



Complementarity Problem Approach to Economic Power Dispatch of Nigeria Power System

¹V. K. Abanihi, ²P. I. Ezomo ³D. Aliu, ⁴P. U. Chinedu, ⁵J. A. Obari, ⁶M. O. Momoh

^{1,3,4,6} Department of Electrical/Computer Engineering,
Edo University, Iyamho, Edo State, Nigeria

² Department of Electrical/Computer Engineering,
Igbinedion University Okada, Edo State, Nigeria

⁵ Department of Computer Engineering,
Ahmadu Bello University, Zaria

ABSTRACT

In this paper, a complementarity problem approach is used to solve the Economic Power Dispatch Problem of Nigeria Power System. Many approaches have been presented for solving Economic Power Discharge Problem; these approaches range from classical methods to more intelligent-based approaches. However, despite significant results of these methods, certain limitations reduce their performances and their suitability for online computation problems. In general, the optimization problem is formulated as Linear Complementarity Problem (LCP) when it is assumed that there is no transmission loss, and Nonlinear Complementarity Problem (NCP) if the transmission losses are included in the power balance equation. In this work, evolutionary programming, fast genetic algorithm, pattern search and hybrid self-adaptive differential evolution methods were also used to solve this problem. The simulation results indicate that the complementarity approach yields a cost value of ₦233.023 as compared to ₦233.624 and ₦233.956 given by evolutionary programming and fast genetic algorithm respectively for the Nigerian power system. The presented approach is more compact and offers superior speed of computation as compared to the evolutionary programming and fast genetic algorithm respectively.

ARTICLE INFO

Article History

Received: February, 2020

Received in revised form: March., 2020

Accepted: April, 2020

Published online: June, 2020

KEYWORDS

Economic Power Dispatch, Linear Complementarity, Nigeria Power system, Karush-Kuhn-Tucker, Evolutionary Programming

INTRODUCTION

Economic Dispatch Problem (EDP) is an important issue in power system operation. The goal of the EDP is to minimize an objective function that reduces the power generation cost while satisfying various physical and operational constraints. The outcome of this approach is expected to improve output scheduling of online units. Under any load condition, EDP determines the power output of each plant (and each generation unit within the plant) which minimizes the overall generation cost (Wood and Wollenberg, 1996). In the traditional EDP, the fuel cost function of a generator is approximately

represented by a quadratic function. Many efforts have been made to solve this problem (Ciornei and Kyriakides, 2013). Several optimization techniques, such as gradient method, lambda iteration and Newton's method have been used. In each of these methods, the result is affected by the incremental cost curves, which are piecewise linear and monotonically increasing, to find the global minimum. Furthermore, (Sharma and Mahor, 2013; Ndunagu *et al.*, 2019a) proved that although conventional linear programming methods are simple and have high search speed, they have certain drawbacks and limitations. Some of these



limitations are inherent in their performance and their holistic dependence on starting points.

During the last two decades, the EDP has been solved using several alternative methods such as Artificial Neural Networks (Abanihi and Ovabor, 2019), Evolutionary Programming (EP) (Surkha and Sumathi, 2011; Yuryerich and Wong, 1999; Somasundaram and Kuppusamy, 2006), genetic algorithms (GA) (Ndunagu *et al.*, 2019b), Fast Genetic Algorithm (FGA) (Kumri and Sydulu, 2009), Particle Swarm Optimization (PSO) (Gang, 2003). As every algorithm is subject to free-lunch theory, there is need to explore the use of more algorithms or approaches on the EDP of the Nigerian Power System.

