International Journal of Electrical and Computer Engineering (IJECE)
Vol. 10, No. 2, April 2020, pp. 1135~1141
ISSN: 2088-8708, DOI: 10.11591/ijece.v10i2.pp1135-1141

Optimal unit commitment of a power plant using particle swarm optimization approach

Boniface O. Anyaka[1], J. Felix Manirakiza[2], Kenneth. C Chike[3], Prince A. Okoro[4]
[1,3,4]Department of Electrical Engineering, University of Nigeria, Nigeria
[2]Department of Electrical and Electronis Engineering, Integrated Polytechnic Regional Centre (IPRC)-Gishari, Rwanda

Article Info

Article history:

Received Dec 4, 2018
Revised Oct 4, 2019
Accepted Oct 12, 2019

Keywords:

Economic load dispatch
Generating unit
Generation cost
Optimization
Particle swarm optimization

ABSTRACT

Economic load dispatch among generating units is very important for any power plant. In this work, the economic load dispatch was made at Egbin Thermal Power plant supplying a total load of 600MW using six generating units. In carrying out this study, transmission losses were assumed to be included into the load supplied. Also, three different combinations in the form of 6, 5- and 4-units commitment were considered. In each case, the total load was optimally dispatched between committed generating units using Particle Swarm Optimization (PSO). Similarly, the generation cost for each generating unit was determined. For case 1, the six generators were committed and the generation cost is 2,100,685.069$/h. For case 2, five generators were committed and the generation cost is 2,520,861.947$/h. For case 3, four generators were committed and the generation cost is 3,150,621.685$/h. From all considered cases, it was found that, the minimum generation cost was achieved when all six generating units were committed and a total of 420,178.878$/h was saved.

Corresponding Author:

Boniface O. Anyaka,
Department of Electrical Engineering,
University of Nigeria,
Nsukka, Enugu State, Nigeria.
Email: boniface.anyaka@unn.edu.ng

1. INTRODUCTION

For efficient and reliable operation of power system, proper analysis of operating the system economically is of great importance [1]. For economic operation of generators many variables are considered such as fuel, labour and maintenance cost. For thermal and nuclear plants, the most important variable considered is the fuel cost [2]. Economic load dispatch problem is defined as allocating loads to generating units at minimum cost while satisfying various operational constraints [3-8]. The generators are to be scheduled in such a way that generators with minimum cost are used as much as possible [6]. Several factors contribute in generation cost of a thermal power plant such as the location of load centres and the fuel cost. The cost of power generation particularly in fossil fuel plants is high and economic dispatch helps in saving a significant amount of revenue for a utility company [4]. Most generating stations are faced with the problem of allocation of generators and this lapse leads to non-economical operation of the plants. Non-economical operation of the plants directly leads to higher incremental fuel cost, thus; leading to high tariff of electricity on consumers.

In this study, Particle Swarm Optimization (PSO) technique was used to economically dispatch the load between the generating units and determine the minimum generation cost at Egbin Thermal Power Plant station in Nigeria. These were done after determining the generation cost function of each generating unit using Least Square Estimation Technique. PSO technique was used in this study due to its mathematical simplicity, fast convergence and robustness to solve hard optimization problems. The study will benefit utility companies and consumers of electricity. This will help in reduction of production cost of the utility companies and minimize tariff on consumers.

The solution of economic dispatch problem has been proposed and different algorithms have been developed. Traditional algorithms such as Lambda iteration, gradient, Newton-Raphson methods, etc. were widely employed in solving the Economic Load Dispatch (ELD) problem if their cost functions are piecewise linear [4, 9]. These methods were challenged by the introduction of transmission losses and prohibited zones due to environmental impacts; thus, the use of advanced techniques such as genetic algorithms, evolutionary programming, particle swarm optimization, artificial immune systems, harmony search, Tabu search, artificial neural network, among others are preferred [10-19].

2. RESEARCH METHOD

The Egbin electric power generation station used for this study is a steam thermal plant that makes use of steam to drive its turbines in order to generate electricity. The power station uses natural gas as fuel to fire the boiler. The station was established in 1985 and is located in Egbin village near Ijede town in Ikorodu Local Government Area of Lagos state, Nigeria. At present, the installed capacity of the generating station is 1320MW which consists of six (6) steam-turbine generators each having maximum plant capacity of 220MW [20].

