OPTIMAL FUEL COST OF POWER GENERATION IN NIGERIA: A CASE STUDY OF OMOKU POWER STATION

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ABSTRACT
Nigeria is faced with endemic electricity generation problem which has remained a big obstacle to her becoming one of the developed nations of the world despite her being endowed with vast natural resources. There exist many power generating stations in Nigeria that are not operating at full capacity. Many methodologies of optimizing the cost of fuel in running generating stations are in existence but this study focuses on optimizing the cost of fuel in power generation using maximum output approach (Lagrange Multipliers method of solution) with the MATLAB/SIMULINK and MINITAB software packages as tools for the analysis. The study presents an effort to help in solving high cost of power generation in Nigeria. The aim of this study is to minimize the cost of power generation in Nigeria using Omoku Power Station as a case study. The expected overall outcome is to solve the cost function equations under the given constraints for improved performance. The cost function equations or cost models and constraints for obtaining minimized cost values are formulated for the Omoku generating station turbines as non-linear equations. The two (2) different test cases of the six (6) turbines at the Omoku power generating station were considered by keeping the generated power constant within 24 hours of operation daily for a month and varying the number of hours of operation of the station yielded only 3% fuel cost saving while varying the generated power between 18 MW and 25 MW under fixed operating hours a month yielded 32% fuel cost saving. The results so obtained from the varied exercises showed huge savings in fuel consumption better when the operating hours are kept constant. These results showed that the fuel cost of power generation can be minimized with maximum output. The system will assist operators in power generation stations or the Generating Companies of Nigeria (GENCOS) to minimize their costs of power generation so as to plan for generation in the most economic and efficient manner.

Keywords: Optimal cost, power generating stations, fuel cost, MATLAB/SIMULINK and MINITAB software packages.

1.0 INTRODUCTION
The high demand and use of power in various industries and organizations is one amongst many reasons that necessitated the issue of power generation optimization. Nigeria expends millions of naira on daily, monthly and annual basis to generate power from fossil fuels (oil and natural gas) and nuclear energy to meet the needs of industries and individuals in their energy demands (Oluwatoyin *et al*., 2019; Obi *et al*., 2021). Notwithstanding the energy needs of these industries and individuals, the power generating companies try to device a means of reducing the running costs of their generating systems and cost incurred due to technical and non-technical losses in order not to be financially exhausted (Uthman, 2017; Udodiri *et al*., 2022; Obi *et al*., 2022; Chiogu, 2023).
Nigeria is challenged with gross electricity problems, which are obstructing its development not minding the availability of enormous natural resources in the country (Sambo *et al*., 2010; Uhunmwagho and Okedu, 2014; Adoghe *et al*., 2023). It is widely acknowledged that there exists strong correlation between socio-economic development and availability of electricity (Falk *et al*., 2021; Moses and Oludolapo 2021; Obi *et al*., 2021, Ukoima and Ekwe 2021). Reliable power production is essential to the profitability of electricity utilities

(Haruna *et al*., 2017) and this can only be achieved when the power generators are efficiently scheduled and optimized (Buraimoh *et al*., 2017). However, efficient generation is dependent on investment cost, fuel cost, maintenance cost especially on protection schemes as any shortfall in this will result in huge financial implications, operation cost, number and capacity of generators (Oviroh and Jen, 2018; Soto, 2018; Nwachi *et al*., 2022). Large scale storage of generated electricity is of utmost importance (Elshurafa, 2020), and in order to match supply with demand of electricity, optimization of electric power generation for expansion planning and cost-solving can be solved in isolation from one period to the next in a consistent and continuous program for different look-ahead periods. Hence, this paper looks at the optimal cost of one generating station in Nigeria and various ways of improving its performance which will serve as a model to the other generating stations in Nigeria.

1.1 Concept of Optimization (Optimal Cost)

An optimization problem is the one requiring the determination of the optimal (maximum or minimum) value of a given function known as the objective function subject to a set of stated restrictions or constraints placed on the variables concerned and they are often difficult to solve (Nikhitha-Pai, 2019; Alena *et al*., 2022).
Optimization is equally a process of deriving the best result under given circumstances that electricity is generated at the minimum possible cost (Seung-Ju and Yourim, 2020). Optimization methods are modeled to give the "best" values of system design and operating policy variables –values that will lead to the highest levels of system performance. Therefore, the target is to get the cost of generation to be less than the cost of selling power, hence, there should be reduction in generation cost and ultimately fuel cost (Haruna *et al*., 2017). The elements that make up the expenditure of a power plant which include: Cost of Fuels, Labour Cost, Cost of Maintenance and repairs, Cost of stores (other than fuel), Supervision and Taxes are critically evaluated
The generator cost is typically represented by four curves –fuel cost, heat rate, input/output (I/O) and incremental cost and these are generally represented as cubic or quadratic functions and piecewise linear functions. They went further to state that thermal power plant uses a quadratic fuel cost function such as the fuel curve Equation (1).

$$C_i(P_{gi}) = a + bP_{gi} + cP_{gi}^2 \quad (1)$$

where

i = unit number (generator)
Ci = operating cost of unit
Pgi = Electrical power output (power generation) of a unit
a, b & c = fuel cost coefficients of unit i.

Lagrange multipliers were used to analyze the model. Fuel is the heaviest cost item of operating cost in a thermal power station. Fuel quality and maximum economy of its use are very important considerations in a thermal plant design. In hydro plants, the absence of fuel factor in cost is responsible for lowering operating cost.