In this paper, a Complementarity Problem approach is presented to solve the economic Dispatch Problem (EDP) with quadratic cost function which is defined on the Nigeria Power System. The problem formulation is based on the minimization of the generation cost subject to demand and transmission losses constraints and constraints introduced by upper and lower bounds on generated power of each unit. Two cases are considered: (i) without transmission losses and ii) subject to transmission losses. In case (i), the

$$\begin{aligned} \min F_1 &= \sum_{i=1}^n F_i(P_i) \\ &= \sum_{i=1}^n a_i P_i^2 + b_i P_i + c_i \end{aligned} \quad (1)$$

Subject to:

$$\sum_{i=1}^n P_i = P_D \quad (2)$$

$$P_{i,\min} \leq P_i \leq P_{i,\max} \quad \text{for } i = 1, 2, \dots, n \quad (3)$$

where:

i unit number

n number of units

F_i fuel cost function of the unit i

P_i power from i th generator

P_D demand load

$P_{i,\max}$ upper limit of the i^{th} generator

$P_{i,\min}$ lower limit of the i^{th} generator

Equation (3) can be written in the following form (Laan and Talman, 1989):

problem formulation results finally in a Linear Complementarity Problem (LCP). In case (ii), the problem becomes nonlinear and it is formulated in a compact form as a Nonlinear Complementarity Problem (NCP).

The economic dispatch problem is a mathematical optimization problem. The goal of the solution is to achieve the optimal power dispatches from various power generating units for a determined time period to minimize the total generation cost while satisfying the specified constraint. The most commonly minimized function is the total cost of real power generation. The individual costs are assumed to be functions of active power generation and represented by quadratic equations. The constraints are the power balance equation and the upper and lower limits on the generated power by each unit.

A. Economic Dispatch without Transmission Losses

In this case the problem is to minimize the objective function subject to constraints of the demand load and minimum and maximum limits on the power output of the units. The mathematical optimization problem is as follows:



$$P_i^1 = P_i - P_{i,\min} \geq 0, \quad P_i^{11} = P_{i,\max} - P_i \geq 0 \quad (4)$$

Adding these equations we obtain:

$$P_i^1 + P_i^{11} = P_{i,\max} - P_{i,\min} \quad (5)$$

And since $P_i^{11} \geq 0$ this equation can be written in term of P_i^1

$$P_i^1 \leq P_{i,\max} - P_{i,\min} \quad (6)$$

The first equation in (4) can be written in terms of the new variable P_i^1 to obtain the power from the i^{th} generator:

$$P_i = P_i^1 + P_{i,\min} \quad (7)$$

Substituting (7) in (1) and (2) the optimization problem can be expressed in terms of P_i^1 as follows:

$$\text{minimize } F_i = \sum_{i=1}^n F_i(P_i^1 + P_{i,\min}) \quad (8)$$

Subject to the following constrains:

$$\sum_{i=1}^n P_i^1 = P_D - \sum_{i=1}^n P_{i,\min} \quad (9)$$

$$P_i^1 \geq 0 \quad (10)$$

Constraint (9) can be written in the form of two inequality constants:

$$\sum_{i=1}^n P_i^1 \leq P_D - \sum_{i=1}^n P_{i,\min} \quad - \sum_{i=1}^n P_i^1 \leq -P_D + \sum_{i=1}^n P_{i,\min} \quad (11)$$

The Problem described by the (8), (10), and (11) is an optimization problem, which contains both equality and inequality constrains, needs the deployment of the Karush-Kuhn-Tucker (KKT) optimality conditions (Han *et al.*, 2011). Therefore these equations are rewritten in matrix form as follows:

$$\min F_i = (P^1)^i DP^i + g^i P^i + k^i \quad (12)$$

Subject to:

$$eP^1 \leq P_D - eP_{\min} \quad -eP^1 \leq -P_D + eP_{\min} \quad IP^1 \leq P_{\max} - P_{\min}, \quad P^1 \geq 0 \quad (13)$$

$$\text{Here } D = \begin{bmatrix} a_1 & 0 & \cdots & 0 \\ 0 & a_2 & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & a_n \end{bmatrix}, \quad g = \begin{bmatrix} b_1 + 2a_1P_{1,\min} \\ b_2 + 2a_2P_{2,\min} \\ \vdots \\ b_n + 2a_nP_{n,\min} \end{bmatrix}$$

$$\text{And } k = \begin{bmatrix} c_1 + b_1P_{1,\min} + a_1P_{1,\min}^2 \\ c_2 + b_2P_{2,\min} + a_2P_{2,\min}^2 \\ \vdots \\ c_n + b_nP_{n,\min} + a_nP_{n,\min}^2 \end{bmatrix}$$

e is $1 \times n$ vector of ones, I is $n \times n$ identity matrix,

$$P^1 = [P_1^1, P_2^1 \dots P_n^1]^T, P_{\min} = [P_{1,\min}, P_{2,\min}, \dots, P_{n,\min}]^T$$

$$\text{And } P_{\max} = [P_{1,\max}, P_{2,\max}, \dots, P_{n,\max}]^T \quad (13)$$

