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Water Cycle Algorithm for Small Scale Electrical Economic Power Dispatch Problem

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Abstract

Efficient and optimal planning of economic electrical power dispatch problem is an integral part of economic electrical energy generation planning and it is the need of time for the electrical engineers to browse this area in multi-scale planning scenarios. Intelligent and Optimization techniques based on evolutionary computing, metaheuristic,biological base,nature inspired, search method establish their applications in the area of electrical economic power dispatch planning(EEPDP) to reach global optimal solution for this multi scale, multi-decision, multi-objective combinatorial problem subjected to different constraints. In this paper, water cycle algorithm (WCA) has been proposed to solve electrical economic power dispatch problem for three and six unit system.This is based on how the streams and rivers flow downhill towards the sea and recycle in nature The suggested technique is tested on small scale system of three and six unit system of EEPDP considering various equality and inequality constraints . Test results are compared with other techniques grey wolf optimization(GWO),cuckoo search(CS),artificial bee colony(ABC),firefly algorithm(FA),particle swarm optimization(PSO),shuffled frog leap (SFL) ,bacteria foraging algorithm(BFO),harmony search(HS) applied in literature.Convergence of solution with iteration is presented for both cases.Simulation results proved that the WCA technique is better as compared to other nature inspired,heuristic,metaheuristic techniques to find global minima and maintain the solution quality in terms of low fuel cost.

***Keywords**: Water Cycle Algorithm (WCA), Electrical Economic Power Dispatch Problem (EEPDP),particle swarm optimization(PSO),harmony search(HS)*

1. Introduction

The EEPDP is an imperative area of today's power system planning. The purpose of the EEPDP is to find the optimum generation among the existing units, such that the total generation cost is minimized while simultaneously satisfying the power balance equations and various other constraints in the system. Shazia Khan[1] presents economic load dispatch (ELD) as the process of scheduling the generating units in such a way to fullfill the load demand with satisfied constraints to minimize the total production cost of the thermal power plant. In this paper the ELD problem is solved by an improved version of particle swarm optimization technique with a inertia weight improved (IWIPSO), which enhances the ability of particles to explore the solution spaces more effectively and increases their convergence rates. Proposed algorithm is established through its application for 13 & 15 generator systems with various constraints. AlRashidi, M.R.[2] presents a comprehensive coverage of different PSO

