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On Optimal Planning of Electric Power Generation Systems

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Abstract. Adequate electric power generation depends on many factors which include: investment cost, fuel cost, maintenance cost, operation cost, number and capacity of generators. And because of the increasing demand for electric energy day in day out due to exponential increase in population, industries and organizations, there is need for optimal future planning in an attempt to meet the demand of the people. In this work, we present a linear programming model which based on integer formulation of electric power system generation in an attempt to optimally planning, minimize, and predict the future cost of generation. The model was solved using an iterative optimization method named 'branch and bound' and real life data was used for better understanding. The result obtained shows that the cost of generation can be minimized with maximum output and the future cost of generation can also be determined for optimal planning.

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Generation, Future cost. Optimal planning, Linear programming, Branch and Bound,

1. Introduction

Adequate Electric power supply is a prerequisite to any nations development, its facilitates the widespread establishment of industries as well as improving the standards of living which vary directly with the power availability per capital of any nation. In generating electric power to meet the require demands of the population, dependency of the unity, operation cost of station, operation cost of the equipment according to the occupied standard, the technical and operational constraints imposed by the equipment capacity among others must put into consideration, Aderinto and Bamigbola (2012), Khodr and Gomz (2002), and kaarath and Pardalos (2009).

The power generation industry utilizes economic dispatch in making generation scheduling decision and expansion. The optimal decision of generating units has the potentials of saving a nation or power industries millions of dollars. With these views, we have interest in the application of this concept to study electric power generating system. In a nation like Nigeria, where there is need for more generations of electric power because of the increasing in demand every day. Electric power can be generated via gas turbine, hydro turbine, combined cycle, diesel turbine, and steam turbine, Aderinto and Bamigbola (2017). However, gas turbine is gaining grounds in Nigeria because of its availability (when compare to other types of electric power plants), and to minimize the wastage from gas production in the country. This research is centered on gas turbine mode of generation.

2. Literature Review

Several authors have researched on electric power generation, the Branch and Bound method, and the likes in solving electric power generation problems. Aderinto and Bamigbola (2017) studied optimal control of air pollution through electric power generation systems. Salaudeen and Aderinto (2014) explored the use of iterative methods to solve electric power flow problems. In (2012), Aderinto and Bamigbola used Runge kutta fourth order method to qualitatively studied electric power generation systems model. Land and Doig (1960) described Branch and Bound method as an optimization algorithm designed for finding optimal solutions of various discrete and combinatorial optimization problems. Basically for solving Linear and non-linear integer programming problems. Youngho and Yanfei (2012) used Branch and Bound to solve dynamic linear programming model developed for meeting the supply of power across the Asia countries and meeting the need of the people. Among other authors who studied Branch and Bound technique are Gupta and Payal (2012), Khodr and Gomez (2002) to mention a few.

In this work, the aim is to optimally forecast an electric power generation systems and in order to do that we formulate an integer linear programming model that would minimize the cost of electric power generation and predict the future cost of generation. The model was solved with Branch and Bound algorithm using a real data collected from a power station for better understanding of the system.

3. Materials and Method

The mathematical representation puts into consideration many factors influencing power generation such as investment cost, fuel cost, operation and maintenance cost, number of generators and its capacities. The issue of the cost of electric power generation has received some considerable attention from various researchers. In this work, we formulate a linear programming problem model for electric power generation system and apply Branch and Bound method to solve the model. Real life data focusing on gas turbine was used. The goal of the model is to help engineers to analyze and get exact result in considering cost of power generation in an attempt to reduce the problem of excessive budgeting.

3.1. **Linear Programming.** Linear programming is a powerful quantitative technique designs to solve allocation problems. It indicates the planning of decision variables which is directly to achieve the optimal result considering the limitations within which the problem is to be solved.

