Diminution of real power loss by novel Galápagos Penguin Algorithm

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ABSTRACT
In this work Galápagos Penguin Algorithm (GPA) has been applied to solve optimal reactive power problem. Galápagos penguins’ foraging activities are modeled to solve the problem. As a team Galápagos Penguin feed on food and by intra-group communication it communicates each other. Once a Galápagos penguin finds a superior food source then it will act as new-fangled local guide in which Foraging of the team is an autocatalytic procedure. To dive in-depth Galápagos Penguin takes up extra energy to find out about the information of food. Until the oxygen get exhausted Galápagos Penguin execute the recurring dives, subsequently it will move around to another group in search of food. Galápagos penguin modernizes its group membership based on food availability degree of different groups. In standard IEEE 14, 30, 57, 118, 300 bus systems Proposed Galápagos Penguin Algorithm (GPA) is evaluated and simulation results show the GPA reduced the power loss efficiently.

1. Introduction
Reactive power problem plays a key role in secure and economic operations of power system. Optimal reactive power problem has been solved by variety of types of methods like Newton’s method, interior point method, successive quadratic programming method [1, 2, 3, 4, 5, 6] has been utilized to solve the optimal reactive power problem. However many scientific difficulties are found while solving problem due to an assortment of constraints. Evolutionary techniques such as gravitational search, Ant Lion Optimizer, symbiotic organism search algorithm [7, 8, 9, 10, 11, 12, 13, 14, 15, 16] are applied to solve the reactive power problem, but the main problem is many algorithms get stuck in local optimal solution & failed to balance the Exploration & Exploitation during the search of global solution. In this work, Galápagos Penguin Algorithm (GPA) has been applied to solve optimal reactive power problem. Galápagos Penguin is a sea bird [17] and its wings are perfect for swimming; it stays under the water for up to 20 min. Normally Galápagos Penguin feed on krill, small fish, squid, and crustaceans. Galápagos Penguin are forced to come to the surface for air after every foraging journey and is restricted by the oxygen reserves also the speed at which they make use of it. Through intra-group communication Galápagos Penguin communicates each other and when one Galápagos penguin finds a superior food source then it act as new-fangled local guide in which Foraging of the team is an autocatalytic procedure. When there is food shortage in the group Galápagos penguin will transfer to unite another group. Galápagos Penguin modernizes its group membership based on food availability degree of different groups. In the proposed algorithm both the exploration and exploitation has been balanced in order to obtain the optimal solution. Validity of the Proposed Galápagos Penguin Algorithm (GPA) has been tested in standard IEEE 14, 30, 57, 118, 300 bus systems and results show the projected GPA reduced the power loss effectively.

2. Problem formulation
Objective of the problem is to reduce the true power loss:

\[ F = P_L = \sum_{i \in \text{Nbr}} g_k \left( V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij} \right) \] (1)

where \( F \) - objective function, \( P_L \) - Power loss.
Voltage deviation given as follows:

\[ F = P_L + \omega_v \times \text{Voltage Deviation} \] (2)

\( \omega_v \) - Weight factor.
Voltage deviation given by:

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

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2405-8440/© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
2.1. Constraint (equality)

\[ P_G = P_D + P_L \]  

(4)

where \( P_G \) and \( P_D \) indicates the power generation and power demand.

2.2. Constraints (inequality)

\[ P_{\text{slack}}^\text{min} \leq P_{\text{slack}} \leq P_{\text{slack}}^\text{max} \]  

(5)

\[ Q_{gi}^\text{min} \leq Q_{gi} \leq Q_{gi}^\text{max}, \ i \in N_g \]  

(6)

\[ V_i \leq V_i^\text{max}, \ i \in N \]  

(7)

\[ T_i \leq T_i^\text{max}, \ i \in N_T \]  

(8)

\[ Q_i^\text{min} \leq Q_i \leq Q_i^\text{max}, \ i \in N_C \]  

(9)

where reactive power compensators indicated by \( Q_i \), dynamic tap setting of transformers –dynamic indicated by \( T_i \), level of the voltage in the generation units given by \( V_i \), slack generator indicated by \( P_{\text{slack}} \), level of voltage on transmission lines symbolized by \( V_i \), generation units reactive power indicated by \( Q_i \), apparent power symbolized by \( S_i \).