2.0 SUMMARY OF LITERATURE REVIEW

Aderinto *et al*., (2021) considered the optimization of the electric power system with transient stability restrictions and proposed the LAHC method to address the TSCOPF problem. The answers produced by the LAHC algorithm are effective and precise in resolving the TSCOPF problem and can be used to discover a worldwide, stable and monetary solution for the power system. Pazheri *et al*., (2018) concentrated on minimization of fuel cost and transmission loss during power dispatch and formulated an optimization problem with objectives of minimization of both fuel cost and transmission loss using MATLAB simulations. Khare *et al*., (2018) arrived at the conclusion that generation cost changes as a result of factors such as location, age maintenance practices and operation efficiency of the power plant and a detailed study of generation. Aderinto *et al*., (2018) analyzed five (5) power generating stations and two (2) power generators with real life data using branch and bound algorithm. Their result showed that the model and the method can assist in Economic Load Dispatch (ELD) of electric power generation. Buraimoh *et al*., (2017) carried out optimization analysis by formulating ELD problem using MATLAB Software packages which displays the efficiency and cost-effectiveness of operating and generating power in the expanded grid. Yusuf *et al*., (2017) looked at optimization approach to power generation and scheduling and using the data obtained from the Bureau of Statistics modelled then as a non-linear programming problem (polynomial of second degree). Their result showed that the original cost of electricity production is not shown in the consumer tariff, to be cost-reflective and provide financial incentives for immediate investments in the industry. Uthman (2017) developed a study in an effort to solve optimal power flow (economic dispatch) problem by minimizing the cost of generation using the Lagrangian multiplier method. Induja *et al*., (2016) experimented the fuel cost minimization for a thermal power plant using Particle Swarm Optimization algorithm.

From the reviewed literatures, no study has been conducted on the optimal cost of power generating stations in Nigeria with a view to reducing the cost of generation of electricity in Nigeria and this is the gap this paper wants to fill. Earlier studies dwelt on economic load dispatch, optimization of generated power and maximization of power generation schedules. Also, most studies were done using Lagrange multipliers and Particle Swarm Optimization (PSO). This study therefore, deviated from the norm by using two software packages to do the optimal costing of fuel used in power generation stations that gave almost similar results showing that the study was properly conducted. Hence, in this paper, the theory of optimal cost would be extracted and adopted from the study carried out by Uthman (2017) with regards to Lagrange multipliers method of solution and applied to the power station in Omoku generating station to minimize the cost of power generation in Nigeria using Lagrange method to model the equations and MATLAB/SIMULINK and MINITAB software packages as a tool for analysis of the modeled equations.

3.0 METHODOLOGY

The materials used for this work are MATLAB/SIMULINK R2013b software, MINITAB 18 Statistical software, and a Dell Window10 laptop.

3.1 Model Formulation

The operating capacity of Omoku power generating station, Rivers State Nigeria is shown in Table 1.

Table 1: Installed/operating capacity of Omoku power generating station, Rivers State Nigeria

Station	IPP
Type (Gas/Steam/Hydro)	Gas
Rating (MVA)	24.14
Terminal Voltage (kV)	11
Rated P.F. (P.U)	0.8
Rating (MW)	25
Annual Operating Hours (Hours)	8760
Present Capability at Peak (MW)	80
Efficiency (%)	23
Fuel Cost (US Cent/kWh)	15
Total Operating Hours up to end of November 2015	8016
Planned De-Commissioning (End of Life Cycle)	25 years
Unit Transformer Voltage Ratio (kV/kV)	11 kV/33 kV

Vital information obtained from the Table 1 are given in Table 2

Table 2: Omoku power generating station figures

Installed capacity	150 MW
Operating capacity	126 MW
Diesel Cost/MWh ($0.15/KWh) in Naira@305.9	₦45,885/MWh
Hours/day	24 hr/day
Hours/month	720 hrs/month

Total load served by six (6) turbines is 150 MW (150,000 KW)
For Omoku power system with six (6) turbines, we have the equation thus

$$C_i = x_i + y_iP_i + r_iP_i^2 \quad (2)$$

Reducing the cost of the total power generated by all the turbines can be achieved by minimizing the Equation (2).

For n turbines in the Omoku generating station (6 in this case), the total fuel burnt by all plants is

$$C_t = \sum_{i=1}^{6}(x_i + y_iP_i + r_iP_i^2) \quad (3)$$

This equation is known as the objective function (OF)

So, minimize Equation (3)

$$C_t = \sum_{i=1}^{6}(x_i + y_iP_i + r_iP_i^2) \quad (4)$$

For Omoku Power system with six (6) turbines, we have the equation thus

$$Ct = \sum_{i=1}^{n}\sum_{j=1}^{n}(x_iP_{ij}) \quad (5)$$

$$Ct = \sum_{i=1}^{6}\sum_{j=1}^{6}(x_iP_{ij}) \quad (6)$$

where

$x_i, y_i,$ etc = fuel cost coefficients (in Naira/MWh)

n = number of turbines

P_i = real power generated by each unit

Ci = Fuel cost of each turbine

Ct = Total fuel cost of the six turbines combined P_{ij} = real power generated by each unit

Table 3: Varied operational capacity and fixed operational hours in a month

Turbine No.	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Installed capacity (MW)	25	20	18	20	25	18	126
Fuel cost/day (₦/MWh)	1,147,125	917,700	825,930	917,700	1,147,125	825,930	5,781,510
Fuel cost/month (₦/MWh)	34,413,750	27,531,000	24,777,900	27,531,000	34,413,750	24,777,900	173,445,300
Total operating hours	720	720	720	720	720	720	
Fuel cost coefficient	1593.23	1274.58	1147.13	1274.58	1593.23	1147.13	
Fuel cost coefficient parameter	x_1	y_1	r_1	t_1	u_1	v_1	
Total hourly expenditure (₦/hr)	1593.23	1274.58	1147.13	1274.58	1593.23	1147.13	

