International Journal of Hybrid Information Technology
Vol. 9, No.6 (2016), pp. 221-230
http://dx.doi.org/10.14257/ijhit.2016.9.6.19

Development of a Novel Evolutionary Algorithm Considered Thunderstorm Mechanisms for Optimizing an Economic Dispatch

A.N. Afandi[1], H. Suswanto[2], I. Fadlika[3], Mardji[4] and Yunis Sulistyorini[5]

[1,2,3]Electrical Engineering, Universitas Negeri Malang, Jatim, Indonesia
[4]Engineering Faculty Member, Universitas Negeri Malang, Jatim, Indonesia
[5]Department of Mathematical Education, IKIP Budi Utomo, Jatim, Indonesia
[1]an.afandi@ieee.org, [1]an.afandi@um.ac.id, [2]h_arias2000 @yahoo.com,
[3]irham.fadlika.ft@um.ac.id, [4]mardji@um.ac.id, [5]yunis.sulistyorini@gmail.com,

Abstract

This paper introduces a novel intelligent computation adopted from a natural phenomenon entitled Thunderstorm Algorithm (TA) which is applied to optimize an economic dispatch under various technical constraints and environmental requirements. These studies used an IEEE-62 bus system as the sample model for demonstrating ability of TA while searching the optimal solution. Obtained results show that TA gives good performances for determining the optimal solution. This demonstration also describes that the optimal solution is searched in faster convergence and shorter time. This computation also performs its characteristic in smooth and stable processes for completing all steps. In detail, the optimal solution is obatined in 22 steps for 15,586 $/h after pointing at 28,858 $/h at the first streaming. Based on executions, the computation needed 2.5 s for the streaming and it also needed 0.09 for covering the dead tracks included 0.5 s for the replacement.

***Keywords**: economic dispatch, operating cost, power system, thunderstorm algorithm*

1. Introduction

Presently, various intelligent computations are more popular than classical approaches. It has shifted classical usages in many implementations related to optimization problems in many disciplines, such as, quadratic programming; gradient search; Newton's method; dynamic programming; linear programming; lambda iteration; and Lagrangian relaxation [1]-[4]. Moreover, it has been applied to cover huge areas with many operational constraints for replacing weaknesses of classical approaches throughout numerous developments to improve classical approaches using optimization techniques. Since the early idea of an intelligent computation, many methods have been proposed as evolutionary algorithms depended on own inspirations, for examples, genetic algorithm; neural network; simulated annealing; evolutionary programming; ant colony algorithm; particle swarm optimization; and harvest season artificial bee colony algorithm [5]-[11].

As long as implementations, classical approaches are useful and accurate for searching solutions even it suffers for large systems and multi spaces [12]. In addition, these difficulties are also presented in complicated mathematical programs on the base of the method for huge models or large systems. To cover these points, many algorithms have been proposed for introducing new approaches conducted to phenomena or entities in nature [1]-[3], [6]-[10]. In detail, these algorithms are composed to mimic swarm behaviors of entities or mechanisms of natural processes in nature, which are presented in designed hierarchies as own procedures and principles for guiding the computational process while searching the solution. Thus, the hierarchies and procedures are given in certain statements covered its steps for the pseudo-codes or sequencing orders.

ISSN: 1738-9968 IJHIT
Copyright © 2016 SERSC

Recently, intelligent computations have been advanced to increase its performances in various improved names of the evolutionary algorithm [5]-[7], [10]-[12]. Furthermore, these developments are used to maintain each ability to get out of optimal results and to find out solutions shortly based on principles of own inspirations presented in its hierarchies and procedures. In particular, many studies have been done to understand other phenomena or behaviors in nature in order to propose other new methods. In line with these efforts, this paper presents an adoption of a natural phenomenon as an inspiration for developing a novel evolutionary algorithm. The inspiration is associated with a thunderstorm mechanism during deploying charges on the striking moment at the cloud to cloud or cloud to the earth [13]-[14]. In particular, this proposed idea will be implemented on an economic dispatch to assess an operational problem of a power system.

