SOLVING ECONOMIC LOAD DISPATCH PROBLEM FOR OPTIMIZATION OPERATION OF ELECTRICAL POWER GENERATION IN NIGERIA

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Abstract

Due to the high demand for electric power, it is of utmost necessity to operate generating power plants economically, which gives rise to the need for Economic Load Dispatch. Economic Load Dispatch (ELD) is the process of allocating power generated by the plants/units to fulfil load demand to minimize generation fuel cost. This paper presents a method of solving the problem of economic load dispatch (ELD). Various methods and approaches have been used when it involves the ELD, some of which are genetic algorithm, lambda iteration method, Newton-Raphson method, gradient method, dynamic programming, artificial intelligence, firefly algorithm, artificial bee colony technique, particle swarm optimization method, BAT, ANT technique, etc. For the purpose of this research work, the Particle Swarm Optimization (PSO) technique is applied due to its quick

Keywords: *Economic Load Dispatch (ELD), Particle Swarm Optimization (PSO), Constraints, Loss Coefficients, Fuel Cost.*

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convergence and efficiency. To get the best result, the MATLAB 2016a software was used by considering six generating units of a generating station. A Particle Swarm Optimization (PSO) population size of 150 is considered, with load demand varying between 150MW, 200MW, 250MW, 300MW and 350MW. The result shows that the Particle Swarm Optimization (PSO) technique was indeed capable of obtaining higher quality solutions efficiently for Economic Dispatch Load (ELD) problems before 3000 iterations of each of the aforementioned load demand at a minimal generating fuel cost of ₦2,636.09/hr, ₦3,045.55/hr, ₦3,507.86/hr, ₦4,039.35/hr and ₦4,613.06/hr respectively and power losses of 0.181MW, 0.320MW, 0.528MW, 0.756MW and 0.909MW respectively (based on the input data).)..

Introduction

Diverse methods are used to generate electrical power, which is categorized into conventional and non-conventional means. The conventional means include the fossil fuels (oil, gas and coal) and non-conventional, referred to as renewables such as wind, solar, tidal, biomass, etc. (Deexit & Prakasa, 2018). The Nigerian power system is of three stages; generation, transmission and distribution.

For the electrical network interconnection, energy crisis and repeated hikes in price, it is essential to reduce the running costs of generating electrical energy. A saving in the power system's operation results in a significant reduction in the overall operating cost and quantity of fuel consumed. (Mahesh, 2012).

The primary aim of modern electrical utility is to ensure the provision of quality and reliable power supply to the consumers at the minimum cost while operating to meet the limits and constraints imposed on the

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generating units and environmental considerations. This aim can, however, be achieved through the Economic Load Dispatch (ELD) techniques. ELD is an idea to minimize the cost of electricity generation without leaving out quality and reliability. Different methods have been used in solving ELD problems ranging from the traditional methods, which include the lambda iteration method, Newton-Raphson method and Gradient method (Musinguzi & Mukiibi, 2019) and the modern heuristic methods, which include Dynamic programming, Genetic Algorithm, Artificial intelligence, Particle swarm optimization method, etc. (Prakash, 2013) These modern methods are used majorly in complex ELD problems.

Power plants in thermal and gas generating stations require fuel as the primary source of generation. The cost incurred on fuel during generation and all other maintenance and running costs must be accounted for, as failure to do this will lead to increased fuel cost and loss of power due to excess generation. This has given rise to the need to monitor and evaluate how loads can be supplied at the lowest cost using Economic Dispatch Load (ELD). Therefore, for the purpose of this research work, the Particle Swarm Optimization Method (PSO) will be used to solve ELD problems using the MATLAB software.

This project is, however aimed at providing a solution to the economic dispatch load problem in Nigeria for optimization of electrical power generation with objectives ranging from; evaluating the effect of applying the optimal power flow constraints on the results obtained in economic load dispatch, applying Particle Swarm Optimization method in solving economic load dispatch problem; determining if the generating units should be operated concurrently or there should be an alternate switch of power between the generating units under consideration.

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LITERATURE REVIEW

Economic load dispatch is dated as early as 1920's where engineers were concerned with the challenge of economic distribution of generated electricity or the proper allocation of the load among the generating units available. Prior to 1930, various methods were in use such as:

(a) the base load method where the next most efficient unit is loaded to its maximum capability, then the second most efficient unit is loaded, etc.

