Nigerian Journal of Technology (NIJOTECH)
Vol. 41, No. 2, March, 2022, pp.302-310
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v41i2.12

Optimal Unit-Commitment Generation Scheduling Using Genetic Algorithm: A Case Study of A 10-Generator Power System Network

O. E. Ozoemena[1,*], A. Adamu[2]

[1,2]*Department of Electrical/Electronic Engineering, University of Abuja, Abuja, NIGERIA.*

Abstract

Generation Scheduling is a complex optimisation problem. The aim is to get an optimal combination of generating units for optimal operation. In this paper, Genetic Algorithm (GA) is presented as a viable optimisation tool to solve a fuel cost-based unit-commitment problem. The power system network adopted for the study is a 10-generator network. The prime objective here is to prepare the best economic start-up and shutdown schedules of the generators which meets the forecasted load demand plus reserve for a particular time interval while at the same time satisfying various system constraints. The implementation was done with the GA Toolbox in MATLAB 2018a. Results obtained were compared to the ones obtained with Lagrangian Relaxation optimisation technique and the comparison shows that Genetic Algorithm led to a slight reduction in fuel cost by ₦ 522,452.20 for the 24-hour period.

Keywords: Generator Scheduling, Genetic Algorithm, Optimisation, Unit Commitment.

1.0 INTRODUCTION

In Power System planning and operation, a Generator Scheduling Problem (GSP) determines hourly ON/OFF time schedules for the generators. In otherwords, generator scheduling involves the switching ON and OFF of power plants over a specified time horizon [1]. Hence, the objective or goal is to minimise operating cost while maximising output and meeting all plant and system constraints.

Again, generator scheduling basically involves the following:

- Determination of start-up times
- Determination of shut down times
- Loading levels
- Spinning reserve for each unit for a given scheduling period [2].

Some of the constraints that must be factored into the solution are:

- Total power generated = Total load demanded + system losses
- Enough spinning reserve to cover for generation shortfalls
- Unit loading must fall between its minimum and maximum allowable rating
- Ramping limits for each unit must not be violated
- Minimum up and down times of each unit must be observed.

Generator Scheduling (GS) is a complex optimisation problem[1] due to increase in search space, number of generating units and various system and environmental constraints. It involves the solving of nonlinear equations using some optimisation criterion [3]. In GS, the exact optimal solution can be obtained by enumeration but practically, it may not be applicable to today's systems which are very large and require large computational times.

This leads to two common problems:

1. Algorithm can easily be caught in a local minimum solution as the problem is not a convex one. Conventional techniques may converge at a local minimum instead of a unique global minimum especially if the initial conditions is far off the global optimum.
2. Most of the power system control variables e.g. transformer tap positions, reactor banks, etc. in the algorithm have integer values.

Evolutionary Computation (EC) tools which operate by mimicking biological population genetics in search for the optimal solution has the ability of solving such complex problems [4]. EC is implemented via Evolutionary Strategies [5]. Evolutionary Programming [6]. and Genetic Algorithm [7]. This paper focuses on the

***Corresponding author (Tel:** +234 (0) 8039255700**)**

Email addresses: obinnaozoemenaemmy@gmail.com (O. E. Ozoemena) and ayubaadamu2@gmail.com (A. Ayuba)

last one; genetic algorithm for searching for the optimal unit commitment generation scheduling in a generation system with 10 units.

2.0 LITERATURE REVIEW

Different techniques have been developed to tackle the challenges inherent in generation scheduling [8]. These can broadly be classified as Deterministic, Meta-heuristic and Hybridised methods [1].

Partial enumeration or Deterministic schemes include Dynamic Programming (DP) [9], Branch and Bound [10, 11], Integer Programming [12].They require large computational times and computer memory [1]. To tackle this, the heuristic methods viz Priority List [13], Lagrangian Relaxation (LR) [14], and the modified DP [15] were developed. The drawback of these schemes is that, though they give an optimal solution for small networks[16], their solutions are far away from global optimal solution in large systems [1].The LR is the most promising of the above techniques because of its great ability to learn from past knowledge and optimality of the rules [1].

Furthermore, to optimise the computational time, especially in generator scheduling problems, Meta-heuristic methodologies (Artificial Intelligence methods) have been developed. These include Simulated Annealing [17, 18], Particle Swarm Optimisation (PSO) [19] Artificial Neural network (ANN) [20]. Ant Colony[21]., Tabu Search [22, 23], Evolutionary Programming [24], and GA [25, 26] which give highly optimal solutions [1]

Finally, the Hybridised methods combine the deterministic and Meta-heuristic techniques to further optimise computational time and search space and used widely to solve unit commitment problems [22-29].