2. Thunderstorm Algorithm

At the first time, Benjamin Franklin was pioneered to demonstrate how to catch a phenomenon in nature from sky. He tried to understand a natural mechanism through his idea for explaining what happen during striking the lighting. He tested the theory of lightning using a kite as an erected flying object while waiting for the completion of the spire [13]-[15]. After that, he noticed the string stretching out and a spark jumped while the rain fallen during the storm had soaked the line and made it conductive in the thunderstorm. In nature, a thunderstorm occurs randomly throughout an atmospheric discharge, which typically occurs during possibility factors such as volcanic eruptions or dust storms. Contrasted to hurricanes, a thunderstorm affects relatively small areas. Despite its small size, the thunderstorm is dangerous because thunderstorm produces the multiple lightning.

In nature, a thunderstorm can be recognized by cloud shapes and a pre signal, such as, like a puffy shape expanded to begin the growing upwards of the potential striking path between clouds and the earth. This phenomenon can be defined for the charge from atmospheric materials for the thunderstorm and it is very important things to observe covered in the moisture; unstable air; and lifting force. By considering the charge, a lightning process is an electric discharge in the form of a spark in a charged cloud. In addition, thunder’s clouds are charged with the negative charge deployed in the lower part and the positive charge centre is located at the opposite up [13], [16]-[19]. In particular, studies of thunderstorms have been rapidly advanced during the past century and many efforts have been made towards for understanding the multiple lightning, thunderstorm mechanisms, and their consequences. In detail, multiple lightning developments are produced by several steps in terms of charge separation; leader formation; and discharge channel, associated with the cloud up sites and the earth surface as presented in Figure 1. This figure shows deployed positions of the charges in the cloud within multiple striking to reach the earth’s surface.

Recently, natural behaviours and mechanisms become more attracting topics for searching suitable models and understanding the phenomena. These works are conducted to observe and test various characteristics for analyzing curious issues in many aspects in order to recognize natural processes and sequencing mechanisms [18]-[22]. Many behaviours of entities and mechanisms of processes have been selected to become inspirations for developing certain computational methods given in various names as evolutionary algorithms [5]-[11]. In this section, by considering a phenomenon of thunderstorm, its mechanisms are adopted as an inspiration to present a new intelligent computation. This method is used to pretend its processes in nature presented in an evolutionary algorithm using certain hierarchies. These hierarchies are performed using several stages to explain the adoption of mechanisms in pseudo-codes for introducing

Copyright © 2016 SERSC

thunderstorm algorithm (TA) based on the natural inspiration of thunderstorm mechanisms as illustrated in Figure 2.