Theorem 3.2. *Given a standard linear programming problem, the existence of basic solution follows the existence of feasible solution, and existence of basic solution follows the existence of any optimal solution.*

Proof: (See Sharma 2009)

3.3. **Branch and Bound Method.** Branch and Bound algorithm are used to solve problems that are integer based and all we are looking for are decision variables to be integers. The algorithm consists of a systematic enumeration of all candidates solutions, where large subsets of fruitless candidates are fathomed using upper and lower bounds of the quality being optimized. After some iterations, if what we obtained as solution is an integer, then it is an optimal solution, If not you then branch to form a sub problem. The algorithm starts by initialization, node selection that is branching step, bounding step (better integer solution finding), fathoming step and finally end. For details on the Algorithm see Land and Doig (1960), Sharma (2009).

4. Formulation of the Model

For the purpose of this research, we considered Gas Power Station (GPS) because of the availability of gas in Nigeria. This model is written as an integer linear program. The objective function of cost of power generation is a single cost minimization problem presented as;

Minimize (Investment cost) + (Fuel cost) + (Operation and Maintenance cost)

$$\text{Minimize } \sum_{i=1}^{N} C_i x_i + \sum_{i=1}^{N} F_c P_i + \sum_{i=1}^{N} (C_o P_i + C_m P_i) \tag{4. 1}$$

i.e.,

$$\text{Minimize } \sum_{i=1}^{N} C_i x_i + F_c P_i + (C_0 P_i + C_m P_i) \tag{4. 2}$$

subject to

$$\sum_{i=1}^{N} (P_i - P_L) \geq P_d \text{ (active power balance limits)} \tag{4. 3}$$

$$P_{i^{min}} \leq P_i \leq P_{i^{max}} \text{ (active power generation limits)} \tag{4. 4}$$

$$Q_{i^{min}} \leq Q_i \leq Q_{i^{max}} \text{ (reactive power generation limits)} \tag{4. 5}$$

$$V_{i^{min}} \leq V_i \leq V_{i^{max}} \text{ (bus voltage limits)} \tag{4. 6}$$

$$Q_{ci^{min}} \leq Q_{ci} \leq Q_{ci^{max}}, x_i \geq P_{i^{min}}, i = 1, 2, \ldots, N \text{ (active power generation limits)} \tag{4. 7}$$

Where, c_i is the investment cost coefficient at i^{th} generator ($ / W), x_i is decision variable associate with total cost of power generated, N is number of generators, F_c is the fuel cost coefficient ($MW/Year), C_0 is the operation cost coefficient ($MW/Year), C_m is the maintenance cost coefficient ($MW/Year), P_i is real power generated at i^{th} generator (MW), P_d = electricity demand (MW), P_L = power loss (MW), $P_{i^{min}}$ is the minimum power output at index i, $P_{i^{max}}$ is the maximum power output at index i, $V_{i^{min}}$ is the minimum voltage, $V_{i^{max}}$ is the maximum voltage.
Equation (4.1) is the objective function while equations (4.3) - (4.7) are the constraints, and are respectively active balance equations, active power generation limits, reactive power generation limits, bus voltage limits, and VAr source installation limits.

5. Numerical Application

The formulated model was solved with Branch and Bound method using real life data. 2 and 5 generators were considered. Maple 18 was used as computational software, Alper and Martin (2004). The case study for this research was 336MW Papalanto Gas Turbine Power Plant Olorunshogo, Ogun state, Nigeria. This generating station has eight (8) power plant. The other information for the power station is found in the tables 5.1, 5.2, and 5.3 below. Table 5.1 contains the information about investment, fuel cost coefficient and number of plant, cost of operation and maintenance and information about electric power loads. Table 5.2 presents the limit of power expected from each generator. Table 5.3 gives the number of generators, total megawatt, total voltage and capacity of generator.

