

LP Model: A Panacea to Electricity Generation Cost

Otasowie Owolafe, Abidemi S. Akindana

Department of Computer Science, Federal University of Technology, Akure, Nigeria

Abstract

The power system in modern world is required to ensure that electrical energy demands of a society or country are met. This has led to the growth in complexity of power system interconnection and demands which has shifted the focus of power system to enhancing performance, increasing customer focus and reliability in electricity generation within minimal cost when serving the load demands. In this work, we aim to minimize the total generation cost in thermal power stations using Egbin thermal power station as a case study, while satisfying the load demand. This thesis presents the formulation of the electricity generation cost function as a linear function and solves the cost minimization problem using linear programming approach. The proposed algorithm was implemented in MATLAB and was tested using three generating units of Egbin thermal power station in Nigeria. The result obtained was compared with existing works. The results revealed that the proposed algorithm possesses the merit of achieving optimal solution for reducing the generation fuel cost that satisfies both generation limits and equality constraints of power loss.

1. Introduction

The Energy exists in various forms and these forms can be converted from one to another. Electrical energy, according to Rajput, [9], is the most preferred of all forms of energy even though it has often been cited as the most complex system ever built. Electricity was first discovered during the 1820s by Michael Faraday, a British scientist although the electric power industry began its operations in the 1880s and has since evolved into one of the largest industries as it provides power to millions of industrial, commercial, and residential users with very high quality, reliability and great affordability. The main aim of modern electrical power utility is to optimize electricity generation in order to provide high quality and reliable power supply to the consumers at the lowest possible cost while operating in such a way that it meets the constraints imposed on it by its environment and the individual constraints of each generating units and that of the generation stations as a whole. In modern society, reliable power delivery is fundamental for a large portion of our daily

lives and this can only be made possible with optimized generation and effective transmission of generated powers to check production costs and maintenance related costs which will ultimately reduce the total costs involved in generation and delivery of reliable electricity.

Since generation stations are the first point of call when it comes to electric power generation, before connecting to transmission lines and distribution substations, the analysis and computation of all generation components is of great concern to electric power engineers and scientists at large. Mehta et al., [10] stated that the social structures and the industrial development of any country depends primarily on low cost and uninterrupted supply of electrical energy, hence all the factors involved in this complex system must be considered.

The difficulty in developing a method for economic dispatch that simultaneously satisfies the constraints imposed by load demand has necessitated the design of a model that solves and optimizes economic dispatch problems with low electricity generation cost while maintaining the quality delivered. If cost expended on electricity is high from generation, it ultimately increases the cost of other components involved in the electricity value chain. Although several research works have been carried out on the generation of power systems, but in these works, several cost related factors in electricity generation were left out. Most of these research works were carried out with little emphasis on the cost involved in electricity generation while their main focus was on the quality delivered to meet the load demands, hence the need for this work. In this research work, an optimized model to minimize electricity generation costs was developed.

2. Related Works

Increasing numbers of research works has been carried out on electricity and how to reduce total costs over transmission and distribution of electricity right from the generating stations. Since 1920, several power engineering experts, investors and interested scholars have conducted relevant research on the determination of the optimal output of a number of electricity generation facilities, to meet the load

demand at lowest possible cost employing different kinds of transmission and operational constraints, mathematical programming and optimization techniques.

Al-Sumait et al. [1] worked on the Solution of Different Types of Economic Load Dispatch Problems Using a Pattern Search Method. In his work, he implemented the pattern search method using a set of MATLAB files on cost coefficients of the fuel cost and the combined objective. His work proved that the PS methods will be very efficient when solving a wide range of optimization problem in the area of power system. However, since this method do not require information about the gradient or higher derivatives of the objective function to search for an optimal solution.

Huang et al. [11] carried out a research on developing a Three-Stage Optimal Approach for Power System Economic Dispatch Considering Microgrids. This was to determine the optimal reschedules from the original dispatch solutions since finding an optimal solution is difficult because of the significant effects of the inclusion of microgrids (MGs) in power systems because large volumes of import and export power flows has resulted in complicated power dispatch. The proposed method was coded using MATLAB and an IEEE 14-bus test was carried out to verify its feasibility and accuracy. On verification, the results demonstrated that the approach was helpful for optimal dispatch and can also be utilized to solve the area power dispatch problems because of the distribution systems formed as MGs Although his approach can only be applied where electric dispatch problem is much more complex, optimum results may not be obtained for an infeasible situation.

