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State-of-the-Art Approach to Economic Load Dispatch on Nigerian Hydro-Thermal Electric Power System: A Review

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ABSTRACT

The need to efficiently minimize the cost of power generation of fossil fueled fired-plants is indeed a thing of great concern in grid energy management. One way to achieve this is to optimally schedule the power output of all the connected thermal plants on the system. Recently, population-based artificial intelligence (AI) algorithms are promising alternative means of addressing ELD problems as against the conventional lambda iterative technique which had been previously applied. The adoption of these AI techniques is largely due to possession of good processing speed, mild computational complexity coupled with less computational time. This paper therefore presents various AI algorithms that had been used and identifies types of ELD problems so far addressed. Based on the review, diverse algorithms had been used to address convex ELD problem, however scanty works have been referenced on non-convex ELD, even cases of emission of gases, multiple fuel option, spinning reserve requirement and ramp rate limit are yet to be researched on Nigerian hydro-thermal plants. It was also observed that less attention has been drawn to aspect of reactive power dispatch on Nigerian grid. It is hoped that this review will be an eye opener to Nigerian researchers as regards other aspects of ELD problems that had received less attention.

1. Introduction

Economic load dispatch (ELD) problem like other major aspects of power systems planning -unit commitment, optimal power flow and load forecasting- is one of the main optimization problems that pivot efficient economic planning and operation of modern power systems [1]. The usage of electrical energy in this modern society is skyrocketing daily and as such, the power demanded from the connected hydro-thermal plants consequently gets increased [2]. The cost of generating electrical power from these thermal plants depend largely on the cost of fossil fuel used to power the plants and most time the cost of the fuel is extremely high, hence the need to optimize the power output of thermal plants in such a way to minimize the total fuel cost becomes imperative [3]. Greater fuel cost savings can be enjoyed via optimal scheduling of each plant's power output [4], ELD aims at appropriate apportioning of power demand on the systems among committed generators in a manner that is most economical without neglecting satisfaction of all the physical and operational constraints [2, 5]. In another perspective, ELD is a tool for optimizing the total cost of power generation without violating both the system and operational limits [6]. It is a central tool in grid energy management system; such that for given load demand, it ensures that the dispatches on each thermal plant are optimally combined with a view to minimize both the total network losses and total fuel cost of real power generation [4].

The fuel cost of generation and the quantity of power supplied are key factors that guide the process of apportioning power dispatches on the fossil-fueled thermal plant. In the formulation of simple ELD problem a quadratic function is used to model the relationship existing between both the real power generated and fuel cost of generation. The real power output is treated as an optimization problem with minimization of fuel cost as the objective function. This objective function has to be subjected to both equality and inequality constraints [7]. This type of ELD formulation described above is referred to as convex ELD; the formulation of convex ELD is based on the assumption that the incremental fuel cost curves of the units increases monotonically in piecewise-linear functions manner [8]. However, real input-output features of fossil fueled plants are known for higher order non-linearities and discontinuities. This feature is a function of effect of ramp rate limits, valve-point loading, presence of multiple fuel option, gas emission and many other characteristics as detailed [9].

The electrical energy demanded in Nigeria is fed from interconnected hydro-thermal plants, however, the power demanded is more than what is generated from these interconnected hydro-thermal plants [10]. To buttress this fact, it was reported in 2001 that power generated slide down from the installed capacity of about 5,600 MW to 1,750 MW approximately while the electrical load demanded was estimated to have risen to about 6,000 MW. Based on research findings of authors in [10], only nineteen (19) out of the seventy-nine installed generating units were in operation as at the time of writing this review. In addition, 67% of the total load demand is being supplied by thermal (Afam, Egbin, Sapele, Delta,) plants while the remaining 33% is provided by hydro-based (Kainji, Shiroro, Jebba) plants [11, 12]. In recent times, the concept of ELD on Nigerian grid is gradually becoming a research field of interest, and the need to optimally dispatch the energy demanded on the available plants calls for urgent attention. Figure 1 depicts one line diagram representation of a typical Nigerian 330 kV grid systems, it has 31-buses.