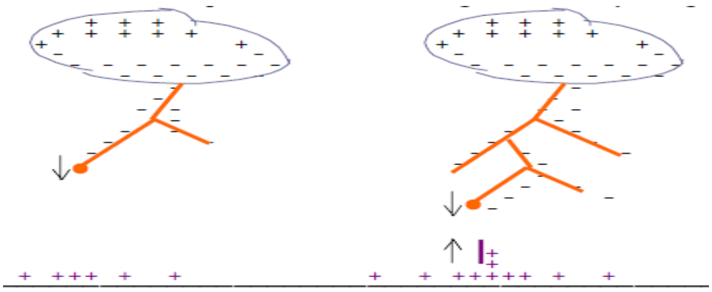

Figure 1. Illustration of the Striking Propagation

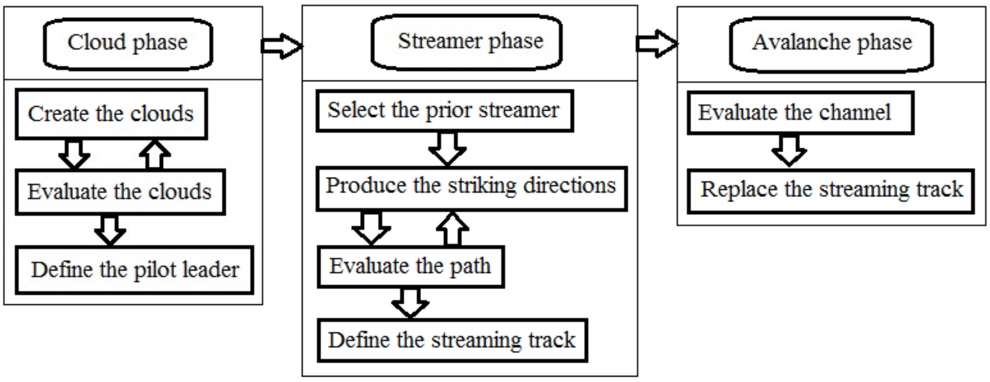

Figure 2. Hierarchy Processes of Thunderstorm Algorithm

As given in Figure 2, the searching mechanism of TA for selecting a solution is conducted to striking processes and channeling avalanches for releasing the population of the cloud charge. In addition, the cloud charge is populated using a certain procedure for the possibility clouds. Moreover, this algorithm is also consisted of various distances for the streamer deployed by a hazardous factor for striking targets. Each solution is located randomly based on the generating random directions of multiple striking points. According to Figure 2, TA is executed using several steps for defining and selecting the optimal solution. The generating population set is initiated at the first step as the cloud charge associated with many technical constraints and limitations. In this phase, various combinations are provided for all computations while searching the solution. In principle, the sequencing computation of TA is given in pseudo-codes in terms of Cloud Phase: Streamer Phase; and Avalanche Phase. Cloud Phase is used to produce the cloud charges, and to evaluate the clouds before defining the pilot leader. Another step, Streamer Phase, is implemented to select the prior streamer and to guide the striking directions included the path evaluation for defining the streaming track. The final process is Avalanche Phase used to evaluate the channels, replace the streaming track for keeping the streamer. Moreover, main functions of this novel algorithm are presented in following mathematical statements for the cloud charge; striking direction; and probability:

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

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

Probability charge: $$\mathrm{prob}Q_{sj} \begin{cases} \dfrac{Q_{sj}^{m}}{\Sigma Q_{s}^{m}} & \text{for m} \\ \dfrac{Q_{sj}^{n}}{\Sigma Q_{s}^{n}} & \text{for n} \end{cases}, \quad (3)$$

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 h^{th}, 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), $j \in (1,2,..,a)$, a is the number of variables, m is the cloud size.

3. Economic Dispatch

In this section, TA is used to assess a power system operation approached using an economic dispatch (ED) for defining economically integrated structures while delivering energy from generator sites to some areas of the load centre. In general, the power system interconnection is divided into three main sections and it covers generation; transmission and sub transmission; distribution and utilization [1]. Moreover, integrated structures of the power system are built for large interconnections of electric networks. The interconnected power system is subjected to provide high quality and reliable power supply to meet the total power demand of consumers at the lowest possible cost while satisfying various constraints imposed in generating units and the system. By concerning in the ED, these processes are conducted to the operating cost reduction while producing power outputs to meet a total demand.

The ED becomes a crucial problem since the power system operation is focused on the technical cost of products and services for searching the optimal operation and planning of power generations. This problem also becomes important works to decrease the running charges of electric energy. To reduce the operating cost, the power system is managed using an economic strategy for providing electric energy from various types of generating units to supply load centers. Moreover, this strategy is commonly performed by a minimized total fuel cost of generating units while producing the total power output troughout the ED problem [23]. In these works, the ED also covers an environmental protection for reducing atmospheric emissions at thermal power plants approached using an emission dispatch (EmD) problem for decreasing pollutants [24]. This emission dispatch is subjected to reduce various pollutant discharges, for examples, CO; CO_2; SO_x; and NO_x [3], [6], [25], [26]. By considering ED and EmD problems, these studies are presented in single objective function as the economic and emission dispatch (EED) problem under operational limitations.

