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UNIT I: SECURITY CONCEPTS

Power system security; Factors affecting system security; Different operating states of power systems; energy control centers and its functions; Necessity for regulation of system frequency and voltage; Power systems control problems; P - F and Q - V control structure; SCADA systems.

PART A - 2 Marks

TWO MARK QUESTIONS AND ANSWERS

1. What are the functions of control center?

System monitoring contingency analysis security constrained optimal power flow.

2. What is the function of system monitoring?

System monitoring provides up to date information about the power system.

3. Define SCADA system? (Nov 2013)

It stands for supervisory control and data acquisition system, allows a few operators to monitor the generation and high voltage transmission systems and to take action to correct overloads.

4. What are the states of power system? (Nov 2013) (Nov 2014)

Normal state alert mode contingency mode emergency mode. Define normal mode? The system is in secure even the occurrence of all possible outages has been simulated the system remain secure is called normal mode.

5. Define alert mode?

The occurrence of all possible outages the system does not remain in the secure is called alert mode.

6. What are the distribution factors?

Line outage distribution factor, generation outage distribution factor.

7. Define state estimation?

State estimation is the process of assigning a value to an unknown system state variable based on measurements from that system according to some criteria.

8. Define post contingency?

This is the state of the power system after a contingency has occurred. Define secure dispatch? This is state of the power system with no contingency outages, but with correction to the operating parameters to account for security violations.

9. What are the priorities for operation of modern power system?

Operate the system in such a way that power is delivered reliably. Within the constraints placed on the system operation by reliability considerations, the system will be operated most economically.

10. Denote the hierarchical level used in EMS. (Nov 2012)

- System control level
- Area control level
- Remote terminal unit(RTU)

11.What are the objectives of automatic generation control? (Apr 2015)

- To hold frequency at or very close to a specified nominal value.
- To maintain the correct value of interchange power between control areas.
- To maintain each unit's generation at the most economic value.

12. What is network topology?

In order to run the state estimation, we must know how the transmission lines are connected to the load and generation buses. This information is called network topology.

13. What are the functions of SCADA? (Nov 2014) (Apr 2013) (Apr 2013)

- Monitoring
- Alarm
- Control and indication of AGC.
- Data logging
- Data acquisition
- ON/OFF control
- RAISE/LOWER command to speed changer
- Display

14. Mention four types of SCADA systems and its application area (Nov 2013)

TYPE1: Small distribution systems, Small hydro stations, HVDC links.

TYPE2: Medium sized power systems, power station HVDC link distribution systems.

TYPE3: Regional control centre, distribution systems in large urban areas several hydro power station with cascade control.

TYPE4: National and Regional control centers distributed systems in large urban areas, several hydro power station with cascade control.

15. What are the different operating states a power system can operatin in ? or what are the system security levels?

- Normal state
- Alert state
- Emergency state
- Extremis state
- Restorative state

16. What is emergency state?

The state can be reached either directly from the normal state or vis the alert state. In this state, the equality constraints are unchanged.

17. What is the need for voltage regulation in power system?(Apr 2013) (Nov 2012) (Apr 2015)

knowledge of voltage regulation helps in maintaining the voltage at the load terminals within prescribed limits under fluctuation load conditions, by employing suitable voltage control equipments

18. List out the various needs for frequency regulation in power system. (Apr 2013) (Nov 2010)

- In any power system, if the frequency changes, there won't be required voltage at the receiving end. If we connected two systems in parallel, it will spoil the system.
- The generator turbines are designed to operate at a very precise speed that can be maintained by regulating frequency.
- Constant turbine speed is an important requirement.
- Unusual deviations in the frequency can be detected earlier.

19. What is the purpose of primary ALFC? (Apr 2011)

The circuit primarily controls the steam value leading to the turbine. A speed sensor senses the speed of the turbine. The control of speed in turn controls the frequency.

20. State the difference between p-f and Q-V controls. (Apr 2013)

Change in MW will be felt uniform through out the system but change in MVAR is not felt uniform. Change in MW output does not cause change in voltage level but change in MVAR input affects the frequency control.

21. What is load curve? (Apr 2013)

The curve drawn between the variations of load on the power station with reference to time is known as load curve. There are three types, Daily load curve, Monthly load curve, Yearly load curve

22. What is daily load curve?

The curve drawn between the variations of load with reference to various time period of day is known as daily load curve.

23. What is monthly load curve?

It is obtained from daily load curve. Average value of the power at a month for a different time periods are calculated and plotted in the graph which is known as monthly load curve.

24. What is yearly load curve?

It is obtained from monthly load curve which is used to find annual load factor.

25. What is connected load?

It is the sum of continuous ratings of all the equipments connected to supply systems.

26. What is Maximum demand?

It is the greatest demand of load on the power station during a given period.

27.What is Demand factor?

It is the ratio of maximum demand to connected load.

Demand factor= (max demand)/ (connected load)

28. What is Average demand?

The average of loads occurring on the power station in a given period (day or month or year) is known as average demand. Daily avg demand = (no of units generated per day)/ (24 hours) Monthly avg demand = (no of units generated in month)/ (no of hours in a month) Yearly avg demand = (no of units generated in a year)/ (no of hours in a year)

29. What is Load factor? (Apr 2012) (Dec 2014)

The ratio of average load to the maximum demand during a given period is known as load factor. Load factor = (average load)/ (maximum demand)

30. What is Diversity factor?

The ratio of the sum of individual maximum demand on power station is known as diversity factor. Diversity factor = (sum of individual maximum demand)/(maximum demand).

31. What is Capacity factor?

This is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period. Capacity factor= (actual energy produced)/ (maximum energy that have been produced)

32. What is Plant use factor?

It is the ratio of units generated to the product of plant capacity and the number of hours for which the plant was in operation. Units generated per annum= average load * hours in a year

33. What is Load duration curve? (Nov 2011) (Apr 2013) (Apr 2015)

When the load elements of a load curve are arranged in the order of descending magnitudes the curve then obtained is called load duration curve.

PART B

1. Classify and distinguish between the different power system operating states of power systems and also state how the system states are continuously monitored (11) (Apr 2011) (Apr 2015)

Discuss the different power system operating states of power systems with an example (11) (Nov 2014) (Apr 2014) (Nov 2011)

Discuss the various power system operating states of power systems; with neat diagram (Nov 2013) (7)

POWER SYSTEM SECURITY CONCEPTS- INTRODUCTION

The Power System needs to be operationally secure, i.e. with minimal probability of blackout and equipment damage. An important component of power system security is the system's ability to withstand the effects of contingencies. A contingency is basically an outage of a generator, transformer and or line, and its effects are monitored with specified security limits.

The power system operation is said to be normal when the power flows and the bus voltages are within acceptable limits despite changes in load or available generation. From this perspective, security is the probability of a power system's operating point remaining in a viable state operation.

System security can be broken down into TWO major functions that are carried out in an operations control centre:

(i) Security assessment and
(ii) Security control.

Before going into the static security level of a power system, let us analyse the different operating states of a power system.

The states of power system are classified into FIVE states (ie) Normal, Alert, Emergency, Extreme Emergency and Restorative.

Fig below depicts these states and the ways in which transition can occur from one state to another.

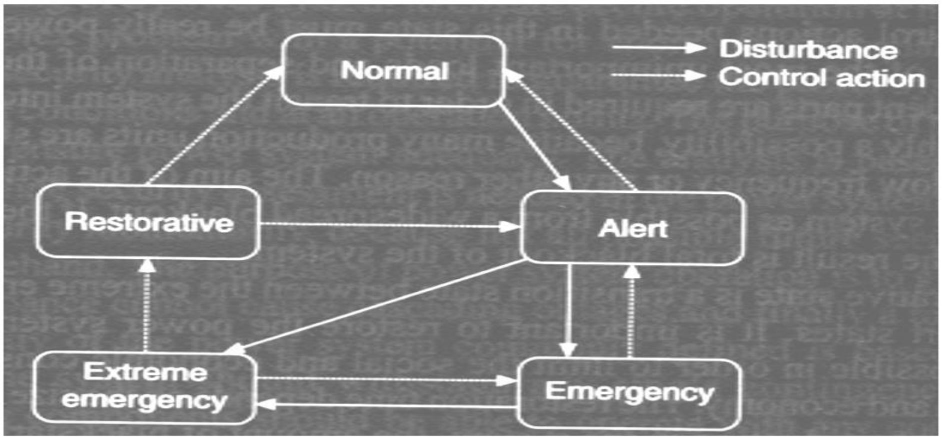


Figure. 1.1 Power system Operating Stages

The operation of a power system is usually in a normal state. Voltages and the frequency of the system are within the normal range and no equipment is overloaded in this state.The system can also maintain stability during disturbances considered in the power system planning. The security of the power system is described by Thermal, voltage and stability limits.The system can also withstand any single contingency without violating any of the limits.

The system transits into the emergency state if a disturbance occurs when the system is in the alert state. Many system variables are out of normal range or equipment loading exceeds short-term ratings in this state. The system is still complete. Emergency control actions, more powerful than the control actions related to alert state, can restore the system to alert state. The emergency control actions include fault clearing, excitation control, fast valving, generation tripping, generation run back-up, HVDC modulation, load curtailment, blocking of on-load tap changer of distribution system transformers and rescheduling of line flows at critical lines.

The extreme emergency state is a result of the occurrence of an extreme disturbance or action of incorrect of ineffective emergency control actions. The power system is in a state where cascading outages and shutdown of a major part of power system might happen. The system is in unstable state. The control actions needed in this state must be really powerful. Usually load shedding of the most unimportant loads and separation of the system into small independent parts are required. Any system can fail due to internal causes or due to external causes or human errors. The above factors are affecting power system security.

2. Explain Q-V control loop and P-F control structure with diagram explain how the voltage and frequency maintained constant (11) (Apr 2013).

With a neat sketch describe the significance of Q-V control loop and P-F control structure in power system operation (11)(Nov 2012).

Draw and explain Q-V control loop and P-F control loop (11) (Nov 2010) (Nov 2009).

NEED FOR VOLTAGE AND FREQUENCY REGULATION IN POWER SYSTEM

A power system is said to be well designed if it gives a good quality of reliable supply, which means that the voltage level must be within reasonable limits.

Practically ,all the equipments on the power system are designed to operate satisfactorily within voltage variation of around 5%.

If the voltage variation is more than a pre-specified value, the performance of the equipments is also sacrificed.

Need for voltage regulation in power system:

Knowledge of voltage regulation helps in maintaining the voltage at load terminals within prescribed limits under fluctuation load condition by employing voltage control equipment.

- ✓ The transmission line and the distribution line need voltage control at various stages to maintain the voltage at the last consumers premises within permissible limits.
- ✓ Variations in supply voltage are determent in various aspects.
- ✓ Below normal voltage substantially reduced the light output from the incandescent lamps, above normal voltage reduces the life of the lamps.
- ✓ Motor operated at below normal voltage draw abnormal high currents and may overheat , even when carrying no more than the rated horse power load.
- ✓ If the voltage of the system deviates from the nominal value , the performance of the device suffers and its life expectance drop.
- ✓ By adjusting the excitation of the generator at the sending end below a certain limit may result in instability of the system and excitation above certain level will result in overheating of the rotor.

- ✓ Service voltage are usually specified by a nominal value and the voltage maintained is ±5% of the nominal value.

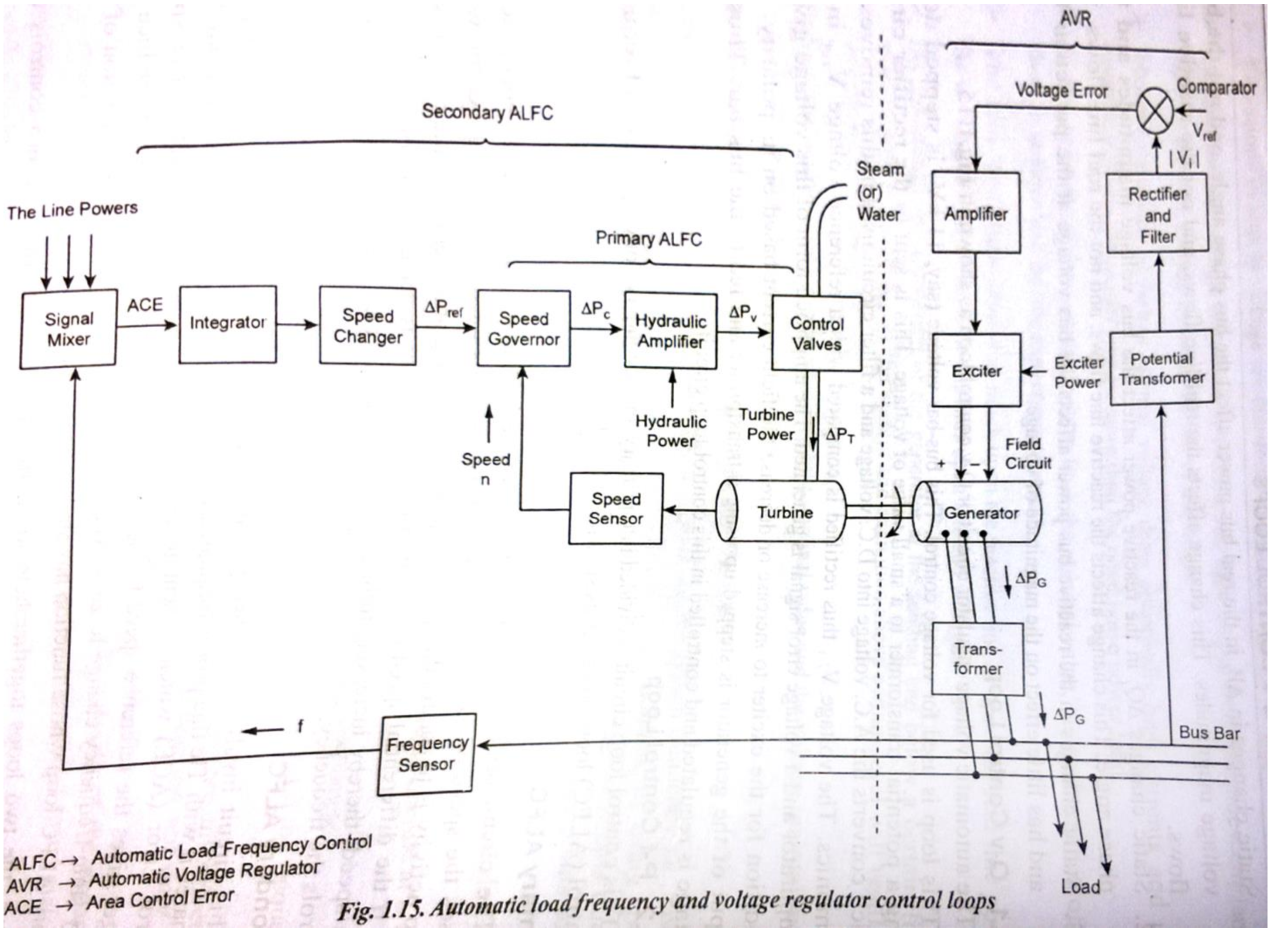
Need for frequency regulation in power system:

Knowledge of frequency regulation helps in maintaining the system frequency (ie)speed of the alternator within prescribed limits under fluctuating load condition ,by using speed governor and integral controller. In a network, considerable drop in frequency occurs due to high magnetising current in induction motor and transformer.

- ✓ In any power system, if the frequency changes there won't be required receiving end voltage. if we connected tow systems in parallel, it will spoil the system.
- ✓ Most of the AC motor runs at a speed that is directly related to the frequency.
- ✓ The overall operation of a power system can be much better controlled if the frequency error is kept within strict limit.
- ✓ A large number of electrical driven clocks are used they all driven by synchronous motor and the accuracy of these clocks is a function not only of a frequency error ,but actually of the integral of this error.
- ✓ When tow system working at different frequencies are to be tied together to make same frequency . frequency converting station or links are required.
- ✓ Constant turbine speed is an important requirement the velocity of the expanding steam is beyond our control and the turbine efficiency required perfect match.

BASIC P-F AND Q-V CONTROL LOOPS

1. static changes in ΔP_i in the real bus power affect the bus phase angle and the bus voltage magnitudes this change affect the real line flows, and not the reactive line flows.
2. static changes in ΔQi in the reactive power affect the bus phase angle and the bus voltage magnitudes this change affect the reactive line flows, and not the real line flows.
3. static changes in the reactive power affect the bus voltage at the particular bus and has little effect on the magnitude of voltage.



ALFC → Automatic Load Frequency Control
AVR → Automatic Voltage Regulator
ACE → Area Control Error

Fig. 1.15. Automatic load frequency and voltage regulator control loops

Figure 1.2 Automatic load frequency and voltage regulator control loops.

Q-V Control loop

The automatic voltage regulation circuit (or) Q-V control loop as shown in fig.

