Hybrid Emperor Penguin Optimization algorithm for solving Optimal Power Flow Problems

M Balasubbareddy[1], Divyanshi Dwivedi [2]

Department of Electrical and Electronics Engineering, Chaitanya Bharathi Institute of technology, Hyderabad

Abstract

In this paper a novel Emperor Penguin Optimization (EPO) algorithm which basically mimics the huddle behavior of emperor penguin is being hybridized with the arithmetic crossover operation of Genetic Algorithm (GA), is proposed named as Hybrid Emperor Penguin Optimization (HEPO) Algorithm used for solving optimal power flow in power systems. This hybridization leads to the better quality of solutions and improve the exploration in search space. The capability and performance of the proposed algorithm is tested on benchmark test functions and IEEE-30 bus test system. Generation fuel cost and severity are considered as objectives for optimal power flow problems. Simulation results show that the proposed algorithm provides an effective and robust high-quality of solutions. The obtained results will be compared with the existing literatures for justifying the superiority of the proposed algorithm.

Keywords: *Optimal Power Flow (OPF), Hybrid Emperor Penguin Optimization (HEPO) Algorithm, arithmetic crossover operation, generation fuel cost and severity.*

1. Introduction

Optimal power flow (OPF) is a vital aspect for the operation and controlling of power system. OPF problem determines the optimal operating state of a power system by optimizing objectives like generation fuel cost, emission of generating units and real power transmission losses with considering specified physical and operating constraints, with some control variables such as generators real output power and voltages, transformer tap setting, phase shifters, switched capacitors and reactors.

Basically, OPF problem consists of a great number of constraints, and it is a nonlinear, non-convex optimization method and for solving OPF problem many conventional methods and evolutionary algorithms have been proposed. Conventional methods include linear programming, non-linear programming, quadratic programming, Newton method, gradient method, and interior point methods [2-10]. They have limitations like converging at local optima and are suitable only for continuous problems. Due to these limitations, they are not suitable for the actual OPF solution. Like in [7] gradient steepest-descent method having exterior penalty functions is proposed, it causes slow convergence rate and to overcome this, Newton algorithm and Quasi-Newton method had been proposed in [8-9]. Then it was being observed that the they did not converges due to improper selection of initial condition then researchers developed linear programming method in [10] but it also fails to provide proper solutions.

However, metaheuristic optimization methods are employed which can easily overcome limitations of conventional methods. In the recent years, they had gain more momentum which leads to the origin of a wide range of heuristic algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Evolutionary Programming (EP), Biogeography Based Optimization (BBO), Moth Flame Algorithm and many more listed in [11].

Furthermore to enhance the performance of existing algorithms these are hybridized, modified or improved to utilize the existing algorithms to its best. Moreover, Cuckoo Search Algorithm (CSA) [12], Fruit Fly Algorithm (FFA) [13] and Harmony search algorithm are hybridized with arithmetic crossover operation [14-16] respectively, to improve the performance of algorithms in terms of convergence rate and enhancing exploration. Considering this approach, in this paper a novel Emperor Penguin Optimization (EPO) [17] is being hybridized with arithmetic crossover operation of genetic algorithm to enhance its random walk and yields for better solutions.

Proposed algorithm named as Hybrid Emperor Penguin Optimization (HEPO) Algorithm is being tested on benchmark test functions and then implemented on IEEE-30 bus test system to verify its creditability. The results obtained through proposed algorithm are compared with the existing literatures.

2. Problem Formulation

Optimal Power Flow (OPF) deals to solve the steady state problem of electric power system through minimizing the objective functions with the consideration of constraints simultaneously. Mathematically OPF is represented by:

$$\text{Min } F_p(x, y) \qquad \forall p = 1,2,.......t$$

$$\text{Subject to: } g(x, y) = 0,$$

$$h(x, y) \le 0$$

where, ‘g’ and ‘h’ are the equality and inequality constraints respectively, ‘x’ is the state vector of dependent variables and ‘y’ is the control vector of system and t is the total number of objectives functions.

The state vector may be represented by:

$$x^T = [P_{g,1}, V_{l,1}....V_{l,NLINE}, Q_{g,1}....Q_{g,NGB}, S_{l,1}....S_{l,NTL}]$$

The control vector may be represented by:

$$y^T = [P_{g,2}.....P_{g,NGB}, V_{g,1}....V_{g,NGB}, Q_{SH,1}....Q_{SH,NC}, T_1....T_{NT}]$$

where $P_{g,1}$ is the real power, $V_{l,1}$ is the load bus voltage, , $Q_{g,1}$ is the reactive power of generator, $S_{l,1}$ is the apparent power of generator $V_{g,1}$ is the generator voltage of slack bus. *NLINE*, *NGB*, *NTL*, *NC* and *NT* are the total number of PQ buses, PV buses, transmission lines, shunt compensators and off-nominal tap transformers respectively.

