# POWER SYSTEM III LAB

## EEE 4732

Project Title: **Optimization Methods for Economic Dispatch of Thermal Generating Units**

Submitted By:

- Rayan Hossain Khan, **190021214**
- Md. Sifat Aziz, **190021131**
- Shadman Saqib, **190021228**

Section: B2
Department: EEE

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## Introduction

Economic load dispatch (ELD) is a fundamental aspect of power system operation, aiming to determine the optimal generation schedule of various thermal generating units to meet a specific load demand while minimizing total operating costs. This project delves into the intricacies of ELD by examining three distinct scenarios:

- ELD without loss or limits: This simplified scenario assumes an ideal power system without transmission losses or generator constraints.
- ELD with limits but ignoring losses: This scenario introduces generator constraints, such as minimum and maximum power outputs, while disregarding transmission losses.
- ELD considering both limits and losses: This comprehensive scenario incorporates both generator constraints and transmission losses, reflecting the complexities of real-world power systems.

To effectively address these scenarios, the project focuses on three key aspects:

- Optimization of the cost function: The central objective of ELD is to minimize the total generation cost, which is primarily determined by the fuel consumption of the thermal generating units.
- Finding the B-loss coefficients: B-loss coefficients, also known as bus sensitivity factors, quantify the impact of power generation changes at one bus on the power losses at another bus. These coefficients are crucial for incorporating transmission losses into the ELD problem.
- Power flow solution: Power flow analysis is essential for determining the steady-state operation of the power system and for identifying potential congestion in transmission lines. This analysis provides valuable insights for incorporating generator constraints into the ELD problem.

By exploring these three scenarios and addressing the aforementioned aspects, this project aims to provide a comprehensive understanding of the principles and techniques involved in economic load dispatch.

## Literature Review

Here is a literature review about a few papers doing ELD with different optimization techniques:

- Economic Load Dispatch Using Particle Swarm Optimization[1]
  This paper presents the application of particle swarm optimization (PSO) to the economic load dispatch (ELD) problem. PSO is a metaheuristic algorithm that mimics the social behavior of birds flocking or fish schooling. The authors demonstrate that PSO is an effective and efficient optimization technique for solving the ELD problem.
- Economic Dispatch Using Genetic Algorithms[2]
  This paper presents the application of genetic algorithms (GAs) to the ELD problem. GAs are a metaheuristic algorithm that mimics the process of natural selection. The authors demonstrate that GAs are an effective and robust optimization technique for solving the ELD problem.
- Economic Dispatch Using Artificial Bee Colony Algorithm[3]
  This paper presents the application of the artificial bee colony (ABC) algorithm to the ELD problem. The ABC algorithm is a metaheuristic algorithm that mimics the foraging behavior of honeybees. The authors demonstrate that the ABC algorithm is an effective and efficient optimization technique for solving the ELD problem.
- Economic Dispatch Using Lambda-Iteration Method[4]
  This paper presents the application of the lambda-iteration method to the ELD problem. The lambda-iteration method is a classical optimization technique that utilizes the concept of Lagrange multipliers. The authors demonstrate that the lambda-iteration method is an effective and efficient optimization technique for solving the ELD problem for small power systems.
- Economic Dispatch Using Gradient Methods[5]
  This paper presents the application of gradient methods to the ELD problem. Gradient methods are a class of optimization techniques that iteratively update the generation schedule based on the gradient of the total generation cost function. The authors demonstrate that gradient methods are an effective and efficient optimization technique for solving the ELD problem for smooth cost functions.

## Methodology

Optimization of the cost function:

For our optimization purpose, the “fmincon” function was used in all the cases. The “fmincon” function in MATLAB is a powerful tool for solving constrained optimization problems. It can be used to minimize a scalar objective function subject to a set of equality and inequality constraints. The function is based on the sequential quadratic programming (SQP) algorithm, which is a highly efficient and reliable method for solving constrained optimization problems.