- ✓ This loop is used for a voltage control this bus bar voltage (say 11KV) is stepped down using a potential transformer to a small value of voltage.
- ✓ +This is sent to the rectifier circuit which converts the AC voltage into DC voltage and a filter circuit used in this removing the harmonics.
- ✓ The voltage V_i , thus rectified is compared with a reference V_{ref} in the comparator and a voltage error signal is generated
- ✓ The amplified form of this voltage gives a condition for the excitation to increasing or decreasing the field current based on its polarity.
- ✓ The output of the generator is stepped up using a transformer and fed to the bus bar. Thus the voltage is regulated and controlled in this control loop circuit.

P-f Control loop:

This control loop circuit is divided into

1. Primary ALFC
2. Secondary ALFC as shown in fig.

Primary ALFC:

The circuit primarily controls the steam valve leading to the turbine .a speed sensor senses the speed of the turbine. This is compared with a reference speed ,governor whose main activity is to control the speed of the steam by closing and opening of the control value (ie)if the differential speed is low , then the control value is opening to let out the steam at high speed , thereby increasing turbine speed and vice versa the control of speed in turn controls the frequency.

Secondary ALFC:

This circuit involves a frequency sensor that senses the frequency of the bus bar and compares it with tie line power frequencies in the signal mixer. The output of this is an area control error (ACE) which is sent to the speed changer through integral. the speed changer gives the reference speed to the governor . Integral controller is used to reduce the steady state frequency change to zero. After this part of the circuit, is the introduction of the primary ALFC loop whose function has already been described.

Thus the two loops together help in controlling the speed which in turbine controls the frequency , since $N \alpha f$ Using the relation Speed $N = 120 f/P$ Where, f= frequency (Hz) , P= No.of poles

3. What is meant by systems; energy control centers Discuss the various control functions carried out in ECC (11) (Nov 2014)

Explain the functions of energy control centers (11) (Apr 2014)

What is meant by systems; energy control centers Discuss the various control functions carried out in ECC(11) (Nov 2013)

Draw the schematic diagram of energy control centers Discuss the various control functions carried out in ECC (11)(Apr 2013)

ENERGY CONTROL CENTRE OR SYSTEM CONTROL CENTRE

Introduction:

- ✓ When the power systems increase in size –the number of substations, transformers, switchgear and so on –their operation and interaction become more complex.
- ✓ Main feature
  1. Increases system reliability
  2. Increases economical feasibility
- ✓ Real time operation are two aspects

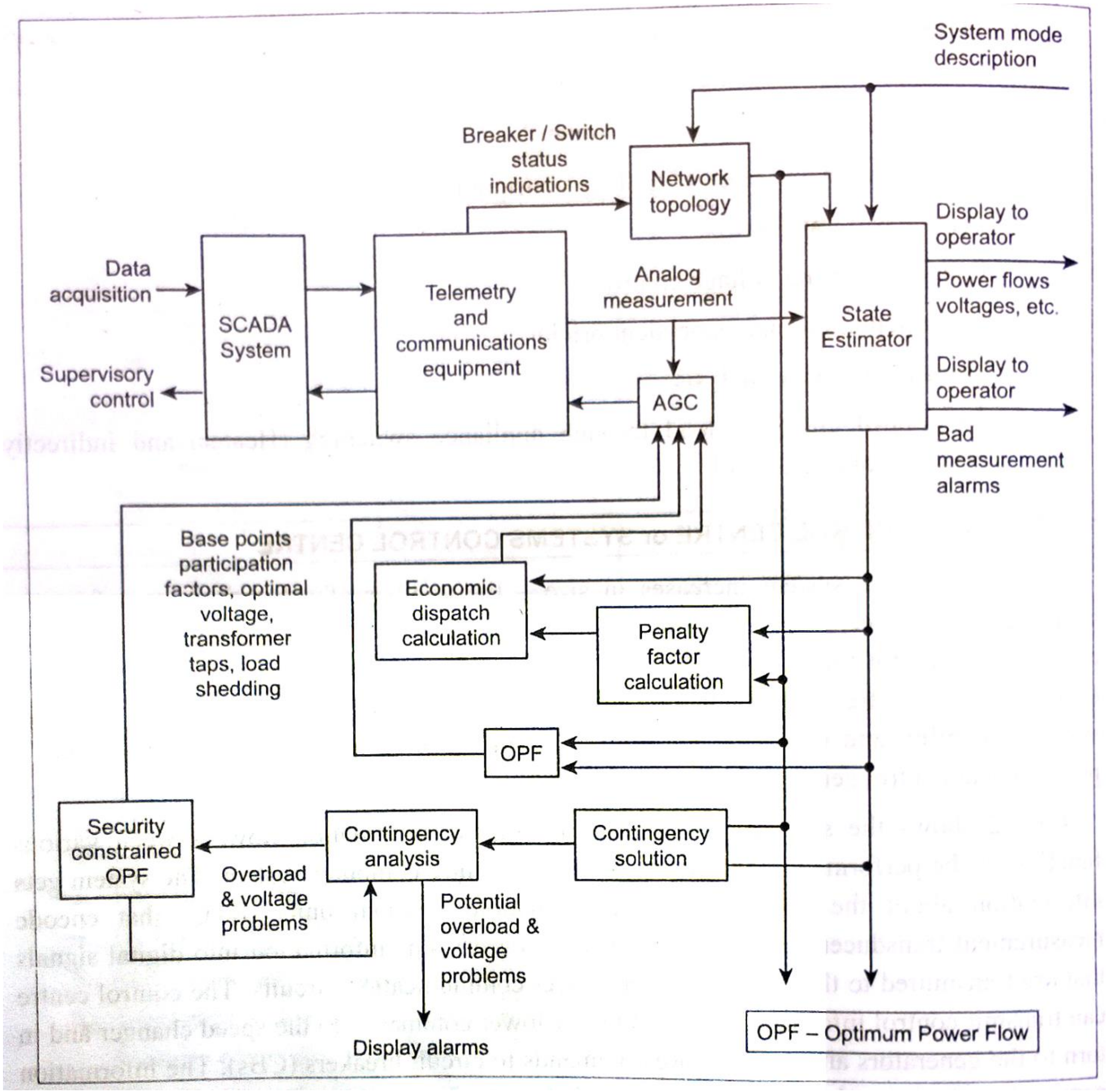


Figure 1.3 Energy control centre

a. **Three level controller :**
   1. Turbine –governor to adjust generation to balance changing load – instantaneous control.
   2. Automatic generation control(AGC) maintains frequency and net power interchange –action repeated 2-6 sec interval.
   3. Economic dispatch control (EDC) distributes the load among the units such that fuel cost is minimum- executed at 5-10 minutes interval.

b. **primary voltage control :**
   1. Excitation control regulate generation bus voltage.
   2. Transmission voltage control devices include
      - ✓ SVC(**S**tatic **V**AR **C**ontroller)
      - ✓ Shunt capacitors
      - ✓ Transformer taps

Automatic generation control (AGC)

Objective of (AGC):

1. To hold frequency at or very closed to a specified nominal value.
2. To maintain the correct value of interchange power between control value.
3. To maintain each units generation at the most economical value.

Network topology:

We must know how the transmission lines are connected to the load and generator buses.It program must have a complete description of each substation and how the transmission lines are attached to the substation equipment.

State estimator:

The electrical model of the transmission system is sent to the state estimation program together with the analog measurements.

The output of the state estimator consists of all voltage magnitudes and phase angle, transmission line MW and MVAR flow and bus loads and generations calculated from the line flows. These quantities, together with the electrical model, provide the basic for the Economic dispatch program, contingency analysis program and generator corrective action program. since the complete electrical model of the transmission system is available , we can directly calculation bus penalty factors, participation factors, optimal voltage etc.

Contingency analysis:

- ✓ That model possible system trouble before they arise .
- ✓ Alarm the operation of any potential over loads or out of the limit voltage.

ENERGY CONTROL ENERGY FUNTION

The practice of all communication links between equipment and the control centre could be interrupted and still, electric service is being maintained.

Monitoring: Fulfils the function – both normal and emergency conditions

Normal conditions:

1.Normal situation is delegated to the digital computer and selective monitoring is performed by human.

2.Less serious case- exceeding normal limit are routinely handled by digital computer.

Emergency Conditions:

1.Digital computer is used to process the incoming steam of data to detect abnormalities- alarm the human operation via light, buzzer, CRT presentation.

2.More serious case – detected by digital computer may cause suspension of normal control function.

3.In emergency such as loss of a major generator or excess power demands by a neighbouring utility on the tie lines. many alarm could be detected and the system could enter an emergency state.

4. Explain the different functions that are performed by SCADA systems in detail (11)(Apr 2015)

Explain the different functions that are performed by SCADA systems and Write the Functions of SCADA and its types (Apr 2014)

Describe with neat diagram real time control of power system (11)(Nov 2010)

DATA ACQUISITION AND CONTROL

Data acquisition remote control is performed by computer system called SCADA.

SCADA:

- ✓ Master station
- ✓ Remote terminal unit[RTU]

Master station communicates to the RTU for observing and controlling plants. RTU are installed at generating station or transmission substation or distribution substation.

computer aided data acquisition scheme:

- ✓ steady state reading can be acquired simultaneously from various instrument location and saved for future analysis.
- ✓ transient may be in the form of voltage or current fluctuation . using a data acquisition system the transient can be decreased and analysed.

Energy control centre level:

Level	System	Monitoring and control
First level	Generating station and sub stations	Local control center
second level	Sub transmission and transmission network	Area load dispatch centre
Third level	Transmission system	State load dispatch centre
Fourth level(top level)	Interconnected power system	Regional control centre

SCADA (Supervisory Control And Data Acquisition):

It consists of a master station and RTU linked by communication channel.

The hardware components can be classified into

1. Process computer and associated hardware at energy control centre
2. RTU and the associated hardware at the remote stations.
3. Communication equipment that links the RTU and process computers at the master station.

System hardware configurations:

Supervisory Control And Data Acquisition system allows a few operators to monitor the generation and HV transmission system.

- Consistent with principles of high reliability and fail safe features
- Usually one computer, the online-units, is monitoring and controlling the power system
- The online computer periodically updates a disk memory shared between two computers

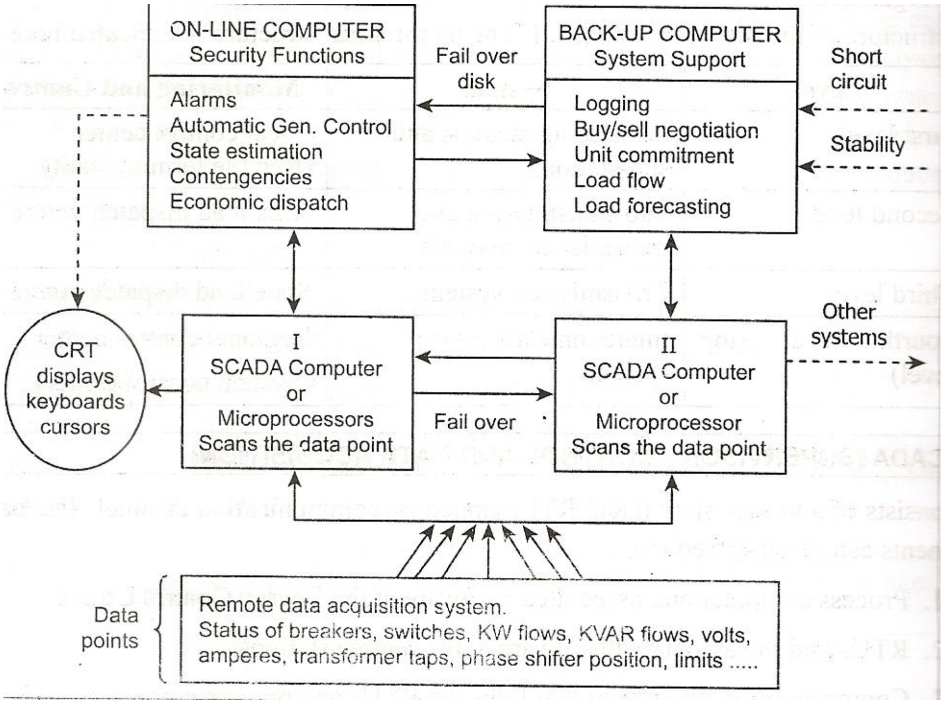


Figure 1.4 Digital computer control and monitoring for power system.

- The back-up computer may be executing off-line batch programs such as load forecasting
- Upon a fail over, the stored information of the common disk is inserted in the memory of the on-line computer.
- The information used by the on-line computer has a maximum age of update cycle (typically 30 sec)
- All the peripheral equipment is interfaced with the computer through input-output microprocessors that have been programmed to communicate as well as preprocess the analog information, check for limits, convert to another system of units and so on.
- The microprocessors can transfer data in and out of computer memory without interrupting the CPU. As a result of these precautions, for all the critical hardware functions, there is often a guaranteed 99.8%.
- The most critical function have the fastest scan cycle. Typically, the following categories are scanned every 2 seconds.
- All status points such as switchgear position, substation loads and voltages, transformer tap position and capacitor banks
- The line flows and interchanges schedules

- Generator loads, voltage, operating limits and boiler capacity
- Telemetry verification to detect failures and errors in the remote bilateral communication links between the digital computer and the remote equipment
- The turbine generators are often command to new power levels every 4 seconds
- The absolute power output of each units response capability is typically adjusted every 5 minutes by the computer executing an economic dispatch program to determine the base power settings.

TYPES OF SCADA SYSTEM AND AREA OF APPLICATION

1. Small distribution system (substation control centre) small hydro stations, HVDC links.
2. Medium sized power system (plant control centre) power station HVDC link distribution systems
3. Regional control centre, distribution system in large urban areas several hydro power stations with cascade control
4. National and regional control centre distributed system in large urban areas several hydro power stations with hydro control.

Master station:

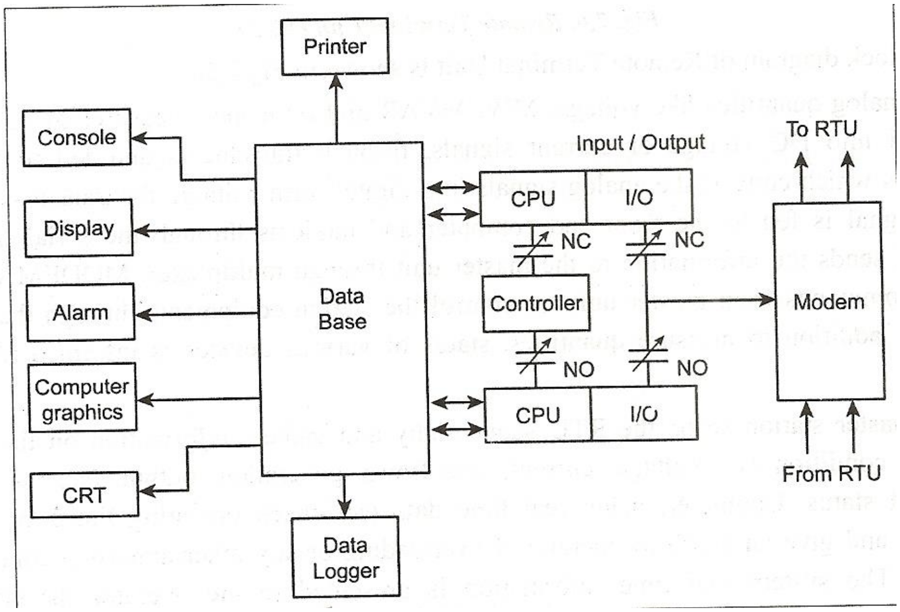


Figure 1.5 Master station.

Master unit is provided with the digital computer with associated interfacing devices and hardware to receive information from RTU. The hardware at the master station includes following

1. Process computer
2. CRT display
3. Printer
4. Data logger
5. Computer graphics
6. Control console
7. Keyboard
8. Alarm panel
9. Instrument panel
10. Modem
11. Multiplexer

Remote terminal units[RTU]:

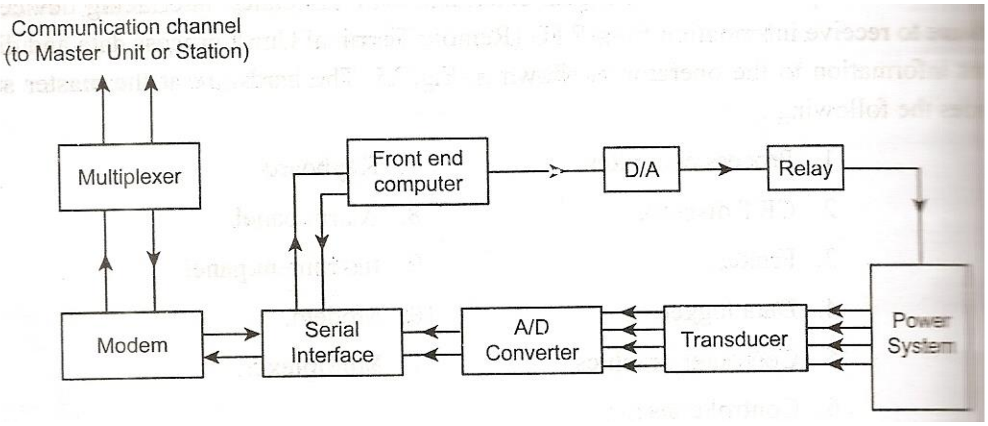


Figure 1.6 Remote terminal unit (RTU)

The RTU's are installed at selected power stations and substation.

