Economic Dispatch Solution for Generating units through Optimization

Muhammad Nazeer¹, Shazmina Jamil², Mohsin³, Jibran Ullah Khan⁴

¹,²,³,⁴ Department of Electrical Energy System Engineering, US-Pakistan Center for Advanced Studies in Energy (US-PCASE), UET Peshawar
muhammadnazeer@gmail.com¹, shazminajamil@yahoo.com², malakmohsin5533@gmail.com³, jibrank787@gmail.com⁴

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Abstract— The complex nature of the modern power system is because of the interconnection of the generating units and day by day increased load demand. The main purpose of the power system is to tantalize the load needs and generate reliable and cheap energy i.e. cost of generation should be optimum i.e. operating every generating unit in such a way to optimize the cost. The cost function of every generating unit is different from other generating unit, so load has to be divided among various generating units to obtain optimum generation. The optimization of power system is done by Economic load dispatch (ELD). ELD is of immense importance in power system operation and planning (PSOP). The primary purpose of ELD is to pacify the load needs at lowest cost while satiating all kind of equality and inequality constraints. Power system has highly non-linear input output characteristics because of different generation constraints. In ELD cost function of each and every generating unit is equated as quadratic function. Numerous methods have been devised to figure out ELD problem incorporating conventional methods like Lambda iteration method and Gradient method, and artificial intelligent method like Particle Swarm Optimization, Generic Algorithms etc.

In this thesis optimization of generating units is done through General Algebraic Modelling System (GAMS). GAMS is a modelling system used for mathematical programming and optimization on a large scale. It helps to develop a mathematical model similar to their corresponding mathematical expression and gives more accurate results.

Keywords— Optimization, ELD, GAMS.

I. INTRODUCTION

The one and only single most extremely important objective of the power system is to dispatch reliable and cheap energy to its consumer. In order to achieve that goal economic load dispatch (ELD) is very critical factor in power system operation and planning. Economic load dispatch is stated as the practice for the allocation of load to the generating units in order to satisfy the load demand in such a way to minimize the cost of energy generation while all the constraints either equality or inequality constraints are satisfied. In other words, it helps to achieve optimum generation schedule for every generating unit in power system.

In the beginning the economic load dispatch concept was developed to cater different load variations in a given period by running most efficient unit first until it reaches its maximum limits, after that second most efficient unit starts increasing its generation to pacify the load requirements in case of load increasing during peak hours’ duration until its maximum range is reached, and so next most efficient unit will start increasing its generation and so on, the drawback of this logic was that was that the cost of operation increased as during light load hours the units were running at their lower efficiency causing more problems [1]. After that lots of approaches have been developed to figure out economic load dispatch problem. The traditional approach to figure out economic load dispatch problems are lambda iteration method, Newton Raphson method and gradient method, Participation Factor Method and Base Point Method [2]. The problem related to these methods are such that they used only for those generating whose fuel-cost characteristic curve is linear and increases in a monotonic way this leads to extremely high operating cost as because of different constraints the input/output characteristics is non-linear in nature [3]. The effective way to solve the ELD problem in an accurate way is to have the smoothly increasing and continuous nature of the cost curve [4]. Highly intelligent algorithms are used to solve constrained economic load dispatch problem which includes Particle Swarm Optimization, Genetic Algorithms (GA), Evolutionary programming, neural networks, Hopfield neural networks [5]. Some of these methods can result in slow convergence except Particle Swarm Optimization [6].

Different constraints such as transmission losses, load demand balance, quadratic nature of a cost functions, and valve point loading effect made the economic load dispatch...
problem a nonlinear optimization problem in a power system operation and planning, conventional methods are not able to solve such a nonlinear problem so far that different techniques have been developed to figure out such complex problem while handling these constraints in order to get real time results [7]. Further development in the solution of Economic load dispatch of thermal power unit have been made by considering the optimum amount of heat release, for that purpose different Heuristics and meta Heuristic techniques have been developed [8]. Optimum emission of flue gases in the air in order to maintain the environment clean and free from the oxides of carbon, sulphur and nitrogen [9].

