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Economic Load Dispatch Optimization for Thermal Power Plant Using Particle Swarm Optimization and Lambda Iteration

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ABSTRACT: Nigeria's socioeconomic growth cannot improve effectively if the rate of electricity generation and dispatch continues at its current status which is due to several challenges facing the country's power industry. This study investigates the optimization of Economic Load Dispatch for six thermal power generators using Particle Swarm Optimization (PSO) and Lambda Iteration methods. The primary objective is to minimize fuel costs while meeting a total power demand of 600MW. The study employs quadratic cost functions obtained from historical datas derived from input-output characteristics of the generators and simulates both methods using MATLAB. Results indicate that PSO achieves superior cost efficiency with a total generation cost of N507,103,545 compared to N507,232,335 using Lambda Iteration. PSO with a 0.0254% improvement in cost over the Lambda iteration method, and saves about ₦128,790.0, which is minor but could be significant for large-scale dispatches Furthermore, PSO demonstrates faster convergence and greater flexibility, making it a more effective tool for modern power systems. The findings underscore the potential of advanced optimization techniques like PSO in enhancing operational efficiency and cost-effectiveness in power generation.

KEYWORDS: PSO, Economic Load dispatch, Lambda, MATLAB, Generation.

1. INTRODUCTION

Economic Load Dispatch (ELD) is a critical optimization problem in power systems, aiming to allocate generation across multiple units to minimize costs while satisfying demand and operational constraints. Nigeria's power sector faces challenges such as inefficient generation and high operational costs, necessitating innovative approaches to ELD. This study focuses on the comparative analysis of PSO and Lambda Iteration methods for solving ELD problems in a thermal power station. Also considering normal operating conditions, the generating capability is less than the load demand and losses, as such scheduling of different generating units is done in accordance to the load demand in order to reduce the price of generation and supply reliable power to end users. (Zaineb, 2021)

In this perspective, the operation of a power network with minimum generation cost is one of the very important principles that can be achieved by optimal load dispatch. Using the optimal dispatch process, the load demand can be addressed at a minimum cost (Kumar, et. al 2016).

Traditional algorithms such as Lambda iteration, Base Point Participation Factor, Gradient method and Newton method can solve ELD problems effectively, if and only if the fuel-cost curves of the generating units are piece-wise linear and monotonically increasing. Practically, the input to output characteristics of the generating units are highly non-linear, non-smooth and discrete in nature owing to prohibited operating zones, ramp rate limits and multi-fuel effects. (Haruna. et al 2017). As a result of this inherent nonlinearity, the practical ELD problem becomes a challenging non-convex optimization problem, which is difficult to solve using the traditional methods. Methods like Dynamic Programming (DP), Genetic Algorithm (GA), Evolutionary Programming (EP), Artificial Intelligence (AI), and Particle Swarm Optimization (PSO) solve non-convex optimization problems efficiently and often achieve a fast and near global optimal solution (U.O Lazarus et al 2021). Among them Particle Swarm Optimization (PSO) was developed through simulation of a simplified social system, and has been found to be robust in solving continuous non-linear optimization problems.

2. REVIEW OF RELATED WORKS

The progress of Economic Load Dispatch transcends far back as the early 1920's, when engineers were concerned with the problem of economic allocation of generation or the proper division of the load among the generating units available. A good Economic dispatch can enhance the power quality but Practical Economic dispatch (ED) problems have highly non-linear objective function with rigid equality and inequality constraints. To solve both constraints, numerous studies have been carried out on how the Economic Dispatch problem can be optimized by using particle swarm optimization and other methods.

Nguyen et al. (2023) discuss a Modern version of the Economic Load Dispatch (MELD) problem with the contribution of renewable energies and conventional energy, including wind, solar and thermal plants. Two meta-heuristic algorithm including Particle Swarm Optimization (PSO) and Equilibrium Optimizer (EO) are applied to determine the optimal solutions for MELD.

Tijanni et al. (2022) presented on the Optimization approaches to Generation Dispatch problems in review of Nigerian Power system. It highlighted on the problem of power system planning that need to be solved accurately considering different factors and constraints.

