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Solving Economic Load Dispatch Problem using Quadratically Constrained Quadratic Programming

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Abstract: *Economic load dispatch (ELD), is a key parameter for any workable power system. This is a method which allows us to manage active power generated from any utility in a way that is both cost-effective and complies with all network restrictions. There are various methods like LIM, and Newton-Raphson available some of the conventional approaches of solving ELD. The fuel cost curve shows incline at increasing level of generation, which must increase linearly for all of these conventional approaches to work. However, in actuality, a generator's input-output characteristics are very much non-linear. This creates many difficult non-convex optimisations challenge. There are many conventional and non-conventional techniques are present which can handle nonconvex optimisation problems quickly and nearly optimally. In this study, the Lambda-iterative approach and QCQP (Quadratically Constrained Quadratic Programming) were used to solve the ELD problem, and the outcomes were compared. The GAMS environment has been used for all of the analyses.*

Keywords: Economic Load Dispatch, Optimization, Quadratically Constrained Quadratic Programming, GAMS.

I. INTRODUCTION

The economic load dispatch problem, which tries to disperse the output of each generator in order to reduce the cost of production for the stated load schedule subject to certain limits, is one of the main problems in the power system. The regular demand of load in a power system can be predicted. Models from statistics, analysis, and technology may be used in the forecasting. Cost-based ELD aims to reduce generation costs while observing the equality, inequality, and other limitations. Price-based ELD is distinct from cost-based ELD. Increasing the profit of the generating company is the goal of price-based ELD. Even though the price-based ELD equality constraint may be broken, other technical requirements must still be met.

G P Dixit, et al. [1] proposed “Artificial-Bee-Colony (ABC) algorithm approach to resolve dispatch solution. Subject to typical constraints, the goal is to minimise the nonlinear function, which is the over-all cost of fuel of heat producing systems. The proposed ABC technique was tested on a Crete Island system with eighteen heat generator units and a convex quadratic cost-function, as well as a typical IEEE thirty bus system with six generating-units and a 15-generating-unit system with emission limits.

V Hosseinnezhad & E Babaei [2] in their paper presented “a θ-Particle Swarm Optimization approach for Economic Dispatch solution at Power Utilities. Practical restrictions such as losses during transmission, and banned operational areas can be easily addressed by the suggested methodology, which also addresses non-smooth cost function caused by usage of valve point possessions. As a result, placements in θ-PSO are determined using phase angle mapping. The suggested algorithm's performance was evaluated on systems with various number of generating units, and at different levels of complexity.

In this paper, Bikash Das and T. K. Sengupta [3] discussed about the ELD problem using bio-inspired-algorithms like PSO and TLBO. For four separate networks of 3, 6, 15, and 20 generating units, the algorithms are utilised to determine a solution which is optimum with the minimum fuel-cost for varying load demand. The analysis was conducted without taking into account line losses while addressing line losses for various load demands.

As analytical methods experiences sluggish convergence and the curse of dimensionality, PSO can be a useful tool for solving large-scale nonlinear optimization problems. By giving an overview of fundamental PSO, Shubham Tiwari, et al. [4] present a thorough review of the topic of optimization solution for ED problem. This work introduces Classic PSO as an optimization method for solving quadratic cost functions with constraints of generator and power losses that are dependent on constraints

In their paper, Leena Denial et al. [5] suggest a novel technique to solving the ELD problem which deals with the constriction of the RRL. It creates a time-varying dynamic economic load dispatch, in where load dispatch is computed for each defined time interval, results are used for training an artificial-neural-network (ANN) which is based on the LMA. The Levenberg Marquardt algorithm-based DELD is faster and more precise. This algorithm is put to the test on nine different generating units, with the results being shown and debated.

In their research, Gaurav Chauhan et al. [6] used MiPower version 9 programming to determine the ideal generator scheduling. The lambda-iteration-method is used to solve the economic-dispatch (ED) problem for a 6-generating unit system including and neglecting losses. The ELD solution for this is investigated using MiPower programming. MiPower is a very sophisticated computer programme that is very simple to use. It comes with a set of modules that may be used to perform a wide range of energy framework design and inspection tasks.Umamaheswari Krishnasamy and Devarajan Nanjundappan [7] examined that combining an unbiased probabilistic neural network with biogeography-based optimization can help reduce the operational cost for maintenance of any power generating unit based on wind energy. In order to estimate wind output one hour in advance, a WPNN is used to maintain a steady supply of electricity. For a better result, the BBO technique was employed in combination with SQP.

