

ORIGINAL RESEARCH ARTICLE

Novel scientific design of hybrid opposition based—Chaotic little golden-mantled flying fox, White-winged chough search optimization algorithm for real power loss reduction and voltage stability expansion

Lenin Kanagasabai

Department of Electrical and Electronics Engineering, Prasad V. Potluri Siddhartha Institute of Technology, Kanuru, Vijayawada, Andhra Pradesh 520007, India; gklenin@gmail.com

ABSTRACT

In this paper hybrid opposition based—Chaotic little golden-mantled flying fox algorithm and White-winged chough search optimization algorithm (HLFWC) is applied to solve the loss dwindling problem. Key objective of the paper is real power loss reduction, voltage deviation minimization and voltage stability expansion. Proposed little golden-mantled flying fox algorithm is designed based on the deeds of the little golden-mantled flying fox. Maximum classes have single progenies at a period afterwards of prenatal period. This little procreative production means that when populace forfeiture their figures are deliberate to ricochet. In White-winged chough search optimization algorithm magnifying the encumbrance element in a definite assortment will pointedly enlarge the exploration region. In a coiled exploration, the position of any White-winged chough can differ in numerous scopes to cover the exploration region, predominantly in the projected problem. Hybrid opposition based—Chaotic little golden-mantled flying fox algorithm and White-winged chough search optimization algorithm (HLFWC) is accomplished by integrating the actions of little golden-mantled flying fox and White-winged chough. Through the hybridization of both algorithms exploration and exploitation has been balanced throughout the procedure. Proposed hybrid opposition based—Chaotic little golden-mantled flying fox algorithm and White-winged chough search optimization algorithm (HLFWC) is corroborated in IEEE 30 and 57 systems. From the simulation results it has been observed that real power loss reduction, voltage deviation minimization and voltage stability expansion has been achieved.

Keywords: transmission; loss; little golden-mantled flying fox; White-winged chough

ARTICLE INFO

Received: 2 June 2023
Accepted: 6 August 2023
Available online: 4 September 2023

COPYRIGHT

Copyright © 2023 by author(s).
Journal of Autonomous Intelligence is
published by Frontier Scientific Publishing.
This work is licensed under the Creative
Commons Attribution-NonCommercial 4.0
International License (CC BY-NC 4.0).
<https://creativecommons.org/licenses/by-nc/4.0/>

1. Introduction

Endorsing a satisfactory quantity of reactive power is spirited for the reliable operation of power transmission systems as the reactive power insufficiency may lead to severe voltage collapse and primary power disruptions. Covering numerous directive measures, reactive power planning has become a mystifying issue that supports to the safe and economic growth of power systems. Many researchers worked in this problem; Hybrid PSO-tabu^[1], Ant lion^[2], QTLBO^[3], Harmony search^[4], Improved stochastic fractal search^[5], Pseudo-gradient search^[6], Many methods and test procedures^[7,8], Seeker optimization^[9], Self-adaptive real coded Genetic algorithm^[10], Methodologies and test functions^[11–18], Modified evolutionary algorithm^[19], Enhanced Artificial Bee Colony Optimization^[20], Multi-objective Distribution Feeder Reconfiguration^[21] are applied to solve the problem effectively. In this paper Hybrid Opposition based—Chaotic little golden-mantled flying fox Algorithm and White-winged

chough search Optimization Algorithm (HLFWC) is applied to solve the power loss lessening problem. In opposition based—Chaotic Little golden-mantled flying fox Algorithm Laplace distribution employed to enhance the exploration skill. Then examining the prospect to widen the exploration, a new method endorses stimulating capricious statistics used in formation stage of regulator factor in the algorithm. The perception of opposite number requirements is to be delineated to explicate Opposition based learning. White-winged chough search algorithm delivers dualistic phases of amplification and divergence. In principal phase, the aeronautical formulation is swotted to hustle up the procedure's convergence in the direction of the universal optimal value. In addition, magnifying the encumbrance element in a definite assortment will pointedly enlarge the exploration region. In a coiled exploration, the position of any White-winged chough can differ in numerous scopes to cover the exploration region, predominantly in the projected problem. Consequently, info about the superlative position for a White-winged chough can be well castoff. Concurrently, individual locations are rationalized in an arbitrary way to guarantee that entities are well dispersed to the populace, thus reducing the danger of being wedged in limited regions. The coiled exploration can be accomplished by deviating the space from the preceding location to the preeminent location. Proposed Little golden-mantled flying fox algorithm is designed based on the deeds of the Little golden-mantled flying fox and they possess appearances similar to dog look, scrabbled subsequent ciphers, and condensed posterior segment of the lappet amongst the dual hindmost appendages. Little golden-mantled flying fox are energetic at night. Throughout the epoch of indolence, they stay in foliage or hollows in colony mode. In the course of the epoch of commotion, they utilize flying mode to reach the nutriment possessions. By scarce exclusions, they are inept to use sound waves, depend on sanities of vision and aroma to circumnavigate and discover the nutriment. Little golden-mantled flying fox grasp erotic adulthood gradually and obligate a little procreative production. Maximum classes have single progenies at a period afterwards of prenatal period. This little procreative production means that when populace forfeiture their figures are deliberate to ricochet. A sector of all classes is itemized as endangered, because of obliteration of habitats and hunting. Little golden-mantled flying fox are a widespread nutriment spring in certain zones, prominent to populace deteriorations and extermination. In principal phase, the aeronautical formulation is swotted to hustle up the procedure's convergence in the direction of the universal optimal value. In addition, magnifying the encumbrance element in a definite assortment will pointedly enlarge the exploration region. In a coiled exploration, the position of any White-winged chough can differ in numerous scopes to cover the exploration region, predominantly in the projected problem. Hybrid Opposition based—Chaotic Little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC) is accomplished by integrating the actions of little golden-mantled flying fox and White-winged chough. Through the hybridization of both algorithms exploration and exploitation has been balanced throughout the procedure.

Existence of little golden-mantled flying fox and White-winged chough in Indian subcontinent

In Indian sub-continent both little golden-mantled flying fox and White-winged chough has been secured and safe guarded by the Pontiff SGS in shuka vana, Mysore, Karnataka, India^[18]. All over the world visitors are allowed to visualize the little golden-mantled flying fox and White-winged chough (**Figure 1**).



Figure 1. Pontiff SGS, Visitors with little golden-mantled flying fox and White-winged chough in shuka vana, Mysore, Karnataka, India^[18].

2. Problem formulation

Real power Loss minimization is delineated as,

$$\text{Min } \tilde{F}(\bar{g}, \bar{h}) \quad (1)$$

$$M(\bar{g}, \bar{h}) = 0 \quad (2)$$

$$N(\bar{g}, \bar{h}) = 0 \quad (3)$$

$$g = [VLG_1, \dots, VLG_{Ng}; QC_1, \dots, QC_{Nc}; T_1, \dots, T_{N_T}] \quad (4)$$

$$h = [PG_{slack}; VL_1, \dots, VL_{N_{Load}}; QG_1, \dots, QG_{Ng}; SL_1, \dots, SL_{N_T}] \quad (5)$$

$$F_1 = P_{Min} = \text{Min} \left[\sum_m^{NTL} G_m [V_i^2 + V_j^2 - 2 * V_i V_j \cos \phi_{ij}] \right] \quad (6)$$

$$F_2 = \text{Min} \left[\sum_{i=1}^{N_{LB}} |V_{Lk} - V_{Lk}^{desired}|^2 + \sum_{i=1}^{Ng} |Q_{GK} - Q_{KG}^{Lim}|^2 \right] \quad (7)$$

$$F_3 = \text{Minimize } L_{Maximum} \quad (8)$$

$$L_{Max} = \text{Max}[L_j]; j = 1; N_{LB} \quad (9)$$

$$\begin{cases} L_j = 1 - \sum_{i=1}^{NPV} F_{ij} \frac{V_i}{V_j} \\ F_{ij} = -[Y_1]^1[Y_2] \end{cases} \quad (10)$$

$$L_{Max} = \text{Max} \left[1 - [Y_1]^{-1} [Y_2] \times \frac{V_i}{V_j} \right] \quad (11)$$

Parity constraints,

$$0 = PG_i - PD_i - V_i \sum_{j \in N_B} V_j [G_{ij} \cos[\emptyset_i - \emptyset_j] + B_{ij} \sin[\emptyset_i - \emptyset_j]] \quad (12)$$

$$0 = QG_i - QD_i - V_i \sum_{j \in N_B} V_j [G_{ij} \sin[\emptyset_i - \emptyset_j] + B_{ij} \cos[\emptyset_i - \emptyset_j]] \quad (13)$$