Xin et al. (2022) presents a Diversity-based Parallel Particle Swarm Optimization (DPPSO) to solve the non-convex economic dispatch problem. The population of DPPSO is divided into different groups to maintain diversity in particles so that the optimization capacity can be enhanced.

Uzoechi et al. (2021) paper presented Particle Swarm Optimization (PSO) approach for solving Economic Load Dispatch (ELD) problem for interconnected generating units. It considered most practical operation constraints of the generators.

Al. Mahfazur et al. (2021), uses the conventional approach to resolve ELD problems using the lambda iteration method under two different conditions, which are the transmission system without losses and with losses.

Zaineb et al. (2021) discussed on Economic Load dispatch using Lambda iteration, Particle Swarm Optimization and Genetic Algorithm. The ELD problem was solved using the 3 optimization methods and the respective results at different load demands were calculated considering losses.

Athe et al. (2020) analyzed the optimization of the generation cost of the Sapele Thermal Power Plant using the Particle Swarm Optimization (PSO) approach together with General Algebraic Modeling System (GAMS).

3. METHODOLOGY

3.1 Economic Load Dispatch Problem Formulation

Consider a power network with 'n' number of generator plants and a given power demand of P_D

Each plant i, has a cost-rate curve that gives the cost in ₦/hour as a function of its generation level P_{Gi}(the 3phase power). The actual power generation P_{Gi} is to be allocated to generators so that total cost of generation is minimized. The economic dispatch problem can be addressed as shown below.

The cost function is expressed as a quadratic function of active power.

$$C_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \tag{1}$$

Where a_i, b_i and c_i are fuel cost coefficients.

The total system cost is therefore given by

$$C_T = \sum_{i=1}^{n} C_i(P_{Gi}) \tag{2}$$

The objective function to be minimized is given in equation (2). Hence, the fundamental generation dispatch problem can be formulated mathematically as a minimization problem of the total fuel cost of all available and committed plants. Mathematically,

$$\text{Minimizing } \sum_{i=1}^{n} C_i(P_{Gi}) \tag{3}$$

Where $C_i(P_{Gi})$ is the fuel cost expression for the generator unit. The objective function is to be minimized subject to two basic kinds of constraints.

i. **The Power Balance Equality**: In regards to power balance, it must be the case that the total generation equals the total power demand P_D.

$$\sum_{i=1}^{n} P_{Gi} = P_D \tag{4}$$

ii. **Active Power Constraints:** Physical constraints exist on generation levels as generators cannot exceed their maximum capabilities, represented by P_{Gi}^{max} and clearly, they cannot operate below 0. Most units actually cannot operate at 0; as a result, we will denote the minimum as P_{Gi}^{min}. Therefore, the generation limits are represented by

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \qquad (i = 1,2,\dots,n) \tag{5}$$

where P_{Gi}^{min} and P_{Gi}^{max} are the minimum and maximum generation limits of the i th generator.

For minimizing (or maximizing) a function, the Lagrange multiplier λ is used. Using this method an augmented function is defined as

$$L(P_{Gi}, \lambda) = C_i(P_{Gi}) + \lambda\left(P_D - \sum_{i=1}^{n} P_{Gi}\right) \tag{6}$$

To minimize cost of generation $C_i(P_{Gi})$ subject to energy balance constraint, a necessary condition is that the partial derivative of the Lagrange function defined by $L(P_{Gi}, \lambda)$ with respect to each of its arguments must be zero. Hence, the necessary optimization problems conditions are

$$\frac{\partial L(P_{Gi},\lambda)}{\partial P_{Gi}} = \frac{\partial C_i(P_{Gi},\lambda)}{\partial P_{Gi}} - \lambda = 0 \tag{7}$$

And

$$\frac{\partial L(P_{Gi},\lambda)}{\partial P_{Gi}} = P_D - \sum_{i=1}^{n} P_{Gi} = 0 \tag{8}$$

From equation (7),

$$\frac{\partial C_i(P_{Gi},\lambda)}{\partial P_{Gi}} = \lambda \qquad (i = 1,2,\dots,n) \tag{9}$$