In this proposed thesis Economic Load Dispatch is done through General Algebraic Modelling System (GAMS). GAMS helps to develop mathematical programming in a same way as that of system mathematical expression and performs the function of the optimization of linear, Non-linear and mixed integrals. GAMS used for a large scale optimization techniques and gives most accurate results.

II. RELATED WORK

Lots of work has been done on Economic load dispatch ranging from small scale to a large scale power system optimization. In this regard some of the work is mentioned here as a literature study.

In [10] a multi objective meta heuristic approach for dynamic ELD problem using multi objective PSO (MOPSO). Emission constrained Economic Load Dispatch problem is solved using differential evolution (DE), [11]. A comparative analysis of Genetic approach based on arithmetic crossover with the enhanced Hopfield Neural Network, Fuzzy logic controlled Genetic Algorithms (FLCGA) and advance Hopfield Neural Network, [12].

A Hybrid technique consisting Genetic Algorithm as an optimizer and SQP used for tuning purpose [13]. θ-Particle swarm optimization technique is applied for optimization by changing traditional PSO to θ-PSO by using phase angle vector [14]. Another variant of PSO approach known as Adaptive PSO has been developed and implemented [15]. A Heuristic approach consisting of Iteration PSO associated with variable acceleration coefficient by choosing a proper penalty factor [16]. In [17] above approach is used for combined heat power economic dispatch (CHPED) problem.

Artificial Immune System (AIS) based on evolutionary techniques and colonel selection approach [18]. An Encoding technique based on Genetic Algorithms used for global optimization [19]. A Hybrid Harmony Search (HHS) technique based on Swarm approach meta-heuristic algorithm for the optimization [20]. Another variant of HHS, which is tournament based THS [21].

An iterative PSO developed to get optimum scheduling of power, [22]. In [23] Gravitational Search Algorithm related to law of gravity and mass interaction for the optimization. A hybrid system consists of PSO and SQP is used for optimization [24].

Hybrid approach consist of PSO, Gaussian probability distribution functions and chaotic sequence for power system optimization [25]. A hybrid system of GA with SQP and IPA (interior point algorithm) with their nine variants are implemented for optimization of thermal generating units [26]. In [27] a hybrid technique called Estimation of Distribution and Differential Evolution developed. Another variant of Differential evolutionary approach is developed which include restoration process in case if the constraints are disobeyed [28]. A self-adaptive DE along with GE is implemented for the solution of dynamic economic load dispatch problem [29]. DE practice is implemented on the optimization of thermal power plant along with the integration of renewable energy resource including wind energy in order to solve the combined economic emission dispatch [30].

A meta-heuristic approach based on the insect’s casual nature like Cuckoo and Levy have been developed known as Cuckoo Search Algorithms (CSA), [31]. In [32] and [33] a detailed review of different modifications of Cuckoo algorithms discussed for the purpose of optimization and its significance in the research. to solve this complex nature of ELD a cuckoo algorithm is implemented [34]. A variant of firefly algorithm (MFO) is implemented in [35] for optimization and a comparative analysis is made based on results with different algorithms used in a literature. A multi objective evolutionary technique called chemical reaction optimization has been implemented on DELD, the convergence of presented method is improved by hybridization with differential evolution to get rid of local minima [36].

In [37] different techniques and their hybrid combination based on different has been reviewed and addressed the complexity related to every computational techniques. A review of different hybrid approaches developed for the solution combined economic emission dispatch problem [38]. Another method known as flower pollination Algorithm is used to solve multi objective function of combined economic emission [39]. A quadratic programming approach is presented and compared with different approaches like GAMS, GA, PSO and ED and also with hybrid technique consist of GA, ED and PS [40]. A Moth Flame Optimization (MFO) technique in [41]. A hybrid approach consist of Nelder Mead and pattern search algorithm in which the former performs the function of optimization and the later used to find the best optimum solution [42]. An algorithm based technique known as Social Spider Optimization and its later version (SSSO and ISSO) is implemented in [43]. In [44] SSO is implemented on five models for constrained ELD problem. In [45] a modification of OLC called OLC swarm presented as optimization technique.

