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Internal Assesment Test - I

Sub:	Power System operation & Control							Code:	18EE81/17EE 81
Date:	08/05/2022	Duration:	90 mins	Max Marks:	50	Sem:	7	Branch:	EEE
Answer Any FIVE FULL Questions									

		Marks	OBE CO	OBE RBT
1	Derive the expression for frequency deviation & tie line flow in power system	[10]	CO2	L3
2	Two generators rated 200 MW and 400 MW are 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 the full load of 600 MW in proportion to their ratings, (i) If the load reduces to 400 MW, how is it shared? At what frequency will system operate? (ii) If now the speed changers are reset so that the load of 400 MW is shared at 50 Hz in proportion to their rating. What are the no load frequencies now?	[10]	CO2	L4
3	Draw the diagram of steam turbine governing system and explain the functions of its various components	[10]	CO2	L3
4	With a neat diagram ,explain the general configuration and major components of SCADA	[10]	CO1	L2
5	(a)What are the functions of AGC?	[5+5]	CO2	L2
	(b)Two areas A and B interconnected by tie line. The generating capacity of area A is 25,000 MW and its regulating characteristics is 2.5 % of capacity per 0.1 Hz. Area B has a generating capacity 5000 MW and its regulating characteristics is 1.5 % of capacity per 0.1 Hz. Find each areas share of 800 MW disturbance (load increase) occurring in area B and resulting tie line flow.		CO2	L3
6	Explain the operating states of power system, with a neat diagram showing the transition between the states	[10]	CO1	L2

Solutions

1

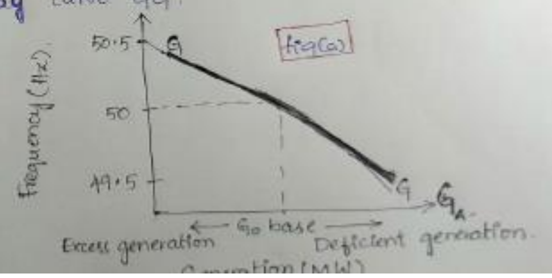
OPERATION WITHOUT CENTRAL COMPUTERS OR AGC. (15)

[EXPRESSION FOR TIE-LINE FLOW POWER AND FREQUENCY DEVIATION]

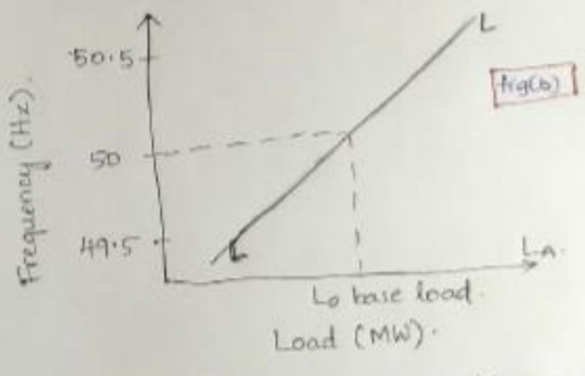
* Power systems are capable of operating without a central computer or AGC.
* This is due to turbine generator speed controls built into generating stations and natural load regulation.
* These characteristics force generators within an area to share load and cause interconnected power areas to share load
* Considering a two area model, with breaker T open (no tie-line flow).

Assumptions :

* Area D represents an operating area of interconnected power system in which sudden load or generation change occurs, Area A forms the rest of the power system.
* Areas share a disturbance in proportion to their generating capacity size and operating characteristics.
* Let the area A overall generation frequency be represented by curve GG.



* The shaft speed and consequently the electrical line frequency changes with load reflected onto the prime mover.
* The generation-frequency characteristic curve has a negative slope or droop.
* The area connected load is defined by curve LL as shown below.



* Basic equations describing generation and load are

$$G_A = G_0 + 10\beta_1 (f_{act} - f_0) \text{ MW} \quad \text{——— (2)}$$

$$L_A = L_0 + 10\beta_2 (f_{act} - f_0) \text{ MW} \quad \text{——— (3)}$$

where G_A = total generation on system A, MW.

G_0 = base generation on system, MW at Hz

L_A = total load on system A, MW.

