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# Unit Commitment and Generation Scheduling of a Thermal Power Plant Using Economic Load Dispatch

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*Abstract*— **Rapid industrialization and reliance on electrical energy has resulted in significant increase for demand of electrical power. Each thermal generating plant contains multiple generating units with varying characteristics in terms of cost and fuel consumption, directly reflected in the production cost of power plant. Fuel Cost-optimization and Profit maximization of a power plant is greatly affected by economic load dispatch and unit commitment. This paper aims to optimize the fuel cost of 14 thermal generating units by optimal allocation, considering varying load demand. Unit commitment of these generating units has been done using priority list, further incorporated in load curves for variable demand in various time periods of a day. After unit commitment, optimization techniques including Iterative, Analytical and Graphical have been used to determine the optimal value of fuel cost. Furthermore, the comparison of fuel cost obtained illustrates that Lambda Iterative has better performance than Graphical and Analytical optimization.**

*Index Terms*— **Economic Load dispatch, Fuel Cost Optimization, Thermal Generating Units, Unit Commitment, Priority List**

## I. Introduction

The efficiency of power distribution system with the ever increasing demand of energy and extensive reliance of customers on electric power has gained vital importance all around the globe. All over the world, the dictate of developing the power system has progressed extensively but unfortunately due to lack of sufficient resources its growth in Pakistan has been narrowed down [1]. Although in comparison with thermal and nuclear power, the unit cost of hydal generation is much less, however, due to seasonal variations, demand of hydal power is more prone to fluctuations [2]. Today the basic problem society is facing while running power system economically is economic scheduling. Ideal unit commitment and economic load dispatch are the two noteworthy issues in economic scheduling [3]. At present, due to quick increase in uncontrollable renewable energy sources, electric power systems face operational difficulties while reduction of controllable resources causes serious issues related to reliability of the system. Economic Load Dispatch in power system is very significant as it save lot of money[4].

Minimization of total cost of generating real power at various power stations while sustaining the load demand and satisfying the losses in transmission links is the main aim of power system operations. This economy of operation is called economic dispatch problem [5]. The problem of economic dispatch is further distributed in unit commitment and load scheduling. This problem contains high level of decision variable and complexities. Conventional approaches to solve this problem is based on analytical methods including priority list (PL), dynamic programming, integer programming and Lagrangian relaxation[6]. Economic load Dispatch is a constraint optimization problem which can be solved easily by heuristic methods and multiple traditional optimization techniques. Heuristic techniques that can be used to solve Economic problems comprise of GA, PSO, and Honey Bee, whereas, the traditional techniques to

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find optimal power availability include graphical, iterative and analytical methods [7].

One way to define the Economic load dispatch would be the process of allocating such optimal levels of generations to the given generating units so that the overall process of electric power transmission and load handling demand is full filled entirely at the most economic levels. For all the interconnected systems where complexity is the significant trait, it becomes necessary to minimize the expenses so that the overall cost of generation for a predefined level of load remains minimum keeping in consideration the loading capacity and constraints of system [8].

If **s**ystem is operating under normal conditions and losses are ignored, the generation capacity may exceed the total required demand. Hence, the objective remains to find optimal values of power load demand given the fact that the cost remains minimum within the certain limitation. This might have been a way to define ''Economic Load Dispatch problem [9]. With the load shedding crisis on the rise in Pakistan, optimization of electrical energy units is a crucial task. In order to reduce the quantity of consumed fuel, the saving in operation and planning of power systems should be the prime objective, the relationship between the cost per hour and output of power units give rise to a curve which can be further translated in the form of quadratic function [10].

The usual problem of economic generation scheduling can be further categorized into two sub problems, i.e., the unit commitment of generating units and the economic dispatch. In unit commitment, the units' reselected which will fulfill the anticipated load supply of the system given that cost remains minimum and the objective of economic load dispatch is the uniform distribution so the total fuel cost of the system is minimized [11]. Unit commitment is an integral part of plant planning operation based on the methodology which finds the economical path for power generation. The prime objective in unit commitment is to find the type of generating units that should be used to determine the most efficient and participating amount of power for a power plant[12]. In unit commitment, the units are committed based on their working efficiency and the unit with most efficient commitment is placed first. Once the most efficient unit is committed, it is followed by the next efficient unit and so on [13]. For solving a unit commitment problem, a new approach is presented called three stage approach. At the first step, a simple procedure to get the feasible solution in a specific time is followed. This gives primary schedule of status of unit. In second step, the hourly value of operating unit is find out following Economic Dispatch technique. To reach at a more feasible and optimal solution, this process follows the third step of solution, called Modification Process. This method produces robust solution [14].

ELD problems are considered very complex in nature so Meta heuristic approaches have been proposed to solve it. Artificial neural network, evolutionary programming, tabu search, genetic algorithm are different Meta heuristic approaches which are generally considered to solve ELD problems [15]. For thermal generating unit scheduling, a novel straight forward method has been presented. This method decomposes solution of Unit commitment problem into further three sub problems. In first step hourly optimum solution is obtained by making the cost function of unit linear. In next step using novel optimization process the minimum time is enforced. In last step using de-commitment method extra reserve is minimized [15]. Thermal Scheduling is also implemented by extended priority list method. To reduce the total cost and to achieve peak load demand, Energy Storage system [16] is integrated. It includes two steps; in first step using priority list method (PL), initial unit commitment schedule is obtained. Unit schedule is modified in the second step [17]. An improved priority list and neighborhood search method (IPL-NS) for ramp rate constraint unit commitment [6] is presented. To get the unit status for UC, a priority list based mixed integer linear programming is formulated. To get the unit status for RUC, neighborhood search (NS) algorithm is produced. Analysis of the numerical result shows that proposed IPL can commit the most economic unit first much better than other existing PL methods [18]. A simple process to solve the economic load dispatch problem is based on using the analytical approach in which the value of incremental cost is calculated with the help of constant lambda so that we can ultimately find the power of generation for the required generation units. Whereas, the incremental cost only signifies the ratio of a small change in input and as the result the change in output power is calculated. This ultimately leads us to determine the fuel cost associated with each generating unit [19]. Another method which can be used to solve the economic dispatch load problem is iterative method in which the incremental fuel cost for each-iteration is

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changed so that a minimum value of the fuel cost is obtained. A significant trait of this method is its rapid convergence for the given optimization problem [20]. Another method which can be used to solve the economic dispatch load problem is iterative method in which the incremental fuel cost for each-iteration is changed to set a minimum value of the fuel cost. A significant trait of this method is its rapid convergence for the given optimization problem the method of lambda ($\lambda$) iteration is used to generate successions of nearly accurate solutions which would ultimately converge and generate the solution of the given problem. The quality of the iterative method is dependent upon the convergence to the final solution [21]. Although the process of optimal allocation of the load demand in an electrical system for an Economic load dispatch (ELD) can be solved by methods such as Lambda iteration yet this method is not efficient with respect to time [22]. Analytical methods are used to analyze the dynamic attributes of thermal generating loads. The accuracy of the analytical method for the simulated system is comparatively more in comparison with other simulation techniques [23].