Gaing [12] worked on Particle Swarm Optimization to Solve Economic Dispatch Considering the Generator Constraints. He was determined to obtain an efficient and high-quality solution to economic dispatch problems within practical power system operation by developing a model with Particle Swarm Optimization (PSO) method to solve Economic Dispatch (ED) problems in power systems using nonlinear characteristics of a generator. The Constraints he considered were the ramp rate limits and prohibited operating zone for the operation of power systems. He was able to determine the optimal generation power of each unit in a power generation station thus minimizing the total generation cost, this was proved in the comparison test with the Genetic Algorithm method in terms of two characteristics of power system. It was tested with the solution quality of generated power, and it was discovered that PSO method can obtain lower average generation cost than the GA method, thus resulting in the higher quality solution. But his work was only limited to non-linear characteristics of generator and only assumed that the incremental cost of the

generating units is monotonically increasing linear functions. This assumption rendered his method infeasible because of the linear characteristics of practical power systems.

In Surekhaet al. [2], Solving Economic Load Dispatch problems using Differential Evolution with Opposition Based Learning which was carried out to prove that Differential Evolution with Opposition Based Learning (DE-OBL) is efficient in producing the optimal dispatch when compared with several other methods. In this work, Opposition Based Learning (DE-OBL) was combined with a Differential Evolution algorithm to solve Economic Load Dispatch problem with non-smooth fuel cost curves considering transmission losses, power balance and capacity constraints. The algorithms were implemented in MATLAB R2008b platform on a core i3 processor, 2.53 GHz, 4 GB RAM personal computer. This work showed that DE-OBL is efficient in the optimal dispatch procedures when compared with several other methods. Although the objective was proven by the searching ability and convergence rate of the proposed method (DE-OBL), however, this approach is not feasible for solving non-linear and discontinuous problems because it suffers from the problem of curse of dimensionality with large computational time

Ajenikoko et al. [3] Optimal Power Flow with Reactive Power Compensation for Cost and Loss Minimization on Nigerian Power Grid System. The technique employed was based on the optimal power flow formulations using Newton-Raphson iterative method for the load flow analysis of the grid system using the method of shunt capacitor placement for cost and transmission loss minimization on Nigerian power grid system was used. The result was verified on a 24-bus, 330kV network interconnecting four thermal generating stations (Sapele, Delta, Afam and Egbin) and three hydro stations to various load points. Newton-based methods are not capable of obtaining quality solutions for Electric Load Dispatch problems due to large number of non-linear characteristics and constraints because Newton-based algorithms struggle with handling a large number of inequality constraints.

Oleka et al. [4] worked on Electric Power Transmission Enhancement: A Case of Nigerian Electric Power Grid. In the research, simulation was carried out in MATLAB platform using power system analysis toolbox where it was discovered that the existing Nigerian national power grid is actually being underutilized due mainly to the radial nature of the network and lack of voltage control devices in the network. The research focus was on active power losses and not the reactive losses on electrical power.

Ramesh et al. [5] worked on Minimization of power loss in distribution networks to discover limitations on the classical methods used in power loss minimization. The aim of their work was due to

the discovery of the weaknesses of using classical methods in handling qualitative constraints and the poor convergence of the result regarding power loss, he compares the results of classical methods with those of three other methods including feeder restructuring, implementation of distributed generation and capacitor placement method. From the analysis of the results, the need for other methods in handling various qualitative constraints and finding multiple optimal solutions was discovered but in his work, he failed to compare the cost of these methods as they are computationally expensive in handling large-scale optimal power flow problems.

Aderinto [6] carried out a research on Optimal Planning of Electric Power Generation Systems. He aimed to optimally forecast an electric power generation system. In this research work, a linear programming model was presented based on integer formulation of electric power system generation and was solved using an iterative optimization method named 'branch and bound' and real-life data was used for better understanding. The research was targeted at helping engineers to analyze and get exact result in considering cost of power generation to reduce the problem of excessive budgeting and assist in economic dispatch of electric power generation.

Salaudeen and Aderinto [13] worked on Voltage Effects on Electric Power Systems Generators via Iterative Methods. The research work was aimed at examining the effect of high voltage on electric power generators with bus admittance matrix, via iterative techniques. The research laid emphasis on the need to monitor the voltage of electric power with time to avoid breakdown of the power systems. However, his work was basically carried out on voltage effects.

Dike et al. [7] worked on Economic Dispatch of Generated Power Using Modified Lambda-Iteration Method because in practical situations and under normal operating conditions, the generating capacity of power plants is more than the total losses and load demand but the fuel costs and distance from the load centers varies in power plants. His objective was to develop improved methods of economic dispatch of generated power from mostly remote locations to major load centers in the urban cities. However, the loss formula and loss coefficients were not fully employed in the examples used in the research.

In all, most of these methods converges rapidly but complexities increase as system size and evaluation terms increases. Generation units are characterized by fuel costs which differs in all units in a generation station, hence the technique to optimize these costs requires incremental fuel cost graphs which are piecewise linear and monotonically increasing. Previous methods flatten out these portions of incremental cost curve.

3. System Design

Electricity generation is carried out in electric power plants and regardless of the type of power plant, the common components includes a boiler, a turbine, a condenser and lastly the pump. Besides these, other components used in power plant solely depends on the type of power plant. Thermal power stations are steam driven hence, the basic operation depends on steam drive which works on the principle of continuous conversion of high temperature and pressure steam into Kinetic energy. This continuous process is popularly called the Rankine cycle and it guarantees the continuous production of power.

