Application of Thunderstorm Algorithm for Defining the Committed Power Output Considered Cloud Charges

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Abstract— This paper presents an application of Thunderstorm Algorithm for determining a committed power output considered cloud charges with various technical constraints and an environmental requirement. These works also implemented on IEEE-62 bus system throughout an operational economic dispatch covered for economic and emission aspects. The results obtained show that statistical and numerical performances are associated with charges. It also presents fast and stable characteristics for the searching speeds. By considering the cloud charge parameter, it contributes to performances and results of Thunderstorm Algorithm. In addition, the introduced algorithm seems strongly to be a new promising approach for defining the committed power output problem.

Keywords—Cloud charge, economic dispatch, intelligent computation, power system, thunderstorm algorithm.

I. INTRODUCTION

Presently, technical problems are more complicated than previous cases included numerous variables for representing physical systems in suitable models as closed as its functions in nature with natural characteristics and behaviours. Many problems have become crucial topics to solve correctly in feasible ranges within high qualities under numerous constraints and environmental requirements for searching the desired performances. To cover these conditions, the problems adopted many parameters are expressed in optimization functions considered potential variables and limitations in order to obtain better solutions within a period time operation. Moreover, these functions are conducted to designed models for presenting real cases in mathematical statements as the objective function constrined by technical conditions and environmental requirements.

By considering mathematical expressions, real problems are solvable easily using various methods of computations associated with its defined functions through traditional or evolutionary approaches. Both methods are commonly used to carry out the problem and applied to evaluate its performances. Actually, these approaches has different characteristics while searching the optimal solution. In detail, traditional methods use mathematical programs given in various versions as the proposed names at the early introduction. As long as the period implementation, popular classical methods are linear programming, lambda iteration, quadratic programming, gradient search, Newton's method, dynamic programming, and Lagrangian relaxation [1], [2], [3], [4]. On the other hand, evolutionary methods use optimization techniques, such as genetic algorithm, neural network, simulated annealing, evolutionary programming, ant colony algorithm, particle swarm optimization, and harvest season artificial bee colony algorthm [5], [6], [7], [8], [9]. These methods have been proposed for replacing classical approaches on the base of its weaknesses considered many phenomena and behaviours in nature with mimicking its mechanisms.

Nowadays, evolutionary methods are frequently used to solve optimization problems, not only for real cases but also for designed themes [10]. These methods are useful for breaking out large systems and multi dimensions constructued using multiple variables and constraints. In particular, many types have been proposed at different times as an introduction early based on its inspirations. Since the first time of the evolutionary idea became a new computation era out of the classical period, many works have been done for developing and improving its performances with modified techniques and phases. Moreover, these developments are also subjected to expand computational performances for increasing abilities to carry out numerous problems with many proposed procedures.

In this paper, a new intelligent computation application is introduced to solve the power system operation problem (PSOP) and it is used to define the balanced power production. In addition, this paper presents its powerful for searching the optimal solution of the PSOP associated with cloud charges.

II. THUNDERSTORM ALGORITHM

At present, the lightning is considered as an atmospheric discharge during thunderstorms or other possibility factors produced by several steps in terms of Charge separation; Leader formation; and Discharge channel. Moreover, the lightning process is defined as an electric discharge in the form of a spark in a charged cloud that the negative and positive charges are deployed at different positions [11], [12], [13]. In addition, a seat of electrical processes can be produced by a thunderstorm and it is rapidly advanced during the continuous lightning in the thunderstorm. In this phenomenon, the defining atmospheric material for the thunderstorm is very important things and urgently observations covered in moisture; unstable air; and lift.

Many studies have been done to observe these phenomena with numerous discussions for searching suitable models and understanding its mechanisms. Various characteristics have been tested and reported for analyzing these curious issues in many studies in order to recognize natural behaviours [14], [15], [16], [11], [12], [17], [18], [19], [20]. In general, the introduced algorithm entitled Thunderstorm Algorithm (TA) has adopted a phenomenon in nature for pretending natural processes performed using several stages to explain the adoption of the inspiration [21]. Furthermore, this inspiration is associated with a natural mechanism conducted to define multiple natural lightning in the computation.
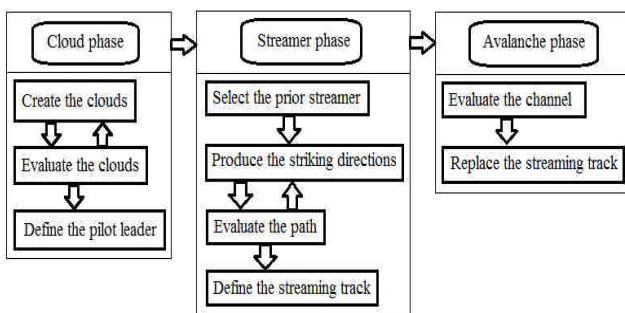