L_0 = base load on system, MW at Hz.

f_{act} = system frequency, Hz

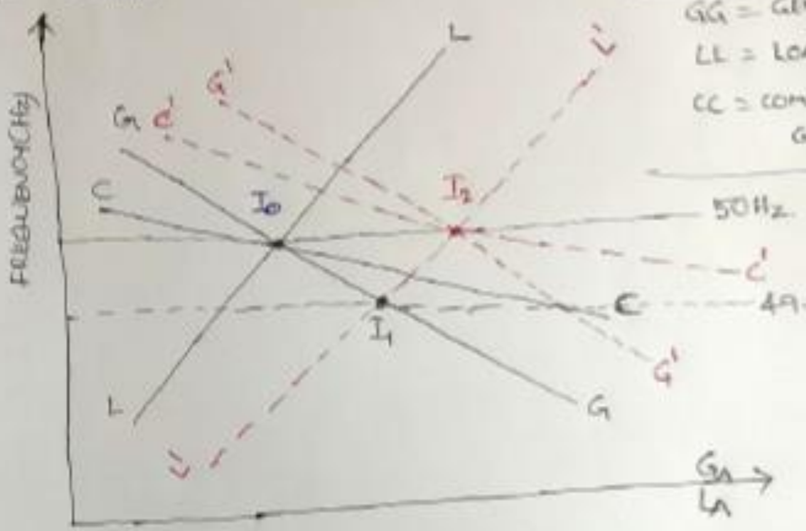
f_0 = base frequency (Hz)

β_1 = contangent of generation - frequency characteristic in MW/0.1 Hz; $\beta_1 < 0$.

β_2 = contangent of load frequency characteristic

(17)

* For a steady-state frequency, total generation must be equal to total effective load and prevailing frequency is defined by point of intersection I_0 of the GG and LL curves.



* Now the generation characteristic and the load characteristic can be added algebraically to obtain the combined area characteristic as shown by curve CC.
* The composite generation load-frequency characteristic is given by

$$G_A - L_A = G_0 + 10B_1(f_{act} - f_0) - L_0 - 10B_2(f_{act} - f_0) \quad \text{---} (4).$$

* Now assume that there's load increase in area A of magnitude to move the load-frequency characteristic to position L'L'.
* The new system frequency be defined by the intersection of GG generation line and new load line L'L' (i.e I_1)

* If it's desired to return to system frequency to 50Hz then it's possible by shifting generation curve GG to G'G'.
* Now the combined characteristic of G'G' and L'L' is shown by c'c'.
* Equation (4) can be written in terms of increments as

$$\Delta_A = G_A - G_0 + L_A - L_0 = 10\beta_1 (f_{act} - f_0) - 10\beta_2 (f_{act} - f_0)$$
$$= 10 B_A X_A (f_{act} - f_0)$$
$$= 10 B_A X_A \Delta f \text{ MW} \quad \text{---} (5)$$

where B_A = Natural regulation characteristic of area A expressed in percent of generation per 0.1 Hz

X_A = Generating capacity of area A in MW.

* ∴ Thus the load increase, Δ_A (or generation decrease) in area A leads to a frequency deviation

$$\Delta f = \frac{\Delta_A}{10 B_A X_A} \text{ Hz. } (< 0) \quad \text{---} (6)$$

* Define a real power tie-line flow, ΔT_L, as a positive quantity out of area, the combined effect on frequency for a load increase (or generation decrease) and positive tie flow on area A is then

$$\Delta f = \frac{\Delta_A + \Delta T_L}{10 B_A X_A} \text{ Hz} \quad \text{---} (7)$$

where $\Delta_A + \Delta T_L$ is net megawatt change.

* Consider areas A and D interconnected with breaker T, closed with generation and load equal 50 Hz in both areas. So no tie-line flow between two areas A and D.
* Some disturbance occurs in D and causes system frequency to drop to 49.9 Hz. Since they are interconnected the generation no longer matches with effective load in area A.
* Now the tie-line flow between A and D is

$$\Delta T_L = \Delta G_A - \Delta L_A \text{ MW} \quad \text{——— (8)}$$

where ΔT_L is the net change in tie-line power flow which is a positive value directed from A to D

ΔG_A — Increase of generation in area A.

ΔL_A — Decrease in load power in area A.

