Real Power Loss Reduction by Amplified Water Cycle Algorithm

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Abstract

In this paper Amplified Water Cycle Algorithm (AWCA) has been used to solve the optimal reactive power problem. Water cycle algorithm (WCA) is a methodology which inspired by the hydrological cycle which happen in nature. In this work water cycle algorithm hybridized with Gravitational Search Algorithm, Chaos theory. In the projected Amplified Water Cycle Algorithm (AWCA) - with reference to the fitness value, population is first alienated into three groups: streams, rivers and sea. Through this hybridization exploration and exploitation is effectively improved. Positions of particles are initially modernized according to gravitational search. Chaos theory is then defined and integrated in water cycle algorithm to modernize the population which will augment explore capability and population diversity. Projected Amplified Water Cycle Algorithm (AWCA) has been tested in standard IEEE 14, 30, 57, 300 bus test system and simulation results show the projected algorithm reduced the real power loss extensively.

Keywords: Optimal Reactive Power, Transmission loss, Gravitational Search Algorithm, Chaos theory, Water Cycle Algorithm.

1. Introduction

Reactive power problem plays an important role in secure and economic operations of power system. Numerous types of methods [1-6] have been utilized to solve the optimal reactive power problem. However many scientific difficulties are found while solving problem due to an assortment of constraints. Evolutionary techniques [7-14] 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 Amplified Water Cycle Algorithm (AWCA) has been used to solve the optimal reactive power problem. Water cycle algorithm (WCA) is a methodology which inspired by the hydrological cycle which happen in nature. Hydrologic cycle is unremitting progression of water in the earth. It is a vital process for the continuous survival of ecosystems. In this work water cycle algorithm hybridized with Gravitational Search Algorithm, Chaos theory. Positions of particles are initially modernized according to gravitational search. Chaos theory is then defined and integrated in water cycle algorithm to modernize the population which will augment explore capability and population diversity. In the projected Amplified Water Cycle Algorithm (AWCA) - with reference to the fitness value, population is first alienated into three groups: streams, rivers and sea. Through this hybridization exploration and exploitation is effectively improved. Projected Amplified Water Cycle Algorithm (AWCA) has been tested in standard IEEE 14, 30, 57, 300 bus test system and simulation results show the projected algorithm reduced the real power loss extensively.

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2. Problem Formulation

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

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

Where \( F \) - objective function, \( P_L \) - power loss, \( g_k \) - conductance of branch, \( V_i \) and \( V_j \) are voltages at buses \( i, j \). Nbr - total number of transmission lines in power systems.

Voltage deviation given as follows:

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

Where \( \text{VD} \) - voltage deviation, \( \omega \) - is a weighting factor of voltage deviation

Voltage deviation given by:

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

Where \( Npq \) - number of load buses

Constraint (Equality)

\[ P_G = P_D + P_L \] (4)

Where \( P_G \) - total power generation, \( P_D \) - total power demand.

Constraints (Inequality)

Upper and lower bounds on the active power of slack bus (\( P_{g_{\text{slack}}} \)), and reactive power of generators (\( Q_{g} \)) are written as follows:

\[ P_{g_{\text{min}}} = P_{g_{\text{slack}}} \leq P_{g_{\text{max}}} \] (5)

\[ Q_{g_{\text{min}}} = Q_{g_{i}} \leq Q_{g_{\text{max}}}, i \in N_g \] (6)

Upper and lower bounds on the bus voltage magnitudes (\( V_i \)) are given by:

\[ V_{i_{\text{min}}} \leq V_i \leq V_{i_{\text{max}}}, i \in N \] (7)

Upper and lower bounds on the transformers tap ratios (\( T_i \)) are given by:

\[ T_{i_{\text{min}}} \leq T_i \leq T_{i_{\text{max}}}, i \in N_T \] (8)

Upper and lower bounds on the compensators (\( Q_c \)) are given by:

\[ Q_{c_{\text{min}}} \leq Q_c \leq Q_{c_{\text{max}}}, i \in N_c \] (9)

Where \( N \) is the total number of buses, \( N_g \) is the total number of generators, \( N_T \) is the total number of Transformers, \( N_c \) is the total number of shunt reactive compensators.
3. Gravitational Search Algorithm

