Economic Load Dispatch for Multi-Generator Systems with Units Having Nonlinear and Discontinuous Cost Curves Using Gravity Search Algorithm

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ABSTRACT

Economic Load Dispatch aims at distributing the load demand between various generation stations in a system such that the total cost of generation is minimum. This is of vital importance since it not only reduces the operation cost of the generation utility but also helps in conserving fast dwindling energy resources.
Modern day power systems are large interconnected systems with a large number of generator units each having its own cost curve. Ideally the cost function of a unit is a quadratic function of the power generated by the unit and the cost curve obtained is a smooth parabola. But in practice cost curves deviate from the idealised one due the several reasons such as valve point effect, multi fuel operation, existence of forbidden zones etc. and as such may not be continuous or analytic. Also for a large interconnected system it becomes essential to consider the effect of transmission losses.
Conventional numerical method based approaches work well with systems without losses but for large systems with losses obtaining convergence becomes difficult as the number of iterations required as well as the computational time are very high. These methods fail entirely if non ideal cost curves are considered. Hence soft computing based methods become essential. Here Gravity Search Algorithm(GSA) has been used to for finding economic load scheduling in a multi generator system, given a certain load demand, and taking into consideration the effects of practical constraints on the idealised load curve. The algorithms for finding the economic scheduling has been written in Matlab and has provided satisfactory results based on the given tolerance values. Also the traditional and soft computing based approaches have been compared to demonstrate the advantages of one over theother.

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1. INTRODUCTION

Economic load dispatch (ELD) is an important optimization task in power system operation for allocating generation among the committed units such that the constraints imposed are satisfied and the energy requirements in terms of Rupee/hour or $/hr are minimized. Improvements in scheduling the unit outputs can lead to significant cost savings. Traditional dispatch algorithms employ Lagrangian multipliers and require monotonically increasing incremental cost curves. Unfortunately, the input–output characteristics of modern units are inherently highly nonlinear because of valve-point loadings, rate limits, etc., and furthermore they may generate multiple local minimum points in the cost function. Classical dispatch algorithms require that these characteristics be approximated; however, such approximations are not desirable as they may lead to suboptimal operation and hence huge revenue loss over-time.

In light of the nonlinear characteristics of the units, there is a demand for techniques that do not have restrictions on the shape of the fuel-cost curves. Classical calculus-based techniques fail to address these types of problems satisfactorily. In the recent years, several attempts have been made by the researchers to solve ELD problems with intelligent techniques, such as hybrid interior point method (IPM) assisted differential evolution (DE) (IPM-DE) ,hybrid DE with biogeography-based optimization (BBO) (DE-BBO), BBO, combined particle swarm optimization (PSO) with real-valued mutation (CBPSO-RVM), improved coordinated aggregation-based PSO (ICA-PSO), quantum PSO (QPSO), ant colony optimization (ACO), hybrid genetic algorithm (GA)-pattern search (PS)-sequential quadratic programming (SQP) (GA-PS-SQP), PSO with both chaotic sequences and crossover operation (CCPSO), new PSO (New PSO), PSO with crazy particles (PSO-Crazy), simple PSO (SPSO), PSO with time varying acceleration coefficients (PSO-TVAC), real coded GA (RCGA), self organizing hierarchical PSO (SOH-PSO), PSO with chaotic and Gaussian approaches (PSOCG) , bacterial foraging with Nelder–Mead algorithm (BF-NM) , new PSO with local random search (LRS) (NPSO-LRS), new PSO (NPSO), PSO with LRS (PSO-LRS), DE combined with SQP (DEC-SQP), improved GA with multiplier updating (IGA-MU), improved fast evolutionary, evolutionary programming (IFEP), Hopfield model (HM).

Gravitational search algorithm (GSA) is one of the latest heuristic optimization algorithms, which was first introduced by Rashedi et al. based on the metaphor of gravitational interaction between masses. GSA is inspired by the Newton theory that says: “Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them”. Gravity is a force, pulling together all matter. Promising results were reported in for benchmark function optimization problems by adopting GSA.

