

Economic Dispatch of Nigeria Power System Using Interior Point Method

M. A. Tijani^{a*}, G. A. Adepoju^b, M. A. Sanusi^a, I. A. Bamikefa^a and K. A. Hamzat^c

^aDepartment of Electrical and Electronic Engineering, Federal Polytechnic, Ede, Nigeria

^bDepartment of Electronic and Electrical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria

^cDepartment of Electrical and Electronics Engineering, Osun State College of Technology, Esa-Oke, Nigeria

Corresponding Author: muhammedtijani@gmail.com

ARTICLE INFO

Received: December, 2019

Accepted: March, 2020

Published: April, 2020

Keywords:

Economic Dispatch
Interior Point Method
Transmission Loss
Thermal Units.

ABSTRACT

Economic Dispatch is a veritable tool in power system because thermal plants largely depend on scarce fossil fuels to generate electricity. The Nigerian power system has grown tremendously since the deregulation regime started; hence the need to find an efficient optimization solution method for its Economic Dispatch problem. This work investigated the use of Interior Point Method (IPM) to solve the Economic Dispatch of the Nigerian power system. The results produced a total cost of 163.3070 Naira/hour and 200.6663 Naira/hour respectively for load demands of 2500 MW and 3500 MW on the Nigeria power system. It is observed that IPM was able to solve the problem efficiently and performed better when compared with Bat Algorithm.

1. INTRODUCTION

Economic Dispatch (ED) process allocates electricity demand of a power system among participating generators while all operational constraints are satisfied to minimize generation cost (Balbo, *et al*, 2012). ED becomes necessary in power systems due to scarcity of generation resources, increased cost of generation and continuously increasing demand for electrical energy (Navid *et al*, 2014). The ED problems are solved using optimization methods. Optimization methods are classified either as deterministic or nondeterministic (Tijani *et al*, 2019).

Example of deterministic optimization method are quadratic programming, linear programming and interior point method (IPM) while nondeterministic optimization methods include particle swarm optimization, ant colony optimization and genetic algorithm among others (Irving and Sterling, 1984). The deterministic optimization methods have the advantages of solving large-scale nonlinear problems with fast convergence, reliability and achieve feasibility (Lin *et al*, 2012). The nondeterministic methods, on the other hand, have the advantages of dealing with discrete power variables, robustness, simplicity and ease of implementation (Raju *et al.*, 2009).

The Nigerian power system has evolved greatly since the deregulation process started and the Power Holding Company of Nigeria was splitted into eighteen successor companies comprising of the Transmission Company of Nigeria (TCN), six generation companies (GenCos) and eleven Distribution Companies (DisCOs) (Olugbenga *et al.*, 2013). Since then, generation of electricity has witnessed

involvement of private companies and the number of generation increased tremendously to meet the ever increasing demands of the Nigerian electricity consumers.

Economic dispatch problem of the Nigerian power system have been carried out using different optimization methods ranging from deterministic to nondeterministic methods. These methods include genetic algorithm (Haruna *et al.*, 2004; Bakare *et al.*, 2005; Orike and Corne, 2013; Olakunle and Folly, 2015; Oluwadare *et al.*, 2016; Okozi *et al.*, 2019), particle swarm optimization (Ibe *et al.*, 2014; Attai, 2015; Amos, *et al.*, 2017; Haruna, *et al.*, 2017; Haruna *et al.*, 2018), differential evolution (Olakunle, *et al.*, 2014), lambda iteration method (Buraimoh *et al.*, 2017), ant colony optimization (Nwohu and Osaremwinda, 2017), firefly algorithm (Ajenikoko *et al.*, 2018) and simulated annealing (Abanihi and Ovabor, 2019).

It is clearly obvious from the literature surveys that about 93% of the published research works concentrated on using nondeterministic optimization methods to solve the ED problems of the Nigerian power system. These nondeterministic methods have the disadvantages of being trapped at local minimum and premature convergence and can produce unreliable results (Raju *et al.*, 2009). This work therefore employed IPM, a deterministic optimization method, which overcomes the shortcomings of the other methods to solve ED problems of the Nigerian power system.