Disparity constraints,

$$P_{gsl}^{min} \leq P_{gsl} \leq P_{gsl}^{max} \quad (14)$$

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}, i \in N_g \quad (15)$$

$$VL_i^{min} \leq VL_i \leq VL_i^{max}, i \in N_L \quad (16)$$

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in N_T \quad (17)$$

$$Q_c^{min} \leq Q_c \leq Q_c^{max}, i \in N_C \quad (18)$$

$$|SL_i| \leq S_{L_i}^{max}, i \in N_{TL} \quad (19)$$

$$VG_i^{min} \leq VG_i \leq VG_i^{max}, i \in N_g \quad (20)$$

Multi objective fitness (MOF) = $F_1 + r_i F_2 + u F_3$

$$= F_1 + \left[\sum_{i=1}^{NL} x_v [VL_i - VL_i^{min}]^2 + \sum_{i=1}^{NG} r_g [QG_i - QG_i^{min}]^2 \right] + r_f F_3 \quad (21)$$

$$VL_i^{minimum} = \begin{cases} VL_i^{max}, & VL_i > VL_i^{max} \\ VL_i^{min}, & VL_i < VL_i^{min} \end{cases} \quad (22)$$

$$QG_i^{minimum} = \begin{cases} QG_i^{max}, & QG_i > QG_i^{max} \\ QG_i^{min}, & QG_i < QG_i^{min} \end{cases} \quad (23)$$

3. Hybrid opposition based—Chaotic little golden-mantled flying fox algorithm and White-winged chough search optimization algorithm

Hybrid opposition based—Chaotic little golden-mantled flying fox Algorithm and White-winged chough search optimization Algorithm is based on the natural actions of little golden-mantled flying fox and White-winged chough. Through the hybridization of both algorithms exploration and exploitation has been balanced throughout the procedure. Proposed little golden-mantled flying fox algorithm is designed based on the deeds of the little golden-mantled flying fox. In the course of the epoch of commotion, they utilize flying mode to reach the nutriment possessions. By scarce exclusions, they are inept to use sound waves, depend on sanities of vision and aroma to circumnavigate and discover the nutriment. Little golden-mantled flying fox grasp erotic adulthood gradually and obligate a little procreative production. Maximum classes have single progenies at a period afterwards of prenatal period. This little procreative production means that when populace forfeiture their figures are deliberate to ricochet. A sector of all classes is itemized as endangered, because of obliteration of habitats and hunting. Little golden-mantled flying fox are a widespread nutriment spring in certain zones, prominent to populace deteriorations and extermination.

Little golden-mantled flying fox passage in the binary exploration zone grounded on the location, rapidity, and incidence vectors and updated in all iterations. The rapidity and incidence of little golden-mantled flying fox “ i ” can be modernized as,

$$M_i^{k+1} = M_i^k + (N_i^k - global_{best}) \Delta_i \quad (24)$$

where M_i^{k+1} and M_i^k are the rapidity of the Little golden-mantled flying fox, N_i^k is the location of the Little golden-mantled flying fox, $global_{best}$ is the present global location.

$$\Delta_i = \Delta^{min} + (\Delta^{max} - \Delta^{min})\delta \quad (25)$$

where Δ^{max} and Δ^{min} are maximum, minimum levels of incidence rate, $\delta \in [0,1]$.

Little golden-mantled flying fox able to alter their locations by means of the V-shaped transferal utility,

$$M(m_i^k) = |2/\pi \tan^{-1}(\pi/2 m_i^k)| \quad (26)$$

$$N_i^{k+1} = \begin{cases} (N_i^k)^{-1} & \text{if } random < M(m_i^{k+1}) \\ N_i^k & \text{if } random \geq M(m_i^{k+1}) \end{cases} \quad (27)$$

where $M(m_i^k)$ is V-shaped transferal utility of little golden-mantled flying fox “ i ”, N_i^{k+1} is the location of the little golden-mantled flying fox, $(N_i^k)^{-1}$ is counterpart of N_i^k .

$$(N_i^{k+1})^{Fresh} = \begin{cases} (N_i^k)^{best} & \text{Random} > L_i^k \\ N_i^{k+1} & \text{otherwise} \end{cases} \quad (28)$$

Fresh solutions are engendered by appraising the little golden-mantled flying fox locations by means of the arbitrary walk,

$$(N_i^{k+1})^{Fresh} = \begin{cases} (N_i^{k+1})^{best} & \text{if } J_i^{k+1} < global_{best} \text{ and } Random < L_i^{k+1} \\ (N_i^k)^{best} & \text{otherwise} \end{cases} \quad (29)$$

where J_i^{k+1} and L_i^{k+1} decibels of Little golden-mantled flying fox.

$$L_i^{k+1} = \beta L_i^k \quad (30)$$

$$Q_i^{k+1} = Q_i^0 (1 - e^{-\alpha k}) \quad (31)$$

where Q_i^0 is primary Throb discharge rate, $0 < \beta < 1$, $\alpha > 0$.

Opposition based—Chaotic little golden-mantled flying fox Algorithm employs Laplace distribution to enhance the exploration skill^[13].

$$function(v) = \begin{cases} \frac{1}{2} \exp(-|v - c|/d), & b \leq c \\ 1 - \frac{1}{2} \exp(-|v - c|/d), & b > c \end{cases} \quad (32)$$

$$function(v; c, d) = 1/2v \exp(-|v - c|/d), -\infty < c < \infty \quad (33)$$

where $c \in (-\infty, \infty)$.

$$O^o = c + d - U \quad (34)$$

Then the movement of the little golden-mantled flying fox in search of nourishment rendering to Levy flight^[14,15] is mathematically articulated as,

$$Q(i + 1) = O(i) - |d(t)| \times H \times Levy(d) \quad (35)$$

$$L(s) \sim |s| - 1 - \beta \text{ where } 0 < \beta < 2 \quad (36)$$

$$L(s, \gamma, \mu) = \begin{cases} \sqrt{\frac{\gamma}{2\pi}} \exp\left[-\frac{\gamma}{2(s - \mu)}\right] \frac{1}{(s - \mu)^{3/2}} & \text{if } 0 < \mu < s < \infty \\ 0 & \text{if } s \leq 0 \end{cases} \quad (37)$$

The lowest and extreme parameters of regulating variables can be modernized inside the key assortment at the culmination of iterations. **Figure 2** shows the image of little golden-mantled flying fox.

$$N_i^{min}(k + 1) = N_i^{min} + \rho[N_i^{best}(k) - N_i^{min}] \quad (38)$$

$$N_i^{max}(k+1) = N_i^{max} - \rho[N_i^{max} - N_i^{best}(k)] \quad (39)$$

where $N_i^{best}(k)$ is the excellent value.

$$\rho, k = 0.80$$

$$N_i(k+1) = N_i^{min}(k+1) + \emptyset[N_i^{max}(k+1) - N_i^{min}(k+1)] \quad (40)$$

$$\emptyset \in [0,1]$$

The preliminary values are obtained by,

$$J_i^{intial} = [J_1^{intial}, J_2^{intial}, J_2^{intial}, \dots, J_{n\text{Little golden-mantled flying fox}}^{intial}] \quad (41)$$

Then the candidate solutions are acquired by,

$$J_i^{k+1} = [J_1^{k+1}, J_2^{k+1}, J_2^{k+1}, \dots, J_{n\text{Little golden-mantled flying fox}}^{k+1}] \quad (42)$$

Global excellent solutions are streamlined by,

$$Global_{best}^{k+1} = \begin{cases} J_{best}^{k+1} & \text{if } J_{best}^{k+1} < Global_{best}^k \\ Global_{best}^k & \text{otherwise} \end{cases} \quad (43)$$

- a. Start
- b. Set the parameter values
- c. Engender the initial position
- d. Position the Little golden-mantled flying fox arbitrarily rendering to the parameter
- e. Apply the chaotic sequence
- f. Apply Opposition points
- g. Apply the preliminary the evaluation
- h. $J_i^{intial} = [J_1^{intial}, J_2^{intial}, J_2^{intial}, \dots, J_{n\text{Little golden-mantled flying fox}}^{intial}]$
- i. *verfiy the limits*
- j. Acquire the global excellent solution
- k. Apply the changeover regulation
- l. $N_i^{k+1} = \begin{cases} (N_i^k)^{-1} & \text{if } random < M(m_i^{k+1}) \\ N_i^k & \text{if } random \geq M(m_i^{k+1}) \end{cases}$
- m. $M(m_i^k) = |2/\pi \tan^{-1}(\pi/2 m_i^k)|$ ($\sigma \times k / \text{iteration maximum}$)
- n. *Engender fresh solutions*
- o. $(N_i^{k+1})^{Fresh} = \begin{cases} (N_i^k)^{best} & \text{Random} > L_i^k \\ N_i^{k+1} & \text{otherwise} \end{cases}$
- p. $(N_i^{k+1})^{Fresh} = \begin{cases} (N_i^{k+1})^{best} & \text{if } J_i^{k+1} < global_{best} \text{ and } Random < L_i^{k+1} \\ (N_i^k)^{best} & \text{otherwise} \end{cases}$
- q. $J_i^{k+1} = [J_1^{k+1}, J_2^{k+1}, J_2^{k+1}, \dots, J_{n\text{Little golden-mantled flying fox}}^{k+1}]$
- r. *verfiy the limits*
- s. Streamline the global excellent solutions
- t. $Global_{best}^{k+1} = \begin{cases} J_{best}^{k+1} & \text{if } J_{best}^{k+1} < Global_{best}^k \\ Global_{best}^k & \text{otherwise} \end{cases}$
- u. $Z^{t+1} = Z^t + R(\text{size}(D)) \oplus \text{Levy}(\beta) \sim 0.01 \frac{u}{|v|^{1/\beta}} (Z_j^t - gb)$
- v. $FS_s = FS_{max} - iter_p \cdot FS_{max} - FS_{min} / iter_{max}$
- w. $M_i(iter) = FS_s * (max_i + min_i - M_e(iter))$
- x. Modernize the Q_i^0 is primary Throb discharge rate
- y. Rationalize the L_i^{k+1} decibels of Little golden – mantled flying fox
- z. $L_i^{k+1} = \beta L_i^k$