1). Optimize

$$C_1 = x_1 + x_1P_1 + x_1P_1^2 \quad (7)$$

$$C_2 = y_1 + y_1P_2 + y_1P_2^2 \quad (8)$$

$$C_3 = r_1 + r_1P_3 + r_1P_3^2 \quad (9)$$

$$C_4 = t_1 + t_1P_4 + t_1P_4^2 \quad (10)$$

$$C_5 = u_1 + u_1P_5 + u_1P_5^2 \quad (11)$$

$C_6 = v_1 + v_1P_6 + v_1{P_6}^2$ (12)
Subject to $18 \leq Pi \leq 126$ MW

Table 4: Fixed operational capacity and varied operational hours in a month

Turbine No.	1	2	3	4	5	6	Total
Installed capacity (MW)	25	25	25	25	25	25	150
Fuel cost/day (₦/MWh)	1,147,125	917,700	825,930	917,700	1,147,125	825,930	6,882,750
Fuel cost/month (₦/MWh)	34,413,750	34,413,750	34,413,750	34,413,750	34,413,750	34,413,750	206,482,500
Total operating hours	720	696	672	648	624	600	
Fuel cost coefficient	1593.23	1648.17	1707.03	1770.25	1838.34	1911.88	
Fuel cost coefficient parameter	x_2	y_2	r_2	t_2	u_2	v_2	
Total hourly expenditure (₦/hr)	1593.23	1648.17	1707.03	1770.25	1838.34	1911.88	

2). Optimize
$C_1 = x_2 + x_2P_1 + x_2{P_1}^2$ (13)
$C_2 = y_2 + y_2P_2 + y_2{P_2}^2$ (14)
$C_3 = r_2 + r_2P_3 + r_2{P_3}^2$ (15)
$C_4 = t_2 + t_2P_4 + t_2{P_4}^2$ (16)
$C_5 = u_2 + u_2P_5 + u_2{P_5}^2$ (17)
$C_6 = v_2 + v_2P_6 + v_2{P_6}^2$ (18)
Subject to $18 \leq Pi \leq 126$ MW

3.2 Method of Data Analysis

The fuel cost of the generating station will serve as the objective function (OF) and the existing or operating capacity will serve as the constraints. This will involve a lot of equations that can only be solved by computer-aided optimization methods.
These Equations (7) to (18) are solved using the following software packages:

a) MATLAB/SIMULINK R2013b software package
b) MINITAB 18 statistical software package

4.0 RESULTS AND DISCUSSION

Varying operating capacity and fixing operating hours in a Month using Matlab/Simulink software package for the analysis by optimizing Equations (7) to (12) as detailed in Table 3 with the data, we have, Figure 1 and Figure 2. From the line graph of Figure 1 and bar chart of Figure 2, it can be deduced that when the operating capacity of the generating station is varied between 18 MW and 25 MW with the operating hours fixed, there is increment in the cost of fuel with increase in the operating capacity.

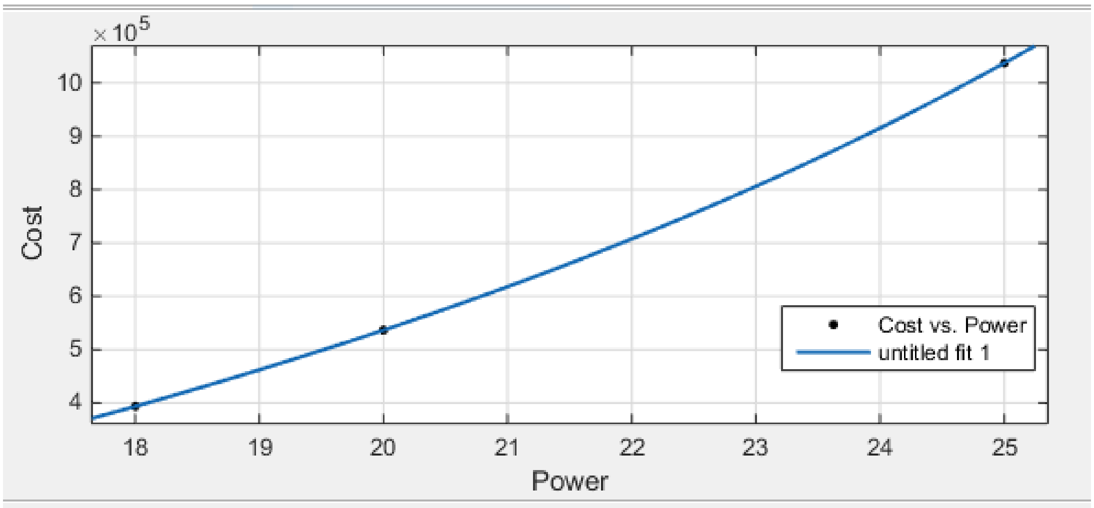

Figure 1: Line graph representation of optimized fuel cost for varied operating capacity and fixed operating hours