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applications in solving optimization problems in the area of electric power systems. It highlights the PSO key features and advantages over other various optimization algorithms. Furthermore, recent trends with regard to PSO development in this area are explored. This paper also discusses PSO possible future applications in the area of electric power systems and its potential theoretical studies. Payal Mistry and Sanjay Vyas[3] presents a successful adaptation of the particle swarm optimization (PSO) algorithm to solve types of economic dispatch (ED) problems in power systems. Economic load dispatch is a non linear optimization problem which is of great importance in power systems. Economic load dispatch is the scheduling of generators to minimize the total operating cost depending on equality and inequality constraints .The transmission line loss has been kept as minimum as possible. The study is carried out for three unit test system for without loss and with loss cases. Shubham Tiwari [4] shows that systematical methods suffer from slow convergence and curse of dimensionality in particle swarm optimization can be an well-organized alternative to solve on large scale non linear optimization problems. This paper presents an overview of basic PSO to provide a complete survey on the problem of economic load dispatch as an optimization problem. The study is carried out for three unit test system and then for six unit generating system for without loss and with loss cases. Adriane B. S. Serapião[5] presents ELD problem of electric power system is to schedule the committed generating units outputs so as to meet the necessary load demand at less operating cost . In this paper, two test systems of these problems are solved by using the Cuckoo Search (CS) Algorithm. A comparison of obtained simulation results by using the CS is carried out against six others swarm intelligence algorithms: Particle Swarm Optimization, Bacterial Foraging Optimization, Artificial Bee Colony, Harmony Search and Firefly Algorithm, Shuffled Frog Leaping Algorithm. The efficiency of each swarm intelligence algorithm is established on a test system comprising three -generators and other containing six-generators. Results denotes the power of the Cuckoo Search Algorithm and confirm its potential to solve the ELD problem. . MM [6] shows that analytical methods suffer from slow convergence and curse of dimensionality can be solved by particle swarm optimization and can be an efficient alternative to solve large scale non linear optimization problems. This paper presents an overview of basic PSO to give a comprehensive survey on the problem of economic load dispatch as an optimization problem. The study is carried out for three unit test system and then for six unit generating system without loss and with loss cases.H Abdi [7] presents optimization as one of the important aspects in power system study fields, especially in power systems, and a variety of models and techniques has been presented in this area. Each model tries to get the best solution as an optimal point, without trapping in local optima. As a powerful tool, modeling based on expert systems and simulation of normal process has an noticeable value in this regard. Since most of power system optimization problems are complex and non-linear with satisfied equality and inequality constraints, the heuristic optimization techniques such as Particle Swarm Optimization (PSO) are considered as realistic and powerful solution schemes to obtain the optimal or quasi-optimal solutions in power system optimization problems.V.Karthikeyan [8] presents Economic Dispatch as an important optimization task in the power system. It is the process of allocating generation among the committed units such that the constraints imposed are satisfied and the energy requirements are minimized. More just, the soft computing method has received supplementary concentration and was used in a quantity of successful and sensible applications. Here, an attempt has been made to find out the minimum cost by using Particle Swarm Optimization (PSO) Algorithm using the data of three generating units. In this work, data has been taken such as the loss coefficients with the max-min power limits and cost function. PSO and Simulated Annealing (SA) are applied to find out the minimum cost for different power demand. When the results are compared with the traditional technique, PSO seems to give a better result with better convergence characteristic. All the methods are executed in MATLAB environment. The effectiveness and feasibility of the proposed method were demonstrated economic dispatch problems .Huynh Thi Thanh Binh[9] presents that the Multi-Area Economic Dispatch problem (MAEDP) in deregulated power system environment for practical multi-area cases with tie line constraints. Our objective is to generate allocation to the power generators in such a manner that the total fuel cost is minimized while all operating constraints are satisfied. This problem is NP-hard. In this paper, we propose Hybrid Particle Swarm Optimization (HGAPSO) to solve MAEDP. The experimental results are reported to show the efficiency of proposed algorithms compared to Particle Swarm Optimization with Time-Varying Acceleration Coefficients (PSO-TVAC) and RCGA. D.N. Jeyakumar [10]presents a successful adaptation of the particle swarm optimisation (PSO) algorithm to solve various types of economic dispatch (ED) problems in power systems such as, multi-area ED with tie line limits, ED with multiple fuel options, combined environmental economic dispatch, and the ED of generators with prohibited operating zones. Numerical examples typical to each type are solved on Matlab 6.5 platform, using both the PSO method and the classical evolutionary programming (CEP) approach. The results obtained show that the proposed PSO based ED algorithm can provide comparable dispatch solutions with reduced computation time for all types of ED problem.Hardiansyah [11] presents economic load dispatch (ELD) problem as a common task in the analytical planning of a power system, which requires to be optimized. This paper presents an effective and reliable water cycle algorithm (WCA) technique for the economic load dispatch problem. The results have been demonstrated on standard 3-generator and 6-generator systems with and without consideration of transmission losses. The final results obtained using PSO are compared with conventional quadratic programming and found to be encouraging. Leandro dos [12] presents the objective of the ELD as the process of scheduling the generating units, so that the system load is supplied entirely and most economically while satisfying all units and system equality and equality constraints.

2. Problem Formulation

The EEPDP problem may be expressed by minimizing the fuel cost of generator units under constraints. Depending on load variations, the output of generators has to be changed to meet the balance between loads and generation of a power system. The power system model consists of n generating units already connected to the system [34-50].

The EEPDP problem can be expressed as.

A. Fuel Cost Model

$$C(PGi) = (ai * PGi^2 + bi * PGi + ci)Rs \tag{1}$$

i=1…..N

where a,b,c are fuel coefficients, PG is power generation in MW,C is fuel cost

B. Constraints

$$P_{Gi} - P_D - P_L = 0 \tag{2}$$

Where PG is power Generation , P_D power demand ,P_L power loss.

$$PGi,min \leq PGi \leq PGi,max \tag{3}$$

where i=1,2……N(Power Limits),PGi,min is the minimum limit of power generation and PGi,max is the maximum limit of power generation.