TABLE 1. Generation Data from Olorunshogo Power Station (Cost Coefficient)

Units	Capacity (MW)	ICC($/Year)	OCC($/MW/Year)	MCC($/MW/Year)	FCC ($/MW)
PG65881B	42	5000000	31801666	477554.92	12569781

TABLE 2. Electric Power Load

State	Load (MW)
Minimum	35
Average	38
Maximum	42

TABLE 3. Electric Power Output

Number of generator	8
Total megawatt	336
Total Voltage	16.3kv

Minimize

$$P = \sum_{i=1}^{5} C_i x_i + \sum_{i=1}^{5} f_c p_i + \sum_{i=1}^{5} c_o p_i + \sum_{i=1}^{5} c_m p_i$$

Subject to

$$\sum_{i=1}^{5} x_i + \sum_{i=1}^{5} p_i + \sum_{i=1}^{5} p_i + \sum_{i=1}^{5} p_i \le -10$$

$$\sum_{i=1}^{5} p_i + \sum_{i=1}^{5} p_i + \sum_{i=1}^{5} p_i \le -10 \le 200$$

$$32 \le p_i \le 42$$

$$x_i, p_i > 0$$

Where p_i and x_i are integers, c_i is the investment cost, f_c is the fuel cost, c_0 is the operation cost, c_m is the maintenance cost.
The problem was solved at $c_i = 1190476.19; i = 1(1)5$, and $p_i = 224246.0184, i = 1(1)5$.
We assume the exchange rate for Dollar to Naira to be 1 dollar to 180 naira.

Solution
$x_i = 42; i = 1(1)5 \quad p_i = 40$
The respective costs are shown in table 4

TABLE 4

Cost	Value ($)
Investment	250,000,000.00
Fuel Cost	12569781.00
Maintenance Cost	31801668.00
Operation Cost	477555.00

Optimal Value (P) = 294849204

Minimize

$$P = \sum_{i=1}^{2} C_i x_i + \sum_{i=1}^{2} f_c p_i + \sum_{i=1}^{2} c_o p_i + \sum_{i=1}^{2} c_m p_i$$

Subject to

$$-\sum_{i=1}^{2} x_i + \sum_{i=1}^{2} p_i + \sum_{i=1}^{2} p_i + \sum_{i=1}^{2} p_i \leq -4$$

$$\sum_{i=1}^{2} p_i + \sum_{i=1}^{2} p_i + \sum_{i=1}^{2} p_i \leq -10 \leq 80$$

$$32 \leq p_i \leq 42$$

$$x_i, p_i > 0$$

where p_i and x_i are integers
The above was solved at $c_i = 1190476.19; i = 1(1)2$, and $p_i = 224246.0184; i = 1(1)2$

Solution
$x_i = 42; i = 1(1)5 \quad p_i = 40$
The respective costs are shown in table 5.5

TABLE 5. Result for 2 generators

Cost	Value ($)
Investment	99999999.00
Fuel Cost	5027913.00
Maintenance Cost	12720666.00
Operation Cost	191023.00

Optimal Value (P) = 117939681

6. INTERPRETATION OF THE RESULT

From the result obtained, Two (2) units of PG6581B was considered with 119047.19 ($/MW/year) and the Maintenance cost of 2380.9523 ($/MW/year), Operation cost coefficient 159008.33($/MW/year) and Fuel cost of 62669.3385. The Optimal Value (P) = 294849204 is obtained which converges with the actual value gotten from the power station (Olorunshogo power station, Ogun state). Also, we considered five (5) generating units of generators with the same cost coefficients and Optimal Value (P) = 117939681 is obtained as presented in tables 5. 4. and 5.5. This shows that the cost of generation can be minimized with maximum generation output. In addition, if we intend to increase the number of generators in future the model is capable of giving us the expected budget

7. CONCLUSION

Generation of electric power system model is formulated as an Integer linear programming model (ILPM) in order to minimize the cost of power generation and predict the future cost of electric power generation. The model was solved by Branch and Bound algorithm using real life data from electric power generating station (five (5) and two (2) power generators) and the result obtained showed that the model and the method can assist in economic dispatch of electric power generation.

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Author's contribution: the first and second authors gave the idea of the main results. All authors contributed to the writing of this paper. All authors read and approved the final manuscript.

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