A Comparative Study of Meta-heuristics Algorithms in evaluation of Economic Load Dispatch Problems in Power Generating Station with Matlab Codes

Osaremwinda OP*, Nwohu MN and Kolo JG

Department of Electrical and Electronics Engineering, Federal University of Technology, Minna, Nigeria

Abstract

This paper presents a comparative study of metaheuristics algorithms in evaluation of economic load dispatch problem in power generating station with MATLAB codes. In this paper, the formulation of the ELD problems using mathematical illustrations and MATLAB codes were presented. This consists of the ELD cost model, Model calculations, cost function and parse solution. It also presents the application of some metaheuristics algorithms (solution algorithms) such as ACSA and PSO in solving ELD problem with MATLAB codes. The ELD problem was modeling using Egbin thermal power station, Nigeria as our case study.

Keywords: Economic Load Dispatch (ELD); Ant Colony Search Algorithms (ACSA); Particle Swarm Optimization (PSO); MATLAB codes

Introduction

Economic Load Dispatch (ELD) is the reduction of the total cost of power generation (which includes fuel consumption and operational cost) of power generating plants while meeting the various loads demand and power losses in the power transmission system. The objective is to apportion the total load demand and total loss among the various generating units at the same time satisfying the system constraints with reduced generation costs. With Economic Load Dispatch, it is expected that the power utilities plan and forecast optimal load dispatch. Several considerations are made during energy scheduling, these amongst others are to find out the existing generating units, the distance between load centers and the generating units, identifying the operating limits of each generating units such as the ramp rate limits, maximum and minimum generation level, prohibited zones [1].

Economic Load Dispatch

Economic load Dispatch is to determine the real and reactive power scheduling in power system this is the minimization of the cost function of different generating units. For economic operation of the power system, the total load demand must be optimally shared among all the generating units with an objective to reduce the total generation cost [1]. This is also to find out the power outputs of all generating units in power system so that the total cost of generation of the system is minimized, while meeting the load demand, system equality and inequality constraints. The essential operation constraints are the power balance constraint, that is, the total generated power must be equivalent to the load demands plus the transmission losses on the power system, and the power limit constraints of the generating units [2-6]. The problem of economic operation of a power system is the allocation of the load (MW) among the various units of generating stations in such a way that, the overall cost of generation for the given load demand is minimum. This is an optimization problem which needs to be resolved as quick as possible. For a given load demand, power flow study can be used to calculate active and reactive power generations, line flows and losses. The study also furnishes some control parameters such as the magnitude of voltage and voltage phase differences. The economic load dispatch problem is the results of various power flow studies, where a particular power flow study result is considered more appropriate in terms of cost of generation. The solution to this problem cannot be optimal unless otherwise all system constraints are met. The problem of economic operation of the power system involves two sub-problems, namely, unit commitment (UC) and economic dispatch (ED). While unit commitment (UC) is an off-line problem, economic dispatch (ED) is an area of online concern. The commitment decisions are made many weeks or months in advance. The decision to commit a generating unit to be able to produce electricity means that the power utility is willing to incur fixed costs related to unit startup in order to have that generating units ready and available to generate electricity in real time. Large turbine or nuclear plant generators with large start-up costs cannot run optimally if their output is determined using a single-period analysis (a “period” in the electric power industry usually refers to a length of time of about an hour). Instead, their operation must be scheduled over a longer period of time, usually weeks or months. A power utility would need a forecast of demand weeks in advance before turning on a generator with a long minimum run time [3]. They would need to study the demand forecast over that period of time and decide the lowest-cost mix of generation units that would meet the demand needed. While the procedure of all ocating committed generating units to satisfy customer load demands within a given operational conditions is referred to as "economic dispatch" or "optimal power flow."

Economic Load Dispatch are usually influence by factors such as high operating cost (fuel cost) and transmission losses. The Economic Load Dispatch requires the generation facilities to plan and forecast optimal energy dispatch. Hence the concept is the optimal selection of the generating units in such an economic manner that the total cost of supplying the dynamic requirements of the system is minimized [4].

