POWER SYSTEM OPERATION AND CONTROL (15EE81)

MODULE – 02

MODULE – 02:

- HYDRO-THERMAL SCHEDULING
- AUTOMATIC GENERATION CONTROL (AGC)

AUTOMATIC GENERATION CONTROL: INTRODUCTION:

- The two important parameters in power system are system voltage and system frequency.
- They have to be continuously controlled to maintain them within acceptable limits.
- Frequency deviations occur due to imbalance between generation and load.
- Hence, the generation has to be continuously vary to keep track of the variable load.

AUTOMATIC GENERATION CONTROL: INTRODUCTION:

- An automatic control system must detect the changes in load demand for an unpredictable small amount.
- Then, it must initiate immediately a set of control actions which will eliminate the load variations as quickly and effectively as possible.
- The control actions are such as to vary the generation to match with load and terminal voltage of generator to bring within acceptable limits.

AUTOMATIC GENERATION CONTROL:

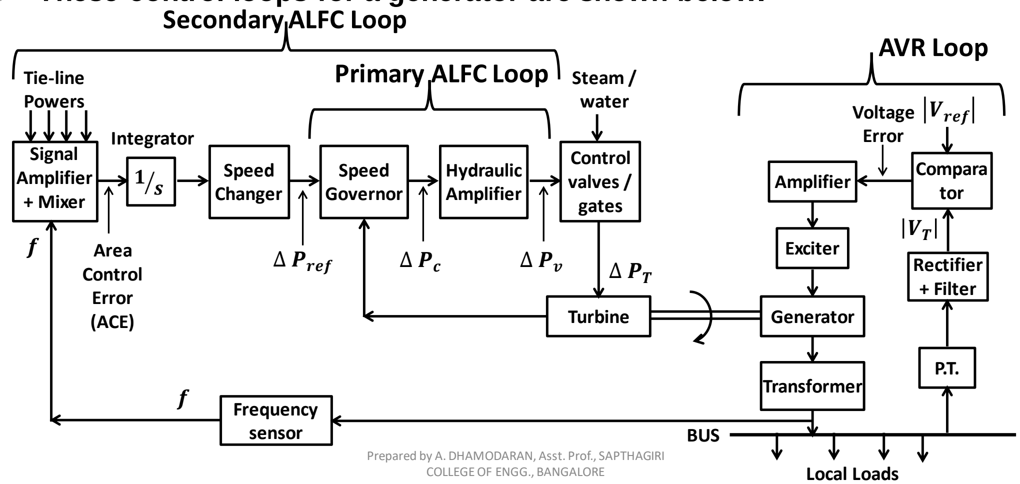
BASIC GENERATOR CONTROL LOOPS:

- **A large generator is equipped with two major control loops;**
- **(i) Automatic Voltage Regulator (AVR) loop.**
- **(ii) Automatic Load Frequency Control (ALFC) loop or AGC (Automatic Generation Control).**

AUTOMATIC GENERATION CONTROL:

BASIC GENERATOR CONTROL LOOPS:

- **These control loops for a generator are shown below.**



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AUTOMATIC GENERATION CONTROL:

BASIC GENERATOR CONTROL LOOPS:

- **(i) AVR Loop:**
  - **It is basically used to control the terminal voltage (V_t) of the generator.**
  - **The terminal voltage (V_t) of the generator is controlled by the field current (I_f) supplied by the exciter.**
  - **To achieve this, the terminal voltage (V_t) is continuously sensed, rectified (into DC) and smoothened.**
  - **This DC signal is compared with a reference value (V_{ref}) which results in an error voltage (V_{error}).**
  - **This error voltage is amplified and applied as input to the exciter which in turn adjusts the field current to the generator.**

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AUTOMATIC GENERATION CONTROL:

BASIC GENERATOR CONTROL LOOPS:

- **(i) AVR Loop:**
  - **By controlling the field current, the terminal voltage (V_t) reaches the reference value.**
  - **Thus the AVR loop controls the terminal voltage (V_t) of the generator.**
- **(ii) ALFC Loop:**
  - **This loop is also called as Automatic Generation Control (AGC) loop.**
  - **It controls the real power output (P_0) of the generator so as to maintain the frequency of the generation as constant.**

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AUTOMATIC GENERATION CONTROL:
BASIC GENERATOR CONTROL LOOPS:
- **(ii) ALFC Loop:**
  - This is achieved by controlling the speed of the prime mover.
  - This control comprises of two inner loops, namely, primary ALFC loop and secondary ALFC loop.
  - The primary ALFC loop is fast in response and it responds to frequency changes due to load variations.
  - It regulates the steam or water flow to the prime mover through the speed governor and control valves/gates to match the real power output of the generator with the load.
  - Typically the time taken for this primary ALFC loop is few sec.
  - This loop performs a coarse speed or frequency control.

AUTOMATIC GENERATION CONTROL:
BASIC GENERATOR CONTROL LOOPS:
- **(ii) ALFC Loop:**
  - The secondary ALFC loop is slower in response.
  - This loop maintains fine frequency adjustments to maintain proper active power interchange with other networks connected through the tie lines.
  - This loop is insensitive to fast load and frequency changes.
  - This loop acts on gradual variations in load and frequency which takes place over several minutes.
- In general, the active power control is related to frequency control, whereas, reactive power control is related to voltage control.
- Thus, AVR and ALFC loops are decoupled.

AUTOMATIC GENERATION CONTROL:
COMMONLY USED TERMS IN AGC:
- **1) CONTROL AREA:**

A part of a power system to which a common generation control is applied.