In their paper, Xiaoyu Wang and Kan Yang [8] proposed a multi-agent glow-worm swarm optimization (MAGSO) algorithm for a large-scale hydropower station's economic load dispatch problem. The MAGSO combines the concepts of GSO and MAS interindividual interaction. Before initiating the evolutionary process, each glow-worm is uniting in the MAS system in this framework. The proposed strategies allow the approach to find the best possible solution and broaden the variety.

In their study, Yue Cao et al. [9] presented "an NSGWO for multi-objective load dispatch of coal-fired power plants that made use of effective quasi sorting, a reference-point selection, and a simulating binary crossover operator. This NSGWO approach showed greater stability besides typical multi-objective approaches, according to benchmark function optimization results" [9]. The NSGWO outperformed all other simulated algorithms in terms of environment aspects like protection, economic aspect as well as the fast processing of the data regarding load dispatch.

In this paper, O. Tolga Altinoz [10] looked at a novel approach for economic emission load dispatch solution. On comparing typical distributed dispatch challenges, the suggested framework connects various non-synchronous generators at various locations to different load centres. Some shared units connected to others are connected to bulk demand locations. As a result, every generator has an impact on the others. Furthermore, the planned framework includes excess power that can be sold to neighbouring regions.The SAR optimization technique, a novel meta-heuristic inspired by human behaviour throughout search and rescue operations, was employed by Mokhtar Said et al. [11] in their study. The CEED and ELD (Combined Emission and Economic Dispatch) issues are resolved using the SAR (ELD). To measure SAR's trustworthiness, researchers compared its performance to that of different metaheuristic approaches. The suggested SAR approach is also compared to various algorithms in the literature. In addition, for a statistical study of all used procedures, various parameters line mean, mode and median are applied and the values are evaluated for 30 diverse rounds.

A. Srivastava and D.K. Das [12] proposed class topper approach of optimization, a novel metaheuristic optimization technique based on human intelligence. This allegedly sophisticated algorithm integrates the idea of remedial classes to strengthen the learning capacity of a class's weaker students. It is a variation on conventional CTO. "To verify the proposed algorithm's capabilities for evaluation and avoiding local minima, 29 benchmark functions are examined. In addition, 7 and 4 cases to examine ELD and CEED equations. This shows how effective every suggested method is at solving these difficult problems" [12].

In his article, Gaurav Dhiman "developed the ground breaking hybrid approach MOSHEPO to address the dispatch problems" [13]. This approach combines the recently developed MOSHO and Emperor Penguin Optimizer, two bio-inspired design optimization techniques. For practical operation, MOSHEPO takes into account numerous properties of generating units, like line losses, different fuel used, loading conditions, and forbidden operation areas, as well as their effective limits. MOSHEPO's effectiveness was tested and compared with variety of standard test systems. To address these flaws, a number of evolutionary algorithms have been implemented to address the ED problem.

The hybrid SCA in a memetic approach was utilised by M.A. Al-Betar et al. [14] to address various prominent electrical engineering problem known as the ELD problem. In order to handle ELD, a group of generators with the cheapest fuel prices are assigned to satisfy a predefined load demand while abiding by a various constraint. "SCA represents new optimisation approach using population as base that uses a mathematical model to get the best solution" [14].In the current scenario induced due to our increasing demand of power and the handling capabilities, Usharani Raut and Sivkumar Mishra [15] believed that the power handelling may be much easier and effective if we integrate our distribution-generators, by doing this we can also save some cost also. A novel multiobjective sine-cosine approach is been taken in this context aiming lower losses and emission, and higher stability of voltage index while maintaining the functioning of distribution generator system stable. The recommended method includes mutation and conversion constraints adjustment to enhance performance at various iteration phases.

II. Problem Formulation

To achieve best goal for economic dispatch we have to solve the main function in the form of quadratic equation. The quadratic equation we are going to deal with is called objective function.

Minimize

$C = \sum_{i=1}^{n} Fi(Pi)$

The above equation overall cost is denoted by C, active power is denoted by P, and generator count is denoted by n.

The Objective Function is subjected to the following constraints:

A. Equality Constraints

This flow of active and reactive powers are the equality constraints shown in the equation below:

$$P_i = P_{gi} - P_{di}$$
$$Q_i = Q_{gi} - Q_{di}$$

Where P_{gi},Q_{gi} active and reactive power generation occur on buses, and P_{di},Q_{di} real and reactive power demands occur on i buses, respectively.