*Corresponding author: Osaremwinda OP, Department of Electrical and Electronics Engineering, Federal University of Technology, Minna, Nigeria, Tel: 2348023098495; E-mail: zolotrainer@yahoo.com

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Formulation of ELD problem

The ELD problem is an optimization problem that determines the power output of each generating units that will amount to the lowest fuel cost.

Minimize $C(x,u)$

Subject to:

$G(x,u)=0$ \hspace{1cm} (2)

$H(x,u) \leq 0$ \hspace{1cm} (3)

Where, $C= \text{cost function}$,

$x= \text{vector of dependent variables (generating cost)}$,

$u= \text{vector of control variables (generator outputs)}$,

$G(x,u)= \text{set of non-linear quality constraints (power balance)}$,

$H(x,u)= \text{set of inequality constraints (limits in generator outputs)}$.

The objective of the Economic Load Dispatch is to minimize the total operating cost of a power system by adjusting the power output of each of the generators connected to the grid, while satisfying the total load demand plus transmission losses within generator limits.

The generator cost curves are modeled with smooth quadratic (objective) function given by eqn. (4) subject to the equality (power balance) and inequality (generation limits) constraints in eqns. (5) and (7) respectively [6].

Minimize the objective function,

$$F_P = \sum_{i=1}^{n_i} \left( \alpha P_i + \beta P_i^2 + \gamma P_i \right)$$ \hspace{1cm} (4)

Subject to power balance equation (equality constraint)

$$\sum_{i=1}^{n_i} P_i = P_{\text{load}} + P_L$$ \hspace{1cm} (5)

The system losses can be determined by means of a power flow equation solution which is expressed in kwh loss formula in eqn. (6)

$$P_L = \sum_{i=1}^{n_i} \sum_{j=1}^{n_j} B_{ij} P_i P_j + \sum_{i=1}^{n_i} B_{ii} P_i^2 + B_{\text{loss}}$$ \hspace{1cm} (6)

And the (generating limits) inequality constraints,

$$P_{\text{min}} \leq P_i \leq P_{\text{max}}$$ \hspace{1cm} (7)

Where $F_P$ is the total generation cost, $\alpha$, $\beta$, $\gamma$ are cost coefficients, $P_{\text{load}}$ is the load demand, $P_i$ is real power generation of unit $i$, $P_t$ is real power generation of unit $j$, $P_L$ is power transmission loss, $n_i$ is number of dispatchable generating plants, $P_{\text{min}}$ and $P_{\text{max}}$ are the minimum and maximum power generation limits respectively also $B_{ii}$, $B_{ij}$ and $B_{\text{loss}}$ are $B$-coefficient [5].

**Operating cost of a thermal plant**

In economic scheduling of different generating plants, the total operating cost is minimal in a Thermal Plant [5]. This generally comprises of the input to the thermal power plant which is expressed in Btu/h or kcal/h and the output in MW.

The input-output curve of a thermal unit is regarded as heat-rate curve and it is usually a graph drawn between fuel input in Btu/h or kcal/h and power output in MW on the x-axis and y-axis, respectively [7-9].

A typical heat-rate curve for a thermal unit is given in Figure 1, while Figure 2 shows the ordinate of heat-rate curve from Btu/h to N/h results in the fuel-cost curve.

Hence, the fuel cost of generator $i$ can be written as a quadratic function of real power generation as shown in eqn. (8).

$$C_i = \alpha_i + \beta_i P_i + \gamma_i P_i^2$$ \hspace{1cm} (8)

Incremental Fuel-cost curve is obtained by plotting the derivative of the fuel-cost curve versus the real power as shown in Figure 3. It is a measure of how costly it will be to produce the next increment of power. It is drawn by taking the incremental fuel cost in N/MWh as an input on the y-axis and real power in MW as output on the x-axis.

$$\frac{dC_i}{dP_i} = \beta_i$$ \hspace{1cm} (9)

The total operating cost includes the fuel cost, the labor cost and maintenance [6].

**Research Methodology**

Economic Load Dispatch problem was formulated using mathematical illustrations and MATLAB codes.

The ELD problem is formulated as minimizing a scalar objective function through the optimal operation of a vector of controls parameters. This is mathematically illustrated in eqns. (1-3) and diagrammatically represented in Figure 4 [9].