2.1. Objective Functions

In this paper, three single objective functions are minimized, which are mathematically expressed below:

a. Generation fuel cost minimization

$$F_1 = \min(F_p(P_{g,m})) = \sum_{m=1}^{NGB} x_m P_{g,m}^2 + y_m P_{g,m} + z_m \$/h \quad (1)$$

where, x_m, y_m and z_m are the fuel cost coefficients of m^{th} unit.

b. Severity function

$$OF_2 = \sum_{x=1}^{NTL}\left[\frac{S_x}{S_x^{max}}\right]^{2m} + \sum_{y=1}^{NB}\left[\frac{V_{y,ref} - V_y}{V_{y,ref}}\right]^{2n} \quad (2)$$

where, S_x^{max} and S_x are the maximum and present apparent powers of x^{th} bus, $V_{y,ref}$ and V_y are the nominal and present voltages at the y^{th} bus and m and n are the coefficients used for penalizing overloads and voltage violations(their value is taken equal to 2).

2.2. Constraints

The equality and in-equality constraints are as follows:

a. Equality constraints

$$\sum_{m=1}^{NGB} P_{g,m} - P_D - P_L = 0, \quad \sum_{m=1}^{NGB} Q_{g,m} - Q_D - Q_L = 0$$

b. Inequality Constraints

(i). Generator constraints

$$V_{g,m}^{\min} \le V_{g,m} \le V_{g,m}^{\max} \text{ and}$$

$$Q_{g,m}^{\min} \le Q_{g,m} \le Q_{g,m}^{\max} \qquad \forall m \in NGB$$

(ii). Voltage at bus and discrete transformer tap settings

$$V_{g,m}^{\min} \le V_{g,m} \le V_{g,m}^{\max} \text{ and}$$

$$T_m^{\min} \le T_m \le T_m^{\max} \qquad \forall m \in NT$$

(iii). Active power generation limits

$$P_{g,m}^{\min} \le P_{g,m} \le P_{g,m}^{\max} \qquad \forall m \in NGB$$

(iv). Reactive power supply by the capacitor banks

$$Q_{SH,m}^{\min} \le Q_{SH,m} \le Q_{SH,m}^{\max} \qquad \forall m \in NC$$

(v). Transmission line loadings

$$S_{l,m} \le S_{l,m}^{\max} \qquad \forall m \in NTL$$

3. Hybrid Emperor Penguin Optimization Algorithm

In Antarctic winter, these emperor penguins congregate together to keep them warm as shown in **Figure 1,** and this huddling mechanism is considered for developing the algorithm.

Basically, this huddling mechanism of emperor penguins occurs in four phases:

- Huddling boundary for emperor penguins will be generated.
- Temperature around huddle will be calculated.
- Distance between the emperor penguins will be determined.
- Effective mover will be relocated.

Figure 1. Huddling mechanism of Emperor Penguin

3.1. Pseudo code for the HEPO algorithm

The steps of HEPO are summarized as follows:

START

Step 1: Initialize the parameters of the proposed algorithm such as number of spotted hyenas $\vec{P}_{EP}$ (t) (t=1,2,….,n) and maximum number of iterations (Max_iter).

Step 2: Initialize vectors T_P, $\vec{M}$, $\vec{N}$, S and r.

while(t<Max_iter***) do***

for (each $\vec{P}_{EP}$***)***

Step 3: Calculate the fitness of each search agents, ***FITNESS*** $(\vec{P}_{EP})$

Step 4: R=Rand [0, 1]

if (R>1) ***then***
T=0
else
T=1
end if

Step 5: Calculate T_P using:

$$T_P = \left(T - \frac{Max\_iter}{t - Max\_iter} \right)$$

where, t and Max_iter are the current and maximum number of iterations and r is the radius of polygon.