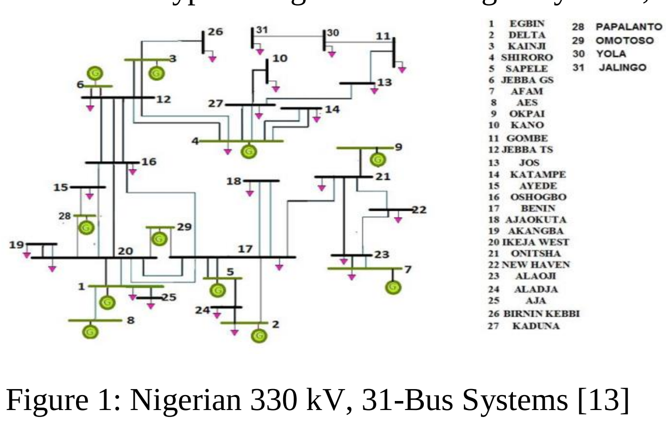

Figure 1: Nigerian 330 kV, 31-Bus Systems [13]

2. Mathematical Modelling of Different Types of ELD Problems

The relationship between the real power out of a thermal plant (MW) and cost of fuel used can be represented using quadratic polynomial given by Equation (1);

$$Cost\ of\ Fuel\ (F) = qP_{Gi}^2 + r_i P_{Gi} + s_i \tag{1}$$

The objective function which represents convex ELD problem will seek to minimize Equation (1);

$$F_{minize} = Cost\ of\ Fuel\ (F) = qP_{Gi}^2 + r_i P_{Gi} + s_i \tag{2}$$

When valve point loading effect is to be accommodated in a non-convex ELD problem formulation, equation (1) becomes;

$$Cost\ of\ Fuel\ (F) = qP_{Gi}^2 + r_i P_{Gi} + s_i + abs\left(a_i sin\left(b_i\left(P_{i,min} - P_i\right)\right)\right) \tag{3}$$

Also, when multiple fuel option is to be accommodated in a non-convex ELD problem formulation, then its mathematical modelling is given as;

$$Cost\ of\ Fuel\ (F) = \begin{cases} q_i P_{Gi}^2 + r_i P_{Gi} + s_i & if\ P_{Gi,min} \le P_{Gi} \le P_{Gi,1} \\ q_i P_{Gi}^2 + r_i P_{Gi} + s_i & if\ P_{Gi,1} \le P_{Gi} \le P_{GI,2} \\ q_i P_{Gi}^2 + r_i P_{Gi} + s_i & if\ P_{Gi,n-1} \le P_{Gi} \le P_{Gi,max} \end{cases} \tag{4}$$

The major pollutants of fossil fuels are Co_2, So_2 and No_X , equation (5) captured the total gas emission in non-convex ELD problem formulation

$$Total_{Emission,i} = \sum_{i=1}^{n}\left(a_i P_i^2 + b_i P_i + c_i + \delta_i \times e^{(\theta_i \times P_i)}\right) \tag{5}$$

The fuel cost is exclusively a function of real power output; this explains why reactive power is usually neglected when ELD problem formulation aimed at minimizing the fuel cost of real power generation.

2.1 The Constraints Formulation

The constraints in ELD problem formulations are equality and inequality constraint;

a. Equality Constraint:-

$$\sum_{i=1}^{k} P_{Gi} = P_{demanded} + P_{Loss} \tag{6}$$

$$P_{Loss} = \sum_{i=1}^{k}\sum_{i=1}^{k} B_{ik} P_i P_k + \sum_{i=1}^{k} P_i B_0 + B_{00} \tag{7}$$

b. Inequality Constraint:-The limit on the generator output is expressed as:

$$PG_{min,i} \le P_{GI} \le PG_{max,i} \tag{8}$$

The statutory bus voltage limits is given by:

$$V_{min,i} \le V_i \le V_{max,i} \tag{9}$$

The inclusion of ramp rate limits is formulated as;

$$max(PG_i^{max}, PG_i^{o} - DR_{Li}) \le PG_i < min(PG_i^{max}, Pg_i^{o} + UR_{Li}) \tag{10}$$