Recently, the EED problem becomes an important task to optimize the total cost of fuel consumptions and the total pollutant production of generating units. Both aspects also become main orientations for reducing the total operating cost and decreasing the total pollutant emission. Nowadays, the EED is one of the obviously interest topics in the power system operation. Many important decisions are made by describing the EED problem for selecting some economical measurements of the power system operation on the desirable decision [1]-[6], [25]-[30]. Technically, the EED is also included penalty and compromised factors. The penalty factor is used to show the rate coefficient of each generating unit for the given load associated with the pollutant production. The compromised factor shows the contribution of ED and EmD problem in the EED. Thus, the dispatching problem is formulated using mathematical statements as follows for the objective function and technical constrints:

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

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

EED: $\Phi = w.F_{tc} + (1-w).h.E_t$, (6)

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

$P_i^{min} \le P_i \le P_i^{max}$, (8)

$Q_i^{min} \le Q_i \le Q_i^{max}$, (9)

$V_p^{min} \le V_p \le V_p^{max}$, (10)

$$S_{pq} \leq S_{pq}^{max}, \ (11)$$

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

4. Method and Implementation

In these studies, the IEEE-62 bus system is selected as a sample model of the power system. This model is used to test TA on the EED problem under various technical limitations and environmental requirements. Technically, this model is consisted of 62 buses; 89 lines; and 32 load buses. This system is also supported by 19 generating units with its coefficients and designed limits as given in Table 1 and Table 2. In detail, these works are required by 10% of the loss limit; 0.5 of the weighting factor; and 0.85 kg/h of the emission standard. This method is also conditioned by other operational constraints in order to search the suitable solution within 5% of voltage violations; 95% of the power transfer capability; and banded on upper and lower power limits. Table 1 illustrates the qudratic and linear coefficients for the fuel cost consumptions covered 19 generating units. In particular, emission coefficients of generating units are listed in Table 2 with completing the power limits for maximum and minimum productions.

Table 1. Fuel cost Coefficients of Generators

Gen	**a $/MWh^2)**	**b ($/MWh)**	**c**
G1	0.00700	6.80	95
G2	0.00550	4.00	30
G3	0.00550	4.00	45
G4	0.00250	0.85	10
G5	0.00600	4.60	20
G6	0.00550	4.00	90
G7	0.00650	4.70	42
G8	0.00750	5.00	46
G9	0.00850	6.00	55
G10	0.00200	0.50	58
G11	0.00450	1.60	65
G12	0.00250	0.85	78
G13	0.00500	1.80	75
G14	0.00450	1.60	85
G15	0.00650	4.70	80
G16	0.00450	1.40	90
G17	0.00250	0.85	10
G18	0.00450	1.60	25
G19	0.00800	5.50	90

Table 2. Emission Coefficients and Power Limits of Generators

Gen	**α (kg/MWh^2)**	**β (kg/MWh)**	**γ**	**P_{min} (MW)**	**P_{max} (MW)**
G1	0.0180	-1.8100	24.300	50	300
G2	0.0330	-2.5000	27.023	50	450
G3	0.0330	-2.5000	27.023	50	450
G4	0.0136	-1.3000	22.070	0	100
G5	0.0180	-1.8100	24.300	50	300
G6	0.0330	-2.5000	27.023	50	450
G7	0.0126	-1.3600	23.040	50	200
G8	0.0360	-3.0000	29.030	50	500
G9	0.0400	-3.2000	27.050	0	600
G10	0.0136	-1.3000	22.070	0	100
G11	0.0139	-1.2500	23.010	50	150
G12	0.0121	-1.2700	21.090	0	100
G13	0.0180	-1.8100	24.300	50	300
G14	0.0140	-1.2000	23.060	0	150
G15	0.0360	-3.0000	29.000	0	500
G16	0.0139	-1.2500	23.010	50	150
G17	0.0136	-1.3000	22.070	0	100
G18	0.0180	-1.8100	24.300	50	300
G19	0.0400	-3.000	27.010	100	600

Furthermore, TA is implemented on a standard model of the power system based on the sequencing orders as depicted in Figure 2. In these works, it is programmed in several sections in terms of the cloud phase; streamer phase; and avalanche phase. These programs are designed in main listed structures presented in the evaluate program, cloud charge program, streamer program, avalanche program, and dead track program using its parameters covered in 1 of the avalanche; 25 of the cloud charge; 100 of streaming flows; and 4 of the hazardous factor. All parameters of TA are collaborated to find out the optimal solution of the EED problem using the IEEE-62 bus system.