Step 6: Calculate the vectors, $\vec{M}$ and $\vec{N}$ using:

$$\vec{M} = (A \times (T_P) + P_G(Accuracy) \times R()) - T_P$$

$$\vec{N} = R()$$

$$P_G(Accuracy) = Abs(\vec{P} - \vec{P}_{EP})$$

where, A maintains gap between the emperor penguins to avoid collision which is considered to be equal to 2, $P_G(Accuracy)$ is the grid accuracy obtained by comparing the difference between emperor penguins and $R()$ is the random function which generates value between [0,1].

Step 7: Calculate the function $S(\vec{M})$ using:

$$S(\vec{M}) = \left(\sqrt{f . e^{-t/l} - e^{-t}} \right)^2$$

where, f and l maintains exploration and exploitation and their values is in the range of [2,3] and [1.5,2] respectively.

Step 8: Update the position of other search agents using Eq. (11):

$$\vec{P}_{EP}(t+1) = \vec{P}(t) - \vec{M} . \vec{D}_{EP}$$

where, $\vec{P}_{EP}(t+1)$ represents the next updated position of emperor penguin.

end for

Step 9: Update the vectors T_P, $\vec{M}$, $\vec{N}$ and S ().

Step 10: Check the boundary limit and then adjust it.

Step 11: Update the position of other search agents using arithmetic crossover operation:

$$\vec{P}_{EP}(t+1) = (1-\lambda)\times\vec{P}_{EP}(t) + \lambda\times\vec{P}_{EP}(t+1)$$

where, λ is a random number between 0 and 1.

Step 12: Update the fitness function accordance to the updated position and identify the best optimal solution. Update if $\vec{P}$ is better than previous optimal solution.

Step 13: t=t+1

end while

Step 14: Return best optimum value $\vec{P}$ obtained.

END

4. Results

4.1. Illustrative Example

In this paper, the proposed algorithm is imposed on benchmark test functions to verify its effectiveness. Unimodal test functions are considered having dimension 30, are listed in **Table 1.**

Table 1. Unimodal benchmark test functions

Function	Range
$f_1(x) = \sum_{i=1}^{n} x_i^2$	[-100,100]
$f_2(x) = \sum_{i=1}^{n} \lvert x_i \rvert + \prod_{i=1}^{n} \lvert x_i \rvert$	[-10,10]
$f_3(x) = \sum_{i=1}^{n-1} [100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2]$	[-30,30]

It can be observed from **Table 2,** that when proposed algorithm is implemented the functions got minimized to the best value as compared to existing algorithms. We can also see that proposed algorithm results out the better values as compared to novel EPO algorithm, thus it validate that the hybridization of existing algorithm with arithmetic crossover operation yields for the better solutions.

Table 2. Comparison results of optimal value of benchmark test functions

Function	GA[17]	SCA[17]	PSO[17]	EPO[17]	HEPO
$f_1(x)$	2.01E-11	1.06E-01	1.40E-08	8.31E-29	1.39E-29
$f_2(x)$	5.10E-17	8.57E-05	1.84E-03	3.32E-40	0.000
$f_3(x)$	4.16E+01	1.98E+03	3.89E+01	4.90E-01	6.986E-02

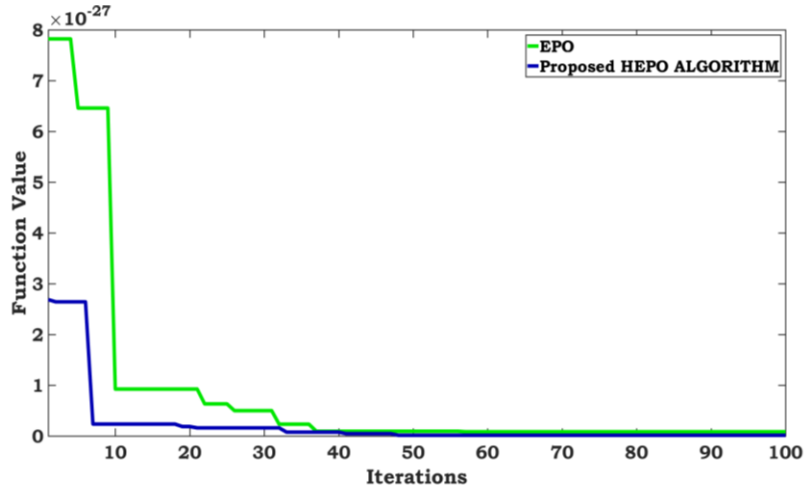

Figure 2. Convergence curve of function $f_1(x)$

For analyzing the convergence characteristics curves are shown in **Figures 2-4,** for the $f_1(x)$, $f_2(x)$, and $f_3(x)$ benchmark test functions, which also proves the effectiveness of proposed algorithm as with proposed algorithm, the convergence occurs fast as compared to EPO algorithm. It can also be seen that smooth variation in convergence is being observed in case of HEPO algorithm.