Fig. 1: Thunderstorm Algorithm's Phases

By considering this phenomenon, its mechanisms are transferred into certain procedures as the sequencing computation presented in pseudo-codes in terms of Cloud Phase; Streamer Phase; and Avalanche Phase [21]. Cloud Phase is used to produce cloud charges and to evaluate the clouds before defining the pilot leader. Another step, Streamer Phase, is supposed to define the prior streamer and to guide striking directions included the path evaluation for defining the streaming track. The final process is Avalanche Phase, which is used to evaluate channels, replace the streaming track for keeping the streamer. In detail, these phases are depicted in Fig. 1.

In these phases, the searching mechanism is conducted to striking processes and channeling avalanches to deploy the cloud charges, which is populated using (1). Moreover, TA is also consisted of various distances of the striking direction related to the hazardous factor for each position of the striking targets as presented in (2). Each solution is located randomly based on the generating random directions of multiple striking targets. In principle, the sequencing computation of TA is given in several procedures as presented in following mathematical main functions.

Cloud charge: $Q_{sj}^m = (1 + k.c).Q_{midj}^m,$ (1)

Striking path: $D_{sj}^n = (Q_{sdep}^n).b.k,$ (2)

Charge's probability: $probQ_{sj} \begin{cases} \dfrac{Q_{sj}^m}{\sum Q_s^m} \text{ for m} \\ \dfrac{Q_{sj}^n}{\sum Q_s^n} \text{ for n} \end{cases},$ (3)

where Q_{sj} is the current charge, Q_{midj} is the middle charges, s is the streaming flow, D_{sj} is the striking charge's position, Q_{sdep} is the deployed distance, n is the striking direction of the hth, k is the random number with [-1 and 1], c is the random within [1 and h], h is the hazardous factor, b is the random within (1-a), n is the striking direction, $j \in (1,2,..,a)$, a is the number of variables, $m \in (1,2,..,h)$.

III. COMMITTED POWER OUTPUT

The power system operation is able to measure using a financial aspect for defining the whole operation, such as fixed cost; maintenance cost; and production cost, in order to the PSOP can be conditioned in an economic portion with the suitable budget. Since the operation is concerned in the technical cost of products and services, the optimal operation and planning are very important things for deciding in the balanced power production. Economically, these problems become urgently issues to decrease running charges of the electric energy while supplying load demands at different places. It also needs to manage using an economic strategy for selecting the optimal operating cost.

To cover these issues, the committed power output (CPO) is more complicated problems included all generating units under technical constraints and environmental requirements. In this problem, the CPO is focused on the generating unit participation for supporting power productions associated with the given load demand. In addition, the CPO is measured in the optimal total cost for the fuel consumption and the pollutant compensation [1], [4], [22], [23], [24], [25]. In detail, this problem is optimized using an integrated economic dispatch (IED) with considering the load dispatch (LD) and the emission

dispatch (ED) [23], [24], [26]. Moreover, The IED is formulated by equation (4) and each fuel cost participation is expressed in (5) for defining the LD as given in (6). In particular, the individual pollutant discharge of generating unit is formed in (7) and the ED's function is presented in (8) for all participants in the CPO. In general, the CPO is commonly approached using main mathematical functions as follows:

IED: $\Phi = w.F_{tc} + (1-w).h.E_t,$ (4)

$F_i(P_i) = c_i + b_i P_i + a_i P_i^2,$ (5)

LD: $F_{tc} = \sum_{i=1}^{ng}(c_i + b_i.P_i + a_i.P_i^2),$ (6)

$E_i(P_i) = \gamma_i + \beta_i.P_i + \alpha_i.P_i^2,$ (7)

ED: $E_t = \sum_{i=1}^{ng}(\gamma_i + \beta_i.P_i + \alpha_i.P_i^2),$ (8)

where Φ is the IED ($/h), w is a compromised factor, h is a penalty factor, F_{tc} is the total fuel cost ($/h), E_t is the total emission (kg/h), F_i is the fuel cost of the ith generating unit ($/h), P_i is a power output of the ith generating unit, a_i; b_i; c_i are fuel cost coefficients of the ith generating unit, ng is the number of generating unit, E_i is an emission of the ith generating unit (kg/h), α_i; β_i; γ_i are emission coefficients of the ith generating unit.