The Karush-Kuhn-Tucker (KKT) Lagrange for the dispatch problem given by (12) and (13) is (Fletcher, 2000):

$$L = (P^1)^t DP^1 + g^t P^1 + k^t + \lambda^t (eP^1 - P_D + eP_{\min}) + \mu^t (-eP^1 + P_D - eP_{\min}) + u^t (IP^1 - P_{\max} + P_{\min}) + y^t (-P^1) \quad (14)$$

Where λ , μ , u , and y are the Lagrange multipliers associated with the constraints. The Karush-Kuhn-Tucker (KKT) necessary optimality conditions for the above problem are:

$$\frac{\partial L}{\partial P^1} = 2DP^1 + g + e^t \lambda - e^t \mu + Iu - y = 0, \frac{\partial L}{\partial \lambda} = eP^1 - P_D + eP_{\min} \leq 0, \frac{\partial L}{\partial \mu} = -eP^1 + P_D - eP_{\min} \leq 0, \quad (15)$$

Introducing the nonnegative slack variables v^+ , v^- , and η the previous KKT conditions can be written as:

$$y - 2DP^1 - e^t \lambda + e^t \mu - Iu = g, v^+ + eP^1 = P_D - eP_{\min}, v^- - eP^1 = -P_D + eP_{\min}, \eta + IP^1 = P_{\max} - P_{\min} \quad (16)$$

Comparing (16) with (5) we conclude that $\eta = P^{11} = [P_1^{11}, P_2^{11}, \dots, P_n^{11}]$. Substituting in the above equation we obtain:

$$y - 2DP^1 - e^t \lambda + e^t \mu - Iu = g, v^+ + eP^1 = P_D - eP_{\min}, v^- - eP^1 = -P_D + eP_{\min}, P^{11} + IP^1 = P_{\max} - P_{\min} \quad (17)$$

where, the nonnegative variables fulfil the following complementarity conditions:

$$y \geq 0, P^1 \geq 0, y^t P^1 = 0, v^+ \geq 0, \lambda \geq 0, v^{+t} \lambda = 0, v^- \geq 0, \mu \geq 0, v^- \mu = 0, u \geq 0, P^{11} \geq 0, u^t P^{11} = 0, \quad (18)$$

The system of (17) and (18) is a standard Linear Complementarity Problem (LCP) which can be written in the following form:

$$w - Mz = q, w \geq 0, z \geq 0, w^t z = 0,$$

where

$$M = \begin{bmatrix} 2D & e^t & -e^t & I \\ -e & 0 & 0 & 0 \\ e & 0 & 0 & 0 \\ -I & 0 & 0 & 0 \end{bmatrix}, q = \begin{bmatrix} g \\ P_D - eP_{\min} \\ -P_D + eP_{\min} \\ P_{\max} - P_{\min} \end{bmatrix}, w = [y v^+ v^- P^{11}]^t \text{ and } z = [P^1 \lambda \mu u]^t \quad (19)$$

Economic Dispatch with Transmission Lines Losses

The EDP is considered here with the presence of transmission losses. Equation (2) is modified to account for such losses as follows:

$$\sum_{i=1}^n P_i = P_D + P_L \quad (20)$$

Where P_L is the total transmission loss and is given by the following equation [1]:

$$P_L = \sum_{i=1}^n \sum_{j=1}^n P_i B_{ij} P_j + \sum_{i=1}^n B_{0i} P_i + B_{00} \quad (21)$$

Using (7) and (21) in (20) the power balance constraint reduces to:

$$eP^1 - \left\{ (P^1)^t B + 2P_{\min}^t B + B_0 \right\} P^1 - P_D - eP_{\min} + P_{\min}^t B P_{\min} + B_0 P_{\min} + B_{00} \quad (22)$$

where B, B₀, and B₀₀ represent the B-coefficients of transmission loss formula.