The hardware components of RTU may include the following

1. Transducers
2. A/D and D/A converters
3. Serial interface
4. Modems
5. Multiplexers
6. Front end computer
7. Control relays

- The analog quantities like voltage, MW,MVAR and frequency measured at stations are converted into DC voltage or current signals through transducers and fed to the A/D converters which converts the analog into digital form suitable for transmission.

- The digital signal is fed to the front end computer and modems through the serial interface.
- MODEM sends the information to the unit through multiplexer. As well as receive commands from master unit to control the station equipment through the control relay. In addition to measure quantities, status of various devices is informed to master station.
- The master station scans the RTU sequentially and gathers information on the system operating condition (ie) voltage, current, line flows, generating output, etc, as well as equipment status.
- Give an alarm- operator if overloading
- The system real time information is presented to the operator through CRT, computer graphic terminals, alarm panels, alarm printer. So that the operator can supervise minute by minute.

FUNCTIONS OF SCADA

It allow a few operators to monitor the generator. The following are the functions of SCADA.

1. Data Acquisition: It provides telemetered measurements and status information to operator
2. Information display
3. Supervisory control

   Circuit breakers: on/off, Generator: stop/start, (raise/lower command)

   a. Electrical breaker control
   b.Voltage regulation
   c.Tap changer control
   d.Capacitor control
   e.Loss reduction
   f.Miscellaneous device control
   g.Load management
   h.Fault isolation
   i.Service restoration
4. Information storage and result display

5. Sequence of events acquisition
6. Remote terminal unit processing
7. General maintenance
8. Runtime status verification
9. Economic modelling
10. Remote start/stop
11. Load matching based on economics
12. Load shedding: provides both automatic and operator-initiated tripping of load in response to system emergencies.

5. Explain about the necessity for regulation of System frequency and voltage

Properly designed power system should have the following characteristics:

1. It must supply power, practically everywhere the customer demands.
2. It must supply power to the customers at all times.
3. It must be able to supply the ever changing load demand at all time.
4. The power supplied should be of good quality.
5. The power supplied should be economical.
6. It must satisfy necessary safety requirements.

The delivered power must meet certain minimum requirements with regards to the quality of the supply. The following determine the quality of the power supply.

i) The system frequency must be kept around the specified 50 Hz with a variation of ± 0.05 Hz.

ii) The magnitude of bus voltages are maintained within narrow prescribed limits around the normal value. Generally voltage variation should be limited to ± 5%. Voltage and frequency controls are necessary for the effective operation of power systems.

Frequency fluctuations are detrimental to electrical appliances. The following are a few reasons why we should keep strict limits on frequency deviations.

* Three phase a.c. motors run at speeds that are directly proportional to the frequency. Variation of system frequency will affect the motor performance.

* The blades of steam and water turbines are designed to operate at a particular speed. Frequency variations will cause change in speed. This will result in excessive vibration and cause damage to the turbine blades.

* Frequency error may produce havoc in the digital storage and retrieval process.

Both over voltage and under voltage are detrimental to electrical appliances.

Electric motors **will tend to run on over speed** when they are fed with higher voltages resulting vibration and mechanical damage. Over voltage may also cause **insulation failure.**

For a specified power rating, when the supply voltage is less, the **current drawn is more** and it will give rise to **heating problems.**

Therefore it is essential to keep the system frequency constant and the voltage variation within the tolerance.

6.What are the factors affecting System security

Factors affecting Power system security:

As a consequence pf many widespread blackouts in interconnected power systems, the priorities for operation of the modern power systems have evolved to the following:

- Operate the system in such a way that power is delivered reliably.
- Within the constraints placed on the system operation by reliability considerations, the system will be operated most economically.
- Characteristics of the Physical system (Generation, Transmission and Distribution systems and Protection Systems)

Any piece of equipment in the system can fail either due to internal causes or due to external causes such as lightning stroke, object hitting transmission towers or human errors in setting relays. Thus , most power systems are designed to have sufficient redundancy to withstand all major failure events.

- Business structures of owning and operatig entities
- The regulatory framework

Methods of enhancing security

- Impractical to achieve complete immunity to blackout
    - Need to strike a balance between economy and security
- Good design and operating practices could significantly minimize the occurrence and impact of widespread outages.
- Reliability criteria
- On-line security assessment

- Robuststability controls
- Real time monitoring and control
- Coordinated emergency controls
- Wide spread use of distributed generation

7. Explain various controls for secure operation

Various controls for secure operation

To ensure secure operation of a power system

i) Corrective action require to improve load bus voltages and frequency. (Excitation control, Load frequency control).

ii) Corrective action required to eliminate the overloads (Emergency control)

iii) Load scheduling (Economic load dispatch, Unit commitment)

iv) Load forecasting

Security constrained Economic dispatch:

It refers to the case when the system is dispatched such that it is in normal, secure state relative to some pre-specified contingency list.

In other words, for any contingency belonging to the list, the scheduling of power flows in the network must ensure secure operation. A Power system is said to be in a secure state if continuity of supply is maintained even if a contingency occurs.

Economic Load Dispatch (Load Scheduling)

The purpose of economic dispatch is to reduce fuel costs for the power system by economic load scheduling. (i.e.,) to find the generation so that fuel cost is minimum, and the total demand and the loss at any instant must be met by the total generation.

Excess generation capability is needed because forced outages may remove some of the exciting generators from the power system, or loss of transmission capacity may make some of the generation inaccessible to the load.

Load Frequency Control

Load frequency control is to maintain the network frequency constant so that the power stations run satisfactorily in parallel and the various motors operating in the system run at desired speed. In order to maintain the frequency constant, it is necessary to achieve a balance between the generation and connected load.

Automatic load frequency control systems are now available for maintaining the frequency within the tolerable limits. Conventional load frequency control is based upon the tie- line bias control where each area tends to reduce the area control error to zero.

Load Forecasting:

The problem of load forecasting is that of estimating the future load demand of a given power system, Depending upon the time period, it may be classified as very short term, short term, medium term and long term technique. Very short term and short term load forecasting are generally required by the system operators for the purpose of economic generation scheduling and load dispatching. Medium term forecast helps in allocation of spinning reserves. The long term load forecasting is essential for power system planning. The construction of large generating plants takes many years. Therefore the planner must determine the generating needs well in advance. This influences the selection and sequence of generation.

Unit Commitment

The unit commitment problem is to minimize system total operating costs while simultaneously providing sufficient spinning reserve capacity to satisfy a given security level. In unit commitment problems we consider,

- A short term load forecast
- System reserve requirements
- System security
- Startup costs for all units
- Minimum level fuel costs for all units
- Incremental fuel costs of units
- Maintenance costs

Emergency Control

Security problem will change with operational conditions. It depends not only upon the reserve capacity in a given situation but also upon the contingency of disturbances. In normal state the system is secure i.e., both equality and inequality constraints are satisfied. If any contingency occurs the system enters to alert state. If security level falls below threshold level the system becomes insecure. Now disconnection of faulty section, rerouting of power, startup of reserve generation, load shedding is done, then the power system is returned to the normal or alert state. These control actions may be done from the central energy control center.

State estimation

For digital computer in short circuit computations, it is necessary to develop a systematic general computational procedure. State estimation is used for load forecasting, economic dispatch and load frequency control. Computing speed and reliability are of primary importance.

Pondicherry University Questions

2 Marks

1. Define SCADA system? (Nov 2013)
2. What are the states of power system? (Nov 2013) (Nov 2014)
3. Denote the hierarchical level used in EMS. (Nov 2012)
4. What are the objectives of automatic generation control? (Apr 2015)
5. What are the functions of SCADA? (Nov 2014) (Apr 2013) (Apr 2013)
6. Mention four types of SCADA systems and its application area (Nov 2013)
7. What is the need for voltage regulation in power system?(Apr 2013) (Nov 2012) (Apr 2015)
8. List out the various needs for frequency regulation in power system. (Apr 2013) (Nov 2010)
9. What is the purpose of primary ALFC? (Apr 2011)
10. State the difference between p-f and Q-V controls. (Apr 2013)
11. What is load curve? (Apr 2013)
12. What is Load factor? (Apr 2012) (Dec 2014)
13. What is Load duration curve? (Nov 2011) (Apr 2013) (Apr 2015)

11 Marks

1. Classify and distinguish between the different power system operating states of power systems and also state how the system states are continuously monitored (11) (Apr 2011) (Apr 2015) (Ref.Pg.No.6,Qn.No.1)

2. Discuss the different power system operating states of power systems with an example (11) (Apr 2014) (Nov 2011) (Nov 2014) (Ref.Pg.No.6,Qn.No.1)

3. Discuss the various power system operating states of power systems; with neat diagram (Nov 2013) (7) (Ref.Pg.No.6,Qn.No.1)

4. Explain Q-V control loop and P-F control structure with diagram explain how the voltage and frequency maintained constant (11)(Apr 2013). (Ref.Pg.No.7,Qn.No.2)

5. With a neat sketch describe the significance of Q-V control loop and P-F control structure in power system operation (11)(Nov 2012). (Ref.Pg.No.7,Qn.No.2)

6. Draw and explain Q-V control loop and P-F control loop (11) (Nov 2010) (Nov 2009).

(Ref.Pg.No.7,Qn.No.2)

7. What is meant by systems; energy control centers Discuss the various control functions carried out in ECC (11) (Nov 2014) (Ref.Pg.No.10,Qn.No.3)

8. Explain the functions of energy control centers (11) (Apr 2014) (Ref.Pg.No.10,Qn.No.3)

9. What is meant by systems; energy control centers Discuss the various control functions carried out in ECC(11) (Nov 2013) (Ref.Pg.No.10,Qn.No.3)

10. Draw the schematic diagram of energy control centers Discuss the various control functions carried out in ECC (11)(Apr 2013) (Ref.Pg.No.10,Qn.No.3)

11. Explain the different functions that are performed by SCADA systems in detail (11)(Apr 2015) (Ref.Pg.No.13,Qn.No.4)

12. Explain the different functions that are performed by SCADA systems and Write the Functions of SCADA and its types (Apr 2014) (Ref.Pg.No.13,Qn.No.4)

13. Describe with neat diagram real time control of power system (11)(Nov 2010) (Ref.Pg.No.13,Qn.No.4)

REFERENCE BOOKS

1. Olle I. Elgerad, “Electric Energy System Theory and Introduction”, Tata Mc Graw Hill publishing company, New Delhi, 2nd edition, 2004.
2. Allen J.Wood, Bruce F. Wollenbarg, “Power Generation, operation and control”,2nd edition, John Wiley and sons, 2008.
3. D.P.Kothari and I.J.Nagrath, " Modern Power System Analysis” Tata Mc Graw Hill publishing company Ltd., 2003.
4. A.K.Mahalanbias, D.P.Kothari & S.I.Ahson, "Computer Aided Power System Analysis and Control" Tata Mc Graw Hill publishing company, New Delhi, 1990.
5. P.S.R. Murty, "Operation and Control in Power Systems" BS Publications, 2005.
6. M. Geraldin Ahila, “Power System Operation and Control” ARS Publications,2008.

UNIT II: LOAD FORECAST AND UNIT COMMITMENT

Load and load duration curves; Load forecasting, components of system load, classification of base load, forecasting of the base load by method of least square fit; Introduction to unit commitments constraints on unit commitment, unit commitment using priority ordering load dispatching and dynamic programming method.

TWO MARK QUESTIONS AND ANSWERS

1. **What is loadcurve?**
   Thecurvedrawn betweenthevariationsof load onthepowerstationwithreference totimeisknownasloadcurve.Therearethreetypes,Dailyloadcurve,Monthlyload curve, Yearly load curve.

2. **What is daily load curve?**

The curve drawnbetween the variations ofload with reference to various time period of day is known as dailyloadcurve.

3. **What ismonthly load curve?**

Itisobtainedfrom dailyloadcurve.Averagevalueofthepoweratamonthfora different time periods are calculated and plotted in the graph which isknown as monthly load curve.

4. **What is yearly load curve?**

Itis obtained frommonthly load curve which is used to findannualloadfactor.

5. **What is connected load?**

It is the sum of continuous ratings of all the equipments connected to supply systems.

6. **What isMaximumdemand?**

Itis the greatest demandofload on the power station during agivenperiod.

7. **What isDemand factor?**

Itis theratioof maximum demand to connectedload.
Demand factor= (max demand)/ (connectedload)

8. **What isAverage demand?**

Theaverage of loadsoccurringon thepowerstationin agivenperiod (day or month or year) is known as averagedemand.

Daily avg demand = (noofunits generated per day)/ (24 hours)

Monthly avg demand =(no of unitsgenerated in month)/ (noof hours in a month)
Yearly avgdemand = (no ofunits generated in a year)/ (no ofhours in ayear)

9. **What isLoadfactor?**

Theratioofaverageloadtothemaximumdemandduringagivenperiodisknown as load factor. Load factor= (average load)/ (maximumdemand)

10. **What isDiversityfactor?**

Theratioofthesum ofindividualmaximum demandonpowerstationisknownas diversity factor.

Diversity factor =(sumofindividual maximum demand)/(maximumdemand).

11. **What isCapacity factor?**

Thisistheratioofactualenergy producedtothemaximum possibleenergy that could have been produced during a given period.

Capacity factor= (actualenergy produced)/(maximumenergy that have beenproduced)

12. **What isPlant use factor?**

Itistheratio of units generated totheproductof plantcapacityandthenumberof hours for which the plantwas in operation.

Units generated perannum= average load * hours in a year

13. **What isLoadduration curve?(April 2015)**

Whentheloadelementsofaload curvearearrangedintheorderofdescending magnitudes thecurve then obtainedis calledload duration curve.

14. **Define Unit commitment?**

Commitment of minmum generator to meet the required demand.

15. **Define spinning reserve? (April 2015)(April /May 2014)**

It is the term describe the total amount of generation availability from all units synchronized on the system.

16. **What is meant by scheduled reserve?**

These include quick start diesel turbine units as well as most hydro units and pumped storage hydro units that can be brought online, synchronized and brought up to full capacity quickly.

17. **What are the thermal unit constraint?**

Minimum up time, minimum down time crew constraints.

18. **Define minimum up time?((April 2013)**

Once the unit is running, it should not be turned off immediately.

19. **Define minimum down time?(Nov 2013)**

Once the unit is decommited, there is a minimum time before it can be recommended.

20. **Define crew constraints?**

If a plant consist of two (or) more units, all the units cannot be turned on at the same time since there are not enough crew members to attend both units while starting up.

21. **What are the two approaches to treat a thermal unit to operating temperature?**

The first allow the unit boiler to cool down and then heat backup to operating temperature in time for a scheduled turn on. The second requires that sufficient energy be input to the boiler to just maintain operating temperature.

22. **What are the techniques for the solution of the unit commitment problem?(Nov 2013)**

Priority list method dynamic programming Lagrange relation

23. **What are the assumptions made in dynamic programming problem?**

A state consists of an array of units with specified units operating and the rest of the time. The startup cost of a unit is independent of the time it has been offline. There are no costs for shutting down the units.

24. **Define long range hydro scheduling problem?**

The problem involves the long range of water availability and scheduling of reservoir water releases. For an interval of time that depends on the reservoir capacities.

25. **What are the optimization technique for long range hydro scheduling problem?**

Dynamic programming composite hydraulic simulation methods statistical production cost.

26.**Define short range hydro scheduling problem?**

It involves the hour by hour scheduling of all generators on a system to achieve minimum production condition for the given time period.

27. **Define system blackout problem?**

If any event occurs on a system that leaves it operating with limits violated, the event may be followed by a series of further actions that switch other equipment out of service. If the process of cascading failures continues, the entire system of it may completely collapse. This is referred as system blackout.

28. **What is meant by cascading outages?**

If one of the remaining lines is now too heavily loaded, it may open due to relay action, thereby causing even more load on the remaining lines. This type of process is often termed as cascading outage.

29**. Define must run constraint?**

Some units are given a must run status during certain times of the year for reason of voltage support on the transmission network.

30**. Define fuel constraints?**

A system in which some units have limited fuel or else have constraints that require them to burn a specified amount of fuel in a given time.

31**. What are the assumptions made in priority list method?**

No load cost are zero unit input-output characteristics are linear between zero output and full load there are no other restrictions startup cost are affixed amount.

32.What is meant by linear sensitivity factor?

Many outages become very difficult to solve if it is desired to present the results quickly. Easiest way to provide quick calculation of possible overloads is linear sensitivity factors.

33.What are linear sensitivity factors?

Generation shift factors line outage distribution factors.

34.What is the uses of line distribution factor?

It is used to apply to the testing for overloads when transmission circuits are lost.

35.What is meant by external equvalencing?