2. METHODOLOGY

Economic Dispatch Problem

Economic operation and security constrained power system is a branch of power system analysis categorized into Unit Commitment (UC) and Economic Dispatch. UC is an offline problem and ED, on the other hand, is an online problem where all allocation of committed generators are done to satisfy customer load demands under a given operational condition (Osaremwinda, *et al.*, 2017). Transmission losses and high fuel costs are some of the factors that influence ED problems (Karakantantis and Vlachos, 2015). The ED problem finds the real power generation for each plant such that the objective function i.e. the total production cost is derived by the following equation (1) (Al-Farsi *et al.*, 2015):

$$\min F_{\text{cost}} = \sum_{i=1}^{N_g} F_i(P_i) \quad (1)$$

The operating cost of each generator when generating a specific output is modelled as in (2):

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \quad (2)$$

Equation (1) is then written as shown in equation (3):

$$F_i(P_i) = \sum_{i=1}^{N_g} (a_i + b_i P_i + c_i P_i^2) \quad (3)$$

Where;

a_i, b_i, c_i = cost coefficients of the i^{th} generating unit.

$F_i(P_i)$ = cost function of the i^{th} generating unit (in Naira/hour)

P_i = real power output of the i^{th} generating unit (in MW)

N_g = total number of generators in the system.

The generating constraints are:

- (i) System Equality Constraints
This is given by the following equation (4):

$$\sum_{i=1}^{N_g} P_i = P_D \quad (4)$$

Where;

P_D = system total power demand

- (ii) System Inequality Constraints
System inequality constraints are the limits put on the system components and operations. The most important one is the power generation limits given in equation (5):

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad i = 1, 2, \dots, N_g \quad (5)$$

Where;

P_i^{\min} = minimum power limit

P_i^{\max} = maximum power limit

Transmission Loss in Economic Dispatch Problem

It is most appropriate to consider the total system transmission loss in the economic allocation between different participating generation units. This consideration leads to economical way of generation dispatch in power systems (Chakrabarti and Hadler, 2010). The power balance equation is such that the sum of the power output from all generating units must be equal to the total load demand and total power losses in the system (Shalini and Lakshmi, 2014).

The power balance equation is the constraint equation given as in (6):

$$\sum_{i=1}^{N_g} P_i = P_D + P_{Loss} \quad (6)$$

P_{Loss} = system total power loss.

There are two common approaches in EDP to include losses: power flow based and B-coefficient based. Power flow based is time consuming and has convergence risk and therefore unsuitable for real-time applications (Huang *et al.*, 2018). The transmission loss is expressed as a function of generator power through Loss Coefficients or the B-Coefficients. This is based on the assumption that the transmission loss is quadratic in the injected bus real power under normal operating conditions (Rahul *et al.*, 2014; Kaur *et al.*, 2015). The transmission line loss equation is given as in (7):

$$P_{Loss} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_i B_{ij} P_j \quad (7)$$

A more general formula containing a linear term and a constant term referred to as Kron's Loss formula is given in equation (8):

$$P_{Loss} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_i B_{ij} P_j + \sum_{i=1}^{N_g} B_{oi} + B_{oo} \quad (8)$$

Where;

B_{ij} = the i^{th} element of loss coefficient square matrix

B_{0i} = the i^{th} element of the loss coefficient vector

B_{00} = the loss coefficient constant.

P_i = real power output of the i^{th} generating unit (in MW)

P_j = real power output of the j^{th} generating unit (in MW)

Interior Point Method

Interior Point Method (IPM) proposed by Kamarkar in 1984 (Kamarkar, 1984) have proven to be a robust and successful method of solving various large scale power system problems (Chiang and Grothey, 2014; Pan *et al.*, 2017). The IPM became an appealing approach to OPF because of the ease of handling constraints by logarithmic barrier functions, speed of convergence and non-requirement of a strictly feasible initial points (Lesaja, 2009). Figure 1 shows the flowchart diagram of IPM. Consider the simplest nonlinear programming optimization problem as shown in equations (9) to (29) as follows:

$$\min f(x) \quad (9)$$

$$\text{subject to } h_i(x) \geq 0 \quad i = 1, 2, \dots, m \quad (10)$$

Introducing slack variable to equation (10) to make all inequality constraints non-negativities

$$\min f(x) \quad (11)$$

$$\text{subject to } h(x) - \omega = 0 \quad (12)$$

$$\omega \geq 0 \quad (13)$$

Replacing non-negativity constraints with logarithmic barrier terms in the objective;

$$\min(x) - \mu \sum_{i=1}^m \log(\omega_i) \quad (14)$$

$$\text{subject to } h(x) - \omega = 0 \quad (15)$$

Incorporating the equality constraints into the objective function using Lagrange multipliers:

$$\min f(x) - \omega \sum_{i=1}^m \log(\omega_i) - y^T(h(x) - \omega) \quad (16)$$

