DETERMINATION OF ECONOMIC OPERATING POINT USING ECONOMIC LOAD DISPATCH

PROJECT REPORT

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CERTIFICATE

This is to certify that this SIMULATION BASED PROJECT titled "**Determination of Economic Operating Point using Economic Load Dispatch**" is the record of work performed by CHETAN PRAKASH and DEEPAK KUMAR, Electrical Engineering students of B.Tech, Delhi Technological University as a part of their Innovative project for the 6th semester. This Simulation-based project was carried out under my supervision.

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ACKNOWLEDGEMENT

We would like to express our deep sense of respect and gratitude to our project mentor Prof. Rachna Garg, Department of Electrical Engineering, Delhi Technological University for providing the opportunity of carrying out this project and being the guiding force behind this work. We are deeply indebted for the support, advice, and encouragement she provided without which this project could not have been a success.

INTRODUCTION

- The optimal system operation deals with the consideration of economy of power system operation, system security, emission in conventional thermal and hydropower plants.
- These considerations may make for conflicting requirements and usually, a compromise has to be made in optimal system operation.
- In this project, we will consider the economy of operation only, which is known as the economic dispatch pr economic scheduling problem.
- The Economic Load Dispatch problem can be partitioned into two sub-problems:

1. **Unit Commitment:** It is the optimum allocation (commitment) of generators (units) at each generating station at various station load levels (including load sharing among committed generators),
2. **Load Scheduling:** It is the optimum allocation of generation to each station for various system load levels.

   We should solve the **Unit Commitment** problem before proceeding with the **Load Scheduling** problem.

OBJECTIVE

- **The main aim of the economic dispatch problem is to minimize the total cost of generating real power(production cost) at various stations while satisfying the loads and the losses in the transmission links.** We are considering the presence of thermal plants only for our project because there is a negligible operating cost at a hydro plant, there is a limitation of availability of power over a period of time which must be used to save maximum fuel at the thermal plants.
- For beginning with economic factors in power system operation, we will focus our attention on the allocation of real power at generator buses.

ECONOMIC SCHEDULING OF GENERATING UNITS:

Economic scheduling problem deals with the allocation of loads among the various units in such a way that the total cost of generation is minimum.

Dynamic Economic Dispatch

Dynamic economic dispatch is a method to schedule the generator outputs with the load demand over a certain period of time so as to operate an electric power system most economically.

- It is an optimization problem taking into account the constraints imposed on system operation by generator ramping rate limits.

- Generally, the economic load dispatch problem involves the solution of two different problems.
- The first is to select optimally out of available generating sources to operate, to meet the expected load.
- In its second aspect, it is required to distribute the load among the generating units in such a manner as to minimize the total cost of supplying.

- Here, we try to minimize the operating cost of generation. The objective function of economic dispatch or economic scheduling problem is the cost function. Thus, the objective function is
  Min (cost function) or Min (C_T)

  $$C_T = \Sigma\, C_i(P_i)$$

  For i=1, 2,..., n
  Where C_T = Total Cost of generation
  P_i = Generation of ith unit in MW

  - The constraints involved in the economic scheduling problem involves two types of constraints namely:
  1. Equality constraints
  2. Inequality constraints

Equality constraints: Equality constraints involve

1. The load flow solution must converge
2. Total generation of generating unit must be equal to the total load demand (neglecting losses) i.e.

$$\Sigma P_i = P_g$$

and the total generation of ith generating unit must be equal to the total load demand including losses (if losses are not neglected) i.e.

$$\Sigma P_i = P_D + P_{loss}$$

Inequality Constraints: These constraints involve

1. Generating limits
   i.e. $P_{min} \le P_i \le P_{max}$
2. Voltage constraints
   i.e. $V_{min} \le V_i \le V_{max}$
3. Transformer tap position
4. Feeder temperature limit

(where, P_i = Generation of ith unit)