- aa. $Q_i^{k+1} = Q_i^0(1 - e^{-\alpha k})$
- bb. Streamline the exploration area
- cc. $N_i^{min}(k + 1) = N_i^{min} + \rho[N_i^{best}(k) - N_i^{min}]$
- dd. $N_i^{max}(k + 1) = N_i^{max} - \rho[N_i^{max} - N_i^{best}(k)]$
- ee. $N_i(k + 1) = N_i^{min}(k + 1) + \emptyset[N_i^{max}(k + 1) - N_i^{min}(k + 1)]$
- ff. Verify the end condition
- gg. Repeat the steps “g” to “ee” until max no of iter. reached
- hh. End

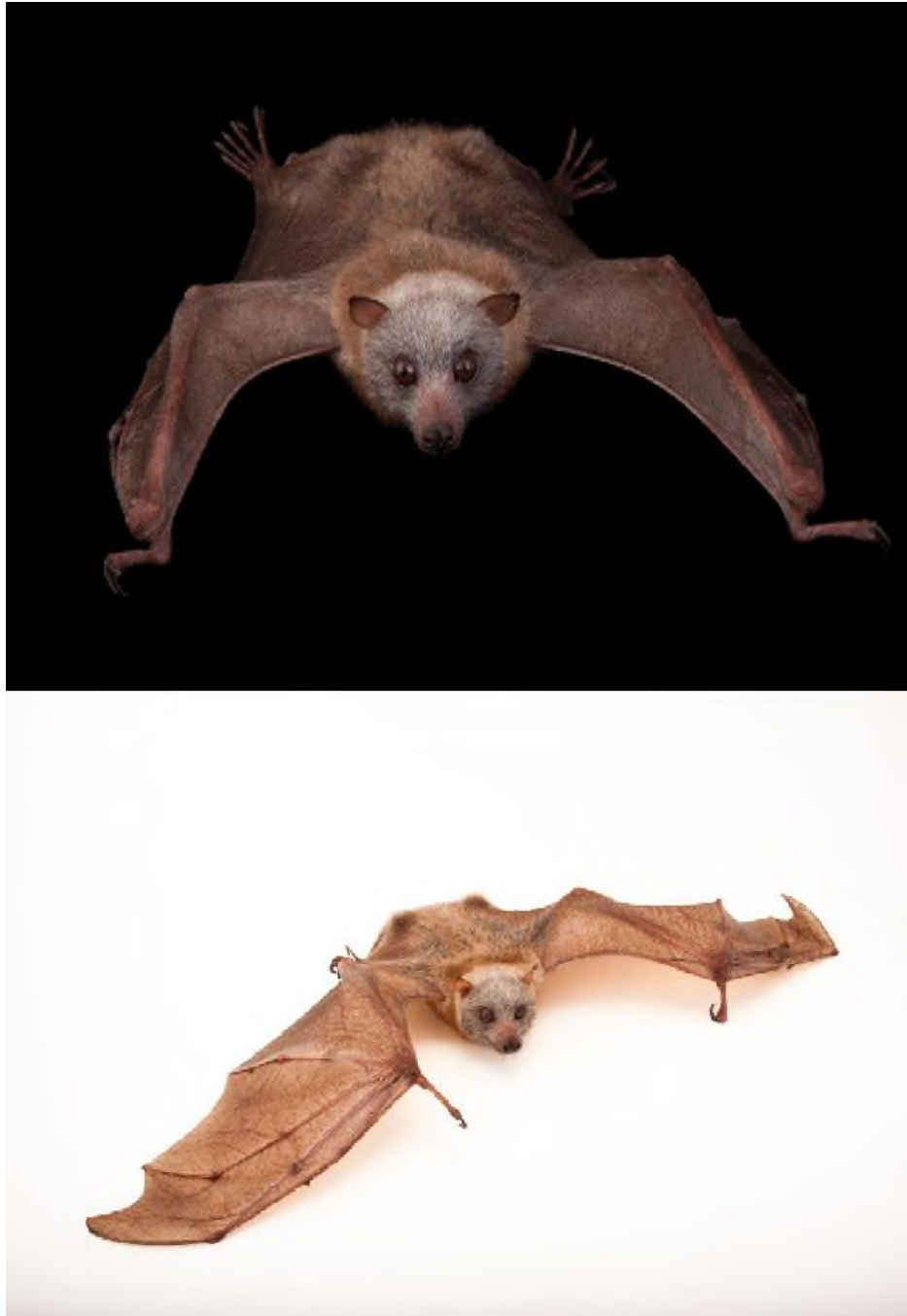


Figure 2. Image representation of little golden-mantled flying fox^[16].

White-winged chough search optimization algorithm

White-winged chough search (WWCS) algorithm is a modern meta-heuristic procedure which is inspired on the elegance comportment of White-winged chough. Dimensions of the White-winged chough group is recognized by Q entities as follows,

$$AC_{i,n} = [ac_{i,l}^1, ac_{i,l}^2, \dots, ac_{i,l}^n] \quad (44)$$

where $AC_{i,n}$ indicate position of White-winged chough in iteration n , $i = 1, 2, \dots, Q$, $l = 1, 2, \dots, \text{Maximum iteration}$.

Every White-winged chough is whispered to have the prospective of remembering the supreme visited position in order to concealment of nutriment up until the contemporary iteration is defined as,

$$S_{i,l} = [s_{i,l}^1, s_{i,l}^2, \dots, s_{i,l}^n] \quad (45)$$

Every White-winged chough “ i ” performance is expressed by an alertness prospect (ALP). Consequently, a whimsical rate w_i homogeneously spread in the middle of 0 and 1. If w_i is enhanced or equivalent to alertness prospect (ALP), then act M is applied, otherwise act N is designated.

$$AC_{i,l+1} = \begin{cases} AC_{i,l} + w_i \cdot H_{i,l} \cdot (S_{i,l} - AC_{i,l}) & w_i > ALP \\ R & \text{otherwise} \end{cases} \quad (46)$$

where $H_{i,l}$ specify the rule of evolution from White-winged chough, $AC_{i,l}$ in the course of supreme location $S_{i,l}$ of a White-winged chough “ j ”, $w_i \in [0, 1]$.

Once the White-winged choughs are custom-made, at that point their position is appraised and reminiscence vector is restructured.

$$S_{i,l+1} = \begin{cases} Fit(AC_{i,l+1}), Fit(AC_{i,l+1}) < Fit(S_{i,l}) \\ S_{i,l} & \text{otherwise} \end{cases} \quad (47)$$

Then a vibrant concentration prospect factor (VCP) applied for augmentation, and it is familiarized by the aptness supremacy of every contender elucidation,

$$VCP_{i,k} = 0.898 \cdot \frac{Fit(X_{i,l})}{\varphi\tau} + 0.1 \quad (48)$$

where $\varphi\tau$ indicate *teh* deprived appropriateness rate perceived up till now.

$$\varphi\tau = \text{maximum } Fit(AC_{i,l+1}) \quad (49)$$

White-winged chough search (WWCS) algorithm delivers dualistic phases of amplification and divergence. In principal phase, the aeronautical formulation is swotted to hustle up the procedure’s convergence in the direction of the universal optimal value. In addition, magnifying the encumbrance element in a definite assortment will pointedly enlarge the exploration region.

The position modernization is demarcated by,

$$AC^{i,iter+1} = EE(t) \times AC^{i,iter} + w_i \times Fit^{iter} \times (global_{best} - AC^{iter}) \quad (50)$$

where EE specify the encumbrance element factor.

$$EE(t) = \exp(-t^2/2(T/40)^2)EE_{max} \quad (51)$$

where T and t is maximum and current iteration.