5. Results and Discussions

In this section, this simulation is addressed to demonstrate an ability of TA for searching the optiml solution of the EED problem. As the proposed algorithm, its ability will be presented in several indicators while carrying out the EED problem for defining an unit commitment of generating units to meet 2,426.2 MW and 1,055.8 MVar of the load demand. By considering this load, TA will be used to select a suitable power output combination with a resionable operating cost as the objective function. In detail, this simulation has been processed in 100 streaming flows with final results as given in following Tables and Figures.

Copyright © 2016 SERSC

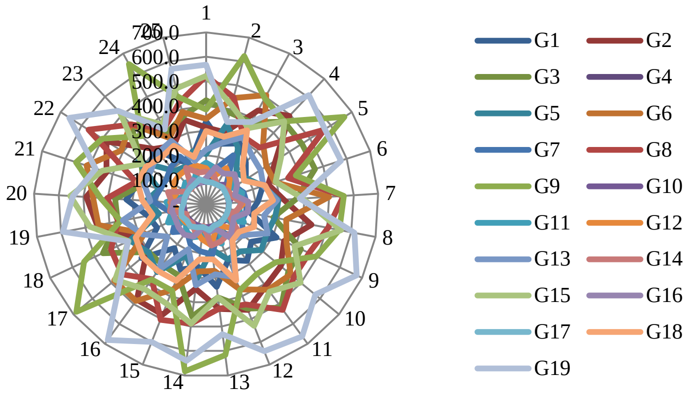

Figure 3. Distributed Cloud Charges

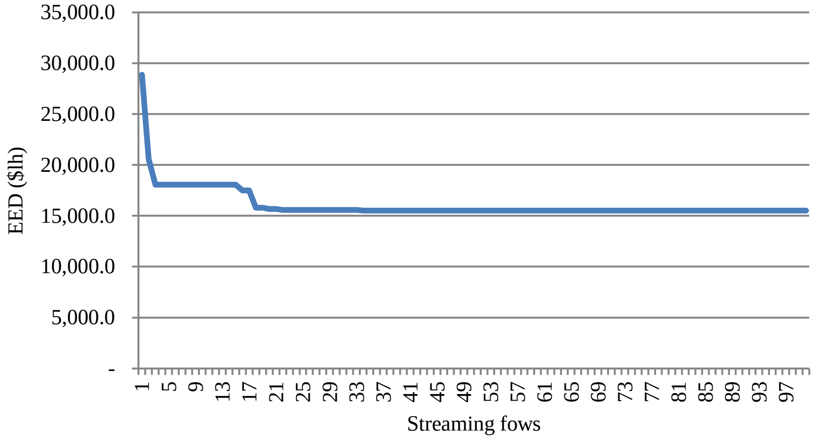

Figure 4. Convergence Speed

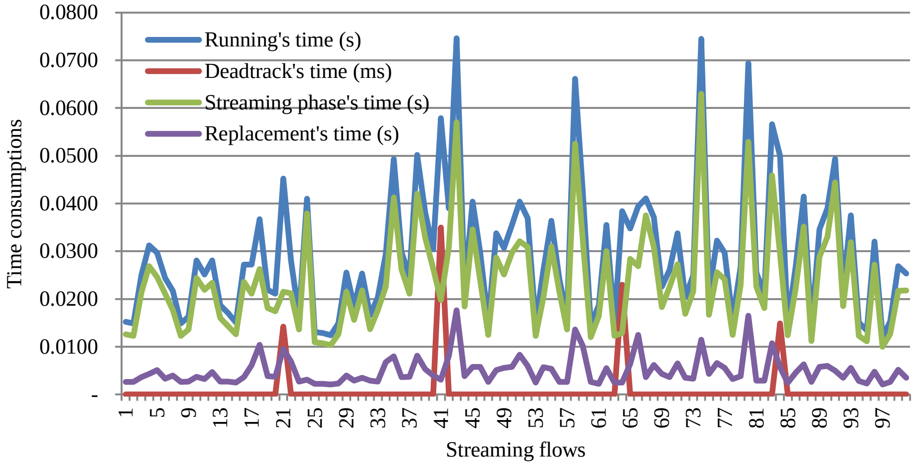

Figure 5. Time Consumption Characteristics

Figure 3 shows a set of charges initialed as the candidate solution of generating units. These charges are produced randomly for 19 generating units in 25 posibility combinations with different own amounts for supporting unit commitments. These cloud charges are generated by considering power constraints for power stations covered in maxmimum and minimum limits. In detail, these charges are searched in 3.09 s while completing the computation with a speed characteric as illustrated in Figure 4. This characteristic also describes performances of the computation with smooth and stable processes while searching the optimal solution in 100 streaming flows. Moreover, the optimal solution of the EED is obatined in 22 steps for 15,586 $/h after pointing at 28,858 $/h for the first streaming. By considering all sequencing orders, time consumptions of the computation are presented in Figure 5 covered for the running's time; streaming phase's time; dead track's time, and replacement's steps. For all executions, the computation needed 2.5 s for the streaming and it also needed 0.09 for covering the dead tracks included 0.5 s for the replacement. In Particular, based on the technical requirements, final results are listed in Table 3 given in terms of power productions; pollutant emissions; and operating fees.