Setting all derivatives to zero:

$$\nabla f(x) - \nabla h(x)^T y = 0 \quad (17)$$

$$-\mu W^{-1} e + y = 0 \quad (18)$$

$$h(x) - \omega = 0 \quad (19)$$

Rewriting equations (17) – (19) give;

$$\nabla f(x) - \nabla h(x)^T y = 0 \quad (20)$$

$$WYe = \mu e \quad (21)$$

$$h(x) - \omega = 0 \quad (22)$$

Applying Newton's method to compute search directions, $\Delta x, \Delta \omega, \Delta y$;

$$\begin{bmatrix} H(x, y) & 0 & -A(x)^T \\ 0 & Y & W \\ A(x) & -I & 0 \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta \omega \\ \Delta y \end{bmatrix} = \begin{bmatrix} \nabla f(x) - \nabla h(x)^T y \\ \mu e - WYe \\ -h(x) + \omega \end{bmatrix} \quad (23)$$

Where;

$$H(x, y) = \nabla^2 f(x) - \sum_{i=1}^m y_i \nabla^2 h_i(x) \quad (24)$$

and

$$A(x) = \nabla h(x) \quad (25)$$

Using equation (23) to solve for $\Delta \omega$ results in the reduced Karush-Kuhn-Tucker (KKT) system:

$$\begin{bmatrix} -H(x, y) & A^T(x) \\ A(x) & WY^{-1} \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} = \begin{bmatrix} \nabla f(x) - A^T(x)y \\ -h(x) + \mu Y^{-1}e \end{bmatrix} \quad (26)$$

Iteration gives:

$$x^{(k+1)} = x^{(k)} + \alpha^{(k)} \Delta x^{(k)} \quad (27)$$

$$\omega^{(k+1)} = \omega^{(k)} + \alpha^{(k)} \Delta \omega^{(k)} \quad (28)$$

$$y^{(k+1)} = y^{(k)} + \alpha^{(k)} \Delta y^{(k)} \quad (29)$$

Nigeria Power System

The usual and the most popular configuration of the system has four thermal station and three hydro-generating stations. Various configurations of the system have evolved due to the deregulation regime and have been used for analysis in literatures. This include, among others, the ten generator power system (Okoyi *et al.*, 2019) and the twenty-four generator power system (Abanihi and Ovabor, 2019). This work used the twenty-four generator system which is a standardized 2015 model of the Nigerian network. It consists of three hydro-generation stations and twenty-one thermal stations. Table 1 shows the limits and the cost coefficients of the generators of the power system considered in this work.

