Power System Operation and Control

Syllabus

Chapter One: Economic Operation of Power Systems

Chapter Two: Power System Stability

Chapter Three: Load Frequency Control, Reactive power Control & Voltage Control

References:

1 Power System Operation And Control, 2009 By S. Sivanagaraju and G. Sreenivasan

2 Power System Operation & Control, by A. M. Kulkarni

3 Operation and Control in Power Systems, Second Edition 2011 By P. S. Murty

CHAPTER ONE

ECONOMIC OPERATION OF POWER SYSTEMS

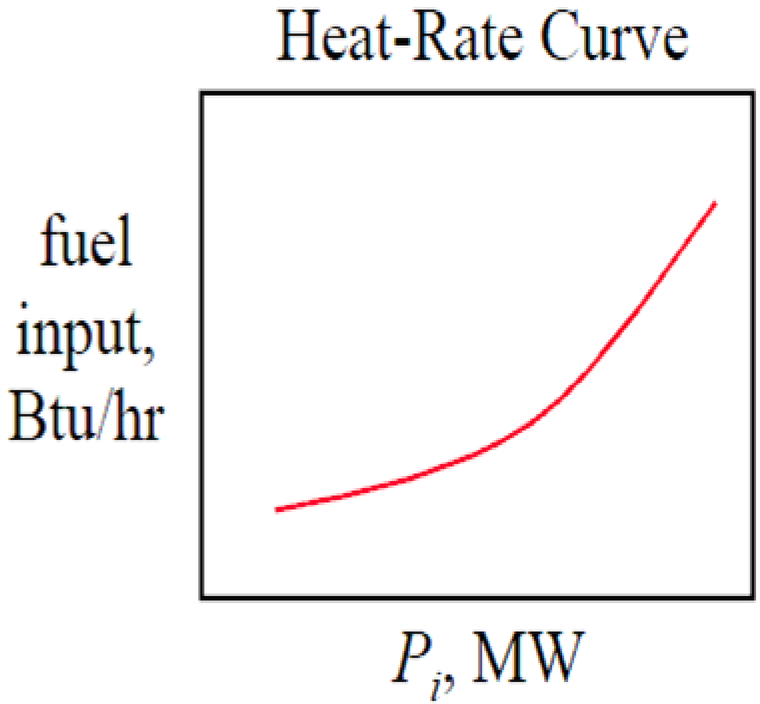
- **For interconnected systems, the objective is to find the real and reactive power scheduling so as to minimize some operating cost or cost function**

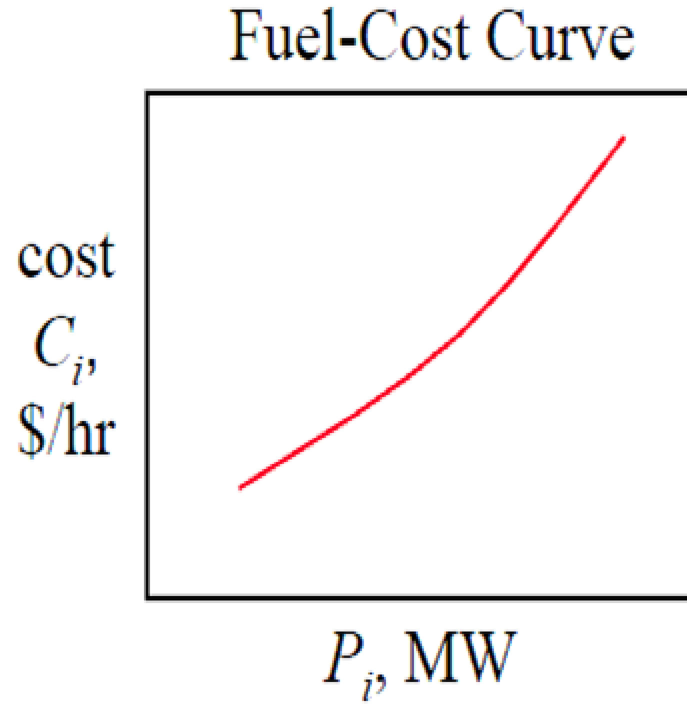
- in practice, power plants are not located at the same distance from the load centers
- power plants use different types of fuel, which vary in cost from time to time