The constraints on the prohibited zones of operation can be expressed as;

$$PG_i \in \begin{Bmatrix} PG_i^{min} \le PG_i < PG_i^{Lower} \\ PG_{ik-1}^{Upper} \le PG_i < PG_{ik}^{Lower} \\ PG_{iZ_i}^{Upper} \le PG_i < PG_i^{max} \end{Bmatrix} \tag{11}$$

3. Related Works on Nigerian Hydro-Thermal Grid Systems

Researchers in [13] carried out performance evaluation of four (4) meta-heuristic algorithms; micro-genetic algorithm (MGA), conventional genetic algorithm (CGA), differential evolution (DE) and particle swarm optimization (PSO). The proposed approaches were independently implemented on Nigerian 330 kV, 31-bus systems. The performance evaluation metrics used are the total fuel cost of generation and total network losses. MATLAB software was used as implementation tool. When transmission line losses were neglected, PSO gave lower fuel cost of ₦908.35 per hour compared to what was obtained via DE. In comparison with MGA and CGA, PSO reported lowest fuel cost of ₦2,346.59 per hour. Similarly, when transmission losses were considered, PSO produced lower fuel cost of ₦7,786.75 per hour when compared to what was obtained via DE. In comparison with MGA and CGA, PSO produced the lowest fuel cost of ₦14,878.08 per hour. The authors reported the convergence of PSO occurred within 750 iterations. High quality solution, faster and stable convergence characteristics are the superior features of PSO.

Presented in [14] was application of FA to address convex ELD problem on two different test case systems (IEEE 30 bus and Nigerian 330 kV, 24 bus). The proposed approach was implemented using MATLAB software. The results obtained on IEEE 30 bus test system was validated with DE, ACO and GA. Thereafter the said approach was implemented on Nigerian hydro-thermal grid. The performance metrics used are fuel cost of generation, total network losses and computational time. The results comparison confirmed the superiority, fast convergence and proficiency of FA over DE, ACO and GA. The authors draw the following conclusions; FA produced the least total fuel cost of generation, network power losses and minimal computational time compared to DE, GA and ACO, also, appropriate choice of values for FA control parameters (size of population, iterations number and coefficient of absorption) enhances the faster convergence of the algorithm [14].

Authors in [15] presented PSO- based ELD on Nigerian 330kV, 31-bus system. Convex-type ELD problem was addressed; quadratic polynomial function was used to model the thermal plant fuel cost. The optimal power output of each of the plant was optimized using PSO. The results of the proposed approach were compared to that obtained via Genetic Algorithm (GA) and DE using the total fuel cost of generation and total network loss as the performance metrics. PSO gave the least fuel cost of production and total network losses compared to GA and ED. Also, the work reported that DE performed fairly well in term of computational burden.

Also, the work of researchers in [16] presented application of ACO technique to address convex ELD problem using Egbin thermal plant as case study. Egbin power station has six (6) generating units. Quadratic cost function was employed to model the relationship between the fuel cost of generation and real power output of each generating units. The power output of each unit within Egbin thermal station was optimized using ACO. The proposed approach was implemented using MATLAB software. The results obtained were compared with Lambda method, for all cases of load demanded investigated; ACO gave the least value of total fuel cost of generation and total network losses. The authors concluded that the proposed approach can effectively handle ELD on coordinated hydro-thermal plant.

Comparative performance evaluation of ACO and PSO on convex ELD was presented in [17]. Egbin thermal station having six generating units was used as the case study. The total load demand on Egbin thermal station is 600 MW. The proposed approaches were implemented independently using MATLAB software, and based on the performance metrics used ACO reduced the operating fuel cost by 0.07% as compared with what obtained through PSO. Also, ACO gave the least total transmission network losses compared to PSO.