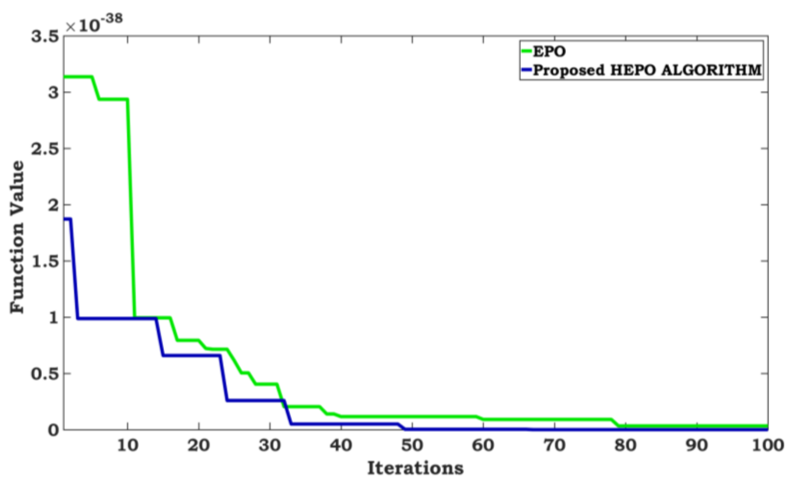

Figure 3. Convergence curve of function $f_2(x)$

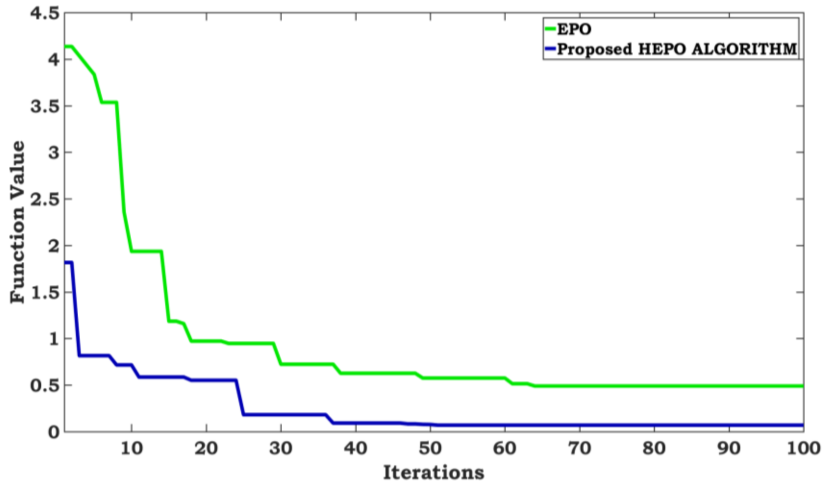

Figure 4. Convergence curve of function $f_3(x)$

4.2. Electrical Test System

The proposed HEPO has been verified on IEEE-30 bus system by solving the OPF problems. Generally, IEEE- 30 bus system consists of 6 generators placed on buses 1, 2, 5, 8, 11 and 13, four off-nominal tap ratio transformers placed between the buses 6-9,6-10, 4-12, 27-28 and two shunt capacitors at buses 10 and 24 [18].

The generation fuel cost and severity factor are solved using proposed algorithm and the results are compared with existing methods. The OPF are tabulated in **Table 3** and we can say that the considered objective functions got minimized to better values by using HEPO algorithm as compared to other existing methods. The convergence characteristics of the proposed method is being compared with other existing methods as shown in **Figures 5-6** and it is clearly shown that the proposed method initiates with better value of considered objective function and at less number of iteration it converges effectively.