3. Galápagos Penguin Algorithm

Galápagos Penguin is a sea bird and its wings are perfect for swimming; it stays under the water for up to 20 min. Normally Galápagos Penguin feed on krill, small fish, squid, and crustaceans. To dive in-depth Galápagos Penguin takes up extra energy to find about the information of food.

Galápagos Penguin are forced to come to the surface for air after every foraging journey and is restricted by the oxygen reserves also the speed at which they make use of it. Galápagos penguins’ foraging activities are modeled as rules as follows;

Rule 1: Galápagos Penguin consists of numerous groups. Depending on food accessibility in the analogous foraging area every group enclose Galápagos penguins.

Rule 2: Based on energy gain each group of Galápagos Penguin starts foraging in an exact depth under the water.

Rule 3: Naturally Galápagos Penguin feed as a team and go behind their local guide. Until the oxygen reserves are depleted they examine the water for food.

Rule 4: Galápagos Penguin comes back on surface to share the information about the locations and abundance of food sources with its local affiliates through intra-group communication.

Rule 5: Through inter-group communication Galápagos Penguin leaves the group to join another group when food availability becomes less.

3.1. Modernization of swimming track

At time \( t+1 \) Galápagos penguin \( j \) swims to a new-fangled location in “\( \Omega \)” as defined by the following equation,

\[ y'_j(t + 1) = y'_j(t) + Q'_j(t) \times \text{random}() \times \left( y_{\text{local best}} - y'_j(t) \right) \]  

(10)

where \( y'_j(t) \) and \( Q'_j(t) \) indicates the Galápagos Penguin movement and oxygen reserve.

Galápagos Penguin follow local leader and swimming is hasten by the oxygen reserve which replicate its fitness condition.

3.2. Modernization of Oxygen reserve

Oxygen reserve of the Galápagos penguin is modernized subsequent to each dive by,

\[ O'_{i+1} = O_i + \left( f(y'_j(t + 1)) - f(y_j(t)) \right) \times \|y'_j(t + 1) - y'_j(t)\| \]  

(11)

Modernization of Oxygen reserve is done with reference to objective function. When new-fangled solution is superior to the preceding one then the oxygen reserve augments. Galápagos Penguin executes recurring dives until the oxygen is exhausted, subsequently Galápagos penguin will move around to another group.

3.3. Communication between intra-group

When one Galápagos penguin finds a superior food source then it act as new-fangled local guide in which Foraging of the team is an autocat-alytic procedure.

3.4. Modernization of food plenty available status

Food available status is linked to a group which indicate the energy content of prey captured by the group and it estimated by the capacity of Eaten Fish (CEF), which is computed by,

\[ CEF'(t + 1) = CEF'(t) + \sum_{j=1}^{N_G} (O'_j - O_j) \]

(12)

3.5. Modernization of group membership

When there is food shortage in the group Galápagos penguin will transfer to unite another group. Galápagos Penguin modernizes its group membership \( Q_i(t+1) \) based on food availability degree of different groups.

\[ Q_i(t+1) = \frac{CEF'(t)}{\sum_{j=1}^{N_G} CEF'(t)} \]

(13)

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\( a \) Solution space generated
\( b \) Within bounded region Galápagos penguin are generated for each groups
\( c \) while end condition is not reached do
\( d \) for each Galápagos penguin oxygen reserve is initialized
\( e \) For every group “i” do
\( f \) For every Galápagos penguin “j” in this group do
\( g \) Position of the Galápagos penguin enhanced as follows;