Gravitational Search Algorithm (GSA) is stimulated from the Newton’s theory and it has been considered as collection of agents (determine the candidate solutions) in which mass value is proportional to the value of fitness function [15]. By the gravity forces, all masses are attracting each other during generations. Algorithm starts with arbitrarily insertion of all agents in exploration space. Throughout all time, gravitational forces from agent \( j \) on agent \( i \) at a precise time \( t \) is described by:

\[
F_{ij}^d(t) = G(t) \frac{M_i(t) \cdot M_j(t)}{R_{ij}(t) + \epsilon} \left( x_i^d(t) - x_j^d(t) \right)
\]

where

\[
G(t) = G_0 \times \exp \left( -a \times \frac{\text{iter}}{\text{maxiter}} \right)
\]

Entire force which act on the agent is calculated by,

\[
F_i^d(t) = \sum_{j=1}^{N} \text{rand}_j F_{ij}^d(t)
\]

Acceleration of the agents computed by,

\[
ac_i^d(t) = \frac{F_i^d(t)}{M_i(t)}
\]

The velocity and position of agents are computed by,

\[
vel_i^d(t + 1) = \text{rand}_i \times vel_i^d(t) + ac_i^d(t)
\]

\[
x_i^d(t + 1) = x_i^d(t) + vel_i^d(t + 1)
\]

4. Chaos Theory

Chaos is a deterministic, arbitrary like procedure found in a nonlinear, dynamical system, which is non-period, non-converging and non-bounded [16]. Variance \( \sigma^2 \) exhibits the converging degree of the particles.

\[
\sigma^2 = \Sigma_{i=1}^{N} \left( \frac{f_i - f_{avg}}{f} \right)^2
\]

\[
f = \max \left\{ 1, \max \left\{ \left| f_i - f_{avg} \right| \right\} \right\}
\]

Simple vibrant system devoid of any stochastic disturbance is formulated by,

\[
y_{id}(t + 1) = \mu y_{id}(t) \left( 1 - y_{id}(t) \right)
\]

Once the preliminary value is \( y_{id}(0) \in \{0.20.0.5.0.70\} \) then by using equation (18) chaotic sequences can be attained. Adaptive chaotic disturbance \( p_c \) is employed at the time of stagnation;

\[
p_{cd}^d(t + 1) = p_{cd}(t) + R_{id}(2 \cdot y_{id}(t) - 1)
\]

\[
R_{id} = \beta | p_{cd}(t) - p_{id}(t) |
\]

5. Amplified Water cycle algorithm

Water cycle algorithm (WCA) starts with presumption of rain. A sea is chosen as the most excellent individual, and a number of value raindrops are picked to indicate a river, remaining raindrops signify the streams flowing into sea and rivers [17].
Array for single solution is aptly described as a “raindrop”. Raindrop is an array of $1 \times N_{\text{var}}$ in a $N_{\text{var}}$ dimensional space and defined as:

$$
\text{Raindrop} = [X_1, X_2, X_3, \ldots, X_n]
$$

(21)

Cost of the raindrop is calculated by using the cost function (C) as follows,

$$
c_i = \text{cost}_i = f(X^i_1, X^i_2, X^i_3, \ldots, X^i_{N_{\text{var}}}) i = 1, 2, \ldots, N_{\text{pop}}
$$

(22)

Where $N_{\text{pop}}$ and $N_{\text{var}}$ are symbolize the number of raindrops and $N_{\text{vec}}$ -Signify the entire number of rivers for a single sea.

$$
N_{\text{vec}} = \text{number os rivers} + 1
$$

(23)

$$
N_{\text{raindrops}} = N_{\text{pop}} - N_{\text{vec}}
$$

(24)

Strength of flow of the raindrops into the sea or the rivers is computed by:

$$
N_{S_n} = \text{round} \left\{ \left[ \frac{\text{cost}_n}{\sum_{i=1}^{N_{\text{pop}}} \text{cost}_i} \right] \times N_{\text{raindrops}} \right\}, n = 1, 2, \ldots, N_{\text{vec}}
$$

(25)

Rivers flow into the sea and the new-fangled position of the rivers and streams can be defined by,

$$
X^i_{\text{stream}} = X^i_{\text{stream}} + \text{rand} \times c \times (X^i_{\text{river}} - X^i_{\text{stream}})
$$

(26)

$$
X^i_{\text{river}} = X^i_{\text{river}} + \text{rand} \times c \times (X^i_{\text{sea}} - X^i_{\text{river}})
$$

(27)

d_{\text{max}} symbolize the evaporation process and the value of $d_{\text{max}}$ adapts consequently,

$$
d^{i+1}_{\text{maximum}} = d^i_{\text{maximum}} - \frac{d^i_{\text{maximum}}}{\text{maximum number of iteration}}
$$