Researchers [18] used lambda iterative technique to handle ELD on the old and expanded Nigerian grid. The old grid has four (4) thermal plants - Sapele, Afam, Egbin, Ugheli- while the expanded has seven (7) thermal plants - Sapele, Afam, Egbin, Ugheli, Olorunsogo, Omotoso and Geregu- The proposed approach was implemented using MATLAB software, the authors concluded that the cost of generation increased exponentially due to operation of most of the thermal plants around their maximum limit. Also, when generating plants was operated closer to the load centre, lower losses will be incurred in the system.

A comprehensive review of ELD problem formulation was reported by [19], the work identified that the idea of generating electricity at minimum cost for purpose of economic dispatch is a strong consideration in power systems operation and planning. Also, the fuel cost formed the major cost in running power plants while other costs may be added to the fuel cost. The derivation of the cost function evidently showed that the incremental fuel-cost curve needs to be minimized. Also, the incremental fuel-cost curve presents an indication how expensive it will be to generate the next increment of power (MW).

Authors in [20] investigated performance evaluation comparison of four (4) different swarm intelligence-based optimization algorithms (PSO, MGA, CGA and DE). A convex ELD problem was addressed using Nigerian 330 kV, 31-bus system as test case system. The performance metrics used are total fuel cost of generation and total network losses, the proposed approaches were implemented using MATLAB software. The results obtained for each algorithm were compared and based on the comparison PSO performed better than CGA, MGA and DE. The work did not give detailed account of computational time for each of the approaches, as the performance of an algorithm is better assessed using computational time.

The work of [21] proffered solution of convex ELD problem on Nigerian 330 kV, 31-bus system using quadratic polynomial cost function via GA and DE. The proposed approaches were independently implemented using MATLAB software. The results obtained were compared based on total fuel cost of generation and total network losses. The assumption in the work was that the contribution of the hydro power plants to the load demanded was fixed. When transmission line losses was included, DE gave the least fuel cost of generation which is $98380.05 compared to what was obtained via MGA and CGA. In all cases of load demanded considered MGA gave a lower total fuel cost of generation compared to CGA, while DE yielded an overall better cost minimization and losses.

Presented in the work of [22] is the application of GA to solve ELD problem, the test system used was Nigerian 330 kV grid system and 3-generating units, the system load demand used in the analysis are 340 MW and 850 MW respectively. The model partner with the Lagrangian method with some special fitness functions to promote cost minimization as well as satisfaction of both equality and inequality constraints while apportioning the generation among the interconnected units. Simulation results for GA outperformed that of Lambda iterative technique in term of minimal total fuel cost of generation and better optimal dispatch. The authors concluded that the model attained good performance with moderate computational burden; appreciable loss minimization coupled with reasonable level of parameter settings was achieved.

Authors in [23] proffered solution to convex ELD problem with quadratic cost function via PSO as optimization technique. The results obtained were validated on two test case systems (IEEE 6-bus and Nigerian 330kV, 31-bus). The proposed approach was implemented in MATLAB optimization tool box. The performance metrics used are total fuel cost of generation and transmission line losses, PSO reported minimized total cost fuel of production and least network losses [23].

Performance evaluation of MGA, Classical -GA and Multi-population-GA (MPGA) for solving non-convex ELD problem on Nigerian 330 kV, 31-bus system was proposed by [24]. The proposed approaches were independently implemented on the test case systems with and without inclusion of transmission losses. The effect of valve point loading was considered in the problem formulation. MATLAB software was used as implementation tool for the analysis. On the basis of fuel cost of production and transmission network with and without losses, MPGA gave the least value. Also, MGA was reported to be faster in finding a quick feasible solution as a result of its small population size.

Authors in [25] addressed ELD problem on thermal plants (Sapele and Afam generating units) located in Southern part of Nigerian 330kV grid systems using PSO. A brief description of Lambda Iteration Method, Gradient Search Method, Base Point and Participation Factor, Linear Programming, Dynamic Programming, Newton's Method were presented. The performance of PSO on ELD with and without inclusion of system transmission losses were investigated in the work. The results obtained with the proposed approach were compared to Lambda iteration method. The authors concluded that PSO converged in less number of iterations, gave the least fuel cost of generation and the total network loss. Also, when transmission line losses were considered the number of iterations required to attain convergence increases whereas for PSO, it has no effect on the number of iterations required to converge and lastly optimal solution obtained by PSO largely depend on the number of particles generated randomly.