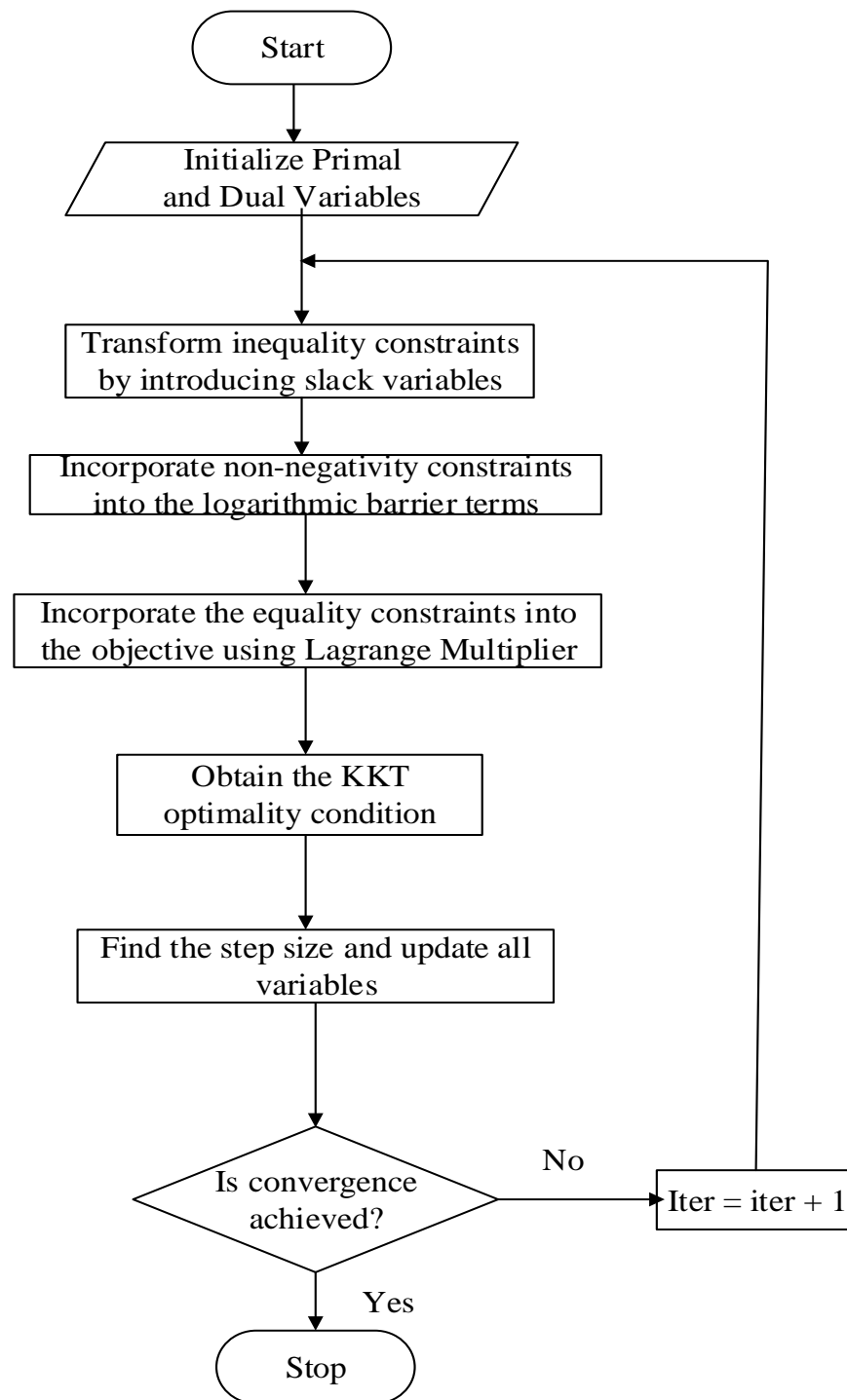


Fig. 1: Primal-Dual Interior Point Method Optimization

Table 1: Limits and Cost Coefficients of Nigerian 21 Thermal Generators (Abanihi and Ovabor, 2019)

S/No.	Name of Station	a	b	c	P _{min} (MW)	P _{max} (MW)
1	Egbin ST (Gas)	0.0000109	0.0284	3.92	118	1100
2	Sapele ST	0.0000591	0.0226	8.10	33	223
3	Delta II-III	0.0000757	0.0326	6.47	10	110
4	Delat IV	0.0000743	0.0334	9.85	22	434
5	Geregu	0.000201	0.0313	1.25	14	450
6	Omotosho	0.0000514	0.0312	4.70	29	480
7	Olorunsogo	0.0000294	0.0313	2.80	10	293
8	Afam IV-V	0.0000384	0.0289	2.03	24	453
9	Sapele GT NIPP	0.0000105	0.0227	5.60	30	373
10	Alaoji NIPP	0.0000200	0.0332	3.00	34	87
11	Geregu NIPP	0.0000223	0.0314	1.00	94	272
12	Olorunsogo NIPP	0.0000287	0.0313	1.70	31	422
13	Omotosho NIPP	0.0000179	0.0313	2.64	20	225
14	Ihovbe NIPP	0.0000200	0.0294	1.00	91	120
15	Okpai	0.0000126	0.0286	4.53	100	475
16	Afam VI	0.0000115	0.0286	8.00	45	656
17	AES	0.0000133	0.0286	4.30	51	242
18	Omoku	0.0000442	0.0314	1.30	3	65
19	Ibom	0.0000189	0.0312	4.60	10	101
20	Trans Amadi	0.0000315	0.0311	1.00	4	31
21	Rivers IPP	0.0000215	0.0318	6.00	20	160