B. Inequality Constraints

The main criteria for putting any unit on bus bar is the power generated P_min must not be lower than the fixed value.

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

The highest reactive power is restricted by the rotor's overheating, whereas the machines constancy restricts the min reactive power. As a result, the reactive power Q must lie inside the inequality criteria for steady operation.

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

When transmission losses are ignored total fuel cost (F_T) is expressed as

$$F_T = \sum_{i=1}^{n} F_i(P_{gi})$$

Equation gives the fuel cost function of the generating unit without valve-point loading.

$$F_i(P_{gi}) = a_i P_{gi}^2 + b_i P_{gi} + c_i$$

An optimization (minimization) procedure using the following objective function can be used to describe the economic load dispatch problem.

$$Min \sum_{i=1}^{n} F_T$$

It can be concluded from the power balance that

$$\sum_{i=1}^{n} P_{gi} = \sum_{i=1}^{n} P_{di} + P_L = P_D + P_L$$

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The load demand for thei_{th} Bus is P_{di}, the power produced by i_{th} unit is P_{gi}, whereas the overall line loss is P_L.
And

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}$$

The overall line losses can be determined by the following

$$P_L = \sum_{i=1}^{n}\sum_{k=1}^{n} P_{gi}P_{gk}B_{ik}$$

B stands for loss coefficient.
The best solution for the Economic Load Displacement Problem with Line Loss is as follows:

$$F_T = min\left[\sum_{i=1}^{n} F_i P_{gi}\right]$$

As a result, for a given number of generating units,

$$\sum_{i=1}^{n} P_{gi} = \sum_{i=1}^{n} P_{di} + P_L = P_D + P_L$$

As a result, transmission losses have the effect of introducing a penalty factor whose value is determined by the plant's position in relation to the loads.
Finding the entire cost of fuel for a period (t) of 24 hours is the goal of quadratic constrained programming. The dispatch interval of one hour is taken into account and the ELD is formed as a dynamic optimal schedule.
Equation 1

$$OF = e = sum(gen, data(gen,'a') * P(gen) * P(gen) + data(gen,'b') * P(gen) + data(gen,'c'));$$

Equation 2

$$sum(gen, P(gen)) = g = load$$
$$P.lo(gen) = data(gen,'Pmin');$$
$$P.up(gen) = data(gen,'Pmax');$$
$$Model\ ED\ /\ eq1, eq2\ /;$$
$$solve\ ED\ using\ QCP\ minimizing\ OF$$

III. Methodology

By applying quadratic constraint programming, the CONOPT solver in GAMS resolves the ELD problem. Studies have been done on how wind integration affects how economically thermal units operate. The steps in the ELD process are

1. **Sets:** Each plant's generating level in MW and the time of day are defined as sets.
2. **Variables:** Variables are decision sets with unknown values and whose values must be computed. Tables that specify the data variables include information on cost coefficients, the maximum and lowest power output of generators, wind generation, etc. Over the sets, they are defined.
3. **Scaler:** Scaler is a fixed quantity at all moment t, similar to power demand.
4. **Equation:** Equation connects collections of data components. The table data in this issue is related to sets via a cost equation.
5. **Solver and model:** In GAMS, the model is the goal equation, and the solve statement calls the model solver.
6. **Output:** Using the GAMS-MATLAB or GAMS-EXCEL interface, there are various ways to plot the output.

IV. Result and Discussion

Methods discussed in previous chapters are implemented on three generating unit system to determine the optimum min cost of energy demand. The three generator units' system was optimised so that the desired result can be obtained. The results obtained from Particle Swarm Optimization (PSO) and Quadratically Constrained Quadratic Programming (QCQP) are compared and analysed in this observation. At first, whole comparison looked similar, but at last, the results were quite affirmative. The QCQP method is also very less resource hungry and the processing time compared to other methods is also quite fascinating. All these simulations are done on GAMS 39.1 environment.
The Lagrange Multiplier approach is implemented on the three-units' cost characteristics:

$$F_1 = 0.00156P_1^2 + 7.92\,P_1 + 561\ \text{Rs/Hr}$$
$$F_2 = 0.00194P_2^2 + 7.85\,P_2 + 310\ Rs/Hr$$
$$F_3 = 0.00482P_3^2 + 7.97\,P_3 + 78\ Rs/Hr$$

The unit operating constraints are:

$$100\ MW \leq P_1 \leq 600\ MW$$
$$100\ MW \leq P_2 \leq 400\ MW$$
$$50\ MW \leq P_3 \leq 200\ MW$$

B-Coefficient Matrix:

[0.75 0.05 0.075

$B = 1e - 4 * 0.05\ 0.15\ 0.10$

0.075 0.10 0.45];

The aforementioned system uses the traditional Lagrange multiplier approach to determine the most cost-effective load dispatch while taking into account loads of 585MW, 600MW, 700MW, and 800MW. The economic load dispatch of the aforementioned loads, without accounting for transmission line losses, with Power Demand, Generator capacity Lambda for each demand and the cost for each demand neglecting losses are shown in table I.