2. ECONOMIC LOAD DISPATCH

The definition of economic dispatch is “The operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities”. In traditional economic dispatch, the operating cost is reduced by proper allocation of the amount of power to be generated by different generating units. Most electric power systems dispatch their own purchased power in a way that may be said to meet this definition.

Generally there are two types of constraints:

a) Equality Constraints
b) Inequality Constraints

a) Equality constraints:

The equality constraints are the basic load flow equations of active and reactive power.

$$P_p = \sum_{q=1}^{n} \left(e_p(e_q G_{pq} + f_p B_{pq}) + f_P(f_q G_{pq} - e_q B_{pq}) \right)$$

$$Q_p = \sum_{q=1}^{n} \left(f_p(e_q G_{pq} + f_q B_{pq}) - f_p(f_q G_{pq} - e_q B_{rq}) \right)$$

p=1,2,3,4....

where e_p and f_p are the real and imaginary components of voltage at the p^{th} node and G^{pq} and ^{Bpq} are the nodal conductance and susceptance between the p^{th} and q^{th} nodes.

b) Inequality constraints:

The KVA loading of a generator can be represented as,

$$\sqrt{P^2 + Q^2}$$

The KVA loading should not exceed a pre-specified value to limit the temperature rise. The maximum active power generated 'P' from a source is also limited by the flame instability of the boiler. If the power generated out of a generator falls below a pre-specified value P_{min}, the unit is not put on the bus bar.

$$P_{min} \leq P \leq P_{max}$$

The maximum reactive power is limited by overheating of rotor and minimum reactive power is limited by the stability limit of machine. Hence, the generator reactive power Q should not be outside the range stated by inequality for it's stable operation.

$$Q_{min} \leq Q \leq Q_{max}$$

1) Input-output curve for Ideal Generator:

The factors influencing power generation are operating efficiencies of generators, fuel cost and transmission losses. The total cost of generation is a function of the individual generation of the sources which can take values within certain constraints. The problem is to determine the generation of different plants such that total operating cost is minimum.

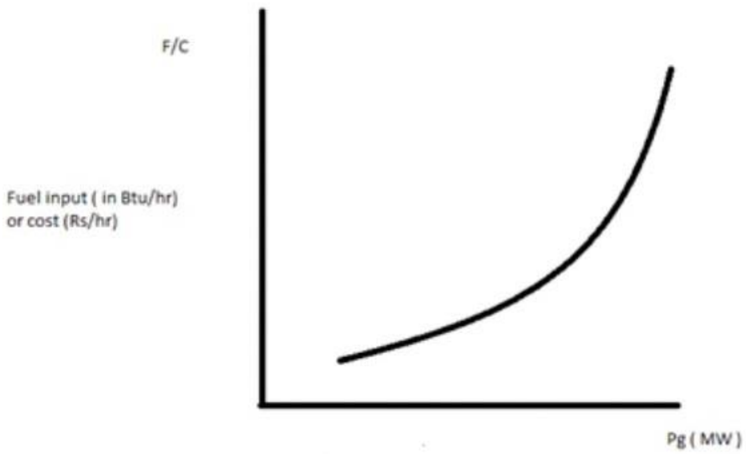

Figure 1. Input-Output characteristics of generator units

Incremental fuel rate=dF/dP
Incremental efficiency = dP/dF

Where F is the fuel input in million Btu per hour and P is the power output in MW. Incremental fuel cost is expressed in terms of Rs per MWhr which is obtained by multiplying the incremental fuel rate by fuel cost in Rs per Btu.

3. PRACTICAL COST CURVES

In practically cost curve are not continuous smooth ones.
Discontinuities arise due to:

3.1. Multi Fuel Operation

Many modern units use multiple fuels depending on power demand for efficient generation. This gives rise to a piecewise continuous cost curve with discontinuities at the points corresponding to the power generations at which change of fuel takes place.