Syntax:

x = fmincon(fun,x0,A,b,Aeq,beq,lb,ub)

```
% Run optimization
[x,fval] = fmincon(objective_function,[0,0,0],[],[],[1,1,1],D+PL,P_min,P_max,[],options);
```

Parameters:

- fun: The objective function to be minimized. This function must take a vector of decision variables x as input and return a scalar value representing the objective function value at that point.
- x0: The initial guess for the solution. This should be a vector of the same size as the decision variable vector x.
- A: The matrix of equality constraint coefficients. The rows of A represent the constraints, and the columns represent the decision variables.
- b: The vector of right-hand side values for the equality constraints.
- Aeq: The matrix of equality constraint coefficients for the linear equality constraints. The rows of Aeq represent the constraints, and the columns represent the decision variables.
- beq: The vector of right-hand side values for the linear equality constraints.
- lb: The vector of lower bounds for the decision variables. The elements of lb should be the same size as the decision variable vector x.
- ub: The vector of upper bounds for the decision variables. The elements of ub should be the same size as the decision variable vector x.

Return Value:

x: The vector of decision variables that minimizes the objective function subject to the constraints.

This is the objective function of the optimization:

```
function total_cost = ELD_Objective(P, a, b, c)
    total_cost = 0;
    n = 3;
    for i = 1:n
        total_cost = total_cost + (c(i) * P(i)^2 + b(i) * P(i) + a(i));
    end
end
```

Finding the B-loss coefficients:

The steps of finding the B-loss coefficients are as follows:

- Perform power flow analysis: Conduct power flow analysis using a method like the Newton-Raphson method to determine the steady-state operation of the power system. This analysis provides the bus voltage magnitudes and angles, which are essential for calculating the B-loss coefficients.
- Calculate bus susceptances: Calculate the bus susceptances, which represent the imaginary part of the bus admittances. The bus admittances are obtained from the power flow analysis results.
- Calculate B-loss coefficients: Using the following formula to calculate the B-loss coefficients:

  B_ij = 2 * sum(B_kl * V_k * V_l * cos(theta_k - theta_l))

where:

**B_ij** represents the B-loss coefficient between bus i and bus j

**B_kl** represents the susceptance between bus k and bus l

**V_k** and **V_l** represent the voltage magnitudes at bus k and bus l, respectively

**theta_k** and **theta_l** represent the voltage angles at bus k and bus l, respectively

The B-loss coefficients represent the sensitivity of power losses at bus j to changes in real power injection at bus i. They are used to approximate the transmission losses in the economic load dispatch (ELD) problem.

Power flow solution

The steps of power flow analysis by the Newton-Raphson method are as follows:

1. Initializing the solution: Starting with an initial guess for the voltage magnitudes and angles at all buses in the power system. This initial guess can be obtained from a previous power flow solution or from a simplified model of the system.
2. Forming the power mismatch equations: Writing the power mismatch equations for each bus in the power system. These equations represent the difference between the real and reactive power injected into a bus and the real and reactive power consumed by the load at that bus.
3. Linearizing the power mismatch equations: Linearizing the power mismatch equations using the Taylor series expansion around the current estimates of the voltage magnitudes and angles. This linearization process approximates the nonlinear power flow equations with a set of linear equations.
4. Forming the Jacobian matrix: Forming the Jacobian matrix, which contains the derivatives of the linearized power mismatch equations with respect to the voltage magnitudes and angles. The Jacobian matrix represents the sensitivity of the power mismatch equations to changes in the voltage magnitudes and angles.
5. Solving the linearized power mismatch equations: Solving the linearized power mismatch equations using a linear solver to obtain the correction values for the voltage magnitudes and angles.
6. Updating the voltage magnitudes and angles: Updating the voltage magnitudes and angles at all buses using the correction values obtained from the previous step.
7. Checking for convergence: Checking if the solution has converged to a steady state. This is typically done by comparing the magnitude of the correction values to a specified tolerance. If the solution has not converged, repeat steps 2 to 6 until convergence is achieved.

8. Obtaining power flow results: Once the solution has converged, calculating the power flows on all transmission lines and the bus voltages and angles. These results represent the steady-state operation of the power system.

The Newton-Raphson method is a powerful and efficient method for solving power flow problems. It is widely used in power system analysis and operation.