THEORY

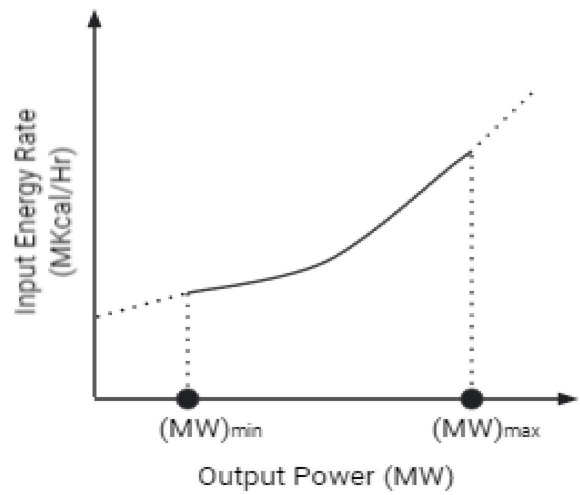
Optimal Operation of Generators on a bus-bar

Generator Operating Cost

The generator operating cost involves fuel cost, labour cost, and maintenance cost. The fuel cost is a variable cost that is meaningful in the case of thermal and nuclear stations but for a hydro station it is not meaningful For economic scheduling of generating units we must define some generator characteristics as follows:

1. Input-output Characteristics:

- The input-output curve or characteristic of a generating unit specifies the input energy rate F, (P) MKCal/hr) or cost of fuel used per hour Ci, (P_{Gi}) (Rs/hr) as a function of the generator power output P_{Gi} as shown.



Input-Output Characteristics of a generating Unit

- It is convenient to express the input-output curves in terms of input energy rate (MKCal/hr) rather than fuel-cost per hour (Rs/hr) because fuel-cost can change monthly or daily in comparison with the fuel energy used per hour or input energy rate at a given output power.

2.Heat-rate Curve :

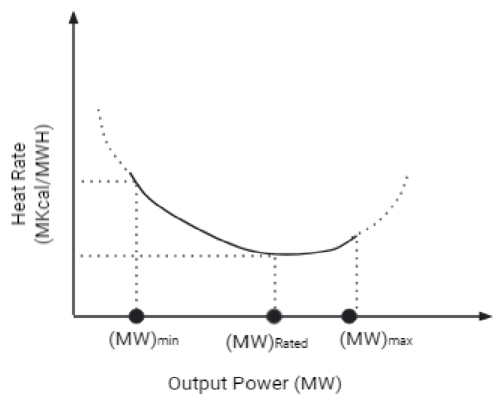
- This characteristic determines the heat energy in MKCal needed to generate one unit of electric energy (MWh). The heat-rate curve or characteristic of a generating unit is shown.
- The heat-rate (efficiency) varies with the output power P and heat-rate (or drop in efficiency) at low and high power limits.
- Typical peak efficiency heat-rates of modern fuel fired plants is around 2.5 MKCal/MWh giving a peak efficiency of around 34%
- The input-output curve can be obtained from the heat-curve as

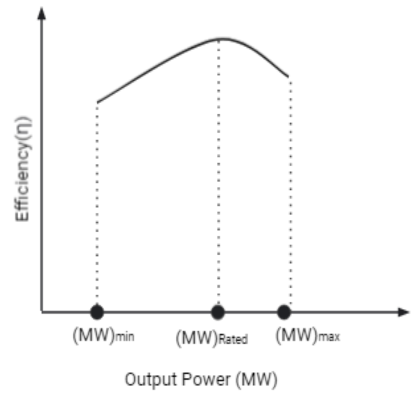
$F_i(P_{Gi})=P_{Gi}H_i(P_{Gi})$ (MKCal/hr)

Where,

$H_i(P_{Gi})$ = heat rate in MKCal/MWh

- The graph of $F_i(P_{Gi})$ is the input-output curve shown.





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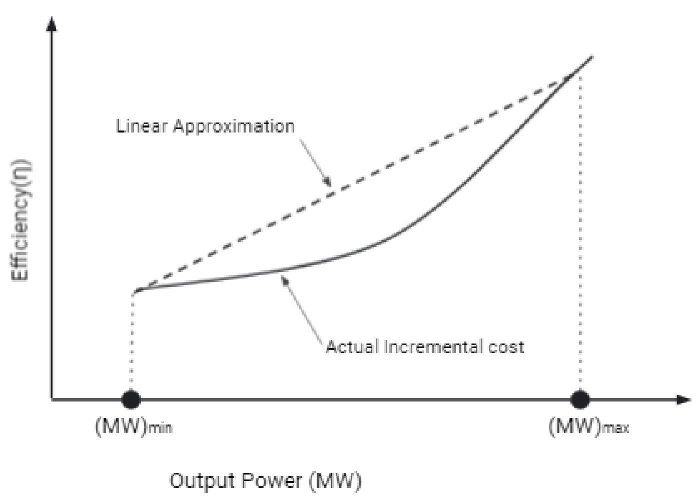
Heat rate curve