The major concern of an economic dispatch problem is to minimize the fuel cost for a given thermal power plant considering a given total load demand subject to operating constraints of a power system. Therefore, it can be formulated mathematically with the objective function and constraints. In any practical case, the fuel cost function of any generating unit is represented by a quadratic function of the real power generation.

$$C_i = AP_i^2 + BP_i + C \quad (1)$$

The incremental fuel-cost curve is a measure of how costly it will be to produce the next increment of power.

$$dC_i / dP_i = 2AP_i + B \quad (2)$$

Thus, the objective function is formulated as

$$Min\ C_T = \sum_{i=1}^{n} C_i(P_i) \quad (3)$$

where

C_T is the total fuel cost,

$C_i(P_i)$ and P_i are the cost functions and real power output of generator ***i*** respectively

n is the number of committed generators.

2.1. System constraints

In this study, the system constraint was classified into equality constraint and inequality constraint

2.1.1. Equality Constraints

As stated in [21], the total power generation must cover the total demand P_D and the real power loss in transmission lines P_L. It is also called power balance equation and is expressed as

$$\sum_{i=1}^{n} P_{Gi} = P_D + P_L \quad (4)$$

2.1.2. Inequality constraints

As stated in [22] the output power of each generator should lie between minimum and maximum limits, so that

$$P_i^{Min} \le P_i \le P_i^{Max} \quad (5)$$

With P_i^{Min} and P_i^{Max} are the minimum and maximum power outputs of the i^{th} generating unit respectively.

2.2. Overview of PSO

The PSO algorithm which was first proposed by Kennedy and Eberhart has been inspired by the Social behavior of a simple system (flock of birds). This algorithm can be effectively useful in solving many non-linear hard optimization problems [10]. Unlike the mathematical methods for solving optimization problems, this algorithm does not need any gradient information about objective or error function and it can obtain the best solution independently [23]. According to the PSO algorithm, a swarm of particles that have predefined restrictions starts to fly on the search space. The performance of each particle is evaluated by the value of the objective function and considering the minimization problem, in this case, the particle with lower value has more performance [24]. The best experience for each particle in iterations is stored in its memory and called personal best (Pbest).

The best value of Pbests (less values) in iterations determines the global best (Gbest). By using the concept of Pbest and Gbest the velocity of each particle is updated in (6)

$$V_i^{k+1} = V_i^k + c1r1\left(X_{pbest} - X_i^k\right) + c2r2\left(X_{gbest} - X_i^k\right) \quad (6)$$

where
V_i^{k+1} : Particle Velocity at current iteration (k+1)
V_i^k : Particle velocity at iteration k
r1, r2: Random number between [0 - 1]
c1, c2: Acceleration constant.
After this, particles fly to a new position:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (7)$$

where
X_i^{k+1}: Current particle position at iteration k+1
X_i^k : Particle position at iteration k

With numerical analysis method, the marginal cost of each unit was determined using least square estimation technique. The incremental cost (marginal cost) for each generating unit was obtained by solving the following equations

$$\sum C_i = N * a + b * \sum P_i \quad (8)$$

$$\sum P_i C_i = a * \sum P_i + b * \sum P_i^2 \quad (9)$$

By solving (8) and (9), the marginal cost function was given as

$$IC_i = a + b * P_i \quad (10)$$

With
IC_i : The incremental cost function of unit i
P_i : Power generated by unit i
N: Samples taken in a period.

The generation cost function of a unit is determined by the area under the marginal cost function; hence the generation function is given by the integration of the marginal cost function of a considered unit. The load dispatch between generating units and minimum generation cost was done using Particle Swarm Optimization (PSO) considering system constraints. For the reason of comparing results, 3 cases were considered namely: test with six generating units, test with 5 generating units and test with 4 generating units. Sample data used in this study are given given in Tables 1-3. Full details of the data used can be found in [25] The data contains power output and energy generated from each of the six generating units at Egbin power plant. A generation cost of 0.07$/KWh was considered [26].

