eigen values and Eigen vectors.

Let

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

Where,

ξ=right eigenvector matrix of J_R

η=left eigenvector matrix of J_R

∧=diagonal eigenvalue matrix of J_R and

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

From (5) and (8), we have

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

or

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

Where ξ_i is the ith column right eigenvector and η the ith row left eigenvector of J_R.

λ_i is the ith Eigen value of J_R.

The ith modal reactive power variation is,

$$\Delta Q_{mi} = K_i \xi_i \tag{9}$$

Where

$$K_i = \sum_j \xi_{ij^2} - 1 \tag{10}$$

Where

ξ_{ji} is the jth element of ξ_i

The corresponding ith modal voltage variation is

$$\Delta V_{mi} = [1/\lambda_i]\Delta Q_{mi} \tag{11}$$

If $|\lambda_i|=0$ then the ith modal voltage will collapse.

In (10), let ΔQ=ek where ek has all its elements zero except the kth one being 1. Then,

$$\Delta V = \sum_i \frac{\eta_{1k}\ \xi_1}{\lambda_1} \tag{12}$$

η_{1k} kth element of η_1

V–Q sensitivity at bus k

$$\frac{\partial V_K}{\partial Q_K} = \sum_i \frac{\eta_{1k}\ \xi_1}{\lambda_1} = \sum_i \frac{P_{ki}}{\lambda_1} \tag{13}$$

To minimize the system real power loss,

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

Voltage deviation magnitudes (VD) is stated as Minimize

$$\mathrm{VD} = \sum_{k=1}^{nl} |V_k - 1.0| \tag{15}$$

Load flow equality constraints are:

$$P_{Gi} - P_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \tag{16}$$

$$Q_{Gi} - Q_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \sin\theta_{ij} \\ +B_{ij} & \cos\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \tag{17}$$

Inequality constraints are:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}, i \in ng \tag{18}$$

$$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max}, i \in nl \tag{19}$$

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max}, i \in nc \tag{20}$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i \in ng \tag{21}$$

$$T_{i}^{min} \leq T_{i} \leq T_{i}^{max}, i \in nt \tag{22}$$

$$S_{Li}^{min} \leq S_{Li}^{max}, i \in nl \tag{23}$$

3. Improved canis rufus floridanus optimization algorithm

Canis Rufus Floridanus optimization algorithm imitates the collective organization and other activities of Canis Rufus Floridanus. α, β and γ are the three fittest candidate solutions has been assumed in the regions of exploration space. Other Canis Rufus Floridanus is denoted as $'\varphi'$ and it will enhance α, β and γ to encircle, hunt, attack prey; in the formulated algorithm searching towards improved solutions. Actions of Canis Rufus Floridanus are mathematically written as:

$$\vec{Z} = \left|\vec{M}.\overrightarrow{X_P}(t) - \vec{X}(t)\right|, \tag{24}$$

$$\vec{X}(t+1) = \overrightarrow{X_P}(t) - \vec{N}.\vec{Z} \tag{25}$$

Where t indicates the current iteration, $\vec{N} = 2\vec{b}.\overrightarrow{r_1} - \vec{b}$, $\vec{M} = 2.\overrightarrow{r_2}$, $\widehat{X_P}$ the position vector of the prey, $\vec{X}$ is the position vector of a Canis Rufus Floridanus, $\vec{b}$ is linearly decreased from 1.99 to 0, and $\overrightarrow{r_1}$ and $\overrightarrow{r_2}$ are random vectors in [0, 1].