* For area D, ΔT_L is the tie-line power flow directed from A to D,

$$\Delta f = \frac{\Delta_D - \Delta T_L}{10 B_D X_D} \text{ Hz} \quad \text{——— (9).}$$

* Let $\Delta_{AD} = \Delta_D$ be the magnitude of the disturbance that occurs in area D and $\Delta_A = 0$

Since the frequency is common to both systems

$$\Delta f = \frac{\Delta T_L}{10 B_A X_A} = \frac{\Delta_{AD} - \Delta T_L}{10 B_D X_D} \text{ Hz} \quad \text{——— (10).}$$

(20)

Solving eq (10) for tie-line flow ΔT_L,

$$\Delta T_L = \frac{(10 B_A x_A)\Delta_{AD}}{10 B_A x_A + 10 B_D x_D} \quad MW \quad \text{—— (11)}$$

→ Expression for Tie-line power.

The net power change in area D is

$$\Delta_{AD} - \Delta T_L = \frac{(10 B_D x_D)\Delta_{AD}}{10 B_A x_A + 10 B_D x_D} \quad MW \quad \text{—— (12)}$$

From eq (12) it is clear that interconnected power system having area A and D both share disturbance as weighted by their generating capacity

$$\Delta_{AD} = 10 B_A x_A \Delta f + 10 B_D x_D \Delta f$$

$$= (10 B_A x_A + 10 B_D x_D)\Delta f \quad MW \quad \text{—— (13)}$$

Eq (13) is rewritten in transfer function form as

$$\frac{\Delta f}{\Delta_{AD}} = \frac{1}{10 B_A x_A + 10 B_D x_D} \quad Hz/MW \quad \text{—— (14)}$$

$$\Delta f = \frac{\Delta_{AD}}{10 B_A x_A + 10 B_D x_D} \quad Hz$$

→ Expression for Frequency Deviation.

2

Solution

(i) The droop characteristics are drawn as in Example 6.4. Since 600 MW is shared in proportion to their rating, unit 1 supplies 200 MW and unit 2 supplies 400 MW, which is their capacity, respectively. Therefore, both the units operate at 100% full-load when supplying 600 MW. We take 100 MW to be the base power. The characteristics are drawn as shown in Fig. 6.12. Unit 1 has a frequency change from 1.04 pu to 1.0 pu from no-load to full-load (2 pu) and unit 2 has a frequency change from 1.05 pu to 1.0 pu from no-load to full-load (4 pu). Thus at $f = 1$ pu, total load is $2 + 4 = 6$ pu. The load now changes to 400 MW. Let x pu be the output of unit 1. Total load is 400 MW = 4 pu. Therefore, the output of unit 2 is $4 - x$ pu. From the figure,

$$\frac{BC}{BO} = \frac{CC_1}{OO_1} \Rightarrow \frac{0.04 - \Delta f}{0.04} = \frac{x}{2} \qquad \text{(i)}$$

$$\frac{AC}{AO} = \frac{CC_2}{OO_2} \Rightarrow \frac{0.05 - \Delta f}{0.05} = \frac{4 - x}{4} \qquad \text{(ii)}$$

