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UNIT COMMITMENT BY MODIFIED WATER EVAPORATION OPTIMIZATION ALGORITHMS

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***Abstract*: The unit commitment problem is the determination of deciding on and off status of on line participating generating units. This paper presents a solution to the unit commitment problem using modified water evaporation optimization algorithm. The unit commitment problem involves determining the start-up and shut-down schedules for generating units to meet the forecasted demand at the minimum cost. The commitment schedule must satisfy the other constraints such as the generating limits, spinning reserve, minimum up and down time, ramp level and individual units.The proposed algorithm gives the committed units and economic load dispatch for each specific hour of operation. Numerical simulations were carried out on ten-generator thermal unit power systems over a 24 hour period. The produced schedule was compared with several other methods. The result demonstrated the accuracy of the proposed method.**

***Keywords*: Generation Scheduling, Unit Commitment, Water evaporation optimization**

1. INTRODUCTION

In power system operation, due to variation of electric load demand and the non-storable nature of energy, and given the hourly electric load forecasting over a period of a day or a week ahead, the power system operators should schedule the on/off status, as well as the power outputs, of the power generating units to meet the forecasted load demand over the time horizon. Thus, in the real time economic operation of thermal plant can be done in two folds, namely, optimal unit selection and scheduling among the online units. The resultant unit commitment (UC) schedule should minimize the power system production cost during the time period, while simultaneously satisfying the system load demand, ramp rate constraints, and operational constraints of the unit. Scheduling the on and off times of the units and minimizing the fuel cost for the hourly generation schedule is the cost-effective way to save a money by turning units off when they are not needed. By incorporating the UC schedule, the electric power utilities may save huge millions of dollars per year in production costs. The electric power system security is still the most important aspect of power system operation and cannot be compromised [1].

Over the years, extensive research has been conducted on developing efficient UC algorithm that can be mainly grouped as (a) numerical based techniques and (b) Heuristic search based techniques [1-27].

In this paper, we propose a new unit commitment method which applies modified Water Evaporation Optimization (WEO) [26] are implemented to handling ramp rates with the aims of achieving the desired solution accuracy, reduce the cost and computational effort in 24 hr time horizon.

2. PROBLEM FORMUATION

The main goal of UC is to minimize overall system generation cost over the scheduled time horizon subject to system and operational constraints.

Objective Function

The objective function of the UC problem comprises of the fuel costs of generating units, the start-up costs of the committed units and shut-down costs of the decommitted units. This constrained optimization problem in common is defined as,

$$Min\ CF = \sum_{t=1}^{T}\sum_{i=1}^{N}\left\{FC_i\left(P_i^t\right)U_i^t + SC_i^t\left(1-U_i^{t-1}\right)U_i^t\right\} \quad (2.1)$$

Where, $FC_i\left(P_i^t\right)$ is the cost function of the i_{th} unit is given by

$$FC_i\left(P_i^t\right)=\sum_{i=1}^{N} a_i\left(P_i^t\right)^2 + b_i P_i^t + c_i \quad (2.2)$$

$$SC_i = \begin{matrix} h\cos t_i\,; & T_i^{down} \le T_i^{off} \le T_i^{down} + cshour_i \\ c\cos t_i\,; & T_i^{off} \ge T_i^{down} + cshour_i \end{matrix} \quad (2.3)$$

FC_i is the fuel cost of i_{th} unit (\$), SC_i^t is the startup cost of i_{th} generating unit (\$). The a_i, b_i, c_i are fuel cost coefficient for i_{th} generating unit and CF is the cost function of on line generating units during time interval of t hours. U_i^t is on/off status of i_{th} generating unit during hour t, P_i^t power output of the i_{th} generating unit during hour t. N is the number of thermal generating units. T is the number of schedule times in hours.

Constraints

Power balance constraint

Power balance constraint states that, the generated power should be sufficient enough to meet the power demand and is given by,

$$\sum_{i=1}^{N} U_i^t P_i^t \qquad t = 1,2,.....,T \quad (2.4)$$

Generated power limits

The generated power of online generating units should lie between its upper and lower limits as given by,

$$P_{i,\min} U_i^t \le P_i^t \le P_{i,\max} U_i^t \quad (2.5)$$

$P_{i,min}$ and $P_{i,max}$ are the minimum and maximum thermal output power at i_{th} unit.