Hunting behavior of Canis Rufus Floridanus are formulated as,

$$\overrightarrow{Z_\alpha} = \left|\overrightarrow{M_1}, \overrightarrow{X_\alpha} - \vec{X}\right|$$

$$\overrightarrow{Z_\beta} = \left|\overrightarrow{M_2}, \overrightarrow{X_\beta} - \vec{X}\right| \tag{26}$$

$$\overrightarrow{Z_\gamma} = \left|\overrightarrow{M_3}, \overrightarrow{X_\gamma} - \vec{X}\right|$$

$$\overrightarrow{X_1} = \overrightarrow{X_\alpha} - \overrightarrow{N_1}\ .\overrightarrow{Z_\alpha}$$

$$\overrightarrow{X_2} = \overrightarrow{X_\beta} - \overrightarrow{N_2}\ .\overrightarrow{Z_\beta} \tag{27}$$

$$\overrightarrow{X_3} = \overrightarrow{X_\gamma} - \overrightarrow{N_3}\ .\overrightarrow{Z_\gamma}$$

$$\vec{X}(t+1) = \frac{\overrightarrow{x_1} + \overrightarrow{x_2} + \overrightarrow{x_3}}{3} \tag{28}$$

Position of Canis Rufus Floridanus was updated by equation (28) and to discrete the position the following equation formulated,

$$flag_{i,j} = \begin{cases} 1 & X_{i,j} > 0.498 \\ 0 & otherwise \end{cases} \quad (29)$$

Where i, indicates the jth position of the ith Canis Rufus Floridanus, $flag_{i,j}$ indicates about the total features of Canis Rufus Floridanus.

In this formulation particle swarm optimization is utilized to enrich the exploration & latter exploitation. Position & velocity of the particles are defined by,

$$v_{t+1}^{i} = \omega_t . v_t^i + cg_1 . Rm_1 . \left(m_t^i - y_t^i\right) + cg_2 . Rm_2 . \left(m_t^g - y_t^i\right) \quad (30)$$

$$y_{t+1}^{i} = y_t^i + v_{t+1}^i \quad (31)$$

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

$$\omega_t = (\omega_{max} - \omega_{min}) . \frac{(t_{max} - t)}{t_{max}} + \omega_{min} \quad (32)$$

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.

To examine the social interactions within the swarm, when a particle i updates its position based on the position of a particle j (the best neighbor of particle i is the particle j) at a given iteration t social interaction happens in the PSO. Weight of an edge (i, j) is equal to the number of times the particle i was the best neighbor of the particle j or vice-versa .Additionally, they used a time window to control the recency of the analysis, so at iteration t with window t_w is defined as follows,

$$I_{ij}^{t_w} = \sum_{t'=t-t_w+1}^{t} \left[\delta_{i,nj(t')} + \delta_{j,ni(t')}\right], with\ t > t_w \geq 1 \quad (33)$$

A_{t_w} measures the diversity in the information flow for a given time window. The communication diversity CD is defined as following,

$$CD(t) = 1 - \frac{1}{|T||S|} \sum_{t'_w \in t} A_{t_w} = t'_w\ (t) \quad (34)$$

Where |S| is the number of particles in the swarm and T is a set of time windows. Thus, swarms exhibiting high CD (low values for A_{t_w}) have the ability to have diverse information flows, while low values for CD imply in swarms with only few information flows (high value for A_{t_w}). An ideal set T would be one taking into account all time windows (i.e., interactions from t_w=1 until t_w=t).

Canis Rufus Floridanus; α, β and γ determine the position of the prey. $\vec{N} = 2\vec{b}.\vec{r_1} - \vec{b}$ directs the exploration & exploitation process by reducing the value from 1.99 to 0.When $|\vec{N}| < 1$ it converged towards the prey & If $|\vec{N}| > 1$ 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.

1: Start
2: Parameters are initialized
3: Positions of Canis Rufus Floridanus are initialized by; b, $\vec{N}$ and $\vec{M}$
4: i =1: population size; j=1:n
5: When (i, j)>0.500; (i) = 1;
6: Else; (j)=0;
7: End if
8: End for
9: Maximum fitness of Canis Rufus Floridanus are computed as follows,
10: Canis Rufus Floridanus with primary fitness value is defined as "α"; Second maximum fitness defined as "β"; Third maximum fitness is defined as "γ"
11: While k < maximum number of iteration; For i=1: population size
12: Periodical revision of Canis Rufus Floridanus has been done
13: End for
14: For i=1: population size; For i=1:n
15: If (i, j)>0.500 ; (j) = 1; Else (j)=0;
16: End if
17: End for
18: Values of b, $\vec{N}$ and $\vec{M}$ are updated & at the same time fitness value of Canis Rufus Floridanus is calculated
19: "α","β" and " γ" values are revised; k=k+1;
20: End while
21: Value of" α "as the optimal characteristic division has been scrutinized again;
22: End