- **2) TIE–LINE:**

  It is a transmission line which is connecting two or more control areas. The active power flows from one control area to another through the tie-lines.

- **3) NET INTERCHANGE:**

  A prearranged net power between control areas flowing on the tie-lines is called as the scheduled net interchange.

  The algebraic sum of powers on the tie-lines of a control area is called the net interchange.

  If it is positive, then there is a power flow out of the control area.

AUTOMATIC GENERATION CONTROL:
COMMONLY USED TERMS IN AGC:
- **4) FREQUENCY:**

  There are different frequency terms commonly used.

(i) System frequency:

The actual frequency of the system voltage.

(ii) Standard frequency:

The frequency intended to be used as reference.

(iii) Rated frequency:

The frequency for which the generating equipment is designed.

(iv) Scheduled frequency:

The frequency which the system attempts to maintain.

AUTOMATIC GENERATION CONTROL:

COMMONLY USED TERMS IN AGC:

- **5) FREQUENCY BIAS:**

  It is the offset in the scheduled net power interchange of a control area.

  It is varied in proportion to the frequency deviation and is in a direction so as to bring the system frequency to the scheduled value.

- **6) TIME DEVIATION:**

  It is the ratio of accumulated or integrated difference between system frequency and rated frequency to the rated frequency.

AUTOMATIC GENERATION CONTROL:

COMMONLY USED TERMS IN AGC:

- **7) TIME BIAS:**

  It is the offset in the scheduled net power interchange of a control area.

  It is varied in proportion to the time deviation in a direction to restore the time deviation to zero.

- **8) LOAD–FREQUENCY CHARATERISTICS:**

  For a control area, it is the change in total area load resulting from a change in frequency.

AUTOMATIC GENERATION CONTROL:

COMMONLY USED TERMS IN AGC:

- **9) STATION CONTROL ERROR:**

  It is the difference between station generation capacity and assigned station generation.

- **10) UNIT CONTROL ERROR:**

  It is the difference between unit generation capacity and assigned unit generation.

FUNCTIONS OF AGC:

- **In a power system, the loads and losses are sensitive to frequency.**
- **If a generating unit is tripped (shut down) or the load on the system is increased, then there is a power mismatch (between generation and demand).**
- **This is initially compensated by extracting kinetic energy from the system inertial storage causing a decrease in system frequency.**
- **As the frequency decreases, the power consumed by the loads also decreases.**

FUNCTIONS OF AGC:

- Generally in large power systems, the equilibrium is obtained when the reduction in frequency sensitive load balances the output of tripped generator or
- The load decrease at a new frequency.
- This equilibrium is achieved in less than 2 sec.
- If the power mismatch is large, then the speed governor has to increase the generation of running units such that the equilibrium is reached.
- This equilibrium is achieved in 10 to 15 sec. after tripping of the generating unit or increase in load on the system.

FUNCTIONS OF AGC:

- The major functions of AGC are, (Also the main requirements of AGC are),
  - The frequency of various bus voltages in the control area are maintained at the scheduled frequency.
  - The tie-line power flows in the control area are maintained at the scheduled levels.
  - The total load on the control area is shared by all the generating units in that area economically by Economic Load Dispatch.

FUNCTIONS OF AGC:

- The modern AGC systems include many more functions as follows.
  - Produce a change in generation acceptable matching the changing load at the scheduled frequency over a scheduled time frame.
  - Schedule the generation to accumulate lower fuel cost over the selected time frame.
  - Maintain a sufficient level of reserved control range and rate.

FUNCTIONS OF AGC:

- Operate the system with higher security margins.
- Provide timely recommendations for changing of outputs of units which are manually controlled.
- Provide meaningful alarms such as display in control center for deviation from desired generation, unit not responding to AGC control signal, anticipated future generation, etc.

SPEED GOVERNORS:

- Speed governors plays an important role in primary control of frequency.
- When the electrical load on the generator increases suddenly, then there is a power mismatch between generation and load demand.
- This is compensated by the kinetic energy stored in the system.
- This leads to a reduction in speed of the turbine and hence a drop in frequency.
- The speed governor reacts to this change in speed and adjusts the turbine input to vary the mechanical power output to match the increased demand and restores the system frequency.

SPEED GOVERNORS:

- In a steam turbine, the governor-controlled valves controls the power input (Steam) to the turbine.
- In a hydro turbine, the governor-controlled gates controls the power input (water) to the turbine.
- The speed control mechanism includes,
  - Relays
  - Levers
  - Servomotors
  - Pressure or power amplifying devices
  - Linkages between speed governor and governor-controlled valves or gates.

GENERAL GOVERNOR OPERATION:

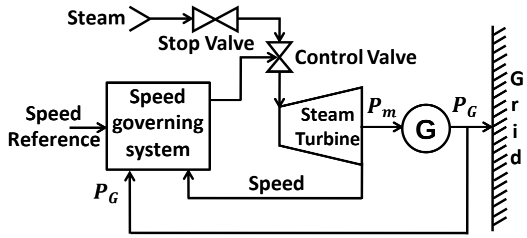
- Speed governors vary the prime mover output automatically for the changes in speed.
- To control the speed or generator output power (MW), the governor system controls the power applied to prime mover shaft.
- First the speed of the system is sensed through a speed–sensing device.
- The output of the speed sensor passes through the signal conditioning and amplification, then operates the control valves/gates to adjust the prime mover output until the system frequency becomes constant.