The approach consists of two main components: the controlling device and the controlled device are shown in Figure 4. The ELD problem is one that involves the optimal set of generating units. This minimizes the operating cost (mainly fuel cost). The controlled device is the generating cost model, while the solution algorithm (SA) is the...
For a thermal generating station, the unit fuel cost is shown in the quadratic form in Figure 2, and the goal is to minimize the total operating cost as in eqns. (10) and (11), subject to the generation limit constraint of eqn. (14), power balance constraint of eqns. (12), ramp-rate limits constraints of eqn. (15), and prohibited operating zones constraints of eqns. (16-18).

Considering a thermal power station of \( i \)th generating units \( G_1, G_2, \ldots, G_n \) delivering powers \( P_{g1}, P_{g2}, \ldots, P_g \) respectively connected to a transmission network as shown in Figure 6. Where \( P_D \) is the total power demand and \( P_L \) is the total power losses. Each unit has its cost function \( C_i \). The task here is to find the combination of the real power generation for all units such that the total generation cost \( C_T \) is minimized [9].

\[
\text{min } C_T = \sum_{i=1}^{N} C_i
\]

\[
= \sum_{i=1}^{N} \alpha_i P_{gi} + \beta_i P_{gi}^2 + \gamma_i P_{gi}^3
\]

Subject to

\[
\sum_{i=1}^{N} P_{gi} = P_{gi} + P_{gi} (\text{for } i = 1, 2, \ldots, N)
\]

\[
P_L = \sum_{i=1}^{N} B_{ij} P_{gi} P_{gj}
\]

Subject to

\[
P_{gi} \leq P_{gi,\text{max}} (\text{for } i = 1, 2, \ldots, N)
\]

Where \( C_i \) is the total generation cost, \( C_i \) is the generation cost of \( i \)th unit, \( \alpha_i, \beta_i, \gamma_i \) are cost coefficients, \( P_D \) is the load demand, \( P_{gi} \) is real power generation of unit \( i \), \( P_{gi} \) is real power generation of unit \( j \), \( P_L \) is power transmission loss, \( N \) is number of dispatchable generating plants, \( B_{ij} \) is B-coefficient, \( P_{gi,\text{min}} \) and \( P_{gi,\text{max}} \) are the minimum and maximum power generation limits respectively.

Considering also the ramp-rate limits and prohibited zone, eqn. (14) is modified as eqn. (15),

\[
\text{max } \left( P_{gi,\text{min}}, P_{gi} - DR \right) \leq P \leq \min \left( P_{gi,\text{max}}, P_{gi} + UR \right)
\]

Where \( P_{gi} \) is the previous output, \( P \) is the present output, \( DR \) and \( UR \) are the down and up ramp-rate limits.

The prohibited zones are described by the following inequality constraints [9],

\[
P_{gi,\text{min}} \leq P_{gi} \leq P_{gi,\text{max}}
\]

\[
P_{gi,\text{min},1} \leq P_{gi,1} \leq P_{gi,\text{max},1}
\]

\[
P_{gi,\text{min},k} \leq P_{gi,k} \leq P_{gi,\text{max},k}
\]

Formulation of economic load dispatch problem

The ELD problem is an optimization problem with an aim to find the optimal combination of committed online power generators that will reduce the total operating cost to meet the total system’s power demand while satisfying equality (power balance) and inequality (generation limits) constraints. This is usually done over a period of one hour. The constraints in a practical generator include minimum and maximum generation limits, power balance, ramp rate limits and prohibited operating zones.
\[ P_{gi} \leq P_{gi,k} \leq P_{gi,max} \]  
(18)

Where \( P_{gi} \) and \( P_{gi,k} \) are lower and upper bounds of the \( k \) prohibited zone of unit \( I \) respectively; \( k \) is the index of prohibited zone, \( zoi \) (Tables 1 and 2).

Using the Matlab codes [7], the ELD was modeled from the concept of ELD problem defined in eqn. (10) through to eqn. (18) above showing the power demand, minimum and maximum generating limits, cost coefficients, ramp-rate limits, prohibited zone and B-coefficient. This is model as a function and called Create Model ( ) as shown Figures 7 and 8.