IV. APPLICATION'S PROCEDURES

In these studies, simulations adopt a standard model of the power system for demonstrating the impact of the cloud charges related to the CPO with various technical constraints. The use of the standard model is commonly approached by researchers for performing own problems, even practical systems are also able to apply for the same problem. In these works, the IEEE-62 bus system is selected as the sample system, which is consisted of 19 generators; 62 buses; and 89 lines as discussed completely in [24]. Technically, it data are presented in Table I; Table II; and Table III for coefficients and power limits which are given in individual generating units.

Table I. Fuel Cost Coefficients

Gen	α	β	γ	Gen	α	β	γ
G1	0.0070	6.80	95	G11	0.00450	1.60	65
G2	0.0055	4.00	30	G12	0.00250	0.85	78
G3	0.0055	4.00	45	G13	0.00500	1.80	75
G4	0.0025	0.85	10	G14	0.00450	1.60	85
G5	0.0060	4.60	20	G15	0.00650	4.70	80
G6	0.0055	4.00	90	G16	0.00450	1.40	90
G7	0.0065	4.70	42	G17	0.00250	0.85	10
G8	0.0075	5.00	46	G18	0.00450	1.60	25
G9	0.0085	6.00	55	G19	0.00800	5.50	90
G10	0.0020	0.50	58	a ($/MWh²), b ($/MWh)			

Table II. Emission Coefficients

Gen	a	b	c	Gen	a	b	c
G1	0.018	-1.81	24.30	G11	0.014	-1.25	23.01
G2	0.033	-2.50	27.02	G12	0.012	-1.27	21.09
G3	0.033	-2.50	27.02	G13	0.018	-1.81	24.30
G4	0.014	-1.30	22.07	G14	0.014	-1.20	23.06
G5	0.018	-1.81	24.30	G15	0.036	-3.00	29.00
G6	0.033	-2.50	27.02	G16	0.014	-1.25	23.01
G7	0.013	-1.36	23.04	G17	0.014	-1.30	22.07
G8	0.036	-3.00	29.03	G18	0.018	-1.81	24.30
G9	0.040	-3.20	27.05	G19	0.040	-3.00	27.01
G10	0.014	-1.30	22.07	α (kg/MWh²), β (kg/MWh)			

Table III. Power Limits of Generators

Gen	P_{min} (MW)	P_{max} (MW)	Q_{min} (MVar)	Q_{max} (MVar)
G1	50	300	0	450
G2	50	450	0	500
G3	50	450	-50	500
G4	0	100	0	150
G5	50	300	-50	300
G6	50	450	-50	500
G7	50	200	-50	250
G8	50	500	-100	600
G9	0	600	-100	550
G10	0	100	0	150
G11	50	150	-50	200
G12	0	50	0	75
G13	50	300	-50	300
G14	0	150	-50	200
G15	0	500	-50	550
G16	50	150	-50	200
G17	0	100	0	150

| G18 | 50 | 300 | -50 | 400 |
| G19 | 100 | 600 | -100 | 600 |

These applications are applied to IEEE-62 bus system as the power system model using several programs, which are compiled together in the sequencing processes based on the pseudo-codes covered the cloud phase; streamer phase; and avalanche phase. Each phase follows its mechanism for involving all parameters of TA in the processes while searching the optimal solution with various charges in the cloud charge phase.

In particular, these processes are run in designed programs in terms of main program; evaluate program; cloud charge program; streamer program; avalanche program; and dead track program. N addition, TA is performed using 1 of the avalanche; 100 of the streaming flows; and 4 of the hazardous factor. Moreover, the tested system feeds the power production for 2,766.7 MW and 1,206.1 MVar of load demands constrained by 10% of the total loss; 0.5 of the weighting factor; 0.85 kg/h of the standard emission; ± 5% of voltage violations at each bus; and 95% of the power transfer capability for the line.