The above is called the coordination equation. Hence, incremental cost of the i^{th} generator becomes:

$$\frac{\partial C_i(P_{Gi},\lambda)}{\partial P_{Gi}} = 2a_i P_{Gi} + b_i \tag{10}$$

Comparing (9) and (10), we get $2a_i P_{Gi} + b_i = \lambda$ (11)

Arranging the equation, we get $P_{Gi} = \frac{\lambda - b_i}{2a_i}$ $(i = 1,2,\dots,n)$ (12)

Substituting this value of P_{Gi} in (8), we get

$$\sum_{i=1}^{n} \frac{\lambda - b_i}{2a_i} = P_D \qquad (13)$$

Alternatively,

$$\lambda = \frac{P_D + \sum_{n=1}^{n} \frac{b}{2a_i}}{\sum_{n=1}^{n} \frac{1}{2a_i}} \qquad (14)$$

Hence, λ is found out with the help of 14) and P_{Gi} is found using (12)

The economic dispatch problem is a constrained optimization problem and it can be mathematically expressed as follows:

$${}_{i=1}^{n}\text{Minimize } F_T = \sum F_i(P_i) \qquad (15)$$

Where, F_T: total generation cost (N/hr)

n: number of generators

P_i: real power generation of i th generator (MW)

$F_i(P_i)$: Generation cost for Pi

3.2 Particle swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is a population based stochastic optimization technique developed by Kennedy and Eberhart in 1995, discovered through simplified social model simulation. It stimulates the behavior of bird flocking involving the scenario of a group of birds randomly looking for food in an area. PSO is motivated from this scenario and is developed to solve complex optimization problems.

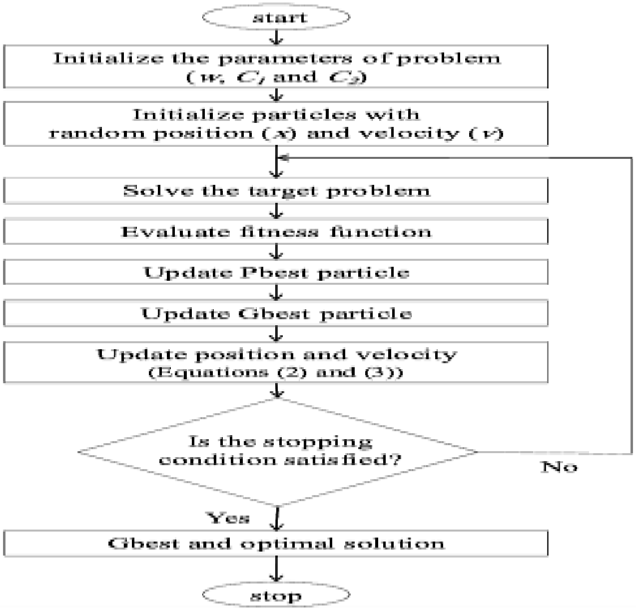

Figure 1: Particle Swarm Optimization (PSO) Flow Chart

3.3 Lambda Iteration

Lambda iteration is a traditional iterative technique used for solving non-linear programming problems such as Economic Load Dispatch (ELD) problems by iteratively updating a set of values known as multipliers or lambdas. These multipliers are used to adjust the objective function of the problem. It also works by using an iterative process to adjust the generation of each unit until the total power generation matches the system demand and all constraints are satisfied.

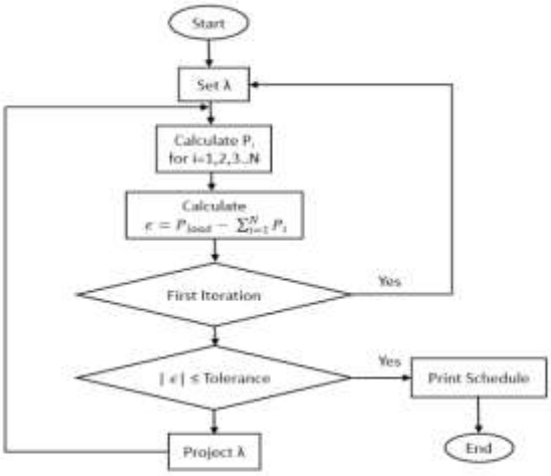

Figure 2: Lambda Iteration Flow Chart

4. RESULTS AND DISCUSSION

This section shows the results obtained from the optimization of the economic load dispatch (ELD) problem for the thermal power station with six generators. The analyses were conducted using two methods which are Particle Swarm Optimization (PSO)and Lambda Iteration method. The results are analyzed in terms of input-output curve of each generators in order to produce a polynomial fit, fuel cost, power distribution across generators, computational efficiency, and the convergence behavior of both methods. Table 1 shows the Generator Cost Coefficient with upper and lower limits of the individual generators for the six generators obtained from historical data.