In [46] a modified HNN method uses two different practices to solve ELD problem in order to minimize the computational time. Differential Evolutionary approach is
implemented and results shown compatibility to those obtained by MHNN and MPSO [47]. The combined heat and power (CHP) day ahead optimization to improvise optimum cost and heat dissipation developed applied on two models which are Electric storage system and thermal storage system [48]. Extension classical Bat Algorithm known as chaotic Bat Algorithm has the issue that operator has to tune the model in order to get the feasible results [49]. An evolutionary approach known as Backtracking Search Algorithms is applies in [50] for optimization purpose. A Meta heuristic approach Grey wolf optimization approach is developed. [51]. In [52] Grey wolf optimization is used for solution of dynamic economic load. Exchange Market Algorithm to achieve globally optimized region [53]. A crisscross optimization approach is developed for optimization on large scale basis of generating units and to achieve better performance [54].

A comparison is made between General Algebraic Modelling System (GAMS) and the quadratic Programming is presented [55] and in [56] optimization is carried out through GAMS, initially ELD was solved using PWL and SOS algorithms which were unable to give optimum schedule for power system. An optimization for the dynamic economic load dispatch is done through GAMS, in results GAMS shown the upper hand over the other available approaches [57].

III. METHODOLOGY

In this paper, Optimization of different generating units is carried out using GAMS as optimization tool on different case studies along with load and generation profiling.

Case 1: this case study includes 26 generating units.

Case 2: Total of 35 generating units are used for optimum scheduling of different generating units.

A. General Algebraic Modelling System

General algebraic modelling system commonly known as GAMS is a high level mathematical programming tool used to solve mathematical models according to the mathematical expressions of that model. Used by both commercial areas and academic institutions in different areas of research for optimization purposes varies from production planning to economic modelling. GAMS is developed to solve linear, nonlinear and mixed integer optimization problem. The basic coding structure of the GAMS comprises Sets, Data, Variable, Equations, Model and solve statement, Output. Different constraints and cost functions of generating units are given in the form of table.

### TABLE I. UNITS CONSTRAINTS AND COST FUNCTION COEFFICIENTS.

| Sr. No | Unit name | $p_{min}$ (MW) | $p_{max}$ (MW) | $c_i$ | $bP$ ($$/MW)$$ | $aP^2$ ($$/MW^2)$$ |
|--------|-----------|----------------|----------------|-------|----------------|------------------|
| 1      | G1        | 2170           | 217            | 2001.32 | 7.1          | 0.00277 |
| 2      | G2        | 2402           | 520.5          | 2202.55 | 7.97         | 0.00313 |
| 3      | G3        | 1638           | 350.7          | 1794.53 | 6.66         | 0.00284 |
| 4      | G4        | 1370           | 274            | 1785.96 | 6.63         | 0.00298 |
| 5      | G5        | 680            | 250            | 1247.83 | 7.97         | 0.00313 |
| 6      | G6        | 665            | 222            | 1249.9  | 7.95         | 0.00313 |
| 7      | G7        | 1320           | 264            | 1755.55 | 7.69         | 0.00294 |
| 8      | G8        | 1292           | 274            | 1801.25 | 8.01         | 0.00125 |
| 9      | G9        | 2200           | 450            | 2855.32 | 7.93         | 0.00235 |
| 10     | G10       | 1320           | 374            | 1798.25 | 6.75         | 0.00196 |
| 11     | G11       | 1320           | 375            | 1815.32 | 5.12         | 0.00149 |
| 12     | G12       | 1320           | 256            | 1915.32 | 6.64         | 0.00155 |
| 13     | G13       | 1320           | 275            | 1720.55 | 9.60         | 0.00160 |
| 14     | G14       | 1320           | 200            | 1650.56 | 8.66         | 0.00187 |
| 15     | G15       | 1320           | 295            | 2390.52 | 6.12         | 0.00785 |
| 16     | G16       | 600            | 200            | 1113.4  | 8.5          | 0.00421 |
| 17     | G17       | 660            | 254            | 1728.3  | 9.15         | 0.00708 |
| 18     | G18       | 600            | 180            | 1285.25 | 8.25         | 0.00902 |
| 19     | G19       | 450            | 195            | 635.5   | 11.154       | 0.00515 |
| 20     | G20       | 330            | 99             | 287.71  | 8.03         | 0.00357 |
| 21     | G21       | 330            | 135            | 455.76  | 6.6          | 0.00573 |
| 22     | G22       | 330            | 110            | 391.93  | 7.01         | 0.00492 |
| 23     | G23       | 1036           | 230            | 1247.15 | 8.15         | 0.00333 |
| 24     | G24       | 727            | 250            | 460.32  | 7.26         | 0.00526 |
| 25     | G25       | 216            | 100            | 107.87  | 8.95         | 0.0001 |
| 26     | G26       | 175            | 50             | 222.21  | 6.45         | 0.0016 |
| 27     | G27       | 3478           | 575            | 3354.96 | 14.36        | 0.00014 |
| 28     | G28       | 1410           | 282            | 1954.96 | 8.8          | 0.00378 |
| 29     | G29       | 1410           | 220            | 1830.85 | 7.8          | 0.00222 |
| 30     | G30       | 1450           | 290            | 1949.72 | 9.18         | 0.00122 |
| 31     | G31       | 669            | 134            | 969.8   | 7.05         | 0.00766 |
| 32     | G32       | 121            | 24.2           | 694.26  | 4.84         | 0.00841 |
| 33     | G33       | 96             | 20             | 278.16  | 4.18         | 0.00766 |
IV. RESULTS