Economic generation and scheduling on Nigeria 330 kV integrated power network at minimum operating cost using the Classical Kirmayer's method and Artificial Neural Network (ANN) was investigated by [26]. The proposed approaches were implemented using Matlab optimization tool box. The integrated network has seventeen (17) generating stations of which, eight plants were owned by Federal Government. The installed and available capacity is 6,256 MW and 2,484MW respectively. The remaining nine (9) are from both National Independent Power Project (NIPP) and the Independent Power Producers (IPP) with total designed capacity of 2,809MW, of which

1,336.5MW is available. The proposed approach was carried out into two stages, stage one has to do with modelling of network in power world simulator while the second stage has to do with optimization of dispatches using ANN. Load demand ranging from 1500MW-6000MW were used. This optimal scheduling prevents the system from being stressed beyond their thermal limit.

The work of [27] solved ELD on short-term basis on Nigerian 31- bus system using DE. Daily dispatches on the thermal plant were done for seven consecutive days; the proposed approach was implemented in MATLAB environment. The results open what should be the contribution of each of the thermal generators for the 8- hourly period in a day. The corresponding real power loss and the total fuel cost of production for each period investigated were computed. The dispatches reflected the best possible power output contribution per each thermal plant in the interconnected system for the given period in a day [27].

Reactive power dispatch with a view to minimize the system losses and enhance system voltage profile was investigated by authors in [28]. The proposed approach was implemented on Nigerian 330kV 31-bus systems; three case studies were conducted on the Nigerian power system implemented using power world simulator linked with DE for power flow calculation. The results revealed that the DE-based reactive power dispatch is an efficient tool in keeping the abnormal bus voltages within the prescribed limits as well as a means to reduce system transmission power losses. Also, the authors concluded that it was pertinent to curtail the number of control devices employed so as to alleviate bus voltage problems, likewise integration of a pre-selection mechanism into the DE to select the control devices was suggested by work.

Authors in [29] proposed a fast and easy to use generic Matlab syntax to solve economic dispatch problems, using modified lambda iterative techniques. The test case system used is 26 bus systems having six thermal generators. The computational results obtained with the said approach produced fairly improved results relative to what was obtained using GA using the same test case system.

Power plants economic operation using computational approach was addressed by [30]. The test case systems used have six (6) and ten (10) thermal units respectively. The simulation results obtained using the proposed methodology were compared to GA. The authors concluded that GA has fairly large computational time and that as the number of generators increases, solution with Lambda approach became complex. The work concluded that minimized fuel cost was obtained with GA compared to Lambda iterative approach.

Researchers in [31] solved ELD problem using Ughelli power station with five (5) generating units as case study. The input-output characteristics of each unit in the concerned station were evaluated accordingly based on historical data and least square approximation approach. The optimal power output of each unit in the Ugheli power station was established, these optimal power output combinations minimized the total fuel cost of generation, however, the proposed approach could not established the total transmission line losses.

Optimal economic dispatch of generation on Nigerian 330 kV grid system was examined by [32]. The formulation incorporated transmission line losses. MATLAB optimization tool box was used to implement the said approach. The results showed that the total fuel cost of generation and the system transmission losses reduced by for 17.07% and 5% respectively. Also incorporation of LTCT at buses where voltage drops were observed comparatively reduced the total generation cost and system losses by 17.18% and 8.6% respectively. The work concluded that the bus voltage magnitude improved fairly with the incorporation of LTCT to the economic dispatch. However, this approach is not popular when it comes to optimal scheduling of plant power output on coordinated thermal plants.

The work of [33] presented application of micro and conventional genetic algorithm to address convex ELD problem on Nigerian hydro-thermal power plants. The proposed approach was validated on IEEE 6-bus test system (3-generating units) and thereafter implemented on Nigerian 330 kV, 31-bus system using MATLAB software as implementation tool. The estimated total load demand on Nigerian grid was 2823.10 MW. Long computational time was identified as the major drawback of conventional genetic algorithm. On the basis of performance metrics used (total fuel cost of generation, total network loss and computational time), micro-genetic algorithm gave the least value compared to conventional genetic algorithm.