3.1 Cost Function of Generation in Thermal Plants

The direct cost of electric energy produced by a thermal power station is the cumulating cost of fuel, capital cost for the plant, operator labor, maintenance, and other cost related factors that includes indirect, social or environmental costs. The determination of optimal output in electricity generation facility to meet the load demand at the lowest possible cost subject to the generation constraints is commonly formulated as an optimization problem. The sole aim of minimizing the total generation cost of power system is to simultaneously satisfies certain constraints on the system. In thermal generation stations, the cost of fuel per unit varies significantly with the power output of the unit and this depends on the load demand on that unit.

The main economic factor in the power system operation is the cost of generating real power which has two components, the fixed cost and the variable cost. The fixed cost covers the capital investment, tax paid, labor charge, salary given to staff and other expenses that are independent of the load on the power. The variable cost is a function of load demands on generating units, losses, daily load requirement and purchase or sale of power. The traditional method of approximating cost functions, generally known as input-output characteristics of a generator is represented as the quadratic function, $F_T = a(P_G)^2 + b(P_G) + c$ represented graphically as shown in Figure 1.

3.2 Derivation of Cost Coefficients

Factors to consider in electricity generation cost includes:

- Type of generation station: Thermal, Hydro or Wind
- Number of generating units in the power plant or under consideration

- The actual Fuel Cost
- Load Demand

In thermal power plants, the optimization of cost requires three attributes:

- Objective Function: This is the fuel Cost, FT
- Variables: Power generated, PG
- Constraints: Minimum and Maximum values of PG

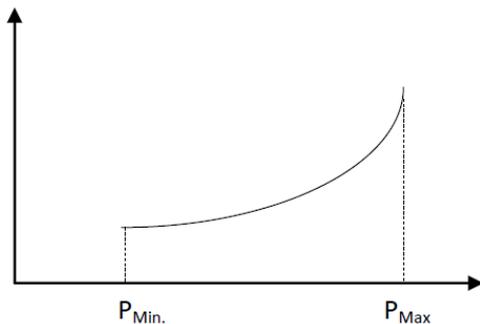


Figure 1. Typical Fuel Cost Curve

These three attributes will form the basis of the linear programming problem. The form of linear programming problem for electricity generation is:

$$\begin{aligned} & \text{Minimize } f(x) \\ & \text{Subject to } g(x) \\ & h(x) \leq 0 \end{aligned}$$

Where $f(x)$ = objective function, $g(x)$ and $h(x)$ are set of equality and inequality constraints respectively. In the proposed model, more than one generating unit was considered, hence the linear programming problem will be re-written as:

$$\text{Min } F_T = F_i(P_{G,i}) \dots 3.1$$

$$\text{Subject to } P_G = P_D + P_L \text{ (Equality constraints in } M_W) \dots 3.2$$

Satisfying constraints

$$(P_{G,i})_{\text{Min}} \leq (P_{G,i}) \leq (P_{G,i})_{\text{Max}} [i \in 1, 2, \dots, n] \text{ (Inequality constraints)}$$

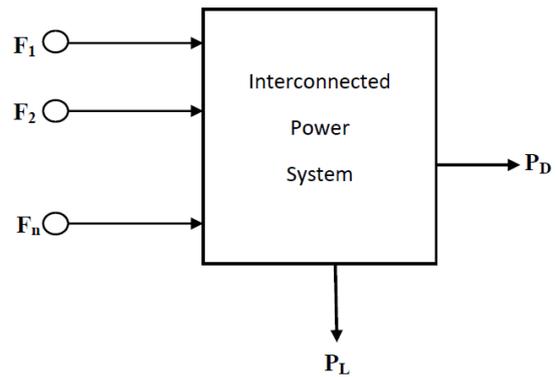


Figure 2. Interconnected System of n-number of Units in Thermal Power Plant

The Figure 2 shows the interconnected system of n-number of units in a thermal plant. The fuel cost function is given as:

$F_T = F(P_G)$ which is represented as the quadratic equation

$$F_T = a(P_G)^2 + b(P_G) + c \dots 3.3$$

Where a, b and c are fuel cost coefficients and for a power plant with several generating units:

$$F(P_G) = a(P_G)^2 + b(P_G) + c \dots 3.4$$

$$\Delta F_T = (a(P_{G2})^2 + b(P_{G2}) + c) - F_1 \dots 3.5$$

We introduce a variable J,

$$J = (\Delta F_T)^2 = \sum_{i=1}^n (a(P_{G,i})^2 + b(P_{G,i}) + c - F_i)^2 \dots 3.6$$