Table I: Optimal distribution of LIM for three generator system

S.no.	Power demand (mw)	P1(mw)	P2(mw)	P3 (mw)	Lambda	Total fuel cost (Rs/hr)
1	585	268.8938	234.2651	81.8411	8.758949	5821.44
2	600	275.9434	239.9339	84.1228	8.780943	5952.99
3	700	322.9408	277.7256	99.335	8.927575	6838.41
4	800	369.9383	315.5174	114.5443	9.074207	7738.50

Table I displays the ELD outcome when transmission line losses are disregarded by the system. Fig. 1 displays the data from tableI versus demand and cost.

To achieve efficient dispatch solution, PSO method was applied on three generator system. The flowchart that was displayed guided the implementation of PSO. Twenty trials were run for each sample load, objective function equation was taken into consideration for every run and also specific characterisation was also compared with the quality, efficacy, convergence and other characteristics, while also observing their evolutionary process.

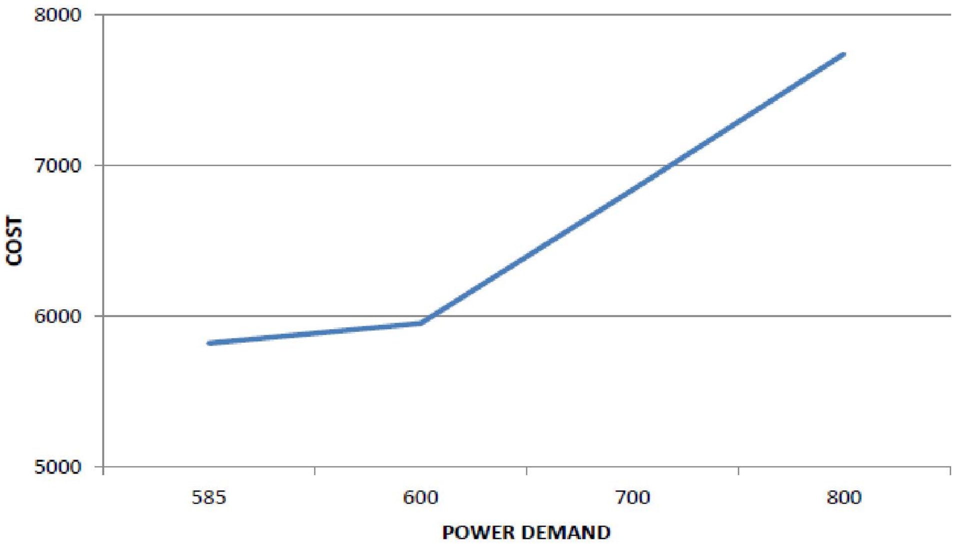

Fig. 1 Cost variation curve

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Table II Optimal Scheduling of a three-unit generator system by PSO method

S.no.	Power demand (mw)	P1(mw)	P2(mw)	P3(mw)	Total fuel cost (Rs/hr)
1	585	269.197877	234.1305213	81.67160164	5821.439522
2	700	322.9600445	277.7589543	99.28100114	6838.414351
3	800	369.3035563	316.0107041	114.6857396	7738.504671