GENERAL GOVERNOR OPERATION:

- In case of mechanical-hydraulic governors, a fly-ball assembly is used as a speed sensing device.
- In case of electro-hydraulic governors, a frequency transducer is used as a speed sensing device.
- The recent electronic governors use frequency deviation and actuate hydraulic devices to control gates/valves without fly-balls.
- There are variety of governor systems available, few of them are listed here.
  - Steam turbine governing system
  - Conventional governor system
  - Electronic-hydraulic governing system

STEAM TURBINE GOVERNING SYSTEM:

- Let us consider a speed governing system for a steam turbine.
- Here, the steam flow to the turbine through the control valve is proportional to the valve opening.



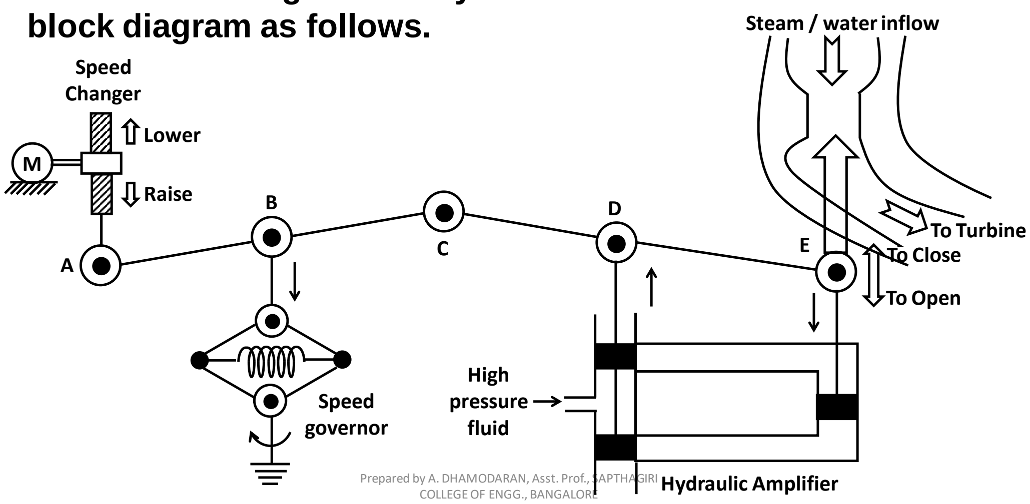
- Hence, when the valve opening changes, the steam flow to the turbine will change which in turn varies the mechanical power output of the turbine and hence, the electrical power output of the generator.

STEAM TURBINE GOVERNING SYSTEM:

- When the generator is started, the speed governing system controls the speed by **regulating the steam flow**.
- After the generator is synchronized to the grid, the speed governor controls the **output power of the unit**.
- In this governing system, the valve output can be changed in following ways.
  - Changing the reference input of the speed.
  - Change in speed or frequency with the reference speed remains the same.
- This system is only **primary regulation** or simply **governor control**.
- **The secondary regulation changes the reference speed**.

CONVENTIONAL GOVERNOR SYSTEM:

- A Conventional governor system can be shown in a functional block diagram as follows.



CONVENTIONAL GOVERNOR SYSTEM:

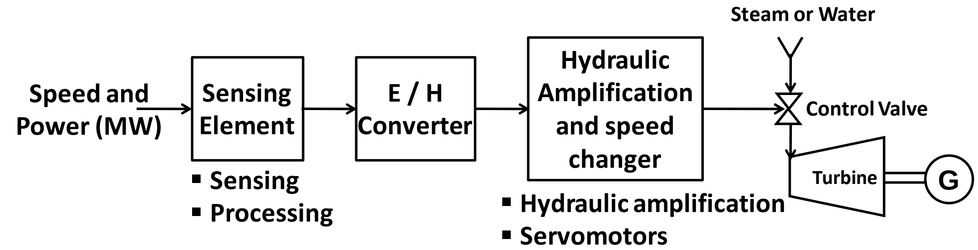
- Major components of conventional governor are,
  - Fly-ball speed governor
  - Linkage mechanism
  - Hydraulic amplifiers
  - Speed changer
- FLY-BALL SPEED GOVERNOR:
  - This is a mechanical device, which is a speed sensitive and directly adjusts the valve opening through the linkage mechanism.
  - It senses the change in speed or power output of the unit and appropriately initiates the valve opening or closing.

CONVENTIONAL GOVERNOR SYSTEM:

- LINKAGE MECHANISM:
  - This system transforms the Fly-ball governor movement to the turbine valve, through a hydraulic amplifier.
  - It provides a feedback from the turbine valve movement.
- HYDRAULIC AMPLIFIERS:
  - It is a hydraulic servomotor inserted between the speed governor and the valve.
  - It is used to build mechanical forces strong enough to operate the steam valves or water gates.
- SPEED CHANGER:
  - It is used to provide the setting of steady-state power output as reference for the control of turbines.

ELECTRONIC HYDRAULIC GOVERNING SYSTEM:

- An Electronic Hydraulic Governing system is shown below.



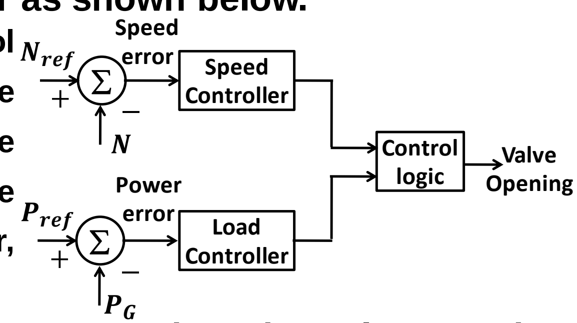
- The electronic sensing element senses the speed and power.
- It is used instead of Fly-ball speed governor in conventional system, which is a mechanical speed sensor.