Taking the first Derivative of J with respect to a, b and c and simplify it, we have

$$\begin{aligned} & (\sum_{i=1}^n (P_{G,i})^4)a + (\sum_{i=1}^n (P_{G,i})^3)b \\ & + (\sum_{i=1}^n (P_{G,i})^2)c = \sum_{i=1}^n F_i(P_{G,i}) \dots 3.7 \end{aligned}$$

$$\begin{aligned} & (\sum_{i=1}^n (P_{G,i})^4)a + (\sum_{i=1}^n (P_{G,i})^3)b \\ & (\sum_{i=1}^n (P_{G,i})^2)b + (\sum_{i=1}^n P_{G,i})c = \sum_{i=1}^n F_i(P_{G,i}) \dots 3.8 \end{aligned}$$

$$(\sum_{i=1}^n (P_{G,i})^2)a + (\sum_{i=1}^n (P_{G,i}))b + nc = \sum_{i=1}^n (F_i) \dots 3.9$$

By using ranges between generation limits and solving equations (7) to (9) we obtain the values of a, b and c. The value of cost coefficients a, b and c derived from the computation is shown in Table 1 and given in equation 13 to 15.

Table 1. Fuel Cost Coefficient with Min and Max Generation Limit

Units	a	b	c	Min	Max
P1	0.186	13.1	2131.1667	55	220
P2	0.186	13.1	2131.1667	55	220
P3	0.186	13.1	2131.1667	55	220

The values of a, b and c above is used to compute the total fuel cost of each unit.

$$F_1(P_{G1}) = 0.186(P_G)^2 + 13.1(P_G) + 2131.1667 \dots 3.10$$

$$F_2(P_{G2}) = 0.186(P_G)^2 + 13.1(P_G) + 2131.1667 \dots 3.11$$

$$F_3(P_{G3}) = 0.186(P_G)^2 + 13.1(P_G) + 2131.1667 \dots 3.12$$

3.3 Formulation of Proposed Model

The model to minimize the cost incurred in generating electricity will be developed using fuel cost as the major variable.

a) Linear Programming

Linear programming (LP) is a special case of mathematical optimization used to achieve the best outcome (for example maximum profit or minimum cost) in problems represented by linear relationships. It has been used extensively in several fields including business and engineering, in the areas of transportation, energy, telecommunications, and manufacturing to solve real life problems. LP has also been proved to be useful in modeling diverse types of problems in planning, scheduling, assignment, and design. More formally, it is a technique for the optimization of a linear objective function, subject to linear equality and linear inequality constraints.

b) Flowchart for Cost Optimization Using Linear Programming

Flowchart is the diagrammatic representation of an algorithm, for the proposed model, the flowchart is given in Figure 3.

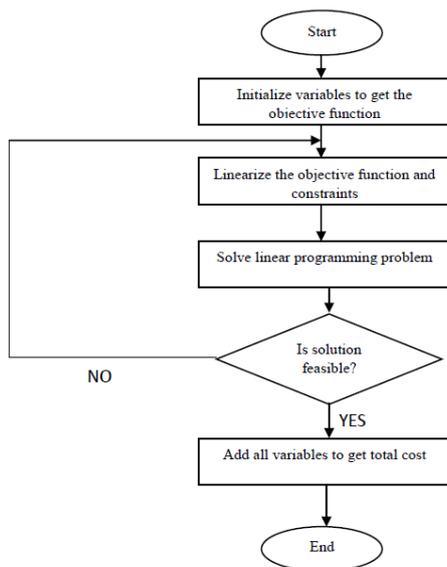


Figure 3. Flowchart of the Model

A model to solve this problem will be formulated by expressing the objective function, equality and inequality constraints mathematically to determine optimal values for electricity costs. For thermal units, the input-output characteristics are usually regarded as the generating unit fuel consumption function. The unit of the generator fuel consumption function is BTU per hour heat input to the unit (or Million BTUs. MBTU/hr.). To solve this problem using linear programming method, we determine the incremental fuel-cost curve by plotting the derivative of the fuel cost curve against the real power so as to formulate our objective function because fuel cost equation is quadratic in nature.

3.4 Piecewise Linear Approximation of Cost Function

The original fuel cost function – objective function is quadratic and nonlinear in nature; therefore it is necessary to formulate a linear function by using a piecewise linear approximation of the cost curves since quadratic equations do not satisfy the requirements of a linear program. From the original cost curve in Figure 1, we will use a series of straight-line segments to approximate the non-linear curve.

