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Thunderstorm Algorithm for Determining Unit Commitment in Power System Operation

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Abstract. Solving the unit commitment problem is an important task in power system operation for deciding a balanced power production between various types of generating units under technical constraints and environmental limitations. This paper presents a new intelligent computation method, called the Thunderstorm Algorithm (TA), for searching the optimal solution of the integrated economic and emission dispatch (IEED) problem as the operational assessment for determining unit commitment. A simulation using the IEEE-62 bus system showed that TA has smooth convergence and is applicable for solving the IEED problem. The IEED's solution is associated with the total fuel consumption and pollutant emission. The proposed TA method seems to be a viable new approach for finding the optimal solution of the IEED problem.

Keywords: *economic dispatch; emission dispatch; evolutionary algorithm; power system operation; thunderstorm algorithm; unit commitment.*

1 Introduction

Present-day power systems are complex systems for conveying electric energy from generating sites to load center areas with high reliability and stability in order to guarantee that the system dynamically serves the customers at a good performance level without outages over the whole time period of operation. Nowadays, in view of environmental concerns, power systems are also required to reduce pollutant emissions when burning fossil fuels at thermal power plants. Power systems are monitored regularly and maintained periodically in order to continue normal operation or recover quickly after being struck by a certain disruption. Technically, a power system is constructed as an integrated structure, which acts as an interconnection system for feeding energy under various constraints and conditional limitations. It is set up as a large system of electric networks with several transmission levels and distribution systems joining all sections in order to involve available generating units for maintaining operation in accordance with energy usage.

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Moreover, this interconnection system is operated continuously to meet the load demand in the sequence of generation, transmission, distribution, and utilization of electric energy [1,2]. These processes are conducted based on the commitment of scheduled generating units at the lowest possible operating cost under the constraint of technical limitations and environmental requirements. Furthermore, finding the lowest cost is commonly approached by solving the economic load dispatch (ELD) problem in order to reduce fuel consumption by the generating units [3]. Recently, efforts to decrease air pollution associated with power production in thermal power plants also affect power system operation. Specifically this means minimizing fuel consumption through the ELD. In addition, the emission discharge of the generating units is presented in an emission dispatch (ED) in accordance with standard emission limitations.

Several methods have been proposed to solve the ELD problem using different approaches to optimize the performance of power systems. These techniques include traditional and evolutionary methods for finding the optimal solution within a desired range of the problem [4,5]. In general, traditional methods are useful and accurate for finding solutions but their performance suffers when applied to large systems and multi-spaces. Such methods also consume a large amount of computation time to complete the task [2,6]. Nowadays, evolutionary methods are often used to replace classical methods [3,7]. Studies taking various aspects into account have been conducted in order to increase performance associated with the ELD problem [2,3,6,7]. Several evolutionary methods have been proposed based on natural processes, such as genetic algorithms (GA) and the harvest season artificial bee colony (HSABC) algorithm. One of the interesting aspects of evolutionary techniques is the inspiration it takes from natural phenomena. For example, GA mimics genetic mechanisms and HSABC is related to the foraging behavior of honeybees. In the present study, a new intelligent computation, called the Thunderstorm Algorithm (TA), is introduced to find the optimal solution of the integrated economic and emission dispatch (IEED) problem based on the ELD and ED problems using a standard model of the IEEE-62 bus system under various constraints for determining unit commitment.

2 Thunderstorm Algorithm

A natural process, i.e. the sequence of events associated with multiple lightning strikes, was the inspiration for the Thunderstorm Algorithm. A lightning strike is an atmospheric discharge that typically occurs during thunderstorms or in circumstances such as volcanic eruptions or dust storms [8,9]. The study of thunderstorms has advanced rapidly since the past century and many efforts have been made towards understanding and evaluating strikes, multiple strikes, thunderstorms and their consequences [8-14].

Mimicking the natural process of a thunderstorm, the Thunderstorm Algorithm goes through a number of stages and procedures. The searching mechanism of TA for selecting solutions is conducted analog to the process of a charged cloud releasing a bolt of lightning. TA uses various distances for the deployed charge streamer, which are determined by a hazardous factor for setting the positions of the strike targets.

