

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 8, Issue 11, November 2019

## Solution to Generator Maintenance Management Using Modified Water Evaporation Optimization Algorithm

R. Anandhakumar

Assistant Professor, Department of Electrical and Electronics, Government College of Engineering, Sengipatti,  
Thanjavur, Tamilnadu, India

**ABSTRACT:** The Generator Maintenance Management (GMM) is a complex combinatorial optimization problem. Essential maintenance must be performed on a number of thermal generators inside a fixed planning horizon while ensuring high system reliability, reducing production cost, prolonging generator life time subject to some unit and system constraints. In this paper a modified water evaporation optimization algorithm is applied to solve the GMM optimization problem efficiently. The efficacy of the proposed algorithm is illustrated with the test system consists of 19 generating units over a 25 weeks planning horizon. The simulation results are compared with existing techniques. The simulation results indicate that modified WEO algorithm can efficiently be used for GMS.

**KEYWORDS:** Generator maintenance management, generator scheduling, modified water evaporation.

### I. INTRODUCTION

The problem of preventive maintenance schedules of generating units is solved for the purpose of maximizing economic benefits and improving reliable operation of a power system subject to satisfying system load demand, allowable maintenance window and crew and resource constraints [1]. The GMM problem has been formulated under economic and reliability criterion [2]. The various optimization techniques like Simulated Annealing (SA) [3], Genetic Algorithm (GA) [4&9], Tabu Search (TS) [5] has been applied to solve the GMM problem. The Constraint Logic Programming (CLP) synthesizes logic programming, constraint satisfaction technique and branch and bound search scheme, has been used to determine the optimal solution [6].

The Meta heuristic based hybrid approaches have also been applied to solve the GMM problem [7&12]. The PSO and its modified versions namely Discrete PSO, Modified Discrete PSO and Multiple Swarm MDPSO have been applied to determine the optimal maintenance schedule [8, 11]. The Bender's decomposition approach has also been applied to power plant preventive maintenance scheduling [10]. The multiple swarms MDPSO has been proposed to solve GMS problems [11]. A novel bio – inspired search algorithm named Artificial Bee Colony (ABC) algorithm has been used to solve GMM problem [13]. A teaching learning based optimization algorithm [14] has also been proposed to solve GMM problem. The evaporation of water is very important in biological and environmental science. The water evaporation from the bulk surface such as a lake or river is different from evaporation of water restricted on the surface of solid materials [15]. Recently the Water Evaporation Optimization algorithm (WEO) has been applied to solve various economic load dispatch problems [16]. In this paper, a modified WEO algorithm is proposed to determine the optimal solution for GMM problems.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 8, Issue 11, November 2019

## II. PROBLEM FORMULATION

The objective function for GMS model

$$\text{Min} \sum_{z=1}^Z \sum_{y=1}^Y [U_{zy} (A_y + B_y P_{yz} + C_y P_{yz}^2)] + \sum_{y=1}^Y FV_y(P_y) \quad (2.1)$$

Where  $FV_y(P_y)$  is expressed as a linear equation of production cost.  $FV_y(P_y) = V_y D_y$

$$D_{yz} = \begin{cases} 1 & \text{if unit } y \text{ start maintenance at week } z \text{ for each time period } z, z = 1, 2, 3, \dots, Z. \\ 0 & \end{cases}$$

The objective function of the problem is subjected to constraints as given below.

a) Load Balance

$$\sum_{z=1}^Z U_{zy} P_{zy} = D_y \quad (2.2)$$

b) Generator Output Limit

$$P_{Y \min} \leq P_{zy} \leq P_{y \max} \quad (2.3)$$

c) Spinning Reserve

$$\sum_{y=1}^Y U_{zy} P_{y \max} \geq D_y (1 + r_z \%) \quad (2.4)$$

d) Maintenance Window

$$U_{zy} = \begin{cases} 1, t \leq e_y, t \geq l_y + d_y \\ 0, S_y \leq t \leq S_y + d_y \\ 0, 1, e_y \leq t \leq l_y \end{cases} \quad (2.5)$$

e) Maintenance Area

$$\sum_{y=1}^Y (1 - U_{zy}) \leq \beta \quad (2.6)$$

f) Crew Constraint

$$\sum_{z=1}^Z \sum_{y=1}^Y (1 - U_{zy}) \leq C_r \quad (2.7)$$

## III. WATER EVAPORATION OPTIMIZATION ALGORITHM

The evaporation of water is very important in biological and environmental science. The water evaporation from bulk surface such as a lake or a river is different from evaporation of water restricted on the surface of solid materials. In this WEO algorithm water molecules are considered as algorithm individuals. Solid surface or substrate with

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 8, Issue 11, November 2019

variable wettability is reflected as the search space. Decreasing the surface wettability (substrate changed from hydrophilicity to hydrophobicity) reforms the water aggregation from a monolayer to a sessile droplet.