In recently proposed methodologies for unit-commitment generation scheduling, [30] used a hybrid of mixed-integer linear programming and state estimation enhanced dynamic programming as a solution to unit commitment problem. Computational time was shortened by this approach. Again, [31] applied a profit-based approach to unit commitment in the face of a restructuring power industry for profit maximisation. The achieved results demonstrated an increase in the profitability for GENCOs in the day-ahead market (DAM) to a great extent. Furthermore, [32] optimised forecasted demand and spinning reserve for large scale power systems by using a novel Adaptive Binary Salp Swarm Algorithm. The efficiency obtained gives credence to the use of metaheuristic methods in unit-commitment problems. [33] applied a multi-step deep reinforcement learning to unit commitment generation scheduling network. A major bottleneck was exponential growth in computational time with increase in network size. [34] presented a linear mixed-integer formulation for unit commitment in short-term hydropower planning for the maximisation of total energy production at all periods. The solution obtained were successful. In these contemporary schemes, there has been an inadequate application of artificial intelligence schemes which are fast gaining foothold in power system design and control.

Genetic algorithm, due to its robustness in finding the optimal solution even in functions having a large number of local optima, is fast becoming a popular technique for solving optimisation problems.

The Unit Commitment generator scheduling problem for a power system network, with N units say, involves:

1) Determine of the start-up/shut down times.
2) Determination of generation levels and load allocation among the units in service or on line (Economic Dispatch) at each time step.

These are done at each time over a specific scheduling period T, so that load demand can be realised/met at minimum operational cost.

2.1 GA Implementation

The main data structure in GA are chromosomes, phenotypes, objective function values and fitness values and are easy to implement when using the MATLAB/Simulink software. The basic GA steps are:

1. Construction of an initial population of chromosomes (usually random)
2. Evaluation of the fitness of each chromosome
3. Performance of fitness scaling (if necessary) – to increase diversity in population
4. Selection of mating pairs of chromosomes – usually the fittest members in the population.
5. Elitism – improves performance of GA
6. Creation of new offspring: first through crossover and secondly through mutation
7. Formation of a population for the next generation
8. If convergence has been attained, the best chromosome is returned, otherwise go to step 2.

2.2 Termination (Convergence Criterion)

1. Maximum generation i.e. GA stops when the specified number of generations have been realised
2. Elapsed time: GA stops when specified time has elapsed. If step 1 happens before step 2, algorithm ends.
3. No change in best fitness for a number of generations.