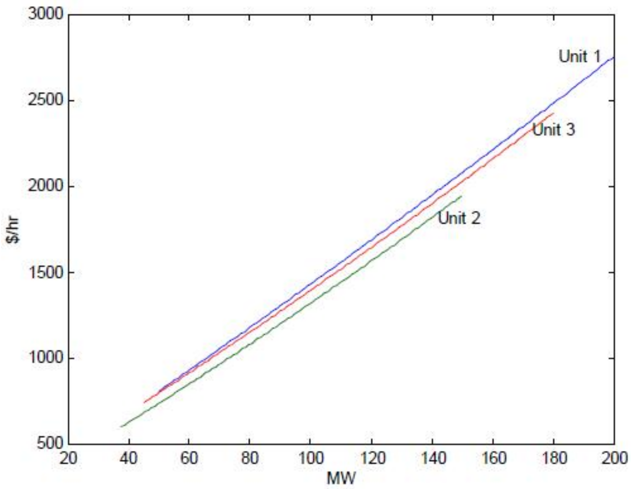

Fig. 2 Cost curves for three-unit-system

Table III: Comparing results of conventional vs PSO method neglecting losses

S.no.	Power demand (mw)	Conventional method (Rs/hr)	PSO method (Rs/hr)
1	585	5821.44	5821.439522
2	700	6838.41	6838.414351
3	800	7738.50	7738.504671

By investigating the accuracy of the answer offered by this method, all the twenty runs depicted the fuel cost for different demands. Losses were neglected while taking the outcome from 585 MW, 700 MW, and 800 MW generator systems.

Table IV: Reliability Evaluation of PSO Method

S.no.	Power demand (mw)	Min (mw)	Mean (mw)	Std deviation (mw)
1	585	5821.439522	5821.44772	0.009738965
2	700	6838.414351	6838.420074	0.006164467
3	800	7738.504671	7738.51086	0.009240757

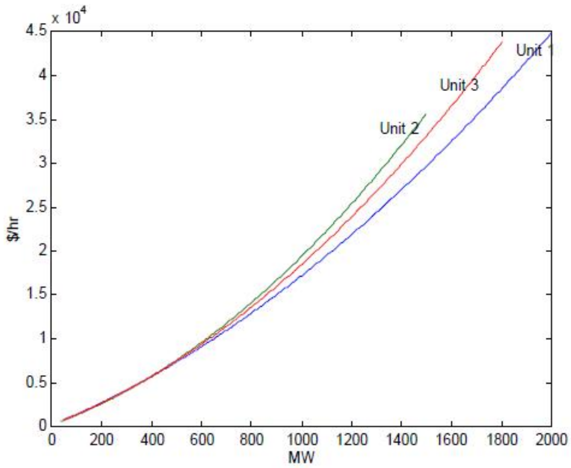

Fig. 3 Cost curves over an expanded operating range

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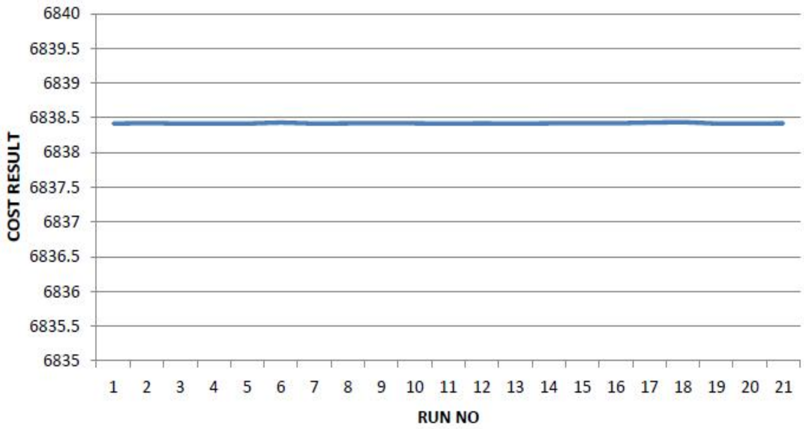

Fig. 4 Reliability evaluation of the three-unit-system (PSO output)

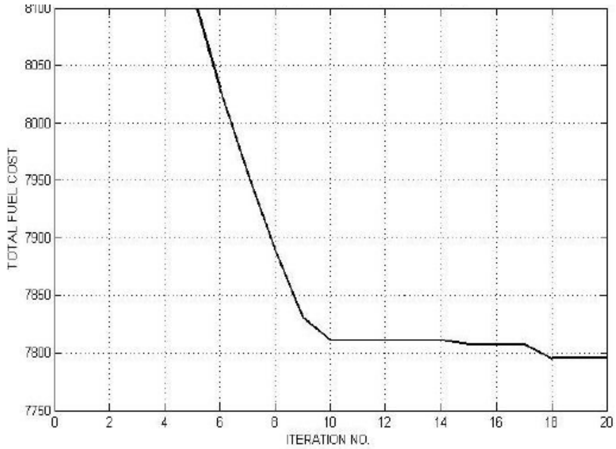

Fig. 5 Convergence characteristics for three generator system

An optimization issue known as a quadratically constrained quadratic programme (QCQP) has the following form:

Table V: The solution for load condition 1 obtained by GAMS Code

	Lower	Level	Upper	Marginal
g1	100.000	268.894	600.000	EPS
g2	100.000	234.265	400.000	-
g3	50.000	81.841	200.000	EPS

The minimized Objective Function value is

OF = **5821.439**

Table VI: The solution for load condition 2 obtained by GAMS Code

	Lower	Level	Upper	Marginal
g1	100.000	275.943	600.000	-1.29E-11
g2	100.000	239.934	400.000	-
g3	50.000	84.123	200.000	-6.33E-11

The minimized Objective Function value is

OF = **5952.988**

Table VII: The solution for load condition 3 obtained by GAMS Code

	Lower	Level	Upper	Marginal
g1	100.000	322.941	600.000	-
g2	100.000	277.726	400.000	EPS
g3	50.000	99.334	200.000	EPS

The minimized Objective Function value is

OF = **6838.414**

Table VIII: The solution for load condition 4 obtained by GAMS Code

	Lower	Level	Upper	Marginal
g1	100.000	369.938	600.000	EPS
g2	100.000	315.517	400.000	-
g3	50.000	114.544	200.000	EPS

The minimized Objective Function value is

OF = **7738.503**

Table IX: Economic Load Dispatch using QCQP method for three generator system

S. no.	Power Demand (MW)	P_1 (MW)	P_2 (MW)	P_3 (MW)	Total Fuel Cost (Rs/hr)
1	585	268.894	234.265	81.841	5821.439
2	600	275.943	239.934	84.123	5952.988
3	700	322.941	277.726	99.334	6838.414
4	800	369.938	315.517	114.544	7738.503

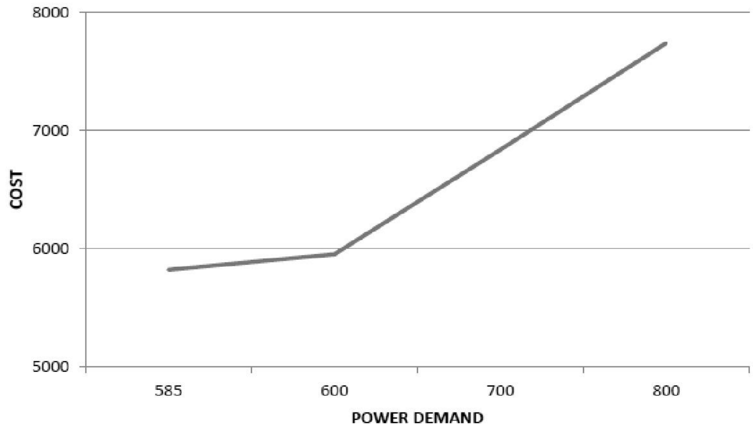

Fig.6Cost curve for QCQP 3-unit system

Table X: Comparison of results between conventional method, PSO method and QCQP method

S.no.	Power Demand (MW)	Conventional Method (Rs/Hr)	PSO Method (Rs/Hr)	QCQP Method (Rs/Hr)
1	585	5821.44	5821.44	5821.439
2	700	6838.41	6838.42	6838.414
3	800	7738.50	7738.50	7738.503

V. Conclusion

In conclusion, the dissertation provided a realistic economic load dispatch with all the specifics of all the frequently encountered limitations. In order to get better outcomes for particular examples of economic dispatch problems, research was focused on enhancing quadratically constrained quadratic programming. The Lambda Iteration Method (LIM), also known as its modified version, was used as a starting point. QCQP algorithm-based simulation followed by experimental research using GAMS software. In order to achieve this, a variety of hypotheses have been investigated, including the use of LIM as a standalone algorithm and the combination of QCQP with other successful ED problem-solving algorithms to create hybrid techniques that make use of its topological structure.

The CONOPT solver in GAMS 39.1.0 has been used to solve the optimal dispatch problem, which has been phrased as a non-linear problem. In a 24-hour period, the generators must maintain a balance between generation and load every hour. The 24-hour ELD findings and comparison data show the effectiveness of the suggested methodology when all limitations are adhered to. The robustness of the solution is confirmed by the short execution time of 1.609 seconds. The outcomes are plotted using MATLAB GAMS interface. Results from the first test system are compared to those from the Lambda iteration method, and the suggested methodology yields superior results with shorter execution times. The cost savings are demonstrated by the 24-hour optimal scheduling of thermal plants.

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