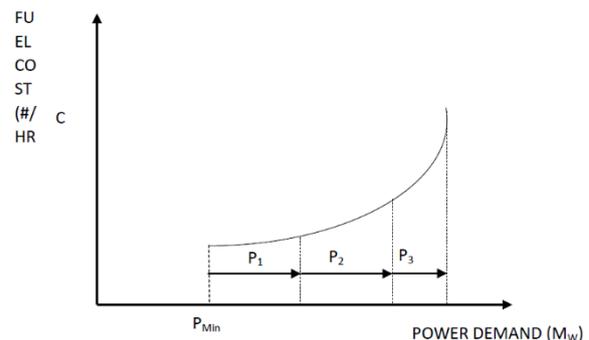


Figure 4. Incremental Linear Approximation of Cost Curve of Thermal Plant

From the graph shown in Figure 4, C represents the cost function, P_1 , P_2 , and P_3 represents generation increments per unit and based on the generation limits imposed on the system, the value of P1 ranges from 0 to some maximum value $(P_1)_{Max}$, $(P_2)_{Max}$, and $(P_3)_{Max}$

$$\text{i.e. } 0 \leq (P_i) \leq (P_i)_{Max}$$

$$(P_i)_{Min} \leq (P_i) \leq (P_i)_{Max}$$

Hence, the total cost per unit

$$= (P_i)_{Min} + (P_i)_1 + (P_i)_2 + (P_i)_3 \dots 3.13$$

Where the value of i varies from 1 to n based on the number of generating units in the plant, in this case, we considered three units. So, we determine the increment in the cost function C with the slope of each line segment corresponding to the line therefore, we denote the approximate cost function, F as $C(P)$ for each unit. Hence, we have:

$$C(P_1, P_2, P_3) = C(P_{Min}) + S_1P_1 + S_2P_2 + S_3P_3 \dots 3.14$$

For a single unit, where P_1 , P_2 and P_3 are generation increments for the unit. From equation 18, the line segment shows a clearly linear function form in its variables which will serve as the objective function of the linear programming model. Therefore, our linear programming model for electricity generation aims to:

$$\text{Minimize } F_T = C(P_1, P_2, P_3)$$

Subject to $P_G = P_D + P_L$ in M_W (Equality constraints)

Satisfying constraints $(P_G)_{Min} \leq (P_G) \leq (P_G)_{Max}$

$[P_G \in 1, 2, \dots, n]$ (Inequality constraints)

4. Result and Performance Evaluation

A system is not useful unless it is implemented and tested to ensure that the system works fine and all its functionalities are in place as well as effective, this section will highlight the results obtained from linear programming solution to the problem and show its comparison with two other optimization techniques to show its effectiveness.

4.1. Model Implementation

The model will be implemented by solving the linear programming problem of minimizing the objective function subject to the constraints on the system. From Table 1, the values of a , b and c was used to compute the total fuel cost of each of the three units of the thermal plant as follows:

$$C1(P1) = F1(PG,1) = 0.186(PG)^2 + 13.1(PG) + 2131.1667 \quad 55 \leq (PG,1) \leq 220 \dots 4.1$$

$$C2(P2) = F2(PG,2) = 0.186(PG)^2 + 13.1(PG) + 2131.1667 \quad 55 \leq (PG,2) \leq 220 \dots 4.2$$

$$C3(P3) = F3(PG,3) = 0.186(PG)^2 + 13.1(PG) + 2131.1667 \quad 55 \leq (PG,3) \leq 220 \dots 4.3$$

From equations 4.1 to 4.3, we set ranges between the minimum and maximum values and find out the values of $C1(P1)$, $C2(P2)$, $C3(P3)$ as illustrated in table 2.

The Table 2 shows the incremental cost of the three units. To observe the change in the slope of these increments, we select break points (BP) and find the slope.

Table 2. Incremental Values and Cost within Specified Min. and Max. Limit

$(P_{n,1})$	$C(P_{n,1})$	$(P_{n,2})$	$C(P_{n,2})$	$(P_{n,3})$	$C(P_{n,3})$	$(P_{n,4})$	$C(P_{n,4})$
75	4159.9167	105	5557.3167	150	8281.1667	190	11334.767
75	4159.9167	140	7610.7667	180	10515.567	200	12191.167
110	5822.7667	150	8281.1667	190	11334.767	210	13084.767

Table 3. Slope for the Linear Approximation of the Cost Curve

Unit	BP1 ($S_{n,1}$)	BP2 ($S_{n,2}$)	BP3 ($S_{n,3}$)
1	46.58	60.53	76.34
2	53.09	64.36	83.78
3	61.46	76.34	87.50

The Table 3 shows the calculated slope between the values for each unit within the minimum and maximum range.

a) Objective Function

The approximate piecewise linear cost curves for the three units will form the objective function.

$$C1(P_{1,1}, P_{1,2}, P_{1,3}) = C1(P_{1Min}) + S_{1,1}P_{1,1} + S_{1,2}P_{1,2} + S_{1,3}P_{1,3} \dots 4.4$$

$$C2(P_{2,1}, P_{2,2}, P_{2,3}) = C2(P_{2Min}) + S_{2,1}P_{2,1} + S_{2,2}P_{2,2} + S_{2,3}P_{2,3} \dots 4.5$$

$$C3(P_{3,1}, P_{3,2}, P_{3,3}) = C3(P_{3Min}) + S_{3,1}P_{3,1} + S_{3,2}P_{3,2} + S_{3,3}P_{3,3} \dots 4.6$$