Such a behavior is consistent with how the layout of individuals changes to each other as the algorithm progresses. And the decreasing wettability of surface can represent the decrease of objective function for a minimizing optimization problem. Evaporation flux rate of the water molecules is considered as the most appropriate measure for updating individuals which its pattern of change is in good agreement with the local and global search ability of the algorithm and make this algorithm have well converged behavior and simple algorithmic structure. The details of the water evaporation optimization algorithm are well presented in (Kaveh and Bakhshpoori, 2016).

In the WEO algorithm, each cycle of the search consists of following three steps (i) Monolayer Evaporation Phase, this phase is considered as the global search ability of the algorithm (ii) Droplet Evaporation Phase, this phase can be considered as the local search ability of the algorithm and (iii) Updating Water Molecules, the updating mechanism of individuals.

### (i) Monolayer Evaporation Phase

In the monolayer evaporation phase the objective function of the each individuals  $Fit_i^t$  is scaled to the interval [-3.5, -0.5] and represented by the corresponding  $E_{sub}(i)^t$  inserted to each individual (substrate energy vector), via the following scaling function.

$$E_{sub}(i)^t = \frac{(E_{max} - E_{min}) \times (Fit_i^t - Min(Fit))}{(Max(Fit) - Min(Fit))} + E_{min} \quad (3.1)$$

Where  $E_{max}$  and  $E_{min}$  are the maximum and minimum values of  $E_{sub}$  respectively. After generating the substrate energy vector, the Monolayer Evaporation Matrix (MEP) is constructed by the following equation.

$$MEP_{ij}^t = \begin{cases} 1 & \text{if } rand_{ij} \leq \exp(E_{sub}(i)^t) \\ 0 & \text{if } rand_{ij} \geq \exp(E_{sub}(i)^t) \end{cases} \quad (3.2)$$

where  $MEP_{ij}^t$  is the updating probability for the  $j^{th}$  variable of the  $i^{th}$  individual or water molecule in the  $t^{th}$  iteration of the algorithm. In this way an individual with better objective function is more likely to remain unchanged in the search space.

### (ii) Droplet Evaporation Phase

In the droplet evaporation phase, the evaporation flux is calculated by the following equation.

$$J(\theta) = J_o P_o \left( \frac{2}{3} + \frac{\cos^3 \theta}{3} - \cos \theta \right) (1 - \cos \theta) \quad (3.3)$$

where  $J_o$  and  $P_o$  are constant values. The evaporation flux value is depends upon the contact angle  $\Theta$ , whenever this angle is greater and as a result will have less evaporation. The contact angle vector is represented the following scaling function.

$$\theta(i)^t = \frac{(\theta_{max} - \theta_{min}) \times (Fit_i^t - Min(Fit))}{(Max(Fit) - Min(Fit))} + \theta_{min} \quad (3.4)$$

Where the min and max are the minimum and maximum functions. The  $\theta_{min}$  &  $\theta_{max}$  values are chosen between  $-50^\circ < \theta < -20^\circ$  is quite suitable for WEO. After generating contact angle vector  $\Theta(i)^t$  the Droplet Probability Matrix (DEP) is constructed by the following equation.

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 8, Issue 11, November 2019

$$DEP_{ij}^t = \begin{cases} 1 & \text{if } rand_{ij} < J(\theta_i^{(t)}) \\ 0 & \text{if } rand_{ij} \geq J(\theta_i^{(t)}) \end{cases} \quad (3.5)$$

where  $DEP_{ij}^t$  is the updating probability for the  $j^{\text{th}}$  variable of the  $i^{\text{th}}$  individual or water molecule in the  $t^{\text{th}}$  iteration of the algorithm.

