

# (Lantool) Power Generation Cost Minimization Software Application

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**Abstract** Managers of large scale industry like the electricity generation are challenged at many fronts because the tasks involved are complex, influenced by unexpected events and evolve in time. Currently the application of computer methods in this industry has produced tremendous positive results. In this regard, the study presents an effort developed to solve optimal power flow (economic dispatch) problem by minimizing the cost of generation using the lagrangian multiplier method. A decision support system 'Lantool' is presented. The approach is validated by lagrangian method found in technical literatures. The system will assist operators in thermal power plants with the task of planning generation in the most economic way. A result obtained from the application explains the important role decision support systems can play in the management of the electricity generation industry.

**Keywords:** *optimal power flow, minimizing cost, economic dispatch, lagrangian multiplier method, decision support system*

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## 1. Introduction

The rapid growth in power system industry has made the issue of optimization in power generation and transmission very significant. In the recent time, deregulation in power industry has changed the part played by various units in the electricity industry. Services provided by electric power vendors which originally used to be one single entity are now unbundled into three different entities thus production, transmission and distribution. The service providers' compete in providing good electricity delivery and at the same time strive to make profit. To maintain efficiency and security, reliability of supply are not compromised otherwise customer interest and protection will not be guaranteed. In order to achieve these, best practices in economic dispatch [1] or optimal power flow are employed. The objective is to systematically seek the lowest cost of electricity production that will be consistent with electricity demand. To minimize cost, Optimal power flow (OPF) will increase the use of more efficient generating unit and at the same time addresses two issues of concern - better fuel usage, and reduced green house gas emission [2,3,4] that would result from less efficient generation. OPF therefore seeks to minimize the total cost of generating power (production cost) at various stations while satisfying the loads and the losses in the transmission lines. In the case of developing countries like Nigeria where consumption per capita of electricity is very poor mainly due to high

cost of production [5], application of the principles of OPF cannot be over looked. Even when these principles are to be employed the approach to deliver it in a simpler and user friendly manner to enable operators effectively apply it is equally very necessary. It is in view of all these considerations that this paper seeks to present a computer based support system for the electricity generation industry. Computer applications in the form decision support system (DSS) can be a tool used to provide fair and consistent decisions, and at the same time improve the effectiveness of decision making process [6]. A DSS application approach for supporting decision making is typically built for solutions of a certain problem or to evaluate an opportunity. On that note, we present a decision support computer-based tool using Lagrangian multiplier method. The approach was applied to a five-bus network to minimize cost of electricity generation and result is also presented.

Many solution techniques have been proposed and also available to solving optimal power flow problem with varied degree of successes. They can be divided into two main categories, the algorithmic mathematical solution and artificial intelligent solution as reported in several literatures. Among the algorithmic solutions are Interior point (IP) algorithm [7], Simplex algorithm (SA), Quadratic programming (QP), and Dynamic programming (DP) [8]. Langrange relaxation method (LRM) [9,10] Linear programming (LP), Non-linear programming (NLP) and Newton-based methods have also been reported. Currently proposed Artificial Intelligent optimization methods based on heuristics and operational research

presented by researchers have emerged with global optimum solution for power system optimization. They include Expert system (ES), Ant Colony search (ACS) [11], Simulated annealing (SA) [12], Artificial Neural networks (ANN) [13,14,15], Fuzzy logic (FL) [16] and Genetic Algorithm (GA) [17]. Others include Meta heuristic methods such as Tabu search (TS) [18], Particle swarm optimization (PSO) [19,20] and Evolutionary programming (EP) [21,22]. Application of these methods depends on the researchers' area of interest as each method has its own advantages and disadvantages. Even as these optimization methods are effective in finding the global optimal solution, however, when adopted in large-scale real-world system, it would take a long computational time. It therefore explains the fact that there exist a gap between theory and practice in the field of optimization. Attempt to bridge this gap is what this paper seek to present by shifting focus to applying analytical method to solving a real-world problem.

**1.1. OPF Formulations**

Generally, power system can be operated optimally if the principles of equal incremental cost rate are applied to the problem of optimal distribution of loads among the various stations forming a power pool. The most precise way to describe such operation is to use the relation between the input and output parameter as available from the generated data of the individual generators.

The characteristic of this relation is described mathematically as.

$$I = a + bP + cP^2 + dP^3 + \dots + nP^r \quad (1)$$

Where I is the input (cost of fuel) and P is the output (power produced by generator) with positive coefficients a, b, c to n.