Equation (22) can be written in a more compact form as follows:

$$\left\{ e - (P^1)^t B - V \right\} P^1 = 0$$

Here e is 1 x n is vector of ones, and V = 2N + B₀ where $N = P_{\min}^t B$ and

$$Q = P_D - eP_{\min} + \left\{ N + B_0 \right\} P_{\min} + B_{00} \quad (23)$$

Equality constraint given by (23) can be replaced by two inequality constraints

$$\left\{ e - (P^1)^t B - V \right\} P^1 \leq Q - \left\{ e - (P^1)^t B - V \right\} P^1 \leq -Q \quad (24)$$

The Karush-Kuhn-Tucker (KKT) Lagrangian for the dispatch problem defined by the (5), (10), (12), and (24) is:

$$L = (P^1)^t DP^1 + g^t P^1 + k^t + \lambda^t \left[\left\{ e - (P^1)^t B - V \right\} P^1 - Q \right] - \mu^t \left[\left\{ e - (P^1)^t B - V \right\} P^1 - Q \right] + u^t (IP^1 - P_{\max} + P_{\min}) + y^t (-P^1) \quad (25)$$

where λ, μ, u, and y are the Lagrange multipliers associated with the constraints. The KKT necessary optimality conditions for the above problem are:

$$\frac{\partial L}{\partial P^1} = 2DP^1 + g + \left\{ e - 2(P^1)^t B - V \right\}^t \lambda - \left\{ e - 2(P^1)^t B - V \right\}^t \mu + u - y = 0,$$

$$\frac{\partial L}{\partial \lambda} = \left\{ e - (P^1)^t B - V \right\} P^1 - Q \leq 0, \quad \frac{\partial L}{\partial \mu} = -\left\{ e - (P^1)^t B - V \right\} P^1 + Q \leq 0,$$

$$\frac{\partial L}{\partial u} = IP^1 - P_{\max} + P_{\min} \leq 0 \quad (26)$$

Introducing the nonnegative slack variables v⁺, v⁻, and η these KKT conditions can be written as:

$$\begin{aligned} y - 2DP^1 - \left\{ e - 2(P^1)^t B - V \right\}^t \lambda + \left\{ e - 2(P^1)^t B - V \right\}^t \mu - u &= g \\ v^+ + \left\{ e - 2(P^1)^t B - V \right\} P^1 &= Q \\ v^- - \left\{ e - 2(P^1)^t B - V \right\} P^1 &= -Q \quad \eta + IP^1 - P_{\max} + P_{\min} \end{aligned} \quad (27)$$

Substituting η with P¹¹ we obtain:

$$\begin{aligned} y - 2DP^1 - \left\{ e - 2(P^1)^t B - V \right\}^t \lambda + \left\{ e - 2(P^1)^t B - V \right\}^t \mu - u &= g, \\ v^+ + \left\{ e - 2(P^1)^t B - V \right\} P^1 &= Q \\ v^- - \left\{ e - 2(P^1)^t B - V \right\} P^1 &= -Q, \quad P^{11} + IP^1 = P_{\max} + P_{\min} \end{aligned} \quad (28)$$

The nonnegative variables fulfil the following complementarity conditions:

$$y \geq 0, \quad P^1 \geq 0, \quad y^t P^1 = 0, \quad v^+ \geq 0, \quad \lambda \geq 0, \quad (v^+)^t \lambda = 0, \quad P^{11} \geq 0, \quad u \geq 0, \quad (P^{11})^t u = 0, \quad (29)$$