In order to simplify the calculations and memory storage the system is sub divided into 3 sub systems called as external equvalencing.

36.Define max. likelihood criterion?

The objective is to maximize the probability that estimate the state variable x, is the true value of the state variable vector (i.e, to maximize the P(x)=x).

37.Define weighted least-squares criterion?

The objective is to minimize the sum of the squares of the weighted deviations of the estimated measurements z, from the actual measurement.

38.Define minimum variance criterion?

The objective is to minimize the expected value of the squares of the deviations of the estimated components of the state variable vector from the corresponding components of the true state variable vector.

39.State the adv of forward DP approach?

If the start up cost of a unit is a function of the unit is a function of the time it has been offline, then a forward dynamic program approach is more suitable since the previous history of the unit can be computed at each stage.

40.State the dis.adv of dynamic programming method?

It has the necessity of forcing the dynamic programming solution to search over a small number of commitment states to reduce the number of combinations that must be tested in **each period.**

41.What are the known values in short term hydro scheduling problem?

The load, hydraulic inflows & unit availabilities are assumed known. What is meant by telemetry system? The states of the system were measured and transmitted to a control center by means of telemetry system.

42.What are the functions of security constraints optimal power flow?

In this function, contingency analysis is combined with an optimal power flow which seeks to make changes to the optimal dispatch of generation. As well as other adjustments, so that when a security analysis is run, no contingency result in violations.

11 Marks

1. Enumerate the components of system load.(Nov-2013)

COMPONENT OF SYSTEM LOAD

System load characteristics

Load is a device that takes energy from the network. The load ranges from a few watt night lamps to mega watt induction motor.

The various load devices can be classified into the following categories

1. Motor devices
2. Heating equipment
3. Lighting equipment
4. A diversity of electronic gear.

From electrical point of view the multi use of devices are characterized by vast difference in regard to

i) Size
ii) Symmetry (single to three phase)
iii) Load constancy(with reference to time, frequency and voltage)
iv) Use cycle(regular or random use)

CHARACTERISTICS OF TYPICAL SYSTEM LOAD

1. Although individually of random type, the composite loads as we encounter at substation levels are of high predicable character.
2. Although the loads are time variant, the variations are relatively slow. From minute to minute, we have an almost constant load. A minute is a long time period compared with the electrical time constants of the power system and this permit us to consider the system operating in a steady state.
3. A typical load always consumes reactive power. Motors are always inductive(with exception of over-excited synchronous machines).
4. A typical load is always symmetric. In case of large motors (> few horse powers). This symmetry is automatic, since they are always designed for a balanced 3-phase operation. In case of single phase devices, the symmetry comes about by statistical effects and intentional distribution of loads between phases.

2. **Describe about the load curve and load duration curve. State the difference between these two curves and mention and the importance of these curves.(Nov 2013)**

LOAD CURVES

The curve showing the variation of load on the power station with respect to time is known as a load curve. It can be plotted o the graph taking load on Y-axis and time on X-axis.

Daily load curve:

The curve showing the variation of load on a whole day or 24 hours with respect to time is known as a daily load curve.

The load variations are recorded half-hourly 2 or hourly on a whole day(24 hours).

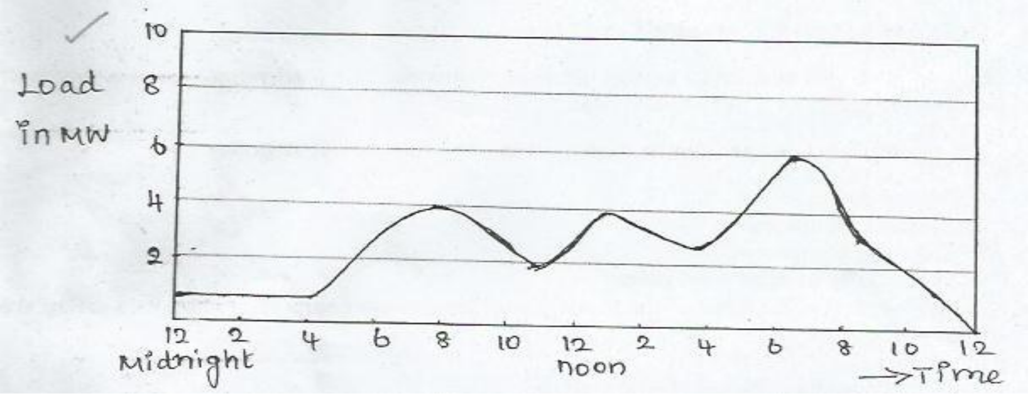


Figure 2.1 Daily load curve

The figure 2.1 shows a typical daily load curve of a power station. It is clear that load o the power station is varying, being maximum at 6 p.m. In this case it may be seen that load curve indicates at a glance. The general character of the load that is being imposed on the plant, such a clear representation cannot be determined from tabulated figures.

Monthly load curve:

The curve showing the variation of load of the month with respect to time is known as a monthly load curve.

It can be obtained from the daily load curves of that month. It can be plotted by calculating the average values of power over a month at different times of the day. It is used to fix the rates of energy or tariff.

Yearly load curve:

The curve showing the variation of load of the year with respect to time is known as a yearly or annual load curve.

It can be obtained from the monthly load curves of that year. It is used to determine the annual load factor.

Importance of load curve:

The daily load curves have obtained a great importance in generation as they supplythe following information readily

i) The daily load curve shows the variations of load on the power station during different hours of the day.

ii) The area under the daily load curve gives number of unit generated in the day. Units generated/day=area (in Kwh) under daily load curve.

iii) The highest point on the load curve represents the maximum demand on the station on the day.

iv) The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

Average Load = Area (in KWH) under daily load curve

----

24 Hours

v) The ratio of the area under the load curve in the total area of rectangle in which it is contained gives the load factor

Load Factor = Average load curve

Maximum demand

= Area (in KWH) under daily load curve

Total area of rectangle in which

vi) The load curve helps in selecting the size and number of generating units.

vii) The load curve helps in preparing the operation schedule of the station.

Load duration curve:

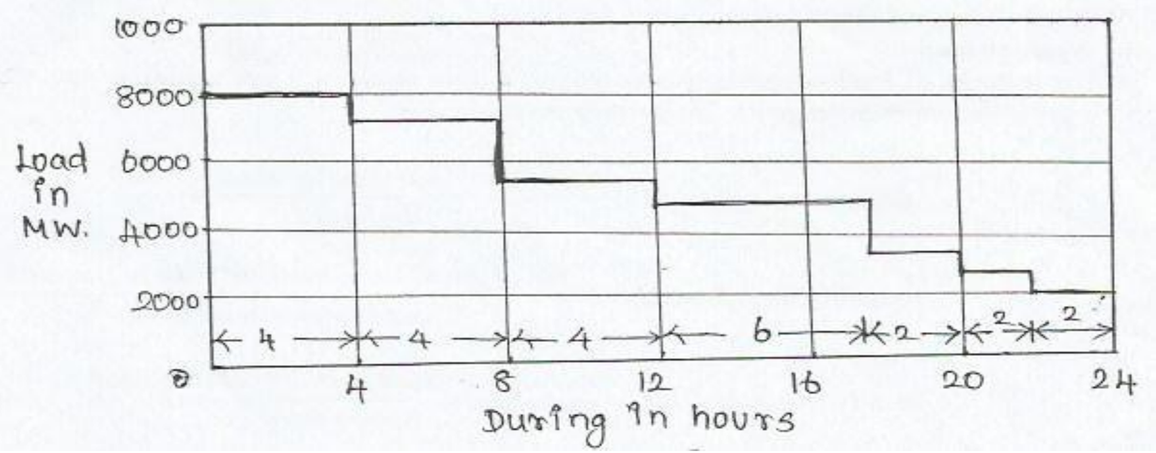


Figure 2.2 Load duration curve

When the load elements of a load curve are arranged in the order of descending magnitude curve thus obtained is called a load duration curve.

The load duration curve is obtained from the same data as the load curve but ordinates are arranged I the order of descending magnitudes. In other words, the maximum load is represented the left and the descending loads are represented to the right in descending order. Hence, the area under load duration curve and load curve are equal.

Fig 2.1 shows the daily load curve, it is clear from daily load curve that load elements in order of descending magnitude 20 MW for 8 hours, 15 MW for 4 hours and 5MW for 12 hours. Plotting this load in order of descending magnitude, we get the daily duration curve shown in fig2.2.

The following points may be noted about load duration curve:

1. The load duration curve gives the data in a more presented form. In other words, it readily shows the number of hours during which the given load has prevailed.
2. The area under the load duration curve is equal to that of the corresponding load curve. Obviously, area under daily load duration curve(in Kwh) will give the units generated in that day.
3. The load duration curve can be extended to include any period of time. By laying out the abscissa from 0 hour to 8760 hours, the variation and distribution of demand for an etire year can be summarized in one curve. The curve thus obtained is called annual load duration curve.

3. Describe how the base loads are classified.(Nov 2013)

Base load and peak load

The changing load on the power station makes its load curve of variable nature. Figure shows the typical load curve of a power station. It is clear that load on the power station varies from time to time. However a close look at the load curve reveals that load on the power station can be considered into two parts namely i) base load ii) peak load

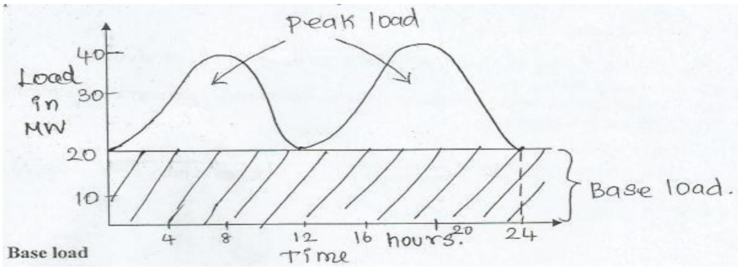


Figure 2.3 Base load and peak load

Base load:

The unvarying load which occurs almost the whole day on the station is known as base load.

Referring to the load curve it is clear that 20 MW of load has to be supplied by the station at all times of day and night i.e. throughout 24 hours. Therefore 20 MW is the base load of the station is almost of constant nature, therefore it can be suitably supplied without facing the problems of variable load.

Peak load:

The various peak demands of load over and above the base load of the station is known as peak load.

From fig it is clear that there are peak demands of load excluding base load. These peak demands of the station generally form a small part of the total load and may occur throughout the day.

Method of meeting the load:

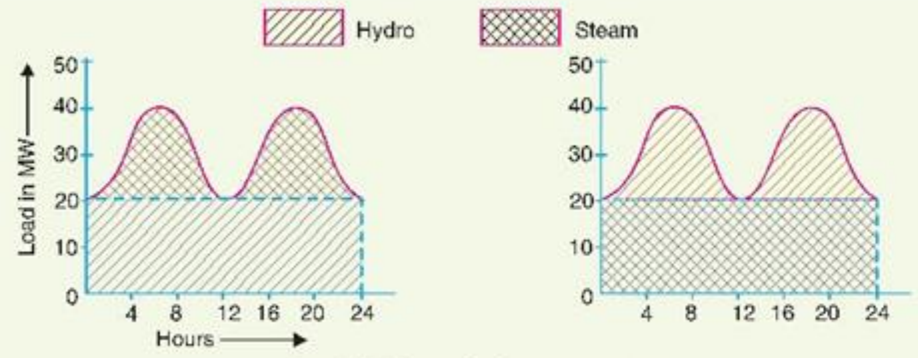
The total load on a power station consists of two parts viz base load and peak load. In order to achieve overall economy, the best method to meet load is to interconnect two different power stations. The more efficient plant is used to supply the base load is known as base load power station. The less efficient plant is used to supply the peak load is known as peak load power station. There is no hard and fast rule for selection of base load and peak load stations as it would depend upon the particular situation.

For example, both hydro-electric and steam power stations are quite efficient and can be used as base load as well as peak load to meet a particular requirement.

The interconnection of steam and hydro plant is a beautiful illustration to meet the load.

When water is available in sufficient quantity as in summer and rainy season, the hydro electric plant is used to carry the base load and the steam plant supplies the peak load as shown in the figure.

However, when the water is not available in sufficient quantity as in winter, the steam plant carries the base load, whereas the hydro electric plant carries the peak load as shown.



Load division on Hydro-steam system.

(*i*) High Flow day

(*ii*) Low Flow day

Fig. 3.14

Figure 2.4 Hydro-electric and steam power station used as base load as well as peak load

4. **Explain the least square fit method of forecasting the base loads.(April 2013)(April / May 2015)**

LOAD FORECASTING

The load on their systems should be estimated in advance. This estimation in advance is known as load forecasting. Load forecasting based on the previous experience without any historical data.

Forecasting of the base load by method of least square fit

The first obvious approximation which can be made is to assume a linear functional relationship. It may be assumed that the basic demand curve is closely approximately by a step function with a step length.

The data may be fitted into a regression equation of the form

$Y = a + b_1 T + b_2 W + b_3 L + b_4 P + F(t) + d$ ---------------------------------- (1)

Where

Y- demand at a fixed time each day

T,W,L,P- corresponding specific meterological factor

a, b_1 b_2 b_3 b_4 – constant

d – day of the week correction

F(t) – polynomial function of the week. The regression coefficient b_1 b_2 b_3 b_4 and d are to be estimated.

In the above equation more factors can be added or some may be removed, if necessary.

In the linear regression technique the data points are fitted into a linear equation of the type

$Y = a_0 + a_1 X$ ------------------ (2)

Where

Y - Dependent variable

X - Independent variable

In the least square curve of fitting method, we minimize the square of the deviation of the dependent variable from its actual to observed variable.

Let

$Y_i = a_0 + a_1 X_i$ ------------------ (3)

If n is the number of observations or data points

$\sum_{i=1}^{n} Y_i = n\, a_o + a_1 \sum_{i=1}^{n} X_i$ -------------------------- (4)

Dividing throughout by n gives

$\sum Y_i \,/\, n = a_o + a_1 \sum X_i \,/\, n$ ------------------------------ (5)

Since $\sum Y_i \,/\, n$, $\sum X_i \,/\, n$ are the mean values of Y & X respectively

$\bar{y} = a_o + a_1\bar{x}$-----------------------------(6)

Where, $\bar{y}$&$\bar{x}$ are the average values

$y_i = Y_i - \bar{y}$

$x_i = X_i - \bar{x}$---------------------------------- (7)

subtracting Y from both sides of equation (3)

$Y_i - \bar{y} = a_0 + a_1 X_i - \bar{y}$

$y_i = a_0 + a_1 X_i - \bar{y}$ -------------------------(8)

Sub (6) in (8)

$y_i = a_0 + a_1 X_i - (a_o + a_1\bar{x})$

$= a_1 (X_i - \bar{x})$

$y_i = a_1 x_i$ ----------------------(9)

i.e. a coordinate transformation is affected. The individual deviation becomes

$|d_i| = |y_i - a_1 x_i|$

and $D = \sum_{i=1} d_i^2 = \sum (y_i - a_1 x_i)^2$------------------------ (10)

to minimize D we get

$dD/da_1 = 0 = -2 \sum x_i (y_i - a_1 x_i)$

$\sum x_i y_i - a_1 \sum x_i^2 = 0$

$a_1 \sum x_i^2 = \sum x_i y_i$

(ie) $a_1 = \sum x_i y_i \,/\, \sum x_i^2$

$$a_1 = \frac{\sum (X_i - \bar{x}) \times \sum (Y_i - \bar{y})}{\sum (X_i - \bar{x})^2} \quad \text{-------------------------- (11)}$$

Then we have found a_1.

$\bar{y} = a_o + a_1\bar{x}$. we get a_0 as $a_0 = Y - a_1 X$

Also $$a_1 = \frac{n\sum X_i Y_i - \sum X_i Y_i}{n \sum X_i^2 - (\sum X_i)^2}$$

$$a_o = \frac{\sum \bar{y} - a_1 \sum X_i}{n}$$

Let us consider $\sum_{i=1}^{n} X = 0$

$a_o = 1/n \ \sum_{i=1}^{n} Y_i$ ------------------- (12)

$$a_1 = \frac{\sum_{i=1}^{n} Y_i X_i}{\sum_{i=1}^{n} X_i^2} \quad \text{---------------------(13)}$$

We are able to compute the constants a and b so as to minimize the error in load forecasting.

METHOD OF LEAST SQUARE

Some of the standard analytical functions are used in trend curve fitting including

1. Straight line
2. Parabola
3. S – curve
4. Exponential
5. Gompertz

By method of exponential form

The expression demand may be expressed by the analytical function.

$P_{Di} = e^{a+b(x_i - x_0)}$

$= e^{a+bX_i}$ ------------ (1)

Where

P_{Di} = Peak load in MW in ith year

x_i = the ith year in which peak load P_{Di} is considered.

x_0 = the basic year.