Operating Costs

- **Factors influencing the minimum cost of power generation**
  - operating efficiency of prime mover and generator
  - fuel costs
  - transmission losses
- **The most efficient generator in the system does not guarantee minimum costs**
  - may be located in an area with high fuel costs
  - may be located far from the load centers and transmission losses are high
- **The problem is to determine generation at different plants to minimize the total operating costs**

- **Generator heat rate curves lead to the fuel cost curves**





- The fuel cost is commonly express as a quadratic function

$$C_i = \alpha_i + \beta_i P_i + \gamma_i P_i^2$$

- The derivative is known as the incremental fuel cost

$$dC_i / dP_i = \beta_i + 2\gamma_i P_i$$

Economic Dispatch

- **The simplest problem is when system losses and generator limits are neglected**
  - minimize the objective or cost function over all plants
  - a quadratic cost function is used for each plant

$$C_{total} = \sum_{i=1}^{n_{gen}} C_i = \sum_{i=1}^{n_{gen}} \alpha_i + \beta_i P_i + \gamma_i P_i^2$$

  - the total demand is equal to the sum of the generators' output; the equality constrant

$$\sum_{i=1}^{n_{gen}} P_i = P_{Demand}$$

- **A typical approach using the Lagrange multipliers**

$$L = C_{total} + \lambda\left(P_{Demand} - \sum_{i=1}^{n_{gen}} P_i\right)$$

$$\frac{\partial L}{\partial P_i} = \frac{\partial C_{total}}{\partial P_i} + \lambda(0-1) = 0 \quad \rightarrow \quad \frac{\partial C_{total}}{\partial P_i} = \lambda$$

$$C_{total} = \sum_{i=1}^{n_{gen}} C_i \quad \rightarrow \quad \frac{\partial C_{total}}{\partial P_i} = \frac{dC_i}{dP_i} = \lambda \quad \forall i = 1,\ldots,n_g$$

$$\lambda = \frac{dC_i}{dP_i} = \beta_i + 2\gamma_i P_i$$

- the second condition for optimal dispatch

$$\frac{dL}{d\lambda} = \left(P_{Demand} - \sum_{i=1}^{n_{gen}} P_i \right) = 0 \quad \rightarrow \quad \sum_{i=1}^{n_{gen}} P_i = P_{Demand}$$

- rearranging and combining the equations to solve for λ

$$P_i = \frac{\lambda - \beta_i}{2\gamma_i}$$

$$\sum_{i=1}^{n_{gen}} \frac{\lambda - \beta_i}{2\gamma_i} = P_{Demand} \qquad \lambda = \frac{P_{Demand} + \sum_{i=1}^{n_{gen}} \frac{\beta_i}{2\gamma_i}}{\sum_{i=1}^{n_{gen}} \frac{1}{2\gamma_i}}$$

Example

- **Neglecting system losses and generator limits, find the optimal dispatch and the total cost in $/hr for the three generators and the given load demand**

$$C_1 = 500 + 5.3P_1 + 0.004P_1^2 \; [\$ / MWhr]$$

$$C_2 = 400 + 5.5P_2 + 0.006P_2^2$$

$$C_3 = 200 + 5.8P_3 + 0.009P_3^2$$

$$P_{Demand} = 800MW$$

Solution

$$\lambda = \frac{P_{Demand} + \sum_{i=1}^{n_{gen}} \frac{\beta_i}{2\gamma_i}}{\sum_{i=1}^{n_{gen}} \frac{1}{2\gamma_i}} = \frac{800 + \frac{5.3}{0.008} + \frac{5.5}{0.012} + \frac{5.8}{0.018}}{\frac{1}{0.008} + \frac{1}{0.012} + \frac{1}{0.018}} = \$8.5 / MWhr$$