ELECTRONIC HYDRAULIC GOVERNING SYSTEM:

- Now, the processing element processes the speed error to obtain valve opening command.
- The processing element comprises of either P or PI or PID controllers.
- Then, the speed error electronic signal is converted to Hydraulic signal in E/H converter.
- This hydraulic signal is amplified in hydraulic amplifier as a primary application to obtain sufficient power to operate the control valves.
- In this type of governing system (a pure governor controller) only speed error is used to control the valve opening.

ELECTRONIC HYDRAULIC GOVERNING SYSTEM:

- With AGC, the load control can also be incorporated in a pure governor controller as shown below.
- Here, with speed control alone operating, the valve opening is decided by the speed error and the derivative of speed error, i.e, rate of change of error.



- With load controller alone operating, the valve opening is determined by output power error.
- A combination of both is used in AGC.

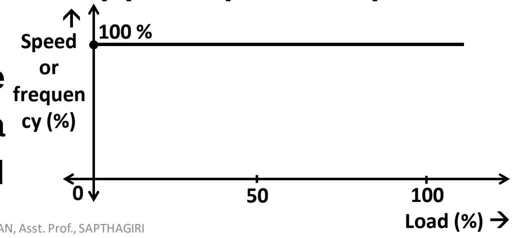
OPERATION MODES OF SPEED GOVERNOR:

- While defining the modes of operation of speed governor, the following points are considered.
  - The normal speed is considered as 100% of rated speed.
  - The full load is considered as 100% of rated load.
- There are two modes of operation of speed governor, namely,

  (i) Isochronous mode operation (ii) Droop mode operation

(i) ISOCHRONOUS OPERATION:

In this mode of operation, the speed governor maintains a constant speed from no-load to full-load.



(i) ISOCHRONOUS OPERATION:

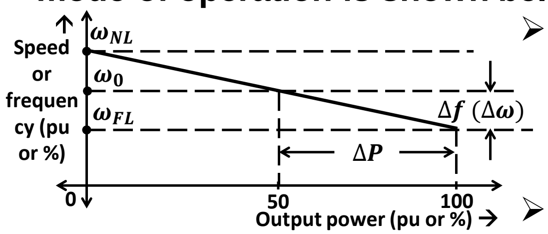
- A prime mover and a generator operating in isochronous mode can maintain the desired output frequency irrespective of load changes.
- This mode is applicable or normally used in isolated systems or when only one generator is required to respond to the load changes.

(ii) DROOP MODE OPERATION:

- In this mode of operation, the speed governor operates in variable speed.
- The speed droop is a decrease in speed or frequency proportional to the load.

(ii) DROOP MODE OPERATION:

- The speed-load characteristic of speed governor in this mode of operation is shown below.



- Here, the steady-state speed regulation is defined as slope of speed-droop characteristic.
- It is denoted by R.
- In the above characteristic, the speed regulation is given by,

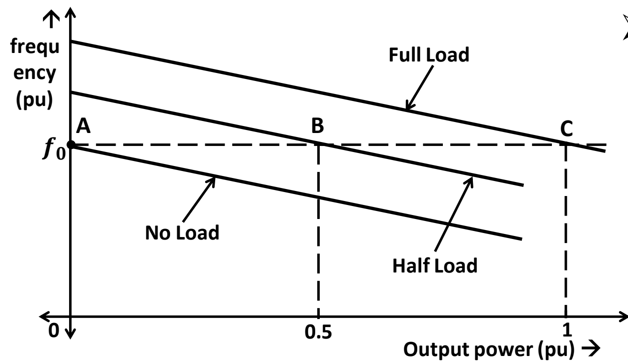
  $R = \frac{\Delta\omega}{\Delta P} = \frac{\Delta f}{\Delta P}\ pu$ Where, Δf and ΔP are measured in pu

  Δf is the change in frequency, $\Delta f = f - f_0$ pu.

  Where, f is the final frequency droop and f_0 is the base frequency.

(ii) DROOP MODE OPERATION:

- For maintaining nominal speed of 1 pu for different output powers, the set point of speed governor can be changed as shown below.



- According to Indian Electricity Grid Code (IEGC), the droop of the speed governors should be set between 3% and 6%.

ISOCHRONOUS AND DROOP MODES IN PARALLEL:

- Let us assume that a unit in speed droop mode is connected to another unit in isochronous mode of operation.
- The unit in isochronous mode is known as swing machine.
- The unit in speed droop mode is known as slave machine.
- Since, the swing machine is running in constant speed, the slave machine will forcibly run at a frequency of swing machine and it is the speed set point of slave machine.
- The power output of slave machine is determined by its speed set point, speed droop and the grid frequency.

ISOCHRONOUS AND DROOP MODES IN PARALLEL:

- Let the load on this parallel system be increased.
- Now, the power output of swing machine will increase to meet the increased load demand.
- But, the power output of slave machine will remain unchanged, because its speed set point is not changed.
- Thus, the system can be loaded until the total load demand on the system is equal to (Maximum power output of the swing machine + set power output of the slave machine).
- If the load demand increases more than this value, then the frequency will drop.

ISOCHRONOUS AND DROOP MODES IN PARALLEL:

- Now, let the load on this parallel system be decreased.
- Now, the power output of swing machine will decrease to meet the decreased load demand.
- But, the power output of slave machine will remain unchanged, because its speed set point is not changed.
- Thus, the system can handle decrease in load demand until the total load demand on the system is equal to (zero power output of the swing machine + set power output of the slave machine).
- If the load demand decreases further, then the frequency will increase which is determined by slave machine.