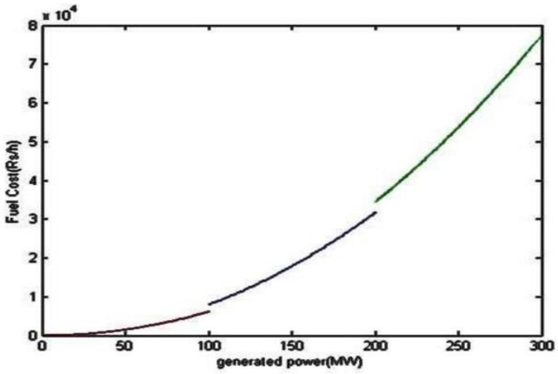

Figure 2. Cost Curve for Multi fuel operation

3.2. Valve Point Consideration

The generating units with multi-valve steam turbines exhibit a greater variation in the fuel-cost functions. The valve opening process of multi-valve steam turbines produces a ripple-like effect in the heat rate curve of the generators. When the valve point effect is considered in the input-output curve, the possibility of non-convex curves must be accounted for if extreme accuracy is desired. If non-convex input-output curves are to be used, equal incremental cost methodology cannot be used, since there are multiple outputs for any given value of incremental cost. Thereby the effects of valve point loading is modelled as a recurring rectified sinusoid contribution and added to the basic quadratic cost function.

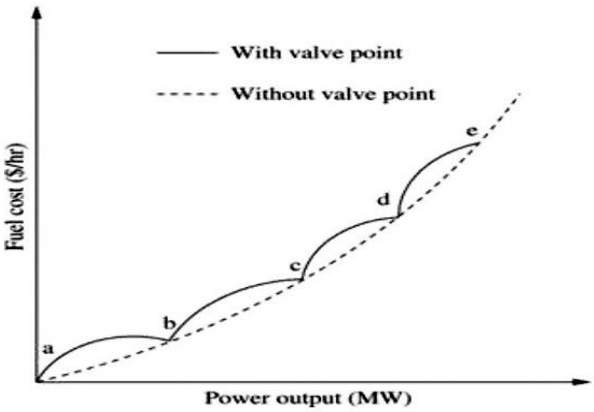

Figure 3. Cost curve with Valve point effect

3.3. Forbidden Zone

There are certain areas in power system where no generation takes place due to vibration of turbine and rotor which is generally known as forbidden zone. This factor gives regions of discontinuity in the input-output curve.

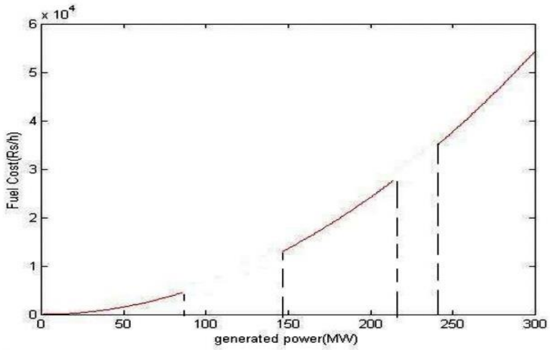

Figure 4. Cost curve for Forbidden zone

These are the various factors which can hamper the linearity of the incremental fuel cost curve; hence the theoretical results will be different from practical ones. During solution of ELD using GSA we have considered effects of multiple fuel operation, forbidden zones and valve point effect.

4. GRAVITY SEARCH ALGORITHM

The classical optimization algorithms are incapable of providing suitable solution for optimization problems containing high dimensional search space as well as nonlinear behaviour. This is because the search space increases exponentially with problem size. Algorithms inspired by the behaviours of natural phenomena are being used as effective methods to tackle such problems. It is shown by many researchers that these algorithms are well suited to solve complex computational problems such as optimization of objective functions, pattern recognition, control objectives, image processing, filter modelling, etc. Various heuristic approaches have been adopted by researches so far, for example Genetic Algorithm, Simulated Annealing, Ant Colony Search Algorithm, Particle Swarm Optimization, etc. These algorithms are progressively analyse or powered by researchers in many different areas. These algorithms solve different optimization problems.

a) Implementation of GSA in ELD program:

The basic principle and mathematical structure of GSA is dealt with in the preceding section. These fundamental steps have to be modified in order to suit the problem at hand, that of Economic Load Despatch for multi generator systems. The implementation of GSA in for the above problem comprises three functions; namely,

- Formulation of a suitable objective function.
- Generation of Initial Sample solutions.
- Development of a GSA based computational

module for calculating the minimum generation cost for a system under given load demand condition.