We represent the objective function of our linear program as Z

$$Z = S_{1,1}P_{1,1} + S_{1,2}P_{1,2} + S_{1,3}P_{1,3} + S_{2,1}P_{2,1} + S_{2,2}P_{2,2} + S_{2,3}P_{2,3} + S_{3,1}P_{3,1} + S_{3,2}P_{3,2} + S_{3,3}P_{3,3} \dots 4.7$$

The Matrix form of our linear program is $Z = C^T X$

$$Z = [46.58P_{1,1} + 60.53P_{1,2} + 76.34P_{1,3} + 53.09P_{2,1} + 64.36P_{2,2} + 83.78P_{2,3} + 61.46P_{3,1} + 76.34P_{3,2} + 87.50P_{3,3}]$$

b) Inequality Constraints

The original constraints are $55 \leq (PG1) \leq 220$, $55 \leq (PG2) \leq 220$ and $55 \leq (PG3) \leq 220$. But to model the cost curves as linear, we will utilize a variable, q which will represent the number of break points from the calculated slope.

i. **Lower Bound:** Since we cannot have a negative amount of generation increment, the new variable must be non-negative and since we can have any amount of generation increment between zero and the upper bound, the lower bound on all the points on the curve, q is zero

ii. **Upper Bound:** The upper bound on the variable are the maximum increment possible i.e. the difference between $P_{1,2} - P_{1,1}$, $P_{1,3} - P_{1,2}$, $P_{1,4} - P_{1,3}$, $P_{2,2} -$

$P_{2,1}$, $P_{2,3} - P_{2,2}$, $P_{2,4} - P_{2,3}$, $P_{3,2} - P_{3,1}$, $P_{3,3} - P_{3,2}$, $P_{3,4} - P_{3,3}$ as shown in table 5.

Unit	$P_{n,2} - P_{n,1}$	$P_{n,3} - P_{n,2}$	$P_{n,4} - P_{n,3}$
1	30	45	40
2	65	40	20
3	40	40	20

c) Equality Constraints

We denote the total load generated as the sum of load demand and the load losses i.e. the sum of the power generated must be equal to the total load demand plus load losses.

$$(P_{G1}) + (P_{G2}) + (P_{G3}) = \text{Load} \dots 4.8$$

Hence equality constraints = $P_{1,1} + P_{1,2} + P_{1,3} + P_{2,1} + P_{2,2} + P_{2,3} + P_{3,1} + P_{3,2} + P_{3,3} = \text{Load} - [(P_{1Min}) + (P_{2Min}) + (P_{3Min})]$.

Table 4. Maximum Increment on Successive Generation Limit Range

$$\begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} P_{1,1} \\ P_{1,2} \\ P_{1,3} \\ P_{2,1} \\ P_{2,2} \\ P_{2,3} \\ P_{3,1} \\ P_{3,2} \\ P_{3,3} \end{pmatrix} = \begin{pmatrix} \text{LOAD} - (\sum_{i=1}^n P_{iMin}) \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

We set 500 MW Power Demand as the benchmark to test, hence given Power Demand of 500 MW

Pseudocode for MATLAB

Using LINPROG Linear Programming Solver to implement Simplex algorithm:

$X = \text{LINPROG}(F,A,b)$ to solve the linear programming problem of the form $Ax = B$
 Minimize Objective function subject to $A * X = B$
 $X = \text{LINPROG}(F,A,b, Aeq, Beq)$ to solve the Linear Programming problem that satisfies both equality and inequality constraints.

$X = \text{LINPROG}(F,A,b, Aeq, Beq, LB, UB)$ defines the set of minimum and maximum values on the variables which satisfies the inequality

constraints so that the solution, X is in range $LB < X < UB$.

Now we introduce a variable, $FVAL = FX$, which will be the minimized objective function value at the solution.

$[X, FVAL] = \text{LINPROG}(F,A,b)$ returns the value of the objective function at X.

$[X, FVAL, EXITFLAG] = \text{LINPROG}(F,A,b)$ returns EXITFLAG which describes the exit condition of LINPROG with reasons if the solver runs into an error.

From MATLAB in-built function, if EXITFLAG is:

> 0 implies LINPROG HAS CONVERGED with X as the solution

= 0 implies LINPROG reached the maximum number of iterations without convergence

< 0 implies the problem is infeasible and LINPROG functions returns FAILED

[X, FVAL, EXITFLAG, OUTPUT]=LINPROG (F, A, b) calls out a structure which returns the number of iterations taken in OUTPUT.iterations and the method used to solve the Linear programming problem in OUTPUT.algorithms. LINPROG function automatically implements Simplex method by default. For 500Mw, the Solution of the linear programming problem shows that the value of FVAL = 14132. We need to add to the value of FVAL (The objective function) the sum of cost functions evaluated at each minimum generation level i.e. $C_1(75) + C_2(75) + C_3(110) = 14142.60$ Therefore, the total cost for the 500Mw load demand = 14142.60 +

14132 = 28274.60 #/Hr. (Naira per Hour).