The figures 3(a-f) shows the curve which represents the relationship between power output (MW) and gas consumed (MMBTU) for the thermal generators unit (GT15-20). The x-axis represents the power output of each generator and it shows the range of power outputs the generator can operate within, determined by its minimum and maximum capacity. While the y-axis represents the fuel consumed (MMBTU), which indicates how much gas the generator uses to produce the corresponding power output. The Blue circles (Data points) represent the measured or given fuel consumption data for the generators at specific power outputs, while the Red line (Polynomial fit)represents a polynomial function fitted to the data points.

Table 2 illustrates the results of the economic load dispatch (ELD) performed using the Particle Swarm Optimization (PSO) algorithm for a total power demand of 600MW. The table details the dispatched power and the corresponding generation cost for each generator unit. Unit GT18 handled the highest share of power, dispatching 121.73MW, followed closely by unit GT20 (117.50MW) and Unit GT19 (115.38MW). This suggests that these units were cost-effective for higher loads within their operational ranges. Unit GT15 was the least utilized, with a dispatched power of 49.75MW, likely due to its higher marginal costs or lower efficiency at higher loads. The total generation cost for meeting the 600MW demand is ₦507,103,545, demonstrating PSO's ability to achieve cost-efficient load dispatch by balancing power allocation among generators. The generation cost for each unit reflects its specific fuel cost function and the amount of power dispatched.

Table 3 presents the results of ELD using the Lambda Iteration method to meet a total power demand of 600 MW. The total load of 600 MW was distributed among the six generators based on the Lambda Iteration method, ensuring adherence to the generators' power limits and fuel cost characteristics. Unit GT18 was the highest-dispatched generator with a power output of 119.61MW and Unit 1 had the lowest power dispatched at 51.73MW. The generation cost for each unit aligns with the power dispatched and in each unit to a total of ₦507,232,335.0

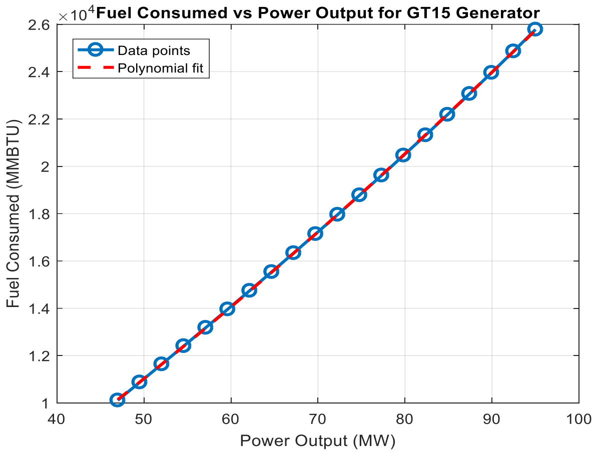

Figure 3(a)

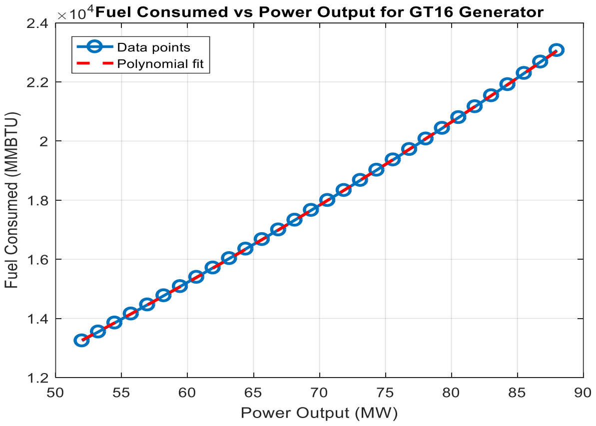

Figure 3(b)