(28)

New-fangled locations of the newly formed streams is defined by,

$$
X^i_{\text{stream}} = X^i_{\text{stream}} + \sqrt{\mu} \times \text{random} \times (U_b - L_b)
$$

(29)

$$
X^i_{\text{stream}} = X^{i+1}_{\text{stream}} + (1 + h_i) \times (X^i_{\text{river}} - X^i_{\text{stream}})
$$

(31)

$$
X^i_{\text{stream}} = X^{i+1}_{\text{stream}} + (1 + h_i) \times (X^i_{\text{sea}} - X^i_{\text{stream}})
$$

(32)

$$
X^i_{\text{river}} = X^{i+1}_{\text{river}} + (1 + h_i) \times (X^i_{\text{sea}} - X^i_{\text{river}})
$$

(33)

In the projected Amplified Water Cycle Algorithm (AWCA) - with reference to the fitness value, population is first alienated into three groups: streams, rivers and sea. Location of streams and rivers are then modernized using Equations (14, 15) in GSA correspondingly, where streams and rivers transfer information each other in their own groups, respectively. Next, the rivers and stream are updated by the Eqs. (31), (32) and (33) . Equations are acquire by combining the chaotic sequence create by chaotic mapping.
1: Input: parameters values are determined
2: Establish the number of streams which flow to the rivers and sea using \( N_{sr} = \text{number of rivers} + 1; N_{\text{raindrops}} = N_{\text{pop}} - N_{sr} \)
3: Preliminary populations are created arbitrarily and it form streams, rivers and sea, with reference to the fitness value
4: Compute the concentration of flow about how many stream flow to their corresponding rivers and sea) by using the equation \( N5_n = \text{round} \left[ \frac{\text{cost}_n}{\text{const}} \times N_{\text{raindrops}} \right], n = 1, 2, \ldots, N_{sr} \)
5: While number of function evaluations \( \leq \) maximum number of function evaluations do
6: Modernize the position of streams and rivers by using the equations \( \text{vel}^i_f(t + 1) = \text{rand}_i \times \text{vel}^i_f(t) + \text{ac}^i_f(t); x^i_f(t + 1) = x^i_f(t) + \text{vel}^i_f(t + 1) \)
7: Engender chaotic sequence and modernize streams flowing to its subsequent rivers and sea by utilizing the equations;
   \( X_{\text{stream}}^{i+1} = x_{\text{stream}}^i + (1 + h_i) \times (X_{\text{river}}^i - x_{\text{stream}}^i); X_{\text{stream}}^i = x_{\text{stream}}^i + (1 + h_i) \times (X_{\text{sea}}^i - x_{\text{stream}}^i) \)
8: Compute the fitness value of the engendered stream- when the fitness value of the produced stream is superior than the analogous river and sea, then swap the position of them.
9: Engender chaotic sequence and modernize rivers flowing to the sea by using the equation;
   \( X_{\text{river}}^{i+1} = x_{\text{river}}^i + (1 + h_i) \times (X_{\text{sea}}^i - x_{\text{river}}^i) \)
10: Compute the fitness value of the engendered river- when the fitness value of the engendered river is superior to the resultant sea, then swap the position of them.
11: When the condition of evaporation process is fulfilled, then perform the raining procedure.
12: Modernize the values of \( d_{\text{max}} \) and \( G \);
13: End while
14: Output: obtained optimal values

6. Simulation results

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

| System      | Variables       | Minimum (PU) | Maximum (PU) |
|-------------|-----------------|--------------|--------------|
| IEEE 14 Bus | Generator Voltage | 0.95         | 1.1          |
|             | Transformer Tap  | 0.9          | 1.1          |
|             | VAR Source      | 0            | 0.20         |

| System      | Q Variables | Q Minimum (PU) | Q Maximum (PU) |
|-------------|-------------|----------------|----------------|
| IEEE 14 Bus | 1           | 0              | 10             |
|             | 2           | -40            | 50             |
|             | 3           | 0              | 40             |
|             | 6           | -6             | 24             |
|             | 8           | -6             | 24             |
Table 3: Simulation results of IEEE –14 system

