HW#3 Solution

(Originally prepared by Qinran Hu)

- **Problem 12.1 in Haadat**

**Solution:**

\[ \Delta P = \frac{\Delta \omega}{R} = - \frac{-59.2 - 60}{0.05} = 0.1 \text{ p.u.} , \]

Hence, \( \Delta P = 0.1 \times 250 = 25 \text{ MW} \).

The increase in the turbine power output is \( 25 \text{ MW} \).

- **Problem 12.2 in Haadat**

**Solution:**

Express the governor speed regulation of each number to a common MVA base. Select 500 MVA for the apparent power base, then

\[ R_1 = \frac{500 \times 0.06}{250} = 0.12 \text{ p.u.}, R_2 = \frac{500 \times 0.064}{400} = 0.08 \text{ p.u.} \Rightarrow R = \frac{1}{R_1 + R_2} = 0.048 \text{ p.u.} , \]

\[ \Delta \omega = -R \Delta P = -0.048 \times \frac{500}{500} = -0.048 \text{ p.u.} , \]

\[ \Delta P_1 = -\frac{\Delta \omega}{R_1} = \frac{0.048}{0.12} = 0.4 \text{ p.u.} , \]

\[ \Delta P_2 = -\frac{\Delta \omega}{R_2} = \frac{0.048}{0.08} = 0.6 \text{ p.u.} , \]

\[ P_1 = 0 + \Delta P_1 = 0.4 \text{ p.u.} = 200 \text{ MW} , \]

\[ P_2 = 0 + \Delta P_2 = 0.6 \text{ p.u.} = 300 \text{ MW} . \]

Hence, load shared by unit 1 is 200 MW, load shared by unit 2 is 300 MW.

- **Problem 12.3 in Haadat**

**Solution:**

Express the governor speed regulation of each number to a common MVA base. Select 1000 MVA for the apparent power base, then

\[ R_1 = \frac{1000 \times 0.04}{400} = 0.1 \text{ p.u.}, R_2 = \frac{1000 \times 0.05}{800} = 0.0625 \text{ p.u.} \Rightarrow R = \frac{1}{R_1 + R_2} = \frac{1}{26} \text{ p.u.} , \]

\[ a) \ \Delta \omega = -R \Delta P = -\frac{1}{26} \times \frac{130}{1000} = -0.005 \text{ p.u.} , \]

\[ \Delta f = -0.005 \times 60 = -0.3 \text{ Hz} , \]

\[ \Delta P_1 = -\frac{\Delta \omega}{R_1} = \frac{0.005}{0.1} = 0.05 \text{ p.u.} , \]

\[ \Delta P_2 = -\frac{\Delta \omega}{R_2} = \frac{0.005}{0.0625} = 0.8 \text{ p.u.} , \]

\[ P_1 = 200 + \Delta P_1 = 200 + 0.05 \times 1000 = 250 \text{ MW} , \]

\[ P_2 = 500 + \Delta P_2 = 500 + 0.08 \times 1000 = 580 \text{ MW} . \]

Hence, the steady-state frequency deviation is -0.3 Hz, and the generation on Unit1 is 250 MW, the generation on Unit2 is 580 MW.

\[ b) \text{ Since } D = 0.804 \text{, we can get } \Delta \omega = -R(\Delta P + D \Delta \omega) , \]

\[ \Delta \omega = -R(\Delta P + D \Delta \omega) \Rightarrow \Delta \omega = \frac{\Delta P}{R + D} = -0.00485 \text{ p.u.} , \]

\[ \Delta f = -0.00485 \times 60 = 0.291 \text{ Hz} , \]

\[ \Delta P_1 = -\frac{\Delta \omega}{R_1} = \frac{0.00485}{0.1} = 0.0485 \text{ p.u.} , \]

\[ \Delta P_2 = -\frac{\Delta \omega}{R_2} = \frac{0.00485}{0.0625} = 0.776 \text{ p.u.} , \]

\[ \Delta P_L = -0.00485 \times 0.0804 \times 1000 = -0.38994 \text{ MW} , \]
Consider a power system with three generating units rated at 100, 200, and 600 MVA. The governor droops for these three units are 4%, 5% and 6%, respectively. Each unit is initially operating at 50% of its rated output. The load is then increased from 450 MW to 550 MW. Find:  

a) The unit area frequency response characteristic $\beta$ on a 100 MVA base; b) the steady-state increase in frequency; and c) the output increase of each unit in both MW and per unit.