With the technique of analytical method, the power demand for various values of incremental cost and fuel cost can easily be calculated [24]. Another technique which is used to calculate the power generation of various thermal generating units with varying load demands is the kirchmayer's method in which iteration is performed until the sum of power outputs of generating units equals the load demand of the system [25]. Quick method is another technique which can be used for optimization of the generation schedule in which the iterative steps for solving the problem are eliminated [26].

**This study undertakes the optimization of test case of a power system, comprising of fourteen thermal generating units.** Our contribution thus extends to application of three traditional optimization techniques (Analytical, Lambda and Graphical) for solving economic load dispatch problem of the given test system. This solution strategy not only helps in determination of optimized cost but also helps in analyzing the fact that which of these techniques yield the desired results.

This paper is organized as follows. The first section highlights the Problem formulation for the given system of thermal generating units, unit commitment of generating units using priority list method followed by Economic Load Dispatch which is translated in the form of N numbers of generating units.

The second section highlights the techniques and their practical implementation to find the optimal cost of system. Finally, in section III the entire work is concluded.

## II. MATHEMATICAL OPTIMIZATION METHODS

The Principal objective of an economic load dispatch problem is to find the most optimal values of loadings for generating units so that the generation cost is minimized which can be done if optimal generation power is allocated to thermal generating units provided the constraints of power-system are met.

The constraints of the system can be put as: the amount of power generation must be equal to the amount of power distributed, the power limitations of the generating units and capacity of each generation unit.

The objective function of the system is

$$\text{Minimize } _{FTC} = \sum_{i=1}^{N} F_i\,(P_{gi}) \text{ ------------------- } \mathbf{(1)}$$

$F_{TC=}$Total Fuel cost of thermal generating units
$F_i$= Fuel cost of $i^{th}$ generating unit.
$P_{gi}$= the generation power of $i^{th}$ generating unit
N= total number of generating units

i= 1, 2 ….N

$$F_{\text{Total fuel cost}} = F_1P_{g1} + F_2P_{g2} + F_3P_{g3} + F_4P_{g4} \text{--------- } \mathbf{(2)}$$

$F_1$=Fuel cost of $1^{st}$ generating unit

$F_{14}$=Fuel cost of $14^{th}$ generating unit

$P_1$=Generation power of $1^{st}$ generating unit

$P_{14}$= Generation Power of $14^{th}$ generating unit

The fuel cost function of thermal generating unit is expressed in the form of quadratic equation stated below

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$F_i\ (P_{gi}) = a_iP_{gi}^2+b_iP_{gi}+c_i$ ------------------------- **(3)**

**$a_i$**= the fuel cost coefficient characterizing the measured losses of the system
**$b_i$**= the fuel cost coefficient which represents the cost of fuel for the $i^{th}$ generating unit
**$c_i$**= the salary and wages (their units are Rs/MW$^2$h,Rs/MWh and Rs/h respectively)

The Power constraints of the system are

$P_{gi\ minimum} \le P_{gi} \le P_{gi\ maximum}$ ---------------------- **(4)**

**$P_{gi\ minimum}$**= Minimum Power Generation of $i^{th}$ generating unit
**$P_{gi\ maximum}$**= Maximum Power Generation of $i^{th}$ generating unit
The power demand constraint of the system is

$$\sum_{i=1}^{N} P(g_i) = P_{Demand} \text{ ---------- } \mathbf{(5)}$$

**$P_{Demand}$**=Total power output demand of the system

The Lagrangian function of the given system can be written by augmentation of provided equality constraint with the desired objective-function.

$L\ (P_{g1},P_{g2}\ ...P_{g14},\ \lambda) = F_{gi}(P_{gi})+\lambda(P_D - P_i)$ ----------- **(6)**

$\lambda$ = Lagrangian Multiplier
Once the problem has been formulated, the Fuel Cost Function Equations of the fourteen thermal generating units have been written as follows

$F_1\ (P_1) = 561+7.92P_1+0.001562P_1^2$ --------------- **(7)**

$F_2\ (P_2) = 310+7.85P_2+0.00194P_2^2$----------------- **(8)**

$F_3\ (P_3)=78+ 7.97P_3 +0.00482P_3$ --------------- **(9)**

$F_4\ (P_4)=500+1.6P_4 + 0.4P_4^2$ ---------------------- **(10)**

$F_5\ (P_5)=720+1.2P_5+ 0.45P_5^2$---------------------- **(11)**

$F_6\ (P_6)=240+1.16P_6+ 0.64P_6^2$ --------------------- **(12)**

$F_7\ (P_7)=400+6P_7+ 0.004P_7^2$ ------------------------ **(13)**

$F_8\ (P_8)=500+6.8P_8+0.002P_8^2$ -----------------------**(14)**

$F_9\ (P_9) =600+6.1P_9+ 0.0022P_9^2$ ------------------- **(15)**

$F_{10}\ (P_{10}) =511+1.6P_{10}+ 0.01P_{10}^2$ ------------------ **(16)**

$F_{11}\ (P_{11}) =622+2P_{11}+0.02P_{11}^2$ ---------------------- **(17)**

$F_{12}\ (P_{12}) =500+5.3P_{12}+ 0.004P_{12}^2$------------------ **(18)**

$F_{13}\ (P_{13}) =400+5.5P_{13}+ 0.006P_{13}^2$------------------- **(19)**

$F_{14}\ (P_{14}) =200+5.8P_{14}+ 0.009P_{14}^2$ ------------------- **(20)**

The maximum and minimum power limitations of the thermal generating units are:

$45 \le Pg_1,\ Pg_2 \le 130$
$50 \le Pg_3,\ Pg_4 \le 140$
$60 \le Pg_5,\ Pg_6 \le 140$
$70 \le Pg_7 Pg_8, \le 140$
$75 \le Pg_9,\ Pg_{10}, \le 127$
$80 \le Pg_{11},\ Pg_{12} \le 127$
$50 \le Pg_{13},\ Pg_{14} \le 190$

**Unit Commitment**
Unit commitment for an electrical system represents a mathematical optimization problem where the generation capacity for a set of electrical generators is aligned to achieve a power demand by minimization of cost. For the system under consideration, Unit commitment of 14 thermal Generating units has been done using the Priority-List method. Initially for solving Unit commitment problem, the maximum values of power for each generating unit is substituted in the fuel cost Function equations **(7 to 20)** and the entire fuel cost function equations are divided by maximum value of generation power.