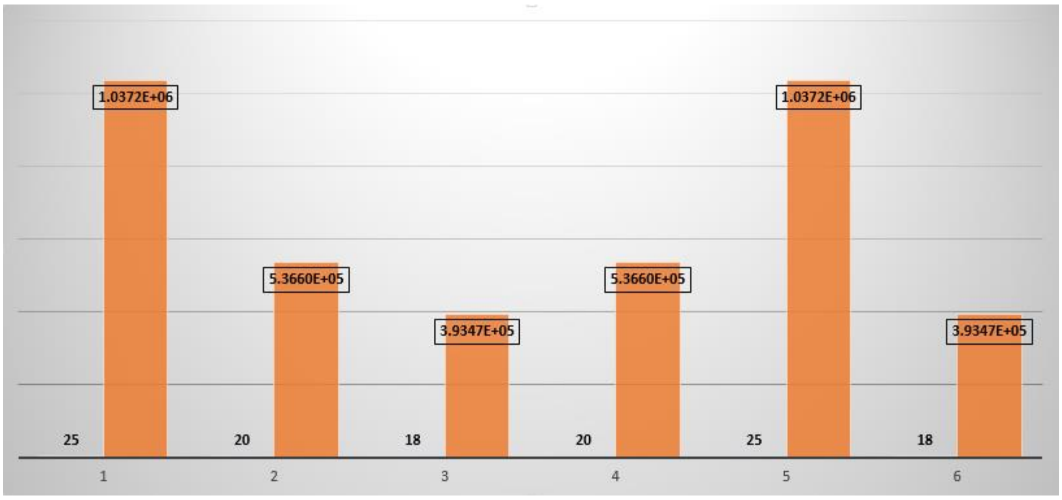

Figure 2: Bar chart representation of optimized fuel cost for varied operating capacity and fixed operating hours

Fuel cost optimization & comparison in naira for varied operating power capacity and fixed operating hours in a month using Matlab approach for the analysis.

Table 5: Varied operating capacity and fixed operating hours in a month using MATLAB

Turbine No.	1	2	3	4	5	6	Total
Fuel cost/month	34,413,750	27,531,000	24,777,900	27,531,000	34,413,750	24,777,900	173,445,300
Optimized fuel cost	31,116,000	16,098,000	11,804,100	16,098,000	31,116,000	11,804,100	118,036,200
Cost differential	3,297,750	11,433,000	12,973,800	11,433,000	3,297,750	12,973,800	55,409,100

The analysis gave rise to 32% cost saving in fuel usage after optimized costing was applied. Fixed operating capacity versus varied operating hours in a month using Matlab/Simulink software package for analysis by optimizing Equations (13) to (18) as detailed in Table 4 with the data, we have Figure 3 and Figure 4. From the line graph of Figure 3 and bar chart of Figure 4, it can be deduced that when the operating capacity of the generating station is fixed between at 25 MW with the operating hours varied, the fuel cost increases minimally with increase in the operating hours.

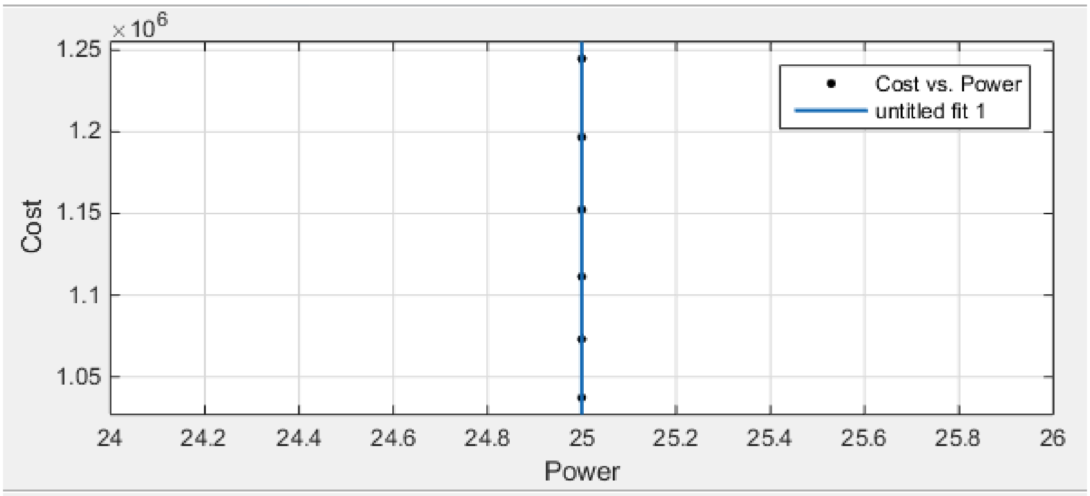

Figure 3: Line graph representation of optimized fuel cost for fixed operating capacity versus varied operating hours in a month.

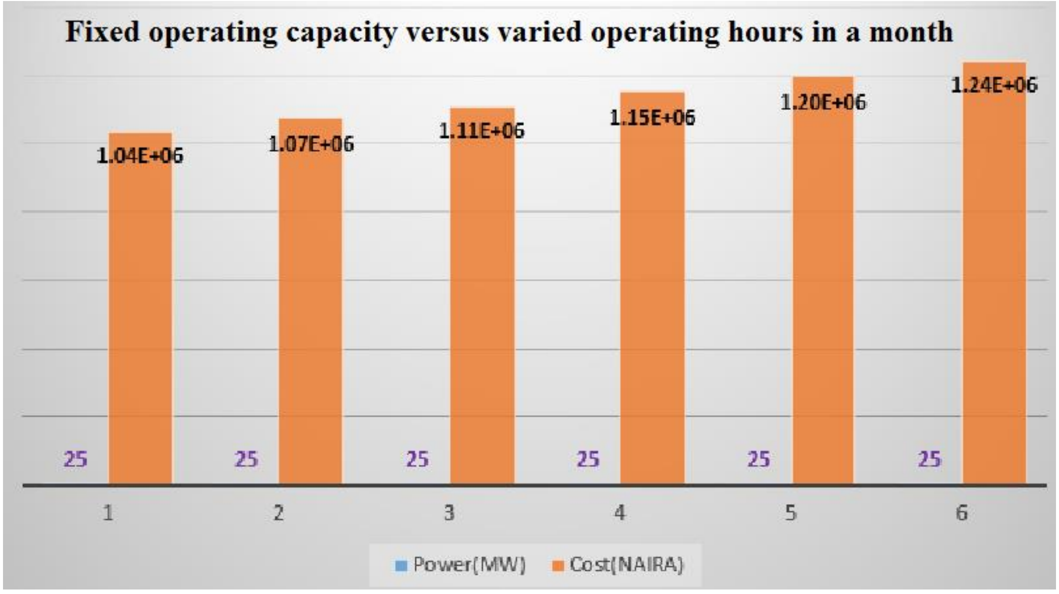

Figure 4: Bar chart graphical representation of optimized fuel cost for fixed operating capacity versus varied operating hours in a month.