**Solution:**  
Express the governor speed regulation of each number to a 100 MVA base. Then

$$R_1 = \frac{100 \times 0.04}{100} = 0.04 \text{ p. u.}, R_2 = \frac{100 \times 0.05}{200} = 0.025 \text{ p. u.}, R_3 = \frac{100 \times 0.06}{600} = 0.01 \text{ p. u.}, \Rightarrow B = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = 165 \text{ p. u.},$$

$$\Delta \omega = -\frac{1}{B} \Delta P = -\frac{1}{165} \times \frac{(550-450)}{100} = -\frac{1}{165} \text{ p. u.}, \text{ } \Delta f = -\frac{1}{165} \times 60 = -0.364 \text{ Hz}$$

$$\Delta P_1 = -\frac{\Delta \omega}{R_1} = \frac{25}{165} = 0.1515 \text{ p. u.} = 15.15 \text{ MW},$$

$$\Delta P_2 = -\frac{\Delta \omega}{R_2} = \frac{40}{165} = 0.2424 \text{ p. u.} = 24.24 \text{ MW},$$

$$\Delta P_3 = -\frac{\Delta \omega}{R_3} = \frac{100}{165} = 0.6061 \text{ p. u.} = 60.61 \text{ MW},$$

Hence, the unit area frequency response characteristic $\beta$ is 165 p.u. The steady-state increase in frequency is -0.364 Hz.  
The output increase of unit 1 is 0.1515 p.u., 15.15 MW.  
The output increase of unit 1 is 0.2424 p.u., 24.24 MW.  
The output increase of unit 1 is 0.6061 p.u., 60.61 MW.

Consider a small two area power system. Both areas have three generating units of identical size (200, 400, 500 MVA). Area A has its governors set for a 5% droop while the Area B governors are set for a 10% droop. The system is operating at 60 Hz when a load of 75 MW is added in Area B. Answer:  

a) After governor action stabilizes and before supplemental control, what is the new system frequency?  
b) How many MW's are picked up in Area A?  
c) What does this say about Area B’s practice of using 10% droop?  
d) What would be the new system frequency if both areas had 5% droop?  
e) What would be the new system frequency if both areas had 10% droop?

**Solution:**  
a) Express the governor speed regulation of each number to a 1000 MVA base. Then take the three units in area A and three units in area B as a whole respectively.

$$R_A = \frac{1000 \times 0.05}{200+400+500} = \frac{1}{22} \text{ p. u.}, R_B = \frac{1000 \times 0.1}{200+400+500} = \frac{1}{11} \text{ p. u.}, \Rightarrow B = \frac{1}{R_A} + \frac{1}{R_B} = 33 \text{ p. u.},$$

$$\Delta \omega = -\frac{1}{B} \Delta P = -\frac{1}{33} \times \frac{75}{1000} = -\frac{1}{33} \times \frac{75}{1000} = -\frac{75}{33000} \times 60 = -0.136 \text{ Hz}$$

$$f_{\text{new}} = f_{\text{original}} + \Delta f = 60 - 0.136 = 59.864 \text{ Hz}.$$  
Hence, after governor action, the new frequency is 59.864 Hz.
b) \[ \Delta P_A = \frac{\Delta \omega}{R_A} = \frac{75 \times 22}{33000} = 0.05 \text{p. u.} = 50 \text{MW}, \]
\[ \Delta P_B = -\frac{\Delta \omega}{R_B} = \frac{75 \times 11}{33000} = 0.025 \text{p. u.} = 25 \text{MW}, \]

Hence, 50MW are picked up from A, 25MW are picked up from B. The additional line flow is 50MW, from A to B.

c) This shows that Area A and Area B do not take the same responsibility of load regulation. Area B leans (relies on) Area A for its governor response.