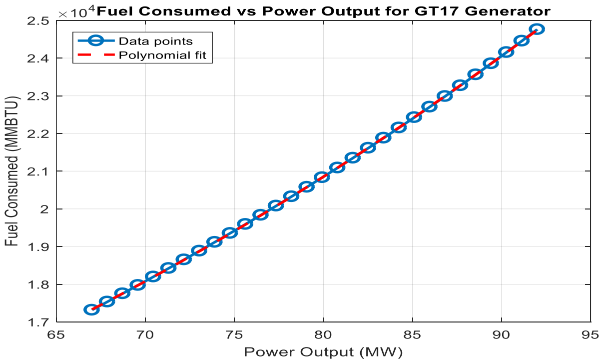

Figure 3(c)

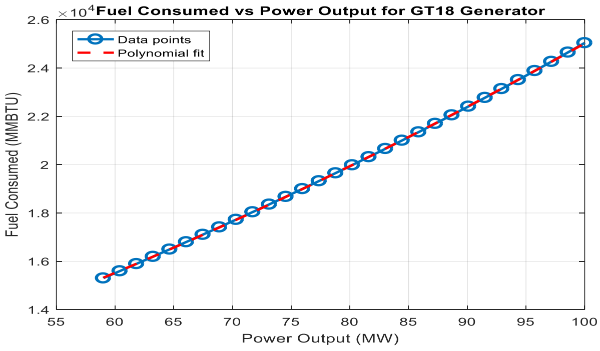

Figure 3(d)

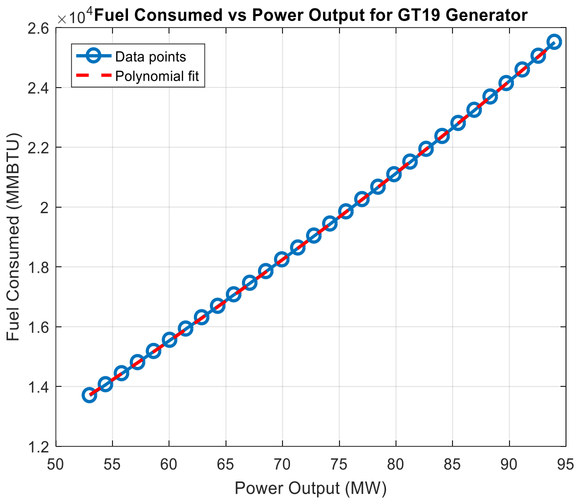

Figure 3(e)

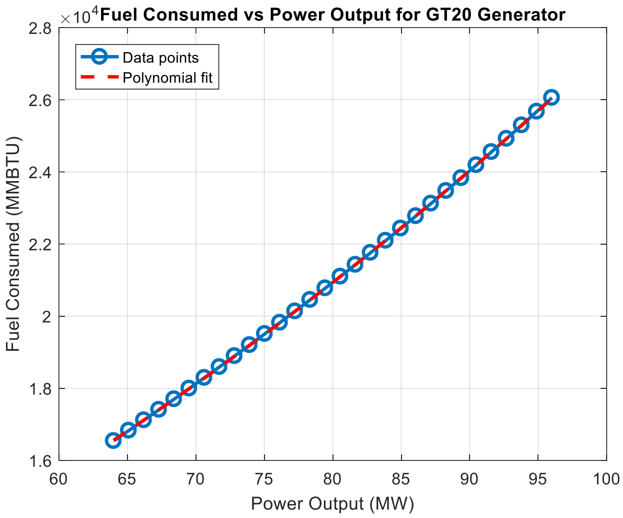

Figure 3(f)

Table 1: Generator Cost coefficient with Minimum and Maximum Power limit.

Unit	a_i	b_i	c_i	P_{imin} (MW)	P_{imax} (MW)
GT15	9.1994	563.7381	0.00175	47	105
GT16	838.669	541.3157	0.13539	52	103
GT17	12.0016	563.1692	0.00198	67	107
GT18	4.0624	563.3740	0.00067	57	115
GT19	2.9843	563.5581	0.00051	53	109
GT20	5.5565	563.3378	0.00088	64	111

Table 2: PSO Dispatched Power & Generation Cost.