Table 1. OPF results for considered objective functions for IEEE-30 bus system

Variables	Generation Fuel Cost, $/h			Severity Factor	
	PSO [14]	HSCA [14]	HEPO	PSO	HEPO
PG1, MW	178.556	176.87	179.0273	97.21162	87.36372
PG2, MW	48.6032	49.8862	47.99741	49.06359	57.58557
PG5, MW	21.6697	21.6135	21.23797	50	50
PG8, MW	20.7414	20.8796	19.20302	34.86501	35

PG11, MW	11.7702	11.6168	12.93995	28.52709	30
PG13, MW	12	12	12.00584	29.80484	29.87013
VG1, p.u.	1.1	1.057	1.1	1.047449	1.075547
VG2, p.u.	0.9	1.0456	1.039964	1.032259	1.065019
VG5, p.u.	0.9642	1.0184	1.059043	0.986924	0.997073
VG8, p.u.	0.9887	1.0265	1.063158	1.018468	1.040401
VG11, p.u.	0.9403	1.057	1.07555	1.011021	1.067992
VG13, p.u.	0.9284	1.057	1.1	1.049806	1.036324
Tap 6-9, p.u.	0.9848	1.0254	0.982487	1.002678	0.944308
Tap 6-10, p.u.	1.0299	0.9726	0.999991	1.015967	1.022904
Tap 4-12, p.u.	0.9794	1.006	1.024599	0.99914	1.047882
Tap 28-27, p.u.	1.0406	0.9644	0.983027	0.982095	0.98666
Qc 10, p.u.	9.0931	25.3591	10.3038	16.85039	20.85585
Qc 24, p.u.	21.665	10.6424	14.609	15.53074	12.88458
Generation Fuel Cost, $/h	**803.454**	**802.03**	**800.0971**	**906.355**	**916.788**
Severity Factor	NA	NA	**2.0876**	**1.436293**	**1.364455**

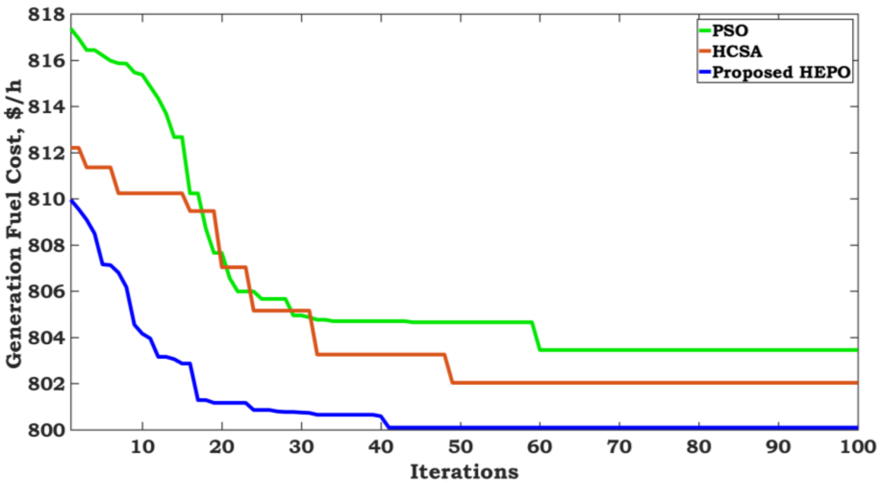

Figure 5. Convergence curve of Generation Fuel Cost

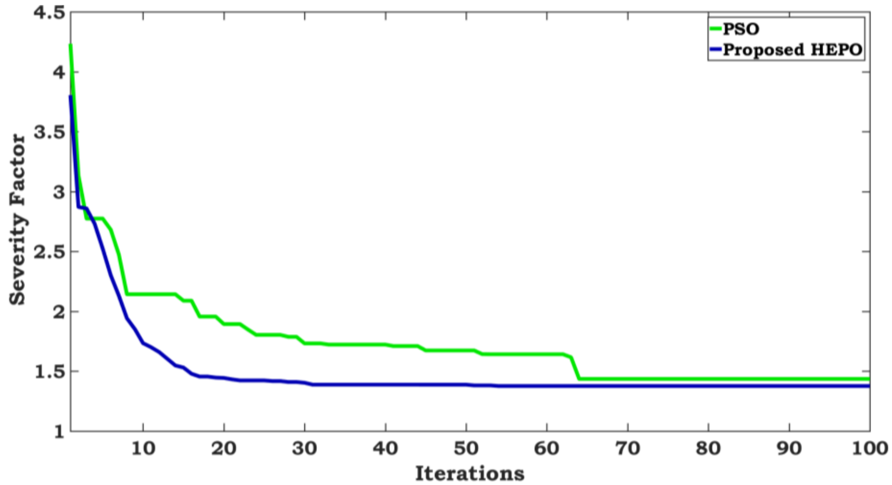

Figure 6. Convergence curve of Severity Factor

5. Conclusion

In this paper, an effective algorithm is proposed with the hybridization of existing EPO and real coded Genetic Algorithm (GA) arithmetic cross-over operation, named as Hybrid Emperor Penguin Optimization (HEPO) Algorithm. It has been being tested on unimodal as well as multi modal benchmark test functions, from which we can concluded that its performance is better as compared to other existing algorithms. Then the proposed algorithm is applied to solve the OPF problems under equality and in-equality constraints for the considered objectives which are generation fuel cost and severity, from which we can conclude that solutions for considered objectives got minimized to the best values as compared to existing EPO algorithm. We can also say that hybridization enhances the rate of convergence and values obtained at initial iteration are less. Thus, the proposed algorithm is effective in terms of performance and capable to obtain the global solution.