ISOCHRONOUS AND DROOP MODES IN PARALLEL:

- Normally, when more generators are operated in parallel, the speed governor of only one unit may be operated in Isochronous mode and all other units must be in droop mode.
- Usually, the unit with largest capacity is considered as Isochronous unit.
- It controls the system frequency and immediately responds to system load changes.
- The units with speed droop characteristics will share the load based on their individual speed controls.

ISOCHRONOUS AND DROOP MODES IN PARALLEL:

Let us consider three units in a power plant A, B and C with ratings of 500 MW, 300 MW and 250 MW respectively operating in parallel. Let the load be 600 MW. Comment on Isochronous and droop modes of the units.

Sol.: The largest capacity unit is to be operated in Isochronous mode and rest of the units in speed droop mode.

- Hence, Unit A is in Isochronous mode and Units B and C are in speed droop mode.
- Let us assume the speed set point of governors in units B and C are such that their power outputs are 250 MW and 150 MW respectively.

$$\Longrightarrow \quad P_B = 250\ MW \quad and \quad P_C = 150\ MW$$

ISOCHRONOUS AND DROOP MODES IN PARALLEL:

- For a given load demand of 600 MW, the power output of unit A is,

$$P_A = Load - P_B - P_C = 600 - 250 - 150 = 200\ MW$$

- So, for a given load of 600 MW, the power outputs of the units are,

$$P_A = 200\ MW, \quad P_B = 250\ MW \quad and \quad P_C = 150\ MW$$

- Let us assume the system frequency be 50 Hz at these power outputs.

ISOCHRONOUS AND DROOP MODES IN PARALLEL:

Case (i):

- Any increase in load above 600 MW will be taken by Unit A as it is operating in Isochronous mode and the system frequency is maintained at 50 Hz.
- ∴ The additional load that can be added without a change in frequency is $= \text{Rating of Unit A} - P_A = 500 - 200 = 300\ MW$
- ∴ Maximum load that can be met by the plant without a change in frequency is, = present load + additional load = 600 + 300 = 900 MW.
- If the load demand increases beyond 900 MW, then the frequency of the system will drop.

ISOCHRONOUS AND DROOP MODES IN PARALLEL:

Case (ii):

- If the load is decreased from 600 MW, the power output of Unit A is to be reduced as it is operating in Isochronous mode and the system frequency is maintained at 50 Hz.
- ∴Minimum load that can be met by the plant without a change in frequency is obtained at zero power output of Unit A.
- Minimum load = $P_A + P_B + P_C = 0 + 250 + 150 = 400\ MW$.
- Any further decrease in load demand below 400 MW will cause the frequency to increase from 50 Hz.
- The Unit A will operate as a motor and will trip because of negative power or reverse power flow.

SPEED REGULATION:

- Let us consider the load on a unit is varying from No-load to Full-load, i.e., 0% to 100%.
- Hence, the change in power output of the unit is,

$$\Delta P = 100 - 0 = 100\ \% = 1\ pu$$

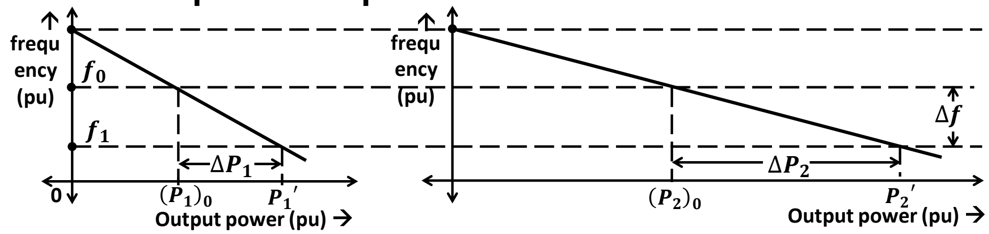
- Let the frequency of operation at No-load be ω_{NL}Hz and that of at Full-load be ω_{FL}Hz.
- Let the base or nominal frequency or speed be ω_0Hz.
- Hence, change in frequency from No-load to Full-load is,

$$\Delta f = \frac{\omega_{FL} - \omega_{NL}}{\omega_0}\ pu = \frac{\omega_{FL} - \omega_{NL}}{\omega_0} * 100\ \%$$

- Hence, governor speed regulation is, $R = \frac{\Delta f}{\Delta P} = \frac{\omega_{FL} - \omega_{NL}}{\omega_0}\ pu$

LOAD SHARING BETWEEN UNITS IN PARALLEL:

- Let us consider two units 1 and 2 connected in parallel with different speed droop characteristics as shown below.



- Let us assume that the power outputs of units 1 and 2 are $(P_1)_0$ and $(P_2)_0$ respectively at an initial frequency of f_0.
- Let the load on the system be increased by an amount ΔP_L, then the units 1 and 2 will slow down in their speed or frequency.

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LOAD SHARING BETWEEN UNITS IN PARALLEL:

- Now, the respective governors of the units will increase their outputs until a common frequency f_1 is reached.
- Let the new power outputs of the units 1 and 2 be $P_1{}'$ and $P_2{}'$ respectively.
- The load shared between units 1 and 2 depends on their speed regulation of governor.
- Change in frequency $\Delta f = (f_1 - f_0)\ pu$, is common for units 1 and 2.