3.Fuel-cost Curve

- The fuel cost $C_i(P_{Gi})$ can be mathematically written as

$$F_i(P_{Gi}) = a_i + b_iP_{Gi} + C_iP_{Gi}^2 \text{ (Rs/hr)}$$

- The slope of the fuel cost curve is i.e. dC_i/dP_{Gi} is called the incremental fuel-cost (IC) and is expressed in Rs/MWh.



- A typical plot of the incremented fuel cost versus power output is shown.
- The incremented fuel cost of production is given by

$$\mathbf{(IC_i) = dC_i/dP_{Gi} = b_i = 2C_iP_{Gi}\ (Rs/MWh)}$$

Which gives a linear relationship.

ECONOMIC SCHEDULING NEGLECTING LOSSES

- Let a power station be having K generators and the active power load (demand) given be then the real power generation for each generator has to be allocated so as to minimize the total cost of production

- Hence, the objective function is:

$$\mathbf{C_T = \Sigma\, C_i(P_{Gi})\ (Rs/hr)} \qquad \text{for } i = 1,2,\dots, k$$

Subject to the inequality constraint

$$\mathbf{P_{Gi\ min} <= P_{Gi} <= P_{Gi\ max}}$$

Where $P_{Gi\ min}$ and $P_{Gi\ max}$ are the lower and upper real power generation limits of the generator.
Hence,

$$\mathbf{\Sigma P_{Gi\ max} >= P_D}$$

- Let us assume that inequality constraint is not effective and

$$\mathbf{\Sigma P_{Gi} = P_D}$$

Method of Lagrange Multipliers

- Method of lagrange multipliers is used to minimize (or maximize) a function with side conditions in the form of equality constraints. Using this method, let us define Lagrangian function as

$$\mathbf{C' = C_T - \lambda[\ \Sigma(P_{Gi} - P_D)]} \qquad \text{...(1)}$$

(where, **λ** is the Lagrangian multiplier)

- Optimal allocation or minimization is achieved when

$$dC'/dP_{Gi} = 0$$

$$dC_i/dP_{Gi} = \lambda \qquad \text{(where, i=1,2 K)}$$

Where. dC_i/dP_{Gi} is the incremented cost of the generating unit expressed in Rs/MWh.

Hence, using equation (A), the condition required for economic operation is

$$dC_1/dP_{G1} = dC_2/dP_{G2} = \ldots = dC_k/dP_{Gk} = \lambda$$

ECONOMIC SCHEDULING INCLUDING LOSSES

- The objection function is, $\Sigma\, C_i(P_{Gi})$ (where, i= 1,2,K)
- The Lagrangian function will be defined as

$$C' = \Sigma\, C_i(P_{Gi}) - \lambda[\, \Sigma(P_{Gi} - P_D - P_{Loss})]$$

(where, i= 1,2,K)

- For optimal allocation or scheduling

$$dC'/dP_{Gi} = 0$$

- Here $\partial P_{Loss}/\partial P_{Gi}$ is called "incremental transmission line losses"

$$dC_i/dP_{Gi} = \lambda\, [\, 1 - \partial P_{Loss}/\partial P_{Gi}\,] \qquad \ldots(2)$$

- Here Li = Penalty factor of i_{th} machine,

$$L_i = 1/[1 - (\partial P_{Loss}/\partial P_{Gi})\,]$$

- Hence, equation (2) can be written as:

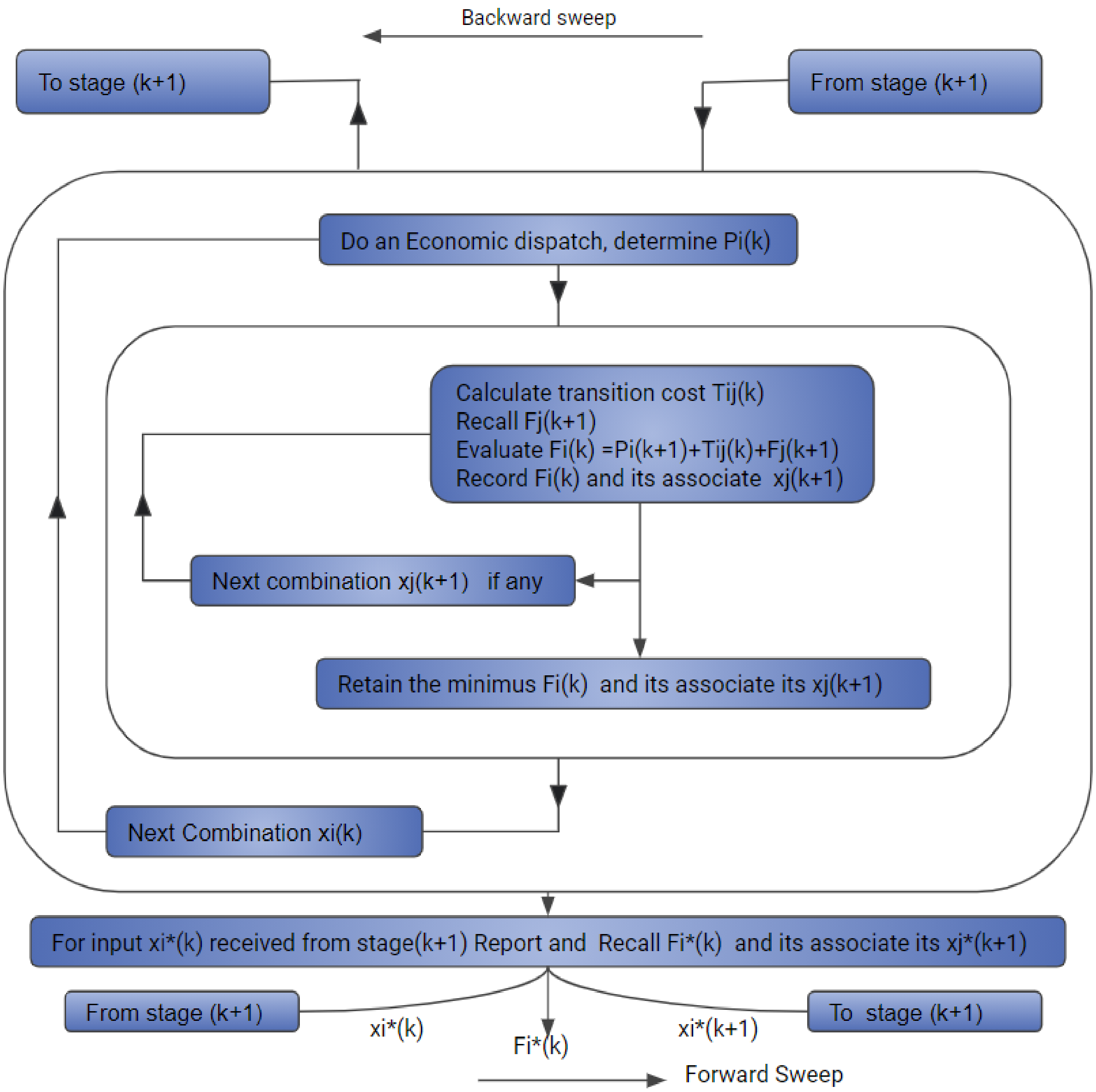
$$L_i\, dC_i/dP_{Gi} = \lambda$$

$$L_1 dC_1/dP_{G1} = L_2 dC_2/dP_{G2} = ... = L_k dC_k/dP_{Gk}$$

HOW IT IS IMPLEMENTED ?