In a coiled exploration, the position of any White-winged chough can differ in numerous scopes to cover the exploration region, predominantly in the projected problem. Consequently, info about the superlative position for a White-winged chough can be well castoff. Concurrently, individual locations are rationalized in an arbitrary way to guarantee that entities are well dispersed to the populace, thus reducing the danger of being wedged in limited regions. The coiled exploration can be accomplished by devious the space from the preceding location to the preeminent location.

$$AC^{t+1} = space \cdot \exp(uy) \cos(2\pi l) + global_{best} \quad (52)$$

where u specify the logarithmic coiled shape, $y \in \{-1,1\}$.

$$space = |global_{best} - AC^t| \quad (53)$$

A Gaussian alteration or arbitrary grounded commotion is added to evade the premature elucidation as follows,

$$AC^{i+1,iter} = \begin{cases} AC^{i,iter} + R, & \text{if } j \geq 0.20 \\ AC^{i,iter} \times G(\mu, \sigma) & \text{otherwise} \end{cases} \quad (54)$$

where $R \in [0,1]$, j is probability of picking the Gaussian alteration or arbitrary grounded commotion.

$$GC_l(a) = \frac{1}{\sqrt{(2\pi)^2 |C_l|}} \exp\left(-\frac{1}{2}(a - \sigma_l)\right)^T \cdot C_l^{-1}(a - \sigma_l) \quad (55)$$

$$\sum_{l=1}^l \delta_l = 1 \quad (56)$$

$$Q(a) \approx \sum_{l=1}^l \delta_k \cdot GC_l(a) \quad (57)$$

Lévy flights are employed as a substitute of constant illogical actions to imitate the elusion performance.

$$Z_i = \frac{a}{|b|^{1/\beta}} \quad (58)$$

$$a \sim N(0, \sigma_a^2); b \sim N(0, \sigma_b^2) \quad (59)$$

$$\sigma_a = \left\{ \frac{\Gamma(1 + \beta) \sin(\pi\beta/2)}{\Gamma[(1 + \beta)/2] \beta^{2(\beta-1)/2}} \right\} \quad (60)$$

Chaotic sequences^[13–15] are integrated in the White-winged chough search (WWCS) algorithm and it will augment the Exploration and Exploitation process.

$$p_{t+1}^* = p_{t+1} - \min(p)/\max(p) - \min(p) \quad (61)$$

Quantum^[13–15] features are reliable pounded of median and it has been integrated with White-winged chough Optimization algorithm.

$$|\Psi|^2 \cdot dx \cdot dy \cdot dz = Q \cdot dx \cdot dy \cdot dz \quad (62)$$

Opposition based learning^[13–15] integrated in the White-winged chough search algorithm and it applies the Laplace distribution to augment the exploration dexterity.

$$S^o = a + b - Z \quad (63)$$

Figure 3 shows the image of White-winged chough.

- a. Start
- b. Set the parameters values
- c. Quixotically create the White-winged chough location
- d. Reminiscence has been hindered rendering to initial location
- e. For each location fitness position has been calculated
- f. step 1: Apply the vibrant concentration prospect factor
- g. $VCP_{i,k} = 0.898 \cdot \frac{Fit(X_{i,l})}{\varphi\tau} + 0.1$
- h. Sch(Ti)is $\frac{d^2\psi}{dz^2} + \frac{2m}{\hbar^2} [G + \gamma\delta(z)]\psi = 0$
- i. $\Psi(z) = \frac{1}{\sqrt{L}} e^{-\frac{|z|}{L}}$
- j. $Q(z) = |\Psi(z)|^2 = \frac{1}{\sqrt{L}} e^{-\frac{|z|}{L}}$

- k. step 2: Create the whimsical rate w_i for each White-winged chough “ i ”
- l. $AC_{i,l+1} = \begin{cases} AC_{i,l} + w_i \cdot H_{i,l} \cdot (S_{i,l} - AC_{i,l}) & w_i > ALP \\ otherwise & \end{cases}$
- m. $AC^{i,iter+1} = EE(t) \times AC^{i,iter} + w_i \times Fit^{iter} \times (global_{best} - AC^{iter})$
- n. $AC^{t+1} = space \cdot \exp(uy) \cos(2\pi l) + global_{best}$
- o. $p_{t+1} = p_t^2 - q_t^2 + a \cdot p_t + b \cdot q_t$
- p. $q_{t+1} = 2p_t q_t + c \cdot p_t + d \cdot q_t$
- q. $p_{t+1}^* = p_{t+1} - \min(p)/\max(p) - \min(p)$
- r. $f(l) = \begin{cases} \frac{1}{2} \exp(-|l - c|/d), & b \leq c \\ 1 - \frac{1}{2} \exp(-|l - c|/d), & b > c \end{cases}$
- s. $S_i(iteration) = X_s * (\text{minimum}_i + \text{maximum}_i - S_e(iteration))$
- t. Step 3: Apply Gaussian alteration or arbitrary grounded commotion
- u. $AC^{i+1,iter} = \begin{cases} AC^{i,iter} + R, & \text{if } j \geq 0.20 \\ AC^{i,iter} \times G(\mu, \sigma) & otherwise \end{cases}$
- v. $GC_l(a) = \frac{1}{\sqrt{(2\pi)^2 |c_l|}} \exp\left(-\frac{1}{2}(a - \sigma_l)\right)^T \cdot C_l^{-1}(a - \sigma_l)$
- w. Modernize the location
- x. $AC_{i,n+1} = A_{i,n} + L$
- y. Identify the Probability of the fresh location
- z. Compute the Fresh locations appropriateness rate
- aa. Streamline the reminiscence once there is an enhancement in appropriateness rate
- bb. Is culmination condition is met; if yes end the iteration or else go to step e
- cc. Stop



Figure 3. Image representation of White-winged chough^[17].

Hybrid Opposition based—Chaotic little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC) is accomplished by integrating the actions of little golden-mantled flying fox and White-winged chough. Through the hybridization of both algorithms exploration and exploitation has been balanced throughout the procedure.

- a. Start
- b. Set the parameter values
- c. Engender the initial position
- d. Position the Little golden-mantled flying fox arbitrarily rendering to the parameter
- e. Apply the chaotic sequence
- f. Apply Opposition points
- g. Apply the preliminary the evaluation
- h. $J_i^{initial} = [J_1^{initial}, J_2^{initial}, J_2^{initial}, \dots, J_{n_{\text{Little golden-mantled flying fox}}}^{initial}]$
- i. *verfiy the limits*
- j. Acquire the global excellent solution
- k. Apply the changeover regulation
- l. $N_i^{k+1} = \begin{cases} (N_i^k)^{-1} & \text{if } \text{random} < M(m_i^{k+1}) \\ N_i^k & \text{if } \text{random} \geq M(m_i^{k+1}) \end{cases}$
- m. $M(m_i^k) = |2/\pi \tan^{-1}(\pi/2 m_i^k)|^{(\sigma \times k / \text{iteration maximum})}$
- n. *Engender fresh solutions*
- o. $(N_i^{k+1})^{Fresh} = \begin{cases} (N_i^k)^{best} & \text{Random} > L_i^k \\ N_i^{k+1} & \text{otherwise} \end{cases}$
- p. $(N_i^{k+1})^{Fresh} = \begin{cases} (N_i^{k+1})^{best} & \text{if } J_i^{k+1} < \text{global}_{best} \text{ and } \text{Random} < L_i^{k+1} \\ (N_i^k)^{best} & \text{otherwise} \end{cases}$
- q. $J_i^{k+1} = [J_1^{k+1}, J_2^{k+1}, J_2^{k+1}, \dots, J_{n_{\text{Little golden-mantled flying fox}}}^{k+1}]$
- r. *verfiy the limits*
- s. Streamline the global excellent solutions
- t. $\text{Global}_{best}^{k+1} = \begin{cases} J_{best}^{k+1} & \text{if } J_{best}^{k+1} < \text{Global}_{best}^k \\ \text{Global}_{best}^k & \text{otherwise} \end{cases}$
- u. $Z^{t+1} = Z^t + R(\text{size}(D)) \oplus \text{Levy}(\beta) \sim 0.01 \frac{u}{|v|^{1/\beta}} (Z_j^t - \text{gb})$
- v. $FS_s = FS_{max} - \text{iter}_p \cdot FS_{max} - FS_{min} / \text{iter}_{max}$
- w. $M_i(\text{iter}) = FS_s * (\max_i + \min_i - M_e(\text{iter}))$
- x. Modernize the Q_i^0 is primary Throb discharge rate
- y. Rationalize the L_i^{k+1} decibels of Little golden – mantled flying fox
- z. $L_i^{k+1} = \beta L_i^k$
- aa. $Q_i^{k+1} = Q_i^0 (1 - e^{-\alpha k})$
- bb. Streamline the exploration area
- cc. $N_i^{min}(k+1) = N_i^{min} + \rho [N_i^{best}(k) - N_i^{min}]$
- dd. $N_i^{max}(k+1) = N_i^{max} - \rho [N_i^{max} - N_i^{best}(k)]$
- ee. $N_i(k+1) = N_i^{min}(k+1) + \phi [N_i^{max}(k+1) - N_i^{min}(k+1)]$
- ff. Quixotically create the White-winged chough location
- gg. Reminiscence has been hindered rendering to initial location
- hh. For each location fitness position has been calculated
- ii. step 1: Apply the vibrant concentration prospect factor

$$\text{jj. } VCP_{i,k} = 0.898 \cdot \frac{Fit(X_{i,l})}{\phi\tau} + 0.1$$

$$\text{kk. } \text{Sch(Ti)}is \frac{d^2\psi}{dz^2} + \frac{2m}{h^2} [G + \gamma\delta(z)]\psi = 0$$