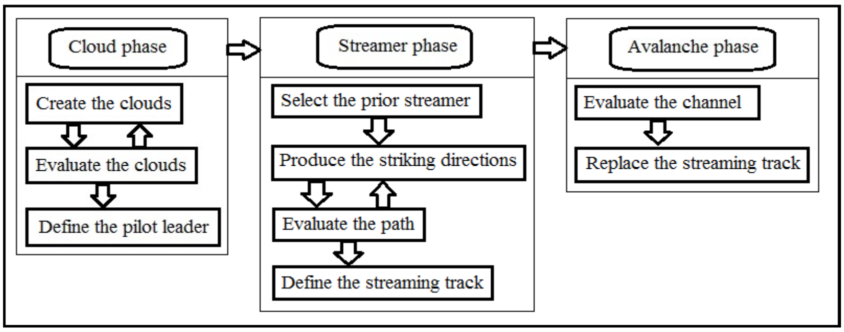

Figure 1 Process hierarchy of thunderstorm algorithm for each phase.

The process sequence of TA is shown in Figure 1 using pseudo-code. The Cloud Phase is used to produce cloud charges. To evaluate the clouds before defining the pilot leader, the Streamer Phase is implemented for selecting the pilot streamer and for guiding the strike direction, including path evaluation for defining the streaming track. The Avalanche Phase is used to evaluate the channels and replace the streamer track. Mathematically, these main mechanisms can be expressed as follows:

Cloud charge:

$$Q_{sj}^{m} = (1 + k.c).Q_{midj}^{m} \tag{1}$$

Striking path:

$$D_{sj}^{n} = (Q_{sdep}^{n}).b.k \tag{2}$$

Charge probability:

$$probQ_{sj}\begin{cases}\frac{Q_{sj}^{m}}{\Sigma Q_{s}^{m}} \text{ for m}\\ \frac{Q_{sj}^{n}}{\Sigma Q_{s}^{n}} \text{ for n}\end{cases} \tag{3}$$

where Q_{sj} is the current charge, k is a random number [-1 and 1], c is a random number within [1 and h], Q_{midj} is the middle charge, s is the streamer flow, j ∈ (1,2,..,a), a is the number of variables, m is the cloud size, D_{sj} is the strike target position, Q_{sdep} is the deployed distance, h is the hazardous factor, b is a random number within (1-a), n is the striking direction.

Eq. (1) is used to simulate a cloud with various charges associated with candidate solutions based on constraints for each cloud. The lightning direction is modeled by Eq. (2), while the charging probability is given by Eq. (3).

3 Unit Commitment

The unit commitment problem is an important task in power system operation because it is concerned with the technical cost of deciding the contribution of individual generating units of power plants in various combinations. Focusing on the technical cost of the power system related to fuel procurement and environmental compensations, economic operation and planning occupy an important position in power production management. These problems are important to investigate in order to decrease the running charges of energy production, which can be managed using an economic cost strategy based on the ELD and ED problems [3,15,16].

The ELD problem, as formulated in Eq. (4), is used to minimize the total fuel cost of the generating units and the total pollutant emissions during operation can be reduced using Eq. (5). The IEED problem is formulated using the ELD and ED problems, which are both optimized together using compromise and penalty factors. Thus, both problems become a single objective function, as given in Eq. (6), which is constrained by numerous limitations, as presented in Eqs. (7) to (11). The IEED can be formulated using the following functions:

$$\text{ELD: } F_{tc} = \sum_{i=1}^{ng} \left(c_i + b_i.P_i + a_i.P_i^2\right) \tag{4}$$

$$\text{ED: } E_t = \sum_{i=1}^{ng} \left(\gamma_i + \beta_i.P_i + \alpha_i.P_i^2\right) \tag{5}$$

$$\text{IEED: } \Phi = w.F_{tc} + (1 - w).h.E_t \tag{6}$$

$$\sum_{i=1}^{ng} P_i = P_D + P_L, \tag{7}$$

$$P_i^{min} \le P_i \le P_i^{max} \tag{8}$$

$$Q_i^{min} \le Q_i \le Q_i^{max} \tag{9}$$

$$V_p^{min} \le V_p \le V_p^{max} \tag{10}$$

$$S_{pq} \le S_{pq}^{max} \tag{11}$$

where P_i is the power output of the i^{th} generating unit, a_i, b_i, and c_i are fuel cost coefficients of the i^{th} generating unit, F_{tc} is the total fuel cost, ng is the number of generating units, α_i, β_i, and γ_i are emission coefficients of the i^{th} generating unit, E_t is the total emission (kg/h), Φ is the IEED ($/h), w is the compromise factor, h is the penalty factor, P_D is the total load demand, P_L is the total transmission loss, P_i^{min} is the minimum output power of the i^{th} generating unit, P_i^{max} is the maximum output power of the i^{th} generating unit, Q_i^{max} and Q_i^{min} are the maximum and minimum reactive powers of the i^{th} generating unit, V_p^{max} and V_p^{min} are the maximum and minimum voltages at bus p, S_{pq} is the total power transfer between bus p and q, S_{pq}^{max} is the power transfer limit between bus p and q.