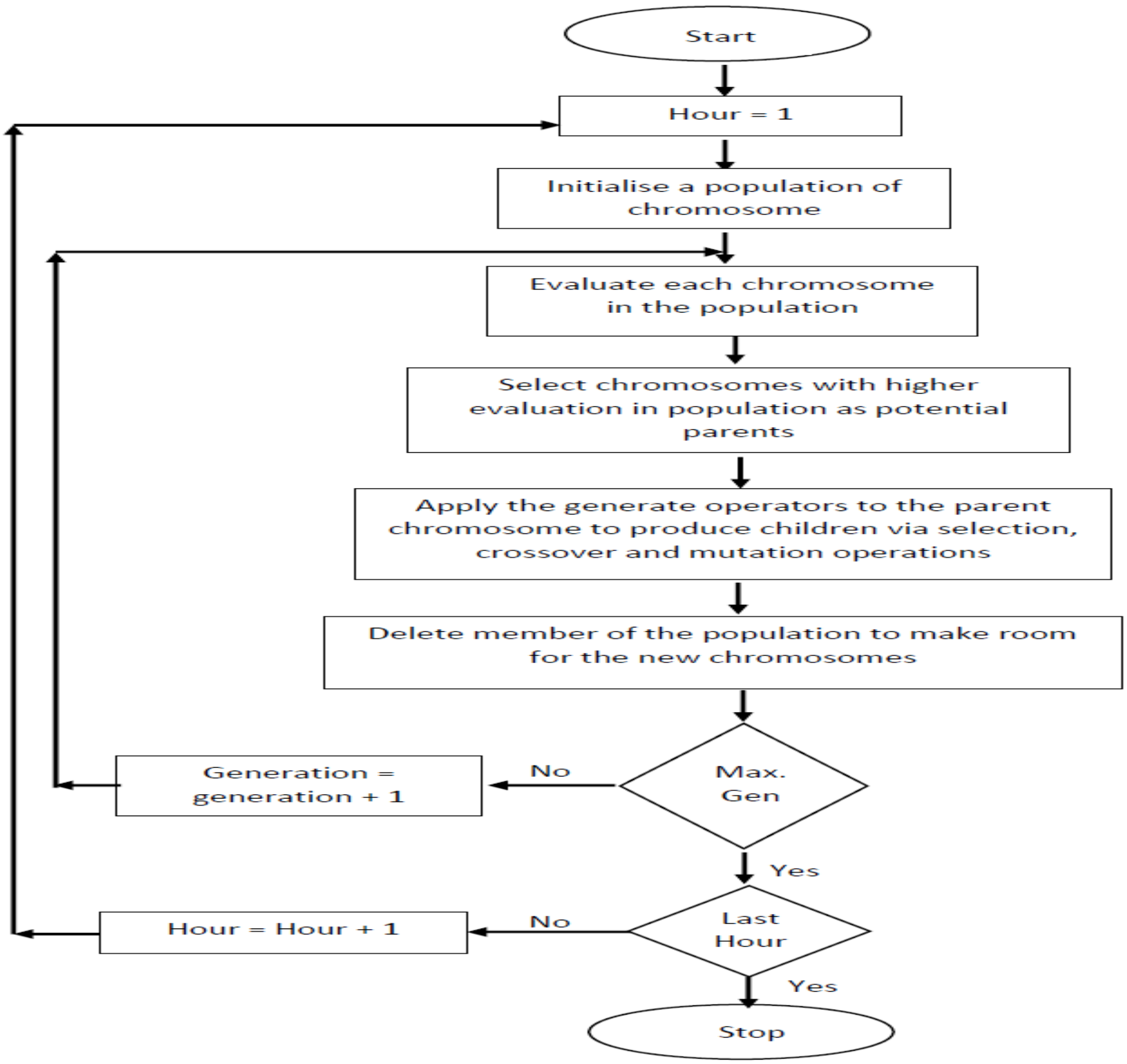

Figure 1: Flowchart for execution of a Genetic Algorithm

3.0 METHODOLOGY

In this paper, the following methodology will be observed:

Step 1: Scan the input generation and load data and utilise the GA parameters like population size (P), Crossover Probability (P_c) and Mutation Probability (P_m) and Maximum Generation Count (g_m).

Step 2: Random generation of initial population of P chromosomes

Step 3: Perform economic dispatch on feasible chromosomes to determine the power and reserve generation values over the complete scheduling time horizon and then evaluate the fitness function.

Step 4: Select the parent chromosomes from the current population using Roulette Wheel Selection mechanism.

Step 5: Perform crossover operation on the selected parent chromosomes to generate the offspring.

Step 6: Perform mutation operation to modify the offspring

Step 7: Apply penalty factor to infeasible solutions and then perform economic dispatch on feasible offspring and then evaluate the fitness values of these offspring.

Step 8: Apply elitism to preserve the best solution found so far.

Step 9: If the maximum number of generations (g_{max}) are not reached, go to Step 4, otherwise stop the procedure and print the optimal generation schedule.

In the process of breeding, elitism is selected over the Roulette Wheel as it gives a chance of reproduction even to the weakest member of the population which the Roulette Wheel process doesn't.

For a 10-unit system, the following data:

Table 1: Unit data for a 10-Unit system

Generator Units, N	P_i^{max}(MW)	P_i^{min}(MW)
Unit 1	455	150
Unit 2	455	150
Unit 3	130	20
Unit 4	130	20
Unit 5	162	25
Unit 6	80	20
Unit 7	85	25
Unit 8	55	10
Unit 9	55	10
Unit 10	55	10

Source [35]

For increased reliability in the system, a spinning reserve R (MW) is added to the hourly load demand to take care of slight changes in the load demand. The value of the reserve is set at 10% of the load demand at a particular hour T. The losses are neglected

3.1 *Unit Commitment Problem Formulation*

Electric power systems around the world experience cycles in terms of power consumed due to the variation in the demand for electricity. In most cases, the demand for electricity during daytime is higher than the demand during night-time. As a result, utilities companies have to plan for generation on hourly basis leading to a unit commitment problem.

The Unit Commitment focuses on the ON and OFF status of the generating units at different time internals. Also, to minimise the fuel consumption, Optimal Power Flow or Economic Dispatch is implemented. Thus, together, the Unit Commitment and Optimal Load Flow study gives a cost saving methodology for power generating companies (GENCOs). This methodology is based on the design used by Parashar et al [36]

3.1.1 Objective Function

The main objective is to determine the optimal unit commitment schedule for each hour for 24 hours and determine which combination has the lowest fuel cost.