Table 1. Power generation parameters for unit-1

Year	Installed capacity in MW	Installed capacity in MWh	Generated capacity (P_i) in MW	Generated capacity in MWh	Operating Time in hours	Generation cost ($)	Generation cost (C_i) per hour ($/h)	$C_i P_i$	P_i^2
2002	220	1,927,200	167.06	1,324,090	7,926	92,686,300	11,694	1953633	27909.04
2003	220	1,927,200	141.86	1,143,541	8,061	80,047,870	9,930	1408698	20124.26
2004	220	1,927,200	177.19	1,339,773	7,561	93,784,110	12,403	2197741	31396.3
2005	220	1,927,200	177.94	1,364,226	7,667	95,495,820	12,456	2216385	31662.64
2006	220	1,927,200	130.91	1,052,177	8,037	73,652,390	9,164	1199620	17137.43
$\sum$			794.96				55,647	8976077	128229.7

Table 2. Power generation parameters for unit-2

Year	Installed capacity in MW	Installed capacity in MWh	Generated capacity (P_i) in MW	Generated capacity in MWh	Operating Time in hours	Generation cost ($)	Generation cost (C_i) per hour ($/h)	$C_i P_i$	P_i^2
2002	220	1,927,200	185.41	1,520,460	8,201	106432200	12,979	2406381	34376.87
2003	220	1,927,200	146.38	1,159,000	7,918	81130000	10,247	1499897	21427.1
2004	220	1,927,200	168.57	1,310,468	7,774	91732760	11,800	1989109	28415.84
2005	220	1,927,200	191.42	1,529,428	7,990	107059960	13,399	2564913	36641.62
2006	220	1,927,200	131.5	919,652	6,994	64375640	9,205	1210458	17292.25
$\sum$			823.28				57,630	9670758	138153.7

Table 3. Power generation parameters for unit-3

Year	Installed capacity in MW	Installed capacity in MWh	Generated capacity (P_i) in MW	Generated capacity in MWh	Operating Time in hours	Generation cost ($)	Generation cost(C_i) per hour ($/h)	$C_i P_i$	P_i^2
2002	220	1,927,200	173.68	1,370,025	7,888	95901750	12,158	2111532	30164.74
2003	220	1,927,200	148.57	1,141,902	7,686	79933140	10,400	1545113	22073.04
2004	220	1,927,200	180.65	1,412,183	7,817	98852810	12,646	2284410	32634.42
2005	220	1,927,200	181.88	1,458,950	8,021	102126500	12,732	2315623	33080.33
2006	220	1,927,200	126.52	918,879	7,263	64321530	8,856	1120512	16007.31
$\sum$			811.3				56,791	9377190	133959.9

3. RESULTS AND ANALYSIS

Using the values given in Tables 1 to 6 the marginal cost function for each unit was obtained as follows:

Unit-1: $IC_1 = -2.6185 + 70.0162 P_1$ (11)

Unit-2: $IC_2 = 4.3213 + 69.9742 P_2$ (12)

Unit-3: $IC_3 = 0.2100 + 69.9987 P_3$ (13)

Unit-4: $IC_4 = 5.1809 + 69.9674 P_4$ (14)

Unit-5: $IC_5 = 0 + 70 P_5$ (15)

Unit-6: $IC_6 = 0 + 70 P_6$ (16)

The generation cost function for each unit were obtained as:

$$C_1 = -2.6185P_1 + 35.0081P_1^2 \quad (17)$$

$$C_2 = 4.3213P_2 + 34.9871P_2^2 \quad (18)$$

$$C_3 = 0.2100P_3 + 34.99935P_3^2 \quad (19)$$

$$C_4 = 5.1809P_4 + 34.9837P_4^2 \quad (20)$$

$$C_5 = 0 + 35P_5^2 \quad (21)$$

$$C_6 = 0 + 35P_6^2 \quad (22)$$

The solved problem was given by (3) as follow:

$$\min \quad C_T = \sum_{i=1}^{6} C_i(P_i)$$

With $\sum_{i=1}^{6} P_1 = 600MW$ and $55MW \le P_i \le 220MW$

The generating units are of the same generation limits and transmission losses were included into the considered load.

Test Case 1:

In this case, six generating units were committed. The power outputs and the generation costs are presented in Table 4.

Table 4. Power outputs and generation cost for six generating units: Test Case-1

Generating Unit	Power Output (MW)	Generation Cost ($\$/h$)
1	100.2256	351399.9065
2	100.6464	354843.6744
3	99.5921	347164.9906
4	100.4835	353748.6969
5	97.8742	335227.5659
6	101.1788	358300.2349
Total	600	2100685.069

Test Case 2:

In this case, only five generating units were committed. The power outputs and the generation costs are presented in Table 5.

Table 5. Power outputs and generation cost for five generating units: Test Case-2

Generating Unit	Power Output (MW)	Generation Cost ($\$/h$)
1	121.9885	520642.9054
2	120.3676	507425.8142
3	120.7055	509959.4983
4	118.2269	489600.6828
5	118.7113	493233.0462
Total	600	2520861.947

Test Case 3:

In this case, only four generating units were committed. The power outputs and the generation costs are presented in Table 6.