### (iii) Updating Water Molecules

In the WEO algorithm the number of algorithm individuals or number of water molecules (nWM) is considered constant in all  $t^{\text{th}}$  iterations, where  $t$  is the number of current iterations. Considering a maximum value for algorithm iterations ( $t_{\max}$ ) is essential for this algorithm to determine the evaporation phase and for stopping criterion. When a water molecule is evaporated it should be renewed. Updating or evaporation of the current water molecules is made with the aim of improving objective function. The best strategy for regenerating the evaporated water molecules is using the current set of water molecules ( $WM^{(t)}$ ). In this way a random permutation based step size can be considered for possible modification of individual as:

$$S = rand \cdot (WM^{(t)} [permutel(i)(j)] - WM^{(t)} [permute2(i)(j)]) \quad (3.6)$$

where  $rand$  is a random number in  $[0,1]$  range,  $permutel$  and  $permute2$  are different rows of permutation functions.  $i$  is the number of water molecule,  $j$  is the number of dimensions of the problem. The next set of molecules ( $WM^{(t+1)}$ ) is generated by adding this random permutation based step size multiplied by the corresponding updating probability (monolayer evaporation and droplet evaporation probability) and can be stated mathematically as:

$$WM^{(t+1)} = WM^{(t)} + S \times \begin{cases} MEP^{(t)} & t \leq t_{\max} / 2 \\ DEP^{(t)} & t > t_{\max} / 2 \end{cases} \quad (3.7)$$

Each water molecule is compared and replaced by the corresponding renewed molecule based on objective function. It should be noted that random permutation based step size can help in two aspects. In the first phase, water molecules are more far from each other than the second phase. In this way the generated permutation based step size will guarantee global and local capability in each phase.

## IV. IMPLEMENTATION OF MWEEO ALGORITHM TO SOLVE GMM PROBLEM

The detailed algorithmic steps for proposed MWEEO algorithm to solve a GMM problem are presented below.

**Step 1:** Initialize total no of generating units, capacity of generating units, maintenance duration, crew requirement, load demand, number of water molecules, maximum number of algorithm iteration ( $t_{\max}$ ),  $MEP_{\min}$ ,  $MEP_{\max}$ ,  $DEP_{\min}$ ,  $DEP_{\max}$ .

**Step 2:** Randomly initialize all water molecules.

**Step 3:** Obtain the maintenance schedule of generating units and compute the objective function given by Eq. (2.1), subject to constraints (2.2) to (2.7) for all water molecules.

**Step 4:** Check whether  $t$  (current iteration)  $\leq t_{\max}/2$ .

**Step 5:** If step 4 is satisfied, then, water molecules are globally evaporated based on monolayer evaporation probability  $MEP$  using Eq. (3.2).

**Step 6:** For  $t > (1+t_{\max}/2)^2$ , Based on  $DEP$  (Eq. 3.5), in the modified evaporation occurs.

**Step 7:** Generate random permutation based step size matrix according to Eq. (3.6).

**Step 8:** Generate evaporated water molecules by adding the product of step size matrix and evaporation matrix to the current set of molecules  $MWM^{(t)}$  by using Eq. (3.7) and update the matrix of water molecules.

**Step 9:** Compare and update the water molecules.

**Step 10:** Return the best water molecule.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 8, Issue 11, November 2019

**Step 11:** If the number of iteration of the algorithm ( $t$ ) becomes larger than the maximum number of iterations ( $t_{\max}$ ), the algorithm terminates. Otherwise go to step 3.

## V. SIMULATION RESULTS AND DISCUSSION

The proposed methodology has been tested with 19-unit system over a planning horizon of 25 weeks is considered. The proposed algorithm is developed in matlab environment and is implemented using Intel (R) Core (TM) i5-4200 CPU@1.60Ghz 2.30 GHz. The MWEO algorithm parameters for all test systems are shown in **Table 5.1**. The simulation is performed for 100 trials and the obtained results for 19-unit system over 25 weeks planning horizon is presented in **Table 5.2**. From the results it is clear that the proposed algorithm obtain the better results with satisfying system constraints. The system particulars are presented in [12]. The optimized cost obtained by the proposed as well as existing algorithm is presented in **Table 5.3**. From the simulation results it is clear that the proposed algorithm obtained the improved results than existing algorithms.

**TABLE 5.1 PROBLEM PARAMETERS OF MWEO**

Problem Parameters	MWEO
Water Molecules (nWM)	100
Maximum Number of Algorithm Iteration ( $t_{\max}$ )	100
$MEP_{\min}$	0.04
$MEP_{\max}$	0.5
$DEP_{\min}$	0.5
$DEP_{\max}$	1

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 8, Issue 11, November 2019

**TABLE 5.2 SIMULATION RESULTS OF 19 GENERATING UNIT SYSTEM**

Maintenance Period	Generating units index of scheduled maintenance																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
5	0	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
6	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
8	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
9	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1
13	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1
18	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
20	1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1
21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0
23	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
24	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