C. Transmission Losses

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{Gi} B_{ij} G_j + \sum_{i=1}^{N} B_{0i} P_{Gi} + B_{oo} \tag{4}$$

Where B_{oo}, B_{ij} , B_{oi} are transmission loss coefficients

3. Water Cycle Algorithm

Water cycle algorithm (WCA) is a novel optimization method for solving constrained engineering optimization problems that proposed in 2012 [51]. In this algorithm sea is best value and stream or river as initial population, adjoined to sea (best value) at last. Water Cycle Algorithm (WCA) has ability to find maximum or minimum value of function with high speed and accuracy, so in this paper, this algorithm is applied to determine the optimum power generation of generators in which fuel cost is minimum. In a problem with N_{var} variables, each raindrop is a 1 × N_{var} array and each array is a solution for problem. These arrays are put in a matrix.

$$Raindrop_i = \boldsymbol{X}_i = | x_1, x_2 .... x_n) | \tag{5}$$

$$Population...raindrops = \begin{bmatrix} raindrop_1 \\ raindrop_2 \\ .... \\ raindrop_i \\ .... \\ raindrop_{NPOP} \end{bmatrix} \tag{6}$$

so N_{pop} is number of raindrops and population raindrops are initial population. Then cost of each raindrop is calculated by cost function.

A. Stream (or river) flow to river (or sea)

All streams and rivers join to the sea at last by expressions:

$$Position_{stream}^{new} = Position_{stream} + rand \times C \times (Position_{river} - Position_{stream}) \tag{7}$$

$$Position_{river}^{new} = Position_{river} + rand \times C \times (Position_{sea} - Position_{river}) \tag{8}$$

where C is a number between 1 and 2. rand is a uniformly distributed random number between 0 and 1. If the solution is given by a stream is better than its connecting river, the positions of river and stream are exchanged (ie stream becomes river and river becomes stream). Such exchange can similarly happen for rivers and sea.

B. Evaporation and Raining

In order to avoid getting trapped in local optima evaporation and raining process is proposed [51]. This is specific prominence for Water Cycle Algorithm (WCA) to comparison other optimization algorithms. Evaporation process end if

$$Position_{sea} - Position_{river} \leq d_{max}$$

(9)

d_{max} is a number near to 0. The value of d_{max} automatically decreases as

$$d_{\max}^{new} = d_{\max} - (d_{\max} / \max iterations)$$

(10)

After evaporation process, raining process begins. In the raining process, the new raindrops are flowing to streams in the different locations. Eq (10) is used for new location of streams.

$$Position_{stream}^{new} = Position_{sea} + \sqrt{U} \times rand_n(1, N_{var})$$

(11)

where U determines rate of search near to the sea. $Rand_n$ is the normally distributed random number.

C. Loop End

In this research, maximum number of iterations (maxiteration) is used as a criterion for end of main loop which at the end loop, the optimal parameters are received. Water Cycle Algorithm (WCA) parameters has been brought in Table 1.

Table 1. Parameter Settings of WCA

Parameters	Value
N_{var}	3
N_{pop}	50
C	2.2
U	0.2
d_{max}	0.0001
maxiterations	1000

D. Algorithm

```
1)Start
2) Initialize   population Xi(i = 1, 2, ..., n)
3) Formulate population matrix
4)Evaluate cost of each rain drop
5)Streams, rivers and sea are located
6)Streams and rivers are flown to sea
7)Check value of river, sea, stream
8)If  (sea<river or river <stream)(yes-go to step 9 else 10)
9)Exchange the position of river with sea
10)Is equation (9) satisfied?(Yes-go to next step else go to step 12)
11)New raindrops are flowing to streams in different locations(Eq .11)
12)Decrease the value of $d_{max}$  (Eq-10)
13)Check the convergence criteria(if yes go to next step else go to step 5)
14)Output results(power generation and cost)
15)End
```

4. Optimal Power Dispatch Formulation using WCA

- The Variables[34-50]

Power Generation (PG) and cost coefficients (a,b,c) of units with objective function as fuel cost, quadratic in nature. Power Generation variable should be initialized as starting point for initial solution in WCA[51].

$$Raindrop_i = \mathbf{X}_i = |\, x_1, x_2 \ldots. x_n) \,| \qquad (12)$$

Where x1,x2…..xn are power generation of each generators and i=1,2….n (total number of generators) and raindrop is the cost value of particular set of power generation.

$$Population...raindrops = \begin{bmatrix} raindrop_1 \\ raindrop_2 \\ \dots\dots\dots \\ raindrop_i \\ \dots\dots\dots \\ raindrop_{NPOP} \end{bmatrix} \qquad (13)$$

- Constraints[34-50]

Equality Constraints: (P_G-P_D-P_L = 0)
(14)

Power generation – Power demand – Power loss=0

In-Equality Constraints: Power Generation should be between minimum and maximum limit of power generation.

$$PGi,min \le PGi \le PGi,max \qquad (15)$$

Variables in constraints should be incorporated in WCA algorithm.

- Stopping Criteria

It is maximum iteration limit for optimum solution(iteration=1000).