$X_i = x_i - x_0$

Taking natural log of equation (1)

$\ln P_{Di} = a + bx_i$

$y_i = a + bx_i$ ----------------------- (2)

Where

$Y_i = \ln P_{Di}$ ------------------------- (3)

Let us consider that from the historical data the peak demands for the consecutive n year are

$P_{D1}, P_{D2} \ldots\ldots\ldots\, P_{Dn}$

Therefore from eqn 3

$Y_1 = \ln P_{D1}$

$Y_2 = \ln P_{D2}$

$Y_n = \ln P_{Dn}$

Corresponding to various values of x_i, there are randomly distributed depicted in fig for an exponential growth as in equation (2)

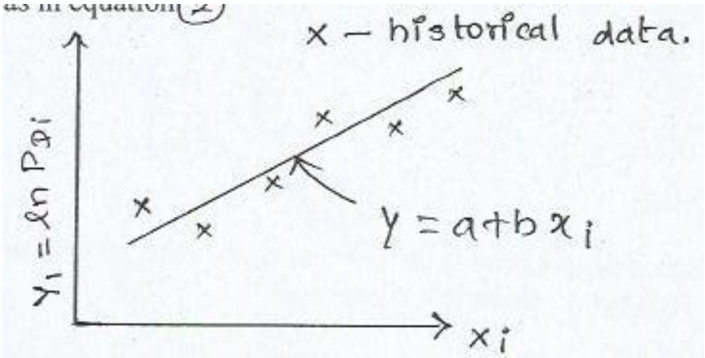


Figure 2.5 Exponential growth of Y

$y_i = a + bx_i$

$| \ d_i \ | = | \ y_i – (a + bx_i) \ |$

In order to predict the demand correctly the sum of the square of the error should be minimum

(ie) $s = \sum^{n}_{i=1} d_i^2 = \sum^{n}_{i=1} [\ y_i – (a + bx_i) \ ]^2$ --------------- (4)

To minimize s we get

$rs/ra = 0$ & $rs/rb = 0$ ----------- (5)

Diff (4) w.r.t a

$rs/ra = \sum^{n}_{i=1} 2 \ [\ y_i – (a + bx_i) \ ] \ (-1) = 0$

$\sum^{n}_{i=1} [\ y_i – (a + bx_i) \ ] = 0$

$\sum^{n}_{i=1} \ y_i = \sum^{n}_{i=1} (a + bx_i)$

$= na + b \sum^{n}_{i=1} \ x_i$ --------------- (6)

Diff equ (4) w.r.t b

$rs/rb = \sum^{n}_{i=1} 2 \ [\ y_i – (a + bx_i) \ ] \ (-x_i) = 0$

$\sum^{n}_{i=1} \ (a + bx_i) \ x_i \ ] - x_i \ y_i = 0$

$\sum^{n}_{i=1} x_i \ y_i = \sum^{n}_{i=1} (a + bx_i)$

$= a \sum^{n}_{i=1} x_i + b \sum^{n}_{i=1} x_i^2$ ------------- (7)

Hence the conditions for the sum of the least square for the error (deviation) to be minimum are given by the above two equations.

Let us consider

$\sum_{i=1}^{n} x_i = 0$ -------------- (8)

Sub (8) in (6) , (7)

$\sum_{i=1}^{n} y_i = na$

$a = 1/n \sum_{i=1}^{n} y_i$ --------------- (9)

$\sum_{i=1}^{n} x_i y_i = b \sum_{i=1}^{n} x_i^2$

$$b = \frac{\sum_{i=1}^{n} x_i^2}{\sum_{i=1}^{n} x_i y_i} \text{ ------------------ (10)}$$

From eqn (9) and (10) we are able to compute the constant a and b so as to minimize the error in load forecasting.

6. **Describe the unit commitment Problem and the constraints associated with it.(April 2013)(Nov 2012)**

Power systems have grown in size and complexity. In power system, the total generation on the system will generally be higher than total load on the system. The total load on the system will generally be higher during the day time and early evening and lower during the early morning and late evening. It is not economical to run all the units available all the time. So, the commitment of a generating unit is difficult. The cost of the system can be saved by turning off generators when they are not needed.

Generating units can be broadly divided into two groups namely thermal and hydro plants. The operation of thermal units involves both full and maintenance cost but no fuel cost is required for hydro plants. Thermal units include steam plants, nuclear plant, diesel and gas turbine plants are used as peak loads.

NEED FOR UNIT COMMITMENT

- Enough units will be committed to supply the system load
- To reduce the loss or fuel cost
- By running the most economic unit, the load can be supplied by that unit operating closer to its best efficiency.
- Difficulties to find unit commitment solution
- Time consuming process
- If the number of units is more, the number of combinations is more in a complex bus system
- If n be the number of units, then the number of combinations will be 2^{n-1}.

STATEMENT OF UNIT COMMITMENT PROBLEM

To select the generating units that will supply the forecasted (estimated load in advance) load of the system over a required period of time at minimum cost as well as provide a specified margin of the operating reserve. This procedure is known as unit commitment.

Tomorrow's unit commitment problem may be stated as follows

Given:

The expected system demand level for the 24 hours of tomorrow and the operating cost, start-up cost and shut-down cost of the available N units.

To determine:

If N generating units, (2^{N-1}) number of combinations will be obtained. From may feasible subset, determine the subset of units that would satisfy the expected demand at minimum operating cost.

Loads vary from time to time. So we are interested. Not only I determining the subset of units satisfying economically the demand in one particular hour .We want 24 subsets to satisfy the 24 consecutive hour demands per day. This involves consideration of start-up cost and shut-down costs as well as constraints on minimum up time /down time of the units.

For unit commitment problems, we consider

- A short term load forecast
- System reserve requirements
- System security
- Start up cost for all units
- Minimum level fuel cost for all units
- Incremental fuel costs of units
- Maintenance cost

CONSTRAINTS IN UNIT COMMITMENT

Each individual power system may impose different rules on the scheduling of units depends on generation make up and load curve characteristics etc. The constraints to be considered for unit commitment are **Spinning reserve**

Thermal constraints:

-Minimum uptime

-Minimum down time

-Crew constraint

Other constraint:

-Hydro constraint

-Must run constraint

-Fuel constraint

Spinning Reserve:

Spinning Reserve is the total amount of generation available from all units synchronized on

The system minus the present load and losses being supplied

Spinning Reserve= total amount of generation - present load +losses

Spinning Reserve must be established so that the loss of one or more units does not cause drop in the system frequency. i.e. if one unit is lost, the Spinning Reserve unit has to make up for the loss in a specified time period.

Spinning Reserve is the reserve generating capacity running at no load.

Reserve has

- To avoid transmission system limitations or bottling of reserves
- To allow some parts of the system to run as islands (some area electrically disconnected)

Reserve capacity:

Capacity in excess of that required to carry peak load

Cold reserves:

It is that reserve generating capacity which is available for service but is not in operation.

Hot reserves:

It is that reserve generating capacity which is in operation but is not in service.

Reserve generating capacity:

The amount of power that can be produced at a given point in time by generating units that are kept available in case of special need. The capacity may be used when unusually high power demand occurs or when other generating units are off-line for maintenance, repairs or refueling.

Reserve generating capacity include quick-start diesel or gas turbine unit or hydro units and pumped storage hydro units that can be brought on-line, synchronized and brought upto full capacity quickly.

Automatic generation control system is used to make up for a generation unit failure and to restore frequency and interchange power through tie-line quickly in the event of generating unit outage.

Reserve margin:

The percentage of installed capacity exceeding the excepted peak demand during a specified period.

Typical rules for spinning reserve set by regional reliability council

- Reserve must be given percentage of forecasted peak demand
- Reserve must be capable of making up the loss of the most heavily loaded unit in a given period of time
- Calculate reserve requirements as a function of the probability of not having sufficient generation to meet the load.

Thermal unit constraints:

A thermal unit can withstand only gradual temperature changes and is required to take some hours to bring the unit on-line. For thermal plants, one hour is the smallest time period that should be considered for unit commitment solution as the start-up and shut-down time for many units is of this order.

The thermal unit constraints are minimum up time, minimum down time and crew constraints.

Minimum up time:

Once the unit is running, it should not be turned off immediately.

Minimum down time:

Once the unit is decommited, there is a minimum time before it can be recommitted.

Crew constraints:

If a plant consists of two or more units, they cannot both be turned on at the same time. Since there are not enough crew members to attend both units while starting up.

Start-up cost:

It is independent upon the down time of the unit i.e. the time interval between shut down and restart.

Start up cost=0, if unit is stopped and started immediately.

a) Start up cost when cooling:

During down-time period, the units' boiler to cool down and then heat backup to operating temperature in time for a scheduled turn on.

Start up cost α cooling of the unit

Start up cost when cooling = $C_c\ (1 - e^{-t/\alpha}) \times F + C_f$

Where,

C_c = cold start cost.

F = Fuel cost.

C_f = Fixed cost.

t = thermal time constant for the unit.

α = time in which the unit was cooled.

b) Start up cost when banking (shut down cost):

During the shut-down period, the boiler may be allowed to cool down and thus no shut cost will be incurred.

Banking requires the sufficient energy to input to the boiler to just maintain operating temperature and pressure.

Start of when banking = $[\ C_t \times t \times F\ ] + C_f$

Where,

C_t = cost of maintaining unit at operating temperature.

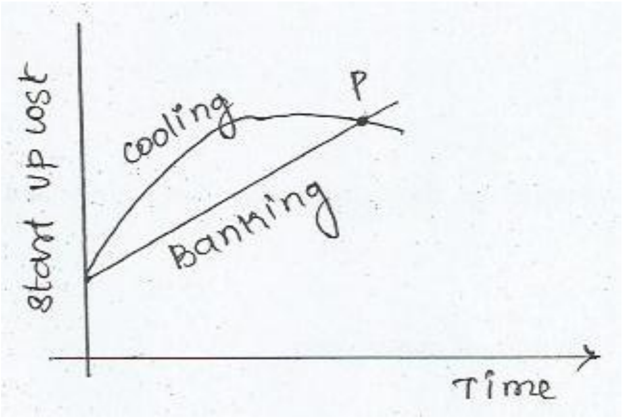


Figure 2.6 start up cost VS Time during cooling and banking period

Fig shows the start up cost Vs time during cooling and banking period. Upto point p cost of banking < cost of cooling.

When the shut down cost is incurred, the unit may be said to be in hot-reserve. Finally, the capacity limits of thermal units may change frequently, so we must consider the thermal constraints for solving unit commitment.

Other constraints

Hydro – constraints:

Unit commitment problem involves only thermal units. In hydro thermal scheduling, to allocate maximum hydro units during rainy seasons and to allocate thermal units during remaining periods. We are not considering hydro units for unit commitment because start up and shut down time, operating costs are negligible. So we can’t get the optimal solution.

Must run constraints:

Some units like nuclear units are given a must run status during certain times of the year to maintain the voltage in the transmission system.

Fuel constraints:

If thermal and hydro sources are available, a combined operation is economic and advantageous i.e. to minimize the fuel cost of thermal unit over a commitment period.

A system in which some units have limited fuel, or else have constraints that require them to burn a specified amount of fuel in a given time, presents a most challenging unit commitment problem.

6. Explain the priority list method used for solving unit commitment problem.(Nov 2013)

UNIT COMMITMENT SOLUTION METHODS

For solving unit commitment problems, we should consider the following

- To form loading pattern for M-periods using load curve
- Commit possible number of units to be operated to meet out the load
- To determine the load dispatch for all feasible combinations of solutios for each load level and satisfied operating limits of each units.

Priority list method (using full load average production cost(FLAPC))

- Priority list method is the simplest unit commitment solution method which consists of creating a priority list unit.
  - The priority list can be obtained by noting full load average production cost of each unit.
- full load average production cost= net heat rate at full load × fuel cost

$$\text{FLAPC} = \frac{C_i\,(P_{Gi})}{(P_{Gi})}$$

$$= \frac{K\,H_i\,(P_{Gi})}{(P_{Gi})}$$

Assumptions

- No load costs are zero
- Unit input-output characteristics are linear between zero output and full load
- Start-up costs are a fixed amount
- Ignore minimum up time and minimum down time

Steps to be followed (or) method of solving

1. Determine the full load average production cost for each units

$$\text{FLAPC} = \frac{K\,H_i\,(P_{Gi})}{(P_{Gi})}$$

2. Form priority order based on average production cost(ascending order).

3. Commit number of units corresponding to the priority order

4. Calculate P_{G1}, P_{G2}, ……. P_{GN} from economic dispatch problem for the feasible combinations only

5. For the load curve shown, each hour load is varying

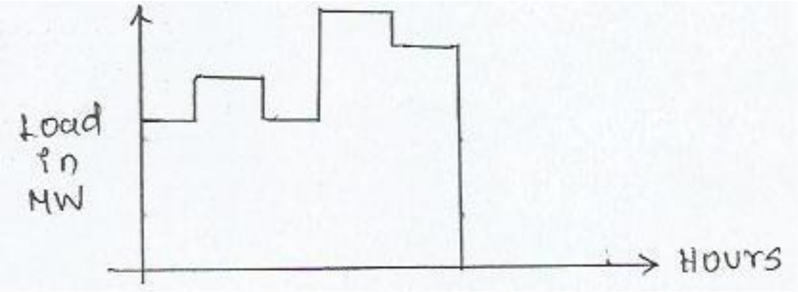


Figure 2.7 Load curve

Assume load is dropping or decreasing, determine whether dropping the next unit will supply generation and spinning reserve

If not, continue as it is

If yes, go to next step

6. Determine the number of hours H, before the unit will be needed again
7. Check H< minimum shut down time
   If yes, go to last step

   If not, go to next step

8. Calculate two costs
   1. Sum of hourly production costs for the next H hours with the unit
   2. Recalculate the same for the unit down + start up cost for either coolig or banking
      If the second case is less expensive, the unit should be on

9. Repeat this procedure until the priority list

Merits:

1. No need to go for N combinations
2. Take only one constraints
3. Ignore the minimum up time and downtime
4. Complication reduced

Demerits:

1. Start-up costs are fixed amount
2. No load costs are not considered.

7. Explain the Dynamic Programming method used for solving unit commitment problem

Forward DP – Algorithm to run forward in time from the initial hour to the final hour

Backward DP - Algorithm to run backward in time from the final hour to the initial hour

The recursive algorithm to compute the minimum cost in hour K with combination I is

$$F_{\cos t}(K,I) = \min_{\{L\}}\left[P_{\cos t}(K,I) + S_{\cos t}(K-1,L:K,I) + F_{\cos t}(K-1,L)\right]$$

$F_{cost}(K,I)$ = Least cost to arrive at state (K,I)

$P_{cost}(K,I)$ = Production cost for state (K,I)

$S_{cost}(K-1,L:K,I)$ = transition cost from (K-1,L) to state (K,I)

Transition from one state at a given hour to a state at the next hour,

State (K,I) = I^{th} combination in hour K

L = “N” feasible states in interval K-1.