4 Method and Sample System

In this work, using the IEEE-62 bus system as a standard model, the IEED problem was solved for determining unit commitment of a power system. Technically, this system has 62 buses, 89 lines, and 32 load buses, as depicted and detailed in [10,15]. This standard system is supported by 19 generating units to provide the energy to meet the load demand with its coefficients and design limits as given in Table 1.

This task was executed using the following technical requirements: a loss limit of 10%; a weighting factor of 0.5; and an emission standard of 0.85 kg/h. The method was also conditioned by operational constraints in order to search the suitable solution within 5% of voltage violations, 95% of the power transfer capability, and the upper and lower power limits as listed in Table 1.

Table 1 Technical parameters of generating units.

Gen	a ($/MWh^2)	b ($/MWh)	c	α (kg/MWh^2)	β (kg/MWh)	γ	P_{min} (MW)	P_{max} (MW)
G1	0.00700	6.80	95	0.0180	-1.8100	24.300	50	300
G2	0.00550	4.00	30	0.0330	-2.5000	27.023	50	450
G3	0.00550	4.00	45	0.0330	-2.5000	27.023	50	450
G4	0.00250	0.85	10	0.0136	-1.3000	22.070	0	100
G5	0.00600	4.60	20	0.0180	-1.8100	24.300	50	300
G6	0.00550	4.00	90	0.0330	-2.5000	27.023	50	450
G7	0.00650	4.70	42	0.0126	-1.3600	23.040	50	200
G8	0.00750	5.00	46	0.0360	-3.0000	29.030	50	500
G9	0.00850	6.00	55	0.0400	-3.2000	27.050	0	600
G10	0.00200	0.50	58	0.0136	-1.3000	22.070	0	100
G11	0.00450	1.60	65	0.0139	-1.2500	23.010	50	150
G12	0.00250	0.85	78	0.0121	-1.2700	21.090	0	100
G13	0.00500	1.80	75	0.0180	-1.8100	24.300	50	300
G14	0.00450	1.60	85	0.0140	-1.2000	23.060	0	150
G15	0.00650	4.70	80	0.0360	-3.0000	29.000	0	500
G16	0.00450	1.40	90	0.0139	-1.2500	23.010	50	150
G17	0.00250	0.85	10	0.0136	-1.3000	22.070	0	100
G18	0.00450	1.60	25	0.0180	-1.8100	24.300	50	300
G19	0.00800	5.50	90	0.0400	-3.000	27.010	100	600

Referring to Figure 1, TA consists of the main program, an evaluation program, a cloud charge program, a streamer program, an avalanche program, and a dead track program. The cloud phase covers creating the clouds, evaluating the clouds, and defining the pilot leader. The streamer phase starts with pilot streamer selection, followed by producing the striking direction. After that, the strike path is evaluated and the streamer track is defined. The final step is the avalanche phase, which is used for channel evaluation and streamer track replacement. In this study, TA was compiled using the following parameter values: 1 for the avalanche; 50 for the cloud charges; 100 for the streaming flows; and 4 for the hazardous factor.

5 Results and Discussions

In this section, the simulation is addressed that was set up to determine unit commitment of generating units based on the IEED problem to select a suitable power output portion for each generating unit at a reasonable operating cost. The simulation was processed in 100 streaming flows considering 2,221.2 MW and 968.1 MVar of power demand applied to the IEEE-62 bus system with the various technical constraints as specified above.