V. RESULTS AND DISCUSSIONS

As given in the previous section, these works consider 2,766.7 MW for the load constrained by various technical limitations. By considering 10% of the total loss; 0.85 kg/h of the standard emission; the equilibrium of the load demand and the power production, the cloud charge distributions are illustrated in following figures. These figures are presented for each cloud size for 25; 50; 75; and 100 charges, which are deployed at different positions randomly in Fig. 2; Fig. 3; Fig. 4; and Fig. 5. According to these figures, charges affect to the cloud's characteristics and charged density within different desired locations. In detail, the highest size has the highest density for the charge.
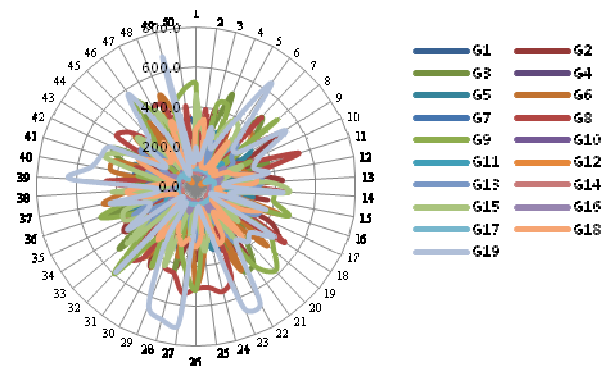

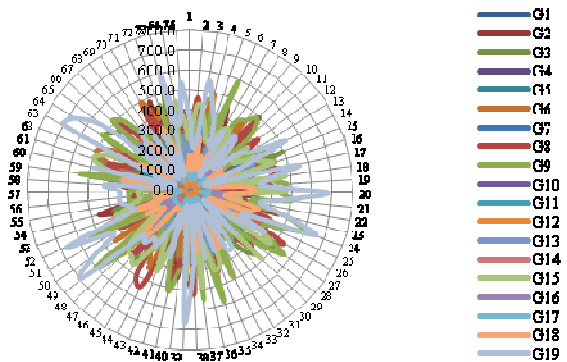*Fig. 2: Cloud's profile with 25 charges*
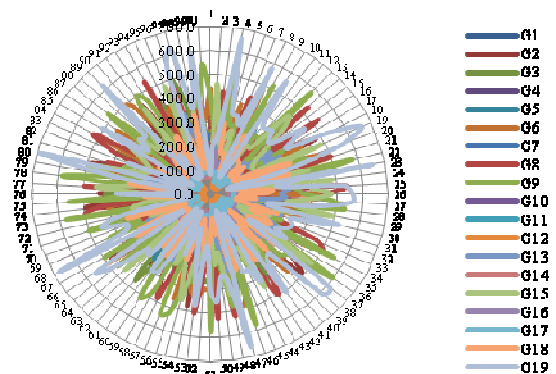

Fig. 3: Cloud's profile with 50 charges

Fig. 4: Cloud's profile with 75 charges

Fig. 5: Cloud's profile with 100 charges

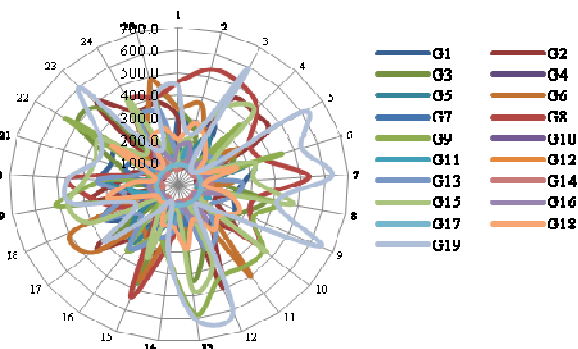Table IV. Statistical Results Based on the Charges

No	Parameters	Cloud charges			
		25	50	75	100
1	Max point ($/h)	17,151	16,633	17,666	16,539
2	Min point ($/h)	16,720	16,120	16,455	15,841
3	Range ($/h)	431	513	1,211	698
4	Mean ($/h)	16,751	16,187	16,613	15,915
5	Median ($/h)	16,720	16,120	16,455	15,841

6	Streaming	14	19	25	30
7	Opt. time (s)	2.6	3.5	5.6	6.2
8	Run time (s)	16.9	17.2	18.5	18.8

Graphically, TA's abilities are give in Fig. 6 and Fig. 7 for streaming flows and time consumptions associated with cloud charges. Fig. 6 presents convergence speeds of computations while finishing all processes for determining optimal solutions in 100 streaming flows with its individual time usage for each process as illustrated in Fig. 7. Moreover, the processes have different started points for searching solutions of the IED as similar as the obtained streaming flows of the optimal points remained in different speeds. For 25 charges, the computation is started at 17,151 $/h before declining to 16,720 for the optimal position obtained in 14 steps with consuming 2.6 s of the running time. This execution also needs around 16.9 s for completing 100 of the streaming flow. In general, the solution is searched in smooth and fast even the cloud charges used different amounts. In detail, its statistical performances are listed in Table IV covered in maximum points; minimum points; range; and median.