From (i) $$\frac{\Delta f}{0.04} = 1 - 0.5x \qquad \text{(iii)}$$

From (ii) $$\frac{\Delta f}{0.05} = 0.25x \qquad \text{(iv)}$$

$$\text{solving we get } \frac{0.05}{0.04} = \frac{1-0.5x}{0.25x}$$

$$\text{or } 0.0125x = 0.04 - 0.02x$$

$$x = 1.23077\ \text{pu}$$

$$= 123.077\ \text{MW}$$

$$4 - x = 2.7692\ \ \text{pu} = 276.923\ \text{MW}$$

$$\Delta f = (0.25x)0.05 = 0.01538\ \text{pu}$$

$$\text{Frequency } f_1 = 1 + \Delta f = 1.01538\ \text{pu}$$

$$= 50.769\ \text{Hz}$$

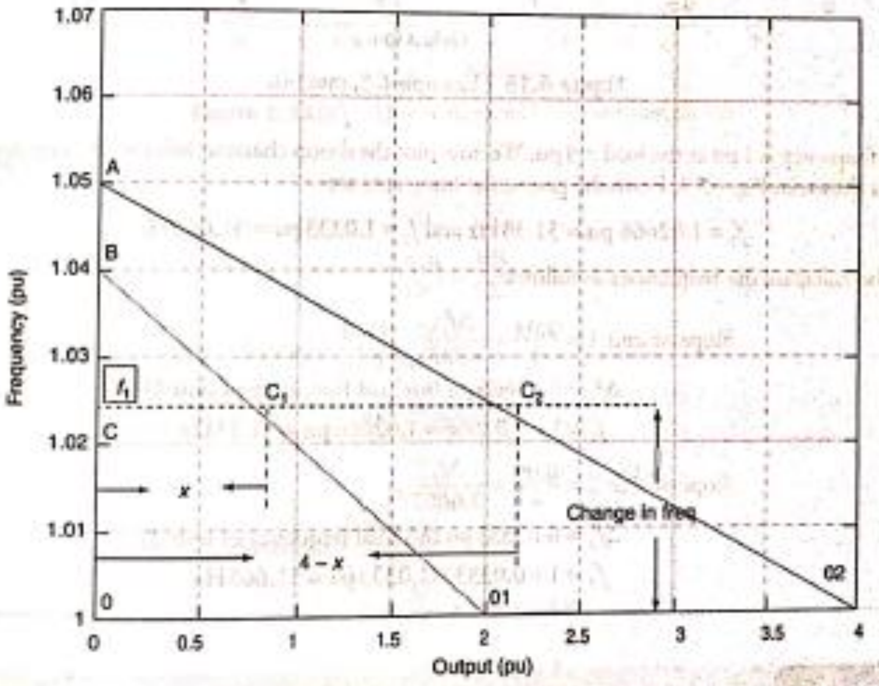


Figure 6.12 Example 6.5, case (i).

(ii) Now the governor settings are changed such that they share 400 MW in proportion to their rating at 50 Hz.

$$\therefore \text{ Output of unit } 1 = 400 \times \frac{2}{6} = 133.33\ \text{MW}$$

$$= 1.3333\ \text{pu}$$

$$\text{Output of unit } 2 = 266.67\ \text{MW}$$

$$= 2.6667\ \text{pu}$$

The characteristics are as shown in Fig. 6.13.

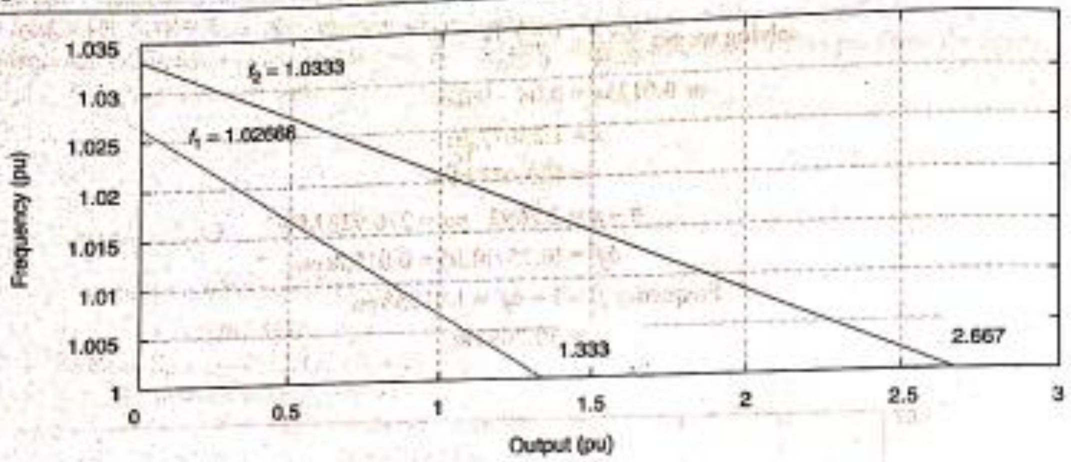


Figure 6.13 Example 6.5, case (ii).

Here, the frequency is 1 pu at the load = 4 pu. We now plot the droop characteristics with same slopes of 4% and 5% as shown in Fig. 6.13. From the graph, the intercepts are

$$f_1 = 1.02666 \text{ pu} = 51.33 \text{ Hz and } f_2 = 1.0333 \text{ pu} = 51.665 \text{ Hz}$$