Alternatively it can be represented graphically as shown in Figure 1:

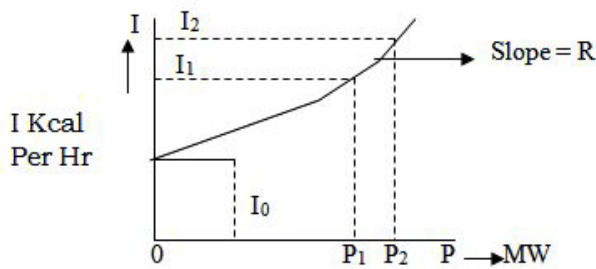


Figure 1. Input – output characteristic of a generator.

I<sub>0</sub> in the above graph represents the amount of input required to keep the generator functioning when there is no load. The slopes of the curve at various load-points give the incremental cost rate. If I<sub>1</sub> and I<sub>2</sub> are the inputs corresponding to the loads P<sub>1</sub> and P<sub>2</sub> respectively, the increase in input required for meeting the increase of load from P<sub>1</sub> to P<sub>2</sub> is given by

$$I_2 - I_1 = \int_{P_1}^{P_2} R_i dP \quad (2)$$

The area under the curve between P<sub>1</sub> and P<sub>2</sub> is the incremental rate. Similarly, from no load to P<sub>1</sub>, the

increase in input I<sub>1</sub> – I<sub>0</sub> is given by the area under the incremental rate curve from P = 0 to P<sub>1</sub>, and Ri is the incremental rate.

By differentiating the expression in equation 1 to the third power, we get the incremental rate characteristic as:

$$R_i = \frac{dI}{dP} = b + 2c(P) + 3d(P^2) \quad (3)$$

However, the theory of incremental rate assumes the following conditions:

- a. That input – output curves are continuous
- b. That first derivatives of the input – output curves are continuous
- c. That value of the incremental rate increases with the increase in output

Hence to minimize I (input) the condition will be

$$\frac{dI}{dP} = 0$$

for generators i = 1 ----- n.

Then

$$\frac{dI_1}{dP_1} = 0 \quad \frac{dI_2}{dP_2} = 0 \quad \frac{dIn}{dPn} = 0 \quad (4)$$

Hence

$$\frac{dI_1}{dP_1} = \frac{dI_2}{dP_2} = \frac{dIn}{dPn} = R \quad (5)$$

Therefore the input will be a minimum for a specified load when the units have the same incremental rate.

**2. Solution to Minimizing Cost of Generation**

With the above background information the objective of generation cost minimization is to schedule generation such that input (I) is minimum for the given total power P, subject to restriction that the sum of P<sub>k</sub> = P (is the total load received), where P<sub>k</sub> is the output of unit k.

Using the lagrangian method, if

$$f (P_1, P_2, \dots, P_k) = 0 \quad (6)$$

And

$$\sum_{k=1}^n P_k - P = 0 \quad (7)$$

Then

$$\sum_{k=1}^n P_k = P$$

If I represent the cost of input, the minimum input cost is realized when

$$\frac{dI_t}{dP_k} = 0 \text{ where } I_t = \sum_{k=1}^n I_k \quad I_t = \text{total input}$$

Applying lagrangian type multiplier where

$$I = I_t - \lambda f \quad \lambda = \text{lagrangian type of multiplier}$$

$$\frac{dI}{dP_k} = \frac{dI_t}{dP_k} - \lambda \frac{df}{dP_k} = 0 \quad (8)$$

Where f is the function of total power received ie

$$f(P_1, P_2, \dots, P_n) = 0 \text{ or } \sum_{k=1}^n P_k - P = 0$$

$$\text{But RHS } \frac{dI_t}{dP_k} - \frac{\lambda d}{dP_k} \left[ \sum_{k=1}^n P_k - P \right] = 0$$

$$\frac{dI_t}{dP_k} - \lambda [1 - 0] = 0 \quad (9)$$

$$\therefore \frac{dI_t}{dP_k} = \lambda \quad \text{and} \quad \frac{d}{dP_k} \left[ \sum_{k=1}^n I_k \right] = \lambda$$

Hence

$$\frac{dI_t}{dP_k} = \lambda \quad (10)$$

The incremental cost of input to k<sup>th</sup> unit in dollar per hour is equal to the incremental cost of the received power. The equation 10 may be rewritten as

$$\frac{dI_1}{dP_1} = \frac{dI_2}{dP_2} = \frac{dI_3}{dP_3} = \dots = \frac{dI_n}{dP_n} \quad (11)$$