The system of (28) and orthogonality conditions (29) form a standard Nonlinear Complementarity Problem (NCP) which can be written as follows:

$$z \geq 0, \quad M(z) \geq 0, \quad z^t M(z) = 0, \quad \text{where } z = \left[P^1 \lambda \mu u \right]^t \quad (30)$$



NUMERICAL EXAMPLES

In this section, a six unit system with their cost function and power limits numerical examples are given to illustrate the developed method. The formulated LCP can be solved using iterative methods, Newton methods, and pivoting methods (Murty, 1983), here the LCP problem is solved using the MATLAB code `pathlcp.m` (written and maintained jointly by Michael C. Ferris and Madison and Todd Munson) (Ferris and Munson, 2000). On the other hand the formulated Nonlinear Complementarity Problem NCP can be solved using different algorithms

$$F_1(P_1) = 0.00156P_1^2 + 7.92P_1 + 561$$

$$F_2(P_2) = 0.00194P_2^2 + 7.85P_2 + 310$$

$$F_3(P_3) = 0.00482P_3^2 + 7.97P_3 + 78$$

$$F_4(P_4) = 0.00139P_4^2 + 7.06P_4 + 500$$

$$F_5(P_5) = 0.00184P_5^2 + 7.46P_5 + 295$$

$$F_6(P_6) = 0.00184P_6^2 + 7.46P_6 + 295$$

Table I shows the results of the proposed method compared with fuzzy logic controlled genetic algorithm (FCGA) (Song *et al.*, 1997) and genetic algorithm based on arithmetic crossover (GAAC) (Yalcoz *et al.*, 2001) when the load demand was 1800 MW. It's clearly evident from this table that the solution of the LCP

addressed in the literature, in this work the MATLAB LMMCP.M developed and written by Kanzow and Petra is used (Kanzow and Petra, 2004). Kanzow and Petra reformulated the NCP to nonlinear Least Square method and then they apply a Levenberg-Marquardt-type method to find the solution.

Examples without Transmission Lines Losses

First test system

The first system has six thermal units with the following cost functions and their associated constraints for each unit:

$$100 \leq P_1 \leq 600$$

$$100 \leq P_2 \leq 400$$

$$50 \leq P_3 \leq 200$$

$$140 \leq P_4 \leq 590$$

$$110 \leq P_5 \leq 400$$

$$110 \leq P_6 \leq 400$$

results in terms of operation costs is exactly the same as that obtained by the GAAC method, while the FCGA method produces higher operational costs. In general, strong correlation is evident between results obtained from all these methods.

Table I: Results of FCGA, GAAC, and LCP for 6-Units System

Method	Load	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	F_1 (\$/h)
FCGA	1800	250.49	215.43	109.92	572.84	325.66	325.66	16585.85
GAAC	1800	248.14	217.74	75.20	587.8	325.56	325.56	16579.33
LCP	1800	247.99	217.71	75.181	588.03	325.53	325.53	16579.33

Second Test System

The second test system is the Nigeria power system, the 2015 version of the grid which essentially a 52-bus, 330-kV network interconnecting twenty-one thermal generating stations and three

hydro stations to various load points. The quadratic cost functions for the various thermal units have been developed as the best curve fits using least square method to their actual operating cost data over a period of five years (2011 – 2015). Table II



presents the cost coefficients so obtained for the twenty-one thermal units and their minimum and maximum loading limits. The network and its parameters suppressed herein can be found in (Abanihi, 2016). The power loss is computed from (20) with loss coefficients obtained via parameter estimation based

on several power flow scenarios (Abanihi, 2016) for its largely radial network structure. The power system is solved for different values of demand load ranging between 2500 MW and 4000 MW. The individual generated power, minimum fuel cost, the total generated power, and the CPU time are shown in Table III.