3. RESULTS AND DISCUSSION

In this work, IPM algorithm was developed to solve the ED problem of the Nigerian 21 thermal generators of the power system. This program was implemented on MATLAB 2016 and run on an Intel Core i5 HP Laptop Computer with a RAM of 4GB and a speed of 1.90GHz. The program considered both equality and inequality constraints and the transmission loss of the system. The results of the power system optimization using IPM as developed in this work and the results of similar work using BAT algorithm from the work of Abanihi and Ovabor (2019) are shown in Table 2.

Table 2 shows the best possible share of each generating station in the different load demands of 2500 MW and 3500 MW respectively. The total power generated in each case equal the sum of the total power demanded plus power losses in the system. The total cost of generation when IPM is used with a total power demand of 2500 MW is 163.3070 Naira/hour with a loss of 14.68 MW. For a total demand of 3500 MW, the total cost using IPM is 200.6663 Naira/hour with a loss of 16.20 MW.

The total cost is 170.8845 Naira/hour with a loss of 11.74 MW and 210.8092 with a loss of 13.67 MW respectively for load demands of 2500 MW and 3500 MW respectively when BAT Algorithm was used. The result comparison from the table shows that IPM gives a lower cost and hence a better result as it minimizes the fuel cost of generation more than the other method.

Table 2: Results of IPM and BAT Optimization for Nigerian 21 Generator System

S/No.	Power Stations	Load on Power System (MW)			
		IPM		BAT Algorithm	
		2500	3500	2500	3500
1	Egbin ST (Gas)	369.03	501.26	496.53	605.55
2	Sapele ST	109.14	139.91	34.98	185.88
3	Delta II-III	18.84	44.12	10.00	98.91
4	Delat IV	22.43	39.12	22.00	84.17
5	Geregu	108.12	199.79	191.27	360.24
6	Omosho	40.01	76.69	320.84	181.14
7	Olorunsogo	72.27	134.12	10.06	232.20
8	Afam IV-V	38.82	61.82	24.00	156.30
9	Sapele GT NIPP	372.82	372.98	101.87	140.67
10	Alaoji NIPP	50.43	86.94	34.00	44.40
11	Geregu NIPP	97.34	171.25	94.00	136.93
12	Olorunsogo NIPP	66.93	135.21	31.02	418.43
13	Omosho NIPP	118.89	207.96	183.65	194.21
14	Ihovbe NIPP	119.65	119.97	92.14	93.23
15	Okpai	116.47	163.95	128.10	113.47
16	Afam VI	281.17	462.63	480.91	74.85
17	AES	241.44	241.96	193.03	171.65
18	Omoku	44.58	64.92	3.00	8.73
19	Ibom	100.55	100.96	24.61	53.38
20	Trans Amadi	30.70	30.97	4.00	8.65
21	Rivers IPP	100.17	159.68	20.00	137.12
Total Cost (Naira/hour)		163.3070	200.6663	170.8845	210.8092
Power Loss (MW)		14.68	16.20	11.74	13.67

4. CONCLUSION

This work has applied IPM to solve the ED problem of the Nigerian power system. The result of the work pointed to the fact that IPM was adequate and efficient in solving ED problems of larger Nigerian thermal plants. It can be vividly observed that IPM gives better results than the BAT algorithm that have earlier been used to solve the problem.

References

- Abanihi, V. K. and Ovabor, K. O. (2019). Economic Load Dispatch of Nigeria Integrated High Voltage Generation and Transmission Grid using Bat Algorithm, *Nigerian Journal of Technology*, 38(3): 680 – 687.
- Ajenikoko, G. A., Olabode, O. E. and Lawal, A. E. (2018). Application of Firefly Optimization Technique for Solving Convex Economic Load Dispatch of Generation in Nigerian 330kV, 24-Bus Grid System, *European Journal of Engineering Research and Science*, 3(5): 77 – 81.
- Al-Farsi, F. N., Albadi, M. H., Hosseinzadeh, N. and Badi, A. H. (2015). Economic Dispatch in Power Systems, *Proceedings of 8th IEEE GCC Conference and Exhibition*, Muscat, Oman, 1 – 4, February, 2015.