UNIT	DISPATCHED POWER (MW)	GENERATION COST (₦)
GT15	49.7505	42,047,760.0
GT16	82.3832	69,628,035.0
GT17	113.2617	95,725,695.0
GT18	121.7299	102,882,795.0
GT19	115.3788	97,515,015.0
GT20	117.4958	99,304,245
TOTAL	**600.0**	**507,103,545**

Table 3: Lambda Iteration for Dispatched power & Generation Cost.

UNIT	DISPATCHED POWER (MW)	GENERATION COST (₦)
GT15	51.73	43,667,925.0
GT16	87.72	74,164,350.0
GT17	111.74	94,391,160.0
GT18	119.61	101,154,255.0
GT19	113.75	96,081,930.0
GT20	115.47	97,772,715.0
Total	**600.00**	**507,232,335.0**

Table 4 Metrics comparison between PSO and Lambda Iterative process

METRICS	PSO	LAMBDA ITERATION
Power Dispatched (MW)	600.00	600.00
Total Generation Cost (₦)	507,103,545.0	507,232,335.0
Highest Dispatch	GT18 (121.7299MW)	GT18 (119.61MW)

Least Dispatch	GT15 (49.7505MW)	GT15 (51.73MW)
Convergence Speed	Fast (20-100 iterations)	Slow (400-1000 iterations)
Handling of Losses	Yes (if modeled)	No
Flexibility	High (handles non-linear and non-convex problems)	Limited to linear/quadratic problems