Fuel cost optimization and comparison in naira for fixed operating capacity and varied operating hours in a month using MATLAB/SIMILINK for analysis

Table 6: Fixed operating capacity and varied operating hours (MATLAB)

Turbine No.	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Fuel cost/month	34,413,750	34,413,750	34,413,750	34,413,750	34,413,750	34,413,750	206,482,500
Optimized fuel cost	26,670,900	32,190,000	33,339,000	34,572,000	35,904,000	37,338,000	200,013,000
Cost differential	7,742,850	2,223,750	1,074,750	-158,250	-1,490,250	-2,924,250	6,469,500

The analysis gave rise to about 3% cost saving in fuel usage after optimized costing was applied. And the more the hours are increased, the more the fuel cost is increasing.

The results obtained using MATLAB/SIMULINK & MINITAB Software for the analysis are same. Optimal cost calculation for varied Operating capacity and fixed operating hours in a month using MINITAB Software package for the analysis by optimizing Equations (13) to (18) as detailed in Table 5 and 6 with the data, we have Table 7, Figure 5 and Figure 6. From the line graph of Figure 5 and bar chart of Figure 6, it can be deduced that when the operating capacity of the generating station is varied between 18 MW and 25 MW with the operating hours fixed, there is increment in the cost of fuel with increase in the operating capacity.

Table 7: MINITAB Optimal cost result of varied operating capacity and fixed operating hours in a month

Fuel coefficient parameters	Fuel coefficient values	Operating power parameter	Operating power values	Optimized fuel cost	Cost Values
x_1	1593.23	P_1	25	C_1	1037193
y_1	1274.58	P_2	20	C_2	536598
r_1	1174.13	P_3	18	C_3	402727
t_1	1274.58	P_4	20	C_4	536598
u_1	1593.23	P_5	25	C_5	1037193
v_1	1147.13	P_6	18	C_6	393466

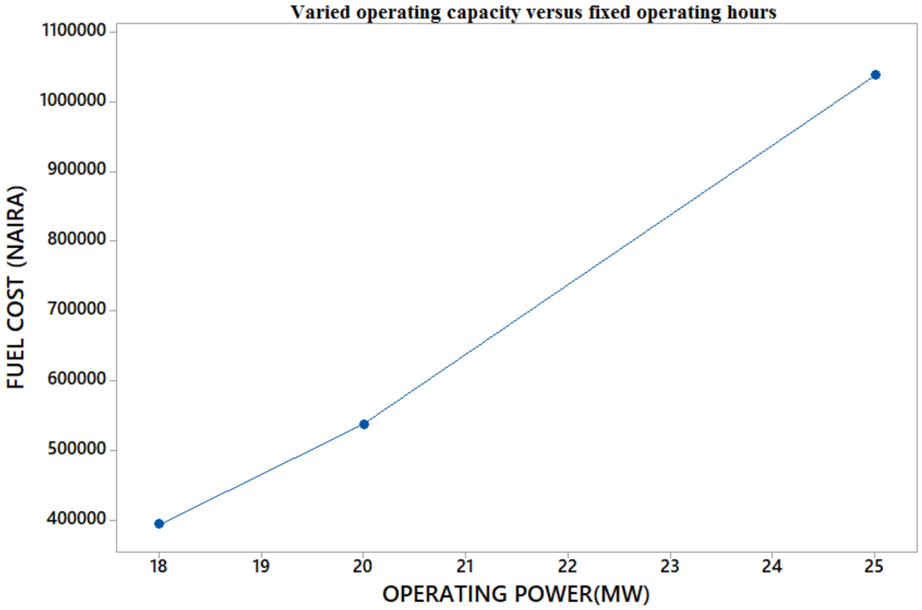

Figure 5: Line graph representation of optimized fuel cost for varied operating Capacity versus fixed operating hours.

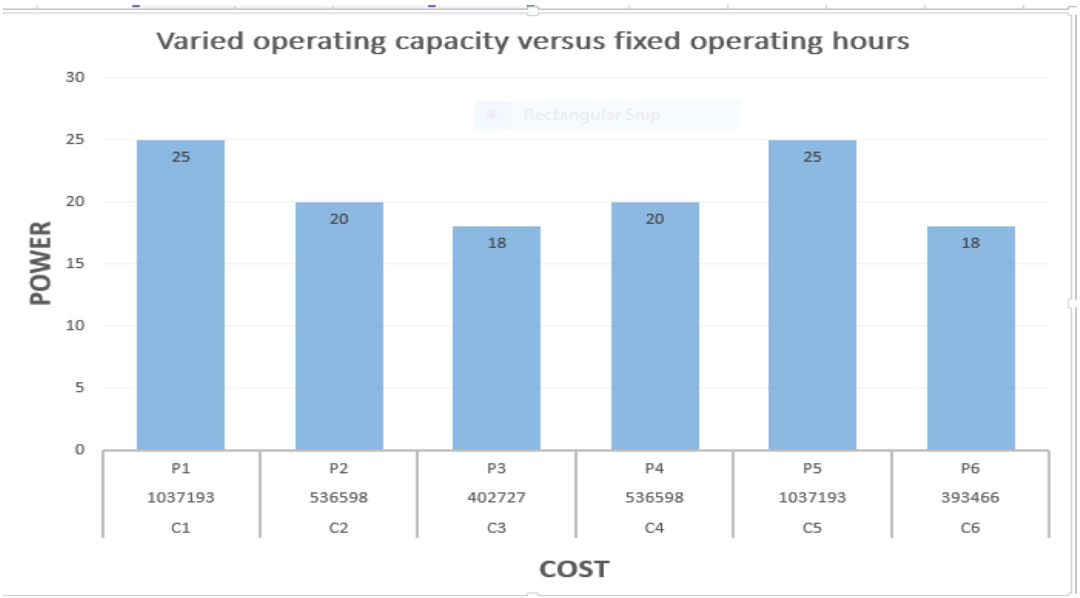

Figure 6: Bar chart graphical representation of optimized fuel cost for varied operating capacity versus fixed operating hours.