Table 6. Power outputs and generation cost for four generating units: Test Case-3

Generating Unit	Power Output (MW)	Generation Cost ($\$/h$)
1	150.85118	796258.615
2	149.1677	779142.6558
3	149.9890	787401.3791
4	149.9913	787819.0351
Total	600	3150621.685

The reason for considering only 3 cases was because of no optimization was found using PSO for the other 3 combination of generating units. From the results obtained, a difference of 420178.878$/h was recorded when six generating units' combination was used ahead of the five and four generating units combinations.

4. CONCLUSION

Using the plant generation data for 5 years from 2002 to 2006 the generation cost functions of 6 generating units at Egbin thermal plant were determined. The economic load dispatch and optimum generation cost for the considered period was determined using Particle Swarm Optimization. Considering a combination of six generating units all operational, the minimum generation cost was obtained as 2,100,685.069$/h. The other possible unit combinations were analysed where the 5-units and 4-unit combinations were considered. From the results obtained from each combination, it was seen that the minimum generation cost was achieved if all six generating units were committed and the power plant was saving a total of 420,178.878$/h.

REFERENCES

[1] J. J. Grainger, "Power System Analysis" Text Book, ISBN 0-07-061293-5
[2] D. Das, "Electrical Power Systems", Text Book, ISBN: 978-81-224-2515-4
[3] S. Nagendra and K. Yogendra, "Multiobjective Economic Load Dispatch Problem Solved by New PSO", *Hindawi Publishing Corporation Advances in Electrical Engineering*, pp. 6, 2015.
[4] X. V. Neto, "Solving non-smooth economic dispatch by a new combination of continuous GRASP algorithm and differential evolution," *Electrical Power and Energy Systems*, pp.13-24, 2017
[5] F. Alkhalil and P. Degobert, "Fuel consumption optimization of a multimachines microgrid by secant method combined with IPPD table," *International Conference on Renewable Energies and Power Quality (ICREPQ'09) Valencia (Spain),* 2009.
[6] A. Bhardwaj, "Literature Review of Economic Load Dispatch Problem in Electrical Power System using Modern Soft Computing," *International Journal of Advance Research in Science and Engineering,* vol. 6(1), 2017.
[7] Y. Wang and H. Xiao "Modeling and Solution of Economic Dispatch Problem for GTCC Units," *Energy and Power Engineering,* vol. 5, pp. 294-299, 2013. available online at: http://www.scirp.org/journal/epe.
[8] M. Y. Malik and H. Gupta "A Review on Combined Economic Load and Emission Dispatch Problem," *IJEDR,* vol. 4(2), 2016
[9] J. P. Fossati, "Unit Commitment and Economic Dispatch in Micro grids," no.10, 2012.
[10] A. Zaraki and M. F. B. Othman, "Implementing PSO to solve economic load dispatch problem," *International Conference of Soft Computing and Pattern Recognition*, 2009.
[11] D. G. B. Amali, and M. Dinakaran, "A Review of Heuristic Global Optimization Based Artificial Neural Network Training Approahes," IAES *International Journal of Artificial Intelligence (IJ-AI),* vol. 6(1), pp. 26-32, 2017.
[12] A. Amen, "Multi-Operator Genetic Algorithm for Dynamic Optimizatio Problems," IAES *International Journal of Artificial Intelligence (IJ-AI),* vol. 6(3), pp. 139-142, 2017.
[13] K. Lenin, "Shrinkage of real power loss by enriched brain storm optimization algorithm," IAES *International Journal of Artificial Intelligence (IJ-AI),* vol. 8(1), pp. 1-6, 2019.
[14] S. Jayalakshmi and R. Aswini, "A Novel Optimization Algorithm Based on Stinging Behavior of Bee," IAES *International Journal of Artificial Intelligence (IJ-AI),* vol. 7(4), pp. 153-164, 2018.
[15] X. Huang, X. Zeng, R. Han and X. Wang, "An enhanced hybridized artificial bee colony algorithm for optimization problems," IAES *International Journal of Artificial Intelligence (IJ-AI),* vol. 8(1), pp. 87-94, 2019.
[16] T. D. Apale and A. B. Patil, "Optimization study of fuzzy parametric uncertain system," IAES *International Journal of Artificial Intelligence (IJ-AI),* vol. 8(1), pp. 14-25, 2019.
[17] W. N. A. Abed, O. A. Imran and I. S. Fatah, "Automatic ɢeneration control based whale optimization αlgorithm," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9(6), pp. 4516-4523, 2019.
[18] M. H. Lokman, I. Musirin, S. I. Suliman, H. Suyono, R. N. Hasanah, S. A. S. Mustafa and M. Zellagui, "Multi-verse optimization based evolutionary programming technique for power scheduling in loss minimization scheme," IAES *International Journal of Artificial Intelligence (IJ-AI),* vol. 8(3), pp. 292-298, 2019.
[19] A. Hamzi and R. Meziane, "Cat Swarm Optimization to Shunt Capacitor Allocation in Algerian Radial Distribution Power System," IAES *International Journal of Artificial Intelligence (IJ-AI),* vol. 7(3) pp. 143-152, 2018.
[20] M. N. Eke, "Long Term Energy Performance Analysis of Egbin Thermal Power Plant, Nigeria," *Nigerian Journal of Technology (NIJOTECH)*, vol. 33(1), pp. 97-103, 2014.
[21] C. Kumar and T. Alwarsamy, "Solution of Economic Dispatch Problem using Differential Evolution Algorithm," *International Journal of Soft Computing and Engineering (IJSCE)*, vol.1(6), 2012.
[22] K. H. Khwee and Abubakar "Hybrid PSO-GSA for Economic Load Dispatch with Valve-Point Effects," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 7(1), 2018.