Applying eqns. (10-18), The Model Calculation for the Economic Load Dispatch problem was formulated and the Load apportioned to various generating units (\( P_{gi} \)), Total generated power (\( P_{Total} \)), Total generation cost (\( C_{Total} \)) and Total power losses (PL) were calculated as shown in Figures 9 and 10.

**Optimization approach**

A main task in the optimization process is constraints handling. The application of the solution algorithm (SA) to solving constrained problems in the ELD involves various techniques of handling constraints, to keep the control variables in feasible region, where all the constraints are satisfied. A technique for handling these constraints constitutes the efficiency within the solution Algorithms to solving this ELD problem [9].

**Simulation Approach (Application of Solution Algorithms to Solve ELD)**

The modeling and program development of Solution Algorithm and the ELD problem were accomplished by using MATLAB R2008b software. All program were ran on Intel (R) 2.60 GHz CPU, 2 GB RAM, Window 7 Computer and the modeled ELD was used to evaluate the

| Gen units | (a) (N/h) | (b) (N/MWh) | (c) (N/MW^2h) | Pmin | Pmax |
|-----------|----------|-------------|---------------|------|------|
| 1         | 2131.1667| 13.1        | 0.186         | 55   | 220  |
| 2         | 2131.1667| 13.1        | 0.186         | 55   | 220  |
| 3         | 2131.1667| 13.1        | 0.186         | 55   | 220  |
| 4         | 2131.1667| 13.1        | 0.186         | 55   | 220  |
| 5         | 2131.1667| 13.1        | 0.186         | 55   | 220  |
| 6         | 2131.1667| 13.1        | 0.186         | 55   | 220  |

Table 1: Generator data of Egbin Thermal power station (six generating units) [8].

| B-coefficient data |
|--------------------|
| 0.000099 | 0.00016 | -0.0002 | -0.0002 | -0.0002 | 0.000015 |
| 0.00014 | 0.00012 | -0.0001 | -0.0001 | -0.0001 | 0.000012 |
| -0.0001 | -0.0001 | 0.00013 | 0.00013 | 0.00012 | -0.0001 |
| -0.0001 | -0.0001 | 0.00014 | 0.00013 | 0.00013 | -0.0001 |
| -0.0001 | -0.0001 | 0.00013 | 0.00013 | 0.00012 | -0.0001 |
| 0.00015 | -0.0001 | -0.0001 | -0.0001 | -0.0001 | 0.000012 |

Table 2: Power Losses (B-coefficient) [8].
effectiveness and efficiency of these algorithms (ACSA and PSO), the case study involving six generating units (Egbin thermal station) were applied.

The objective was to minimize the total operating cost, while satisfying the system constraints under the allowable limits.

The network data (Generator data & B-coefficient) were obtained [8] which were presented in Tables 1 and 2.

The outputs results of the optimization tools which were evaluated are as follows:

- Loads apportioned to the various generating units
- Total Generated Power
- Total Power Loss
- Total Generation Cost.

Application of solution algorithms in solving ELD problem in MATLAB codes

The Create Model, Cost Function modeled in Figures 7 and 8 are
Results from simulation using Power Demand of 600 MW (comparison between PSO and ACSA) is shown in Table 3.

Table 3: Results from simulation using Power Demand of 600 MW (comparison between PSO and ACSA).

| Gen Outputs   | ACSA  | PSO  |
|---------------|-------|------|
| G1            | 84.723| 82.348|
| G2            | 103.562| 103.356|
| G3            | 103.894| 106.174|
| G4            | 108.181| 105.734|
| G5            | 97.475| 97.865|
| G6            | 102.176| 104.654|
| Power Demand(MW) | 600.000| 600.000|
| Total Power Generated(MW) | 600.011| 600.130|
| Total Power Losses | 0.011| 0.130|
| Total Generation Cost | 31870.672| 31891.680|

called into the solution Algorithms as shown in Figures 11 and 12 for ACSA, and PSO, respectively.

Discussion of Results

Table 3 shows that the ACSA has effectively reduced the operating cost by 0.07% as compared with that of PSO.

Conclusion

The ELD problem has been successfully modeled and the Solution Algorithm applied to the modeled ELD problem in power generating station in this paper. Subsequently, results shows that ACSA has effectively minimized the operating cost as compared to that of PSO.

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