- Amos, C., Musa, S. Y. and Thuku, I. T. (2017). Particle Swarm Optimization Based Economic Load Dispatch of Nigeria Hydrothermal Considering Hydro Cost Functions, *International Journal of Engineering Science and Computing*, 7(8): 14689 – 14696.
- Attai, A. U. (2015). Power System Economic Load Dispatch using Particle Swarm Optimization, *International Journal of Advanced Engineering Research and Technology*, 3(6): 202 – 205.
- Bakare, G. A., Aliyu, U. O., Vanagamoorthy, G. K. and Shu'aibu, Y. K. (2005). Genetic Algorithm Based Economic Dispatch with Application to Coordination of Nigerian Thermal Power Plants, *IEEE Power Engineering Society Meeting*, 1: 551 – 556.
- Balbo, A. A., Souza, M. A., Baptista, E. C. and Nepomuceno, L. (2012). Predictor-Corrector Primal-Dual Interior Point Method for Solving Economic Dispatch Problems: A Postoptimization Analysis, *Mathematical Problems in Engineering*, Vol. 2012, 1 – 26.
- Buraimoh, E., Ejidokun, T. O. and Ayamolowo, O.J. (2017). Optimization of Expanded Nigerian Electricity Grid System using Economic Load Dispatch, *ABUAD Journal of Engineering Research and Development*, 1(1): 61 – 66.
- Chakrabarti, A. and Hadler, S. (2010). *Power system Analysis: Operation and Control*, 3rd Edition, PHI Learning Pvt. Ltd. New Delhi, India.
- Chiang, N. and Grothey, A. (2014). Solving Security Constrained Optimal Power Flow Problems by a Structure Exploiting Interior Point Method, *Optimization and Engineering*, 16(1): 1 – 8.
- Haruna, Y. S., Bakare, G. A. and Aliyu, U. O. (2004). Comparison of Economic Load Dispatch using Micro-Genetic Algorithm and other Optimization Techniques, *Nigerian Journal of Tropical Engineering*, 5(1 and 2): 52 – 57.
- Haruna, Y. S., Yisah, Y. A., Bakare, G. A., Haruna, M. S. and Oodo, S. O. (2017). Optimal Economic Load Dispatch of the Nigerian Thermal Power Stations using Particle Swarm Optimization, *The International Journal of Engineering and Science*, 6(1): 17 – 23.
- Haruna, Y. S., Idris, S., Bakare, G. A. and Abu, A. U. (2018). Comparative Analysis of the Economic Load Dispatch Problem of the Nigerian Thermal Power Stations, *Global Science Journals*, 6(4): 243 – 251.
- Huang, W., Yao, K., Wang, F., Zhu, C., Chang, Y., Lee, Y., and Ho, Y. (2018). Derivation and Application of a New Transmission Loss Formula for Power System Economic Dispatch, *Energies*, 11(417): 1 – 19.
- Ibe, A. O., Uchejim, E. E. and Esobinenwu, C. S. (2014). Optimal Load Dispatch in the South/South Zone of Nigeria Power System by Means of Particle Swarm, *International Journal of Scientific and Engineering Research*, 5(11): 128 – 139.
- Irving, M. R. and Sterling, M. J. H. (1985). Economic Dispatch of Active Power by Quadratic Programming Using a Sparse Linear Complementary Algorithm, *Electric Power and Energy System*, 7(1): 2 – 6.
- Kamarkar, N. (1984). A New Polynomial-Time Algorithm for Nonlinear Programming, *Combinatorica*, 4(4): 373 – 395.
- Karakonstantis, I. and Vlachos, A. (2015). Ant Colony Optimization for Continuous Domain Applied to Emission Generation and Economic Dispatch Problem, *Journal of Information and Optimization Science*, 36: 23 – 42.
- Kaur, N., Maninder, and Singh, I. (2015). Economic Dispatch Scheduling using Classical and Newton-Raphson Methods, *International Journal of Engineering and Management Research*, 5(3): 711 – 716.
- Lesaja, G. (2009). Introducing Interior Point Methods for Introductory Optimization Research Cases and/or Linear Programming Cases, *The Open Operational Research Journal*, 3(): 1 – 12.
- Lin, M., Tsai, J. and Yu, C. (2012). A Review of Deterministic Optimization Methods in Engineering and Management, *Mathematical Methods in Engineering*, 2012: 1 – 15.