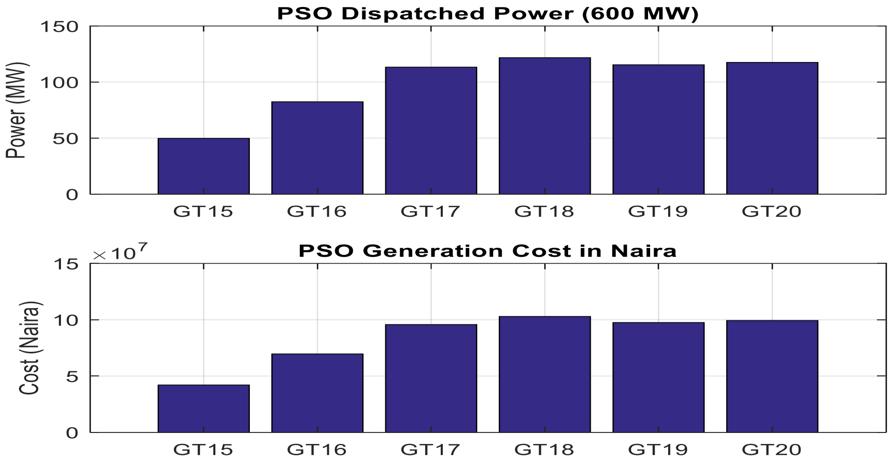

Figure 4: PSO Barchart for Dispatched power and Generation cost

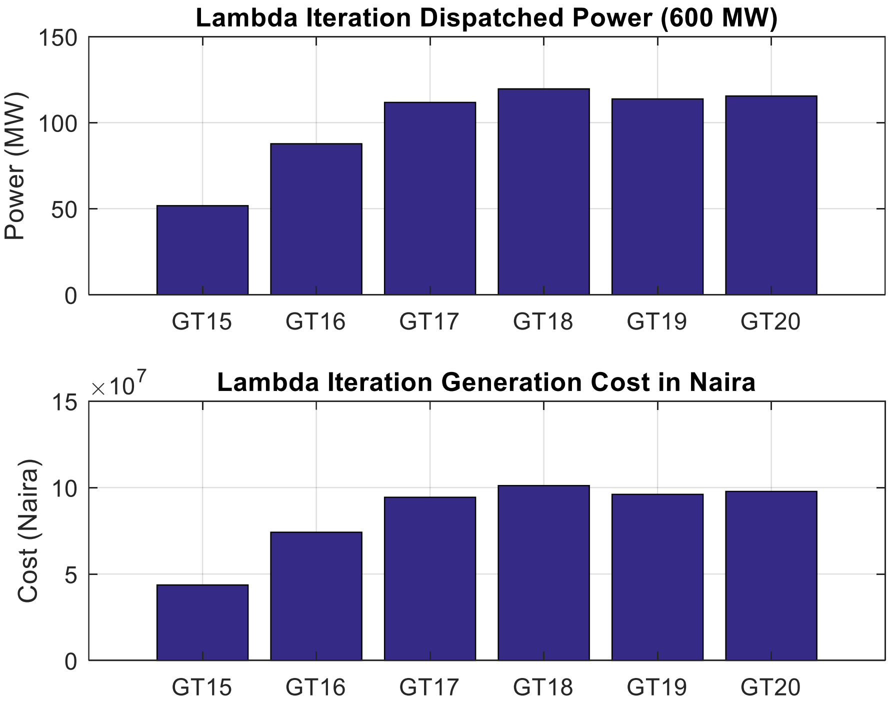

Figure 5: Lambda Dispatched Barchart for Dispatched power and Generation cost

4.1 Comparison of Results of both PSO and Lambda Iterative method

Both methods effectively optimize the dispatch of six thermal generators to the power demand of 600MW. however, the processes cater for different needs. Lambda Iteration excels in minimizing costs under simple constraints but lacks flexibility unlike the PSO. In terms of the power distribution as seen in Table 2 and 3, the total power output from the units varies approaching the load demand. Unit 4 is the highest, generating 121.7299MW and 119.61MW for both PSO and Lambda Iteration respectively. In both methods, unit 4 was tasked with the highest dispatch due to its likely optimal operating range and cost characteristics for higher outputs, followed by unit 6 dispatching around 117.4958MW and 115.47MW for PSO and Lambda respectively. Unit 1 dispatches the least power of 49.7505MW for PSO, with the lowest generation cost of ₦42,047,760.0, while for Lambda iteration unit 1 dispatched the least power of 51.73MW, also having the lowest cost of ₦43,667,925.0. In terms of convergence, PSO method converged more rapidly to the optimal solution in 100 iterations than the Lambda Iteration method that needs up to 1000 iterations to reach its optimal level.

PSO outperformed Lambda Iteration in both cost efficiency and computational speed. PSO achieved a total generation cost of N507,103,545, a marginal improvement over Lambda Iteration's cost of N507,232,335. The power distribution among generators indicated that GT18 handled the highest load due to its optimal cost characteristics.

5. CONCLUSION

The study demonstrates the efficacy of PSO as a robust optimization tool for ELD, particularly in systems with non-linear and non-convex cost functions. Its faster convergence and cost-saving potential make it a valuable approach for real-time energy management in power systems. Lambda Iteration, while effective for simpler systems, lacks the flexibility and computational efficiency required for modern power grids.

6. RECOMMENDATIONS

Utilities and energy providers are encouraged to adopt PSO for economic load dispatch to achieve cost savings and improved efficiency. Future research could explore hybrid optimization methods and the integration of renewable energy sources to enhance sustainability and reduce dependency on fossil fuels.