d) If both areas are using 5% droop,
\[ R_A = \frac{1000 \times 0.05}{200+400+500} = \frac{1}{22} \text{ p. u.}, \quad R_B = \frac{1000 \times 0.05}{200+400+500} = \frac{1}{22} \text{ p. u.}, \Rightarrow B = \frac{1}{R_A} + \frac{1}{R_B} = 44 \text{p. u.}, \]
\[ \Delta \omega = \frac{-1}{B} \Delta P = -\frac{1}{22} \times \frac{75}{1000} = -\frac{75}{22 \times 1000} \text{ p. u.}, \quad \Delta f = -\frac{75}{22 \times 1000} \times 60 = -0.1023 \text{Hz} \]
\[ f_{\text{new}} = f_{\text{original}} + \Delta f = 60 - 0.1023 = 59.8977 \text{Hz}. \]

Hence, the new frequency is 59.8977Hz.

e) If both areas are using 10% droop,
\[ R_A = \frac{1000 \times 0.1}{200+400+500} = \frac{1}{11} \text{ p. u.}, \quad R_B = \frac{1000 \times 0.1}{200+400+500} = \frac{1}{11} \text{ p. u.}, \Rightarrow B = \frac{1}{R_A} + \frac{1}{R_B} = 22 \text{p. u.}, \]
\[ \Delta \omega = \frac{-1}{B} \Delta P = -\frac{1}{22} \times \frac{75}{1000} = -\frac{75}{22 \times 1000} \text{ p. u.}, \quad \Delta f = -\frac{75}{22 \times 1000} \times 60 = -0.2045 \text{Hz} \]
\[ f_{\text{new}} = f_{\text{original}} + \Delta f = 60 - 0.2045 = 59.7955 \text{Hz}. \]

Hence, the new frequency is 59.7955Hz.

> Use the original system in the previous problem. Then: a) Calculate the ACE for Areas A and B given that the Bias is 50 MW/0.1 Hz in A and B; b) Calculate the ACE for Areas A and B given that the Bias constant is 25 MW/0.1 Hz in A and B; c) What are the proper values of Bias and the resulting ACE values?; and d) Other than ACE being wrong, what observations can you make about poorly chosen Bias values.

**Solution:**

**a)** \[ \text{ACE} = \Delta P_{\text{tie}} + \text{Bias} \cdot \Delta f, \]
and \[ \text{Bias} = 50 \text{MW}/0.1 \text{Hz}, \]
Hence,
\[ \text{ACE}_A = 50 - 500 \times 0.136 = -18 \text{MW}, \]
\[ \text{ACE}_B = -50 - 500 \times 0.136 = -118 \text{MW}. \]

**b)** when \[ \text{Bias} = 25 \text{MW}/0.1 \text{Hz}, \]
Hence,
\[ \text{ACE}_A = 50 - 250 \times 0.136 = 16 \text{MW}, \]
\[ \text{ACE}_B = -50 - 250 \times 0.136 = -84 \text{MW}. \]

**c)** As for Area A,
\[ R_1 = 0.05 \times \frac{60}{200} = 0.015 \text{Hz/Mw}, \]
\[ R_2 = 0.05 \times \frac{60}{400} = 0.0075 \text{Hz/Mw}, \]
\[ R_3 = 0.05 \times \frac{60}{600} = 0.006 \text{Hz/Mw}, \]
\[ B_{fA} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = 36.67 \text{MW}/0.1 \text{Hz}. \]
As for Area B,
\[ R_1 = 0.1 \times \frac{60}{200} = 0.003Hz/Mw, \]
\[ R_2 = 0.1 \times \frac{60}{200} = 0.015Hz/Mw, \]
\[ R_3 = 0.1 \times \frac{400}{600} = 0.012Hz/Mw, \]
\[ B_{fA} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = 18.33MW/0.1Hz. \]

Hence,
\[ ACE_A = 50 - 366.7 \times 0.136 = 0.1288MW \approx 0MW, \]
\[ ACE_B = -50 - 183.3 \times 0.136 = -74.9288MW \approx -75MW. \]

**d)** The example in b) shows that the value of Bias cannot be set too low. In such cases, it is possible that AGC would send lower pulses when the frequency is already low. That is to say, it will be better to set Bias value a little bit high to provide adequate response.