(b) "best point loading," where units are successively loaded to their lowest heat rate point, beginning with the most efficient unit and working down to the least efficient unit, etc. (Narashima, 2014)

Some of the previously work done on economic load dispatch problem include;

Pereira, et al. described a method for the Economic Dispatch with security-constrained dispatch that can take into account the system rescheduling capabilities. The methodology is based on the Bender's Decomposition principle which allows the iterative solution of a base-case economic dispatch and separate contingency analysis with generation rescheduling.

Akwukwaegbu, et al. presented a new Parametric Quadratic Programming method to solve an economic load dispatch problem with dc load flow type network security constraints.

N. Deexit and A.S. Prakasa presented a solution to economic load dispatch problem using the artificial bee colony optimization algorithm and particle swarm optimization technique.

And many more other approaches towards solving economic load dispatch problem.

ECONOMIC LOAD DISPATCH

As earlier explained that ELD is an idea to minimize cost of electricity generation without sacrificing reliability and quality. Diverse optimization

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techniques have been used to solve the ELD problem. Some of these techniques are based on classical optimization methods, such as linear programming or quadratic programming to solve ELD problems. Such classical optimization methods are highly sensitive to starting points and often converge to local optimum or diverge altogether (Alsumant, 2007)

Formulation of the Economic Load Dispatch (ELD)

The ELD is formulated using the equation below;

$F_t = \sum_{i=1}^{n} F_i(P_i)$ ------ (i)

Where F_t = total fuel cost (₦/hr)

i = number of generating units up to maximum number, n.

P_i = real power of i generating units (MW)

$F_i P_i$ = Fuel Cost of generating unit i

A polynomial equation is used to represent the fuel cost function of a generating station which is given as;

$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i$

Where a_i, b_i, and c_i are coefficient of fuel cost.

Economic load dispatch is subjected to two categories of constraints which include the equality and inequality constraints.

Equality Constraints

This explains the equation of the basic power balance in conformity with total generated power which is equal to the sum of power demand and transmission loses. Mathematically expressed as;

$\sum_{i=1}^{n} P_i - P_D - P_L = 0$ -------- (2)

Where P_i = real power of i generating units (MW)

P_D= Total System Power Demand (MW)

P_L= Transmission loss of the system (MW)

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Inequality Constraints

These include;

i. Generator constraints: This explains that the KVA loading on a generating unit should not exceed a pre-specified value to avoid overloading, hence rise in temperature. I.e. $P_{i\,min} \leq P \leq P_{i\,max}$.

ii. Voltage constraints: A variation, at certain limits, in voltage magnitudes and phase angles should occur at various nodes. Hence, the operating angle of transmission, for transient stability reasons, should lie between 30 to 45 degrees.

iii. Running spare capacity constraints: This constraint is required to meet the forced outages of one or more alternators on the system and also to meet the unpredicted and unexpected loads on the system.

iv. Transmission line constraints: Real and reactive power flow in the circuit is restricted by the thermal capacity of the transmission line circuit expressed as $C_p \leq C_{p\,max}$ where $C_{p\,max}$ = maximum loading capacity of the Pth line. (Safari & Shayeghi, 2008)

v. Network security constraints: Some constraints of the network are not complied with in the situation of outage either it is a planned or forced one, however, such complications in the constraints is increased in the analysis of a large power system. The nature of this constraint is the same as that of voltage and transmission line constraints (Wadhwa, 2009)

PARTICLE SWARM OPTIMIZATION

PSO is a biologically inspired computational search and optimization technique developed by Eberhart and Kennedy, in 1995, which was inspired by the social behavior of bird flocking and fish schooling in search of food without a leaders. (Narashima, 2014). This algorithm unlike the other mathematical methods does not need any gradient information about the

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error or objective function and can as well obtain the best solution independently (Mosafa & Mekhamer, 2004)

In PSO algorithm, predefined restrictions attached to a swarm of particles begins to fly on the search space. Evaluation of performance of each particle is done by the objective function considering the minimization problem, hence, the particle with low values has more performance. This brings about the Pbest and Gbest. (Musinguzi & Mukiibi, 2019).

Personal best (Pbest): This explains that the position associated with the *i*th particle is the best position that the particle has reached resulting in the maximum fitness value for that particle.

Global best (Gbest): The best values of Pbest (less values) in the iteration determines the Gbest.