Let X be the no of states to search each period

Let N be the no of strategies or paths , to save at each period

Consider two units are running and three feasible combinations as shown below

With Priority list ordering, reducing number by discarding the highest cost schedules at each time interval and saving only the lowest N paths. The flowchart is shown below

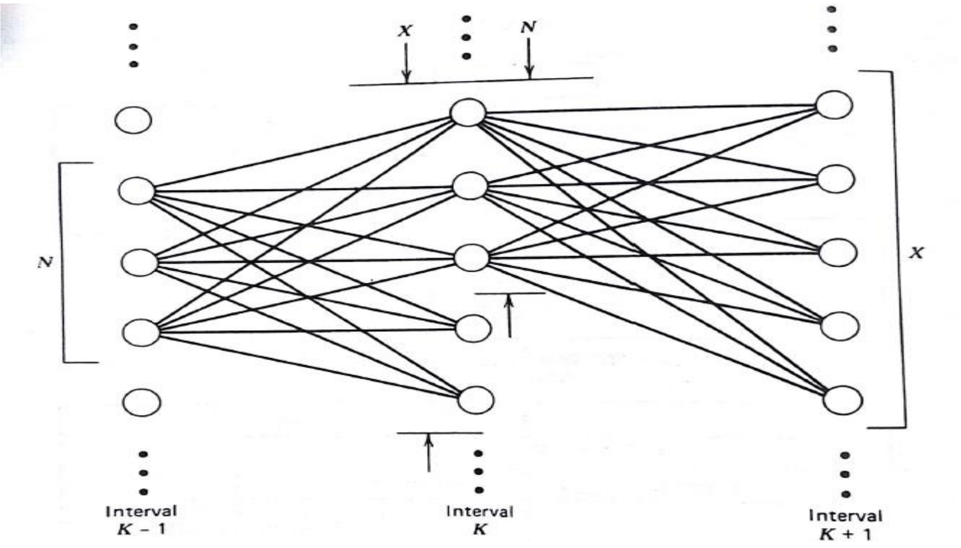
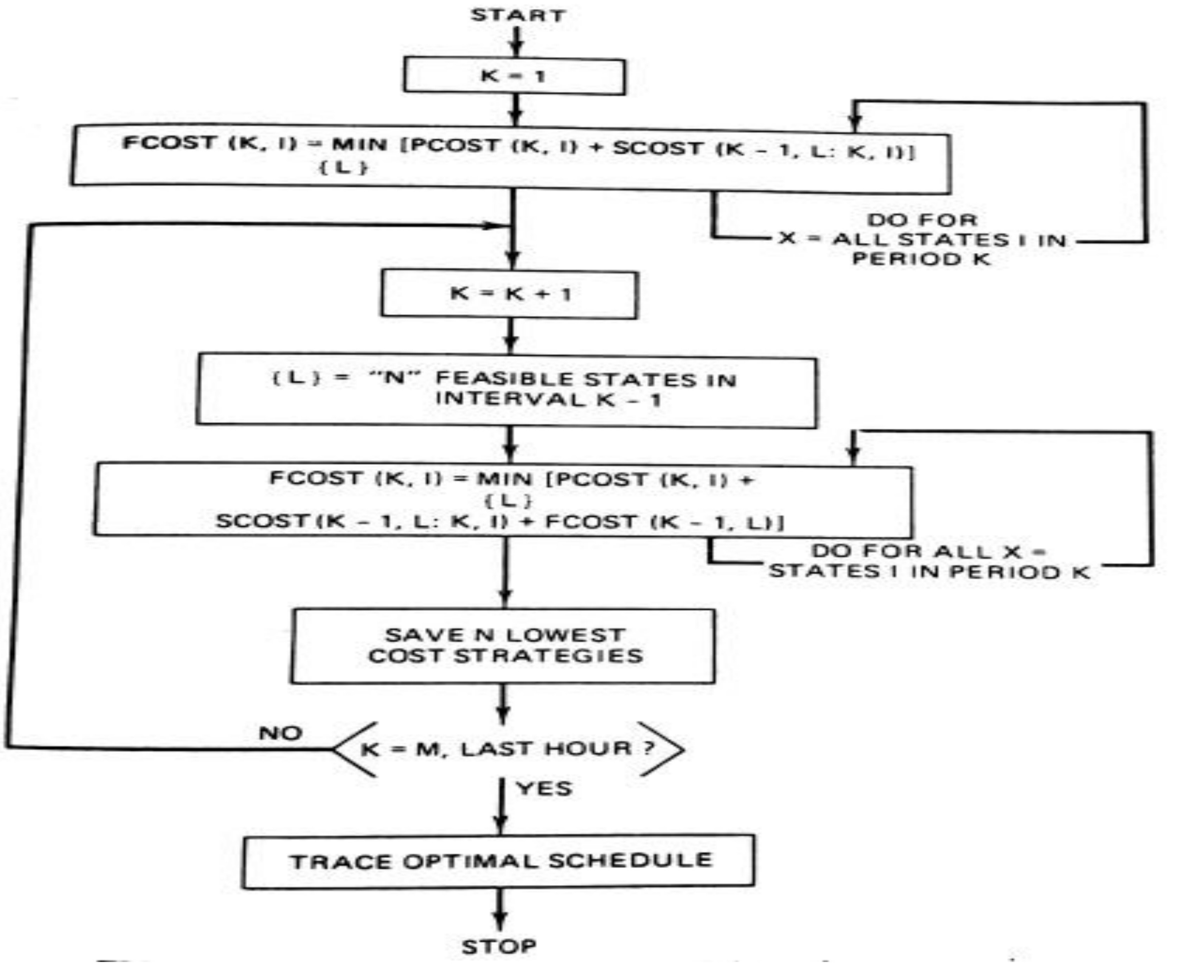


Fig: Dynamic Programming algorithm with N=3 and X=5



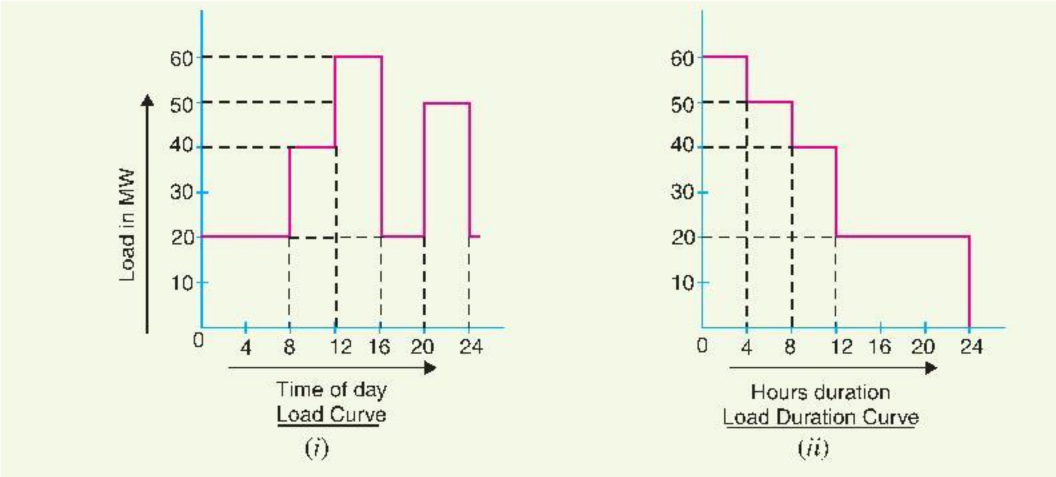
Problems:

1) A power station has the following daily load cycle :

Time in Hours	6 —8	8 —12	12 —16	16 —20	20 —24	24 —6
Load in MW	20	40	60	20	50	20

Plot the load curve and load duratoin curve. Also calculate the energy generated per day

Solution. Fig. 3.9 (i) shows the daily load curve, whereas Fig. 3.9 (ii) shows the daily loadduraton curve. It can be readily seen that area under the two load curves is the same. Note that loadduration curve is drawn by arranging the loads in the order of descending magnitudes.



Units generated/day = Area (in kWh) under daily load curve

$= 10^3 [20 \times 8 + 40 \times 4 + 60 \times 4 + 20 \times 4 + 50 \times 4]$

$= 840 \times 103$ kWh

2) A proposed station has the following daily load cycle :

Time in hours	6—8	8—11	11—16	16—19	19—22	22—24	24—6
Load in MW	20	40	50	35	70	40	20

Draw the load curve and select suitable generator units from the 10,000, 20,000, 25,000, 30,000 kVA. Prepare the operation schedule for the machines selected and determine the load factor from the curve

Solution. The load curve of the power station can be drawn to some suitable scale as shown in Fig. 3.12.

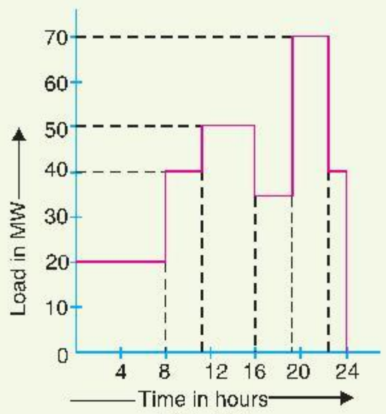


Fig. 3.12

Units generated per day = Area (in kWh) under the load curve

$= 10^3 [20 \times 8 + 40 \times 3 + 50 \times 5 + 35 \times 3 + 70 \times 3 + 40 \times 2]$

$= 10^3 [160 + 120 + 250 + 105 + 210 + 80]$ kWh

$= 925 \times 10^3$ kWh

Average load $= (925 \times 10^3/24) = 38541{\cdot}7$ kW

Load factor $= (38541{\cdot}7 / 70 \times 10^3) \times 100 = 55{\cdot}06\%$

Selection of number and sizes of units : Assuming power factor of the machines to be 0•8, the output of the generatingunits available will be 8, 16, 20 and 24 MW. There can beseveral possibilities. However, while selecting the size and number of units, it has to be borne in mind that (i) one set of highestcapacity should be kept as standby unit (ii) the units shouldmeet the maximum demand (70 MW in this case) on the station(iii) there should be overall economy.

Keeping in view the above facts, 4 sets of 24 MW each maybe chosen. Three sets will meet the maximum demand of70 MW and one unit will serve as a standby unit.

Operational schedule. Referring to the load curve shownin Fig. 3.12, the operational schedule will be as under :

(i) Set No. 1 will run for 24 hours.

(ii) Set No. 2 will run from 8.00 hours to midnight.

(iii) Set No. 3 will run from 11.00 hours to 16 hours and again from 19 hours to 22 hours

3) A base load station having a capacity of 18 MW and a standby station having acapacity of 20 MW share a common load. Find the annual load factors and plant capacity factors oftwo power stations from the following data :

Annual standby station output= 7·35 × 106 kWh

Annual base load station output= 101·35 × 106 kWh

Peak load on standby station= 12 MW

Hours of use by standby station/year = 2190 hours

Solution.

Installed capacity of standby unit

= 20 MW = 20 × 103 kW

Installed capacity of base load plant

= 18 MW = 18 × 103 kW

Standby station

$$\text{Annual load factor} = \frac{\text{kWh generated / annum}}{\text{Max.demand} \times \text{Annual working hours}} \times 100$$

$$= \frac{7.35*10^6}{(12*10^3)*2190} \text{ x } 100 = 28\%$$

$$\text{Annual plant capacity factor} = \frac{\text{kWh output / annum}}{\text{Installed capacity} \times \text{Hours in a year}} \times 100$$

$$= \frac{7.35*10^6}{(20*10^3)*8760} \text{ x } 100 = 4.2\%$$

Base load station. It is reasonable to assume that the maximum demand on the base load station is equal to the installed capacity (i.e., 18 MW). It operates throughout the year i.e., for 8760 hours.

∴Annual load factor $=(101{\cdot}35 \times 10^6)/[(18 \times 10^3) \times 8760] = 64{\bullet}2\%$

As the base load station has no reserves above peak load and it is in continuous operation, therefore, its capacity factor is also 64.2%.

4 .Determine Priority list using Full load average production cost for the given data

Unit No.	**Loading Limits**		**Fuel cost Parameter**			**Fuel cost**
	Min	**Max**	**a_i**	**b_i**	**c_i**	
1	100	400	0.006	7	600	1.1
2	50	300	0.01	8	400	1.2
3	150	500	0.008	6	500	1.0

Solution:

$H_1 = 0.006P^2_{G1} + 7\ P_{G1} + 600$

$H_2 = 0.01P^2_{G2} + 8\ P_{G2} + 400$

$H_3 = 0.008P^2_{G3} + 6\ P_{G3} + 500$

FLAPC$_1$ = K$_1$ x $\frac{H_1 P_{G1}}{P_{G1}}P_{G1}$ = P$_{G1,max}$

$$= \frac{1.1[0.006\,X\,400^2 + 7X400 + 600]}{400} = 11.99$$

FLAPC$_2$ = K$_2$ x $\left.\frac{H_2 P_{G2}}{P_{G2}}\right|P_{G2}$ = P$_{G2,max}$

$$= \frac{1.2[0.01\,X\,300^2 + 8X300 + 400]}{300} = 14.8$$

FLAPC$_3$ = K$_3$ x $\left.\frac{H_3 P_{G3}}{P_{G3}}\right|P_{G3}$ = P$_{G3,max}$

$$= \frac{1.0[0.008\,X\,500^2 + 6X500 + 500]}{500} = 11$$

Priority order: (Arrange FLAP in ascending order)

Unit	**FLAPC**	**Min(MW)**	**Max(MW)**
3	11	150	500
1	11.99	100	400
2	14.8	50	300

Unit Commitment

Combination	Minimum MW from Combination	Maximum MW from Combination
3+1+2	300	1200
3+1	250	900
3	150	500

All the three units would be held on until the load reached 900MW. Units 1 and 3 would be held on until the load reached 500MW, then unit 1 would be dropped.

Pondicherry University Questions

2 MARKS:

1. What is loadcurve?
2. What is daily load curve?
3. What ismonthly load curve?
4. What is yearly load curve?
5. What is connected load?

6. What isMaximumdemand?

7. What isDemand factor?

8. What isAverage demand?

9. What isLoadfactor?

10. What isDiversityfactor?

11. What isCapacity factor?

12. What isPlant use factor?

13. What isLoadduration curve?(April 2015)

14. Define Unit commitment?

15. Define spinning reserve? (April 2015)(April /May 2014)

16. What is meant by scheduled reserve?

17. What are the thermal unit constraint?

18. Define minimum up time?((April 2013)

19. Define minimum down time?(Nov 2013)

20. Define crew constraints?

21. What are the two approaches to treat a thermal unit to operating temperature?

22. What are the techniques for the solution of the unit commitment problem?(Nov 2013)

23. What are the assumptions made in dynamic programming problem?

24. Define long range hydro scheduling problem?

25. What are the optimization technique for long range hydro scheduling problem?

26.. Define short range hydro scheduling problem?

27. Define system blackout problem?

28. What is meant by cascading outages?

29. Define must run constraint?

30. Define fuel constraints?

31. What are the assumptions made in priority list method?

32.What is meant by linear sensitivity factor?

. 33. What are linear sensitivity factors?

34. What is the uses of line distribution factor?

35. What is meant by external equvalencing?

36. Define max. likelihood criterion?
37. Define weighted least-squares criterion?
38. Define minimum variance criterion?
39. State the adv of forward DP approach?
40. State the dis.adv of dynamic programming method?
41. What are the known values in short term hydro scheduling problem?
42. What are the functions of security constraints optimal power flow?

11 MARKS

1. Enumerate the components of system load.(Nov-2013)
2. Describe about the load curve and load duration curve. State the difference between these two curves and mention and the importance of these curves.(Nov 2013)
3. Describe how the base loads are classified.(Nov 2013)
4. Explain the least square fit method of forecasting the base loads.(April 2013) (April / May 2015)
5. Describe the unit commitment Problem and the constraints associated with it.(April 2013)(Nov 2012)
6. Explain the priority list method used for solving unit commitment problem.(Nov 2013)

REFERENCE BOOKS

1. Olle I. Elgerad, “Electric Energy System Theory and Introduction”, Tata Mc Graw Hill publishing company, New Delhi, 2nd edition, 2004.
2. Allen J.Wood, Bruce F. Wollenbarg, “Power Generation, operation and control”,2nd edition, John Wiley and sons, 2008.
3. D.P.Kothari and I.J.Nagrath, " Modern Power System Analysis” Tata Mc Graw Hill publishing company Ltd., 2003.
4.A.K.Mahalanbias, D.P.Kothari & S.I.Ahson, "Computer Aided Power System Analysis

and Control" Tata Mc Graw Hill publishing company, New Delhi, 1990.
5. P.S.R. Murty, "Operation and Control in Power Systems" BS Publications, 2005.
6. M. Geraldin Ahila, “Power System Operation and Control” ARS Publications,2008.

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ASPIRE TO EXCEL
ISO 21001

UNIT III: ACTIVE POWER CONTROL

Power control mechanism of individual machine; mathematical model of speed governing mechanism, speed load characteristics of governing mechanism; Regulation of two generators in parallel; Division of power system into control areas; LFC control of a single area; static and dynamic analysis of uncontrolled system; proportional plus integral control of a single area; LFC control of two area system - uncontrolled case, static and dynamic response; Tie line with frequency bias control of two area.

PART A

TWO MARK QUESTIONS AND ANSWERS

1. **What is the function of LFC?**
   The function of load frequency control on a power system is to change the control valve or gate open of the prime movers as a function of load variation in order to hold system frequency constant.

2. **How is the real power in a power system controlled?**
   The real power in a power system is controlled by controlling the driving torques of the individual turbines of the system.

3. **How can the flow of high pressure steam controlled?**
   By controlling the position of the control valve or gate , control can be exerted over the flow of high pressure steam through the turbine.

4. **What is meant by fly ball speed governor?**
   This is a purely mechanical speed sensitive device coupled directly to the hydraulic amplifier which adjusts the control valve opening via the linkage mechanism.

5. **What is the purpose of speed changer?**
   The speed changer makes it possible to restore the frequency to the initial value after operation of the speed governors have steady state characteristics.

6. **Define inertia constant?**
   inertia constant, H is defined as the ratio of kinetic energy stored in the rotor to the MVA rating of the generator.

$$H=\frac{Wk.E}{Pr}$$

H= inertia constant

$W_{K.E}$= kinetic energy

Pr= rated MVA rating of the generator

7. What is the major controlloopsused in large generators?

The major controlloopsused in largegenerators are

1. Automatic voltage regulator (AVR)
2. Automatic load frequency control (ALFC).

8. What is the use ofsecondary loop?

Aslowersecondaryloopmaintainsthefineadjustmentofthefrequency,andalso byresetactionmaintainsproperMW interchangewithotherpoolmembers.Thisloopis insensitivetorapidload andfrequencychangesbutfocusesinsteadondriftlikechanges which take place over periods of minutes.

9. What is the adv of AVRloop over ALFC?

AVRloopismuchfasterthantheALFCloopandtherefore thereisatendency,for the VR dynamicstosettledown beforetheycanmakethemselvesfeltintheslowerload frequency control channel.