$$\text{ll. } \Psi(z) = \frac{1}{\sqrt{L}} e^{-\frac{|z|}{L}}$$

$$\text{mm. } Q(z) = |\Psi(z)|^2 = \frac{1}{\sqrt{L}} e^{-\frac{|z|}{L}}$$

nn. step 2: Create the whimsical rate w_i for each White-winged chough “i”

$$\text{oo. } AC_{i,l+1} = \begin{cases} AC_{i,l} + w_i \cdot H_{i,l} \cdot (S_{i,l} - AC_{i,l}) & w_i > \text{ALP} \\ R & \text{otherwise} \end{cases}$$

$$\text{pp. } AC^{i,iter+1} = EE(t) \times AC^{i,iter} + w_i \times Fit^{iter} \times (global_{best} - AC^{iter})$$

$$\text{qq. } AC^{t+1} = space \cdot \exp(uy) \cos(2\pi l) + global_{best}$$

$$\text{rr. } p_{t+1} = p_t^2 - q_t^2 + a \cdot p_t + b \cdot q_t$$

$$\text{ss. } q_{t+1} = 2p_t q_t + c \cdot p_t + d \cdot q_t$$

$$\text{tt. } p_{t+1}^* = p_{t+1} - \min(p)/\max(p) - \min(p)$$

$$\text{uu. } f(l) = \begin{cases} \frac{1}{2} \exp(-|l-c|/d), & b \leq c \\ 1 - \frac{1}{2} \exp(-|l-c|/d), & b > c \end{cases}$$

$$\text{vv. } S_i(\text{iteration}) = X_s * (\text{minimum}_i + \text{maximum}_i - S_e(\text{iteration}))$$

ww. Step 3: Apply Gaussian alteration or arbitrary grounded commotion

$$\text{xx. } AC^{i+1,iter} = \begin{cases} AC^{i,iter} + R, & \text{if } j \geq 0.20 \\ AC^{i,iter} \times G(\mu, \sigma) & \text{otherwise} \end{cases}$$

$$\text{yy. } GC_l(a) = \frac{1}{\sqrt{(2\pi)^2 |c_l|}} \exp\left(-\frac{1}{2}(a - \sigma_l)\right)^T \cdot C_l^{-1}(a - \sigma_l)$$

zz. Modernize the location

$$\text{aaa. } AC_{i,n+1} = A_{i,n} + L$$

bbb. Identify the Probability of the fresh location

ccc. Compute the Fresh locations appropriateness rate

ddd. Streamline the reminiscence once there is an enhancement in appropriateness rate

eee. Verify the end condition

fff. Repeat the steps “g” to “aaa” until max no of iter. reached

ggg. End

Computation complexity:

Computation complication is defined as,

$$O(N)$$

$$O(n \log n) = O\left(T(O(s) + O(p))\right)$$

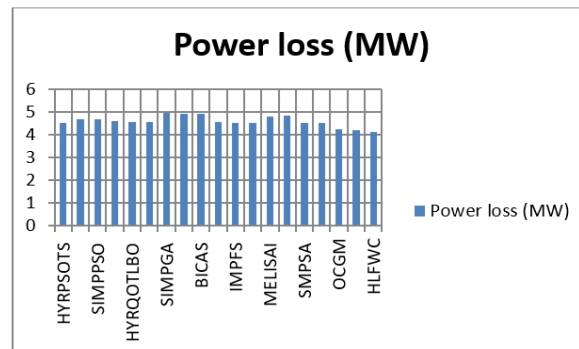
$$O(n^2) = O(t(n^2 + n \times d)) = O(tn^2 + tnd)$$

4. Simulation study

Hybrid Opposition based—Chaotic little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC) is validated in IEEE 30 bus system^[8]. **Table 1** and **Figure 4** give the assessment between the approaches.

Table 1. Assessment of loss.

Method	Loss (MW)	VD (PU)	Stability (PU)
HYRPSOTS ^[1]	4.5213	0.1038	0.1258
SIMPTS ^[1]	4.6862	0.2064	0.1499
SIMPPSO ^[1]	4.6862	0.1354	0.1271
HYRANTLOA ^[1]	4.5900	0.1287	0.1261
HYRQOTLBO ^[2]	4.5594	0.1202	0.1264
BICTLBO ^[2]	4.5629	0.1614	0.1488
SIMPGA ^[3]	4.9408	0.1539	0.1394
SSIPPSO ^[3]	4.9239	0.0892	0.1241
BICAS ^[3]	4.9059	0.0856	0.1191
SIMPFS ^[4]	4.5777	0.0913	0.1180
IMPFS ^[4]	4.5142	0.1220	0.1161
SIMPFS ^[5]	4.5275	0.0890	0.1161
MELISAI ^[6]	4.8193	0.0877	0.1242
MELISAI ^[7]	4.8547	0.374	0.1252
SMPSA ^[9]	4.5317	0.377	0.1252
IPRSSA ^[9]	4.5269	0.0854	0.1245
OCGM	4.2198	0.0831	0.1581
WWCS	4.1987	0.0819	0.1586
HLFWC	4.1062	0.0804	0.1597

**Figure 4.** Assessment between approaches.

Hybrid Opposition based—Chaotic little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC) is corroborated in IEEE 57 bus system^[12]. **Table 2** and **Figure 5** give the assessment between the approaches.

Table 2. Appraisal of power loss.

Method	Loss (MW)	VD (PU)	Stability (PU)
HRDICOA ^[9]	22.376	0.6051	0.2516
HRDICOA1 ^[9]	22.383	0.6155	0.2583
BICWCA ^[9]	26.0402	0.7309	0.2789
SPESA ^[9]	25.3854	0.94	0.2900
SPEFOA ^[9]	26.6541	0.7913	0.2831
BICCOA ^[10]	24.5358	0.6711	0.2757
MELISAI ^[11]	26.88	1.0642	0.2765

Table 2. (Continued).

MELISAI ^[11]	26.92	1.072	0.2517
BICISA ^[11]	26.97	1.0912	0.2594
MODEPSO ^[10]	27.83	1.10	0.2792
MODEEPSO ^[10]	27.42	0.896	0.2901
METFO ^[9]	24.25	0.6782	0.2883
MODEGWA ^[9]	21.171	1.0694	0.2769
SMPGA ^[11]	25.64	1.0729	0.2781
BICPSO ^[11]	25.03	1.0916	0.2772
BICAS ^[11]	24.90	1.0589	0.2788
OCGM	20.12	0.6029	0.2988
WWCS	20.09	0.6021	0.2990
HLFWC	20.02	0.6018	0.2996

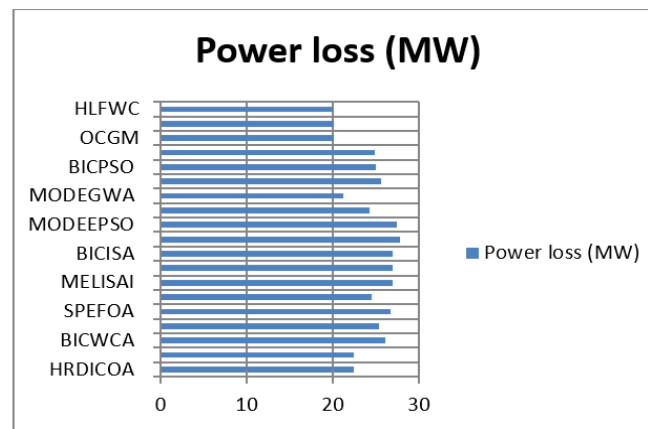
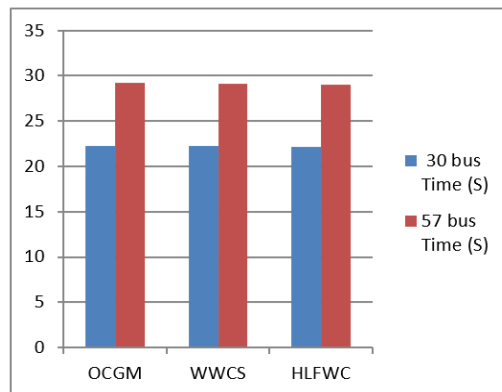
**Figure 5.** Appraisal between approaches.

Table 3 and **Figure 6** show the time taken by Hybrid Opposition based—Chaotic Little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC).

Table 3. Time taken by OCGM, WWCS and HLFWC.

Method	30 bus T (S)	57 bus T (S)
OCGM	22.29	29.18
WWCS	22.22	29.12
HLFWC	22.12	29.07

**Figure 6.** Time taken by Hybrid Opposition based—Chaotic little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC).

Discussion of results

Hybrid Opposition based—Chaotic little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC) reduced the real power loss reduction; Voltage deviation minimization and Voltage stability expansion has been achieved. Real power loss (MW) obtained by HLFWC is 4.1062 for IEEE 30 bus system and for IEEE 57 bus system, Real power loss (MW) obtained by HLFWC is 20.02. Comparison had been done with other standard algorithms. Proposed HLFWC algorithm effectively reduced the power loss and voltage stability also enhanced.

