Load frequency control

Area A
\[ G_1 = 200 \text{ MW} \quad \Delta f = 5\% \] droop
\[ G_2 = 300 \text{ MW} \]
Load 150 MW

Area B
\[ G_1 = 200 \text{ MW} \quad \Delta f = 10\% \] droop
\[ G_2 = 400 \text{ MW} \]
Load 250 MW

Tie line flow \( \Delta P \) of 150 MW

a) Find the initial frequency change if load increases by 50 MW in Area A.

Use a base value of 400 MW

Area A:
\[ R_1 = 0.05 \left( \frac{400}{200} \right) = 0.1 \quad R_2 = 0.05 \left( \frac{400}{300} \right) = 0.067 \]

Area B:
\[ R_1 = 0.10 \left( \frac{400}{200} \right) = 0.2 \quad R_2 = 0.10 \]

\[ \beta_A = \frac{1}{R_1} + \frac{1}{R_2} = 75 \text{ p.u.} \quad \beta_B = \frac{1}{R_1} + \frac{1}{R_2} = 15 \text{ p.u.} \quad \beta = 40 \text{ p.u.} \]
\[ \Delta f = -\frac{\Delta P}{V_B} = \frac{-50}{400} \cdot \frac{1}{40} = -0.0031 \text{ p.u.} \quad / = -0.1875 \text{ Hz} \]

(b) What are the ideal bias settings for each area to ensure proper coordination? (i.e., calculating the ACEs)
- the ideal is to set bias equal to 13
  - Area A: 25 p.u.
  - Area B: 15 p.u.
  - (16.7 MW/0.1 Hz) (10 MW 0.1 Hz)

(c) ACE at these settings
\[ \text{ACE}_A = \Delta f_{B_A} + \Delta P_{tie} = -31.25 + (-50 + 31.25) = -50 \text{ MW} \]
\[ \text{ACE}_B = \Delta f_{B_B} + \Delta P_{tie} = -18.75 + (0 + 18.75) = 0 \text{ MW} \]

Ideal in that only Area A generators see a none zero ACE i.e., they will be raise signals from control center.
Comment

1) Of course in practice, really don't know freq. resp. characteristic for your area. Utilities try to set a little high so that all area contribute at least their fare share to control.

2) Today many generators don't operate with any droop so freq. response is decreasing.

3) This doesn't account for any load response.
Reliability

**Gen. Data**
- Unit 1: 150 MW
- Unit 2: 120 MW

**For = 0.5**

**Load data**
- **Weekday**
  - Peak = 160 MW
  - Off peak = 75 MW

- **Weekend**
  - Peak = 75 MW
  - Off peak = 60 MW

**Prob**
- Outage: NO
- M-F Peak: 10 MW short
  - Prob: (.95)(.05)
- M-F Peak: 40 MW short
  - Prob: (.95)(.05)
- Out at all times: (.05)(.05)

Peak: off-peak are 12 hours
LOLE = 52 weeks \times 7 \text{ days} \times (0.05)(0.05) \\
\quad + 52 \text{ weeks} \times 5 \text{ days} \times (0.95)(0.05) \times 2 \quad = 25.6 \text{ days/yr}

EUE = 52 \text{ weeks} \times 5 \text{ days} \times 12 \text{ hours} \times 10 \text{ MW} \times (0.95)(0.05) \\
\quad + 52 \times 5 \times 12 \times 40 \text{ MW} \times (0.95)(0.05) \\
\quad + 52 \times 5 \times (160 \text{ MW} \times 212 + 75 \times 12) (0.05)(0.05) \\
\quad + 52 \times 2 \times (75 \text{ MW} \times 212 + 60 \times 12) (0.05)(0.05) \\
\quad = 9.6 \text{ GWhr/year}
Optimal Power Flow

Two bus system with 2 generators (unit) at bus 1

Constraints
0.10 \leq P_c \leq 1.75 \text{ p.u.}
0.20 \leq P_c \leq 1.00 \text{ p.u.}
P_2 = -1.5 \text{ p.u.} \text{ (load)}

Lineflow
|P_{12}| \leq 7.0 \text{ p.u.}

Costs are
\begin{align*}
C(P_c) &= 5 + 4P_c + P_c^2 \\
C(P_{c_2}) &= 2 + 6P_{c_2} + 2P_{c_2}^2
\end{align*}

a) Assume a DC load flow and write the complete Lagrangian

b) Show the complete Kuhn-Tucker conditions for a minimum

\begin{align*}
0 &= \lambda_1 - \lambda_2 \\
\delta_1 &= 0 \\
\delta_2 &= \text{unknown} \\
X &= \begin{bmatrix} P_c, P_{c_2}, P_2, P_{c_2}, S_2 \end{bmatrix}
\end{align*}
**Cost function**

\[ C(x) = 5 + 4P_c + 6P_{i2} + P_c^2 + 2P_{i2}^2 \]

**Equality constraints** \( \Xi \): \( f_i = 0 \)

- \( f_1 \): \( P_c + P_{i2} + P_{c2} = 0 \)
- \( f_2 \): \( P_{c2} + 1.5 = 0 \)
- \( f_3 \): \( P_{c2} = P_{i2} (\delta_c) \)
- \( f_4 \): \( P_{i2} = P_{i2} (\delta_c) \)
- \( P_{c2} + 2\delta_c = 0 \)
- \( f_5 \): \( P_{c2} = P_{i2} (\delta_c) \)
- \( P_{c2} + 2\delta_c = 0 \)

**Inequality constraints** \( \mu_i : g_i \geq 0 \)

- \( g_1 \): \( 2 - P_{c2} \geq 0 \)
- \( g_2 \): \( P_{c2} + 2.0 \geq 0 \)
- \( g_3 \): \( P_{c2} - 0.10 \geq 0 \)
- \( g_4 \): \( P_{c2} - 1.75 \geq 0 \)
- \( g_5 \): \( P_{c2} - 0.20 \geq 0 \)
- \( g_6 \): \( P_{c2} + 1.00 \geq 0 \)

\[ L(x, \lambda, \mu) = C(x) + \frac{3}{2} \sum \lambda_i f_i(x) + \frac{\mu}{i=1} \sum \mu_i g_i(x) \]
Apply K-T conditions
1. $\frac{\partial g(x, \lambda, \mu)}{\partial x} = 0$
2. $\frac{\partial g(x, \lambda, \mu)}{\partial \lambda} = 0$
3. $\mu_i g_i(x) = 0 \quad \forall i$
4. $\mu_i \geq 0 \quad \forall i$

5 equations
3 equalities
6 equations