**Priority List Method**
Priority list method is often used to solve the unit commitment neglecting the ramp rate constraints. The objective of the priority list is to commit the most economical generating unit which also satisfies the constraints of unit commitment problem. For 14 thermal generating units, the maximum power limit and associated cost with these units is compiled in the table below.
As it can be seen in Table 2, once the fuel cost is determined, the optimal generation schedule is carried out for fourteen thermal generating units based on priority list. Initially the optimal scheduling is done for 14 thermal generating units at different peak load demand for morning, evening and night duration during seven days of a week. Table 3 represents the generating units which have to be turned on to full fill the morning peak demand throughout the week, Table 4 and Table 5 represents the generating units which have to be turned on for full filling the peak load demand in evening and

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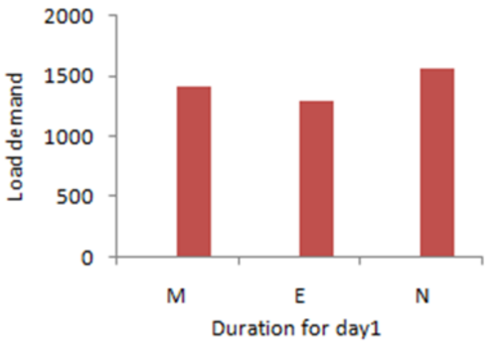
night durations based on maximum power constraint and fuel cost whereas the transmission losses are neglected.

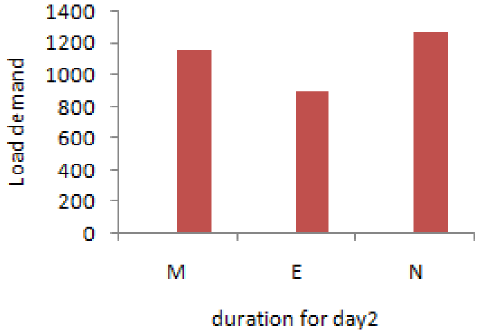
From Table **6**, **7** and **8** it can be seen that priority list for morning evening and night peak load has been tabulated out for three durations of seven days in a week. The units are scheduled in table **6**,**7**&**8** based on the power limitations, fuel cost and the supply they can deliver to fulfill the anticipated demand.

Table 9 represents the scheduling of thermal generating units and the sequences in which generators are turned on to full fill the load requirement for day 1.The load demand 1295 MW is fixed for the entire day and for the variation of demand generating unit 1,unit 4 are turned on. The graph for the daily load demand is drawn between the time periods and the given load demand. From the figure it is evident that the minimum load demand for the day 1 is 1295MW.



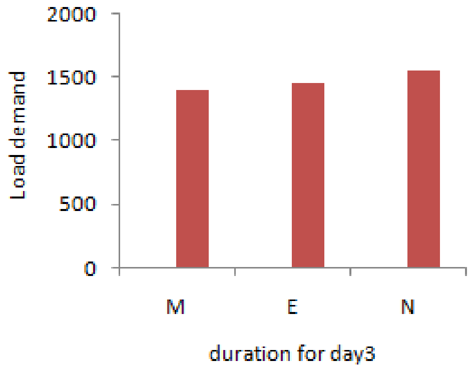

(a)

Table 10 represents the scheduling of thermal generating units and the sequences in which generators are turned on to full fill the load requirement for day 2. The load demand 892 MW is fixed for the entire day and for the variation of demand generating unit 12, unit 8 and 9 are turned on. The graph for the daily load demand is drawn between the time periods and the given load demand. From the figure, it is evident that the minimum load demand for the day 2 is 892 MW.




(b)

Table 11 represents the scheduling of thermal generating units and the sequences in which generators are turned on to full fill the load requirement for day 3. The load demand 1400 MW is fixed for the entire day and for the variation of demand generating unit 4 is turned on. The graph for the daily load demand is drawn between the time periods and the given load demand. From the figure, it is evident that the minimum load demand for the day 3 is 1400 MW.




(c)

Table 12 represents the scheduling of thermal generating units and the sequences in which generators are turned on to full fill the load requirement for day 4. The load demand 1487 MW is fixed for the entire day and for the variation of demand generating unit 4 is turned on. The graph for the daily load demand is drawn between the time periods and the given load demand. From the figure it is evident that the minimum load demand for the day 4 is 1487 MW.

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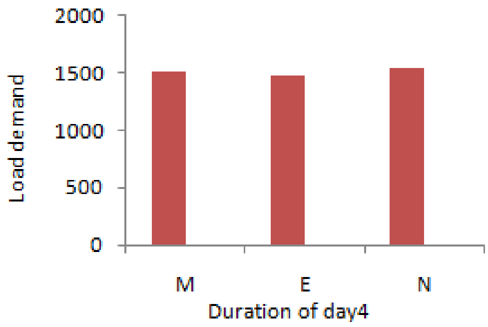
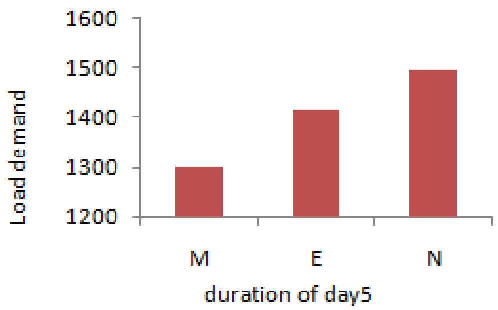


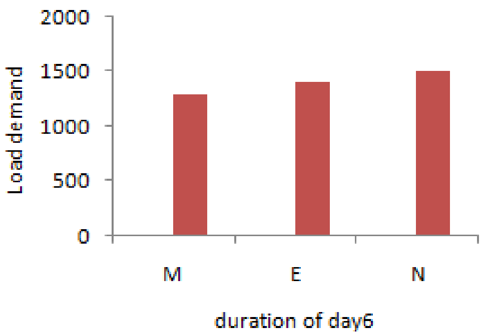

(d)

Table 13 represents the scheduling of thermal generating units and the sequences in which generators are turned on to full fill the load requirement for day 5. The load demand 1299 MW is fixed for the entire day and for the variation of demand generating unit 4 is turned on. The graph for the daily load demand is drawn between the time periods and the given load demand. From the figure it is evident that the minimum load demand for the day 5 is 1299 MW.