5. Conclusion

Hybrid Opposition based—Chaotic little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC) truncated the loss competently. Opposition based—Chaotic little golden-mantled flying fox Algorithm employs Laplace distribution to enhance the exploration skill. Then examining the prospect to widen the exploration, a new method endorses stimulating capricious statistics used in formation stage of regulator factor in the algorithm. The perception of opposite number requirements is to be delineated to explicate Opposition based learning. In White-winged chough search Optimization Algorithm magnifying the encumbrance element in a definite assortment will pointedly enlarge the exploration region. In a coiled exploration, the position of any White-winged chough can differ in numerous scopes to cover the exploration region, predominantly in the projected problem. Consequently, info about the superlative position for a White-winged chough can be well castoff. Concurrently, individual locations are rationalized in an arbitrary way to guarantee that entities are well dispersed to the populace, thus reducing the danger of being wedged in limited regions. The coiled exploration can be accomplished by devious the space from the preceding location to the preeminent location. Hybrid Opposition based—Chaotic Little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC) is accomplished by integrating the actions of little golden-mantled flying fox and White-winged chough. Through the hybridization of both algorithms exploration and exploitation has been balanced throughout the procedure. Proposed Hybrid Opposition based—Chaotic Little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC) is validated in IEEE 30 and 57 systems. From the simulation outcomes it has been witnessed that real power loss lessening, Voltage abnormality minimization and Voltage stability enlargement has been achieved.

Future scope of work

In future Hybrid Opposition based—Chaotic little golden-mantled flying fox Algorithm and White-winged chough search Optimization Algorithm (HLFWC) can be applied to practical systems and other areas of Engineering domain.

Conflict of interest

The author declares no conflict of interest.

References

1. Sahli Z, Hamouda A, Bekrar A, Trentesaux D. Hybrid PSO-tabu search for the optimal reactive power dispatch problem. In: Proceedings of the IECON 2014-40th Annual Conference of the IEEE Industrial Electronics Society; November 2014; Dallas, TX, USA. pp. 3536–3542.
2. Mouassa S, Bouktir T, Salhi A. Ant lion optimizer for solving optimal reactive power dispatch problem in power systems. *Engineering Science and Technology, an International Journal* 2017; 20(3): 885–895. doi: 10.1016/j.jestch.2017.03.006
3. Mandal B, Roy PK. Optimal reactive power dispatch using quasi-oppositional teaching learning based optimization. *International Journal of Electrical Power & Energy Systems* 2013; 53: 123–134. doi: 10.1016/j.ijepes.2013.04.011
4. Khazali AH, Kalantar M. Optimal reactive power dispatch based on harmony search algorithm. *International Journal of Electrical Power & Energy Systems* 2011; 33(3): 684–692. doi: 10.1016/j.ijepes.2010.11.018

5. Tran HV, Pham TV, Pham LH, et al. Finding optimal reactive power dispatch solutions by using a novel improved stochastic fractal search optimization algorithm. *Telecommunication Computing Electronics and Control* 2019; 17(5): 2517–2526. doi: 10.12928/telkomnika.v17i5.10767
6. Polprasert J, Ongsakul W, Dieu VN. Optimal reactive power dispatch using improved pseudo-gradient search particle swarm optimization. *Electric Power Components and Systems* 2016; 44(5): 518–532. doi: 10.1080/15325008.2015.1112449
7. Duong TL, Duong MQ, Phan VD, Nguyen TT. Optimal reactive power flow for large-scale power systems using an effective metaheuristic algorithm. *Hindawi Journal of Electrical and Computer Engineering* 2020; 2020: 6382507. doi: 10.1155/2020/6382507
8. Illinois Center for a Smarter Electric Grid (ICSEG). Working toward a smarter grid. Available online: <https://icseg.iti.illinois.edu/> (accessed on 11 August 2023).
9. Dai C, Chen W, Zhu Y, Zhang X. Seeker optimization algorithm for optimal reactive power dispatch. *IEEE Transactions on Power Systems* 2009; 24(3): 1218–1231. doi: 10.1109/TPWRS.2009.2021226
10. Subbaraj P, Rajnarayan PN. Optimal reactive power dispatch using self-adaptive real coded Genetic algorithm. *Electric Power Systems Research* 2009; 79(2): 374–381. doi: 10.1016/j.epsr.2008.07.008
11. Pandya S, Roy R. Particle swarm optimization based optimal reactive power dispatch. In: Proceedings of the IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT); 5–7 March 2015; Coimbatore, India. pp. 1–5.
12. Illinois Center for a Smarter Electric Grid (ICSEG). The IEEE 57-bus test system. Available online: <https://icseg.iti.illinois.edu/ieee-57-bus-system/> (accessed on 11 August 2023).
13. Macur E, Kiraz B. Opposition based binary particle swarm optimization algorithm for feature selection. In: Proceedings of the 2022 Innovations in Intelligent Systems and Applications Conference (ASYU); 7–9 September 2022; Antalya, Turkey. pp. 1–6.
14. Li B, Huang QB, Jiang W. An improved imperialist competitive algorithm inspired by democratic revolution. In: Proceedings of the 2022 China Automation Congress (CAC); 25–27 November 2022; Xiamen, China. pp. 4742–4747.
15. Li M, Mikki S, Uzoma PC, Penkov OV. An efficient method for the experimental characterization of periodic multilayer mirrors: A global optimization approach. *IEEE Transactions on Nuclear Science* 2023; 70(4): 650–658. doi: 10.1109/TNS.2023.3255892
16. Heaney L, Rosell-Ambal RGB, Tabaranza B, et al. Little golden-mantled flying fox. Available online: <https://www.iucnredlist.org/species/18753/22086307> (accessed on 11 August 2023).
17. Boland CRJ, Heinsohn R, Cockburn A. Deception by helpers in cooperatively breeding White-winged choughs and its experimental manipulation. *Behavioral Ecology and Sociobiology* 1997; 41(4): 251–256. doi: 10.1007/s002650050386
18. Sri Ganapathy Sachchidananda Swamiji. Available online: <https://dattapeetham.org/page/view/sri-ganapathy-sachchidananda-swamiji/accessed%20on%2028.10.2022%20at%208.25> (accessed on 11 August 2023).
19. Lotfi H. Optimal sizing of distributed generation units and shunt capacitors in the distribution system considering uncertainty resources by the modified evolutionary algorithm. *Journal of Ambient Intelligence and Humanized Computing* 2022; 13: 4739–4758. doi: 10.1007/s12652-021-03194-w
20. Lotfi H. Multi-objective network reconfiguration and allocation of capacitor units in radial distribution system using an enhanced artificial bee colony optimization. *Electric Power Components and Systems* 2021; 49(13–14): 1130–1142. doi: 10.1080/15325008.2022.2049661
21. Lotfi H, Azizivahed A, Shojaei AA, et al. Multi-objective distribution feeder reconfiguration along with optimal sizing of capacitors and distributed generators regarding network voltage security. *Electric Power Components and Systems* 2021; 49(6–7): 652–668. doi: 10.1080/15325008.2021.2011486

Appendix A. IEEE 30-Bus System

The IEEE 30-bus test case represents a simple approximation of the American Electric Power system as it was in December 1961^[8]. The equivalent system has 15 buses, 2 generators, and 3 synchronous condensers. The 11 kV and 1.0 kV base voltages are guesses, and may not reflect the actual data. The model actually has these buses at either 132 or 33 kV; what is worth mentioning is that the 30-bus test case does not have line limits^[8]. **Figure A1** shows IEEE 30 bus case system and **Figure A2** gives the test data of IEEE 30 bus system.