$\therefore$ Speed regulation of unit-1, $R_1 = \frac{\Delta f}{\Delta P_1}$ ----------- (1)

where, $\Delta P_1 = P_1{}' - (P_1)_0$

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LOAD SHARING BETWEEN UNITS IN PARALLEL:

Speed regulation of unit-2, $R_2 = \frac{\Delta f}{\Delta P_2}$ -----------(2)

Where, $\Delta P_2 = P_2{}' - (P_2)_0$

From equations (1) and (2),

$$\frac{R_1}{R_2} = \frac{\frac{\Delta f}{\Delta P_1}}{\frac{\Delta f}{\Delta P_2}} = \frac{\Delta P_2}{\Delta P_1} \qquad \Longrightarrow \qquad \frac{R_2}{R_1} = \frac{\Delta P_1}{\Delta P_2}$$

- Thus, the change in power outputs of units is in the inverse ratio of their speed regulation.

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PROBLEMS:

1) **The two prime mover-generator sets are connected in parallel. Both have a 3% droop. The frequency is 50 Hz on full-load. Plot the speed-droop characteristics and comment on load sharing if one generator A has a rating of 500 MW and another generator B has a rating of 300 MW.**

Sol.: Given, $R_1 = R_2 = R = 3\%$ droop $= -0.03$ pu,

Let base frequency = 50 Hz. f_{FL} = 50 Hz = 1 pu at 1 pu Load,

Let f_{NL} be the frequency at No load, i.e., 0 pu Load

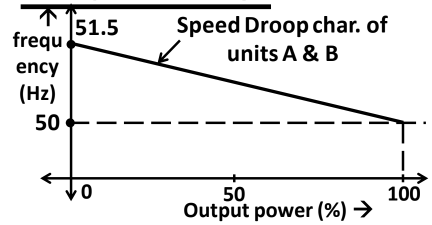
Let the load be increased from no-load to full-load.

Hence, Regulation $R = \frac{\Delta f}{\Delta P}\, pu \quad \Longrightarrow \quad -0.03 = \frac{f_{FL}-f_{NL}}{P_{FL}-P_{NL}} = \frac{1-f_{NL}}{1-0}$

$\therefore f_{NL} = 1.03\, pu = 1.03 * 50 = 51.5\, Hz$ at No load, i.e, 0 pu.

Hence, speed-droop characteristics can be drawn as follows.

PROBLEMS:



Given, Rating of Gen. A = 500 MW

Rating of Gen. B = 300 MW

$\therefore$ At Full-load (100%),

power output = 500 + 300 = 800 MW

frequency = 50 Hz (Given)

For any other load, the load demand is shared in proportion to their capacity and frequency at that load will be determined by speed droop characteristics.

i.e, Fractional share of Gen. A = $\frac{500}{800} = 62.5\%$ and Gen. B = $\frac{300}{800} = 37.5\%$

Let us consider the load to be shared is 400 MW.

$\therefore$ Share of Gen. A = $\frac{500}{800} * 400 = 0.625 * 400 = 250\, MW$ and

Share of Gen. B = $\frac{300}{800} * 400 = 0.375 * 400 = 150\, MW$

PROBLEMS:

The frequency at load of 400 MW can be found as follows.

Let load be decreased from 800 MW (1 pu) to 400 MW (0.5 pu).

Frequency at 800 MW (FL) is 50 Hz (1 pu).

Let freq. at 400 MW be X pu.

$\therefore$ Speed regulation R = $\frac{\Delta f}{\Delta P} \quad \Longrightarrow \quad -0.03 = \frac{X-1}{0.5-1}$

$\therefore$ X = 1.015 pu = 1.015 * 50 = 50.75 Hz

Hence, frequency at the load of 400 MW is 50.75 Hz.

2) **Two identical machines 1 and 2 have speed droop characteristics with speed regulation of 5 % and 2 % respectively. They share an initial load of 100 MW equally operating at nominal frequency of 50 Hz. Now, if there is an increase of 35 MW in the load, how it would be shared among the units 1 and 2?**

PROBLEMS:

Sol.: Given, R_1 = 5 % = – 0.05 pu and R_2 = 2 % = – 0.02 pu

Initial load L_0 = 100 MW at Nominal frequency f_0 = 50 Hz.

Initial power outputs, $P_1 = P_2$ = 100 / 2 = 50 MW at common frequency of f_0 = 50 Hz.

Given, change in load ΔL = + 35 MW

But, $\Delta L = \Delta P_1 + \Delta P_2$ = 35 MW ------------------------ (1)

Where, ΔP_1 and ΔP_2 are change in power outputs of units 1 and 2 respectively.

These change in power outputs of units 1 and 2 is in the inverse ratio of their speed regulation. i.e. $\frac{\Delta P_1}{\Delta P_2} = \frac{R_2}{R_1}$

$\Longrightarrow \frac{\Delta P_1}{\Delta P_2} = \frac{-0.02}{-0.05} = 0.4 \quad \Longrightarrow \Delta P_1 = 0.4\, \Delta P_2$ -------------- (2)

PROBLEMS:

Substituting (2) in (1) gives, 0.4 $\Delta P_2 + \Delta P_2 = 35$

$$\Rightarrow \quad \Delta P_2 = 25\ MW$$

From (2), $\Delta P_1 = 0.4\, \Delta P_2 = 0.4 * 25 = 10\ MW$

$\therefore$, increase in load of 35 MW is shared among units 1 and 2 as,

$\Delta P_1 = 10\ MW$ and $\Delta P_2 = 25\ MW$

New power outputs $P_1{}' = P_1 + \Delta P_1 = 50 + 10 = 60\ MW$

$P_2{}' = P_2 + \Delta P_2 = 50 + 25 = 75\ MW$

3) Two machines 1 and 2 operate in parallel with capabilities of 200 MW and 500 MW respectively. Each has a speed droop characteristics of 4%. Their governors are adjusted so that the frequency is 100% at full load. They supplies a load of 400 MW. Calculate the load shared by each unit and the frequency at this load. Take base frequency is 50 Hz. Use graphical method.