$$F_i(k) = \min_{(x_j(k+1))} \{ P_i(k) + T_{i*j}(k) + F_j(k+I) \}$$

- It is iterative relation embodying the principle that starts with a given combination Xi' at stage k, the minimum unit commitment cost is found by minimizing the sum of the current single-stage cost Fj(k) plus the minimum cumulative cost Fj(k + 1) over the later stages of the study. This is one example of the principle of optimality.
- Principle of Optimality If the best possible path from A to C passes through intermediate point [J, then the best possible path from B to C must be the corresponding part of the best path from A to C.
- Computationally, we evaluate one decision at a time beginning with the final stage N and carry t h e minimum cumulative cost function backward in time to stage k to find the minimum cumulative cost Fi . (k) for the feasible combination Xi" of stage f.
- At each stage, we build a table of results until we reach stage 1, where the input combination x. is definitely known from the initial conditions. The minimum cumulative cost decisions are recovered as we sweep from stage 1 to stage N searching through the tables already calculated for each stage.
- This computational procedure, known as dynamic programming, involves two sweeps through each stage k.
- In the first sweep. which is computationally intensive, we work backward computing and recording for each candidate combination x, of stage k the minimum F(k) and its associated x,(k+ 1). The second sweep in the forward direction does not involve any processing since with x,.(k) identified we merely enter the table of results already recorded to retrieve the value F.(k) and its associated combination x (k 1), which becomes x,.(k+ 1) as we move to the next forward stage. Flow Chart for the Optimal Load Flow is shown below.



Case1. Loading limits and coefficients of Equation for the generating units with no loss.

The system load is to be supplied by combinations of the four generating units of the Table given. Treating Units 1 and 2 as must-run units, determine the power supplied by the generators of each combination and the corresponding production cost in economically loading the units when the system load level is 1100 MW, 1400 MW, 1600 MW and 1800 MW.

- Assuming the start-up cost of each thermal generating unit is 3000 rupees and the shutdown cost is 1500 rupees, determine the optimal unit commitment policy for the four thermal units of the previous case to serve the system load. Only the must-run Units 1 and 2 are to operate at the first and final stages of the load cycle.

Generating Unit no.	Loading Limits	Loading Limits	Fuel cost parameter	Fuel cost parameter	Fuel cost parameter
	Min, (MW)	Max, (MW)	ai, [Rs/(MW^2)]/hr	bi, Rs/MWhr	ci , Rs/hr
1.	100	625	0.0080	8.0	500
2.	100	625	0.0096	6.4	400
3.	75	600	0.0100	7.9	600
4.	75	500	0.0110	7.5	400

Case 2. Loading limits and coefficients of Equation for the generating units with loss.

- The system load is to be supplied by combinations of the four generating units of the Table given. Determine the power supplied by the generators of each combination the corresponding production cost in economically loading the units when the system load level is 1500 MW**.**

Generating Unit no.	Loading Limits	Loading Limits	Fuel cost parameter	Fuel cost parameter	Fuel cost parameter	Loss parameter
	Min, (MW)	Max, (MW)	ai, [Rs/(MW^2)]/hr	bi, Rs/MWhr	ci , Rs/hr	PLoss
1.	10	85	0.0080	7.0	200	0.000218
2.	10	80	0.0090	6.3	180	0.000228
3.	10	70	0.007	6.8	140	0.000179

MATLAB CODE:

CASE 1:

```
clc;
clear all;
mn = [100 100 75 75];
mx = [625 625 600 500];
a = [.0080 .0096 .0100 .0110];
b = [8 6.4 7.9 7.5];
c = [500 400 600 400];
[mn' mx' a' b' c'];

com=[1 1 1 1
    1 1 1 0
    1 1 0 1
    1 1 0 0];
 PGT=[1100 1400 1600 1800];
 disp(' L    Pg1   Pg2   Pg3   Pg4    f1   f2   f3    f4    ft');

 for z =1:4
    disp(strcat('Power Demand ----- ',int2str(PGT(z)),' '));
    fprintf('\n');
    for j = 1:4
        capacity = 0;
        for check=1:4
            capacity=capacity+mx(1,check)*com(j,check);
        end
        if capacity>=PGT(1,z)
            add=0;
            ain=0;
            bt=0;
            for i=1:4
                if com(j,i)
                    ain=ain+(1/a(i));
                    bt=bt+(b(i)/a(i));
                end
            end
            at=1/ain;
            L=at*(PGT(1,z)+bt);
            for g= 1:4
                pg(1,g)= ((L-b(g))/a(g)*com(j,g));
            end
            pg=round(pg);

            for v= 1:4
                if pg(1,v)>mx(v)
```

```
            temp=pg(1,v);
            pg(1,v)=mx(v);
            temp=temp-mx(v);
            add=add+temp;
          end
        end
        if add~=0
          for w = 1:4
            if pg(1,w)~=0
              if pg(1,w)<mx(w)
                temp1=mx(w)-pg(1,w);
                if temp1<=add
                  pg(1,w)=mx(w);
                  add+add-temp1;
                else
                  pg(1,w)=pg(1,w)+add;
                  L=(pg(1,w)*a(w))+b(w);
                end
              end
            end
          end
        end

        for f =1:4
          cost(1,f) = (.5*a(f)*pg(1,f).^2+b(f)*pg(1,f)+c(f))*com(j,f);
        end
        cost=round(cost);
        total_cost=sum(cost(1,:))*4;
        value(1,:)=[L,pg(1,:),cost(1,:),total_cost];
        fprintf('%.3f %.2f %.2f %.2f %.2f %.2f %.2f %.2f %.2f %.2f \n',value(1,:));
      else
        disp('------------------------infeasible------------------------------');
      end
    end

End
```