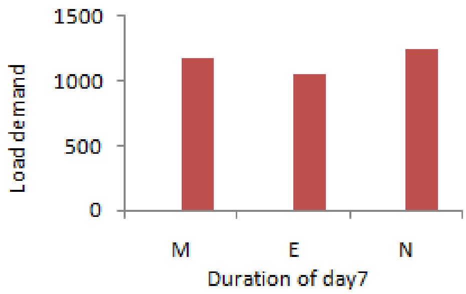

(e)

Table 14 represents the scheduling of thermal generating units and the sequences in which generators are turned on to full fill the load requirement for day 6.The load demand 1295MW is fixed for the entire day and for the variation of demand generating unit 9 and 1 are turned on. The graph for the daily load demand is drawn between the time periods and the given load demand. From the figure it is evident that the minimum load demand for the day 6 is 1295MW.




(f)

Table 15 represents the scheduling of thermal generating units and the sequences in which generators are turned on to full fill the load requirement for day 7. The load demand 1050MW is fixed for the entire day and for the variation of demand generating unit 2,8,9 are turned on. The graph for the daily load demand is drawn between the time periods and the given load demand. From the figure it is evident that the minimum load demand for the day 7 is 1050 MW.




(g)

**Figure 1**. Load Demand Curve for (a)day1 (b)day2 (c)day3 (d)day4 (e)day5 (f)day6 (g) day7

Afterwards the minimum load of all the various given loads during the entire week is determined as shown in Table 16: 892 MW (evening load demand). The priority against this load demand is fixed and to full fill the requirements of load demand during morning and night for the case of entire week further generating units are added to it.

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## Fuel cost comparison of thermal generating units of non-fixed priority list and fixed priority list

Table 17 represents the non-fixed Priority list and sequencing of thermal generating units. The second column represents the peak load demand during morning, evening and night duration, whereas the third column represents the respective thermal generating units. The fourth column represents the respective fuel cost associated with thermal generating units. From the table it is clear that the minimum fuel cost for non-fixed priority thermal generating units is 52.3 Rs. /hr.

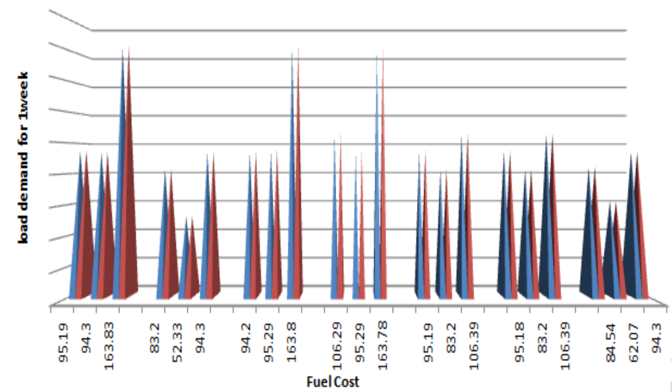


**Figure 2.** fuel cost and load demand for non-fixed priority list

The figure1 elaborates the relationship between fuel cost and load demand. From the graph it is clear that for the lowest load demand in the case of non-priority fixed thermal generating unit is 892MW and the fuel cost with respect to it is 52.33.

## Fuel cost comparison of thermal generating units of fixed priority list

### a. For Morning Peak Load Demand:

Table 18represents the Priority list and sequencing of thermal generating units for a fixed priority list in the case of morning peak load demand. From the table it is clear that the minimum fuel cost for non-fixed priority thermal generating units is 83.2 Rs.

The figure2 reflects the cost and fuel curve for morning peak load demand and the from the graph it is evident that the minimum load demand is 1155 MW and the respective cost associated with it is 83.2 Rs/hr.

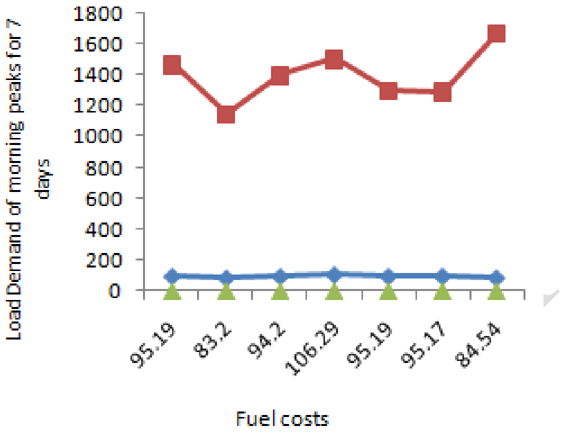


**Figure 3.** Fuel Cost and load demand curve for fixed priority list generators in morning peak time

### b. For Evening Peak Load Demand:

Table 19 represents the Priority list and sequencing of thermal generating units for a fixed priority list in the case of evening peak load demand.. From the table it is clear that the minimum fuel cost for non-fixed priority thermal generating units is 53.2.

The figure3 reflects the cost and fuel curve for evening peak load demand and from the graph it is evident that the minimum load demand is 892 MW and the respective cost associated with it is 52.33 Rs/hr.

**Table 1.** Fuel cost calculation of thermal generating units for fixed priority (Evening Peak Load Demand)

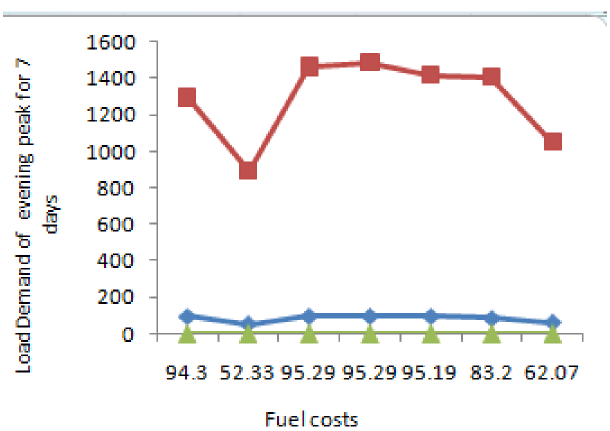


**Figure 4.** Fuel Cost and load demand curve for fixed priority list generators in evening peak time

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**c. For Night Peak Load Demand:**
Table 20 represents the Priority list and sequencing of thermal generating units for a fixed priority list in the case of night peak load demand. From the table it is clear that the minimum fuel cost for non-fixed priority thermal generating units is 94.1Rs. /hr.
The figure4 reflects the cost and fuel curve for night peak load demand and from the graph it is evident that the minimum load demand is 1242 MW and the respective cost associated with it is 94.39Rs/hr.