Table 3. Unit Commitment of the EED Problem for 19 Generating Units

Gen	Power (MW)	Pollutant Productions (kg/h)			Operating Costs ($/h)		
		Emissi.	Std. Emiss.	Catch. Emiss.	Fuel Cost	Compen-sation	Total Cost
G1	288.1	996.8	244.9	751.9	2,634.95	56,391.0	59,025.95
G2	67.5	8.6	57.4	-	325.06	-	325.06
G3	266.7	1,707.1	226.7	1,480.5	1,502.83	111,034.7	112,537.53
G4	96.9	23.8	82.4	-	115.82	-	115.82
G5	201.2	388.9	171.0	217.9	1,188.57	16,340.9	17,529.47
G6	250.0	1,464.5	212.5	1,252.0	1,433.75	93,901.7	95,335.45
G7	90.0	2.7	76.5	-	517.65	-	517.65
G8	75.0	6.5	63.8	-	463.19	-	463.19
G9	90.0	63.1	76.5	-	663.85	-	663.85
G10	94.9	21.1	80.6	-	123.43	-	123.43
G11	99.0	35.6	84.2	-	267.61	-	267.61
G12	97.9	12.7	83.2	-	185.13	-	185.13
G13	264.1	802.0	224.5	577.5	899.26	43,310.6	44,209.86
G14	22.5	3.1	19.1	-	123.28	-	123.28
G15	75.0	6.5	63.8	-	469.06	-	469.06
G16	70.0	3.6	59.5	-	210.05	-	210.05
G17	91.9	17.5	78.1	-	109.22	-	109.22
G18	293.5	1,043.9	249.5	794.4	882.40	59,583.0	60,465.40
G19	90.0	81.0	76.5	4.5	649.80	338.3	988.10
Total	2,624.2	6,689.0	2,230.7	5,078.7	12,764.9	380,900.2	393,665.1

From Table 3, it is known that the unit commitment of generating units inline the system is produced totally around 2,624.2 MW. It means that the power system has 198 MW of the loss during conveying energy to the load area around 2,426.2 MW. It can be understand that the lines of the power system consume the power around 7.6%. As the implication of this unit commitment, generating units also produce individually power outputs within various portions of the pollution. In total, the emission is produced around 6,689 kg/h even the pollution is also limited totally by 2,230.7 kg/h. The higher contributors for the emission are released from G1; G3; G6; and G18. Caused by over productions, these emission should be filtered at generating units around 5,078.7 kg/h. Furthermore, as the consequencies of the combination, the power system is operated using

393,665.1 $/h for the fuel procurement and the emission compensation. In detail, 12,764.9 $/h is spent for the fuel consumption and 380,900.2 $/h is used to provide protectors or to pay the pollutant compensation.