PROBLEMS:

Sol.: Given, $(P_1)_{FL} = 200\ MW$ and $(P_2)_{FL} = 500\ MW$

$R_1 = R_2 = R$ = 4% droop = – 0.04 pu Base frequency = 50 Hz

Let the base power be 100 MW.

$\therefore\ (P_1)_{FL} = 200\ MW = 2\ pu$ and $(P_2)_{FL} = 500\ MW = 5\ pu$

Given that frequency at Full-load = 100 % = 1 pu = 50 Hz.

Let the frequency at no-load be "X" Hz.

The speed regulation R indicates drop in frequency from no-load to full-load.

$\therefore$ The frequency at no-load is R% greater than that at full-load.

Hence, frequency at no-load is 4% greater than that at full-load.

$\therefore$ Frequency at no-load, X = 104% of frequency at FL = 1.04 pu

X = 1.04 pu = 1.04 * 50 Hz = 52 Hz.

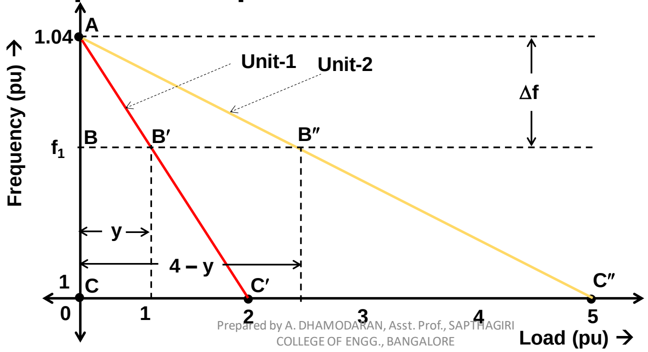
PROBLEMS:

Now, the no-load points are, frequency = 1.04 pu, Load = 0 pu

The full-load points are,

frequency = 1 pu, Load $(P_1)_{FL} = 2\ pu$ and $(P_2)_{FL} = 5\ pu$

- Hence, the speed-droop characteristic can be drawn as follows.



PROBLEMS:

- Now, given that the load supplied = 400 MW = 4 pu.
- Let the frequency at this load be f_1 Hz. (Point B as shown)
- Hence, for this load, let the power output of unit-1 be "y" pu.
- Then, the power output of unit-2 will be (4–y) pu
  (Total load = power output of unit-1 + power output of unit-2)
- Let us assume that the units are operated from no-load to a total load of 4 pu.
- Hence, from the figure, the frequency deviation $\Delta f = (f_1 - 1.04)$
- Let us mark the points A, B and C on the y-axis, B′ and C′ on unit-1 curve and B″ and C″ on unit-2 curve as shown in figure.
- Now, for unit-1 characteristic, there are two right-angled triangles ABB′ and ACC′. Similarly for unit-2, ABB″ and ACC″.

PROBLEMS:

For Unit-1: With similar Δ^{le}s ABB′ and ACC′, $\frac{AB}{AC} = \frac{BB'}{CC'}$

$$\Rightarrow \frac{\Delta f}{1-1.04} = \frac{y}{2-0} \quad \Rightarrow \Delta f = -0.02\,y \text{ -------------------- (1)}$$

For Unit-2: With similar Δ^{le}s ABB″ and ACC″, $\frac{AB}{AC} = \frac{BB''}{CC''}$

$$\Rightarrow \frac{\Delta f}{1-1.04} = \frac{4-y}{5-0} \quad \Rightarrow \Delta f = -0.008\,(4-y) \text{ ------------------ (2)}$$

- From (1) and (2), $-0.02\,y = -0.008\,(4-y)$

  $\Rightarrow \quad y = 1.1429\,pu$
- ∴ The power output of unit-1, y = 1.1429 pu = 114.29 MW and
- The power output of unit-2, (4–y) = 4 – 1.1429 = 2.8571 pu = 285.71 MW
- From (1), $\Delta f = -0.02\,y = -0.02 * 1.1429 = -0.022858$ pu
- ∴ $\Delta f = (f_1 - 1.04) = -0.022858 \Rightarrow f_1 = 1.017142$ pu = 50.857 Hz
- Hence, frequency at the load of 400 MW, f_1 = 50.857 Hz

PROBLEMS:

4) Two generators A & B rated 200 MW and 400 MW operating in parallel. The droop characteristics of their governors are 4% and 5% respectively from no-load to full-load. The speed set points are such that the generators operate at 50 Hz when sharing a load of 400 MW in proportion to their ratings. What are the no-load frequencies now?

Sol.: Given that,

Rating of Unit-A $(P_A)_r$ = 200 MW and of Unit-B $(P_B)_r$ = 400 MW

R_1 = 4% droop = – 0.04 pu and R_2 = 5% droop = – 0.05 pu

Load demand P_D = 400 MW at a frequency of f = 50 Hz = 1 pu

(Base frequency = 50 Hz and base power = rated power in units)

FL total power output = 200+400 = 600 MW

PROBLEMS:

Given: Load of 400 MW is shared in proportion to their ratings.