10. What is the diff. between large and small signal analysis?

Large signalanalysis is used where voltage andpowermayundergosudden changes ofmagnitudethatmayapproach100percent of operating values.Usuallythistypeof analysis leads to differential equations of non-lineartype. Smallsignal anaysis isusedwhen variableexcursionsarerelativelysmall,typicallyatmostafewpercentof normaloperating values.

11. What is the exciter?

TheexciteristhemaincomponentinAVRloop.ItdeliverstheDC powertothe generatorfield.Itmusthaveadequatepowercapacity andsufficientspeedofresponse (rise time lessthan 0.1 sec).

12. What is the functionof AVR?

Thebasic roleof theAVR istoprovideconstancyof thegeneratorterminalvoltage during normal, small and slow changes in the load.

13. Explain about staticAVR loop?

InastaticAVRloop,theexecutionpowerisobtaineddirectlyfrom thegenerator terminals or fromthe station service bus. The AC power is rectified bythyristor bridges and fedintothemaingeneratorfieldviasliprings.Staticexciters areveryfastandcontributeto proved transientstability.

14. Writethe static performance ofAVR loop?

TheAVRloopmustregulatetheterminal|V|towithinrequiredstatic accuracy limit. Have sufficient speed ofresponse. Be stable.

15. What is the disadvantage of high loopgain? Howis to be eliminated?

Highloopgainisneededforstatic accuracybutthiscauses undesirabledynamic response,possiblyinstability.ByaddingseriesAND/ORfeedbackstabilitycompensation to the AVR loop, thisconflictingsituation can beresolved.

16. What are the effects of generator loading inAVR loop?

Addedloaddoesnotchangethebasicfeatures of theAVRloop,itwillhowever affectthevaluesofbothgainfactorKf andthefieldconstant.Highloadingwillmakethe generatorworkathigher magneticsaturationlevels.Thismeanssmallerchangesin |E|for incremental increases in if,translatinginto thereductionof KF.Thefield timeconstantwill likewisedecreasesasgeneratorloadingclosing thearmaturecurrentpaths.This circumstancepermitstheformationof transient statorcurrentstheexistenceof whichyields a lower effective field induction.

17. What are the functions of ALFC?

ThebasicroleofALFC‟sistomaintaindesiredMWoutputofagenerator unit andassistincontrollingthefrequencyoflargeinterconnection.TheALFCalsohelpsto keepthenet interchange of power betweenpoolmembersatpredeterminedvalues.Control shouldbeapplied insuch afashion thathighlydifferingresponsecharacteristicsof unitsof varioustypes are recognized. Also unnecessary poweroutputchanges shouldbe kept ata minimum in ordertoreduce wearof controlvalves.

18. Specifythe dis.advof ALFC loop?

The ALFC loop will main control only during normal changes in load and frequency.Itistypicallyunableto provideadequatecontrolduringemergencysituations, when largeMWimbalances occur.

19. Howis the realpower in a power system controlled?

Therealpowerinapowersystemisbeingcontrolledbycontrolling thedriving torque of theindividual turbines of the system.

20. What isthe need forlarge mechanicalforces in speed-governing system?

Verylarge mechanicalforcesareneededtoposition themainvalveagainstthehigh streampressure and these forces areobtained via several stages of hydraulicamplifiers

21. What is the control loops used in large generators?

The major control loops used in large generators are 1.automatic voltage regulator (AVR) 2.automatic load frequency control (ALFC).

22. What is the use of secondary loop?

A slower secondary loop maintains the fine adjustment of the frequency, and also by reset action maintains proper MW interchange with other pool members.

This loop is insensitive to rapid load and frequency changes but focuses instead on drift like changes which take place over periods of minutes.

23. What is the adv of AVR loop over ALFC?

AVR loop is much faster than the ALFC loop and therefore there is a tendency, for the AVR dynamics to settle down before they can make themselves felt in the slower load frequency control channel.

24. What is the difference between large and small signal analysis?

Large signal analysis is used where voltage and power may undergo sudden changes of magnitude that may approach 100 percent of operating values. Usually this type of analysis leads to differential equations of non-linear type. Small signal analysis is used when variable excursions are relatively small, typically at most a few percent of normal operating values.

25. What is the exciter?

The exciter is the main component in AVR loop. It delivers the DC power to the generator field. It must have adequate power capacity and sufficient speed of response (rise time less than 0.1 sec).

26. What is the function of AVR?

The basic role of the AVR is to provide constancy of the generator terminal voltage during normal, small and slow changes in the load.

27. Explain about static AVR loop?

In a static AVR loop, the execution power is obtained directly from the generator terminals or from the station service bus. The AC power is rectified by thyristor bridges and fed into the main generator field via slip rings. Static exciters are very fast and contribute to improved transient stability.

28. Write the static performance of AVR loop?

The AVR loop must regulate the terminal |V| to within required static accuracy limit. Have sufficient speed of response. Be stable.

29.What is the dis.adv of high loop gain? How is to be eliminated?

High loop gain is needed for static accuracy but this causes undesirable dynamic response, possibly instability. By adding series AND/OR feedback stability compensation to the AVR loop, this conflicting situation can be resolved.

30. **What are the effects of generator loading in AVR loop?**

Added load does not change the basic features of the AVR loop; it will however affect the values of both gain factor Kf and the field constant. High loading will make the generator work at higher magnetic saturation levels. This means smaller changes in |E| for incremental increases in if, translating into the reduction of KF.

The field time constant will likewise decreases as generator loading closing the armature current paths. This circumstance permits the formation of transient stator currents the existence of which yields a lower effective field induction.

31. What are the functions of ALFC?

The basic role of ALFC's is to maintain desired MW output of a generator unit and assist in controlling the frequency of large interconnection. The ALFC also helps to keep the net interchange of power between pool members at predetermined values. Control should be applied in such a fashion that highly differing response characteristics of units of various types are recognized. Also unnecessary power output changes should be kept at a minimum in order to reduce wear of control valves.

32. Specify the dis.adv of ALFC loop?

The ALFC loops will main control only during normal changes in load and frequency. It is typically unable to provide adequate control during emergency situations, when large MW imbalances occur.

33. How is the real power in a power system controlled?

The real power in a power system is being controlled by controlling the driving torque of the individual turbines of the system.

34. What is the need for large mechanical forces in speed-governing system?

Very large mechanical forces are needed to position the main valve against the high stream pressure and these forces are obtained via several stages of hydraulic amplifiers

ACTIVE POWER CONTROL

PRIMARY CONTROL

The Speed Change from Synchronous speed initiates the governor control action resulting in all participating generator – Turbine units taking up the change in load, and stabilizes the system frequency.

SECONDARY CONTROL

It adjusts the load references set points of selected Turbine – Generator units so as to give nominal value of frequency.

The frequency control is a matter of speed control of the machines in the generating stations, the frequency of a power system is dependent entirely upon the speed at which the generates are rotated by their prime movers. All prime movers, Whether they are steam or hydraulic turbines, are equipped with speed governors which are purely mechanical speed sensitive devices, to adjust the gate or control value opening for constant speed.

$$N = \frac{120f}{P}$$

Where, N = Speed (rpm)

F = frequency (Hz)

P = No of poles.

So, the frequency of the system can be varied by varying by varying the speed of the turbine. Frequency is closed related to real power balance of the overall network. Normal operating conditions, the system generators run synchronously and generate power which is drawn by all the loads and real power losses.

Power system operation at a lower frequency than the specified maximum permissible change in frequency is $\pm$0.5Hz affects the quality of power supply.

Definitions :

1.Speed – Governor : It comprises of the elements which are directly responsive to speed, and whose positions influence the action of other elements of speed governing systems.

2.Speed – Control mechanism : It includes all equipment like relays, Pilot valve, servomotor, pressure or power amplifying devices, levers and linkages existing between the speed – governor and governor – controlled values.

3. Governor – Controlled valves : This includes those values that control the input to the turbine, and that are normally actuated by the speed governor with the help of speed control mechanism,

4.Speed – Changer (or) speeder motor : It is a device by means of which the speed govering system may be adjusted to change the speed or power output of the Turbine in operation.

5.Speed – Governing System : This includes the speed – Governor, speed – Control mechanism, governor- controlled values and speed changer.

1. What are the components of speed governing mechanism of an alternator derive the transfer function with an aid of block diagram (11) (Nov 2011) (Nov 2014)

Describe speed governing mechanismwhich control the real power system derive the transfer function (11) (Apr 2011) (Apr 2014)

Using Schematic diagram explain operating features of speed governing mechanism(11) (Nov 2013)

Explain the speed governing mechanismin apower system derive the transfer function (11) (Apr 2013)

Describe the speed governing mechanism of a power system and develop the mathematical model for the same (11) (Nov 2012)

Explain the mathematical model of speed governing mechanism(11) (Nov 2010)

FUNDAMENTALS OF SPEED GOVERNING MECHANISM AND MODELLING

The Speed Governing System of the steam Turbine. By controlling the position of the control value or gate, we can exert control over the flow of high pressure Steam (or water) through the turbine.

Fly ball speed governor:

It is purely mechanical speed – sensitive device coupled directly to the hydraulic amplifier which adjusts the control value opening via the linkage mechanism.

As the load increase, speed of the Turbine decrease and the speed changer gives raise command, so the fly balls move outwards and the point B moves downwards and the reverse happens with the increased speed.

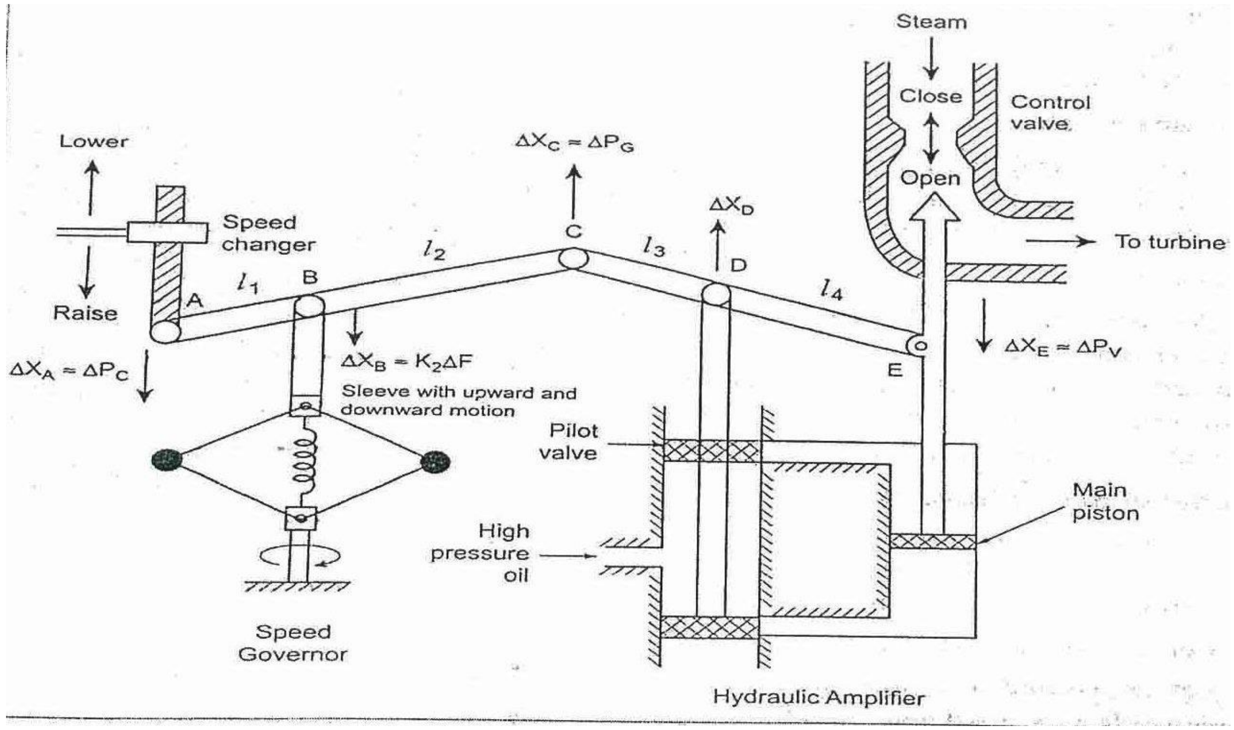


Figure 3.1 Schematic diagram of speed governing mechanism

Speed changer:

- It makes it Possible to restore the frequency to the initials (nominal) value after the operation of the speed governors which has steady state characteristics.

- A Small download movement of the linkage point A Corresponds to an increase ΔP_c in the reference power setting.

Hydraulic amplifier :

It consists of pilot valve and main piston with this arrangement, a low power pilot valve movement is converted into high power level movement is converted into high power level movement of the oil – servomotor piston. The input to this amplifier is the position X_D of the pilot Valve. The output is the position X_E of the main piston. Hydraulic amplification is necessary so that the steam valve or gate could be operated against high pressure steam.

Linkage mechanism :

- ABC is a rigid link pivoted at B and CDE is another rigid link pivoted at D. The function of the link mechanism is to control the steam valve or gate
- We get feedback from the movement of the steam valve via link CD.

Working :

As load increases, the speed of the turbine decreases, the speed changer gives raise command and fly balls outwards and the point B moves downloads and D moves upwards and high pressure oil enters into the upper pilot valve and presses the main piston downwards and opens the valve or gate (ie) increases the flow of steam to the turbine. Thereby, speed of flow of steam to the turbine increases and maintains constant frequency.

MODEL OF SPEED GOVERNOR

We shall develop the mathematical model Based on small deviations around a nominal steady state. Consider the steam is operating under steady state and is delivering power P_G from the generator at nominal frequency f. Let $X_s$be the steam value setting. Let us assume that raise command ΔP_c to the speed changer, the point A be moved downwards by a small amount ΔX_A which causes the turbine power output to change.

$$\text{Therefore } \Delta X_A = k_c \Delta P_c$$

Let assume +ve direction for downward movement and –ve direction for upward movement.

Movement of c:

1) ΔX_A contributes$\left[\frac{-l_2}{l_1}\right]\Delta X_A = -k_1 k_c \Delta P_c$
2) Increase in frequency Δfcauses the fly balls to moves outwards so that B moves downloads by a proportional amount $k_2 \Delta f$

$$\text{Therefore } \Delta X_c = -k_1 k_c \Delta P_c + k_2 \Delta f --------(1)$$

Movement of d:

It is contributed by $\Delta X_c$and ΔX_E. The movement ΔX_D is the amount by which the pilot valve opens, thereby moving the mains piston and opening the steam valve by ΔX_E

$$\Delta X_D = \left[\frac{l_4}{l_3 + l_4}\right]\Delta X_c + \left[\frac{l_3}{l_3 + l_4}\right]\Delta X_E$$

$$= k_3\Delta X_c + k_4\Delta X_E ---------- (2)$$

Movement of Δx_e:

The volume of oil admitted to the cylinder is thus proportional to the line integral of ΔX_D.

$$\Delta X_E = k_5 \int_0^t -\Delta X_D dt ------- (3)$$

Taking L.T of equation (1), (2),(3)

$$\Delta X_c(s) = -k_1 k_c \Delta P_c(s) + k_2 \Delta f(s) --------(4)$$

$$\Delta X_D(s) = k_3\Delta X_c(s) + k_4\Delta X_E(s) ---------- (5)$$

$$\Delta X_E(s) = \frac{-k_5}{s}\Delta X_D(s) ------- (6)$$

Sub. Equation (5)in (6), we get

$$\Delta X_E(s) = \frac{-k_5}{s}[k_3\Delta X_c(s) + k_4\Delta X_E(s)]$$

$$\Delta X_E(s)\left[1 + \frac{k_4k_5}{s}\right] = \frac{-k_5k_3}{s}[\Delta X_c(s)] ------(7)$$

$$\Delta X_E(s)\left[1 + \frac{k_4k_5}{s}\right] = \frac{-k_5k_3}{s}[-k_1k_c\Delta P_c(s) + k_2\Delta f(s)]$$

$$\Delta X_E(s)\left[\frac{s + k_4k_5}{s}\right] = \left[\frac{k_5k_3k_1k_c\Delta P_c(s) - k_2k_5k_3\Delta f(s)}{s}\right]$$

$$\Delta X_E(s) = \frac{k_5k_3k_1k_c\left[\Delta P_c(s) - \frac{k_2}{k_1k_c}\Delta f(s)\right]}{k_4k_5\left[1 + \frac{s}{k_4k_5}\right]}$$

$$\Delta X_E(s) = \frac{k_3k_1k_c\left[\Delta P_c(s) - \frac{k_2}{k_1k_c}\Delta f(s)\right]}{k_4\left[1 + \frac{s}{k_4k_5}\right]}$$

This equation can be written as,

$$\Delta X_E(s) = \left[\Delta P_c(s) - \frac{1}{R}\Delta f(s)\right] \times \frac{k_G}{1 + sT_G} ------(8)$$

Where,

$R = \frac{k_2}{k_1 k_c} = speedregulationofthegovernorin \frac{Hz}{MW}$.