6. Conclusions

This paper introduces a development of thunderstorm algorithm applied to an economic dispatch for defining a unit commitment of generating units using an IEEE-62 bus system based on the EED problem. Results obtained shows that it has smooth convergence speeds with the short time consumption. The proposed algorithm seems strongly to be a new promising approach for defining the unit commitment based on the solution quality and the computational efficiency while searching the optimal solution of the EED problem. In addition, The EED has been solved in various individual power outputs as the unit commitment. These power productions are also associated with emission discharges at each generating unit. Moreover, these results are obtained in the optimized operating cost. From these works, future studies in real power system applications and observations of the algorithm's parameters are devoted to further themes.

References

[1] A.A. El-Keib, H.Ma and J.L. Hart, "Environmentally constrained ED using the lagrangian relaxation method", IEEE Trans. Power Systems, vol. 9, issue. 4, **(1994)**, pp. 1723-1729.

[2] Ahmed Farag, Samir Al-Baiyat and T.C. Cheng, "Economic load dispatch multiobjective optimization procedures using linear programming techniques", IEEE Trans. Power Systems, vol. 10, issue. 2, **(1995)**, pp. 731-738.

[3] Mukesh Garg and Surender Kumar, "A survey on environmental economic load dispatch using lagrange multiplier method", International Journal of Electronics & Communication Technology, vol. 3, issue. 1, **(2012)**, pp.43-46.

[4] S. Subramanian and S. Ganesa, "A simplified approach for ED with piecewise quadratic cost functions", International Journal of Computer and Electrical Engineering, vol. 2, no. 5, **(2010)**, pp. 793-798.

[5] I. G. Damausis, A. G. Bakirtzism and P. S. Dokopoulos, "Network Constrained Economic Dispatch using Real Coded Genetic Algorithm", IEEE Trans. Power Systems, vol. 18, no. 1, **(2003)**, pp. 198-205.

[6] R.Gopalakrishnan and A.Krishnan, "A novel Combined Economic and Emission Dispatch Problem Solving Technique using Non-dominated Ranked Genetic Algorithm", European Journal of Scientific Research, vol. 64, no. 1, **(2011)**, pp. 141-151.

[7] A.N. Afandi and H. Miyauchi, "Improved Artificial Bee Colony Algorithm Considering Harvest Season for Computing Economic Disatch on Power System", IEEJ Transactions on Electrical and Electronic Engineering, vol. 9, no. 3, **(2014)**, pp. 251-257.

[8] B. Sahu, A. Lall, S. Das and T. Manoj Patra, "Economic Load Dispatch in Power System Using Genertic Algorithm", International Journal of Computer Applications,vol. 67, no. 7, **(2013)**, pp. 17-22.

[9] Z.-L. Gaing, "Particle Swarm Optimization to Solving the ED Considering the Generator Constraints", IEEE Trans. Power Systems, vol. 18, no. 3, **(2003)**, pp. 1187-1195.

[10] C. Christoper Columbus and S.P. Simon, "A Parallel ABC for Security Constrained Economic Dispatch using Shared Memory Model", Proc. EPSCICON, IEEE Conference Publication, **(2012)**, pp. 1-6.

[11] S.L. Ho, S. Yang, H.C. Wong, K.W.E. Cheng and G. Ni, "An Improved Ant Colony Optimization Algorithm and Its Application to Electromagnetic Devices Designs", IEEE Transactions on Magnetics, vol. 41, no. 5, **(2005)**, pp. 1764-1767.

[12] A.N. Afandi, "Optimal Solution of the EPED Problem Considering Space Areas of HSABC on the Power System Operation," International Journal of Engineering and Technology, vol. 7, no. 5, **(2015)**, pp. 1824-1830.

[13] K. C. Wiens, S. A. Rutledge and S. A. Tessendorf, "The 29 June 2000 Supercell Observed during STEPS. Part II: Lightning and Charge Structure", Journal Atmos. Sci., **(2005)**, pp. 4151-4177.

[14] http://www.meteohistory.org/2004proceedings1.1/pdfs/01krider.pdf, accessed on 7th March **(2016)**.