- Fuel Cost Function:

In this paper, the fuel cost (FC) function is [30, 37]:

Table 2: Forecasted load Pattern for 10-unit, 24 hour system

T(Hrs)	P_D(MW)	T(Hrs)	P_D(MW)	T(Hrs)	P_D(MW)	T(Hrs)	P_D(MW)
1	700	7	1150	13	1400	19	1200
2	750	8	1200	14	1300	20	1400
3	850	9	1300	15	1200	21	1300
4	950	10	1400	16	1050	22	1100
5	1000		1450	17	1000	23	900
6	1100	12	1500	18	1100	24	800

Source [35]

$$FC_i = a_i + b_iP_i + c_iP_i^2 \qquad (1)$$

- Start-Up Cost:

  The start-up cost is the cost incurred when a generating unit comes up. It depends on the time the generating unit has been OFF before start-up. It can be represented by an exponential cost curve as shown in equation (2) [2, 28].

$$SC_i = \sigma_i + \delta_i\{1 - e^{(-T_{OFF\,i}/\tau_i)}\} \qquad (2)$$

Alternatively, the Start-Up Cost can be found using equation (3) [37]

$$SC_{i,t} = \begin{Bmatrix} HS_i, if\ T_{DOWN_i} \le T_{OFF_i} \le T_{DOWN_i} + T_{COLD_i} \\ CS_i,\ if\ T_{OFF_i} > T_{DOWN_i} + T_{COLD_i} \end{Bmatrix} \qquad (3)$$

Equation (3), based on its simplicity and also its successful implementation in [37] will be adopted for this paper.

- Shut-Down Cost:

  This is given a constant value for each unit

  Thus, total cost of production, TC_i is given as

$$TC_i = \sum_{t=1}^{T}\sum_{i=1}^{N}\left[FC_{i,t} + SC_{i,t} + SD_{i,t} + PF_j\right] \qquad (4)\ [37]$$

3.1.2 Fitness Function

A binary alphabet is chosen to enable the problem in GA Toolbox. N represents the number of units (10 in this case) and T represents the scheduling period (24 hours). The matrix (T x N) is produced describing the complete optimal schedule of all N generating units in the t-hour period where a "1" or "0" at any location indicates that that particular unit is ON of OFF at that time interval respectively.

To discourage the selection of solution with violated constraints, a penalty function is added to the fitness function. It is chosen to be sufficiently large and is proportional to the amount of constraint violations.

$$TC_i = \sum_{t=1}^{T}\sum_{i=1}^{N}\left[FC_{i,t} + SC_{i,t} + SD_{i,t} + PF_j\right] \quad (5)$$

3.1.3 Constraints

3.1.3.1 System constraints

Load/Power Demand (PD) Constraints i.e. generated power from all committed units must meet the system load demand [38].

$$\sum_{t=1}^{T}\sum_{i=1}^{N} U_{i,t}P_{i,t} = PD_t \quad (6)$$

1. Spinning Reserve (SR) Constraint: This is the total amount of generation capacity available from all units synchronised (spinning) on the system minus the present load demand. There are various methods for determining the spinning reserve [39, 40]. The one adopted for this paper is the one computed as a percentage of the forecasted load demand which is the most commonly used approach; 10 % of the forecasted load demand for a particular hour t is computed as the Spinning/System Reserve [41] (Table 3). With the spinning reserve, slight changes in load demand which might occur in-between hours are taken care of.

$$\sum_{t=1}^{T}\sum_{i=1}^{N} U_{i,t}P_{i,t} \geq PD_t + SR_t\, m \quad (7)$$

3.1.3.2 Unit constraints

Generation Limits: This represents the minimum loading below which it is not economical to load the unit, and the maximum loading limit above which the unit should not be loaded [1, 38].

$$U_{i,t}P_{min_i} \leq P_{i,t} \leq U_{i,t}P_{max_i} \quad (8)$$

$$1 \leq i \leq N\,,\, 1 \leq t \leq T$$

1. Minimum Up/Down Time: If the unit is running, it cannot be turned OFF before a certain minimum time elapses and if it is down, it cannot be loaded before a certain time elapses [37].

$$T_{OFF_i} \geq T_{DOWN_i}\ 1 \leq i \leq N \quad (9)$$

$$T_{ON_i} \geq T_{UP_i} \quad (10)$$

$$U_{i,t} = \begin{cases} 0 \rightarrow 1, if\ T_{OFF_i} \geq T_{DOWN_i} \\ 0 \rightarrow 1, if\ T_{ON_i} \geq T_{UP_i} \\ 0\ or\ 1, otherwise \end{cases} \quad (11)$$

Table 3: Forecasted Hourly Load Pattern with Reserve MW

T(Hrs)	P_D(MW)	R(MW)	TOTAL
1	700	70	770
2	750	75	825
3	850	85	935
4	950	95	1045
5	1000	100	1100
6	1100	110	1210
7	1150	115	1265
8	1200	120	1320
9	1300	130	1430
10	1400	140	1540
11	1450	145	1595
12	1500	150	1650
13	1400	140	1540
14	1300	130	1430
15	1200	120	1320
16	1050	105	1150
17	1000	100	1100
18	1100	110	1210
19	1200	120	1320
20	1400	140	1540
21	1300	130	1430
22	1100	110	1210
23	900	90	990
24	800	80	880

Key parameters in the execution of the algorithm using Genetic Algorithm in MATLAB.
Population size, P = 50
Crossover Probability, $P_c = 0.7$
Mutation Probability, $P_m = 0.1$
Penalty Factor, PF = 100000
Maximum Generation, $g_m = 51$
The simulation is performed using the GA Toolbox in MATLAB 2018a.