4. Simulation results

The efficiency of the proposed Improved Canis Rufus Floridanus (ICRF) optimization algorithm is demonstrated by testing it on standard IEEE-30 bus system. The IEEE-30 bus system has 6 generator buses, 24 load buses and 41 transmission lines of which four branches are (6-9), (6-10), (4-12) and (28-27) - are with the tap setting transformers. The lower voltage magnitude limits at all buses are 0.95 p.u. and the upper limits are 1.1 for all the PV buses and 1.05 p.u. for all the PQ buses and the reference bus. The simulation results have been presented in Tables 1, 2, 3 &4. The optimal values of the control variables along with the minimum loss obtained are given in Table 1. Corresponding to this control variable setting, it was found that there are no limit violations in any of the state variables.

Table 1. Results of ICRF–ORPD optimal control variables

Control variables	Variable setting
V1	1.03100
V2	1.03200
V5	1.03900
V8	1.03100
V11	1.00000
V13	1.03000
T11	1.0000
T12	1.0000
T15	1.0000
T36	1.0100
Qc10	3
Qc12	2
Qc15	2
Qc17	0
Qc20	3
Qc23	2
Qc24	3
Qc29	2
Real power loss	4.2406
SVSM	0.2462

Optimal Reactive Power Dispatch (ORPD) problem together with voltage stability constraint problem was handled in this case as a multi-objective optimization problem where both power loss and maximum voltage stability margin of the system were optimized simultaneously.

Table 2 indicates the optimal values of these control variables. Also it is found that there are no limit violations of the state variables. It indicates that voltage stability index has increased from 0.2462 to 0.2485, which is an improvement in the system voltage stability.

To determine the voltage security of the system, contingency analysis was conducted using the control variable setting obtained in case 1 and case 2. The Eigen values equivalents to the four critical contingencies are given in Table 3. From this result it is observed that the Eigen value has been improved considerably for all contingencies in the second case.

Table 2. Results of ICRF-Voltage stability control reactive power dispatch (VSCRPD) optimal control variables

Control Variables	Variable Setting
V1	1.04500
V2	1.04100
V5	1.04000
V8	1.02900
V11	1.00000
V13	1.03000
T11	0.09000
T12	0.09000
T15	0.09000
T36	0.09000
Qc10	2
Qc12	2
Qc15	2
Qc17	3
Qc20	0
Qc23	2
Qc24	2
Qc29	3
Real power loss	4.9886
SVSM	0.2485

Table 3. Voltage stability under contingency state

Sl.No	Contingency	ORPD Setting	VSCRPD Setting
1	28-27	0.1419	0.1434
2	4-12	0.1642	0.1650
3	1-3	0.1761	0.1772
4	2-4	0.2022	0.2043

Table 4. Limit violation checking of state variables

State variables	limits		ORPD	VSCRPD
	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	38.820	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

In the Table 5 shows the proposed algorithm powerfully reduces the real power losses when compared to other given standard algorithms.

Table 5. Comparison of real power loss

Method	Minimum loss
Method; Evolutionary programming (Wu and Ma, 1995)	5.01590
Method; Genetic algorithm (Durairaj *et al*., 2006)	4.6650
Method; Real coded GA with Lindex as SVSM (Devaraj, 2007)	4.5680
Method; Real coded genetic algorithm (Jeyanthy and Devaraj, 2010)	4.50150
Proposed ICRF method	4.24060

5. Conclusion

In this paper, the Improved Canis Rufus Floridanus (ICRF) Optimization Algorithm has been successfully solved Optimal Reactive Power Dispatch problem. Efficiency of the projected Improved Canis Rufus Floridanus (ICRF) Optimization Algorithm has been evaluated in standard IEEE 30 bus test system. Real power losses are reduced by the proposed algorithm when compared to other standard algorithms & voltage stability index has increased from 0.2462 to 0.2485, which is an improvement in the system voltage stability. To determine the voltage security of the system, contingency analysis was conducted using the control variable setting obtained.