The research work comprises of total 35 generating units to be economically dispatched in order to get the inexpensive energy from the traditional power system. In this work two case studies have been carried out with 26 generating units and other with 35 generating units. The results are shown in the form of tables and graphs.

A. Optimization of 26 units at 15000MW load demand.

In this section the optimization of 26 generating units dispatched in order to meet the load of 15000 MW load including losses associated with power system is discussed. Table below shows the results of how much power should be generated from each unit on the basis of the cost function of individual generating unit given in table below.

Negative value of marginal cost shows that the unit is hitting the maximum range so its marginal cost will be less than that of the system marginal cost by an incremental cost of the unit. Zero or EPS shows that the generating unit is operating within the allowable range of generation so its incremental cost will be same as that of system marginal cost, the positive value shows that the generating unit is operating at its minimum allowable range of generation limit, so its marginal cost should be greater than that of system marginal cost by incremental cost of the generating units.

| Unit | Generation (MW) | incremental cost $/MWh |
|------|----------------|-----------------------|
| g26  | 175            | -4.21676630288306    |
| g25  | 216            | -2.23974630288306    |
| g11  | 1320           | -2.18366630288306    |
| g22  | 330            | -0.98006630288306    |
| g21  | 330            | -0.85546630288306    |
| g20  | 330            | -0.85106630288306    |
| g12  | 1320           | -0.50526630288306    |
| g13  | 511.645719650957 | 0         |
| g1   | 766.160426459827 | EPS     |
| g2   | 521.927524422215 | EPS     |
| g3   | 805.856743465328 | EPS     |
| g4   | 773.031258872997 | EPS     |
| g5   | 521.927524422215 | EPS     |
| g6   | 525.122412601128 | EPS     |
| g7   | 603.27658212297  | EPS     |
| g8   | 1290.90652115323 | EPS     |
| g9   | 703.673681464482 | EPS     |
| g10  | 1144.7107915518  | EPS     |
| g14  | 689.108637134509 | EPS     |
| g15  | 325.940528846055 | EPS     |
| g16  | 325.091009843594 | EPS     |
| g23  | 463.533498931391 | EPS     |

The table below gives the system marginal cost and the total generation cost in order to meet the total load demand.

| Load (MW) | System marginal cost $/MWh | Generation (MW) | Total cost of generation in $ |
|-----------|---------------------------|----------------|-------------------------------|
| 15000     | 11.23726630288306         | 15000          | 173065.176140                 |

The graphical representation shows the results from most economical generating unit at left and most expensive unit at right of the graph shown in Fig below.