4. Discussion of Findings

Open access papers addressing ELD on Nigerian grid were carefully sorted and reviewed from 2005 till date. On the basis of literatures reviewed, a summary table which caption authors name and year of publication, solution methodologies, types of ELD, inference drawn and performance metrics used is thus presented.

Table 1: **Summary of ELD Problem Formulation on Nigerian 330 kV Grid Systems**

Author's Names & Year of Publication	**Solution Methodologies**	**Types of ELD**	**Inference Drawn**	**Performance Metrics**
Haruna *et al.*, (2018)	μGA, CGA, DE and PSO	Convex	PSO was reported to be superior in terms of high quality solution, faster and stable convergence characteristics.	1.Total fuel cost 2. Total network losses
Ajenikoko, Olabode and Lawal, (2018)	FA	Convex	FA outperformed DE, GA and ACO.	1.Total fuel cost 2.Total network losses 3. Computational time
Amos, Musa and Thuku, (2017)	PSO	Convex	1. PSO gave least value compared to GA and DE in terms of performance metrics used. 2. DE demonstrated least computation burden.	1.Total fuel cost 2.Total network losses
Nwohu and Osaremwinda (2017)	ACO	Convex	1. ACO performed better than Lambda iterative technique. 2. Lambda technique	1.Total fuel cost 2.Total network losses

			experienced greater computational burden coupled with long computation time. 3. Lambda technique is mostly suitable for relatively small network.	
Osaremwinda, Nwohu and Kolo, (2017)	ACO	Convex ELD only on Egbin thermal plant	1. ACO reduced the operating fuel cost by 0.07% as compared with that of PSO. 2. Least network losses was recorded with ACO.	1.Total fuel cost 2.Total network losses
Buraimoh, Ejidokun and Ayamolowo, (2017)	Lambda iterative technique	Convex	Plant power output optimal dispatch is a mean of lowering the system network losses.	1.Total fuel cost 2.Total network losses
Idoniboyeobu and Braide, (2017)	Review of ELD	-	-	-
Haruna *et al.*, (2017)	PSO, MGA, CGA and DE	Convex	PSO performed better than CGA, μGA and DE.	1.Total fuel cost 2.Total network losses
Awodiji and Folly, (2017)	μGA, CGA and DE	Non-Convex (with inclusion of valve point loading effect).	1. In all cases considered, MGA gave a lower total fuel cost of generation compared to CGA. 2. DE yielded an overall better cost minimization and losses.	1.Total fuel cost 2.Total network losses
Oluwadare *et al.*, (2016)	GA	Convex	GA outperformed Lambda iterative technique.	1.Total fuel cost 2.Total network losses
Attai (2015)	PSO	Convex	-	1.Total fuel cost 2.Total network losses
Awodiji, and Folly,(2015)	μGA, CGA and MPGA	Convex	1. MPGA obtained better results in term of minimized production cost than both μGA and GA. 2. MGA was faster in finding a quick feasible solution as a result of its small population size.	1.Total fuel cost 2.Total network losses
Ibe, Uchejim and Esobinenwu, (2014)	PSO and Lambda Iterative technique	Convex ELD on Sapele and Afam power plant units	1. PSO converged in less no of iterations compared to Lambda iterative technique. 2. Performance of PSO depends largely on randomly generated particles.	1.Total fuel cost 2.Total network losses
Omorogiuwa, and Onohaebi,	Classical Kirmayer's	Convex	ANN performed better than Classical Kirmayer's method	1. Optimal dispatches 2. Total fuel cost