[14] T. J. Lang, S. A. Rutledge and K. C. Wiens, "Origins of Positive Cloud-to-Ground Lightning Flashes in the Stratiform Region of a Mesoscale Convective System", Geophys. Res. Lett., doi:10.1029/2004GL019823.

[15] L. D. Carey, S. A. Rutledge and W. A. Petersen, "The Relationship between Severe Storm Reports and Cloud-to-Ground Lightning Polarity in the Contiguous United States from 1989 to 1998", Mon. Wea. Rev., **(2003)**, pp. 1211–1228.

[16] C.P.R Suanders, H. Bax-Norman, E.E. Ávila and N.E. Castellano, "A Laboratory Study of the Influence of Ice Crystal Growth Conditions on Subsequent Charge Transfer in Thunderstorm Electrification", Q. J. R. Meteorol. Soc, vol. 130, **(2004)**, pp. 1395–1406.

[17] D.R. Macgorman, W.D. Rust, P. Krehbiel, W. Rison, E. Bruning and K. Wiens, "The Electrical Structure of Two Supercell Storms during STEPS", Mon. Wea. Rev., **(2005)**, pp. 2583–2607.

[18] E. R. Mansell, D. R. Macgorman, C. L. Zeigler and J. M. Straka, "Charge Structure and Lightning Sensitivity in a Simulated Multicell Thunderstorm", Journal Geophys. Res., vol. 110, **(2005)**, pp. 1-24.

[19] C. Barthe, M. Chong, J.-P. Pinty, C. Bovalo and J. Escobar, "Updated and Parallelized Version of an Electrical Scheme to Simulate Multiple Electrified Clouds and Flashes over Large Domains", Geosci. Model Dev., vol. 5, **(2012)**, pp. 167-184.

[20] W. D. Rust, "Inverted-Polarity Electrical Structures in Thunderstorms in the Severe Thunderstorm Electrification and Precipitation Study (STEPS)", Atmos. Res., **(2005)**, pp. 247–271.

[21] M. Stolzenburg and T. C. Marshall, "Charge Structure and Dynamics in Thunderstorms", Space Sci. Rev., vol. 30, **(2008)**, pp. 355-372.

[22] H. Chahkandi Nejad, R. Jahani and M. Mohammad Abadi, "GAPSO-Based Economic Load Dispatch of Power System", Australian Journal of Basic and Applied Sciences, Vol. 5, no.7, **(2011)**, pp. 606-611.

[23] M.A. Abido, "Environtment/Economic Power Dispatch using Multiobjective Evolutionary Algorithms", IEEE Transactions on Power System, vol. 18, issue 4, **(2003)**, pp. 1529-1539.

[24] Y. Cheng, W. Xiao, W.-J. Lee and M. Yang, "A New Approach for Missions and Security Constrained Economic Dispatch", Proc. NAPS, IEEE Conference Publication, Starkville USA, **(2009)**, pp. 1-5.

[25] K. S. Kumar, V. Tamilselvan, N. Murali, R. Rajaram, N. S. Sundaram and T. Jayabarathi, "Economic Load Dispatch with Emission Constraints using Various PSO Algorithm", WSEAS Transaction on Power System, vol. 9, no. 3, **(2008)**, pp. 598-607.

[26] Y. Fu, M. Shahidehpour and Z. Li, "AC Contingency Dispatch Based on Security Constrained Unit Commitment", IEEE Transactions on Power Systems, vol. 21, no. 2, **(2006)**, pp. 897-908.

[27] B.H. Chowdhury, S. Rahman, "A Review of Recent Advances in Economic Dispatch", IEEE Trans. On Power Systems, vol. 5, no. 4, **(1990)**, pp.1248-1259.

[28] T. Yalcinoz and M. J. Short, "Large-scale ED using an improved hopfield neural network", IEEE Proc. Gener. Transm. Distrib. vol. 144, no. 2, **(1997)**, pp. 181-185.

[29]Y. Abdelaziz, S. F. Mekhamer, M. A. L. Badr and M. Z. Kamh, "ED using an Enhanced Hopfield Neural Network", Electric Power Components and Systems, vol. 36, no. 7, **(2008)**, pp. 719-732.

Copyright © 2016 SERSC