5. Test System

This case study incorporates three and six generating units. The coefficients of fuel cost and the limits of the generation units are given in Table 2 and 3.

$$Boo = 0.056, Bio = 0.001 \times \left[-0.3908, -0.1297, 0.7047, 0.0591, 0.2161, -0.6635\right] \qquad (16)$$

This case study incorporates three generating units. The coefficients of fuel cost and the capacities of the generation units are mentioned in Table 1.

Table 2. Generator Data for Test System III (Load Demand-150 MW)

Unit	a($/MW2)	b($/MW)	c($)	PG_{min}(MW)	PG_{max}(MW)
1	0.008	7	200	10	85
2	0.009	6.3	180	10	80
3	0.007	6.8	140	10	70

This case study incorporates three generating units. The coefficients of fuel cost and the limits of the generation units are given in Table 2.

$$Boo = 0.030523, Bio = 0.001 \times \left[0.3, 3.1, 1.5\right] \qquad (17)$$

$$Bij = 0.01 \times \left[0.0218, 0.1193, 0.0028; 0.0093, 0.0228, 0.0017; 0.0028, 0.0017, 0.0179\right] \qquad (18)$$

Where Boo,Bij,Bio are transmission loss coefficients

Table 3. Generator Data for Test System II (Load Demand – 700 MW)

Unit	a($/MW2)	b($/MW)	c($)	PG_{min}(MW)	PG_{max}(MW)
1	0.007	7	240	100	500
2	0.005	10	200	50	200
3	0.009	8.5	220	80	300
4	0.009	11	200	50	150
5	0.0080	10.5	220	50	200
6	0.0075	12	120	50	120

$$Bij = 0.001 \times \begin{bmatrix} 0.14,0.17,0.15,0.19,0.26,0.22; \\ 0.17,0.6,0.13,0.16,0.15,0.2; \\ 0.15,0.13,0.65,0.17,0.24,0.19 \\ 0.19,0.16,0.17,0.71,0.3,0.25; \\ 0.26,0.15,0.24,0.3,0.69,0.32; \\ 0.22,0.2,0.19,0.25,0.32,0.85 \end{bmatrix} \quad (19)$$

Where Bio,Boo,Bij are loss coefficients

6. Simulation Results

Table 4. Results Comparison With other Techniques on Three Unit System [44]

Parameters	**WCA**	CS[44]	ABC[44]	FA[44]
PG1 (MW)	**29.52**	33.490	33.049	32.729
PG2 (MW)	**72.21**	64.116	61.764	63.843
PG3 (MW)	**50.25**	55.126	57.872	56.151
Cost ($/hr)	**1594.988**	1600.46	1600.51	1600.47

In Table 4, result comparison has been shown of WCA algorithm with other algorithms like grey wolf optimization(GWO),cuckoo search(CS),artificial bee colony(ABC),firefly algorithm(FA),particle swarm optimization(PSO),shuffled frog leap (SFL) ,bacteria foraging algorithm(BFO),harmony search(HS) applied in literature. Power generation of each units and total fuel cost is compared. From results we can see that proposed method results in less fuel cost as compared to other algorithms.

Table 5. Results Comparison with other Techniques on Three Unit System [44]

Technique	Cost($/hr)
WCA	**1594.988**
CS[44]	1600.46
ABC[44]	1600.51
FA[44]	1600.47
PSO[52]	1600.60
SFL[52]	1600.67
BFO[52]	1600.02
HS[52]	1600.58

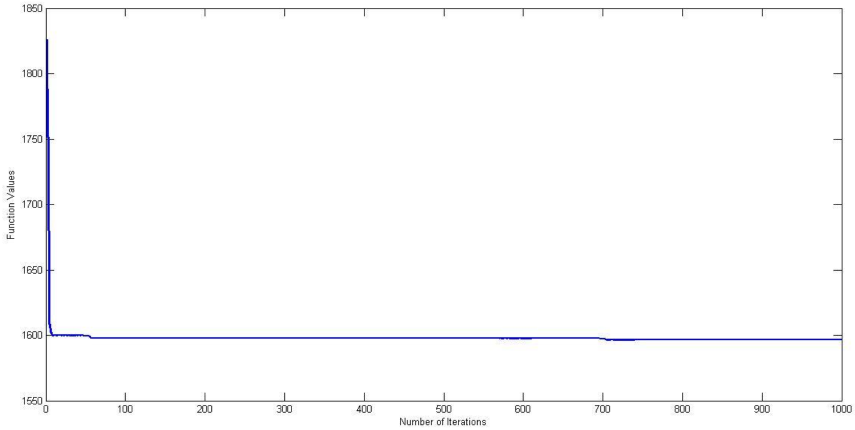

Figure 1. Convergence of Solution With Iteration for 3 Unit System

Table 6.Results Comparison With other Techniques on Six Unit System (Power Demand-700 MW) [12]