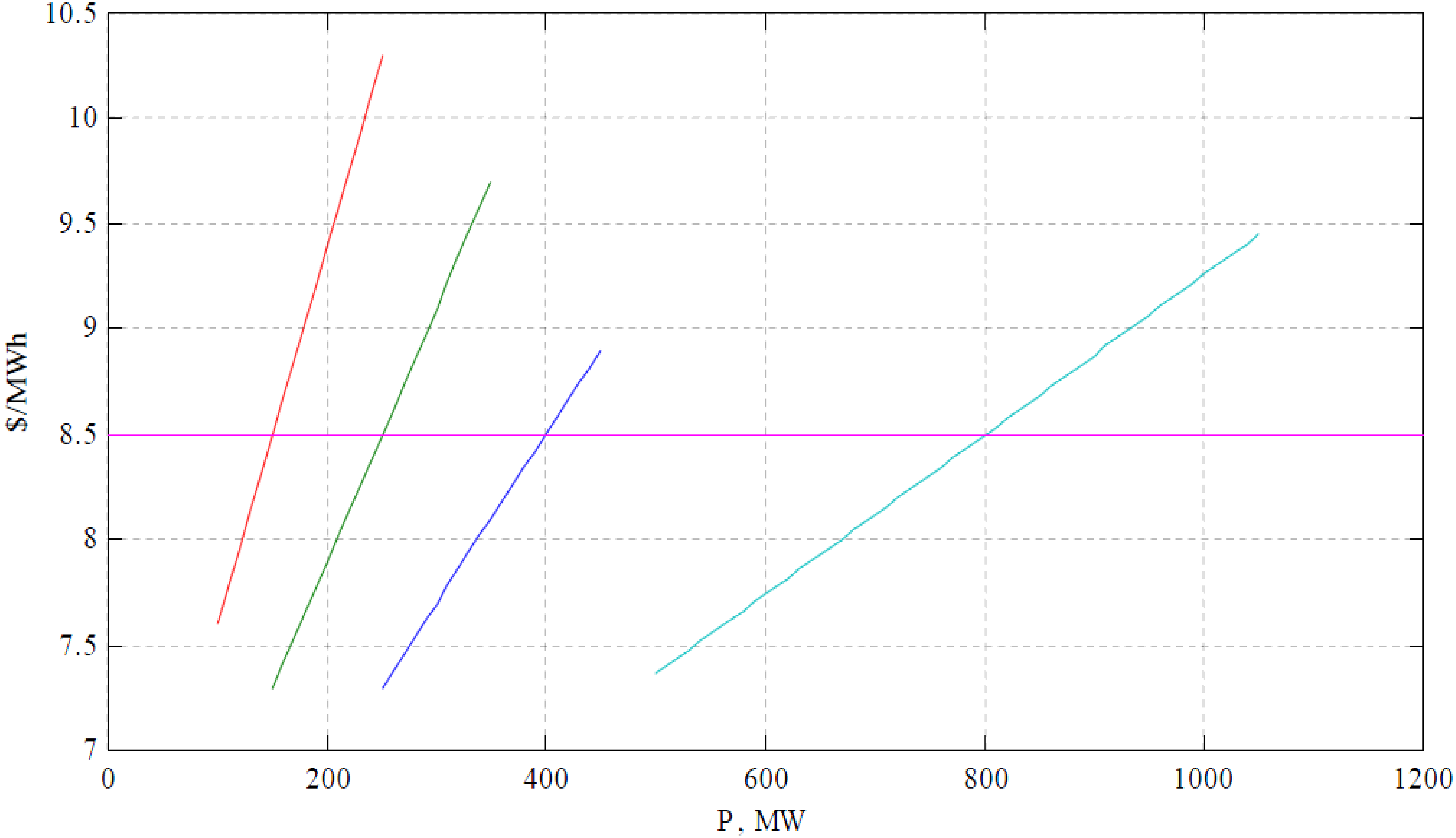
$$P_1 = \frac{8.5 - 5.3}{2(0.004)} = 400\,MW$$

$$P_i = \frac{\lambda - \beta_i}{2\gamma_i} \qquad P_2 = \frac{8.5 - 5.5_i}{2(0.006)} = 250\,MW$$

$$P_3 = \frac{8.5 - 5.8}{2(0.009)} = 150\,MW$$

$$P_{Demand} = 800 = 400 + 250 + 150$$

Fuel Cost Curves



- Solve again using iterative methods

$$\Delta P = P_D^{sch} - P_D^{cal} \quad , \quad P(\lambda) = \sum \frac{\lambda - \beta_i}{2\gamma_i}$$

$$\left(\partial P / \partial \lambda \right) = \sum dP_i / d\lambda = \sum \frac{1}{2\gamma_i}$$

$$\Delta \lambda^{[k]} = \frac{\Delta P(\lambda)^{[k]}}{\left(\partial P / \partial \lambda \right)^{[k]}} = \frac{\Delta P = P_D^{sch} - P_D^{cal}}{\frac{1}{2\gamma_1} + \frac{1}{2\gamma_2} + \frac{1}{2\gamma_3}}$$

$$\lambda^{[k+1]} = \lambda^{[k]} + \Delta \lambda^{[k]}$$