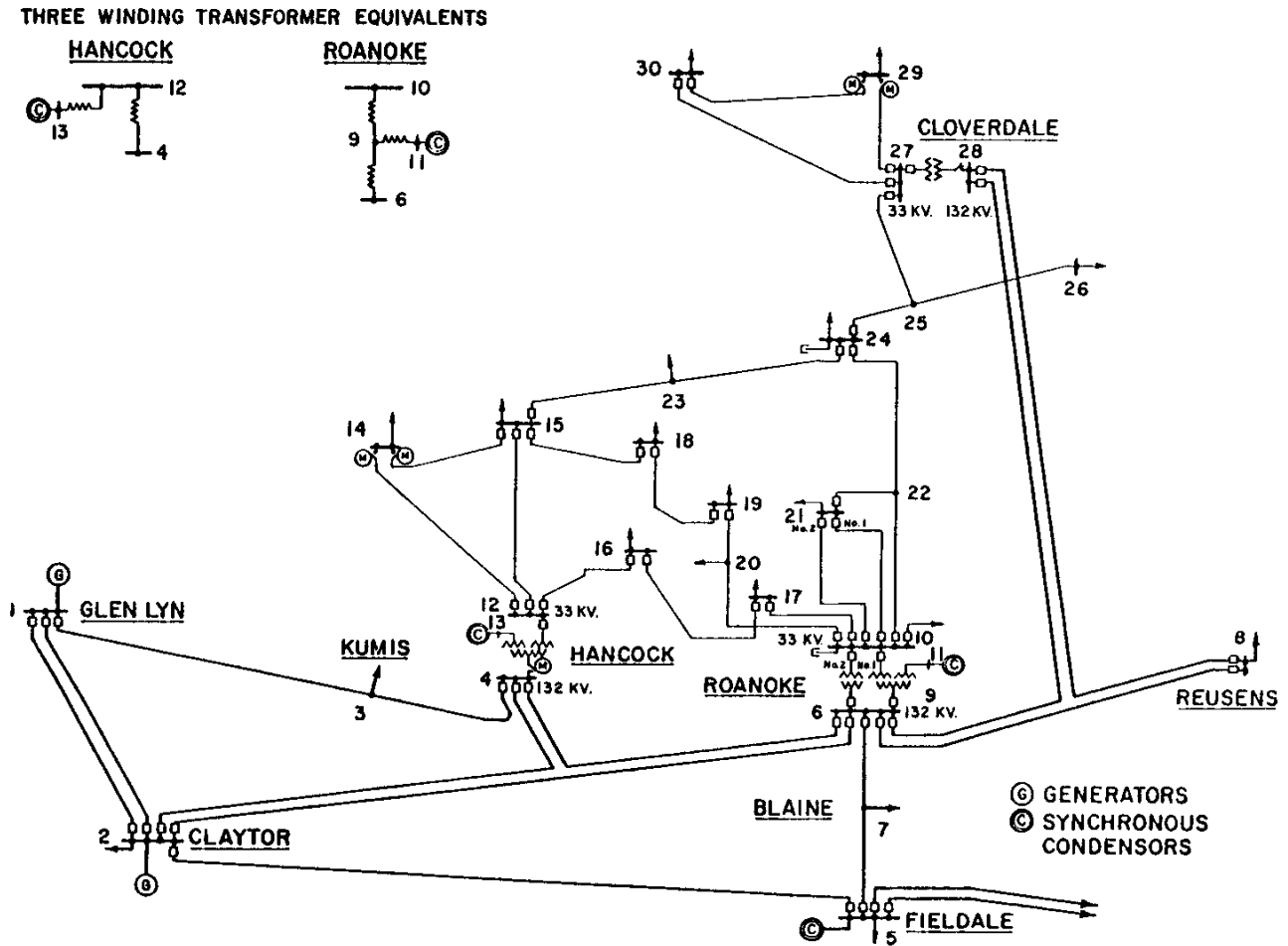


Figure A1. IEEE 30-bus test^[8].

```

08/20/93 UW ARCHIVE          100.0 1961 W IEEE 30 Bus Test Case
BUS DATA FOLLOWS          30 ITEMS
1 Glen Lyn 132 1 1 3 1.060 0.0 0.0 0.0 260.2 -16.1 132.0 1.060 0.0 0.0 0.0 0.0 0
2 Claytor 132 1 1 2 1.043 -5.48 21.7 12.7 40.0 50.0 132.0 1.045 50.0 -40.0 0.0 0.0 0
3 Kumis 132 1 1 0 1.021 -7.96 2.4 1.2 0.0 0.0 132.0 0.0 0.0 0.0 0.0 0.0 0
4 Hancock 132 1 1 0 1.012 -9.62 7.6 1.6 0.0 0.0 132.0 0.0 0.0 0.0 0.0 0.0 0
5 Fieldale 132 1 1 2 1.010 -14.37 94.2 19.0 0.0 37.0 132.0 1.010 40.0 -40.0 0.0 0.0 0
6 Roanoke 132 1 1 0 1.010 -11.34 0.0 0.0 0.0 0.0 132.0 0.0 0.0 0.0 0.0 0.0 0
7 Blaine 132 1 1 0 1.002 -13.12 22.8 10.9 0.0 0.0 132.0 0.0 0.0 0.0 0.0 0.0 0
8 Reusens 132 1 1 2 1.010 -12.10 30.0 30.0 0.0 37.3 132.0 1.010 40.0 -10.0 0.0 0.0 0
9 Roanoke 1.0 1 1 0 1.051 -14.38 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0
10 Roanoke 33 1 1 0 1.045 -15.97 5.8 2.0 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.19 0
11 Roanoke 11 1 1 2 1.082 -14.39 0.0 0.0 0.0 16.2 11.0 1.082 24.0 -6.0 0.0 0.0 0
12 Hancock 33 1 1 0 1.057 -15.24 11.2 7.5 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
13 Hancock 11 1 1 2 1.071 -15.24 0.0 0.0 0.0 10.6 11.0 1.071 24.0 -6.0 0.0 0.0 0
14 Bus 14 33 1 1 0 1.042 -16.13 6.2 1.6 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
15 Bus 15 33 1 1 0 1.038 -16.22 8.2 2.5 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
16 Bus 16 33 1 1 0 1.045 -15.83 3.5 1.8 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
17 Bus 17 33 1 1 0 1.040 -16.14 9.0 5.8 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
18 Bus 18 33 1 1 0 1.028 -16.82 3.2 0.9 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
19 Bus 19 33 1 1 0 1.026 -17.00 9.5 3.4 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
20 Bus 20 33 1 1 0 1.030 -16.80 2.2 0.7 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
21 Bus 21 33 1 1 0 1.033 -16.42 17.5 11.2 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
22 Bus 22 33 1 1 0 1.033 -16.41 0.0 0.0 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
23 Bus 23 33 1 1 0 1.027 -16.61 3.2 1.6 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
24 Bus 24 33 1 1 0 1.021 -16.78 8.7 6.7 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.043 0
25 Bus 25 33 1 1 0 1.017 -16.35 0.0 0.0 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
26 Bus 26 33 1 1 0 1.000 -16.77 3.5 2.3 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
27 Cloverdle 33 1 1 0 1.023 -15.82 0.0 0.0 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
28 Cloverdle 132 1 1 0 1.007 -11.97 0.0 0.0 0.0 0.0 132.0 0.0 0.0 0.0 0.0 0.0 0
29 Bus 29 33 1 1 0 1.003 -17.06 2.4 0.9 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
30 Bus 30 33 1 1 0 0.992 -17.94 10.6 1.9 0.0 0.0 33.0 0.0 0.0 0.0 0.0 0.0 0
-999

BRANCH DATA FOLLOWS          41 ITEMS
1 2 1 1 1 0 0.0192 0.0575 0.0528 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
1 3 1 1 1 0 0.0452 0.1652 0.0408 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
2 4 1 1 1 0 0.0570 0.1737 0.0368 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
3 4 1 1 1 0 0.0132 0.0379 0.0084 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
2 5 1 1 1 0 0.0472 0.1983 0.0418 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
2 6 1 1 1 0 0.0581 0.1763 0.0374 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
4 6 1 1 1 0 0.0119 0.0414 0.0090 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
5 7 1 1 1 0 0.0460 0.1160 0.0204 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
6 7 1 1 1 0 0.0267 0.0820 0.0170 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
6 8 1 1 1 0 0.0120 0.0420 0.0090 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
6 9 1 1 1 0 0.0 0.2080 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
6 10 1 1 1 0 0.0 0.5560 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
9 11 1 1 1 0 0.0 0.2080 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
9 10 1 1 1 0 0.0 0.1100 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
4 12 1 1 1 0 0.0 0.2560 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
12 13 1 1 1 0 0.0 0.1400 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
12 14 1 1 1 0 0.1231 0.2559 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
12 15 1 1 1 0 0.0662 0.1304 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
12 16 1 1 1 0 0.0945 0.1987 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
14 15 1 1 1 0 0.2210 0.1997 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
16 17 1 1 1 0 0.0524 0.1923 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
15 18 1 1 1 0 0.1073 0.2185 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
18 19 1 1 1 0 0.0639 0.1292 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
19 20 1 1 1 0 0.0340 0.0680 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
10 20 1 1 1 0 0.0936 0.2090 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
10 17 1 1 1 0 0.0324 0.0845 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
10 21 1 1 1 0 0.0348 0.0749 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
10 22 1 1 1 0 0.0727 0.1499 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
21 22 1 1 1 0 0.0116 0.0236 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
15 23 1 1 1 0 0.1000 0.2020 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
22 24 1 1 1 0 0.1150 0.1790 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
23 24 1 1 1 0 0.1320 0.2700 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
24 25 1 1 1 0 0.1885 0.3292 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
25 26 1 1 1 0 0.2544 0.3800 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
25 27 1 1 1 0 0.1093 0.2087 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

28 27 1 1 1 0 0.0 0.3960 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0
27 29 1 1 1 0 0.2198 0.4153 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0
27 30 1 1 1 0 0.3202 0.6027 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0
29 30 1 1 1 0 0.2399 0.4533 0.0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0
8 28 1 1 1 0 0.0636 0.2000 0.0428 0 0 0 0 0.0 0.0 0.0 0.0 0.0
6 28 1 1 1 0 0.0169 0.0599 0.0130 0 0 0 0 0.0 0.0 0.0 0.0 0.0
-999
LOSS ZONES FOLLOWS          1 ITEMS
1 IEEE 30 BUS
-99
INTERCHANGE DATA FOLLOWS          1 ITEMS
-9
1 2 Claytor 132 0.0 999.99 IEEE30 IEEE 30 Bus Test Case
TIE LINES FOLLOWS          0 ITEMS
-999
END OF DATA

```

Figure A2. Test data (IEEE 30 bus)^[8].