Input; solution space, maximum distance
Output; K region centers in the space (solution)
Center of the primary group arbitrarily chosen and indicated by \( C_0 \)
\( i \leftarrow 1 \)
While \( i < Kdo \)
Center \( C_i \) arbitrarily chosen for the subsequent group
\( j \leftarrow 0 \)
While \( j < Kdo \)
When distance \((C_i, C_j) > \text{maximum distance} \) then
\( j \leftarrow j + 1 \)
Otherwise chose Center \( C_i \) again
End if
End while
\( i \leftarrow i + 1 \)

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4. Simulation results

In standard IEEE 14 bus system the validity of the projected Galápagos Penguin Algorithm (GPA) has been tested, Table 1 shows the constraints of control variables. Table 2 shows the limits of reactive power generators and comparison results with particle swarm optimization (PSO), modified particle swarm optimization (MPSO), self-adaptive real coded Genetic algorithm (SAGRA), Evolutionary Programming (EP) are presented in Table 3.

Then the proposed Galápagos Penguin Algorithm (GPA) has been tested, in IEEE 57 Bus system. Table 7 shows the constraints of control variables, Table 8 shows the limits of reactive power generators and comparison results with particle swarm optimization (PSO), modified particle swarm optimization (MPSO), self-adaptive real coded Genetic algorithm (SAGRA), Evolutionary Programming (EP) are presented in Table 6.

### Table 1. Constraints of control variables.

| System     | Variables        | Minimum (PU) | Maximum (PU) |
|------------|------------------|--------------|--------------|
| IEEE 14 Bus| Generator Voltage| 0.95         | 1.1          |
|            | Transformer Tap  | 0.9          | 1.1          |
|            | VAR            | 0            | 0.2          |

### Table 2. Constrains of reactive power generators.

| System     | Variables Q Minimum (PU) | Q Maximum (PU) |
|------------|--------------------------|----------------|
| IEEE 14 Bus| 1                        | 10             |
|            | 2                        | -40            |
|            | 3                        | 40             |
|            | 6                        | -6             |
|            | 8                        | -6             |

### Table 3. Simulation results of IEEE – 14 system.

| Control variables | Base case | MPSO [19] | PSO [19] | EP [19] | SAGRA [19] | GPA |
|-------------------|-----------|-----------|----------|---------|------------|-----|
| VG-1              | 1.060     | 1.101     | 1.100    | NR*     | NR*        | 1.010 |
| VG-2              | 1.045     | 1.085     | 1.086    | 1.097   | 1.094      | 1.012 |
| VG-3              | 1.010     | 1.055     | 1.056    | 1.016   | 1.036      | 1.017 |
| VG-6              | 1.070     | 1.069     | 1.067    | 1.097   | 1.099      | 1.020 |
| VG-8              | 1.090     | 1.074     | 1.060    | 1.053   | 1.078      | 1.002 |
| Tap 8             | 0.978     | 1.018     | 1.019    | 1.04    | 0.95       | 0.900 |
| Tap 9             | 0.969     | 0.975     | 0.988    | 0.94    | 0.95       | 0.901 |
| Tap 10            | 0.932     | 1.024     | 1.008    | 1.03    | 0.96       | 0.924 |
| QC-9              | 0.19      | 14.64     | 0.185    | 0.18    | 0.06       | 0.146 |
| PG                | 272.39    | 271.32    | 271.32   | NR*     | NR*        | 271.64 |
| QC (Mvar)         | 82.44     | 75.79     | 76.79    | NR*     | NR*        | 74.79  |
| Reduction in Ploss (%) | 0    | 9.2       | 9.1      | 1.5     | 25.2       | 24.14  |
| Total Ploss (Mw)  | 13.550    | 12.293    | 12.315   | 13.346  | 13.216     | 10.279 |

NR* - Not reported.