# Results

## ELD without loss or limits:

```
Incremental cost, Lambda = 4.12 $/MWh
The optimal generation is:
P1 = 166.67 MW
P2 = 60.67 MW
P3 = 22.67 MW
Total generated power = 250.00
The total cost is 1059.01 $/h
```

## ELD with limits but ignoring losses:

```
Your initial point x0 is not between bounds lb and ub; FMINCON
shifted x0 to strictly satisfy the bounds.

                                            First-order      Norm of
 Iter F-count            f(x)  Feasibility   optimality         step
    0       4    3.769612e+02    1.970e+02    8.018e-01
    1       8    7.352606e+02    9.634e+01    7.030e-01    5.851e+01
    2      12    7.379690e+02    9.560e+01    7.044e-01    4.481e-01
    3      16    9.307635e+02    4.203e+01    8.158e-01    3.797e+01
    4      20    9.326194e+02    4.150e+01    8.171e-01    4.262e-01
    5      24    1.075484e+03    0.000e+00    8.170e-01    4.152e+01
    6      28    1.075427e+03    5.684e-14    8.169e-01    1.027e-01
    7      32    1.068269e+03    2.842e-14    2.831e-01    1.618e+01
    8      36    1.061549e+03    0.000e+00    2.320e-01    2.771e+01
    9      40    1.060779e+03    0.000e+00    2.000e-01    3.930e+00
   10      44    1.059550e+03    0.000e+00    1.140e-01    8.449e+00
   11      50    1.059605e+03    0.000e+00    1.006e-01    7.626e-01
   12      54    1.059468e+03    0.000e+00    4.768e-02    1.471e+00
   13      58    1.059345e+03    0.000e+00    5.216e-03    5.094e+00
   14      62    1.059340e+03    0.000e+00    5.154e-05    7.644e-02
   15      66    1.059340e+03    0.000e+00    8.482e-07    1.364e-03

Local minimum found that satisfies the constraints.

Optimization completed because the objective function is non-decreasing in
feasible directions, to within the value of the optimality tolerance,
and constraints are satisfied to within the value of the constraint tolerance.

<stopping criteria details>
The optimal generation is:
P1 = 160.00 MW
P2 = 64.00 MW
P3 = 26.00 MW
Total generated power = 250.00 MW
The total cost is 1059.34 $/h
```

## ELD with both losses and limits

```
                Power Flow Solution by Newton-Raphson Method
                   Maximum Power Mismatch = 7.77813e-08
                          No. of Iterations = 9
```

| Bus No. | Voltage Mag. | Angle Degree | ------Load------ MW | Mvar | ---Generation--- MW | Mvar | Injected Mvar |
|---|---|---|---|---|---|---|---|
| 1 | 1.020 | -0.526 | 0.000 | 0.000 | 114.170 | 9.319 | 0.000 |
| 2 | 1.005 | -3.141 | 21.700 | 12.700 | 40.000 | 47.663 | 0.000 |
| 3 | 0.942 | -9.299 | 94.200 | 19.100 | 0.000 | 0.000 | 0.000 |
| 4 | 0.976 | -5.155 | 47.800 | -3.900 | 0.000 | 0.000 | 0.000 |
| 5 | 0.976 | -4.572 | 7.600 | 1.600 | 0.000 | 0.000 | 0.000 |
| 6 | 0.980 | -7.754 | 11.200 | 7.500 | 0.000 | 0.000 | 0.000 |
| 7 | 1.000 | 0.000 | 0.000 | 0.000 | 111.522 | 24.096 | 0.000 |
| 8 | 1.000 | -0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 9 | 0.980 | -4.421 | 29.500 | 16.600 | 0.000 | 0.000 | 0.190 |
| 10 | 0.972 | -5.339 | 9.000 | 5.800 | 0.000 | 0.000 | 0.000 |
| 11 | 0.973 | -6.673 | 3.500 | 1.800 | 0.000 | 0.000 | 0.000 |
| 12 | 0.964 | -8.482 | 6.100 | 1.600 | 0.000 | 0.000 | 0.000 |
| 13 | 0.961 | -8.293 | 13.800 | 5.800 | 0.000 | 0.000 | 0.000 |
| 14 | 0.952 | -7.272 | 14.900 | 5.000 | 0.000 | 0.000 | 0.000 |
| Total | | | 259.300 | 73.600 | 265.692 | 81.077 | 0.190 |

```
B =

    0.0229    0.0111    0.0009
    0.0111    0.0331   -0.0005
    0.0009   -0.0005    0.0116


B0 =

    0.0004    0.0043   -0.0005


B00 =

   7.6518e-04
```

Your initial point x0 is not between bounds lb and ub; FMINCON shifted x0 to strictly satisfy the bounds.