If the incremental rate of k<sup>th</sup> unit is written as R<sub>ik</sub>, then

$$R_{i1} = R_{i2} = R_{i3} = \dots = R_{ik} = \dots = R_{in} = \lambda \quad (12)$$

Using symbol, C, for incremental production cost in dollar per hour then:

$$C_{i1} = C_{i2} = C_{i3} = \dots = C_{ik} = \dots = C_{in} = \lambda. \quad (13)$$

Where λ, the lagrangian multiplier, is the incremental cost of received power in dollar per hour.

In other words, suppose we have a five-bus power system network in a one line diagram as shown in Figure 2, we can develop an computer based algorithm for the optimal distribution cost using the above an analytical solution.

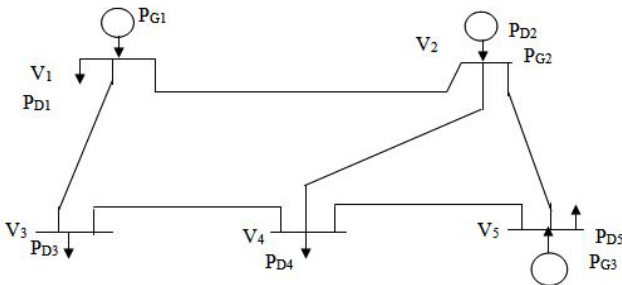


Figure 2. One-Line Diagram of a Five Bus System

### 2.1. Algorithm for the Optimal Power Flow of the Five-Bus Network

For x MW to be generated from P<sub>G1</sub>, P<sub>G2</sub>, and P<sub>G3</sub> (where the P<sub>Gi</sub>'s are of equal capacity) that would service the combined external load y in P<sub>D3</sub>, P<sub>D4</sub> optimally i.e. x = y, we proceed follows:

1. Obtain the cost functions for each of the generators P<sub>G1</sub>, P<sub>G2</sub>, P<sub>G3</sub> as follows:

$$C_1 = aP_1^2 + bP_1 + c$$

$$C_2 = aP_2^2 + bP_2 + c$$

$$C_3 = aP_3^2 + bP_3 + c$$

2. for optimal economic allocation of load y we apply the lagrangian method, where:

$$C_1 = C_2 = C_3 \quad \text{and} \quad C_1 = dC_1 / dP_1,$$

$$C_2 = dC_2 / dP_2, \quad C_3 = dC_3 / dP_3.$$

3. differentiate the C<sub>1</sub>, C<sub>2</sub>, and C<sub>3</sub> with respect to P<sub>G1</sub>, P<sub>G2</sub>, and P<sub>G3</sub>.
4. solve for P<sub>1</sub>, P<sub>2</sub>, and P<sub>3</sub> by equating the differential for minimum cost.
5. add P<sub>1</sub>, P<sub>2</sub>, and P<sub>3</sub> the total will be equal to y, the total load to service i.e P<sub>1</sub>+ P<sub>2</sub>+P<sub>3</sub> = y.

### 2.2. Algorithm for the Optimal Cost Savings in the Five-Bus Network

To obtain cost saving effected by the optimal allocation instead of equal division of load we proceed as:

1. let P<sub>G1</sub>', P<sub>G2</sub>' and P<sub>G3</sub>' = x' (x' is one-third of x and (P<sub>Gi</sub>')'s are of equal capacity).
2. obtain the cost function (C<sub>i</sub>')'s of P<sub>1</sub>' P<sub>2</sub>' P<sub>3</sub>' as follows:

$$C_1' = a(P_1')^2 + bP_1' + c$$

$$C_2' = a(P_2')^2 + bP_2' + c$$

$$C_3' = a(P_3')^2 + bP_3' + c$$

3. obtain increased cost of input for P<sub>1</sub>' as

$$\Delta C_1 = C_1' - C_1 \text{ per unit } (\$/h)$$

4. Saving in cost of input for P<sub>2</sub>'

$$\Delta C_2 = C_2 - C_2' \text{ per unit } (\$/h)$$

5. Saving in cost of input for P<sub>3</sub>'

$$\Delta C_3 = C_3 - C_3' \text{ per unit } ((\$/h))$$

6. Net increase cost is

$$C_{net} = \Delta C_1 - \Delta C_2 - \Delta C_3 \text{ per unit } (\$/h)$$

7. for 24 hours we obtain C<sub>day</sub> = C<sub>net</sub> \* 24 hours, C<sub>day</sub> is the daily cost saving for running the three generators.