- Navid, M. A., Khodakhast, I., Mojtaba, H. and Abdolmohammad, D. (2014). Solution of Economic Power Dispatch Problems by Ant Colony Optimization Approach, *International Journal of Mathematical and Computational Sciences*, 8(11): 1403 – 1407.
- Nwohu, M. N. and Osaremwinda, O. P. (2017). Evaluation of Economic Load Dispatch Problem in Power Generating Stations by the use of Ant Colony Search Algorithms, *International Journal of Research Studies in electrical and Electronics Engineering*, 3(1): 20 – 29.
- Okozi, S. O., Ogbonna, G. C., Olubiwe, M. and Ezugwu, E. O. (2019). Solution to the Economic Dispatch Problem of the Nigerian Power System using Genetic Algorithm, *Nigerian Journal of Technology*, 38(4): 1036 – 1047.
- Olakunle, A. O., Bakare, G. A. and Aliyu U. O. (2014). Short-Term Economic Dispatch of Nigerian Thermal Power Plants Based on Differential Evolution Approach, *International Journal of Scientific and Engineering Research*, 5(3): 1 – 6.
- Olakunle, A. O. and Folly, K. A. (2015). Economic Load Dispatch of Power System using Genetic Algorithms with Valve-Point Effect, *Advances in Swarm and Computational Intelligence Lecture Notes in Computer Science*, 9140: 276 – 284.
- Olugbenga, T. K., Jumah, A. A. and Philips, D. A. (2013). The Current and Future Challenges of Electricity Market in Nigeria in the Face of Deregulation Process, *African Journal of Engineering*, 1(2): 1 – 7.
- Oluwadare, S. A., Iwasokan, G. B., Olabode, O., Olusi, O. and Akinmorin, A. E. (2016). Genetic Algorithm-Based Cost Optimization Model for Power Economic Dispatch, *British Journal of Applied Science and Technology*, 15(6): 1 – 10.
- Orike, S. and Corne, D. W. (2013). Constrained Elitist Genetic Algorithm for Economic Load Dispatch: Case Study on Nigerian Power System, *International Journal of Computer Applications*, 76(15): 27 – 33.
- Osaremwinda, O. P., Nwohu, M. N. and Kolo, J. G. (2017). A Comparative Study of Meta-Heuristics Algorithm in Evaluation of Economic Load Dispatch Problems in Power Generating Stations with MATLAB Codes, *Journal of Electrical and Electronic Systems*, 6(4): 1 – 6.
- Pan, S., Jian, J. and Yang, L. (2017). A Hybrid MILP and IPM for Dynamic Economic Dispatch with Valve Point Effect, *International Journal of Electrical Power and Energy System*, 2018(97): 290-298
- Rahul, D., Nikita, G. and Harsha, S. (2014). Economic Load Dispatch Problem and MatLab Programming of Different Methods, *International Conference of Advanced Research and Innovation (ICARI – 2014)*, Pp. 202 – 207.
- Raju, P., Vaisakh, K. and Raju, S. (2009), An IPM-EPSo Based Hybrid Method for Security Enhancement using SSSC, *International Journal of Recent Trends in Engineering*, 2(5): 208 – 212.
- Shalini, S. P. and Lakshmi, K. (2014). Solving Environmental Economic Dispatch Problem with Lagrangian Relaxation Method, *International Journal of Electronic and Electrical Engineering*, 7(1): 9 – 20.
- Tijani, M. A., Adepoju, G. A., Hamzat, K. A. and Sanusi, M. A. (2019). A Review of Optimization Approach to Power Flow Tracing in a Deregulated Power System, *Arid Zone Journal of Engineering, Technology and Environment*, 15(2): 435- 448.