Therefore, the relationship between Pbest and Gbest is mathematically expressed as;

$V_i^{t+1} = V_i^t + c_1 r_1 (X_{pbest} - X_i^t) + c_2 r_2 (X_{gbest} - X_i^t)$

Where V_i^{t+1} = particle velocity at current iteration (t+1)

V_i^t = particle velocity at iteration t

$r_1 r_2$ = random number between 0 and 1

$c_1 c_2$ = acceleration constant

Afterwards, particle fly into a new position

$X_i^{t+1} = X_i^t + V_i^{t+1}$

Where X_i^{t+1} = current particle position at iteration (t+1)

X_i^t = particle position at iteration t

V_i^{t+1} = particle velocity at current iteration (t+1)

SOFTWARE USED (MATLAB)

MATLAB is a programming language just like the C, Java, Python, etc. used for computing of technical inputs. It is developed by MathWorks. It is a

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platform that allows for matrix manipulations, data and function plotting, algorithm implementation and creation of user interfaces as well as interfacing with other language written programs.

METHODOLOGY

This research presents a rapid solution to the constrained Economic Load Dispatch (ELD) problem using the Particle Swarm Optimization (PSO) technique to determine the optimal generation quantity of each unit. The MATLAB R2016a software is used to run the PSO algorithm

PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) technique is a modern practical approach used to solve the problem of economic load dispatch. In this project, the Particle Swarm Optimization (PSO) method was used because of its quick convergence and reliability as compared to other methods of solving load dispatch problems. In addition, the PSO has the flexibility to control the balance between the global and local exploration of search.

Procedure for PSO (Particle Swarm Optimization) method for solving ELD problem

Below is the step by step process to achieve the process of optimization in the MATLAB software;

1. Insert the upper and lower limit of power generated in each unit, hence, determine Fmax and Fmin. Initialize randomly the population individually according to the limit of each unit including individual dimensions, searching points, and velocities. These initial individuals

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must be feasible candidate solution that satisfies the practical operation constraints.

2. For each individual Pi of the population, the B-coefficient loss formula is employed to determine the transmission loss, PL.
3. Determine for individual Pi in the population the evaluation value using the evaluation function
4. Compare individual's evaluation value with its $Pbest$. The best evaluation value among $Pbest$ is denoted as $gbest$.
5. Velocity member of individual is modified according to the velocity update equation below;

Vidt+1 = ωVidt + c1r1 (Pbestid -Pit) + c2r2 (Gbestd -Pit)

i = 1, 2 …, n d= 1, 2…, m where n= population size and m= number of units

6. If Vidt+1 > Vdmax, then Vidt+1 = Vdmax

If Vidt+1 < Vdmin, then Vidt+1 = Vdmin

7. Modification of member position of individual Pi using the equation below;

Pidt+1 = Pidt + Vidt+1

8. If the evaluation value of each individual is better than the previous $pbest$, the current value is set to be $pbest$. If the best $pbest$ is better than $gbest$ the value is set to be $g$best.