Minitab approach in fuel cost optimization and comparison in naira for varied operating power capacity versus fixed operating hours in a month. By optimizing Equations (13) to (18) as detailed in Table 8 with the data which results in Table 8, Figure 7 and Figure 8. From the line graph of Figure 7 and bar chart of Figure 8 above, it can be deduced that when the operating capacity of the generating station is fixed between at 25 MW with the operating hours varied, the fuel cost increases minimally with increase in the operating hours.

Table 8: MATLAB optimal cost result of varied operating capacity and the fixed operating hours in a month

Turbine No.	1	2	3	4	5	6	Total
Fuel cost/month	34,413,750	27,531,000	24,777,900	27,531,000	34,413,750	24,777,900	173,445,300
Optimized fuel cost	31,115,790	16,097,940	12,081,810	16,097,940	31,115,790	12,081,810	118,591,080
Cost differential	3,297,960	11,433,060	12,960,090	11,433,060	3,297,960	12,960,090	54,854,220

The analysis gave rise to 32% cost saving in fuel usage after optimized costing was applied. The results obtained using MATLAB/SIMULINK & MINITAB software for the analysis are same.

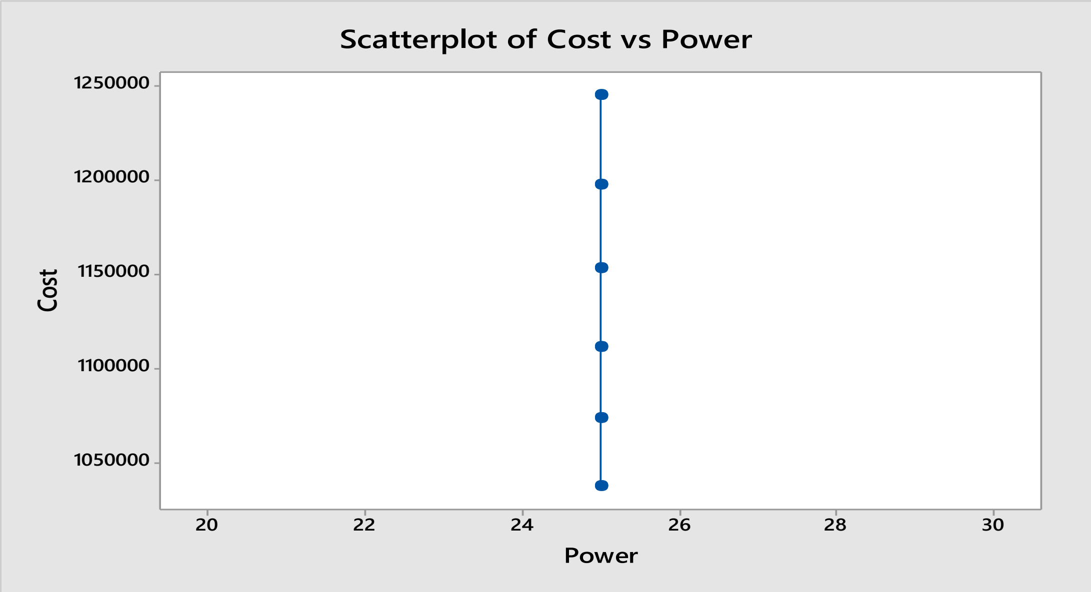

Figure 7: Line graph representation of optimized fuel cost for fixed operating capacity versus varied operating hours.

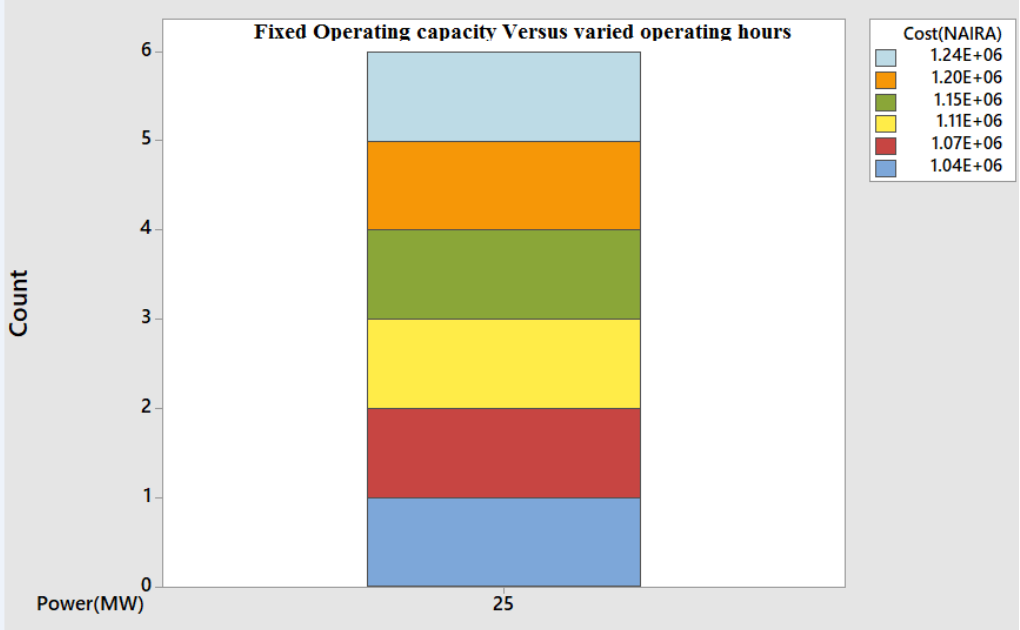

Figure 8: Bar chart representation of optimized fuel cost for fixed operating capacity versus varied operating hours

Fuel cost optimization and comparison in naira for fixed operating capacity versus varied operating hours in a month using MINITAB approach in the analysis.