4.0 RESULTS

The unit characteristics are adopted from [35].

4.1.1 Objective Function

The main objective is to determine the optimal unit commitment schedule for each hour for 24 hours and determine which combination has the lowest fuel cost.

- Fuel Cost Function:

In this paper, the fuel cost (FC) function is:

Table 4: Unit Characteristics for 10-Unit System

Unit No	a (₦/h)	b (₦/MWh)	c (₦/MW²h)	T_{UP} (h)	T_{DOWN} (h)	HS_i (₦/hr)	CS_i (₦/hr)	T_{COLD_i} (h)	Initial State
1	365,000	5,909.35	0.1752	8	8	1,642,500	3,285,000	5	8
2	354,050	6,299.90	0.1132	8	8	1,825,000	3,650,000	5	8
3	255,500	6,059.00	0.7300	5	5	200,750	401,500	4	-5
4	248,200	6,022.50	0.7702	5	5	204,400	408,800	4	-5
5	164,250	7,190.50	1.4527	6	6	328,500	657,000	4	-6
6	135,050	8,124.90	2.5988	3	3	62,050	124,100	2	-3
7	175,200	10,125.10	0.2884	3	3	94,900	189,800	2	-3
8	240,900	9,460.80	1.5075	1	1	10,950	21,900	0	-1
9	232,725	9,953.55	0.8103	1	1	10,950	21,900	0	-1
10	244,550	10,143.35	0.6315	1	1	10,950	21,900	0	-1

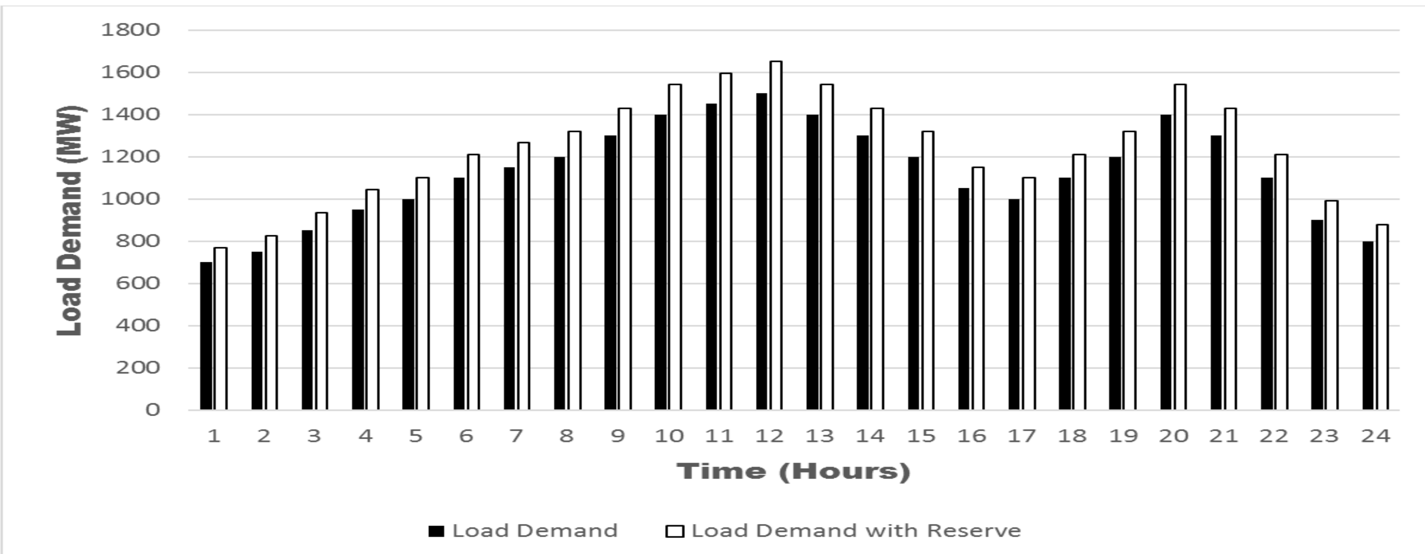

Figure 2: Graphical Representation of Forecasted Load against Over the 24-Hour Period