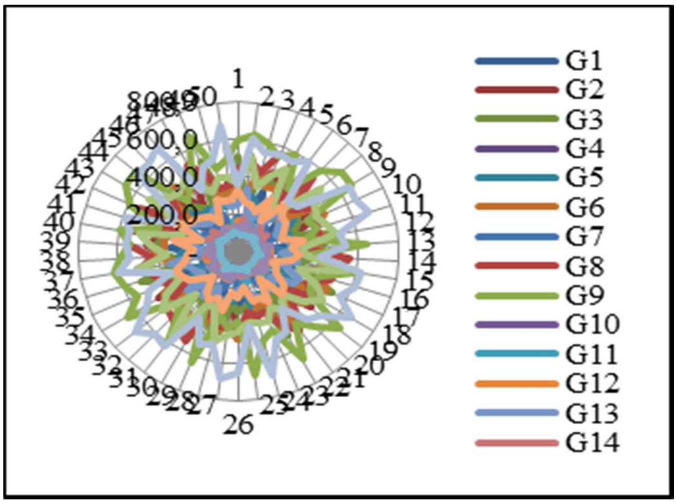

Figure 2 Initial cloud charges.

A population set of charges is initiated as candidate solutions produced randomly in the cloud phase for 50 charges of the 19 generating units, as depicted in Figure 2. Figure 3 shows that convergence of the IEED problem was obtained after 17 streaming flows, consuming 0.55 seconds for completing all processes, as illustrated in Figure 4. Figure 5 shows the unit commitment of the generating units within the system to meet the load demand. In addition, several results are listed in Table 2 concerning the unit commitment with its implications for the pollutant contribution and operating costs.

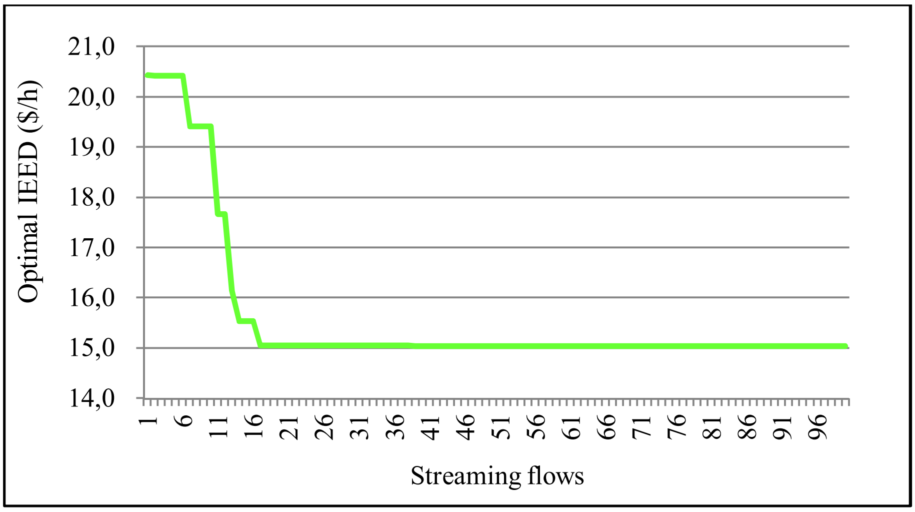

Figure 3 Convergence speed.

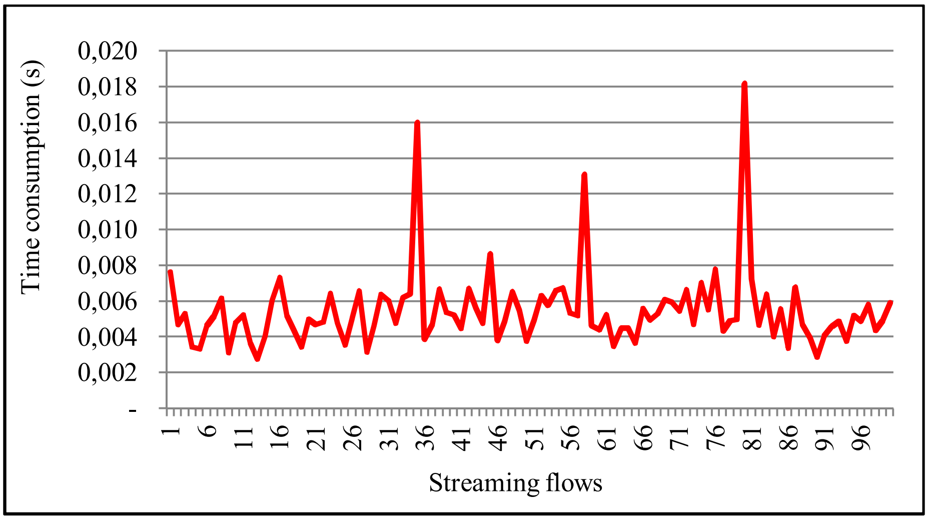

Figure 4 Time consumption.