Table 9: MATLAB optimal cost result of fixed operating power and varied operating hours

Turbine No.	1	2	3	4	5	6	Total
Fuel cost/month	34,413,750	34,413,750	34,413,750	34,413,750	34,413,750	34,413,750	206,482,500
Optimized fuel cost	31,115,790	32,194,710	33,339,360	34,572,030	35,904,990	37,338,000	204,464,880
Cost differential	3,297,960	2,219,040	1,074,390	-158,280	-1,491,240	-2,924,250	2,017,620

The above analysis gave rise to about 0.1% cost saving in fuel usage after optimized costing was applied. And the more the hours are increased, the more the fuel cost is increasing. The results obtained using MATLAB/SIMULINK differed by about 2.9% from using MINITAB Software for the analysis.

5.0 CONCLUSION

An optimization problem, which minimizes or maximizes a real function, is of great importance in engineering education. This work however, was particularly concerned with the optimal cost of fuel consumption in power generation stations. It looked at the financial side of fuel usage with a view to minimizing the rate at which money is being spent in the purchase of fuel to power generating stations. This was considered essential due to huge sums of expended by industries to service their operations with power and the need for fuel cost minimization. The study presents a committed effort developed to solve the optimal cost problem by optimizing the cost of generation using the MATLAB/SIMULINK and MINITAB software packages. This approach was validated by using both packages and the outcome compared separately. To determine the optimal cost of power generation in Nigeria with Omoku generating station as a case study, necessary information surrounding the running of the turbines at the station were assembled. Six (6) turbines in Omoku generating station were considered. The fuel consumption per day and by implication per month was calculated based on the available information on the station. Also, the cost in naira expended in purchasing this fuel was calculated. It is on this calculation that all the information used to further this work was anchored.

The information calculated was then analyzed and suitable methods were adopted to solve the problems generated to obtain a solution. Two case studies were carried out using these two software packages, viz: MATLAB/SIMULINK and MINITAB. The optimization with the two software packages yielded almost the same results. The following analogies are derived from the analyses: The first assumption is to vary the maximum generated power magnitude of 25 MW between 18 MW and 25 MW while the operating hours for a month of 30 days (720 hours) are fixed or kept constant. It was seen that this yielded about fifty–five million, naira in fuel cost savings. This meant reduction from about one hundred- and seventy-three-million-naira cost before optimization to one hundred and eighteen million naira after optimization. The second case study was when the generated power is fixed or kept constant at 25 MW and the hours of operation varied in the month. This yielded a cost saving in fuel of about six million naira caused by reduction due to optimization of the fuel cost from two hundred and six million to two hundred million naira using MATLAB/SIMULINK software package and two million reduction using MINITAB software package.
From the analysis, much fuel cost saving was recorded when the generated power was varied with the hours of operation fixed or kept constant giving rise to about thirty two percent (32%) followed by three percent (3%) cost saving when the generated power is kept fixed at 25 MW and the hours of generation varied. The authors therefore deem it necessary to recommend this optimal cost method of fuel cost reduction to the Generation Companies of Nigeria (GENCOS) and the National Control Centre (NCC) at Oshogbo, Osun State as it will help them in reducing as much as possible the cost of fuel usage in power generation stations in Nigeria.

REFERENCES

Aderinto, Y. O., Afolabi, A. O. and Issa, I. T. (2018). On Optimal Planning of Electricity Power Generation Systems. *Journal of Mathematics*, Vol. 50, No. 1, pp. 89-95.

Aderinto, Y. O., Salaudeen, L. O., Bamigbola, M. O. and Jimoh, F. M. (2021). Optimization of Electric Power System with Transient Stability Constrained. *Mathal Journal of Islamic and Middle Eastern Multidisciplinary Studies*, Vol. 6, No. 3, pp. 167-174.

Adoghe, A. U., Adeyemi-Kayode, T. M., Oguntosin, V. and Amahia, I. I. (2023). Performance Evaluation of the Prospects and Challenges of Effective Power Generation and Distribution in Nigeria. *Heliyon*, Vol. 9, No. 3, pp. 1-17.

Alena, V., Miroslav, G. and Luboslav (2022). Selected Mathematical Optimization Methods for Solving Problems of Engineering Practice. *Energies*, Vol. 15, No. 6, pp. 1-22.

Buraimoh, E., Ejidokun, T. O. and Ayamolowo, O. J. (2017). Optimization of an Expanded Nigeria Electricity Grid System using Economic Load Dispatch. *ABUAD Journal of Engineering Research and Development (AJERD)*, Vol. 1, No. 1, pp. 61-66.

Chiogu. E. (2023). Petroleum Industry Act and Gas Sector Optimization. *The Journal of Law and Policy*, Vol. 3, No. 1, pp. 143-164.

Elshurafa, A. M. (2020). The Value of Storage in Electricity Generation: A Qualitative and Quantitative Review. *Journal of Energy Storage*, Vol. 32, No. 4, pp. 1-18.

Falk, J., Angelmahr, M. and Schade, W. (2021). Socio-Economic Impacts and Challenges Associated with the Electrification of a Remote Area in Rural Tanzania Through a Mini-Grid System. *Energ. Ecol. Environ*, Vol. 6, pp. 513-530.