We can also calculate the frequencies as follows:

$$\text{Slope of unit } 1 = \frac{0.04}{2} = \frac{\Delta f_1}{1.333}$$

$$\Delta f_1 = 0.02666 \text{ pu (no load frequency of unit 1)}$$

$$f_1 = 1 + 0.02666 = 1.02666 \text{ pu} = 51.33 \text{ Hz}$$

$$\text{Slope of unit } 2 = \frac{0.05}{4} = \frac{\Delta f_2}{2.6667}$$

$$\Delta f_2 = 0.03333 \text{ pu (no load frequency of unit 2)}$$

$$f_2 = 1 + 0.0333 = 1.0333 \text{ pu} = 51.665 \text{ Hz}$$

3

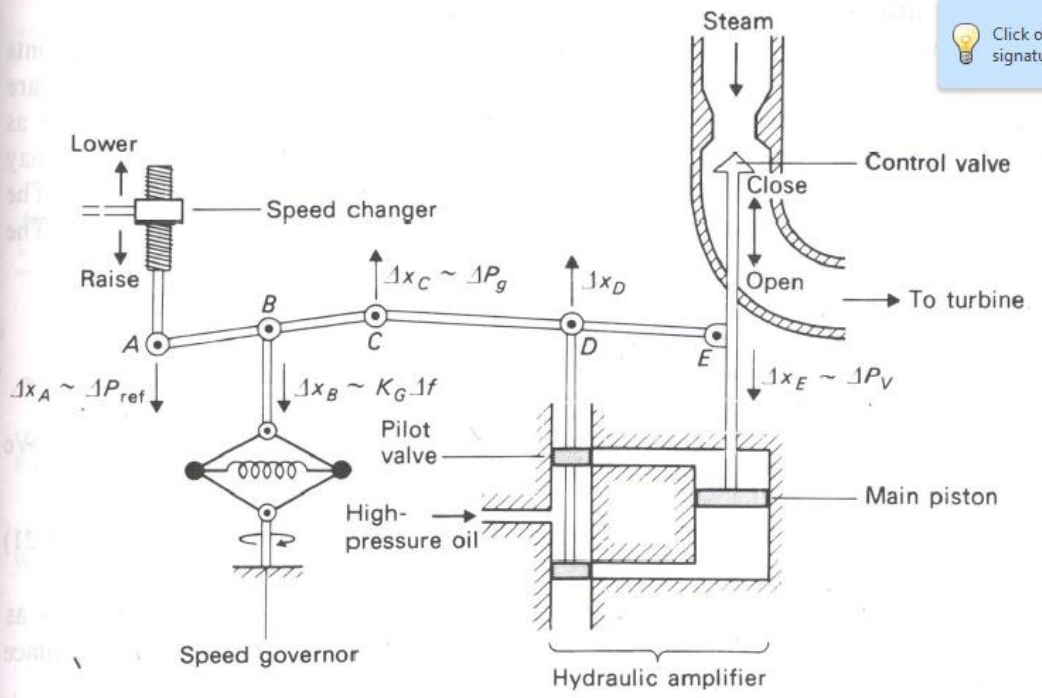


Figure 9-7 Simplified functional diagram of the primary ALFC loop.

Steam Turbine Governing System

Consider the governing system for a steam turbine as shown in Fig. 6.2.

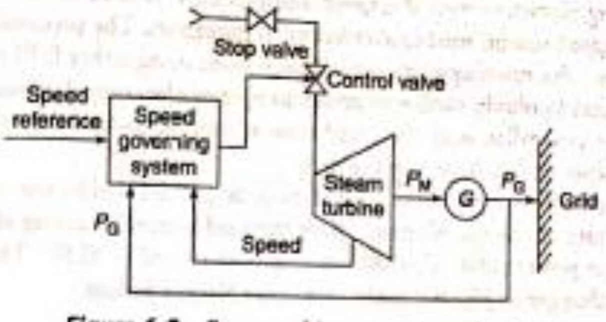


Figure 6.2 Steam turbine governing scheme.

In the operating range, the steam flow through the control valve is proportional to the valve opening. When the valve opening changes, the steam flow to the turbine changes, changing the mechanical power output of the turbine and hence the electrical power of the generator. The rate of speed change depends on the inertia of the entire rotor system. When the turbine-generator unit is being started, the governing system controls the speed by regulating the steam flow. After the unit has been synchronized to the grid, the governor increases the output to load the unit. Referring to the figure, we can see that the valve output can be changed by changing the reference input or by a change in the speed (reflected in the change in frequency) with the reference speed remaining the same. This is the primary regulation or simply governor control. The *secondary regulation* changes the reference setting by using the load-frequency control.

Conventional Governor

The conventional governor is shown in Fig. 6.3.

The major components are discussed below.

Fly ball speed governor: This is a mechanical device, which is speed sensitive and directly adjusts the valve opening via the linkage mechanism. It senses the change in speed or power output and appropriately initiates valve opening or closing.