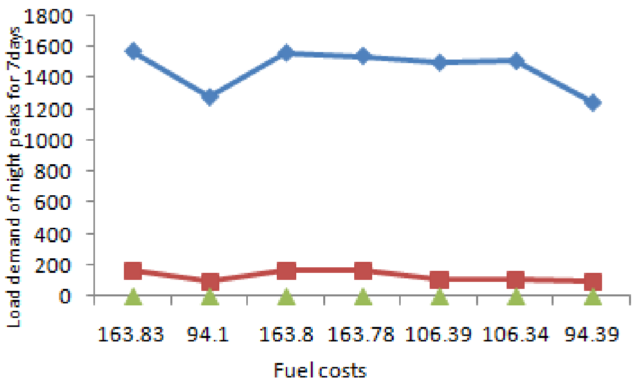


**Figure 5.** Fuel Cost and load demand curve for fixed priority list generators in night peak time

## III. Optimization-Techniques and Implementation

Once the unit are optimally committed the next step is to employ economic load dispatch (ELD).

### a. Graphical Method

The table 21 represents the derivatives of fuel cost. Once the derivatives are calculated the equation are further simplified for generation power of individual thermal generating units**.**

$$\sum_{i=1}^{N} P_{gi} = P_{Demand} \quad \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(21)}$$

$P_{Demand}$= Total Power demand of the system = 2020MW
$P_{gi}$ =Power of generation for the i$^{th}$ Unit.

$$\sum_{i=1}^{N=14} P_{gi} = P_1 + P_2 + P_3 + \ldots + P_{14}$$

= (λ -7.92/ 0.003124) + (λ -7.82/ 0.00388) + ( λ -7.97/ 0.00964) + (λ -1.6/ 0.8) +( λ -1.2/ 0.9)+ (λ -1.2/ 0.9)+ (λ -1.16/ 0.128) + (λ -6/ 0.008) + (λ -6.8/ 0.004) + (λ -6.9/ 0.0044) +(λ-1.6/ 0.02)+ (λ -2.0/ 0.04) + (λ -5.3/ 0.008 ) +(λ -5.5/ 0.012) + (λ -5.8/ 0.018)

Now according to the constraint of equality in equation (**21**) by substituting the value of $P_{gi}$ and $P_{Demand}$ the following equation is obtained

(λ -7.92/ 0.003124) + (λ -7.82/ 0.00388) + ( λ -7.97/ 0.00964) + (λ -1.6/ 0.8) +( λ -1.2/ 0.9 )+ (λ -1.2/ 0.9)+ (λ -1.16/ 0.128) + (λ -6/ 0.008) + (λ -6.8/ 0.004) + (λ -6.9/ 0.0044) + (λ -1.6/ 0.02)+ (λ -2.0/ 0.04) + (λ -5.3/ 0.008 ) +(λ -5.5/ 0.012) + (λ -5.8/ 0.018) = $P_{Demand}$

Taking lambda as common from the above expression, the value of cost calculated for thermal generating units is calculated as follows:
$P_{Demand}$= 1600MW

$$\lambda = \frac{P_{Demand} + 11352.4}{1632.373}$$

**λ**=7.93Rs/MW

### b. Analytical Method

Fuel cost coefficients a, b, and c represented in Table are taken from equations of fuel cost against each input power whereas Incremental fuel cost is denoted in Table 22. Incremental fuel cost "Lambda" was calculated by using equation $\lambda = \frac{P_D + \sum_{i=1}^{N} \frac{b_{gi}}{2_{ci}}}{\sum_{i=1}^{N} \frac{1}{2_{ci}}}$. Moreover, the power generation of each generator was determined by using values of Fuel cost coefficients and incremental fuel cost "**λ**" by expending and finally the total power of generation was calculated by adding all power generations of generator $P_{generation\ Total} = P_1+P_2+P_3 \ldots P_{14}$ in the last column.

### c. Lambda Iterative Method

Fuel cost coefficients a, b, and c represented are taken from equations of fuel cost function against each input power. Initially a suitable value of **λ** is assumed twice i-e **λ**1,2 and using the values of fuel cost coefficient b, a.

$$Pi = \frac{\lambda - bi}{2ai},$$

the values of generation power for fourteen thermal generating units has been calculated and results are shown in Table 24. If the sum of power generation of

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thermal generating units is not equal to the total power demand of the system, repeat the process with updated values of lambda using the equation

$\boldsymbol{\lambda}$^(k+1)=$\boldsymbol{\lambda}$^(k)+Δ$\boldsymbol{\lambda}$^(k) .

Where k =previous value of lambda.

Δ$\boldsymbol{\lambda}$^(k) =ΔP/∑(1/2c)

## IV. Conclusions and Recommendation

This paper presents the unit commitment and economic load dispatch of 14 thermal generating units for optimum power allocation at minimum fuel cost. Considering the variable power capacity of generating units and need for fuel cost optimization, the thermal generating unit are first scheduled using unit commitment. The priority list method is then used for optimal allocation of generating units to meet the power demand for three durations of a day and load demand curves for various load demands have been plotted. Once the units are optimally allocated and fuel cost comparison has been drawn, Economic Load dispatch has been carried out considering the equality and inequality constraints. The calculations and analysis is carried out using three optimization techniques which are Analytical Method, Graphical Method and Iterative Method. The resulted optimized fuel cost obtained from these three methods is represented in Table 26.

The cost calculated by three optimization techniques is similar for the two methods while the graphical methods exhibit contradiction from the rest. This highlights the fact that the computational accuracy of analytical and iterative method is less because they are basically based iterative processes. Another result that can be deduced is that Economic Load Dispatch isn't possible if the thermal generating units are operated beyond or below their respective loading generation capacity because it will violate the power limitations. Although the fuel cost in this paper is optimized using traditional optimization but it is recommended that this problem should be solved using Evolutionary Algorithms which have the capability to optimize the complex multimodal systems because in spite of exceptional advancements made in classical methods, they generally have the tendency to get stuck in the local optimum and yield poor convergences if the number of variables are more.