CASE 2:

```
clc;
clear  all;
ip=fopen('loss_data.m','r');
data=fscanf(ip,'%f',[6,3]);
data=data';
const=data(:,1);
```

```
beta=data(:,2);
gamma=data(:,3);
pmin=data(:,4);
pmax=data(:,5);
ploss=data(:,6);
lambda=input('Enter the assumed value of lambda : \n');
p=zeros(3,1);
loss=0;
demand=input('Enter the demand : \n');
deltap=1;
iteration=0;
while abs(deltap)>.0001
   iteration=iteration+1;
for i=1:3
   p(i)=(lambda-beta(i))/(2*[gamma(i)+lambda*ploss(i)]);
   loss=loss+ploss(i)*p(i)^2;
end
deltap=demand+loss-sum(p);
loss=0;
if abs(deltap)>0
   k=0;
   for i=1:3
     k=k+(gamma(i)+ploss(i)*beta(i))/(2*[gamma(i)+lambda*ploss(i)]^2);
   end
end
   deltalambda=deltap/k;
lambda=lambda+deltalambda;
end
for i =1:3
   Fc(i)=const(i)+gamma(i)*p(i)^2 + beta(i)*p(i);
end
fprintf('P1 = %.3f \nP2 = %.3f\nP3 = %0.3f\n',p);
fprintf('F1 = %.3f \nF2 = %.3f\nF3 = %0.3f\n',Fc);
Fuel_cost = Fc(1)+Fc(2)+Fc(3);
fprintf('Total Fuel cost = %.f\n',Fuel_cost);
fprintf('Number of iterations = %0.0f\n',iteration);
fprintf('Actual Value of lambda = %.f\n',lambda);
```

RESULT :

Case 1:

```
       L          Pg1        Pg2        Pg3        Pg4        f1         f2         f3         f4         ft
Power Demand -----1100

     10.09        261        384        219        235       2860       3565       2570       2466      45844

    10.805        351        459        291          0       3801       4349       3322          0      45888

    10.774        347        456          0        298       3758       4316          0       3123      44788

    12.073        509        591          0          0       5608       5859          0          0      45868

Power Demand -----1400

    10.804        350        459        290        300       3790       4349       3312       3145      58384

    11.716        465        554        382          0       5085       5419       4347          0      59404

    11.711        464        553          0        383       5073       5407          0       4079      58236

    ------------------------------------------------------infeasible------------------------------------------------------------
Power Demand -----1600

     11.28        410        508        338        344       4452       4890       3841       3631      67256

    12.324        541        617        442          0       5999       6176       5069          0      68976

    12.336        542        618          0        440       6011       6188          0       4765      67856

    ------------------------------------------------------infeasible------------------------------------------------------------
Power Demand -----1800

    11.756        470        558        386        387       5144       5466       4394       4126      76520

     13.48        625        625        558          0       7063       6275       6565          0      79612

    ------------------------------------------------------infeasible------------------------------------------------------------
    ------------------------------------------------------infeasible------------------------------------------------------------
>> |
```

Case 2:

Command Window

```
Enter the assumed value of lambda :
15
Enter the demand :
1500
P1 = 539.882
P2 = 517.903
P3 = 640.297
F1 = 6310.960
F2 = 5856.807
F3 = 7363.877
Total Fuel cost = 19532
Number of iterations = 12
Actual Value of lambda = 20
>>
```

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