Linkage mechanism: This transforms the fly ball movement to the turbine valve, through a hydraulic amplifier and provides a feedback from the turbine valve movement.

Hydraulic amplifiers: It is a hydraulic servomotor interposed between the governor and the valve to build mechanical forces strong enough to operate the steam valves or water gates.

Speed changer: It is used to provide a steady-state power output setting for the turbines.

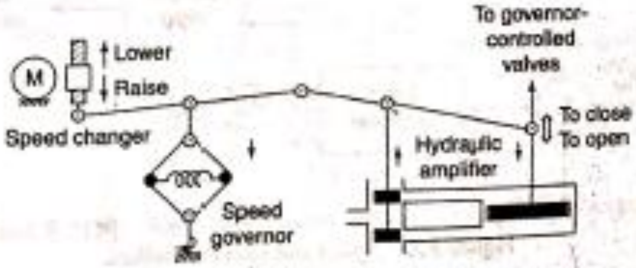


Figure 6.3 Conventional governor.

4

3. ***EMS:*** Energy management systems incorporate all features of SCADA and also includes other computations, such as load flows, state estimation, contingency analysis, etc. It includes extensive capabilities of record keeping and data exchange.
4. ***DMS:*** Distribution management systems are meant to monitor and control distribution feeder loads. DMS today includes topology analysis and load flow programs that allow identification of problems and restoration of services.
5. ***LMS:*** Load management system is meant to manage the peak load and is useful for demand-side management. It can be a stand-alone program or integrated into EMS or DMS.
6. ***AMR:*** Automatic meter reading is incorporated into LM systems.

12.1.2 Telemetry

Telemetry refers to the technique used in transmitting and receiving information or data over a medium. Typical data in a power system are the measurements of voltage, power flows, circuit breaker status, etc. The information is transmitted over a medium, such as cable, telephone, internet or radio. The information can come from multiple locations.

12.1.3 Data Acquisition

It refers to the method used to access and control the information or data from the equipment that is being controlled or monitored. The data are then forwarded via the telemetry system. The information can be either in an analog or in a digital form. It is the data obtained from sensors, meters, actuators, control equipment like relays, valves, etc.

With the above definitions, we can now define SCADA as *a collection of equipment that will provide an operator at a remote location with enough information to determine the status of a particular piece of equipment or an entire substation/power system, and cause actions to take place regarding that equipment or facility without being physically present at the location of the fault*[1].

12.2 Components of SCADA System

The general configuration is shown in Fig. 12.1[2]. Basically, SCADA systems collect information from the site (field) of the equipment, transfer it to a central computer facility and display the information to the operator to facilitate the control of the entire system from the central control center. In a SCADA system, the geographically dispersed sites contain either a remote terminal unit (RTU), which is a computer, or a programmable logic controller (PLC), which controls local actuators and monitor the sensors. The communication equipment allows transfer of information or data from the RTU/PLC to the central control center which houses a master terminal unit (MTU).The communication could be via telephone, radio, cable or satellite. The software of the SCADA system is programmed to tell the system what to monitor, what are the operating ranges, when to initiate alarms, controls, etc. Further, the system may consist of intelligent electronic devices (IEDs) that are smart sensors, at times combining a sensor, low level intelligent control, a communication system and program memory in one device. The IEDs can communicate directly with the MTU. Other components are the human–machine interface(HMI), also called the man–machine interface (MMI)that allows the operator to monitor the state of a process under control, modify

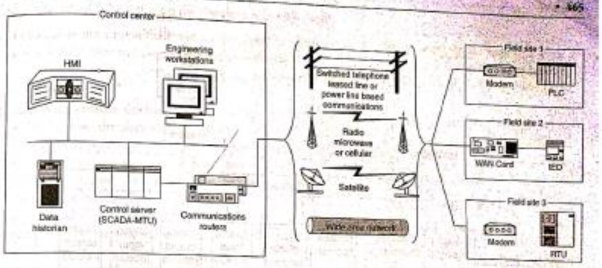


Figure 12.1 General SCADA configuration.

control settings if necessary, and permits the operator to override any automatic control previously set, should an emergency arise. The HMI is also responsible for displays, reports, historical information, status information, etc.