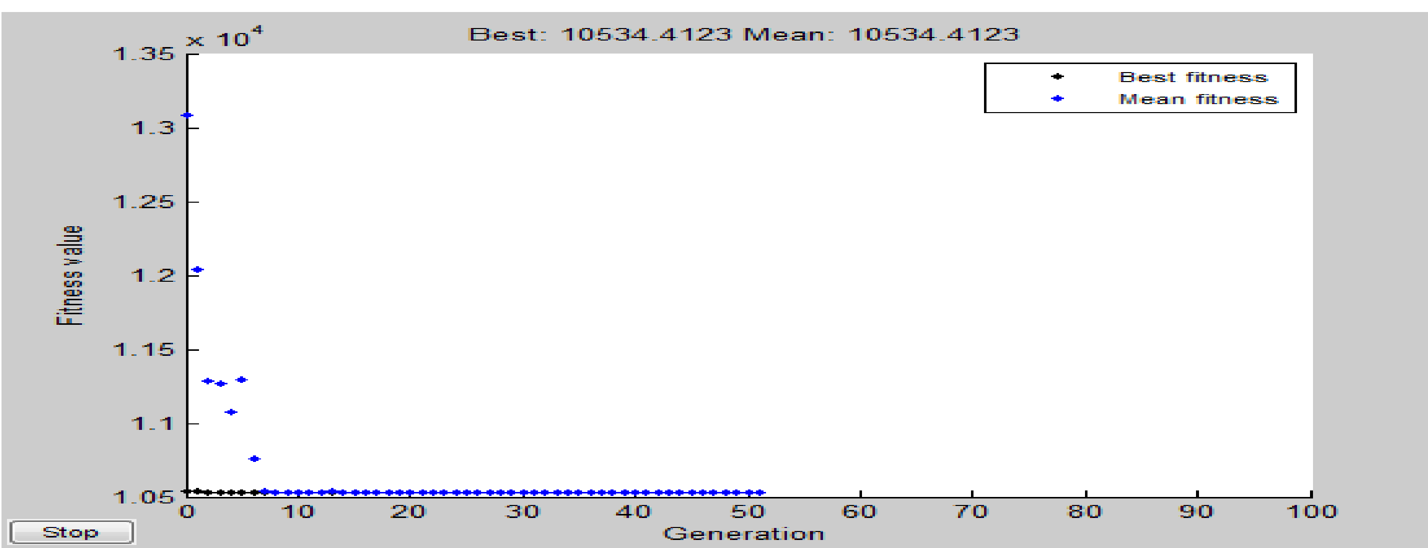

Figure 3: Result of simulation for Cost at 2nd Hour

Table 2 shows the total cost incurred for the unit commitment optimal scheduling for all 24 hours.

Table 5: Performance Comparison of GA with the LR Optimisation Technique

Method	Optimal/Best Cost (₦)
LR [42]	206,470,692.50
GA	205,948,240.30

DIFFERENCE = ₦ 522,452.2

5.0 CONCLUSION

Various methods can be applied to get the optimal solution of a Unit Commitment Problem (UCP). From results in this study, GA led to a cost saving of ₦ 522,452.20 in total production cost over the LR technique in the implementation of a 10-generator network unit commitment scheduling problem over a 24-hour period, making it a suitable method for providing optimal solution to UCPs.

From the review of GA-based generator scheduling by Bukhari et al [1], it is observed that hybrid GA methodologies emerged as one of the best among all the proposed GA strategies but no literature was found for a hybrid GA-ANN system. A recommendation for future works is the use of a hybrid GA-ANN system for generator scheduling: GA can be used to train (determine the weights and threshold values) a neural network which is used to code a Generator Scheduling Unit Commitment Problem (GS-UCP). This is capable of representing quite large domains, and again, it would improve the ease of handling non-trivial constraints.

NOMENCLATURE

a_i, b_i, c_i = Fuel cost coefficients of i^{th} unit
CS_i = Cold start-up cost of i^{th} unit at hour t in Naira per hour (δ_i)
HS_i = Hot start-up cost of i^{th} unit at hour t in Naira per hour (σ_I)
j = index for dimension of a chromosome
N = Number of generating units
$P_{i,t}$ = Real power generation of i^{th} unit at hour t in MW
P_{max} = Maximum power generation capacity of i^{th} unit in MW
P_{min} = Minimum power generation capacity of i^{th} unit in MW
PD_t = Load demand at hour t in MW
PF_j = Penalty associated with the violated constraint j
SC = Start-up cost of i^{th} unit at hour t in Naira per hour
SR_t = Spinning reserve at hour t in MW
T = Number of scheduling time intervals in hours
$T_{DOWN\ i}$ = Minimum down time of i^{th} unit in hours
$T_{OFF\ i}$ = Continuously-off time of i^{th} unit till time (t-1) hours
$T_{ON\ i}$ = Continuously-on time of i^{th} unit till time (t-1) hours
$T_{UP\ i}$ = Minimum up time of i^{th} unit in hours
τ_I = Cooling time constant

REFRENCES

[1] S. B. A. Bukhari, A. Ahmad, S. A. Raza and A. U. M. Zaki, "Genetic Algorithm Based Generator Scheduling - A Review," *World Applied Sciences Journal*, 30(12), 2014, pp. 1826-1833.