## Appendix

**Table 2** Calculation of Unit Commitment for 14 generating units

| Fuel Cost of Generating Units | Fuel Cost Equations of Thermal Generating Units |
|---|---|
| $F_1(P_1) / P_{1\,max}$ | $=(569+7.92(130)+0.001562)(130)^2)\div(130)$<br>=12.499 |
| $F_2(P_2)/P_{2max}$ | $=(310+7.85(130)+0.00194(130)^2)\div(130)$<br>= 10.48 |
| $F_3(P_3)/P_{3\,max}$ | $=(78+7.97(130)+0.00482(130)^2)\div(130)$<br>=9.19 |
| $F_4(P_4)/P_{4max}$ | $=(500+1.6(130)+0.4(130)^2)\div(130)$<br>= 57.44 |
| $F_5(P_5)/P_{5\,max}$ | $=(720+1.2(140)+0.45(140)^2)\div(140)$<br>=69.34 |
| $F_6(P_6)/P_{6\,max}$ | $=(240+1.16(140)+0.64(140)^2)\div(140)$<br>= 92.47 |
| $F_7(P_7)/P_{7\,max}$ | $=(400+6(140)+0.004(140)^2)\div(140)$<br>=9.41 |
| $F_8(P_8)/P_{8\,max}$ | $=500+6.8(140)+0.002(140)^2)\div(140)$<br>=10.65 |
| $F_9(P_9)/P_{9\,max}$ | $=(600+6.1(127)+0.0022(127)^2)\div(127)$<br>=11.10 |
| $F_{10}(P_{10})/P_{10\,max}$ | $=(511+1.6(127)+0.01(127)^2)\div(127)$<br>=6.89 |
| $F_{11}(P_{11})/P_{11max}$ | $=(622+2(127)+0.02(127)^2)\div(127)$<br>=9.43 |
| $F_{12}(P_{12})/P_{12max}$ | $=(500+5.3(127)+0.004(127)^2)\div(127)$<br>= 9.74 |
| $F_{13}(P_{13})/P_{13max}$ | $=(400+5.59(190)+0.006(190)^2)\div(190)$<br>= 8.85 |
| $F_{14}(P_{14})/P_{14max}$ | $=(200+5.8(190)+0.009(190)^2)\div(190)$<br>=8.56 |

**Table 3.**Power limits and associated cost of generating units

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| Generator (G) | Maximum power $P_{max}$(MW) | Maximum Fuel Cost Rs per MWh |
|---|---|---|
| **1** | 130 | 12.09 |
| **2** | 130 | 10.48 |
| **3** | 130 | 9.19 |
| **4** | 130 | 57.44 |
| **5** | 140 | 69.34 |
| **6** | 140 | 92.47 |
| **7** | 140 | 9.41 |
| **8** | 140 | 10.65 |
| **9** | 127 | 11.10 |
| **10** | 127 | 6.89 |
| **11** | 127 | 9.43 |
| **12** | 127 | 9.74 |
| **13** | 190 | 8.85 |
| **14** | 190 | 8.56 |

**Table 4**. Morning Peak Load demand and required generating units.

| Scheduling of Thermal Generating units | Day1 | Day2 | Day3 | Day4 | Day5 | Day6 | Day7 |
|---|---|---|---|---|---|---|---|
| **Load Demand** | 1568 | 1277 | 1557 | 1538 | 1495 | 1505 | 1242 |
| G1 | On | Off | On | On | On | On | Off |
| G2 | On | On | On | On | On | On | On |
| G3 | On | On | On | On | On | On | On |
| G4 | On | Off | On | On | Off | Off | Off |
| G5 | Off | Off | Off | Off | Off | Off | Off |
| G6 | Off | Off | Off | Off | Off | Off | Off |
| G7 | On | On | On | On | On | On | On |
| G8 | On | On | On | On | On | On | On |
| G9 | On | On | On | On | On | On | On |
| G10 | On | On | On | On | On | On | On |
| G11 | On | On | On | On | On | On | On |
| G12 | On | On | On | On | On | On | On |
| G13 | On | On | On | On | On | On | On |
| G14 | On | On | On | On | On | On | On |

| Scheduling of Thermal Generating units | Day1 | Day2 | Day3 | Day4 | Day5 | Day6 | Day7 |
|---|---|---|---|---|---|---|---|
| **Load Demand** | 1417 | 1155 | 1400 | 1505 | 1299 | 1295 | 1172 |
| G1 | Off | Off | Off | On | Off | Off | Off |
| G2 | On | On | On | On | On | On | On |
| G3 | On | On | On | On | On | On | On |
| G4 | Off | Off | Off | Off | Off | Off | Off |
| G5 | Off | Off | Off | Off | Off | Off | Off |
| G6 | Off | Off | Off | Off | Off | Off | Off |
| G7 | On | On | On | On | On | On | On |
| G8 | On | On | On | On | On | On | Off |
| G9 | On | Off | On | On | On | On | Off |
| G10 | On | On | On | On | On | On | On |
| G11 | On | On | On | On | On | On | On |
| G12 | On | On | On | On | On | On | On |
| G13 | On | On | On | On | On | On | On |
| G14 | On | On | On | On | On | On | On |

**Table 5.** Evening Peak load demand and required generating units.

**Table 6.** Night Peak Load demand and required generating units

| Scheduling of Thermal Generating units | Day1 | Day2 | Day3 | Day4 | Day5 | Day6 | Day7 |
|---|---|---|---|---|---|---|---|
| **Load Demand** | 1295 | 892 | 1463 | 1487 | 1417 | 1410 | 1050 |
| G1 | Off | Off | On | On | Off | Off | Off |
| G2 | On | Off | On | On | On | On | Off |
| G3 | On | On | On | On | On | On | On |
| G4 | Off | Off | Off | Off | Off | Off | Off |
| G5 | Off | Off | Off | Off | Off | Off | Off |
| G6 | Off | Off | Off | Off | Off | Off | Off |
| G7 | On | On | On | On | On | On | On |
| G8 | On | Off | On | On | On | On | Off |
| G9 | On | Off | On | On | On | On | Off |
| G10 | On | On | On | On | On | On | On |
| G11 | On | On | On | On | On | On | On |
| G12 | On | On | On | On | On | On | On |
| G13 | On | Off | On | On | On | On | On |
| G14 | On | On | On | On | On | On | On |

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**Table 7.** Priority List for morning load demand

| Days | Morning load demand | Priority list for Morning Load Demand |
|---|---|---|
| **Day1** | 1417 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| **Day2** | 1155 | [G10,G14,G13,G3,G7,G11,G12,G2,G8] |
| **Day3** | 1400 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| **Day4** | 1505 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] |
| **Day5** | 1299 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| **Day6** | 1295 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| **Day7** | 1172 | [G10,G14,G13,G3,G7,G11,G12,G2] |

**Table 8.** Priority List for evening load demand

| Days | Evening peak load demand | Optimal Scheduling of thermal generating units Evening Peak Load Demand |
|---|---|---|
| **Day1** | 1295 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| **Day2** | 892 | [G10,G14,G13,G3,G7,G11] |
| **Day3** | 1463 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] |
| **Day4** | 1487 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] |
| **Day5** | 1417 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| **Day6** | 1410 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| **Day7** | 1050 | [G10,G14,G13,G3,G7,G11,G12] |

**Table 9.** Priority List for night load demand

| Days | Night peak load demand | Optimal Scheduling of thermal generating units Night Peak Load Demand |
|---|---|---|
| **Day1** | 1568 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1,G4] |
| **Day2** | 1277 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| **Day3** | 1557 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1,G4] |
| **Day4** | 1538 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1,G4] |
| **Day5** | 1495 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] |
| **Day6** | 1505 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] |
| **Day7** | 1242 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |

**Table 10.** Priority List for 14 thermal generating units for Day1

| Day 1 | Duration | Load Demand | Minimum Load Demand | Priority List of Minimum Peak load Demand<br>**[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9]** |
|---|---|---|---|---|
| **Day 1** | Morning | 1417 | 1295 | [G1] |
| | Evening | 1295 | | **[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9]** |
| | Night | 1568 | | [G1,G4] |

**Table 11.** Priority list of 14 thermal generating units for day 2

| Days | Duration | Peak Load Demand | Minimum Load Demand | Priority List of Minimum Peak load Demand<br>**[G10,G14,G13,G3,G7,G11]** |
|---|---|---|---|---|
| **Day2** | Morning | 1155 | 892 | [G12,G2,G8] |
| | Evening | 892 | | **[G10,G14,G13,G3,G7,G11]** |
| | Night | 1277 | | [G12,G2,G8,G9] |

**Table 12.** Priority list of 14 thermal generating units for day 3

| Days | Duration | Peak Load Demand | Minimum Load Demand | Priority List of Minimum Peak Load Demand<br>**[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1]** |
|---|---|---|---|---|
| **Day 3** | Morning | 1400 | 1400 | **[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1]** |
| | Evening | 1463 | | **[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1]** |
| | Night | 1557 | | [G4] |

**Table 13.** Priority list of 14 thermal generating units for day 4

| Days | Duration | Peak Load Demand | Minimum Peak Load Demand | Priority List of Minimum Peak load Demand **[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1]** |
|---|---|---|---|---|
| Day4 | Morning | 1505 | 1487 | **[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1]** |
| | Evening | 1487 | | **[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1]** |
| | Night | 1538 | | **[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1]** |

**Table 14**. Priority list of 14 thermal generating units for day 5

| Days | Duration | Peak Load Demand | Minimum Load Demand | Priority List of Minimum Peak load Demand<br>**[G10,G14,G13,G3,G7,G11,G12,G2,G8,G9]** |
|---|---|---|---|---|
| Day5 | Morning | 1299 | 1299 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| | Evening | 1417 | | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] |
| | Night | 1495 | | [G1] |

**Table 15.** Priority list of 14 thermal generating units for day 6

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| Days | Duration | Peak Load Demand | Minimum Load Demand | Priority List of Minimum Peak load Demand [G10,G14,G13,G3,G7,G11, G12,G2,G8] |
|---|---|---|---|---|
| Day6 | Morning | 1295 | 1295 | **[G10,G14,G13,G3,G7,G11,G12,G2, G8]** |
| | Evening | 1410 | | [G9] |
| | Night | 1505 | | [G9,G1] |

**Table 16.** Priority list of 14 thermal generating units for day 7

| Days | Duration | Peak Load Demand | Minimum Load Demand | Priority List of Minimum Peak load Demand [G10,G14,G13,G3,G7,G11,G12] |
|---|---|---|---|---|
| Day7 | Morning | 1172 | 1050 | [G2] |
| | Evening | 1050 | | **[G10,G14,G13,G3,G7,G11,G12]** |
| | Night | 1242 | | [G2,G8,G9] |

**Table 17.** Priority list of 14 thermal generating units for a week.

| Time Period | Peak Load Demand. | Minimum Load Demand Throughout the week | Minimum Load Demand for the entire week = 892 [G10,G14,G13,G3,G7,G11] |
|---|---|---|---|
| Morning | 1505(Max) | 892 | [G12,G2,G8,G9,G1] |
| Evening | 892[27] | | [G10,G14,G13,G3,G7,G11] |
| Night | 1568(Max) | | [G12,G2,G8,G9,G1,G4] |

**Table 18**. Fuel cost comparison of thermal generating units of non-fixed priority list

| Days | Peak load demand | Non Fixed Priority list of thermal generating units | Sum of fuel costs of non-fixed thermal generating units |
|---|---|---|---|
| Day1 | 1417 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 95.2 |
| | 1295 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 94.3 |
| | 1568 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1,G4] | 163.8 |
| Day2 | 1155 | [G10,G14,G13,G3,G7,G11,G12,G2,G8] | 83.2 |
| | 892 | [G10,G14,G13,G3,G7,G11] | 52.3 |
| | 1277 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 94.3 |
| Day3 | 1400 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 94.2 |
| | 1463 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 95.3 |
| | 1557 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1,G4] | 163.8 |
| Day4 | 1505 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 106.3 |
| | 1487 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 95.3 |
| | 1538 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1,G4] | 163.8 |
| Day5 | 1299 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 95.2 |
| | 1417 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 83.2 |
| | 1495 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 106.4 |
| Day6 | 1295 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 95.2 |
| | 1410 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 83.2 |
| | 1505 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 106.4 |
| Day7 | 1172 | [G10,G14,G13,G3,G7,G11,G12,G2] | 84.5 |
| | 1050 | [G10,G14,G13,G3,G7,G11,G12] | 62.0 |
| | 1242 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 94.3 |

**Table 19**. Fuel cost calculation of thermal generating units for fixed priority (Morning Peak Load Demand)

| Days | Morning peak load demand | Priority list thermal generating units Morning Peak Load Demand | Fuel Cost for thermal generating units in the morning for fixed priority list |
|---|---|---|---|
| Day1 | 1417 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 95.2 |
| Day2 | 1155 | [G10,G14,G13,G3,G7,G11,G12,G2,G8] | 83.2 |
| Day3 | 1400 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 94.2 |
| Day4 | 1505 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 106.3 |
| Day5 | 1299 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 95.2 |
| Day6 | 1295 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 95.2 |
| Day7 | 1172 | [G10,G14,G13,G3,G7,G11,G12,G2] | 84.5 |

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**Table 20.** Fuel cost calculation of thermal generating units for fixed priority (Evening Peak Load Demand)

| Days | Evening peak load demand | Optimal Scheduling of thermal generating units Evening Peak Load Demand | Fuel cost for thermal generating units in the evening for fixed priority list |
|---|---|---|---|
| Day1 | 1295 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 94.3 |
| Day2 | 892 | [G10,G14,G13,G3,G7,G11] | 52.33 |
| Day3 | 1463 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 95.3 |
| Day4 | 1487 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 95.3 |
| Day5 | 1417 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 95.3 |
| Day6 | 1410 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 83.2 |
| Day7 | 1050 | [G10,G14,G13,G3,G7,G11,G12] | 62.1 |