References

Bjelogrlic M., Calovic M. S., Ristanovic P., Babic B. S. (1990). Application of Newton's optimal power flow in voltage/reactive power control. *IEEE Trans Power System*, Vol. 5, No. 4, pp. 1447-1454. https://doi.org/10.1109/59.99399

Deeb N. I., Shahidehpour S. M. (1998). An efficient technique for reactive power dispatch using a revised linear programming approach. *Electric Power System Research*, Vol. 15, No. 2, pp. 121-134. https://doi.org/10.1016/0378-7796(88)90016-8

Devaraj D. (2007). Improved genetic algorithm for multi – objective reactive power dispatch problem. *European Transactions on electrical power*, Vol. 17, pp. 569-581. https://doi.org/10.1002/etep.146

Durairaj S., Devaraj D., Kannan P. S. (2006). Genetic algorithm applications to optimal reactive power dispatch with voltage stability enhancement. *Journal of the Institution of Engineers (India): Electrical Engineering Division*, Vol. 87, pp. 42-47.

Granville S. (1994). Optimal reactive dispatch through interior point methods. *IEEE Transactions on Power System*, Vol. 9, No. 1, pp. 136-146. https://doi.org/10.1109/59.317548

Grudinin N. (1998). Reactive power optimization using successive quadratic programming method. *IEEE Transactions on Power System*, Vol. 13, No. 4, pp. 1219-1225. https://doi.org/10.1109/59.736232

Hu Z. C., Wang X. F., Taylor G. (2010). Stochastic optimal reactive power dispatch: Formulation and solution method. *International Journal of Electrical Power & Energy Systems*, Vol. 32, No. 6, pp. 615-621. https://doi.org/10.1016/j.ijepes.2009.11.018

Jeyanthy P. A., Devaraj D. (2010). Optimal reactive power dispatch for voltage stability enhancement using real coded genetic algorithm. *International Journal of Computer and Electrical Engineering*, Vol. 2, No. 4, pp. 734-740. https://doi.org/10.7763/IJCEE.2010.V2.220

Lee K. Y., Park Y. M., Ortiz J. L. (1984). Fuel-cost minimisation for both real and reactive-power dispatches. *Proceedings Generation, Transmission and Distribution Conference*, Vol. 131, No. 3, pp. 85-93. http://dx.doi.org/10.1049/ip-c:19840012

Mei R. N. S., Sulaiman M. H., Mustaffa Z. (2016). Ant lion optimizer for optimal reactive power dispatch solution. *Journal of Electrical Systems*, Special Issue AMPE2015, pp. 68-74.

Morgan M., Abdullah N. R. H., Sulaiman M. H., Mustafa M., Samad R. (2016). 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, pp. 8884-8888.

Morgan M., Abdullah N. R. H., Sulaiman M. H., Mustafa M., Samad R. (2016). 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*, Vol. 12, No. 1, pp. 121-132.

Mukherjee A., Mukherjee V. (2015). Solution of optimal reactive power dispatch by chaotic krill herd algorithm. *IET Generation, Transmission & Distribution*, Vol. 9, No. 15, pp. 2351-2362. https://doi.org/10.1049/iet-gtd.2015.0077

Pandiarajan K., Babulal C. K. (2016). Fuzzy harmony search algorithm based optimal power flow for power system security enhancement. *International Journal of Electrical Power & Energy Systems*, Vol. 78, pp. 72-79. https://doi.org/10.1016/j.ijepes.2015.11.053

Wu Q. H., Ma J. T. (1995). Power system optimal reactive power dispatch using evolutionary programming. *IEEE Transactions on Power Systems*, Vol. 10, No. 3, pp. 1243-1248. https://doi.org/10.1109/59.466531

Yan W., Yu J., Yu D. C., Bhattarai K. (2006). A new optimal reactive power flow model in rectangular form and its solution by predictor corrector primal dual interior point method. *IEEE Transactions on Power Systems*, Vol. 21, No. 1, pp. 61-67. https://doi.org/10.1109/TPWRS.2005.861978