[2] S. O. Orero and M. R. Irving, "A Genetic Algorithm for Generator Scheduling in Power Systems," *International Journal of Electrical Power and Energy Systems*, 18(1), 1996, pp. 19-26.

[3] S. N. Singh and S. C. Srivastava, *Genetic Algorithm and its Applications in Power System Problems*, 1998.

[4] S. O. Orero and M. R. Irving, "A Genetic A lgorithm Modelling Framework and Solution Technique for Short Term Optimal Hydrothermal Scheduling," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 13(2), 1998.

[5] T. Back, F. Hoffmeister and H. P. Schwefel, "A Survey of Evolution Strategies," in *In R.K. Below, L.B. Booker (Eds) Proceedings of the Fourth International Conference on Genetic Algorithms*, 1991

[6] L. J. Hogel, A. J. Owens and M. J. Walsh, "Artificial Intelligence Through Simulated Evolution", John Wiley, 1966.

[7] J. H. Holland, "Adaptation in Natural and Artificial Systems", Ann Arbor: University of Michigan Press, 1975

[8] N. P. Padhy, "Unit Commitment - A Bibliographical Survey," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 19(2), 2004, pp. 1196-1205.

[9] P. P. Van Den Bosch and G. Honderd, "A Solution of the Unit Commitment Problem via Decomposition and Dynamic Programming," *Institute of Electrical and Electronics Engineers Transactions on PAS*, 1981.

[10] A. I. Cohen and M. Yoshima, "A Branch and Bound Algorithm for Unit Commitment," *Institute of Electrical and Electronics Engineers Transactions on PAS*, 102, 1983, pp. 444-451.

[11] C. L. Chen and S. C. Wang, "Branch and Bound Scheduling for Thermal Units," *Institute of Electrical and Electronics Engineers Transactions on Energy Conversion*, 8(2), 1993, pp. 184-189.

[12] J. F. Dopazo and H. M. Merril, "Optimal Generator Maintenance Scheduling Using Integer Programming," *Institute of Electrical and Electronics Engineers Transactions on Power*

Application Systems (PAS), 14(5), 1975, pp. 1537-1545.

[13] T. Senjyu, K. Shimabukuro, K. Uezato and T. Funabbashi, "A Fast Technique for Unit Commitment Problem by Extended Priority List," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 18(2), 2003, pp. 882-888

[14] W. Ongsakul and N. Petcharaks, "Unit Commitment by Enhanced Adaptive Lagrangian Relaxation," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 19(1), 2004, pp. 620-628.

[15] Z. Ouyang and S. Shahidehpour, "An Intelligent Dynamic Programming for Unit Commitment Application," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 6(3), 1991, pp. 1203-1209.

[16] J. D. Digalakis and K. G. Margaritis, "A Multipopulation Cultural Algorithm for the Electrical Generator Scheduling Problem," *ELSEVIER Mathematics and Computers in Simulation*, 60, 2002, pp. 293-301.

[17] A. H. Mantawy, Y. L. Abdel-Magid and S. Z. Selim, "A Simulated Annealing Algorithm for Unit Commitment," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 13(1), 1998, pp. 197-204.

[18] F. Zhuang and F. D. Galiana, "Unit Commitment by Simulated Annealing," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 5(1), 1990, pp. 311-318.

[19] B. Zhao, C. Guo, B. Bai and Y. Cao, "An Improved Particle Swarm Optimisation Algorithm for Unit Commitment," *International Journal of Eolectrical Power and Energy Systems*, 28(7), 2006, pp. 482-490.

[20] H. S. Musoke, S. K. Biswas, E. Ahmed, P. Cliff and W. Kazibwe, "Simultaneous Solution of Unit Commitment and Dispatch Problems Using Artificial Neural Networks," *International Journal of Electrical Power and Systems*, 15(3), 1993, pp. 193-199.

[21] T. Sum-Im and W. Ongsakul, "Ant Colony Search Algorithm for Unit Commitment," in *Proceedings of the 2003 Institute of Electrical and Electronics Engineers on International Conference on Industrial Technology*, 2003.

[22] C. A. Rajan and M. Mohan, "An Evolutionary Programming-Based Tabu Search Method for Solving the Unit Commitment Problem," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 19(1), 2004, pp. 577-585.