### 3. Results

Results obtained from 'Lantool' decision support application is shown in Table 2 for various load demands. As expected the difference between operating the station optimally as against equal distribution is clearly identified in the table as NetSave. The daily cost saving (NetSave) for each of the load demands per day is also shown.

### 4. Discussion

In the analysis of optimal load division between the various units of a plant, it is expected that the available

data on cost is absolutely correct. The implementation of the ‘Lantool’ program is based on data set for the test cases of Table 1. The table shows generator input cost data as C1, C2, C3, while P1, P2, P3, are power generated data for  $P_{g1}$ ,  $P_{g2}$ , and  $P_{g3}$  respectively for the five-bus network in Figure 2. The input cost function is derived from equation 3 with all coefficients positive. (The coefficients for input cost equations are obtained using Matlab Curve Fitting Toolbox). Line plots of cost versus power output is

shown in Figure 3. The optimum economy is achieved if every unit (i.e.  $P_{g1}$ ,  $P_{g2}$ , and  $P_{g3}$ ) operates at the same incremental cost(IC) as seen in Figure 4. At any point on the incremental cost plot, the three generators are operated optimally and fuel utilization is seen to be less. Screen shots of cost with output of simulation, daily cost saving and incremental cost plot/data is shown in Figure 5 and Figure 6. The output of daily net saving per load demand when multiplied by 30 days will give the cost savings per month.

Table 1. Sample of output power and cost of input in \$ per hour

P1 (MW)	P2 (MW)	P3 (MW)	C1 (\$/hour)	C2 (\$/hour)	C3 (\$/hour)
24.1	24.1	24.1	598.740 5	581.8886	503.3648
20.8	20.8	20.8	535.232	525.4784	461.8112
21.5	21.5	21.5	548.6125	537.335	470.48
22.3	22.3	22.3	563.9645	550.9574	480.4832
16.6	16.6	16.6	455.978	455.5736	411.4448
22.7	22.7	22.7	571.6645	557.7974	485.5232
22.9	22.9	22.9	575.5205	561.2246	488.0528
22.7	22.7	22.7	571.6645	557.7974	485.5232
25.3	25.3	25.3	622.1045	602.7254	518.9072
23.4	23.4	23.4	585.178	569.8136	494.4048
24.2	24.2	24.2	600.682	583.6184	504.6512
25.1	25.1	25.1	618.2005	599.2406	516.3008
23.6	23.6	23.6	589.048	573.2576	496.9568
22.4	22.4	22.4	565.888	552.6656	481.7408
22	22	22	558.2	545.84	476.72
23.3	23.3	23.3	583.2445	568.0934	493.1312
17.3	17.3	17.3	469.0645	467.0774	419.6432
22	22	22	558.2	545.84	476.72
25.7	25.7	25.7	629.9245	609.7094	524.1392
22.7	22.7	22.7	571.6645	557.7974	485.5232
26.1	26.1	26.1	637.7605	616.7126	529.3968
26.2	26.2	26.2	639.722	618.4664	530.7152
24.3	24.3	24.3	602.6245	585.3494	505.9392
25.9	25.9	25.9	633.8405	613.2086	526.7648

Table 2. Sample result of Optimal vs Equal distribution cost from LanTool per load demand

EQD	L1	L2	L3	L4
Load	55.0001	75.0001	90.0001	100.0001
Gen1cost	488.472	616.25	715	920
Gen2cost	484.167	597.5	686	872
Gen3cost	431.889	515	582	728
OPD				
Load	55.0001	75.0001	90.0001	100.0001
Gen1cost	173.8032	323.5005	439.5947	686.107
Gen2cost	427.0709	539.0336	625.8461	810.2329
Gen3cost	716.8009	791.6816	849.8279	973.0873
	2084.471	1788.825	1625.552	1213.746
NetSave	2084.471	1788.825	1625.552	1213.746

Key: EQD = Equal Distribution of load. OPD = Optimal Distribution of load : L1,L2,L3,L4 = load demand (MW).