**Table 21.** Fuel cost calculation of thermal generating units for fixed priority (Night Peak Load Demand)

| Days | Night peak load demand | Optimal Scheduling of thermal generating units Night Peak Load Demand | Fuel cost for thermal generating units in the night for fixed priority list |
|---|---|---|---|
| Day1 | 1568 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1,G4] | 163.8 |
| Day2 | 1277 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 94.1 |
| Day3 | 1557 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1,G4] | 163.8 |
| Day4 | 1538 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1,G4] | 163.8 |
| Day5 | 1495 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 106.4 |
| Day6 | 1505 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9,G1] | 106.3 |
| Day7 | 1242 | [G10,G14,G13,G3,G7,G11,G12,G2,G8,G9] | 94.4 |

**Table 22.** Input data of Real Power Generation and respective calculated derivative

| Derivative of Cost Function (Rs/ MWh) | Results | Generated Powers (MW) |
|---|---|---|
| $\lambda = dF_1/dP_1$ | $7.92+0.003124P_1$ | $P_1=\lambda -7.92/ 0.003$ |
| $\lambda = dF_2/dP_2$ | $7.85+0.00312P_2$ | $P_2=\lambda -7.82/ 0.003$ |
| $\lambda = dF_3/dP_3$ | $7.97+0.0096P_3$ | $P_3=\lambda -7.97/ 0.009$ |
| $\lambda = dF_4/dP_4$ | $1.60+0.84P_4$ | $P_4= \lambda -1.6/ 0.800$ |
| $\lambda = dF_5/dP_5$ | $1.20+0.9P_5$ | $P_5=\lambda -1.2/ 0.900$ |
| $\lambda = dF_6/dP_6$ | $1.16+2(0.064)P_6$ | $P_6= \lambda -1.16/ 0.128$ |
| $\lambda = dF_7/dP_7$ | $6+0.0087P_7$ | $P_7= \lambda -6/ 0.008$ |
| $\lambda = dF_8/dP_8$ | $6.8+.004P_8$ | $P_8=\lambda -6.8/ 0.004$ |
| $\lambda = dF_9/dP_9$ | $6.1+0.0044P_9$ | $P_9=\lambda -6.9/ 0.004$ |
| $\lambda = dF_{10}/dP_{10}$ | $1.6+0.02P_{10}$ | $P_{10}= \lambda -1.6/ 0.020$ |
| $\lambda = dF_{11}/dP_{11}$ | $2.0+0.04P_{11}$ | $P_{11}= \lambda -2.0/ 0.040$ |
| $\lambda = dF_{12}/dP_{12}$ | $5.3+0.008P_{12}$ | $P_{12} =\lambda -5.3/ 0.008$ |
| $\lambda = dF_{13}/dP_{13}$ | $5.5+0.012P_{13}$ | $P_{13}= \lambda -5.5/ 0.012$ |
| $\lambda = dF_{14}/dP_{14}$ | $5.8+0.018P_{14}$ | $P_{14}= \lambda -5.8/ 0.018$ |

**Table 23.** Input fuel cost coefficient and Generation Power of 14 Units in MW

| Fuel Coefficients | A | B | C |
|---|---|---|---|
| P1 | 0.001 | 7.920 | 561 |
| P2 | 0.002 | 7.850 | 310 |
| P3 | 0.005 | 7.970 | 78 |
| P4 | 0.400 | 1.600 | 500 |
| P5 | 0.450 | 1.200 | 720 |
| P6 | 0.064 | 1.160 | 240 |
| P7 | 0.004 | 6.000 | 400 |
| P8 | 0.002 | 6.8000 | 500 |
| P9 | 0.002 | 6.100 | 600 |
| P10 | 0.010 | 1.600 | 511 |
| P11 | 0.020 | 2.000 | 622 |
| P12 | 0.004 | 5.300 | 500 |
| P13 | 0.006 | 5.500 | 400 |
| P14 | 0.009 | 5.800 | 200 |

**Table 24.** Result Generation power of thermal generating units in MW

| Fuel Coefficients | $\lambda$=7.59 |
|---|---|
| P1 | 103.000 |
| P2 | -64.910 |
| P3 | -38.000 |
| P4 | -38.000 |
| P5 | 7.400 |
| P6 | 7.1 |
| P7 | 50 |
| P8 | 199 |
| P9 | 340 |
| P10 | 299 |
| P11 | 139 |
| P12 | 287 |
| P13 | 174 |
| P14 | 99.800 |
| ∑Pi | 1600 |

**Table 25.** Values of Fuel cost coefficient and Generation Power of 14 Units in MW

| Fuel Coefficients | A | B | C |
|---|---|---|---|
| P1 | 0.001 | 7.92 | 561 |
| P2 | 0.001 | 7.85 | 310 |
| P3 | 0.004 | 7.97 | 78 |
| P4 | 0.4 | 1.6 | 500 |
| P5 | 0.45 | 1.2 | 720 |
| P6 | 0.06 | 1.16 | 240 |
| P7 | 0.004 | 6 | 400 |
| P8 | 0.002 | 6.8 | 500 |
| P9 | 0.002 | 6.1 | 600 |
| P10 | 0.01 | 1.6 | 511 |
| P11 | 0.02 | 2 | 622 |

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| | | | |
|---|---|---|---|
| **P12** | 0.004 | 5.3 | 500 |
| **P13** | 0.006 | 5.5 | 400 |
| **P14** | 0.009 | 5.8 | 200 |

**Table 26.** Resulted fuel cost of thermal generating units in MW

| Fuel Coefficients | λ1=6.49 | λ2=7.59 | λ3=7.6 |
|---|---|---|---|
| **P1** | -457 | -209.40 | -102 |
| **P2** | -350 | -67 | -64 |
| **P3** | -153 | -39 | -38 |
| **P4** | 6.101 | 7.480 | 7.5 |
| **P5** | 5.800 | 7.100 | 7.100 |
| **P6** | 41.00 | 50.200 | 50.300 |
| **P7** | 61.00 | 198 | 200 |
| **P8** | -77.00 | 197.50 | 200 |
| **P9** | 88 | 338 | 340 |
| **P10** | 244 | 299 | 300 |
| **P11** | 112 | 139 | 140 |
| **P12** | 148 | 286 | 287 |
| **P13** | 82 | 174 | 175 |
| **P14** | 38 | 99 | 100 |
| **∑Pi** | -209.400 | 1586 | 1603 |

**Table 27.** Fuel Cost obtained for the three optimization techniques.

| Graphical Method | Analytical Method | Iterative Method |
|---|---|---|
| **λ** = 7.93 Rs/MWh | **λ** = 7.59Rs/MWh | **λ**= 7.6 Rs/MWh |

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