From Table 2 it can be seen that the integrated generating units produce a total power output of around 2,462.8 MW to meet 2,221.2 MW of load demand with 9.81% of loss (around 241.6 MW). As a result of this unit commitment, the system produces various portions of pollution with several generating units being under the allowed standard emission (G1, G4, and G5). Moreover, the system also incurs 187,212.7 $/h of operating costs spent on fuel and pollutant compensations.

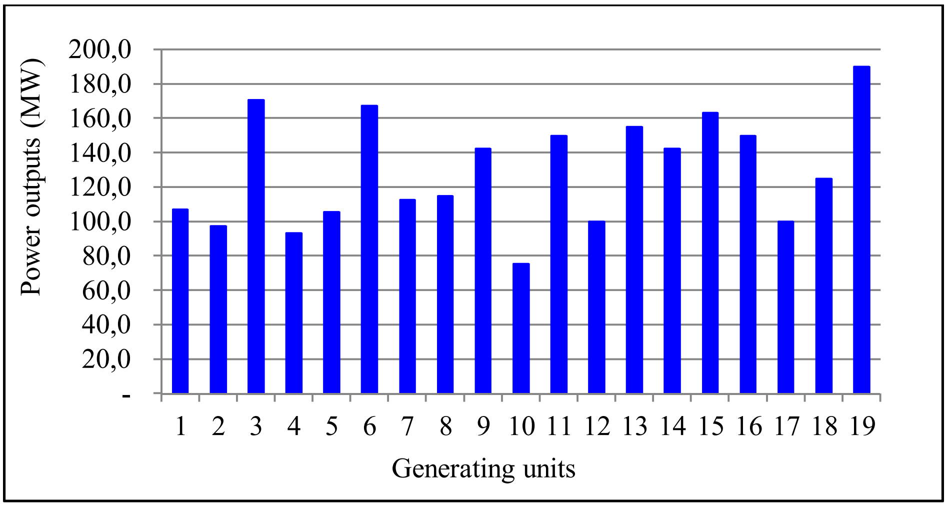

Figure 5 Individual power outputs.

Table 2 Several results of unit commitment for generating units.

Gen	Power (MW)	Pollutant production (kg/h)			Operating Cost ($/h)		
		Emiss.	Std. emiss.	Catch. emiss.	Fuel	Compen-sation	Total cost
G1	107.2	37.1	91.1	-	904.40	-	904.4
G2	97.5	97.0	82.9	14.1	472.28	1,057.8	1,530.1
G3	170.6	561.3	145.0	416.3	887.70	31,219.6	32,107.3
G4	93.4	19.3	79.4	-	111.20	-	111.2
G5	105.6	33.8	89.7	-	572.49	-	572.5
G6	167.5	534.1	142.4	391.8	914.31	29,381.6	30,295.9
G7	112.6	29.6	95.7	-	653.58	-	653.6
G8	115.0	160.1	97.8	62.4	720.19	4,678.5	5,398.7
G9	142.6	384.1	121.2	262.9	1,083.38	19,714.0	20,797.4
G10	75.3	1.3	64.0	-	106.99	-	107.0
G11	150.0	148.3	127.5	20.8	406.25	1,557.0	1,963.3
G12	100.0	15.1	85.0	-	188.00	-	188.0
G13	155.0	176.2	131.8	44.4	474.13	3,333.7	3,807.9
G14	142.5	136.3	121.1	15.2	404.38	1,141.7	1,546.1
G15	163.2	498.0	138.7	359.3	1,020.00	26,949.3	27,969.3
G16	150.0	148.3	127.5	20.8	401.25	1,557.0	1,958.3
G17	100.0	28.1	85.0	-	120.00	-	120.0
G18	124.8	78.8	106.1	-	294.81	-	294.8
G19	190.0	901.0	161.5	739.5	1,423.80	55,463.3	56,887.1
Total	**2,462.8**	**3,987.8**	**2,093.4**	**2,347.4**	**11,159.14**	**176,053.5**	**187,212.7**

6 Conclusions

In this paper, the Thunderstorm Algorithm was introduced to determine unit commitment of generating units based on the IEED problem, in which the ELD and ED problems are combined in view of reduction of fuel consumption and adherence to emission standards respectively. Based on the obtained results it can be concluded that TA has smooth convergence and low computation time. The proposed method can be used to select unit commitment. In a future study, the performance of the algorithm will be evaluated based on the application in a real power system.

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