Then the proposed Galápagos Penguin Algorithm (GPA) has been tested, in IEEE 30 Bus system. Table 4 shows the constraints of control variables, Table 5 shows the limits of reactive power generators and comparison results with particle swarm optimization (PSO), modified particle swarm optimization (MPSO), self-adaptive real coded Genetic algorithm (SAGRA), Evolutionary Programming (EP) are presented in Table 3.

### Table 4. Constraints of control variables.

| System     | Variables     | Minimum (PU) | Maximum (PU) |
|------------|---------------|--------------|--------------|
| IEEE 30 Bus| Generator Voltage | 0.95         | 1.1          |
|            | Transformer Tap | 0.9          | 1.1          |
|            | VAR            | 0            | 0.2          |

### Table 5. Constrains of reactive power generators.

| System     | Variables Q Minimum (PU) | Q Maximum (PU) |
|------------|--------------------------|----------------|
| IEEE 30 Bus| 1                        | 10             |
|            | 2                        | -40            |
|            | 5                        | -40            |
|            | 8                        | -10            |
|            | 11                       | -6             |
|            | 13                       | -6             |

### Table 6. Simulation results of IEEE – 30 system.

| Control variables | Base case | MPSO [19] | PSO [19] | EP [19] | SAGRA [19] | GPA |
|-------------------|-----------|-----------|----------|---------|------------|-----|
| VG-1              | 1.060     | 1.101     | 1.100    | NR*     | NR*        | 1.010 |
| VG-2              | 1.045     | 1.086     | 1.072    | 1.097   | 1.094      | 1.012 |
| VG-5              | 1.010     | 1.047     | 1.038    | 1.048   | 1.053      | 1.063 |
| VG-8              | 1.010     | 1.057     | 1.048    | 1.033   | 1.059      | 1.001 |
| VG-12             | 1.082     | 1.048     | 1.058    | 1.092   | 1.099      | 1.020 |
| VG-13             | 1.071     | 1.068     | 1.080    | 1.091   | 1.099      | 1.041 |
| Tap11             | 0.978     | 0.983     | 0.987    | 1.01    | 0.99       | 0.902 |
| Tap12             | 0.969     | 1.023     | 1.015    | 1.03    | 1.03       | 0.910 |
| Tap15             | 0.932     | 1.020     | 1.020    | 1.07    | 0.98       | 0.900 |
| Tap36             | 0.968     | 0.988     | 1.012    | 0.99    | 0.96       | 0.901 |
| QC10              | 0.19      | 0.077     | 0.077    | 0.19    | 0.19       | 0.063 |
| QC24              | 0.043     | 0.119     | 0.128    | 0.04    | 0.04       | 0.109 |
| PG (MW)           | 306.9     | 299.54    | 299.54   | NR*     | NR*        | 298.67 |
| QC (Mvar)         | 133.9     | 130.83    | 130.94   | NR*     | NR*        | 130.73 |
| Reduction in Ploss (%) | 0    | 8.4       | 7.4      | 6.6     | 8.3        | 18.18 |
| Total Ploss (Mw)  | 17.55     | 16.07     | 16.25    | 16.38   | 16.09      | 14.358 |

NR* - Not reported.
### Table 7. Constraints of control variables.

| System   | Variables   | Minimum (PU) | Maximum (PU) |
|----------|-------------|--------------|--------------|
| IEEE 57 Bus | Generator Voltage | 0.95 | 1.1 |
| Transformer Tap | 1.0 | 1.1 |
| VAR Source | 0 | 0.20 |

### Table 8. Constraints of reactive power generators.

| System   | Variables   | Q Minimum (PU) | Q Maximum (PU) |
|----------|-------------|----------------|----------------|
| IEEE 57 Bus | 1 | -140 | 200 |
| 2       | -17 | 50 |
| 3       | -10 | 60 |
| 6       | -8 | 25 |
| 8       | -140 | 200 |
| 9       | -3 | 9 |
| 12      | -150 | 155 |