| Control variables | Base case | MPSO [21] | PSO [20] | EP [19] | SARGA [19] | AWCA |
|-------------------|-----------|-----------|----------|---------|------------|------|
| $V_{G}^{-1}$      | 1.060     | 1.100     | 1.100    | NR*     | NR*        | 1.020|
| $V_{G}^{-2}$      | 1.045     | 1.085     | 1.086    | 1.029   | 1.060      | 1.029|
| $V_{G}^{-3}$      | 1.010     | 1.055     | 1.056    | 1.016   | 1.036      | 1.022|
| $V_{G}^{-6}$      | 1.070     | 1.069     | 1.067    | 1.097   | 1.099      | 1.030|
| $V_{G}^{-8}$      | 1.090     | 1.074     | 1.060    | 1.053   | 1.078      | 1.013|
| $T_{a}p$          | 1.078     | 1.018     | 1.019    | 1.04    | 0.95       | 0.902|
| $T_{a}p$          | 0.969     | 0.975     | 0.988    | 0.94    | 0.95       | 0.919|
| $Q_{C}^{-1}$      | 0.932     | 1.024     | 1.008    | 1.03    | 0.96       | 0.932|
| $Q_{G}$           | 272.39    | 271.32    | 271.32   | NR*     | NR*        | 271.60|
| Reduction in PLoss (%) | 0 | 9.2 | 9.1 | 1.5 | 2.5 | 23.46 |
| Total PLoss (Mw)  | 13.550    | 12.293    | 12.315   | 13.346  | 13.216     | 10.370|

NR* - Not reported.

Then the proposed Amplified Water Cycle Algorithm (AWCA) has been tested, in IEEE 30 Bus system. Table 4 shows the constraints of control variables, Table 5 shows the limits of reactive power generators and comparison results are presented in Table 6.

Table 4 – constraints of control variables

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

Table 5: Constrains of reactive power generators

| System | Variables | Q Minimum (PU) | Q Maximum (PU) |
|--------|-----------|----------------|----------------|
| IEEE 30 Bus | 1 | 0             | 10             |
|         | 2 | -40           | 50             |
|         | 5 | -40           | 40             |
|         | 8 | -10           | 40             |
|         | 11| -6            | 24             |
|         | 13| -6            | 24             |

Table 6: Simulation results of IEEE –30 system

| Control variables | Base case | MPSO [21] | PSO [20] | EP [19] | SARGA [19] | AWCA |
|-------------------|-----------|-----------|----------|---------|------------|------|
| $V_{G}^{-1}$      | 1.060     | 1.101     | 1.100    | NR*     | NR*        | 1.030|
| $V_{G}^{-2}$      | 1.045     | 1.086     | 1.072    | 1.097   | 1.094      | 1.021|
| $V_{G}^{-5}$      | 1.010     | 1.047     | 1.038    | 1.049   | 1.053      | 1.044|
| $V_{G}^{-8}$      | 1.010     | 1.057     | 1.048    | 1.033   | 1.059      | 1.019|
| $V_{G}^{-12}$     | 1.082     | 1.048     | 1.058    | 1.092   | 1.099      | 1.059|
| $V_{G}^{-13}$     | 1.071     | 1.068     | 1.080    | 1.091   | 1.099      | 1.049|
| $T_{a}p$          | 0.978     | 0.983     | 0.987    | 1.01    | 0.99       | 0.909|
| $T_{a}p$          | 0.969     | 1.023     | 1.015    | 1.03    | 1.03       | 0.912|
| $T_{a}p$          | 0.932     | 1.020     | 1.020    | 1.07    | 0.98       | 0.909|
Control variables | Base case | MPSO [21] | PSO [20] | EP [19] | SARGA [19] | AWCA
---|---|---|---|---|---|---
Tap36 | 0.968 | 0.988 | 1.012 | 0.99 | 0.96 | 0.900
QC10 | 0.19 | 0.077 | 0.077 | 0.19 | 0.19 | 0.091
QC24 | 0.043 | 0.119 | 0.128 | 0.04 | 0.04 | 0.119
PG (MW) | 300.9 | 299.54 | 299.54 | NR* | NR* | 298.89
QG (Mvar) | 133.9 | 130.83 | 130.94 | NR* | NR* | 130.24
Reduction in PLoss (%) | 0 | 8.4 | 7.4 | 6.6 | 8.3 | 16.80
Total PLoss (Mw) | 17.55 | 16.07 | 16.25 | 16.38 | 16.09 | 14.60

NR* - Not reported.

Then the proposed Amplified Water Cycle Algorithm (AWCA) has been tested, in IEEE 57 Bus system. Table 7 shows the constraints of control variables, Table 8 shows the limits of reactive power generators and comparison results are presented in Table 9.