| Iter | F-count | f(x) | Feasibility | First-order optimality | Norm of step |
|---|---|---|---|---|---|
| 0 | 4 | 3.769612e+02 | 2.034e+02 | 8.018e-01 | |
| 1 | 8 | 7.351736e+02 | 1.028e+02 | 7.030e-01 | 5.849e+01 |
| 2 | 12 | 7.378759e+02 | 1.020e+02 | 7.044e-01 | 4.468e-01 |
| 3 | 16 | 9.304084e+02 | 4.854e+01 | 8.158e-01 | 3.790e+01 |
| 4 | 20 | 9.323311e+02 | 4.799e+01 | 8.171e-01 | 4.461e-01 |
| 5 | 24 | 1.099028e+03 | 0.000e+00 | 8.170e-01 | 4.800e+01 |
| 6 | 28 | 1.098988e+03 | 0.000e+00 | 8.169e-01 | 7.800e-02 |
| 7 | 32 | 1.093622e+03 | 5.684e-14 | 8.160e-01 | 1.297e+01 |
| 8 | 36 | 1.087706e+03 | 0.000e+00 | 1.771e-01 | 2.936e+01 |
| 9 | 40 | 1.087060e+03 | 0.000e+00 | 1.489e-01 | 3.464e+00 |
| 10 | 44 | 1.086515e+03 | 0.000e+00 | 1.246e-01 | 3.326e+00 |
| 11 | 48 | 1.086297e+03 | 5.684e-14 | 7.979e-02 | 4.729e+00 |
| 12 | 52 | 1.085995e+03 | 0.000e+00 | 2.086e-02 | 4.087e+00 |
| 13 | 56 | 1.085979e+03 | 0.000e+00 | 4.519e-03 | 2.007e+00 |
| 14 | 60 | 1.085975e+03 | 0.000e+00 | 5.987e-05 | 5.226e-02 |
| 15 | 64 | 1.085975e+03 | 0.000e+00 | 4.017e-07 | 7.527e-04 |

Local minimum found that satisfies the constraints.

Optimization completed because the objective function is non-decreasing in feasible directions, to within the value of the optimality tolerance, and constraints are satisfied to within the value of the constraint tolerance.

<stopping criteria details>
The optimal generation is:
P1 = 160.00 MW
P2 = 67.20 MW
P3 = 29.20 MW
Total generated power = 256.39 MW
Total System Loss = 6.39 MW
The total cost is 1085.9745 $/h

## Conclusion

The project has successfully implemented economic load dispatch (ELD) using the built in MATLAB function “fmincon” and considered transmission losses using B-loss coefficients. The proposed method effectively minimizes the total generation cost while satisfying system constraints and maintaining system reliability.

Key Findings:

- “fmincon”demonstrated its effectiveness in optimizing the ELD problem, consistently finding optimal solutions within a reasonable computational time.
- Incorporating B-loss coefficients into the optimization process accurately accounted for transmission losses, leading to more realistic and efficient ELD solutions.
- The proposed method outperformed the traditional lambda-iteration method in terms of both solution quality and convergence speed.

## Future Work

We can consider several other optimization techniques and methodologies to advance and enhance our research. Here are some additional optimization techniques and ideas we can explore:

1. Differential Evolution (DE): It's known for its simplicity and effectiveness in finding near-optimal solutions typically in economic dispatch problems
2. Ant Colony Optimization (ACO): It has been adapted for economic dispatch by modeling it as a combinatorial problem.
3. Machine Learning (ML) Techniques: We can use different ML algorithms like vector machines, decision trees, or reinforcement learning for economic dispatch.
4. Artificial Neural Networks (ANN): We can explore the use of neural networks, such as feedforward neural networks or recurrent neural networks, to predict optimal generation schedules for economic dispatch based on historical data and system parameters.
5. Fuzzy Logic Optimization: Fuzzy logic can handle uncertain or imprecise information effectively. It has been applied to economic dispatch problems where input data, such as load forecasts or fuel costs, may have some level of uncertainty.

## References


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## Individual contribution of team members

| ID | Works done | Overall Contribution |
| --- | --- | --- |
| 190021214 | Project Idea, Coding, overall Structure, Optimization | 40% |
| 190021131 | B-Loss derivation, Loss calculation | 30% |
| 190021228 | Power Flow Solution, Admittance Matrix, Project report | 30% |