9. If the number of iterations reaches the maximum, move to Step 10. Else, go to Step 2.

10. Individual with the latest gbest is the optimal generated power of each unit with the minimum total generation cost.

Flow chart

The flow chart for the summarization of PSO to solve ELD problem is shown below

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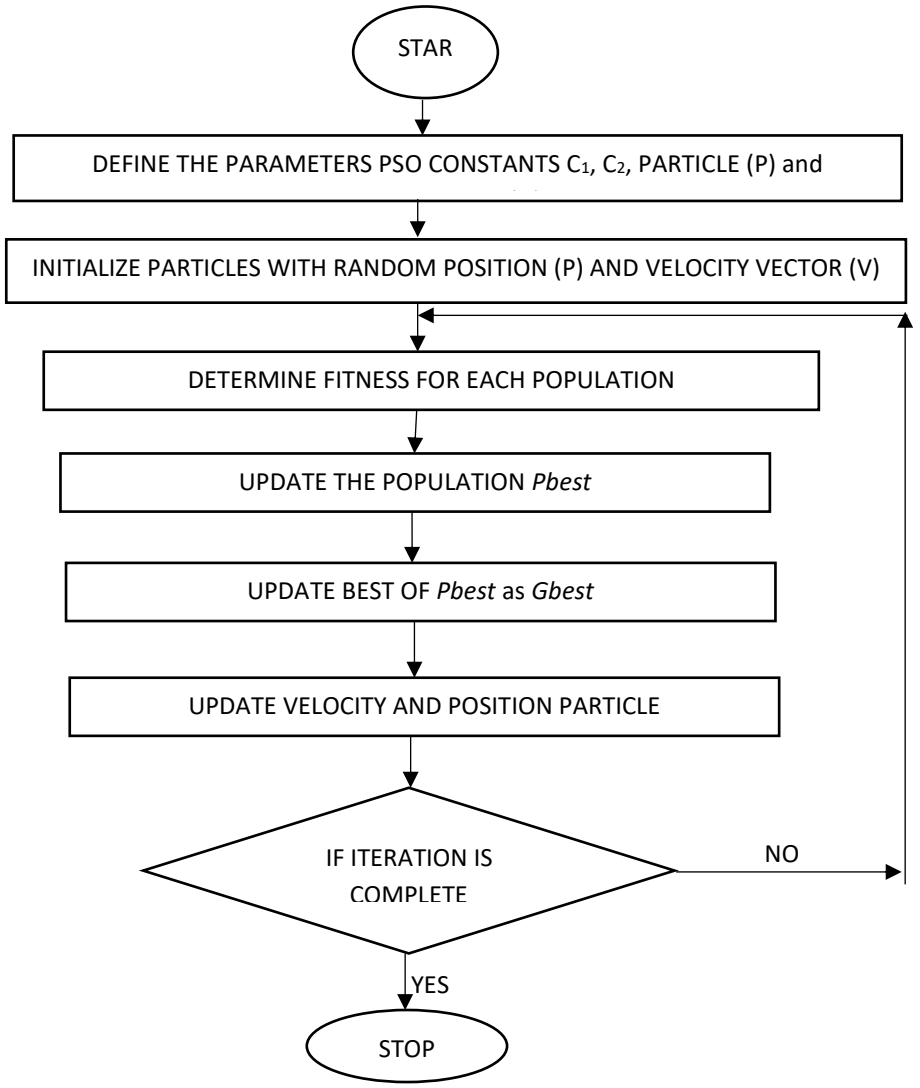

Figure 1: Flow chart of PSO (Particle Swarm Optimization) method

PLANT DATA

The table below shows the plan data of interest which are γ, β, α, maximum power and minimum power. γ, β, α represents fuel cost factors or fuel cost coefficients. The data below is gotten from the generating station logs data sheet.

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Unit	γ (₦/MW²)	β (₦/MW)	α (₦)	Pmin (MW)	Pmax (MW)
1	0.007	7	240	20	100
2	0.0095	10	200	20	50
3	0.009	8.5	300	20	80
4	0.009	11	150	20	50
5	0.008	10.5	200	20	50
6	0.0075	12	120	20	50

Table 1: Plant data for selected generating plants

NETWORK LOSSES

Power stations are scattered geographically, hence, the transmission network losses must be taken into consideration to acquire economic dispatch. Network loss is a function of generation unit. To determine these losses, two methods are used; one is the penalty factor method and the other is the B coefficient method.

The B coefficient method is common amongst power utility industry, in this method, network losses are expressed as a quadratic function

PL= PmBmnPn

Where Bmn are constants called B coefficients or loss coefficients.

For the purpose of matrix dimension conformity, six by six loss coefficients of each generating units will be considered. Therefore, the loss coefficients of the above network is;

B = [0.000017 0.000012 0.000007 -0.000001 -0.000005 -0.000002
0.000012 0.000014 0.000009 0.000001 -0.000006 -0.000001
0.000007 0.000009 0.000031 0.000000 -0.000010 -0.000006
-0.000001 0.000001 0.000000 0.000024 -0.000006 -0.000008
-0.000005 -0.000006 -0.000010 -0.000006 0.000129 -0.000002
-0.000002 -0.000001 -0.000006 -0.000008 -0.000002 0.000150]

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Bo = [0 0 0]

Boo = [0]

PSO PARAMETERS

Listed below are the parameters used for the Particle Swarm Optimization (PSO) technique;

Population size= 150

Maximum number of iteration= 3000

Inertia weight factor: ωmax =0.9 & ωmin = 0.4

Acceleration constant: C1= C2= 2

Error gradient= 1e-06

RESULTS AND DISCUSSION

The potency of the Particle Swarm Optimization (PSO) technique is tested with six generating units' system to solve the Economic Load Dispatch (ELD) problem. The program was written in the MATLAB 2016a software. The generator cost coefficients, generation limits and loss coefficients of the six units were gotten from generating station log data sheet. The loss coefficients obtained are used to evaluate the power loss in the network configuration. Afterwards, the economic load dispatch program, psotest.m is executed. This program prompts the user to input the power demand PD and for the purpose of this study 150MW, 200MW, 250MW, 300MW and 350MW were used and the table below shows the result.