Table 7 – constraints of control variables

| System | Variables      | Minimum (PU) | Maximum (PU) |
|--------|----------------|--------------|--------------|
| IEEE 57 Bus | Generator Voltage | 0.95 | 1.1 |
|         | Transformer Tap | 0.9 | 1.1 |
|         | VAR Source | 0 | 0.20 |

Table 8: Constrains 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 [21] | PSO [20] | CGA [19] | AGA [19] | AWCA |
|---|---|---|---|---|---|---|
| VG 1 | 1.040 | 1.093 | 1.083 | 0.968 | 1.027 | 1.021 |
| VG 2 | 1.010 | 1.086 | 1.071 | 1.049 | 1.011 | 1.023 |
| VG 3 | 0.985 | 1.056 | 1.055 | 1.056 | 1.033 | 1.030 |
| VG 6 | 0.980 | 1.038 | 1.036 | 0.987 | 1.001 | 1.022 |
| VG 8 | 1.005 | 1.066 | 1.059 | 1.022 | 1.051 | 1.029 |
| VG 9 | 0.980 | 1.054 | 1.048 | 0.991 | 1.051 | 1.017 |
| VG 12 | 1.015 | 1.054 | 1.046 | 1.004 | 1.057 | 1.039 |
| Tap 19 | 0.970 | 0.975 | 0.987 | 0.920 | 1.030 | 0.947 |
| Tap 20 | 0.978 | 0.982 | 0.983 | 0.920 | 1.020 | 0.930 |
| Tap 31 | 1.043 | 0.975 | 0.981 | 0.970 | 1.060 | 0.931 |
| Tap 35 | 1.000 | 1.025 | 1.003 | NR* | NR* | 1.017 |
| Tap 36 | 1.000 | 1.002 | 0.985 | NR* | NR* | 1.002 |
| Tap 37 | 1.043 | 1.007 | 1.009 | 0.900 | 0.990 | 1.001 |
| Tap 41 | 0.967 | 0.994 | 1.007 | 0.910 | 1.100 | 0.992 |
| Tap 46 | 0.975 | 1.013 | 1.018 | 1.100 | 0.980 | 1.014 |
| Tap 54 | 0.955 | 0.988 | 0.986 | 0.940 | 1.010 | 0.969 |
Then IEEE 300 bus system [18] is used as test system to validate the performance of the Projected Amplified Water Cycle Algorithm (AWCA). Table 10 shows the comparison of real power loss obtained after optimization.

| Parameter | Method EGA [23] | Method EEA [23] | Method CSA [22] | AWCA |
|-----------|-----------------|-----------------|-----------------|-------|
| PLOSS (MW) | 646.2998        | 650.6027        | 635.8942        | 617.0271 |

7. Conclusion

In this paper Amplified Water Cycle Algorithm (AWCA) has been successively solved the optimal reactive power problem. In the proposed Amplified Water Cycle Algorithm (AWCA) - with reference to the fitness value, population is first alienated into three groups: streams, rivers and sea. Through the hybridization of Gravitational Search Algorithm, Chaos theory with water cycle algorithm exploration and exploitation has been effectively improved. Projected Amplified Water Cycle Algorithm (AWCA) has been tested in standard IEEE 14, 30, 57, 300 bus test system and simulation results show the projected algorithm reduced the real power loss extensively. Percentage of the reduction of power loss is 23.46 %, 16.80%, 21.93% respectively.

References

[1] K. Y. Lee.(1984). “Fuel-cost minimisation for both real and reactive-power dispatches,” Proceedings Generation, Transmission and Distribution Conference, vol/iissue: 131(3), pp. 85-93.

[2] N. I. Deeb.(1998). “An efficient technique for reactive power dispatch using a revised linear programming approach,” Electric Power System Research, vol/iissue: 15(2), pp. 121–134.

[3] M. R. Bjelogrlic, M. S. Calovic, B. S. Babic. (1990). "Application of Newton's optimal power flow in voltage/reactive power control", IEEE Trans Power System, vol. 5, no. 4, pp. 1447-1454.