Haruna, Y. S., Yisah, Y. A., Bakare, G. A., Haruna, M. S. and Oodo, S. O. (2017). Optimal Economic Load Dispatch of the Nigerian Thermal Power Stations Using Particle Swarm Optimization (PSO). *The International Journal of Engineering and Science (IJES)*, Vol. 6, No. 1, pp. 17-23.

Induja, P., Kamalesh, M. S. and Senthilnathan, N. (2016). Fuel Cost Minimization for Thermal Plant using Particle Swarm Optimization (PSO) Algorithm. *Pak. J. Biotechnology*, Vol. 13, pp. 81-84.

Khare V., Bhargava A. & Mishra P. (2018). Estimation of Generation Cost of Electricity at 500 MW. *International Journal of Scientific Research Engineering & Technology (IJSRET)*, Vol. 7, No. 4, pp. 308-311.

Moses, J. B. K. and Oludolapo, A. O. (2021). Relationship Between Electricity Consumption and Economic Development. *Proceeding of the International Conference on Electrical, Computer and Energy Technologies (ICECET)*, Cape Town, South Africa, 9-10 December, 2021, pp. 2-8.

Nikhitha-Pai, I. V. (2019) "A Road Map of Optimization Problem Solving Techniques, Nomenclature and Algorithms. *International Journal of Engineering and Advanced Technology (IJEAT)*, Vol. 8, No. 6, pp. 5068-5071.

Nwachi, G. U., Obi, P. I., Amako, E. A. and Ezeonye, C. S. (2022). Modeling and Simulation of a Coordinated Power System Protection using Overcurrent Relay. *Nigerian Research Journal of Engineering and Environmental Sciences*, Vol. 7, No. 1, pp. 238-249.

Obi, P. I., Amako, E. A. and Ezeonye, C. S. (2022). Comparative Financial Evaluation of Technical Losses in South Eastern Nigeria Power Network. *Bayero Journal of Engineering and Technology (BJET)*, Vol. 17, No. 2, pp. 41-51.

Obi, P. I., Ezeonye, C. S. and Amako, E. A. (2021). Applications of Various Types of Circuit Breakers in Electrical Power Systems: A Review. *Arid Zone Journal of Engineering, Technology & Environment (AZOJETE)*, Vol. 17, No. 4, pp. 481-494.

Obi, P. I., Ezeonye, C. S. and Amako, E. A. (2021). Appropriate Energy Mix to Facilitate Rural Industrial Development and Economic Growth in Nigeria. *Proceedings of 3rd International Conference on Research and Innovations in Engineering*, Uyo, Nigeria, 20-24 September, 2021, pp. 13-28.

Oluwatoyin, A. M., Miebaka-Ogan, T., Popoola, O., Olawande, T., Osabohien, R., Urhie, E., Adediran, O. and Ogunbiyi, T. (2019). Electricity Consumption, Government Expenditure and Sustainable Development in Nigeria: A Co-Integration Approach. *International Journal of Energy Economics and Policy*, Vol. 9, No. 4, pp. 74-80.

Oviroh, P. O. and Jen, T. (2018). The Energy Cost Analysis of Hybrid Systems and Diesel Generators in Powering Selected Base Transceiver Station Locations in Nigeria. *Energies*, Vol. 11, No. 3, pp. 1-20.

Pazheri1 F. R., Othman M. F., Malik, N. H., Al-Ammar E. A. and Rohikaa M. R. (2012). Optimization of Fuel Cost and Transmission Loss in Power Dispatch with Renewable Energy and Energy Storages. *International Conference on Green Technologies-ICGT12, Kerala, India, 18-20 December 2012, pp. 293-296.*

Sambo, A. S., Garba, B., Zarma, I. H. and Gaji, M. M. (2010). Electricity Generation and the Present Challenges in the Nigerian Power Sector. https://www.researchgate.net/publication/228399732_Electricity_Generation_and_the_Present_Challenges_in_the_Nigerian_Power_Sector. Accessed 26/07/2023.

Seung-Ju, L. and Yourim, Y. (2020). Electricity Cost Optimization in Energy Storage Systems by Combining a Genetic Algorithm with Dynamic Programming. *MDPI Journal of Mathematics*, Vol. 8, No. 9, pp. 1-20.

Soto, D. (2018). Modeling and Measurement of Specific Fuel Consumption in Diesel Microgrids in Papua, Indonesia. *Energy for Sustainable Development*, Vol. 45, pp. 180-185.

Udodiri, A. E., Dagde, K. E. and Goodluck, T. O. (2022). Optimization of Diesel Blending Unit in a Nigerian Refinery Company. *Global Scientific Journals*, Vol. 10, No. 1, pp. 1139-1155.

Uhunmwagho, R. and Okedu, K. E. (2014). Issues and Challenges in the Nigerian Electricity Industry: Case of Benin Electricity Distribution Company. *Journal of Energy Technologies and Policy*, Vol. 4, No. 9, pp. 35-39.

Ukoima, K. N. and Ekwe, O. A. (2021). Review of the Impact of Electricity Supply on Economic Growth: A Nigerian Case Study. *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, Vol. 14, No. 1, pp. 28-34.

Uthman S. (2017). Cost Minimization of Power Generation in Kaduna State University: The Lagrange method.

Yusuf, M., Halilu, M., Umar, I. and Filli, K. B. (2017). Effect of Barrel Temperature Feed Composition and Feed Moisture Content on Some Functional Properties of Dakuwa Extrudates from Blends of Sorghum ((Sorghum bicolour L) Groundnut (Arachis hypogeal L) and Tiger nut (Cyperus esculentus). *African Journal of Food Science and Technology*, Vol. 8, No. 9, pp. 150-161.