[23] W. R. Abdul-Adheem, "An enhanced particle swarm optimization algorithm," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9(6), pp. 4904-4907, 2019.
[24] M. Takruri1, M. K. A. Mahmoud and A. Al-Jumaily, "PSO-SVM hybrid system for melanoma detection from histo-pathological images," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9(4), pp. 2941-2949, 2019.
[25] I. Emovon, B. Kareem and M. K. Adeyeri, "Performance Evaluation of Egbin Thermal Power Station, Nigeria," *Proceedings of the World Congress on Engineering and Computer Science 2011*, vol. 2, 2011.
[26] The Nigerian Economic Summit Group, "Comparison of Costs of Electricity Generation in Nigeria," *Report by Heinrich Boll Stiftung*, Abuja, June 2017.

BIOGRAPHIES OF AUTHORS

Boniface O. Anyaka is currently a Senior Lecturer in the Department of Electrical Engineering, Faculty of Engineering, University of Nigeria, Nsukka, Nigeria. He had his M. Eng in Electric Power System/Applied Automatics from the University of Technology, Wroclaw, Poland in 1988 and his Ph.D. from the Department of Electrical Engineering. University of Nigeria, Nsukka in 2011. He has held a number of positions in the university system. He was the director, student's industrial work experience scheme (SIWES), University of Nigeria Nsukka and Enugu campuses between 2006 and 2007. He was the acting Head, Department of Electrical Engineering, University of Nigeria, Nsukka (2011-2013) and the immediate past Associate Dean, Faculty of Engineering, University of Nigeria, Nsukka (2016-2018)Engr. Dr. Anyaka is a registered member of the Council for the Regulation of Engineering in Nigeria (COREN), corporate member, Nigeria Society of Engineers (NSE), member, Solar Energy Society of Nigeria (SESN), and Member Nigeria Institution of Electrical and Electronic Engineers (NIEEE). His major field of research interest are in the areas of power system modelling and renewable energy (Photovoltaic). He has to his credit, over 50 publications in both local and international journals.

J. Felix Manirakiza is an Assistant Lecturer in Electrical and Electronics Engineering, Integrated Polytechnic Regional Centre-Gishari, Rwanda. He has Master's Degree in Power Systems from the University of Nigeria, Nsukka (2019). He obtained a Bachelor's Degree in Electrical Engineering in 2011 from University of Rwanda, College of Science and Technology.

Kenneth C. Chike holds a bachelor degree in Electrical and Electronics Engineering from Igbinedion University, Okada, Nigeria. He is currently a masters Engineering student in the Department of Electrical Engineering, University of Nigeria, Nsukka. His Research area interest is in Power Systems Engineering and Renewable Energy.

Prince A. Okoro, holds a bachelor degree in Electrical Engineering from the Department of Electrical engineering, University of Nigeria, Nsukka. He is currently a masters Engineering student in the Department of Electrical Engineering, University of Nigeria, Nsukka. He is an EnergyNet Student, 2019. He is a cofounder of BEBEQUE LEMITED. His area of interest is in Power Systems Engineering and Green Power Generation through Renewable Energy.