Furthermore, various time consumptions are depicted in Fig. 7 related to cloud charges. This figure illustrates the random time consumptions, which are used to search the optimal solutions and to complete the processes of the IED problem considered LD and ED. By considering these compilations, all results are also provided in Table IV for the optimal time usage and the running time for streaming flows. According to these results, the higher cloud size has longer time consumptions, which are 6.2 s for obtaining the solution and 18.8 s for completing the computation associated with 100 of charges.
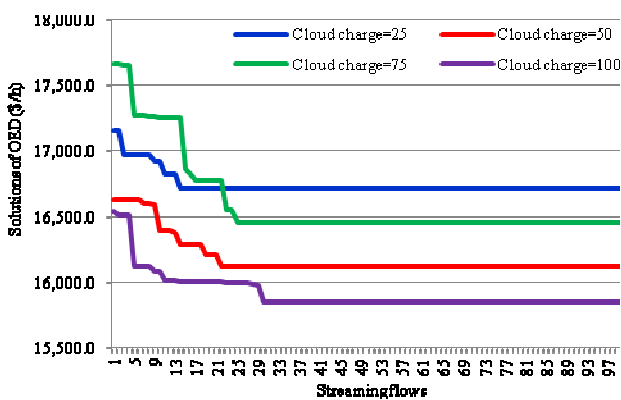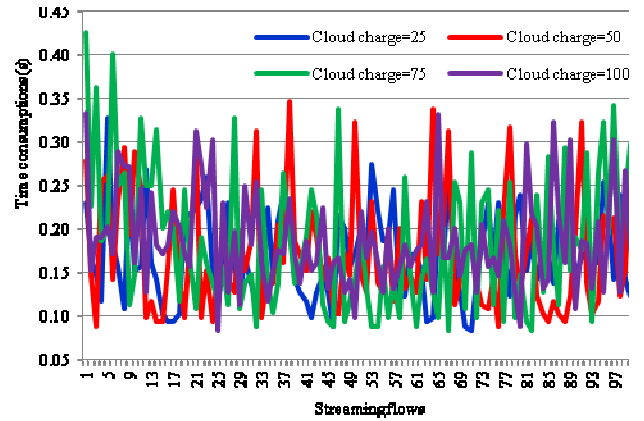

Fig. 6: Convergences considered the charges

Fig. 7: Time consumptions considered the charges

Table V. Power Productions Based on the Charges

Gen	Power outputs (MW)			
	25	50	75	100
G1	105.7	105.7	105.7	105.7
G2	200.0	265.7	376.6	343.4
G3	227.2	78.4	132.1	78.4
G4	99.6	91.9	93.1	91.9
G5	294.2	105.7	190.7	174.6
G6)	395.9	395.2	291.0	186.1
G7	108.6	108.6	166.3	108.6
G8	234.9	227.7	278.8	266.2
G9	87.9	273.6	87.9	239.0
G10	91.9	91.9	91.9	91.9
G11	80.1	147.2	149.1	83.5
G12	105.3	105.3	105.3	105.3
G13	149.3	287.8	105.7	252.7
G14	137.0	150.0	70.8	146.9
G15	90.2	90.2	99.6	90.2
G16	149.6	104.6	104.6	150.0
G17	91.9	91.9	91.9	91.9
G18	105.8	200.8	270.3	292.8
G19	240.7	100.0	210.5	100.0
Total	2,995.8	3,022.1	3,021.9	2,999.0
Load	2,766.7	2,766.7	2,766.7	2,766.7
Loss	229.1	255.4	255.2	232.3

Refer to multiple directions as presented as the hazardous factor in TA's processes, all numerous statistical results are provided in Table IV associated with cloud charges as depicted in Fig. 2 to Fig. 5 for the cloud charge's profiles. In addition, Table IV has been performed by each procedure of TA while determining optimal solutions to meet 2,776.7 MW of the load. This table shows that the cloud charges give impacts on various aspects, such as, maximum points; optimal points; and times.