4.2 Comparative Analysis with Existing System

Several optimization techniques which includes Ant Colony search, Lambda method, Particle swarm optimization, Genetic algorithm and other methods has been used to solve the problem of reducing the electricity generation cost. The result obtained from the optimization using linear programming method will be compared with some of these techniques. To obtain accurate and further prove to compare these techniques, we calculate the total cost on power demand of 400Mw and 600Mw to check for power demands below and above our 500Mw power demand benchmark. The solution shows that the total cost on electricity demand of 400Mw and 600Mw are 21714.70 #/Hr. and 36280.60 #/Hr. respectively. The cost was compared with the result obtained from Ant Colony Search and the Lambda Method optimization techniques in Paul et al. [8] as shown in Table 5.

Table 5. Comparison Table for Three Different Optimization Techniques

POWER DEMAND (M _w)	TOTAL GENERATION COST (#/Hr.) PER METHOD		
	LINEAR PROGRAMMING	ANT COLONY SEARCH	LAMBDA METHOD
400	21714.70	21748.82	21792.68
500	28274.60	28295.40	28322.24
600	36280.60	36288.08	36297.90

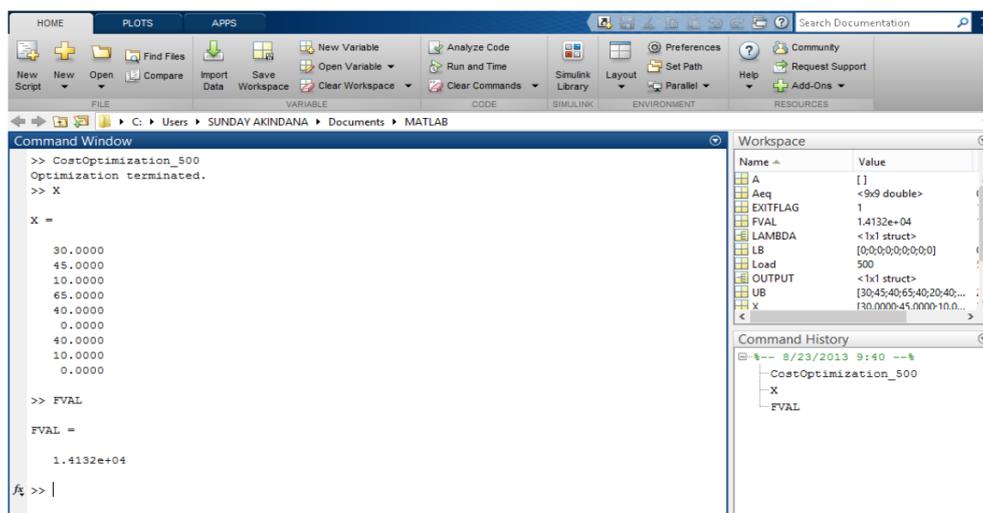


Figure 5. MATLAB Cost Optimization Result for 500MW Power Demand

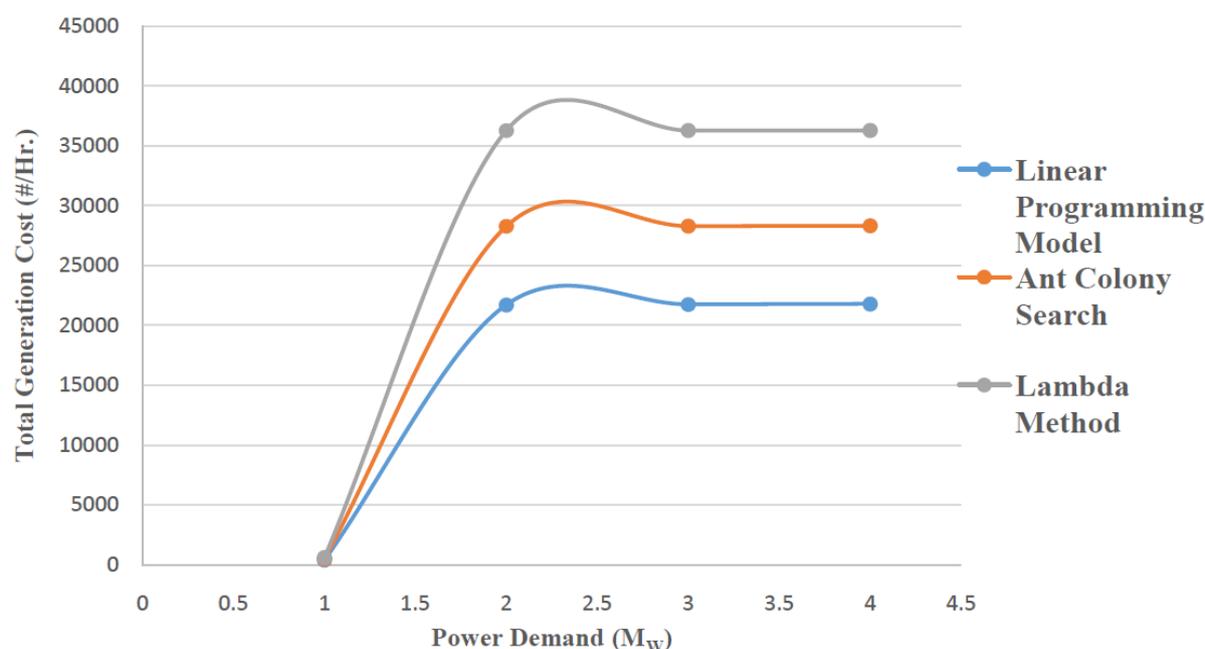


Figure 6. Comparison Chart of Three Optimization Techniques

From Table 5 and the chart in figure 6, it shows that the linear programming approach has effectively minimized and reduced the total generation cost on three separate power demands as compared to that of the two tech. Hence the linear programming approach has offered the best results when compared with the other two optimization methods.

5. Conclusion and Future Work

The development of a linear programming-based cost optimization model for electricity generation has been carried out in this thesis. The model design was carried out using the linear approximation of the quadratic cost function to convert the non-linear form into a linear equation. A linear programming problem was then formed which satisfies the equality and inequality constraints by specifying ranges between the minimum and maximum value of generation limits. The developed technique has been successfully implemented and the performance evaluation was carried out from the analysis as implemented in MATLAB environment and compared with other works. The result obtained from the implementation of the cost minimization model on Egbin thermal