∴ Share of Unit-A (power O/P of unit-A) = $\frac{200}{600} * 400 = 133.33\,MW$

Share of Unit-B (power O/P of unit-B) = $\frac{400}{600} * 400 = 266.67\,MW$

At a load of 400 MW, frequency is f = 50 Hz = 1 pu.

Let the load is being reduced from 400 MW to no-load.

For unit – A, no-load frequency f_1 is found as follows.

Frequency deviation Δf = freq. at no-load – freq. at 400 MW load

∴ $\Delta f = (f_1 - 1)$ pu

Change in power O/P $\Delta P_1 = (0 - 133.3333)/200$ pu = – 0.6667 pu

(Base power = rated power = 200 MW)

But, $R_1 = \frac{\Delta f}{\Delta P_1} \quad \Rightarrow -0.04 = \frac{f_1 - 1}{-0.6667}$

PROBLEMS:

∴ $f_1 = 1.026668$ pu = 1.026668 * 50 Hz = 51.3334 Hz.

∴ The no-load frequency of Unit-A is 51.3334 Hz.

Similarly, For unit – B, no-load frequency f_2 is found as follows.

Frequency deviation Δf = freq. at no-load – freq. at 400 MW load

∴ $\Delta f = (f_2 - 1)$ pu

Change in power O/P, $\Delta P_2 = (0 - 266.6667)/400$ pu = – 0.667 pu

(Base power = rated power = 400 MW)

But, $R_2 = \frac{\Delta f}{\Delta P_2} \quad \Rightarrow \quad -0.05 = \frac{f_2 - 1}{-0.6667}$

∴ $f_2 = 1.03334$ pu = 1.03334 * 50 Hz = 51.667 Hz.

∴ The no-load frequency of Unit-B is 51.667 Hz.

PROBLEMS:

5) Two generators 1 & 2 rated 120 MW and 250 MW are operating in parallel. The governor settings are to give a speed droop of 4% and 3% respectively from no-load to full-load. The settings are such that the generators operate at 50 Hz on full-load output. Determine the percentage adjustment in no-load speed to be carried out in faster machine if the generators have to share the load of 200 MW equally.

Sol.: Given that,

Rating of Unit-1 $(P_1)_r$ = 120 MW and of Unit-2 $(P_2)_r$ = 250 MW

R_1 = 4% droop = – 0.04 pu and R_2 = 3% droop = – 0.03 pu

Load demand P_D = 200 MW.

Since, the load is shared equally, $P_1 = P_2 = \frac{P_D}{2} = 100\ MW$

PROBLEMS:

- Let frequency at the load of 200 MW be f_1 pu.
- Since, the regulation of unit-1 is higher than unit-2, it is considered to be the faster machine.
- Given: The no-load speed (frequency) of the faster machine is to be adjusted. Hence, the no-load frequency of unit-1 is to be adjusted.
- Then, the no-load frequency of unit-2 remains unchanged.
- Given: The unit-2 operate at 50 Hz (1 pu) at full-load output.
- Since, its regulation is 3%, its no-load frequency is 1.03 pu.
- Let the unit-2 be changed from no-load to P_2 = 100 MW.

$\therefore$ $\Delta f = (f_1 - 1.03)$ pu and

ΔP_2 = (100 – 0) MW = (100 – 0) / 250 pu = 0.4 pu

But, $R_2 = \Delta f / \Delta P_2$ $\Rightarrow$ – 0.03 = $(f_1 - 1.03) / 0.4$

PROBLEMS:

$\therefore$ f_1 = 1.018 pu is the frequency at the load of 200 MW.

- Now, the unit-1 has to supply 100 MW for the load of 200 MW at a frequency of f_1 = 1.018 pu.
- Let the no-load frequency of unit-1 be f_{NL} pu.
- Now, let us assume that unit-1 is changed from no-load to P_1=100 MW.

$\therefore$ $\Delta f = f_1 - f_{NL} = (1.018 - f_{NL})$ pu and

ΔP_1 = (100 – 0) MW = (100 – 0) / 120 pu = 0.8333 pu

But, $R_1 = \Delta f / \Delta P_1$ $\Rightarrow$ – 0.04 = $(1.018 - f_{NL})$ / 0.8333

$\therefore$ f_{NL} = 1.051333 pu is the no-load frequency of unit-1 after the adjustment.

- But, given that the regulation of unit-1 is 4%. Hence, the no-load frequency before adjustment is 1.04 pu.

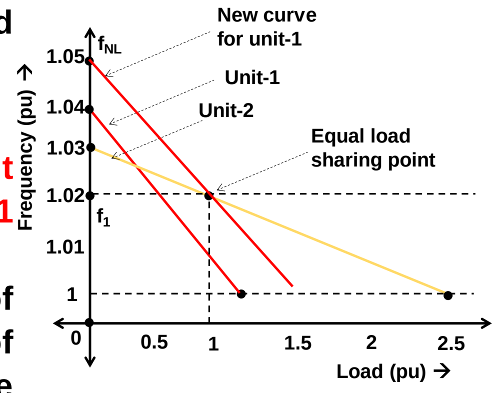
PROBLEMS:

$\therefore$Adjustment (Change) in no-load frequency required for unit-1 is,

$$= \frac{1.051333 - 1.04}{1.04} * 100\% = 1.0897\ \%$$

Hence, **the percentage adjustment required in no-load speed of unit-1 is, 1.0897%.**

The speed-droop characteristics of units 1 & 2 with the adjustment of no-load frequency of unit-1 are shown below. (Base power = 100 MW)



THANK YOU