### Table 9. Simulation results of IEEE – 57 system.

| Control variables | Base case | MPSO [19] | PSO [19] | CGA [19] | AGA [19] | GPA |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----|
| VG 1              | 1.040     | 1.093     | 1.083     | 0.968     | 1.027     | 1.020 |
| VG 2              | 1.010     | 1.086     | 1.071     | 1.049     | 1.011     | 1.012 |
| VG 3              | 0.985     | 1.056     | 1.055     | 1.056     | 1.033     | 1.031 |
| VG 4              | 0.980     | 1.038     | 1.036     | 0.987     | 1.001     | 1.010 |
| VG 5              | 1.005     | 1.066     | 1.059     | 1.022     | 1.051     | 1.023 |
| VG 6              | 0.980     | 1.054     | 1.048     | 0.991     | 1.051     | 1.010 |
| VG 7              | 1.015     | 1.054     | 1.046     | 1.004     | 1.057     | 1.043 |
| VG 8              | 0.970     | 0.975     | 0.987     | 0.920     | 1.030     | 0.954 |
| VG 9              | 0.978     | 0.982     | 0.983     | 0.920     | 1.020     | 0.932 |
| VG 10             | 1.043     | 0.975     | 0.981     | 0.970     | 1.060     | 0.921 |
| VG 11             | 1.000     | 1.025     | 1.003     | NR*       | NR*       | 1.014 |
| VG 12             | 1.000     | 1.020     | 0.985     | NR*       | NR*       | 1.002 |
| VG 13             | 1.043     | 1.007     | 1.009     | 0.900     | 0.990     | 1.003 |
| VG 14             | 0.967     | 0.994     | 1.007     | 0.910     | 1.100     | 0.991 |
| VG 15             | 0.975     | 1.013     | 1.018     | 1.100     | 0.980     | 1.012 |
| VG 16             | 0.955     | 0.988     | 0.986     | 0.940     | 1.010     | 0.970 |
| VG 17             | 0.955     | 0.979     | 0.992     | 0.950     | 1.080     | 0.961 |
| VG 18             | 0.900     | 0.983     | 0.990     | 1.030     | 0.940     | 0.960 |
| VG 19             | 0.930     | 1.015     | 0.997     | 1.090     | 0.950     | 1.002 |
| VG 20             | 0.985     | 0.975     | 0.984     | 0.900     | 1.050     | 0.951 |
| VG 21             | 0.958     | 1.020     | 0.990     | 0.900     | 0.950     | 1.000 |
| VG 22             | 0.958     | 1.001     | 0.988     | 1.000     | 1.010     | 1.002 |
| VG 23             | 0.980     | 0.979     | 0.980     | 0.960     | 0.940     | 0.960 |
| VG 24             | 0.940     | 1.002     | 1.017     | 1.000     | 1.000     | 1.001 |
| VG 25             | 0.1       | 0.179     | 0.131     | 0.084     | 0.016     | 0.173 |
| VG 26             | 0.059     | 0.176     | 0.144     | 0.008     | 0.015     | 0.161 |
| VG 27             | 0.063     | 0.141     | 0.162     | 0.053     | 0.038     | 0.141 |
| VG 28             | 1278.6    | 1274.4    | 1274.8    | 1276     | 1275     | 1270.10 |
| VG 29             | 321.08    | 272.27    | 276.58    | 309.1    | 304.4    | 272.32 |
| Reduction in PLoss (%) | 0 | 15.4 | 14.1 | 9.2 | 11.6 | 23.69 |
| Total PLoss (MW) | 27.8 | 23.51 | 23.86 | 25.24 | 24.56 | 21.213 |

NR* - Not reported.