References

*[1]. J. Carpentier, "Contribution to the economic dispatch problem", Bulletin Society Francaise, Electricians 3, **(1962)**, 431-447.*
*[2]. Xie, K., Song, Y.H, "Dynamic optimal power flow by interior point methods", IET Proceedings Generation, Transmission and Distribution, 148(1), **(2002)**, 76– 84.*
*[3]. Javad Lavei, Anders Rantzer, Stephen Low, "Power flow optimization using positive quadratic programming", **(2011)**, 18th IFAC (Italy).*
*[4]. El-Hawary, J.A.M.M.E., Adapa, R, "A review of selected optimal power flow literature to 1993. part i: nonlinear and quadratic programming approaches", IEEE transactions on power systems, Vol. 14, **(1999A)**, No. 1.*

[5]. El-Hawary, J.A.M.M.E., Adapa, R., "A review of selected optimal power flow literature to 1993. part ii: newton, linear programming and interior point methods" . IEEE Transactions on Power Systems, 14(1), ***(1999b)****, 105–111.*
[6]. O. Alsac, B. Stott, "Optimal load flow with steady-state security", IEEE Transactions on Power Systems, ***(1973)****, T73 484-3.*
[7]. K. Lee, Y. Park, J. Ortiz, "A united approach to optimal real and reactive power dispatch", IEEE Trans. Power App. Syst. 104, ***(1985)****, 1147-1153.*
[8]. David I. Sun, Bruce Ashley, Brian Brewer, A. Hughes, William Tinney, "Optimal power flow by newton approach, IEEE Transaction on Power Apparatus and Systems", Vol. PAS-103, ***(1984)****, No.10.*
[9]. S.N. Talukdar, T.C. Giras, V.K. Kalya, "Decompositions for optimal power flows", IEEE Trans. Power App. Syst. PAS-102, ***(1983)****, 3877–3844.*
[10]. G. Fahd, G.B. Sheble, "Optimal power flow emulation of interchange brokerage systems using linear programming", IEEE Trans. Power Syst. 7, ***(1992)****, 497-504.*
[11]. Mohamed Ebeed, Salah Kamel, Francisco Jurado, "Optimal Power Flow Using Recent Optimization Techniques", Classical and Recent Aspects of Power System Optimization, ***(2018)****, 157-183.*
[12]. Amir Hossein Gandomi, Xin-She Yang, Amir Hossein Alavi, "Cuckoo search algorithm: a metaheuristic approach to solve structural optimization problems", Engineering with Computers, ***(2013)****, 17–35.*
[13]. Bo Xing, Wen-Jing Gao, "Fruit Fly Optimization Algorithm", Innovative Computational Intelligence: A Rough Guide to 134 Clever Algorithms, ***(2013)****, 167-170*
[14]. M. Balasubbareddy, S. Sivanagaraju, V. Suresh Chintalapudi, "Multi-objective optimization in the presence of practical constraints using non-dominated sorting hybrid cuckoo search algorithm", Eng Sci Technol Int J, ***(2015)****.*
[15]. M. Balasubba Reddy, "Multi-objective optimization in the presence of ramp-rate limits using non-dominated sorting hybrid fruit fly algorithm", Ain Shams Engineering Journal, ***(2016)****, 895-90.*
[16]. Qun Niu , Hongyun Zhang, Xiaohai Wang , Kang Li , George W. Irwin, "A hybrid harmony search with arithmetic crossover operation for economic dispatch", Electrical Power and Energy Systems 62, ***(2014)****, 237–257.*
[17]. Gaurav Dhiman, Vijay Kumar, "Emperor Penguin Optimizer: A Bio-inspired Algorithm for Engineering Problems', Knowledge-Based Systems, (2018).
[18]. M. A. Abido, "Optimal Power Flow Using Tabu Search Algorithm", Electric Power Components and Systems Volume 30, (2002), Issue 5.