[4] S. Granville.(1994). “Optimal reactive dispatch through interior point methods,” IEEE Transactions on Power System, vol/iissue: 9(1), pp. 136–146. http://dx.doi.org/10.1109/59.317548

[5] N. Grudinin.(1998). “Reactive power optimization using successive quadratic programming method,” IEEE Transactions on Power System, vol/iissue: 13(4), pp. 1219–1225. http://dx.doi.org/10.1109/59.736232
[6] Wei Yan, J. Yu, D. C. Yu , K. Bhattachari. (2006). "A new optimal reactive power flow model in rectangular form and its solution by predictor corrector primal dual interior point method", IEEE Trans. Pwr. Syst., vol.21, no.1, pp.61-67. http://dx.doi.org/10.1109/TPWRS.2005.861978

[7] Aparajita Mukherjee, Vivekananda Mukherjee. (2015). “Solution of optimal reactive power dispatch by chaotic krill herd algorithm”, IET Gener. Transm. Distrib., Vol. 9, Issue. 15, pp. 2351–2362.

[8] Hu. Z., Wang. X. & Taylor. (2010). “Stochastic optimal reactive power dispatch: Formulation and solution method”. Electr. Power Energy Syst., vol. 32, pp. 615-621. http://dx.doi.org/10.1016/j.ijepes.2009.11.018

[9] Mahaletchumi Morgan, Nor Rul Hasma Abdullah, Mohd Herwan Sulaiman, Mahfuzah Mustafa and Rosdiyana Samad. (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.

[10] Pandiarajan, K. & Babulal, C. K. (2016). “Fuzzy harmony search algorithm based optimal power flow for power system security enhancement”. International Journal Electric Power Energy Syst., vol. 78, pp. 72-79.

[11] Mahaletchumi Morgan, Nor Rul Hasma Abdullah, Mohd Herwan Sulaiman, Mahfuzah Mustafa and Rosdiyana Samad. (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, 12-1.

[12] Rebecca Ng Shin Mei, Mohd Herwan Sulaiman, Zuriani Mustaffa. (2016). “Ant Lion Optimizer for Optimal Reactive Power Dispatch Solution”, Journal of Electrical Systems, "Special Issue AMPE2015", pp. 68-74.

[13] Gagliano A., Nocera F. (2017). Analysis of the performances of electric energy storage in residential applications, International Journal of Heat and Technology, Vol. 35, Special Issue 1, pp. S41-S48. DOI: 10.18280/ijht.35Sp0106.

[14] Caldera M., Ungaro P., Cammarata G., Puglisi G. (2018). Survey-based analysis of the electrical energy demand in Italian households, Mathematical Modelling of Engineering Problems, Vol. 5, No. 3, pp. 217-224. DOI: 10.18280/mmep.050313

[15] E. Rashedi, S. Nezamabadi, and S. Saryazdi, "GSA: A Gravitational Search Algorithm", Information Sciences, vol. 179, no. 13, pp. 2232-2248, 2009.

[16] O. Abdel-Raouf, I. El-henawy and M. Abdel-Baset "chaotic Harmony Search Algorithm with Different Chaotic Maps for Solving Assignment Problems "International Journal of Computational Engineering & Management, Vol. 17, pp. 10-15 ,2014.

[17] Hadi Eskandar , Ali Sadollah , Ardesht Bahreininejad , Mohd Hamdi, (2012) , “Water cycle algorithm - A novel metaheuristic optimization method for solving constrained engineering optimization problems”, Computers and Structures, 110-111, p.151-166, November, doi>10.1016/j.compstruc.2012.07.010.

[18] IEEE, “The IEEE-test systems”, (1993), http://www.ee.washington.edu/rsearch/pstca/.

[19] Subbaraj, P. and P.N. Rajnarayan, 2009. Optimal reactive power dispatch using self-adaptive real coded Genetic algorithm. Electr. Power Syst. Res., 79(2): 374-38.

[20] Pandya, S. and R. Roy, 2015. Particle swarm optimization based optimal reactive power dispatch. Proceeding of the IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), pp: 1-5.

[21] Ali Nasser Hussain, Ali Abdulabbas Abdullah and Omar Muhammed Neda, (2018) ,“Modified Particle Swarm Optimization for Solution of Reactive Power Dispatch”, Research Journal of Applied Sciences, Engineering and Technology 15(8): 316-327, 2018 DOI:10.19026/rjaset.15.5917.

[22] S. Surender Reddy, “Optimal Reactive Power Scheduling Using Cuckoo Search Algorithm”, International Journal of Electrical and Computer Engineering, Vol. 7, No. 5, pp. 2349-2356. 2017.

[23] S.S. Reddy, et al., “Faster evolutionary algorithm based optimal power flow using incremental variables”, Electrical Power and Energy Systems, vol. 54, pp. 198-210, 2014.