S/N	POWER DEMAND (MW)	Unit 1 (MW)	Unit 2 (MW)	Unit 3 (MW)	Unit 4 (MW)	Unit 5 (MW)	Unit 6 (MW)	POWER LOSS (MW)	TOTAL FUEL COST (₦/hr)
1	150	50.181	20	20	20	20	20	0.181	2,636.09
2	200	90.973	20	29.347	20	20	20	0.320	3,045.55
3	250	99.999	20	70.528	20	20	20	0.528	3,507.86
4	300	99.999	44.223	79.988	20	36.543	20	0.756	4,039.35

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5	350	99.999	49.999	79.998	50	49.999	20.913	0.909	4,613.06

Table 2: Test result of PSO method for 6 generating units

From the result above, it can be inferred that the Particle Swarm Optimization (PSO) method produces an accurate answer with lower cost of generation. Load demands of 150MW, 200MW, 250MW, 300MW and 350MW was considered and at 3000 iterations, a total fuel cost of ₦2,636.09/hr, ₦3,045.55/hr, ₦3,507.86/hr, ₦4,039.35/hr and ₦4,613.06/hr with respect to the load demand was calculated and the losses on each generation are 0.181MW, 0.320MW, 0.528MW, 0.756MW and 0.909MW respectively.

In addition, Particle Swarm Optimization method (PSO) provides a more economical solution to the problem of Economic Load Dispatch (ELD). The graph of below however shows that with respect to the input data of the generating stations, unit 1 is best used as more load is taken by it due to its low fuel cost on generation;