Table II: Nigeria Generation Unit's Data

S/N	Power Stations	P_{min} (MW)	P_{max} (MW)	Cost Coefficients		
				a(\$/MW ² h)	b(\$/MWh)	c(\$/h)
1	Egbin ST(gas)	118	1100	0.0000109	0.0284	3.92
2	Sapele ST	33	223	0.0000591	0.0226	8.10
3	Delta II-III	10	110	0.0000757	0.0326	6.47
4	Delta IV	22	434	0.0000743	0.0334	9.85
5	Geregu	14	450	0.0000201	0.0313	1.25
6	Omotosho	29	480	0.0000514	0.0312	4.70
7	Olorunsogo	10	293	0.0000294	0.0313	2.80
8	Afarm IV-V	24	453	0.0000834	0.0289	2.03
9	Sapele GT (NIPP)	30	373	0.0000105	0.0227	5.60
10	Alaoji (NIPP)	34	87	0.0000200	0.0332	3.00
11	Geregu (NIPP)	94	272	0.0000223	0.0314	1.00
12	Olorunsogo (NIPP)	31	422	0.0000287	0.0313	1.70
13	Omotosho (NIPP)	20	225	0.0000179	0.0313	2.64
14	Ihovbe (NIPP)	91	120	0.0000200	0.0294	1.00
15	Okapi	100	475	0.0000326	0.0286	4.53
16	Afam VI	45	656	0.0000115	0.0286	8.00
17	AES	51	242	0.0000133	0.0286	4.30
18	Omoku	3	65	0.0000442	0.0314	1.30
19	Ibom	10	101	0.0000189	0.0312	4.60
20	Trans Amadi	4	31	0.0000315	0.0311	1.00
21	Rivers IPP	20	160	0.0000215	0.0318	6.00

Table III: Results Using LCP for Nigeria Power System

S/N	Power Stations	Loads on Power Stations			
		2500MW	3000MW	3500MW	4000MW
1	Egbin ST(gas)	496.5275	122.8602	605.3239	288.83
2	Sapele ST	34.9763	133.5573	185.8841	196.448
3	Delta II-III	10.001	19.9982	98.9096	88.8314
4	Delta IV	22.0039	61.0326	84.1693	107.2724
5	Geregu	191.2735	189.9218	360.2352	442.2986
6	Omotosho				
7	Olorunsogo	320.8359	68..6196	181.1366	179.6815
8	Afarm IV-V	10.0625	29.9109	232.2028	278.7401
9	Sapele GT (NIPP)	24	324.9404	156.3046	296.502
10	Alaoji (NIPP)	101.8654	190.6673	140.6664	116.6221



S/N	Power Stations	Loads on Power Stations			
		2500MW	3000MW	3500MW	4000MW
11	Geregu (NIPP)	94.0002	221.9574	136.9487	198.4023
12	Olorunsogo (NIPP)	31.0156	233.4077	418.4326	365.4274
13	Omotosho (NIPP)	183.6467	119.7283	194.2104	141.7964
14	Ihovbe (NIPP)	92.1441	103.9853	93.2798	112.531
15	Okapi	128.1011	272.8071	113.4729	233.0529
16	Afam VI	480.9069	497.5713	74.8461	585.8328
17	AES	193.03	192.9541	171.6475	119.293
18	Omoku	3	49.1825	8.7339	23.1311
19	Ibom	24.605	58.368	53.3774	63.081
20	Trans Amadi	4	9.1717	8.6454	28.773
21	Rivers IPP	20.0003	51.7764	137.1203	85.2807
Total Cost (\$/h)		170.8845	192.1326	210.8092	234.0267
Total Power (MW)		2500	3000	3500	4000
CPU time (s)		18.92	20.56	19.53	21.34

Examples with Transmission Losses

Here, the Nigeria power system considering losses is used as a third test case. The solution of the obtained NCP produces the amount of the generated power of each unit that results in the minimum generation cost. As mentioned previously the MATLAB program (LMMCP.M) written by Kanzow and Petra (Kanzow and Petra, 2004) is used to solve the problem. The obtained results for different load demand are shown in Table IV.

The results of the proposed formulation of the Nigeria power system

are compared with other methods such as Evolutionary Programming IDE (Surkha and Sumathi, 2011) and EP-OPF (Yuryerich and Wong, 1999), fast genetic algorithm approach (FGA) (Kumri and Sydulu, 2009), Pattern Search (PS) and a combination of Genetic Algorithm and Pattern Search (GA-PS) (Labbi and Attous, 2010), and Hybrid Self-adaptive Differential Evolution Methods SADE-ALM (Thitithasrongchai and Eua-arpon, 2007). The load demand was 4000 MW and the obtained results are shown in Table V.