station considering both equality and inequality constraints have proved that Linear Programming approach to cost minimization of electricity generation has a competitive edge under variable load demand and is efficient, accurate and capable of minimizing the fuel cost of generators and satisfies each and every constraint on power generation. The model also attains good performance with moderate computations, since its variables are simplified hereby reducing the execution time and helps the accuracy of the result since constraints on power generation are taken into consideration.

6. References

- [1] Al-Sumait, J. S., Sykulski, J. K., and Al-Othman, A. K. (2008). Solution of different types of economic load dispatch problems using a pattern search method. *Electric Power Components and Systems*, 36(3), 250–265. <https://doi.org/10.1080/15325000701603892>.
- [2] Surekha, P., and Sumathi, S. (2012). Solving economic load dispatch problems using differential evolution with opposition-based learning. *WSEAS Transactions on Information Science and Applications*, 9(1), 1–13.
- [3] Ajenikoko, G. A., and Olabode, E. (2016). Optimal Power Flow with Reactive Power Compensation for Cost and Loss Minimization on

Nigerian Power Grid System, 02(09), 107–119.
<https://doi.org/10.11591/ijeei.v5i3.284>.

[4] Oleka, E. U., Ndubisi, S. N., and Ijamaru, G. K. (2016). Electric Power Transmission Enhancement: A Case of Nigerian Electric Power Grid. *American Journal of Electrical and Electronic Engineering*, 4(1), 33–39. <https://doi.org/10.12691/ajeee-4-1-5>.

[5] Ramesh, L., and Chowdhury, S. (2009). Minimization of power Loss in distribution networks by different techniques. *International Journal of ...*, 632–638. <http://waset.org/journals/waset/v28/v28-96.pdf>.

[6] Aderinto, Y. O. (2018). On Optimal Planning of Electric Power Generation Systems, 50(1), 89–95.

[7] Dike, D. O., Adinfono, M. I., and Ogu, G. (2013). Economic Dispatch of Generated Power Using Modified Lambda- Iteration Method. *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, 7(1), 49–54. <http://www.academia.edu/download/33664027/H0714954.pdf>.

[8] Paul, O. O., and Nwohu, M. N. (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), 2454–9436. <https://doi.org/10.20431/2454-9436.0301004>.

[9] Rajput, P.K., (2003). *Textbook of Power Plant Engineering*. Laxmi Publication Ltd, New Dellhi.

[10] Mehta, V., and Metha., R., *Principles of Power Systems*. S. Chand, 2002.

[11] Huang, W.-T.; Yao, K.-C.; Wu, C.-C.; Chang, Y.-R.; Lee, Y.-D.; Ho, Y.-H. A Three-Stage Optimal Approach for Power System Economic Dispatch Considering Microgrids. *Energies* 2016, 9, 976.

[12] Gaing, Z., (2003) “Particle swarm optimization to solving the economic dispatch considering the generator constraints.” in *IEEE Transactions on Power Systems*, vol. 18, no. 3, pp. 1187-1195, Aug.

[13] Salaudeen, L., Aderinto, Y., (2015). Voltage Effects on Electric Power Systems Generator via Iterative Methods. *Ilorin Journal of Science*. Vol. 2.