Table VI. Emissions Based on the Charges

Gen	Pollution productions (kg/h)			
	25	50	75	100
G1	34.1	34.1	34.1	34.1
G2	847.2	1,692.3	3,765.9	3,059.3
G3	1,162.8	33.9	272.6	33.9
G4	31.5	20.8	22.4	20.8
G5	1,049.9	34.1	333.5	257.0
G6)	4,209.8	4,193.0	2,093.8	704.3
G7	28.7	28.7	156.5	28.7
G8	1,310.2	1,211.9	1,991.3	1,782.1
G9	54.8	2,146.3	54.8	1,547.6
G10	20.8	20.8	20.8	20.8
G11	12.7	142.4	147.7	16.2
G12	20.4	20.4	20.4	20.4
G13	155.1	994.4	34.1	716.1
G14	121.5	158.1	8.3	148.9
G15	51.3	51.3	87.4	51.3
G16	149.2	45.4	45.4	150.5
G17	20.8	20.8	20.8	20.8
G18	34.3	386.4	850.4	1,037.2
G19	1,622.8	127.0	1,167.5	127.0
Total	10,938.0	11,362.2	11,127.8	9,777.0

Table VII. Operational Fees Based on the Charges

Gen	Operating costs (kg/h)			
	25	50	75	100
G1	909.0	909.0	909.0	909.0
G2	1,473.7	2,327.2	4,199.4	3,581.6
G3	1,819.3	409.3	805.6	409.3
G4	135.3	119.6	122.0	119.6
G5	2,417.7	590.3	1,281.9	1,134.6
G6)	4,640.6	4,626.3	2,766.6	1,376.8
G7	643.4	643.4	1,081.8	643.4
G8	2,289.1	2,179.0	3,018.9	2,799.9
G9	675.5	3,406.3	675.5	2,748.6
G10	131.3	131.3	131.3	131.3
G11	228.4	469.3	477.3	238.0
G12	205.4	205.4	205.4	205.4
G13	532.6	1,504.5	338.2	1,207.0
G14	449.4	505.3	225.0	491.6
G15	582.5	582.5	656.3	582.5
G16	474.6	308.3	308.4	476.5
G17	119.6	119.6	119.6	119.6
G18	261.8	720.8	1,211.5	1,397.8
G19	2,689.0	783.5	2,185.7	783.5
Total	20,678.3	20,540.9	20,719.6	19,356.1

Final results of the PSOP based on the CPO are presented in the IED as provided in Table V covered cloud charges for the individual power production. This table also provides the committed power output and the total loss to meet the load. According to this table, it is known that generating units contribute to the power procurement with different capacities as own scheduled power productions. Its pollutant productions are listed in Table VI for 19 generating units. Specifically G10 feeds to the power to the system in the constant amount of 91.9 MW. This condition is also given by G1 and G17 produced in 105.7 MW and 91.9 MW. In total, generating units deliver the power to the load center from 2,995.8 MW to 3,022.1 MW with various amounts of the power loss related to the each cloud charge as given in Table V. As the impact of the environmental requirement, these power productions also discharge pollutants around 9,777.0 kg/h to 11,362.2 kg/h corresponded to cloud charges with individual contributions for the emissions as given in Table VI. In detail, the higher pollutant contributors are G2; G3; G5; G6; G8; and G19.

By considering the whole selections for determining the optimal solutions of the IED problem, the cheapest operation is determined using the higher cloud charge as provided in Table VII presented totally for fuel costs and emission cost compensations. This operation needs around 19,356.1 $ for existing generating units during producing power outputs to meet the load demand. In accordance to individual power productions, several generators spent the budget in high procurement. Practically, power outputs of generating units are associated with the load to set fixed power outputs. The least operating cost becomes a very crucial decision for operating the system in the cheapest budget. In this case, the expensive operations are belonged to several generating units while producing powers, such as, G2; G3; G5; G6; and G19, even these payments are depended on cloud charges. For all compositions of cloud charges, the cheapest operation is existed by G17 with spent in 119.6 $/h.

VI. CONCLUSIONS

This paper evaluates cloud charge impacts of Thunderstorm Algorithm on the power system operation problem presented in the operational economic dispatch based on load and emission dispatches. By considering technical constraints and the cloud charges, the results demonstrated successful application this algorithm for solving the problem using the IEEE-62 bus system. The performances indicate that the small size of the cloud charge has faster iteration and shorter time consumption. Moreover, cloud charges influenced to the committed power output combination for 19 generating units. Finally, from these works, implementations on real and larger systems are subjected to the future studies.

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