Parameters	**WCA**	GWO[44]	CS[44]	ABC[44]	FA[44]
PG1 (MW)	**307.39**	272.2641	324.113	323.043	293.312
PG2 (MW)	**78.169**	85.45712	76.859	54.965	79.546
PG3 (MW)	**150.0**	168.5936	158.094	147.354	123.334
PG4 (MW)	**65.28125**	60.89443	50.000	50.000	69.700
PG5 (MW)	**50**	73.64845	51.963	85.815	79.546
PG6 (MW)	**60.15**	50.13542	50.000	50.233	63.778
Cost ($/hr)	**8353.388**	8352.0153	8356.06	8372.27	8388.45

In Table 5 and 6 , result comparison has been shown of WCA algorithm with other algorithms like grey wolf optimization(GWO),cuckoo search(CS),artificial bee colony(ABC),firefly algorithm(FA), in literature. Power generation of each units and total fuel cost is compared. From results,bold numerals we can see that proposed method gives better results as compared to other algorithms in literature results in less fuel cost which proofs the economic benefit of proposed method WCA.

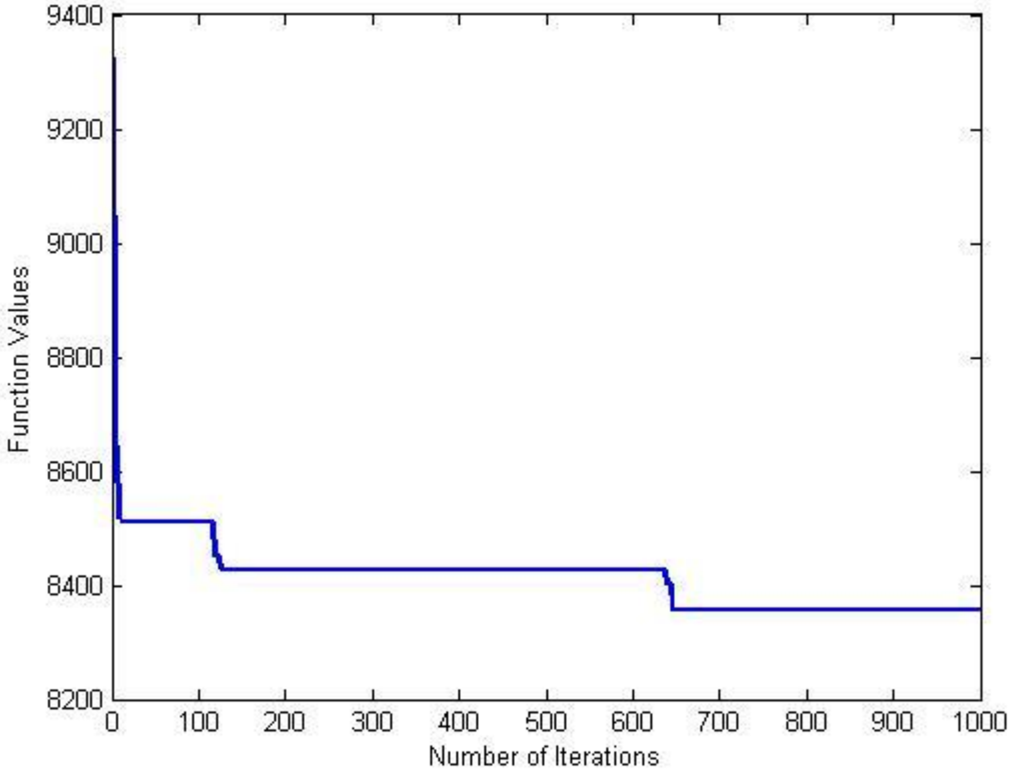

Figure 2. Convergence of Solution With Iteration For 6 Unit System

Figure 1 and 2 shows the high speed convergence of solution with iteration using WCA for 3 and 6 unit system

7. Conclusion

An application of WCA in EEPDP has been proposed. Proposed technique is tested on small scale three and six unit system .Test results reflects the minimum operating cost, optimum power generation and high speed convergence of solution of proposed method . A contrast has been made with other techniques presented in literature. It is superior than other techniques presented in literature in terms of fuel cost and power generation. Hence, WCA algorithm is robust and directed to optimal global solution in EEPDP.

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