REFERENCES

1. Abdul Wahab N., Mohamed A. and Aini H. (2011) “Fast Transient Stability Assessment of Large Power System using Probabilistic Neural Network with feature reduction techniques”, Int. J. Expert Systems with Applications 38, pp. 11112–11119.
2. Al. Mahfazur Rahman & Md. F Islam,(2021) “Analysis of Economic Load Dispatch for a Power System Network”. The SEU Journal of Electrical and Electronics Engineering (SEUJEE), Volume 01, pp 2710-2130, 2021.
3. Alayande A.S, J.T. Olowolaju, & I. K. Okakwu (2019). Solving Optimal Generation Dispatch Problem in Power Networks through PSO and Lambda Iteration Techniques”, Nigerian Journal of Technology (NIJOTECH), Vol. 38, No. 1, pp. 165-176.
4. Alrashidi M.R., El-Hawary M. E. (2009). Application of computational intelligence Techniques for solving Optimal Power Flow problem. Electric power System. Res., Vol. 79, No. 4, pp. 694-702.
5. Athe, O. D. C. Idoniboyeobu, & S. L. Braide(2020), Optimization of Generation Cost for Economic Operation of Sapele Thermal Power Plant using Particle Swarm Optimization Method; American Journal of Engineering Research (AJER) Volume-9, pp. 167-179.
6. Buraimoh, E., Ejidokun, T. O. and Ayamolowo, O. J. (2018) “Optimization of an Expanded Nigeria Electricity Grid System using Economic Load Dispatch”, ABUAD Journal of Engineering Research and Development, Vol. 1 No. 1, pp.61-66, Oct. 2018.
7. Gabir S., and M. Agieb, (1998) “Constrained Economic Dispatch Problem and applications” Proceedings of IEEE Int. Conference on Optimal power flowvol. 67, no.8, pp.184–202.
8. Haruna, Y, S., Idris S., G. A. Bakare & A. U. Abu, (2018). Comparative Analysis of the Economic Load Dispatch Problem of the Nigerian Thermal Power Stations. GSJ: Vol.6, Issue 4, April 2018.
9. Haruna Y.S., Yisah Y.A., Bakare G.A, Haruna M.S., & Ooda 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), 2017, vol. 6, No.1, pp. 17-23.
10. Kennedy and R. C. Eberhart, (1995) “Particle swarm optimization”, Proceedings of IEEE International Conference on Neural Networks (ICNN’95), Vol. iv, pp. 1942-1948, Perth, Australia.
11. Kumar, V. J. Saraswat, (2016) “A Review on Optimization Techniques for Economic Load Dispatch Problem,” International Research Journal of Engineering & Technology, vol. 3, No.7, pp. 375-379.
12. Lazarus O. K, Uzoechi, T. J. Ibechem & Ernest Ezugwu (2021); Evaluation of Optimal Power Dispatch of the Nigerian Power System Using PSO Technique. American Journal of Engineering Research (AJER), Volume-10, Issue-03, pp-01-18. 2021.
13. Narasimha L., V Rao (2014) “PSO Technique for Solving the Economic Dispatch Problem Considering the Generator Constraints” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 3.
14. Nguyen, H. D., Truong K. H., Le N.A. (2023). The Application of Equilibrium Optimizer for solving modern economic load dispatch problem considering renewable energies and multiple fuel thermal units. Department of Power Delivery, Ho Chi Minh City University of Technology (HCMUT) IJRED 2023.
15. Okozi S. O., Ogbonna G. C., Olubiwe M. & Ezugwu E. O. (2019)‘Solution to the Economic Dispatch Problem of the Nigerian Power System using Genetic Algorithm’, Nigerian Journal of Technology

(NIJOTECH) Vol. 38, No. 4, October 2019, pp. 1036 – 1047.

16. Soleymani S., M. Hayatdavudi (2014),"Solving Economic Load Dispatch Using A Novel Method Based on PSO Algorithm & GAMS Software" International Journal Of Scientific &Technology Research Volume 3.
17. Tijanni M. A., Adepoju G. A., Okelola M O., (2022) Optimization Approaches to Generation Dispatch problems: Review of Nigerian Power System. Nigerian Journal of Technological Development , vol 19, No 2.
18. Xin J., Yu L., Li N. (2022). A diversity-based parallel particle swarm optimization for non convex economic dispatch problem. IEEE 9th Power India International conference (PIICON), Vol 25, issue 3 pp.393-399.
19. Zaineb N. J. (2021); Economic Load Dispatch using Lambda Iteration, Particle Swarm Optimization & Genetic Algorithm International Journal for Research in Applied Science and Engineering Technology (IJRASET), Vol 9.
20. Zajmi, L. A, Jaharadak, A. A. (2018). Concepts, methods and Performance of Particle Swarm Optimization, Back propagation, and Neural networks. Applied Computational Intelligence and Soft computing, vol. 2018, pp. 1-7.
21. Zhang, Y., Wang, S., & Ji, G. (2010). A comprehensive survey on Particle Swarm Optimization Algorithm & its Applications. Mathematical Problems in Engineering, vol. 2015, pp.137.