Table IV: Results Using NCP for Nigeria Power System Considering Losses

S/N	Power Stations	Loads on Power Stations			
		2500MW	3000MW	3500MW	4000MW
1	Egbin ST(gas)	205.9341	308.5983	352.4037	512.4149
2	Sapele ST	124.1365	45.3026	40.4529	198.8422
3	Delta II-III	69.7759	40.1432	103.8878	59.9598
4	Delta IV	40.302	173.8483	307.3493	133.892
5	Geregu	333.5606	416.8211	28.3088	369.9527
6	Omotosho	191.7182	148.1312	76.353	466.7263
7	Olorunsogo	16.5794	34.4268	272.045	42.9636
8	Afarm IV-V	97.5681	153.2491	240.1686	128.8502
9	Sapele GT (NIPP)	33.7228	90.9435	346.7002	172.1573
10	Alaoji (NIPP)	64.1003	54.2467	84.2063	85.0616
11	Geregu (NIPP)	258.3033	193.955	169.4776	152.7668
12	Olorunsogo (NIPP)	304.197	384.362	264.9911	365.7073
13	Omotosho (NIPP)	112.1517	107.0225	171.7743	22.2689



S/N	Power Stations	Loads on Power Stations			
		2500MW	3000MW	3500MW	4000MW
14	Ihovbe (NIPP)	110.3343	108.4835	91.7641	115.1168
15	Okapi	106.0276	161.626	122.4395	204.706
16	Afam VI	82.9434	251.2419	419.4505	513.4202
17	AES	103.1335	57.9065	240.9073	204.4638
18	Omoku	49.1567	12.2706	11.4436	38.894
19	Ibom	30.4134	78.3965	64.326	60.3256
20	Trans Amadi	15.7154	20.057	16.91	18.2197
21	Rivers IPP	149.9973	158.9679	74.6404	133.2903
Total Cost (\$/h)		171.9445	192.4928	211.9579	234.637
Total Power Loss (MW)		24.18	26.78	38.23	56.34
CPU time (s)		22.5	24.63	23.6	25.62

Table V: Results of IDE, EP-OPF, FGA, PS, GA-PS, SADE-ALM AND NCP for 6-Unit System

Method	F_T (\$/h)	P_L (\$/h)	CPU Time
IDE	233.023	53.91	24.38
EP-OPF	233.624	54.28	24.71
FGA	233.956	54.97	24.93
PS	234.026	55.21	25.01
GA-PS	234.345	55.91	25.27
SADE-ALM	234.601	56.01	25.42
NCP	234.637	56.34	25.62

CONCLUSION

In this paper a new approach for the formulation of the economic power dispatch problem is presented. The problem without transmission losses taken into account in the power balance equation is formulated as Linear Complementarity Problem (LCP). Taking into account transmission losses the problem gets hard nonlinear, and formulated to present an efficient solution. Recently many efficient algorithms and software have been devised and developed. Real time example like the Nigeria power system shows that, in comparison with other methods, the presented approach provides an efficient, time saving, highly accurate, and cost effective technique with evident strong correlation with other well-known established techniques.

REFERENCES

Abanihi, V. K. (2016) Economic Load Dispatch of Nigeria Integrated High Voltage Generation and

- Transmission Grid, Ph.D Thesis, University of Benin, Benin, Nigeria.
 Abanihi, V. K. & Ovabor, O. K. (2019) Economic Load Dispatch of Nigeria Integrated High Voltage Generation and Transmission Grid using Bat Algorithm. *Nigerian Journal of Technology* 38(3).
 Ciornei, I. and Kyriakides, E. (2013) "Recent methodologies and approaches for the economic dispatch of generation in power systems," *International Transactions on Electrical Power*, vol. 23, vol, 7, pp. 1002-1027.
 Ferris, M. C. and Munson, T. S. (2000). Complementarity problems in GAMS and the PATH solver. *Journal of Economic Dynamics & Control*, (24) 165-188 [Online]. Available <ftp://ftp.cswise.edu/math-prog/solvers/path/matlab>.
 Fletcher, R. (2000) *Practical Methods of Optimization*, John Wiley.
 Gang, Z. I. (2003) "Particle swarm optimization to solving the