1) Formulation of objective function:

An objective function forms the basis of any optimization model. It is the function whose value is to be optimized (either maximized or minimized depending on the problem). In case of ELD the value of the objective function is to be minimized. The problem of ELD has the factors that are to be considered for any solution, namely,

- The cost of generation.
- Transmission loss or cost of transmission cost.
- Mismatch between sum of power demand and transmission losses and the generated power obtained from ELD solution.

We mostly consider systems with transmission losses in our project. Also in any solution set of the power balance equation,

$$\sum Pg = Pl + Pd$$

where *Pg*= power generated by each unit;
Pl= power loss in each line;
Pd= total power demand,

obtained by classical numerical methods or by meta heuristic approach would not satisfy the equation perfectly, creating a mismatch between the two sides. The equation under such conditions can be approximated as:

$$|\sum Pg - \sum Pl - Pd| = \delta$$

where δ is a small deviation.
Thus we see all three factors play a role in case of a ELD problem and so the objective function in general is taken to be a linear combination of the three factors; ie
Objective Function = X1*Cost of generation + X2*Cost of loss+ X3*mismatch

Where, X1, X2 and X3 are weights assigned to the three factors respectively. However in order to minimise the objective function the factor with the highest weight age is optimised more at the cost of the factors having lesser weights.

For most of our problems we have concentrated on the cost of generation alone and taken X1, X2 and X3 to be 1, 0 and 0 respectively.

2) Generation of initial sample solutions:
As is the case for any stochastic method GSA also needs a set for initial sample solutions in order to start computations towards the best result. From equality constraint of ELD solutions we have,

$$\sum Pg - Pl - \sum Pd = 0$$

where the loss of power due to transmission Pl can be expressed using transmission loss or B coefficients as:

$$Pl = \sum_{i=1}^{n} \sum_{j=1}^{n} PiBijPj$$

Substituting the value of Pl in the equation 3.22 we get a second order equation involving the power generated by the various generating units. If we assume the system comprise of 'n' generating units then we randomly allocate power generations with the respective permissible range of operation for (n-1) units following the equation:

$$P_g^i = P^i_{min} + \text{rand (i) X } (P^i_{max} - P^i_{min})$$

where P_g^i denotes the generation by the i^{th} unit P^i_{min} and P^i_{max} denote the minimum and maximum permissible generation of the i^{th} unit respectively.
rand (i) denotes a random number between 0 and 1.

The allocation of generations to (n-1) units reduces equation $\sum Pg - Pl - \sum Pd = 0$ to a quadratic equation in P_g^n. If the solution of this equation yields a real value for P_g^n such that $P_{min}^n < P_g^n < P_{max}^n$ then the solution set represent a valid solution and is taken to be a part of the initial population.

3) Development of a GSA based computational module for calculating the minimum generation cost for a system under given load demand condition:
Taking into consideration the basic steps of GSA listed in the previous section, a GSA based ELD module for a generalised system having n generators is implemented as follows:

- A 'n' dimensional space is used for the problem.
- Each solution set of the population is treated as a point mass, the mass assigned to it being inversely proportional to the cost of generation (or the value of the objective function) since it is a minimization problem.
- The new positions of the masses are the modified power generations allocated to the 'n' generating units.
- Step d is repeated till the exhaustion of allowed number of iterations in order to obtain the best possible solution.

5. RESULTS

16 Generator lossless systems using Lagrangian multiplier:

- Power Demand(MW) =3000
- Lambda = 4.830629999976126
- Total Generation Cost ($/h) = 9.637785672117201e+003
- Total Generated Power = 2.999997340557906e+003
- Elapsed Time = 15.371956240090096 seconds

16 Generator systems with transmission loss using GSA:

- Power Demand(MW) = 2630
- Total Power Generation = 2.657131496253033e+003
- Total Generated Cost ($/h) = 3.254862358344061e+004
- Total Loss = 27.104321170969200
- Elapsed Time = 2.837629 seconds

The following results obtained for 10 generating units by considering multiple fuel systems and valve point effect using GSA:

- Total generation (MW) = 2700
- Power Demand (MW) = 2700
- Total generation cost ($/h) = 624.0555
- Elapsed time = 18.693614 seconds

Generation allocated to various units of 10 unit multiple fuel system:

Unit = 1 Generation=218.37 Fuel Type = 2
Unit = 2 Generation=209.488 Fuel Type = 1
Unit = 3 Generation=280.608 Fuel Type = 1
Unit = 4 Generation=241.794 Fuel Type = 3
Unit = 5 Generation=276.266 Fuel Type = 1
Unit = 6 Generation=241.388 Fuel Type = 3
Unit = 7 Generation=291.162 Fuel Type = 1
Unit = 8 Generation=237.886 Fuel Type = 3
Unit = 9 Generation=426.576 Fuel Type = 3
Unit = 10 Generation=276.463 Fuel Type = 1

The Figure of variation of total cost and loss with iterations have shown in Figure 5 and Figure 6 respectively,

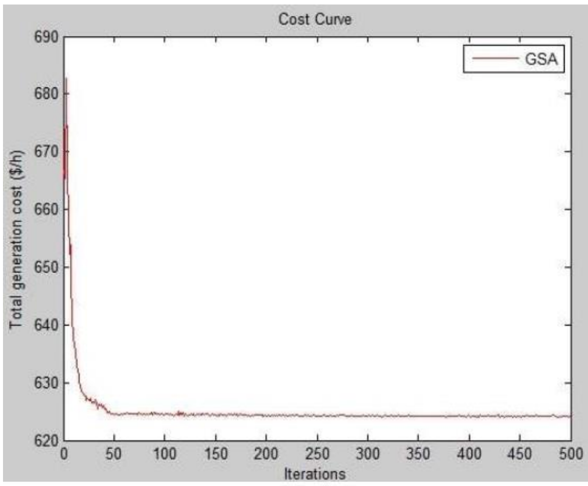

Figure 5. Variation of total cost with iterations

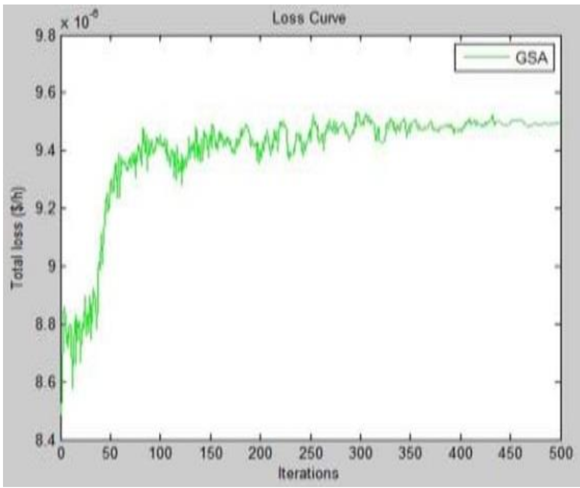

Figure 6. Variation of total loss with iterations

6. DISCUSSION

From comparison of the various results obtained and observations made during the execution of the MATLAB codes the following points were noted:

1) The Lagrangian Multiplier method used for 16 generator systems having no transmission losses gave much slower convergence than GSA used for 16 generator system having transmission losses.

For GSA based system the execution time did not increase linearly with the number of units. The increase of execution time reduced with the increase in the number units. Hence it is advantageous for systems having large number of units.

7. CONCLUSION

In this project, Gravity Search Algorithm has been used as a tool for solving ELD problem for practical generating units having nonlinear or discontinuous cost curves in an efficient way. GSA has proved to be quite efficient in solving the problem both in terms of execution time and the minimisation of the objective function. The execution time depended on the number of units considered and the types of nonlinearities or discontinuities included in the definition of the cost curve of the units. As such the execution time increased at a rate slower than that of the increase in the number of units and thus GSA based solutions were found to be more efficient for larger systems.

8. FUTURE WORK

This project concentrates mainly on the minimisation of generation cost and in most cases losses, mismatch and other factors have not been weighed into the objective function. Hence there is scope for including of these factors into the objective functions and study the effects it has on the results. The objective functions may be further generalised to develop a optimization module for Optimal Power Flow Management (OPFM).

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