The major components of a SCADA system are thus classified as:

1. Field instrumentation,
2. Remote stations,
3. Communication network,
4. Central monitoring station and
5. Software.

12.2.1 Field Instrumentation

This refers to all the sensors and actuators that are interfaced directly to the equipment. They generate the analog and digital signals that are monitored by the remote station. The generated signals are conditioned to be compatible with the RTU/PLC at the remote station. The analog outputs of sensors have standard industry values like 0–5 V, 0–10 V, 0–20 mA, etc. Digital outputs of sensors are used to define the status of the equipment like On-OFF, Full-Empty, Open-Closed, etc.

12.2.2 Remote Station

Field instrumentation connected to the plant/substation/equipment which is being monitored and controlled is interfaced to the remote station to allow manipulation at a remote site. The remote station may be an RTU or a PLC. The RTU is a computer with good interfacing for communication and flexible programmability. The PLC is used mostly in industries. It has very good programmability. Modern PLCs also have extensive communication features and radio units for use with SCADA systems. A typical RTU unit is shown in Fig. 12.2.

5a

6.4 Functions of AGC

In a power system the loads and losses are sensitive to frequency. If a generating unit is tripped or the load on the system is increased, the power mismatch is initially compensated by extracting the kinetic energy from system inertial storage causing a decline in system frequency. As the frequency decreases, the power taken by the loads also decreases. Equilibrium in larger systems is generally obtained when the reduction in frequency sensitive load balances the output of the tripped generator or the load increase at the new frequency. If equilibrium is reached it is in less than 2 s.

If the mismatch is large, then the governor action has to increase the generation of the units such that equilibrium is reached, when the reduction in the power taken by the loads plus the increase in generation makes up for the mismatch. Such equilibrium is reached in 10–15 s after tripping of a unit or connection of additional load. The main requirement of the AGC is to ensure the following:

1. The frequency of the various bus voltages are maintained at the scheduled frequency.
2. The tie-line power flows are maintained at the scheduled levels.
3. The total power is shared by all generators economically (economic dispatch).

The first two functions are realized using the ALFC, whereas the third has been extensively dealt with in Chapter 3. Apart from this, modern AGC strategies[2] include many more functions. Some of them are listed here.

1. Yield a generation trend acceptably matching the trend required to serve the changing load at the scheduled frequency, over the selected time frame.
2. Schedule generation to accumulate lower fuel cost over the selected time frame, which includes recognizing undesirable generation ranges in different units and avoiding sustained operation in these ranges.
3. Maintain a sufficient level of reserved control range and sufficient level of control rate.
4. Operate the system with higher security margins.
5. Provide timely recommendations for changing of outputs of units which are manually controlled.
6. 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.

The design of AGC system depends on the way the units respond to AGC signals. The response characteristics of units vary widely and depend on many factors such as:

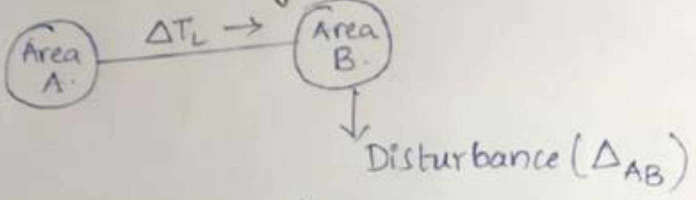
1. Type of generating unit: fossil-fired, nuclear hydro, combined cycle, etc.
2. Type of fuel used: coal, oil, uranium, gas, etc.
3. Type of plant control.
4. Type of plant: once-through boiler, drum-type boiler, pressurized-water nuclear reactor, pumped storage hydro, etc.
5. Operating point of units.
6. Manual control by operators.

In multi-area control, tie-line power deviation dictates the AGC control. This is dealt with in Chapter 7. The speed governors play a vital role in the primary control of the frequency. This is discussed in detail in the next section.

5B

increase) occuring in area B

A.



$X_A = 25{,}000$ MW | $B_A = 2.5\% = 0.025$ MW/0.1 Hz.

$X_B = 5000$ MW | $B_B = 1.5\% = 0.015$ MW/0.1 Hz.

Disturbance $\Delta_{AB} = 800$ MW.

Area A's share ; $\Delta T_L = \dfrac{(10 B_A X_A)\Delta_{AB}}{10 B_A X_A + 10 B_B X_B} = 714.25$ MW. → Tie-line power.

Area B's share ; $\Delta_{AB} - \Delta T_L = 800 \text{ MW} - 714.25 \text{ MW}$

$= 85.75$ MW.