**TABLE 5.3 OPTIMIZED COSTS OF 19 GENERATING UNIT SYSTEM**

S.No	Algorithms	Cost
1	Heuristic	73932889.326
2	GA	73928747.045
3	PSO	76930465.182
4	PSO with multiple change	76930383.249
5	ES	7632895.839
6	ES with multiple mutation	76932699.485
7	ES with multiple mutation and crossover	76932745.216
8	<b>MWEO</b>	<b>73910240.432</b>

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 8, Issue 11, November 2019

## VI. CONCLUSION

The problem of generating optimal maintenance schedules of generating units for the purpose of maximizing economic benefits and improving reliable operation of a power system, subject to satisfying system constraints. In this paper, Water Evaporation Optimization (WEO) algorithm is proposed to solve a challenging power system optimization problem of generating unit maintenance schedule. The proposed algorithm uses global search and local search to select the maintenance units schedule and give the economic schedule. This new algorithm produces better results than the existing methods in addition to satisfaction of the system constraints. From the results, it is clear that the proposed method provides the quality solution with low cost and has a potential for on-line implementation.

## REFERENCES

- [1] A. J. Wood and B. F. Wollenberg, (1996), *Power generation operation and control*, New York: John Wiley & Sons, 1996.
- [2] R. Mukerji, H. M. Merrill, B. W. Erickson and J. H. Parker, (1991), "Power plant maintenance scheduling: Optimizing economics and reliability", *IEEE Trans. Power Systems*, vol. 6, pp. 476-483, May 1991.
- [3] T. Satoh and K. Nara, (1991), "Maintenance scheduling by using simulated annealing method", *IEEE Trans. Power Systems*, vol. 6, pp. 850-857.
- [4] Y. Wang and E. Handschin, (2000), "A new genetic algorithm for preventive unit maintenance scheduling of power systems", *Electrical Power Energy Syst.*, vol. 22, pp. 343-348.
- [5] S. Ibrahim El-Amin, Duffuaa and M. Abbas, (2000), "A Tabu search algorithm for maintenance scheduling of generating units", *Electric Power Syst. Res*, vol. 54, pp. 91-99.
- [6] K. Y. Huang and H. T. Yang, (2002), "Effective algorithm for handling constraints in generator maintenance scheduling", *IEE Proc. Generation, Transmission and Distribution*, vol. 149, pp. 274-282.
- [7] K. P. Dahal and N. Chakpitak, (2007), "Generator maintenance scheduling in power systems using metaheuristic-based hybrid approaches", *Electric Power Syst. Res*, vol. 77, pp. 771-779.
- [8] Y. Yare, G. K. Venayagamoorthy and U. O. Aliyu, (2008), "Optimal generator maintenance scheduling using a modified discrete PSO", *IET Generation, Transmission and Distribution*, vol. 2, pp. 834-846.
- [9] Andrija Volkanovski, Borut Mavko, Tome Boševski, Anton Čauševski, and Marko Čepin, (2008), "Genetic algorithm optimization of the maintenance scheduling of generating units in a power system", *Reliability Eng. Syst. Safety*, vol. 93, pp. 757-767.
- [10] Salvador Perez Canto, (2008), "Application of Benders' decomposition to power plant preventive maintenance scheduling", *Europ. J. Oper. Res*, vol. 184, pp. 759-777.
- [11] Y. Yare and G. K. Venayagamoorthy, (2010), "Optimal-maintenance scheduling of generators using multiple swarms-MDPSO framework", *Engg. App. Artifi. Intelligence*, vol. 23, pp. 895-910.
- [12] Suraj Kumhar and Mantosh Kumar, (2016), "Generator maintenance scheduling of power system using hybrid technique", *International Res. J. Engg and Tech*, vol. 03, No. 02, pp. 418-423.
- [13] Anandhakumar R, Subramanian S and Ganesan S, (2011), "ABC algorithm to thermal units maintenance", *Journal of Computer Science and Engineering*, Vol. 8, No. 1, pp. 21-31.
- [14] Abirami M, Subramanian S, Ganesan S, and Anandhakumar R, (2013), "An efficient unit maintenance scheduling in power systems by teaching learning based optimization", *International Journal of Electrical Engineering*, Vol. 20, No. 5, pp. 189-201.
- [15] Kaveh A, and Bakhshpoori T, (2016), "Water Evaporation Optimization: A novel physically inspired optimization algorithm", *Computer and Structures*, Vol. 167, pp. 69-85.
- [16] Venkadesh R and Anandhakumar R, (2016), "Water evaporation optimization algorithm for various economic load dispatch problems", *Advances in Natural and Applied Sciences*, Vol. 10, No. 17, pp. 102-112.