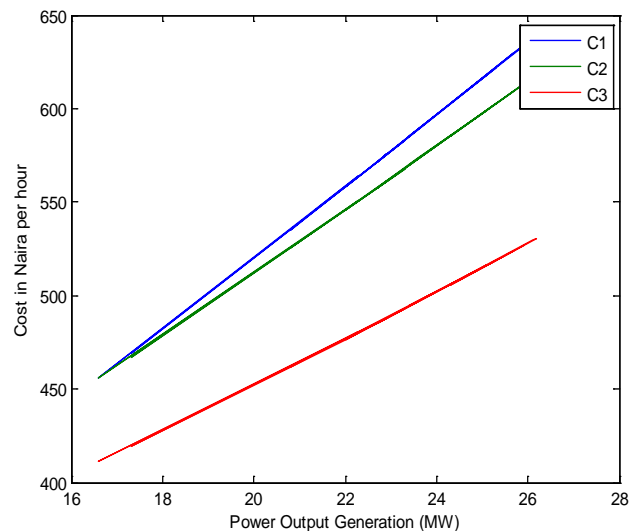


Figure 3. Line Plots of Cost vs Power output Generated for  $P_{g1}$ ,  $P_{g2}$ , and  $P_{g3}$

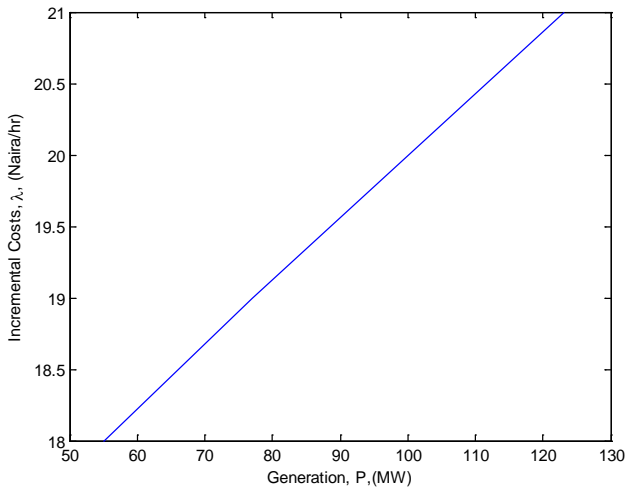


Figure 4. Line Plot of Incremental Cost (Dollar) vs Total Output (MW)  $P_{g1}$ ,  $P_{g2}$ , and  $P_{g3}$

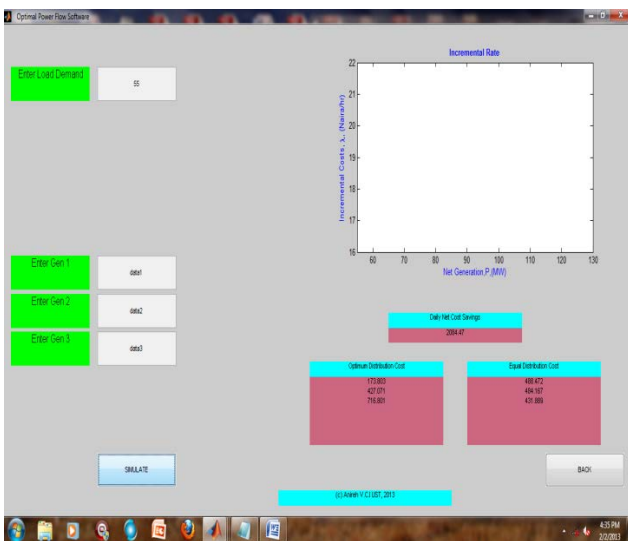


Figure 5. Sample screen for the lagrangian Optimal/Equal distribution cost with output of simulation and daily cost saving data



Figure 6. Sample screen for the lagrangian Optimal/Equal distribution cost with output of simulation, daily cost saving and incremental cost plot/data

### 5. Conclusion

Minimizing cost of fuel in generating electricity is a real world problem and requires practical solution. The

paper presented lantool, a decision support application tool designed to determine the best combination of power generating plant to produce electricity with less fuel cost. It was formulated using the lagrangian multiplier method and developed as an interactive application for operators at gas turbine generating (GTG) plant. The design uses a special object oriented methodology feature of MatLab called handle graphics technology (HGT). This approach provides the application with menu-driven guides that would enable operators with little knowledge of computer navigate through it without difficulty. Lantool can be extended to include an embedded form. When interfaced with a sensor can automatically control the switching of power plant for optimal operation. Simulation data from other stations tested on lantool show no significant difference in result implying that the system can be deployed in a dissimilar geographical location.

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