[23] C. A. Rajan, M. Mohan and K. Manivannan, "Neural-Based Tabu Search Method for Solving Unit Commitment Problem," *Institute of Electrical and Electronics Engineers Proceedings on Generation, Transmission and Distribution*, 150(4), 2003, pp. 469-474.

[24] K. Justa, H. Kita, E. Tanaka and J. Hasegawa, "An EvolutionaryProgramming Solution to the Unit Commitment Problem," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 14(4), pp. 1452-1459, 1999.

[25] C. R. Reeves, Modern Heuristic Techniques for Combinatorial Problems, Blackwell, Oxford, 1993

[26] S. N. Sivanandan and S. N. Deepa, Introduction to Genetic Algorithms, Berlin Heidelberg: Springer-Verlag, 2008

[27] R. Nayak and J. Sharma, "A Hybrid Neural Network and Simulated Annealing Approach to the Unit Commitment Problem," *Computers and Electrical Engineering*, 26(6), 2000, pp. 461-477.

[28] T. Victoire and A. Jeyakumar, "Unit Commitment by a Tabu-Search-Based Hybrid-Optimisation Technique," in *Institute of Electrical and Electronics Engineers on proceedings on Generation, Transmission and Distribution*, 2005.

[29] J. Zhang, T. Q. Liu, P. Su and X. Zhang, "Unit Commitment Optimisation Based on Genetic Algorithm and Particle Swarm Optimisation Hybrid Algorithm," *Journal of Power System Protection and Control*, 2009, p. 9.

[30] D. Putz, D. Schwabeneder, H. Auer and B. Fina, "A C omparison Between Mixed-Integer Linear Programming and DynamicProgramming with State Predictionas Noveltyfor Solving Unit Commitment," *Electrical Power and Energy Systems*, 2021, p. 125.

[31] M. N. Gilvaei, M. H. Imani, M. J. Ghadi, L. Li and A. Golrang, "Profit-Based UnitCommitment for a GENCO Equipped withCompressed Air Energy Storage and Conceentrating Solar Power Units," *Energies*, 14(576), 2021.

[32] C. V. Kumar and M. R. Babu, "An Exhaustive Solution of Power System Unit Commitment Problem Using Enhanced Binary Salp Swarm Optimisation Algorithm," *Journal of Electrical Engineering and Technology*, 2021.

[33] J. Qin, N. Yu and Y. Gao, "Solving Unit Commitment Problems with Multi-step Deep Reinforcement Learning," in *Institute of Electrical and Electronics Engineers on International*

Conference on Communications, Control and Computing Technologies for Smart Grids, 2021.

[34] M. Daadaa, S. Segun, K. Demeester and M. F. Anjos, "An Optimisation Model to Maximise Energy Generation in Short-Term Hydropower Unit Commitment Using Efficiency Points," *International Journal of Electrical Power and Energy Systems*, 2020.

[35] P. Attaviriyanupap, H. Kita, E. Tanaka and J. Hasegawa, "A Hybrid LR-ER for Solving New Profit-Based UC Problem under Competitive Environment," *Institute of Electrical and Electronics Engineers Transactions on Power Systems*, 18(1), 2003, pp. 229-237.

[36] A. Parashar and K. K. Swankar, "A Genetic Algorithm Approach to Solve Unit Commitment Problem," *IOSR Journal of Electrical and Electronic Engineering (IOSR-JEEE)*, 7(3), 2013 pp. 60-64.

[37] P. K. Singhal, R. Naresh, V. Sharma and G. K. Nadakuditi, "Generator Scheduling Under Competitive Environment Using Genetic Algorithm," *International Journal of Enigineering, Science and Technology*, 7(3), 2015, pp. 24-32.

[38] N. R. Patel and N. K. Patel, "Optimal Generation Scheduling for Thermal Units," *International Research Journal of Engineering (IRJET)*, 5(4), 2018, pp. 343-348.

[39] K. S. Tang, K. F. Man, S. Kwong and Q. He, "Genetic Algorithms and their Applications," *Institute of Electrical and Electronics Engineers on Signal Processing Magazines*, 1996, pp. 22-37.

[40] J. C. Christensen, C. A. Durtolina and J. P. Bermudez, "An Approach to Solve the Unit Commitment Problem Using Genetic Algorithm," *Institute of Electrical and Electronics Engineers on Power Engineering Society Summer Meeting*, 1, 2000, pp. 261-266.

[41] H. C. Lee and C. Ha, "Sustainable Integrated Process Planning and Scheduling Optimisation Using a Genetic Algorithm with an Integrated Chromosome Representation," *Sustainability*, 11, 502, 2019

[42] P. K. Singhal, "Generation Scheduling Methodology for Thermal Units Using Lagrangian Relaxation," in *Proceedings of 2nd Institute of Electrical and Electronics Engineers on International Conference on Current Trends in Technology*, 2011.