- economic dispatch considering the generator constraints," IEE. Trans. On Power Systems, vol. 18, pp 1187-1195.
- Han, Y., Young, P and Zimmerle, D. (2011) "Optimization units dispatch for fuel consumption minimization," presented at the 50th IEEE Conference on Decision and Control and European Control Conference, Orlando, FL, USA, December 12-15.
- Kanzow, C. and Petra, S. (2004) "On a semismooth least square formulation of complementarity problems with gap reductions" Optimization Methods and Software, vol. 19, no 5, pp. 507-525.
- Kumri, M. S. and Sydulu, M. (2009) "A fast computational genetic algorithm for economic load dispatch," Int. Journal of Recent Trends in Engineering, vol. 1 no. 1, pp 349-356.
- Laan, G. V. C. and Talman, A. J. J. (1989) "An algorithm for the linear complementarity problem with upper and lower bounds," Journal of Optimization Theory, vol. 62, no. 1, pp. 151-163.
- Labbi, Y. and Attous, D. B. (2010) "A hybrid GA-PS method to solve the economic load dispatch problem," J. of Theoretical and Applied Information Technology, vol. 15, no. 1, pp.61-68.
- Murty, K. G. (1988) Linear Complementarity Linear and Nonlinear Programming, Berlin Heldrmann Verlag.
- Ndunagu J., Abanihi, V. K., Ikheloa, S. and Elaigwu, V. O. (2019a) Economic Load Dispatch of Nigerian Power Network Using a Hybrid of Evolutionary Programming and efficient Particle Swarm Optimization. FUW Trends in Science and Technology Journal 4(3). 697-702.
- Ndunagu, J. N., Abanihi, V. K. & Ovabor, K. O. (2019b) Genetic Algorithm Based Economic Load Dispatch of Nigeria Power Network with Valve Point Loading Effect. *Journal of Engineering Science and Applications* Vol. 12 17 – 28.
- Sharma, J. and Mahor, A. (2013) "Particle swarm optimization approach for economic load dispatch: A review," International Journal of Engineering Research and Applications, vol 3, no 1. Pp. 13-22.
- Somasundaram, P. and Kuppusamy, K. (2006) "Fast computation evolutionary programming algorithm for the economic dispatch problem," European Transactions on Electrical Power, vol. 16. No 1, pp 35-47.
- Song, Y. H., Wang, G. S., Wang, P. Y. and Johns, A. T. (1997) "Environmental/Economic dispatch using fuzzy logic controlled genetic algorithm," IEE Proc. Gener. Tansm. Distrib., vol. 144, pp. 377-382.
- Surkha, P. and Sumathi, S. (2011) "An improved differential evolution algorithm for optimal load dispatch in power systems including transmission losses," IUJEEE, vol. 11, no 2, pp 1379-1390.
- Thitithasmrongchai, B. and Eua-arpon, B. (2007) "self-adaptive differential based optimal power flow for units with non-smooth fuel cost functions." J. of Electrical Systems, vol. 3, no 2. Pp 88 -99.
- Wood, A. J and Wollenberg, B. F. (1996) Power Generation Operation and Control, 2nd ed, New York: Willy.
- Yalcoz, T., Altun, H. and Uzam, M. (2001) "Economic dispatch solution using a genetic algorithm based on arithmetic crossover," in Proc. IEEE Porto Power Tech. Conf., Porto, Portugal.
- Yuryerich, J. and Wong, K. P. (1999) "Evolutionary programming based optimal power flow algorithm," IEEE Trans. On Power Systems, vol. 14, no 4, pp 1245-1250.