### Table 10. Constraints of control variables.

| System   | Variables   | Minimum (PU) | Maximum (PU) |
|----------|-------------|--------------|--------------|
| IEEE 118 Bus | Generator Voltage | 0.95 | 1.1 |
| Transformer Tap | 0.9 | 1.1 |
| VAR Source | 0 | 0.20 |

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Table 11 (continued)

| Control variables | Base case | MPSO [19] | PSO [19] | PSO [19] | CLPSO [19] | GPA |
|-------------------|-----------|-----------|----------|----------|-------------|-----|
| Tap 93            | 0.960     | 1.000     | 0.997    | 1.008    | 0.992       | 1.000 |
| Tap 95            | 0.985     | 0.995     | 1.020    | 1.032    | 1.007       | 0.971 |
| Tap 102           | 0.935     | 1.024     | 1.004    | 0.944    | 1.061       | 1.000 |
| Tap 107           | 0.935     | 0.989     | 1.008    | 0.906    | 0.930       | 0.943 |
| Tap 127           | 0.935     | 1.010     | 1.009    | 0.967    | 0.957       | 1.002 |
| QC 34             | 0.140     | 0.049     | 0.048    | 0.093    | 0.117       | 0.003 |
| QC 44             | 0.100     | 0.026     | 0.026    | 0.093    | 0.098       | 0.022 |
| QC 45             | 0.100     | 0.196     | 0.197    | 0.086    | 0.094       | 0.160 |
| QC 46             | 0.100     | 0.117     | 0.118    | 0.089    | 0.026       | 0.122 |
| QC 49             | 0.150     | 0.056     | 0.056    | 0.118    | 0.028       | 0.041 |
| QC 74             | 0.120     | 0.120     | 0.120    | 0.046    | 0.005       | 0.112 |
| QC 79             | 0.200     | 0.139     | 0.140    | 0.105    | 0.148       | 0.101 |
| QC 82             | 0.200     | 0.180     | 0.180    | 0.164    | 0.194       | 0.152 |
| QC 83             | 0.100     | 0.166     | 0.166    | 0.096    | 0.069       | 0.124 |
| QC 105            | 0.200     | 0.189     | 0.190    | 0.089    | 0.090       | 0.152 |
| QC 107            | 0.060     | 0.128     | 0.129    | 0.050    | 0.049       | 0.130 |
| QC 110            | 0.060     | 0.014     | 0.014    | 0.055    | 0.022       | 0.002 |
| PG(MW)            | 4374.8    | 4359.3    | 4361.4   | NR*      | NR*         | 4362.14 |
| QG(MVAR)          | 795.6     | 604.3     | 653.5    | NR*      | NR*         | 610.10 |
| Reduction in PLOSS(%) | 0        | 11.7      | 10.1     | 0.6      | 1.3         | 13.89 |
| Total PLOSS (Mw)  | 132.8     | 117.19    | 119.34   | 131.99   | 130.96      | 114.347 |

NR* - Not reported.

Table 12. Comparison of real power loss.

| Parameter | Method EGA [21] | Method EEA [21] | Method CSA [20] | GPA |
|-----------|----------------|----------------|-----------------|-----|
| PLOSS (MW) | 646.2998 | 650.6027 | 635.8942 | 610.1509 |

5. Conclusion

In this work Galapagos Penguin Algorithm (GPA) successfully solved the optimal reactive power problem. Through intra-group communication Galapagos Penguin communicates each other and when one Galapagos penguin finds a superior food source then it acts as a newborn leader in which Foraging of the team is an autocatalytic procedure. When there is food shortage in the group Galapagos Penguin will transfer to unite another group. Deeds Galapagos Penguin is modeled to solve the problem effectively. In standard IEEE 14, 30, 57, 300 bus systems Galapagos Penguin Algorithm (GPA) have been tested and power loss has been reduced efficiently. Percentage of the power loss reduction has been improved. In future this work can be expanded to application of the proposed GPA algorithm to multi-objective reactive power optimization problem. Also to practical systems the projected algorithm can be applied in real time systems.

Declarations

Author contribution statement

Kanagasabai Lenin: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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