Spinning reserve requirement

Spinning reserve is essential to maintain system reliability; sufficient spinning reserve must be available at every time period. Usually, the spinning reserve is given as some percentage of the total power demand.

$$\sum_{i=1}^{N} U_i^t P_{i,\max} \ge LD_t + SR_t \quad (2.6)$$

SR_t spinning reserve at hour t, LD_t load demand during hour t.

Minimum up and down time

This constraint helps to determine shortest time periods during which a unit must be on or down.

$$\begin{matrix} HR_i^{t,on} \ge MU_i \\ HR_i^{t,off} \ge MD_i \end{matrix} \quad (2.7)$$

$HR_i^{t,on}$ and $HR_i^{t,off}$ are number of hours at unit i is continuously online and offline unit until t_{th} hour. MU_i is the minimum up time hours and MD_i is the minimum down time hours.

Ramp rate

Because of the physical restrictions on thermal generating units, the rate of generation changes must be limited within certain ranges. The ramp rate limits confine the output movement of a generating unit between adjacent hours.

$$P_i^t - P_i^{t-1} \le RU_i$$
$$P_i^{t-1} - P_i^t \le RD_i \quad (2.8)$$

3. 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 variable wettability is reflected as the search space. Decreasing the surface wettability (substrate changed from hydrophility 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.

$$MEP_{ij}^t = \begin{cases} 1 if\ rand_{ij} \le \exp\left(E_{sub}(i)^t\right) \\ 0 if\ rand_{ij} \ge \exp\left(E_{sub}(i)^t\right) \end{cases} \quad (3.2)$$

where MEP_t^{ij} isthe 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 Θ, 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 Θ_{min}& Θ_{max} values are chosen between $-50^o<\Theta<-20^o$ is quite suitable for WEO. After generating contact angle vector $\Theta(i)^t$ the Droplet Probability Matrix (DEP) is constructed by the following equation.

$$DEP_{ij}^{t}=\begin{cases}1 if\ rand_{ij}<J\left(\theta_i^{(t)}\right)\\0 if\ rand_{ij}\geq J\left(\theta_i^{(t)}\right)\end{cases} \tag{3.5}$$

where DEP^t_{ij} 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.

(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^{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:

$$S=rand.\left(WM^{(t)}\left[permute1(i)(j)\right]-WM^{(t)}\left[permute2(i)(j)\right]\right) \tag{3.6}$$

where rand is a random number in [0,1] range, permute1and permute 2 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:

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

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.

4. IMPLEMENTATION OF MWEO ALGOTIHM TO SOLVE UC PROBLEM

The detailed algorithmic steps for proposed MWEO algorithm to solve an UC problem are presented below.

Step 1: Initialize total no of generating units, generator power limits, ramp rate limits, minimum uptime, minimum downtime, 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 ON/OFF status of generating units by applying priority list method and compute the objective function given by Eq. (2.1), Eq. (2.4) and Eq. (2.8) 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

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.

5. SIMULATION RESULTS AND DISCUSSION

In this case study, the same 10-unit system with 10% spinning reserve is considered. The ramp rate constraints are imposed in the system and its effect in the test system results are analyzed. The WEO algorithm parameters for all test systems are shown in **Table 5.1**. The simulation is performed for 100 trials and the obtained best generation schedule for 10-unit system considering ramp rate constraint is presented in **Table 5.2**.

TABLE 5.1 PROBLEM PARAMETERS OF WEO & MWEO ALGORITHM

Problem Parameters	WEO	MWEO
Water Molecules (nWM)	10	10
Maximum Number of Algorithm Iteration (t_{max})	100	100
MEP_{min}	0.03	0.03
MEP_{max}	0.6	0.5
DEP_{min}	0.6	0.5
DEP_{max}	1	1