Appendix B. IEEE 57-Bus System

The IEEE 57-bus test case represents a simple approximation of the American Electric Power system (in the U.S. Midwest) as it was in the early 1960s^[12]. IEEE 57-bus test case system has 57 buses, 7 generators, and 42 loads. **Figure A3** shows IEEE 57 bus case system and **Figure A4** gives the test data of IEEE 57 bus system.

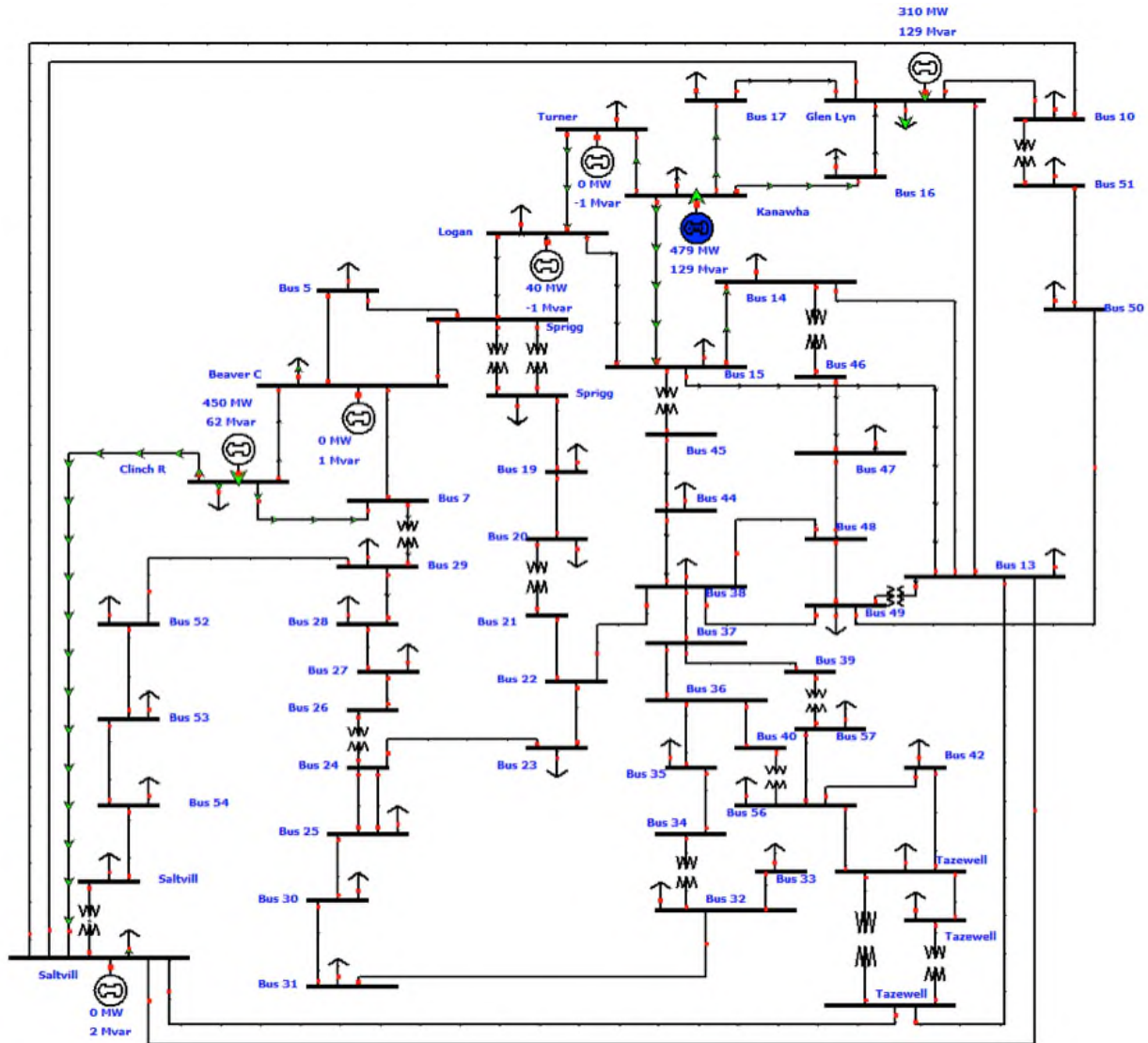


Figure A3. IEEE 57 bus case system^[12].

08/25/93 UW ARCHIVE										100.0 1961 W IEEE 57 Bus Test Case									
BUS DATA FOLLOWS										57 ITEMS									
1 Kanawha	V1	1	1	3	1.040	0.0	55.0	17.0	128.9	-16.1	0.0	1.040	0.0	0.0	0.0	0.0	0.0	0.0	0
2 Turner	V1	1	1	2	1.010	-1.18	3.0	88.0	0.0	-0.8	0.0	1.010	50.0	-17.0	0.0	0.0	0.0	0.0	0
3 Logan	V1	1	1	2	0.985	-5.97	41.0	21.0	40.0	-1.0	0.0	0.985	60.0	-10.0	0.0	0.0	0.0	0.0	0
4 Sprigg	V1	1	1	0	0.981	-7.32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
5 Bus 5	V1	1	1	0	0.976	-8.52	13.0	4.0	0.0	0.0									

11	13	1	1	1	0	0.0223	0.0732	0.0188	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0													
12	13	1	1	1	0	0.0178	0.0580	0.0604	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0													
12	16	1	1	1	0	0.0180	0.0813	0.0216	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0													
12	17	1	1	1	0	0.0397	0.1790	0.0476	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0													
14	15	1	1	1	0	0.0171	0.0547	0.0148	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0													
18	19	1	1	1	0	0.4610	0.6850	0.0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0													
19	20	1	1	1	0	0.2830	0.4340	0.0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0													
21	20	1	1	1	0	0.0	0.7767	0.0	0	0	0	0	1.043	0.0	0.0	0.0	0.0	0.0	0.0													
21	22	1	1	1	0	0.0736	0.1170	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
22	23	1	1	1	0	0.0099	0.0152	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
23	24	1	1	1	0	0.1660	0.2560	0.0084	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
24	25	1	1	1	0	0.0	1.1820	0.0	0	0	0	0	1.000	0.0	0.0	0.0	0.0	0.0	0.0													
24	25	1	1	1	0	0.0	1.2300	0.0	0	0	0	0	1.000	0.0	0.0	0.0	0.0	0.0	0.0													
24	26	1	1	1	0	0.0	0.0473	0.0	0	0	0	0	1.043	0.0	0.0	0.0	0.0	0.0	0.0													
26	27	1	1	1	0	0.1650	0.2540	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
27	28	1	1	1	0	0.0618	0.0954	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
28	29	1	1	1	0	0.0418	0.0587	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
7	29	1	1	1	0	0.0	0.0648	0.0	0	0	0	0	0.967	0.0	0.0	0.0	0.0	0.0	0.0													
25	30	1	1	1	0	0.1350	0.2020	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
30	31	1	1	1	0	0.3260	0.4970	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
31	32	1	1	1	0	0.5070	0.7550	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
32	33	1	1	1	0	0.0392	0.0360	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
34	32	1	1	1	0	0.0	0.9530	0.0	0	0	0	0	0.975	0.0	0.0	0.0	0.0	0.0	0.0													
34	35	1	1	1	0	0.0520	0.0780	0.0032	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
35	36	1	1	1	0	0.0430	0.0537	0.0016	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
36	37	1	1	1	0	0.0290	0.0366	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
37	38	1	1	1	0	0.0651	0.1009	0.0020	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
37	39	1	1	1	0	0.0239	0.0379	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
36	40	1	1	1	0	0.0300	0.0466	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
22	38	1	1	1	0	0.0192	0.0295	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
11	41	1	1	1	0	0.0	0.7490	0.0	0	0	0	0	0.955	0.0	0.0	0.0	0.0	0.0	0.0													
41	42	1	1	1	0	0.2070	0.3520	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
41	43	1	1	1	0	0.0	0.4120	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
38	44	1	1	1	0	0.0289	0.0585	0.0020	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
15	45	1	1	1	0	0.0	0.1042	0.0	0	0	0	0	0.955	0.0	0.0	0.0	0.0	0.0	0.0													
14	46	1	1	1	0	0.0	0.0735	0.0	0	0	0	0	0.900	0.0	0.0	0.0	0.0	0.0	0.0													
46	47	1	1	1	0	0.0230	0.0680	0.0032	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
47	48	1	1	1	0	0.0182	0.0233	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
48	49	1	1	1	0	0.0834	0.1290	0.0048	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
49	50	1	1	1	0	0.0801	0.1280	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
50	51	1	1	1	0	0.1386	0.2200	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
-999																																
LOSS ZONES FOLLOWS							1 ITEMS																									
1 IEEE 57 BUS																																
-99																																
INTERCHANGE DATA FOLLOWS							1 ITEMS																									
-9																																
1 8 Clinch Rv V1 0.0 999.99 IEEE57 IEEE 57 Bus Test Case																																
TIE LINES FOLLOWS							0 ITEMS																									
-999																																
END OF DATA																																

Figure A4. IEEE 57 bus data^[12].