B. Optimization of 35 units at 15000MW load demand.

Total of 35 generating units are used for optimum scheduling of these plants. The load along with losses is taken as the load demand 26359 MW. In below gives the optimum scheduling of the generating unit is illustrated.

The table below gives the optimum scheduling and incremental cost of each generating units.
The table below gives the system marginal cost and the total cost of generation.

**TABLE IV. UNIT’S DISPATCHED GENERATION AND INCREMENTAL COSTS**

| Unit name | Generation (MW) | Unit marginal cost       |
|-----------|-----------------|--------------------------|
| g33       | 96              | -7.60739449154909        |
| g32       | 121             | -6.38289449154909        |
| g26       | 175             | -6.23761449154909        |
| g25       | 216             | -4.26059449154909        |
| g11       | 1320            | -4.20451449154909        |
| g34       | 500             | -3.00811449154909        |
| g22       | 330             | -3.00091449154909        |
| g21       | 330             | -2.87631449154909        |
| g20       | 330             | -2.87191449154909        |
| g31       | 669             | -2.78283449154909        |
| g12       | 1320            | -2.5261449154909         |
| g8        | 1292            | -2.0181449154909         |
| g10       | 1320            | -1.3371449154909         |
| g6        | 665             | -1.14521449154909        |
| g5        | 680             | -1.0313449154909         |
| g30       | 1450            | -0.5401449154909         |
| g35       | 1310            | -0.059144915490904       |
| g1        | 1140.391572509  09 | 0                     |
| g13       | 1143.160778609  09 | EPS                  |
| g14       | 1229.423774197  54 | EPS                  |
| g15       | 454.6569739840  18 | EPS                  |
| g16       | 565.0967329630  75 | EPS                  |
| g17       | 290.1210799116  59 | EPS                  |
| g18       | 277.6116680459  59 | EPS                  |
| g19       | 204.28629603445 72 | EPS                  |
| g2        | 844.7467238896  31 | EPS                  |
| g23       | 766.9841578902  54 | EPS                  |
| g24       | 570.1629744818  53 | EPS                  |
| g28       | 589.6976840673  4  | EPS                  |
| g29       | 1229.305065664  21 | EPS                  |
| g3        | 1161.639875272  | EPS                  |

The table below gives the system marginal cost and the total cost of generation.

**TABLE V. SYSTEM MARGINAL AND TOTAL GENERATION COST**

| Load (MW) | System marginal cost | Generation (MW) | Total generation cost in $ |
|-----------|----------------------|-----------------|-----------------------------|
| 2635      | 13.25811449154909    | 91              | 26359                       |
| 9         | 13.25811449154909    | 91              | 313223.669360               |

The graphical representation of each generating unit’s marginal cost is given as,

**Figure 2. Units marginal cost.**

**CONCLUSION**

One of the main objectives of the power system is to provide cheaper and uninterrupted energy to its consumers and to reduce losses associated with power systems by economically dispatching generating units in a power system in order to meet the load requirements which should financially benefit both the generating utility and energy consumers. General Algebraic Modelling System is one of the most efficient and mathematical programming software for the optimization on large scale in which mathematical algorithm is defined based on mathematical expressions of the system. GAMS used for the optimization purpose on a large
scale system is one of the easy software platform is user friendly, easy handling and takes less time for the execution of program and gives best results. Different scenarios for optimization of Pakistan power system is discussed in this work including optimum dispatching. At the end, results shown the dispatching of hydro-thermal generating units available in the research studies gives the most economical solution for optimization problem.

Future work on this area of study can be done by considering multi-objective function associated with power system. Research can be extended for the optimization of power system along with different constraints associated with unit commitment such as ramp rates etc. further extension can be made to consider the optimal power flow scenario for power system. Due to rapid trend towards renewable sources. Integration of renewable energy sources with the classical power system is one of the complex job. So solution can be developed for the optimum dispatching and integration of renewable energy resources with conventional grids.

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