(2014)	method and ANN.		based on the performance metrics used.	3. Total network losses
Awodiji, Bakare and Aliyu (2014)	Lambda Iterative technique	Convex on short term basis	Nil	1. Total fuel cost 2. Total network losses
Bakare *et al.*, (2014)	DE	Reactive power dispatch	1. DE-based reactive power dispatch is an efficient tool in keeping the abnormal bus voltages within the prescribed limits. 2. Incorporation of pre-selection mechanism into the DE to select the control devices was suggested by work.	1. Total fuel cost 2. Total network losses
Dike, Adinfono and Ogu, (2013)	Modified lambda iterative technique	Convex	Fairly improved result relative to GA was obtained.	1. Total fuel cost 2. Total network losses
Adefarati, Oluwole and Sanusi, (2013)	GA and Lambda iterative technique	Convex	1. GA has fairly large computational time as the number of generators increased. 2. The solution become complex with Lambda iterative techniques when the no of generators increased.	1. Total fuel cost 2. Total network losses 3. Computational time
Adetona, Babayomi, and Damis (2013)	Lambda iterative technique	Convex ELD on 5 generators Ughelli power station	1. Optimal power output combinations obtained was able to minimize the total fuel cost. 2. The work was unable to establish the total system transmission losses.	Total fuel cost
Adebayo, Adejumobi and Adepoju, (2012)	Lambda iterative technique incorporating application of LTCT for optimization	Convex	1. A Fair improvement in bus voltage magnitude was achieved with the incorporation of LTCT. 2. The approach is rarely used for optimal dispatches on thermal plants.	1. Optimal Dispatches 2. Total fuel cost 3.Total network losses
Bakare *et al.*, (2005)	μGA, CGA	Convex	1. CGA exhibited long computational time which was overcome using μGA.	1.Total fuel cost 2. Total network loss 3. Computational time

5. Conclusion

This paper presents a review of state-of-the-art approach to economic load dispatch on Nigerian hydro-thermal electric power systems. The review was able to establish that much work has been done on this concept using different state-of-the-art algorithms. The common performance metrics found in the literatures reviewed are total fuel cost of generation, total network losses and computational time. Only few researchers gave detailed account of the computational time, and computation time is one of the best metric to measure the performance of an algorithm most especially for swarm intelligence and population-based algorithms.

It is pertinent to open up new research gap for the researchers in this field of research, in line with this objective, this review work was able to establish that less attention has been drawn to formulation of ELD that capture all the input-output characteristics of a typical thermal plants. Only research paper presented by Awodeji and Folly (2015) made a frantic effort to incorporate effect of valve point loading, cases of multiple fuel option, ramp rate limit, emission of gases and spinning reserve requirement are yet to be researched on Nigerian 330 kV, hydro-thermal plants. It is expected that future works on this concept should integrate the above mentioned characteristics in their ELD problem formulation.

Nomenclature

F	Cost of fuel used by thermal plant i^{th}
P_{Gi}	Real power output of thermal plant i^{th}
q_i, r_i and s_i	Constant fuel cost coefficients of thermal plant i^{th}
a_i and b_i	Unit i^{th} constant coefficient due to incorporation of effect valve point loading.
$a_j[kg/MW^2-h]$	Gas emission coefficient
$b_j[kg/MWh]$	Gas emission coefficient
$c_j[kg/h]$	Gas emission coefficient
P_{Gi}	Real power output of thermal plant i^{th}
$P_{demanded}$	Total real power demanded
P_{Los}	Power loss during transmission
K	Number of buses
P_i	Real power delivered at bus *i*
P_j	Real power delivered at bus *k*
B_{ik}	Loss coefficients
$PG_{min,}$	Lower limits for real power output for a thermal plant i^{th}
$PG_{max,}$	Upper limits for real power output for a thermal plant i^{th}
V_{min}	Minimum statutory bus voltage limits
V_{max}	Maximum statutory bus voltage limits
PG_i^o	Previous operating point for thermal plant i^{th},
DR_{Li}	Down ramp limit
UR_{Li}	Up ramp limit
Z_i	Number of prohibited zones in the thermal plant i^{th}
k	Index of prohibited zones of thermal plant i^{th}
$P_{i,k}^{Lower}$	Lower limit of the k^{th} prohibited zone
P_{ik}^{Upper}	Upper limit of the k^{th} prohibited zone of thermal plant i^{th}.

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