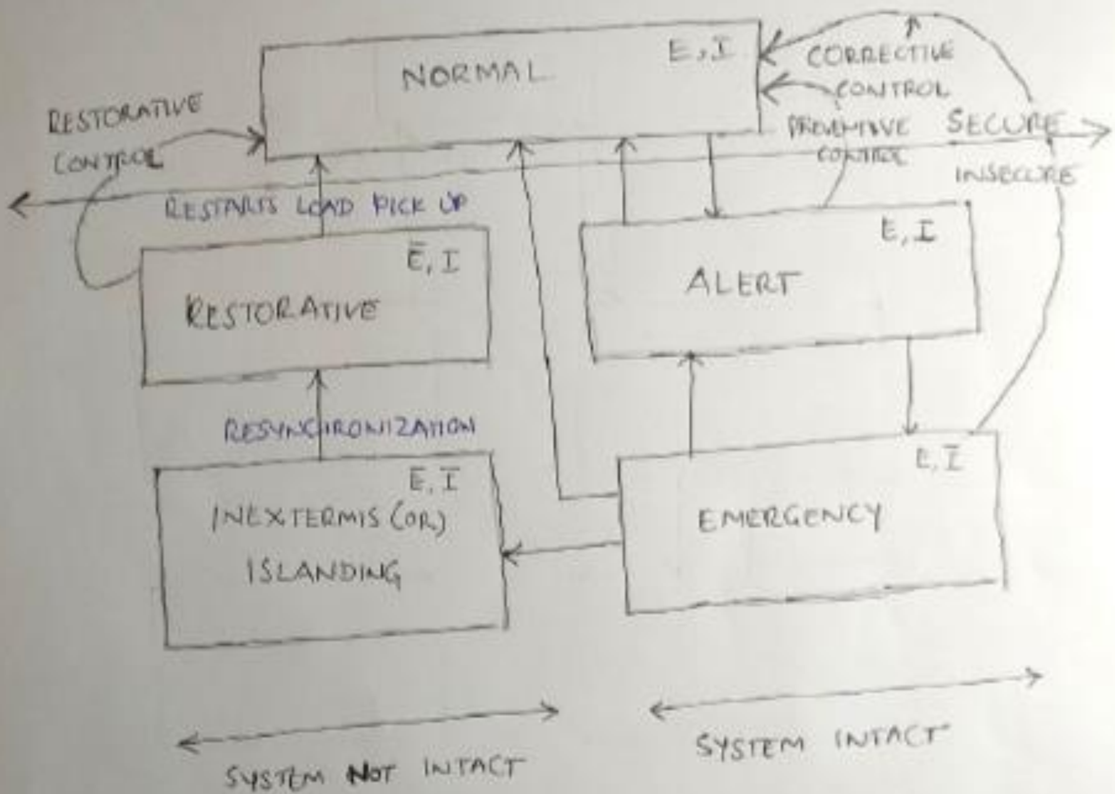
Frequency deviation ; $\Delta f = \dfrac{\Delta_{AB}}{10 B_A X_A + 10 B_B X_B}$

$= 0.11$ Hz.

6

②.

OPERATING STATES OF POWER SYSTEM :



*NORMAL :

All constraints equality, inequality (E, I) are satisfied, with enough power generation reserve is available. Incase of any generator outage, the reserve from other generators can supply the load without any interruption.

* ALERT:

All constraints equality, inequality (E, I) are satisfied, but reserve power generation is zero. As a result, in the event of a loss of generator, the remaining generators can't supply the load, load shedding has to happen. The power system can be brought back to normal state through preventive control action.

* EMERGENCY:

In this state, the equality constraint is satisfied, while the inequality constraint is violated. Corrective control is used to bring the system back to normal operating state directly or through ALERT state.

* In-extermis or islanding:

In this state, the power system enters into an islanded mode of operation, where both equality and inequality states are violated. Once the system comes to this state it cannot go back to the emergency state. In this state, the large power system is

(4)

separated into small areas or Islands, where the loads are supplied from generators. All the tie lines connecting the areas are open and they work in an indepedent mode of operation. Sytem reliability is more important in this stage than economic operation.

*. RESTORATIVE MODE:

In this mode, the power systems has to be restored through several steps by switching generators and transmission lines. This is a difficult task and requires strategies for bringing on the generator and synchronizing it to the grid. Improper sequence will cause tripping