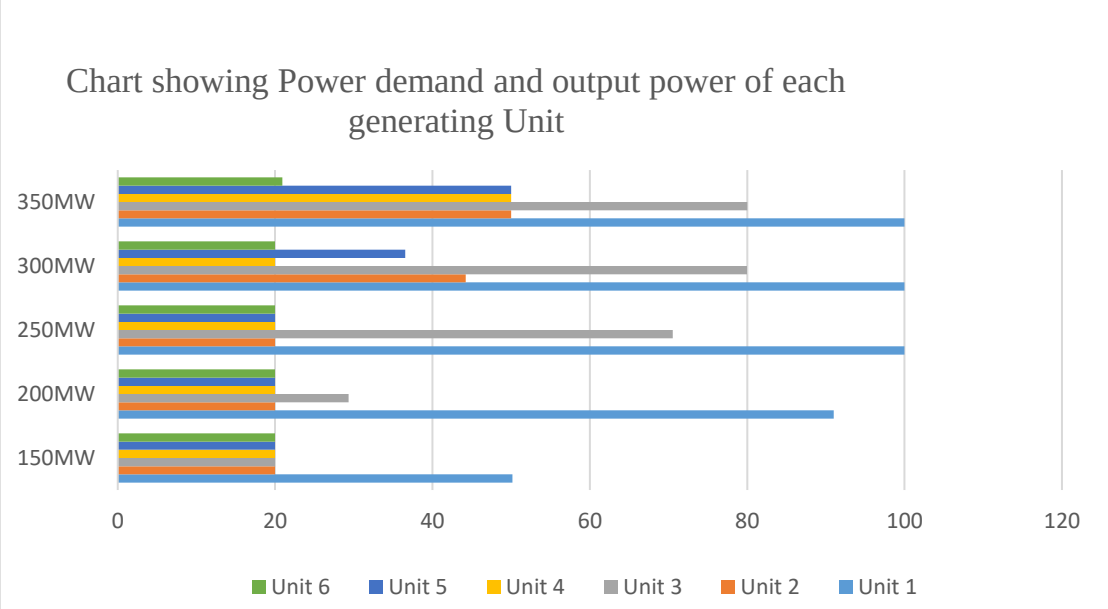

Fig 2: Chart showing power demand and output power of each generating unit

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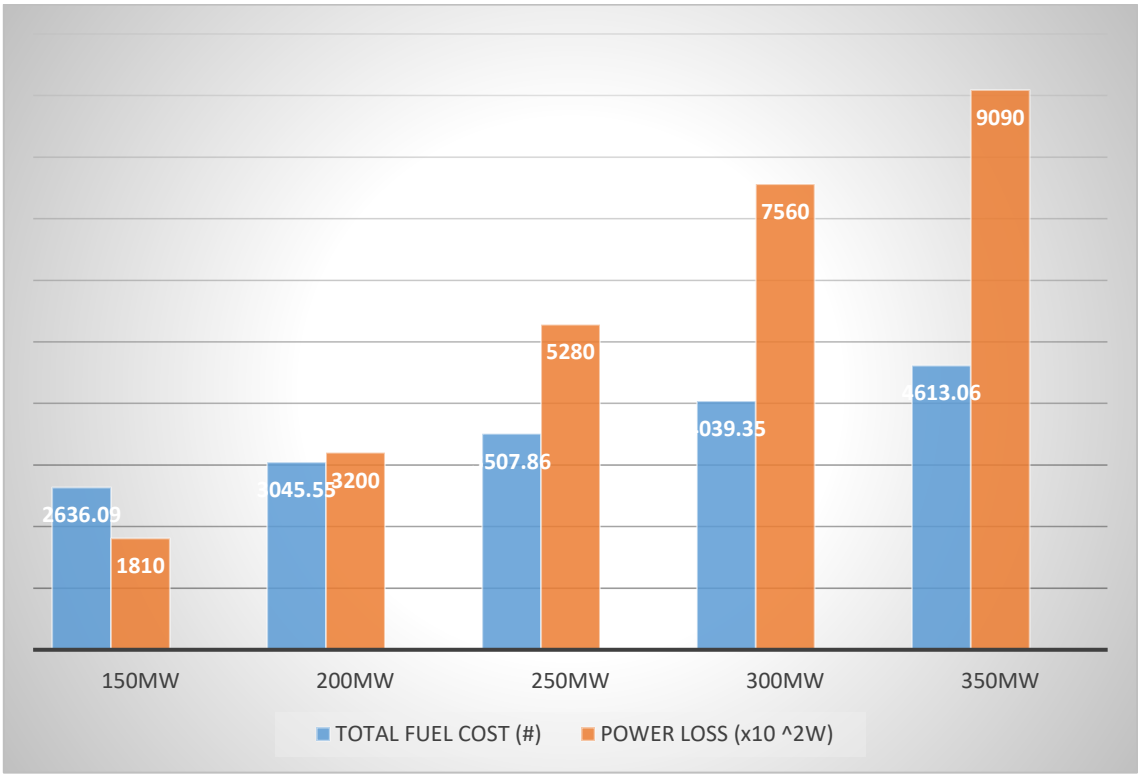

Figure 3: Chart showing Power demand with respect to the Total fuel cost of each and power loss in watt (x10²)

The chart above however represents the relationship between the load power demand in Megawatts and the total fuel cost on each load demand in naira as well as the power losses on each demand. However, it can be inferred from the above that the higher the load demand, the more the fuel cost as well as an increase in loss on the power line.

CONCLUSION

The aim of the research was achieved by using the Particle Swarm Optimization (PSO) technique. It can however be inferred from the result that running the generating stations concurrently will bring about reduced cost. From the result table, it explains that running only unit 4 and unit 6 of the generating units will incur more cost as compared to the other

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generating units, hence, concurrent running to meet load demands will ensure reduced cost, reliable transmission, and prevent system overloading.

By critically analysing the result of the ELD, the load demands of 150MW, 200MW, 250MW, 300MW and 350MW was considered and the generating cost of the scheduled generating units are ₦2,636.09/hr, ₦3,045.55/hr, ₦3,507.86/hr, ₦4,039.35/hr and ₦4,613.06/hr respectively, the power loss of the load demands are 0.181MW, 0.320MW, 0.528MW, 0.756MW and 0.909MW respectively. The convergence characteristic of the PSO algorithm for the six-unit system is plotted. There is improvement in the system complexity as it converges, hence, solution for higher order systems can be acquired in much less time duration than the conventional method. The reliability of the PSO algorithm for different runs of the program is pretty good, which shows that irrespective of the run of the program, it is capable of obtaining same result for the problem. Particle Swarm Optimization (PSO) method always provides converged solution which does not require initial value of lambda. However, the result of the PSO on the ELD problem is as a result of the input data which may vary based on the data and loss coefficients.

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