TABLE 5.2 OPTIMAL CLASSICAL UC SCHEDULE USING MWEO FOR THE STANDARD 10-UNIT SYSTEM

Hours	1	2	3	4	5	6	7	8	9	10	Run cost	Start up cost
1	455	244	0	0	0	0	0	0	0	0	13,683.1296	0
2	455	295	0	0	0	0	0	0	0	0	14,554.4997	0
3	455	370	0	0	25	0	0	0	0	0	16,809.4485	900
4	455	455	0	0	40	0	0	0	0	0	18,597.6677	0
5	455	390	0	130	25	0	0	0	0	0	20,020.0195	560
6	455	360	130	130	25	0	0	0	0	0	22,387.0445	1100
7	455	410	130	130	25	0	0	0	0	0	23,261.9795	0
8	455	455	130	130	30	0	0	0	0	0	24,149.3685	0
9	455	455	130	130	85	20	0	0	0	0	27,251.0560	860
10	455	455	130	130	162	33	25	10	0	0	30,057.5503	60
11	455	455	130	130	162	73	25	10	10	0	31,916.0611	60
12	455	455	130	130	162	80	25	43	10	10	33,890.1629	60
13	455	455	130	130	162	33	25	10	0	0	30,057.5503	0
14	455	455	130	130	85	20	25	0	0	0	27,251.0560	0
15	455	455	130	130	30	0	0	0	0	0	24,150.3407	0
16	455	310	130	130	25	0	0	0	0	0	21,513.6595	0
17	455	260	130	130	25	0	0	0	0	0	20,641.8245	0
18	455	360	130	130	25	0	0	0	0	0	22,387.0445	0
19	455	455	130	130	30	0	0	0	0	0	24,150.3407	0
20	455	455	130	130	162	33	25	10	0	0	30,057.5503	490
21	455	455	130	130	85	20	25	0	0	0	27,251.0560	0
22	455	455	0	0	145	20	25	0	0	0	22,735.5210	0
23	455	420	0	0	0	20	0	0	0	0	17,645.3636	0
24	455	343	0	0	0	0	0	0	0	0	15,426.0190	0

The total cost obtained by WEO& MWEO in comparison with existing algorithms and RCGWO (**Rameshkumar et al, 2015**) presented in **Table 5.3** indicates that MWEO obtain the minimum fuel cost of $563933.The objective value versus iterations for the 10-unit system with ramp rate constraints is shown in **Figure 5.1**. The converged results indicate that the proposed algorithm is highly competitive with recent techniques.

TABLE 5.3 COMPARISON OF TOTAL FUEL COST WITH EXISTING ALGORITHMS FOR TEST SYSTEM

Methods	Fuel Cost	Methods	Fuel Cost
LR	565825	BFA	564842
SA	565828	QIEP	563938
GA	565825	QIBPSO	563977
EP	564551	IPPDMM	563977
LRGA	564800	SFLA	564769
ELR	563977	GSA	563938
ALR	565508	BC	563990
BCGA	567327	OIA	563938
ICGA	566404	TLBO	563938
ASSA	563983	QOTLBO	563937
LRPSO	563,938	IPLNS	563977
IPSO	563,954	RCGWO	563936.50
BCDE	563977	**WEO**	**563934.1**
		MWEO	**563933**

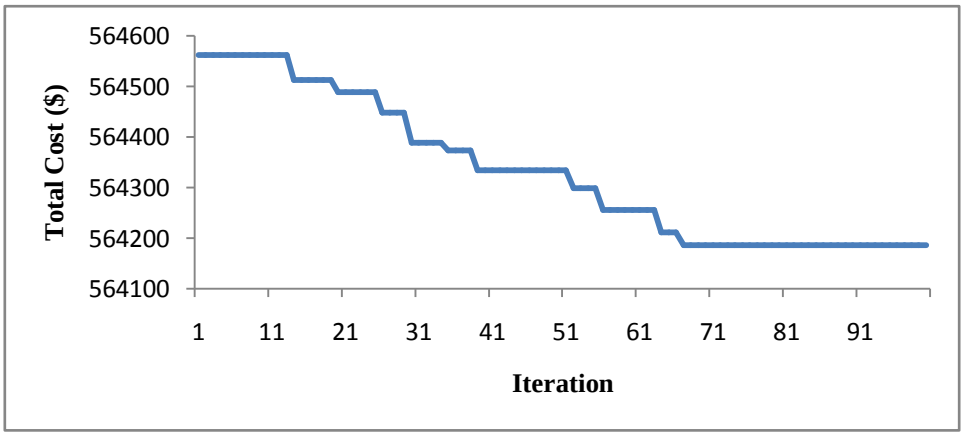

FIGURE 5.1 CONVERGENCE CURVE OF THE TEST SYSTEM

6. CONCLUSION

The effective unit commitment saves fuel costs and is a necessary contribution to the operating on/off plans of thegenerating units. In this paper, a modified water evaporation optimization based solution algorithm for solving the unitCommitment problem is presented. The proposed algorithm uses global search and local search to select thecommitted units and give the economic schedule for each specific hour. 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.

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