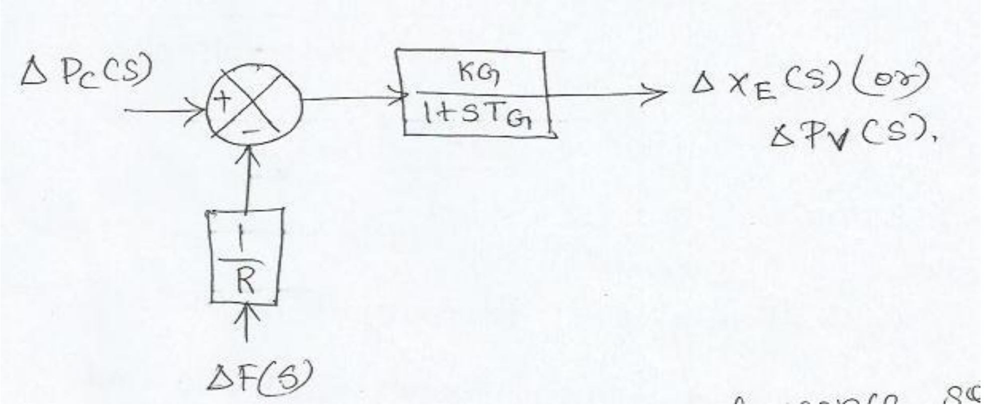
$$k_G = \frac{k_3 k_1 k_c}{k_4} = Gainofthegovernor.$$

$$T_G = \frac{1}{k_4 k_5} = Timeconstantofthegovernor.$$

Value of $T_G < 100$ msec.

The output of a generating as a gives system frequency can be varied only by changing its load reference or control point which is integrated with the speed governing mechanism.

Block diagram of speed governor.



The adjustment of load reference set point is accomplished by operating the "speed changer motor" this in effect moves the speed droop char UP down.

REGULATION OF ALTERNATORS

% Regulation up = $\frac{E_0 - V}{V} \times 100$

Where ,

E_0 = No load voltage

V – No load Voltage.

% Speed regulation = $\frac{\text{Percent speed or frequency change}}{\text{Percent Power output Change}}$

$$= \frac{f_{NL} - f_{FL}}{f^0}$$

Where ,

f_{NL} – Steady State frequency at no load.

f_{FL}– Steady state frequency at full load.

f^0 – Nominal or rated frequency.

NECESSITY FOR PARALLEL OPERATION

Alternators may be put in parallel because of the following reasons.

- Local or regional power use may exceed the power of a single available generator.
- Parallel Alternators allow one or more units to be shut down for scheduled or emergency maintenance while the load is being supplied with power.
- Generators are in efficient at part load, so shutting down one or more generators allows the remaining load to be carried with less machines that are efficiently loaded.
- Available machine prime movers and generators can be matched for economic cost and flexible use.

REQUIREMENTS FOR PARALLEL OPERATION

Alternators to be operated in parallel should meet the following requirements.

1. They must have the same output voltage rating.

2. The rated speeds of the machines should be such as to give the same frequency.

3.The alternators should be the same type so as to generate voltage of the same waveform, they may differ in their KVA rating.

4. The alternators should have reactance in their armatures, otherwise, they will not operate in parallel successfully.

CONDITIONS FOR PROPER SYNCHRONISING

1. The Terminal voltage of the incoming machine must be exactly equal to that of the other or of the bus bars connecting them.
2. The speed of the incoming machine must be such that, its frequency equals bus bar frequency.
3. The phase of the incoming machine voltage must be the same as that of the bus – bar voltage relative to the load.
4. The phase sequence of the incoming machine is the same as that of the bus bars.

CONCEPT OF CONTROL AREA

- A control area is defined as a system to which a common generation control scheme is applied
- The electrical interconnection within each control area is very strong as compared to the Ties with the neighboring areas.
- All the generators in a control area swing in coherently or it is characterised by a single frequency.
- It is necessary to be considered as many control area as number of coherent group.

2. With a block diagram explain the proportional and integral load frequency control of single area system. Describe the dynamic response of load frequency control (11) (Apr 2014)

Develop a transfer function model of single area system and evaluate its closed loop servo and regulatory response (11) (Apr 2013)

LOAD FREQUENCY CONTROL OF SINGLE AREA SYSTEM

To analyze the LFC of an isolated system, first build mathematical model from the block diagram.

Let ΔP_c be the incremental control input.

Let ΔP_D be the incremental disturbance input.

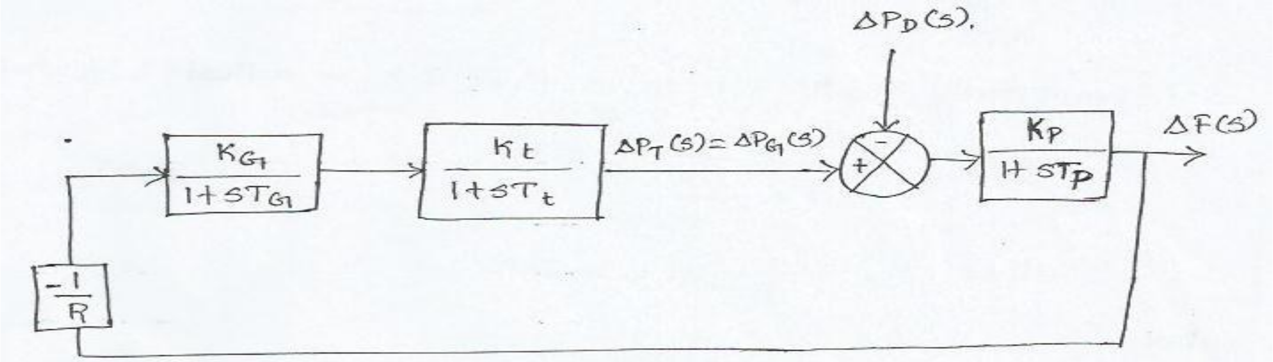
The incremental control input is due to the change in the speed changer setting, while the incremental disturbance is due to the change in load demand.

There are two responses :

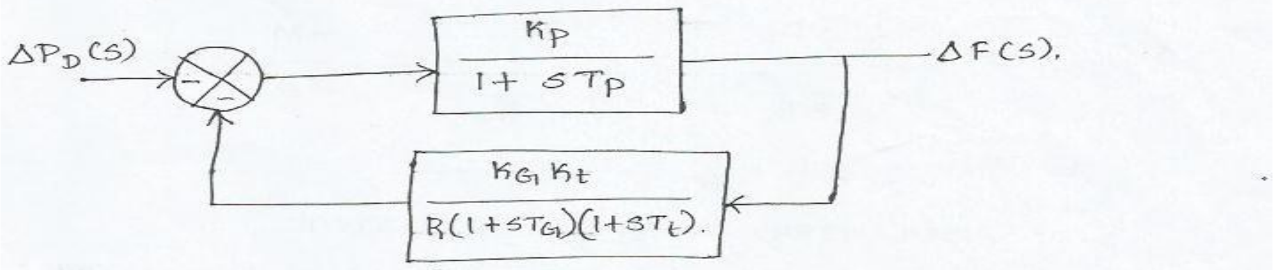
1. Steady state or static response.
2. Dynamic state response.

STATIC ANALYSIS OF UNCONTROLLED CASE

Consider the speed changer has a fixed setting under this condition $\Delta P_c = 0$ and the load demand changes . This is known as free governor operation.



Using block reduction Technique



$$\Delta F(s) = \frac{\frac{k_p}{1+sT_p}}{1+\frac{k_p}{1+sT_p}\times\frac{k_p k_G k_t}{R(1+sT_G)(1+sT_t)}}\times[-\Delta P_D(s)]$$

$$\Delta F(s) = \frac{\frac{k_p}{1+sT_p}}{1+sT_p+\frac{k_p k_G k_t}{R(1+sT_G)(1+sT_t)}}\times[-\Delta P_D(s)]$$

For a step load change$\Delta P_D(s) = \frac{\Delta P_D}{s}$

$$\Delta F(s) = \frac{-k_p}{1+sT_p+\frac{k_p k_G k_t}{R(1+sT_G)(1+sT_t)}}\times\left[\frac{\Delta P_D}{s}\right]$$

Apply final value theorem,

$$\Delta f_{stat} = \lim_{s\to 0} s.\Delta F(s) = \frac{-k_p}{1+\frac{k_p k_G k_t}{R}}\times\Delta P_D$$

Practically $k_G k_t = 1, [k_t is fixed \& k_G adjusted by changing]$

$$\Delta f_{stat} = \frac{-k_p}{1+\frac{k_p}{R}}\times\Delta P_D$$

Since $k_p = \frac{1}{B} \& \Delta P_D = M$

Where,

B = Load damping constant.

ΔP_D= Increase in load.

$$\Delta f_{stat} = \frac{-\frac{1}{B}\Delta P_D}{1+\frac{1}{BR}} = \frac{-M}{B+\frac{1}{R}} = \frac{-M}{\beta}$$

Where,

$$\beta = B+\frac{1}{R}$$

$\beta = Area frequency response coefficient.$

The system performance in terms of how the change in power effects the change in frequency is evaluated through AFRC.

In practice $B<<\frac{1}{R}$, neglecting B

$$\Delta f_{stat} = -R\Delta P_D Hz.$$

$$\frac{\Delta f_{stat}}{\Delta P_D} = -R[HZ/MW]$$

Where,

R = Speed Regulation.

Δf_{stat}= Change in steady state frequency.

$$\Delta f_{stat} = -R\Delta P_D Hz.$$

When several generator with governor speed regulation R$_1$, R$_2$……… R$_n$ are connected to the system. The steady state deviation in frequency.

$$\Delta f_{stat} = \frac{-\Delta P_D}{B + \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}}$$

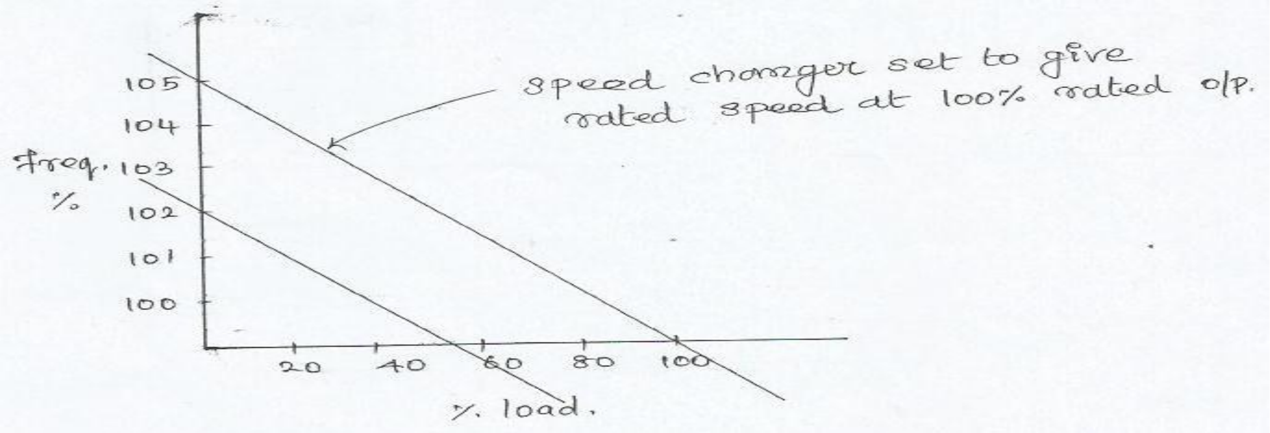


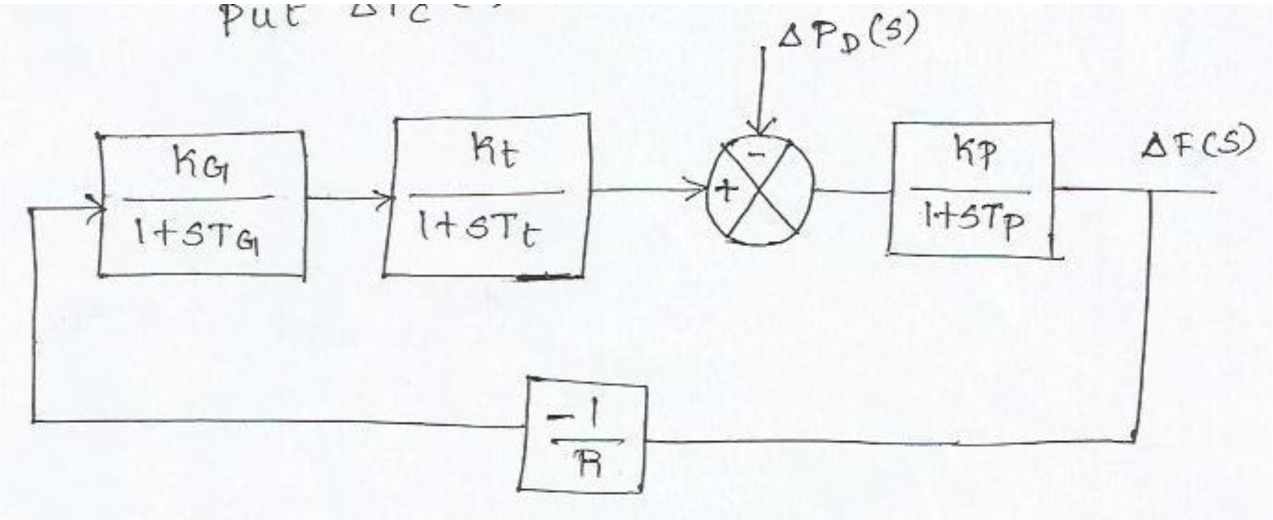
Figure 3.2 % Frequency VS % Load

DYNAMIC ANALYSIS OF UNCONTROLLED CASE OF SINGLE AREA

A static response of LFC loop will inform about frequency accuracy, whereas the dynamic response of LFC loop will inform about the stability of the loop.

To obtain the dynamic response representing the changing frequency as a function of time for a step change in load.

Put $\Delta P_c(s) = 0$



$$\Delta F(s) = \frac{\frac{k_p}{1+sT_p}}{1+\frac{k_p k_G k_t}{R(1+sT_G)(1+sT_t)}} \times [-\Delta P_D(s)]$$

Take LT $^{-1}$ for an expression $\Delta F(s)$ is tedious, because the denominator will be third order.

Assumptions,

1.The action of speed governor and turbine is instantaneously compared with rest of the power system.

2.The time constant of the power system T_p-= 20sec.

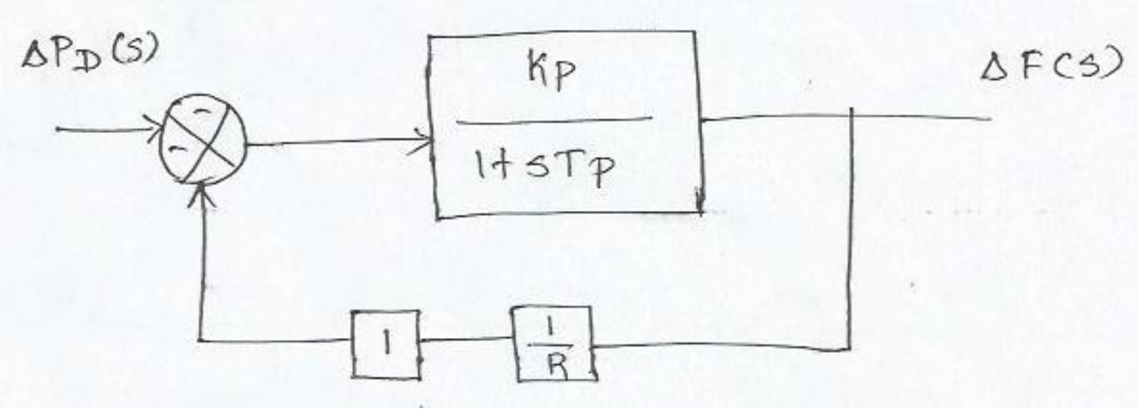
Time constant of governor T_G = 0.4 sec.

Time constant of Turbine T_t = 0.5 sec

Approximate Analysis.

Let $T_t = T_G = 0$

$K_G K_t = 1$



$$\Delta F(s) = \frac{k_p}{1 + sT_p \times \frac{k_p}{R}} \times [-\Delta P_D(s)]$$

For a step change$\Delta P_D(s) = \frac{\Delta P_D}{s}$

$$\Delta F(s) = \frac{k_p}{T_p\left[s + \frac{1}{T_p} + \frac{k_p}{RT_p}\right]} \times \left[\frac{-\Delta P_D}{s}\right]$$

$$= \frac{-\Delta P_D k_p}{T_p s\left[s + \frac{R+k_p}{RT_p}\right]}$$

Applying partial fraction method,

$$\Delta F(s) = \frac{-\Delta P_D k_p}{T_p}\left[\frac{A}{s} + \frac{B}{s + \left[\frac{R+k_p}{RT_p}\right]}\right]$$

$$As + A\left[\frac{R + k_p}{RT_p}\right] + Bs = 1$$

Comparing the coefficients,

$$A + B = 0.$$

$$A = \frac{RT_p}{R + k_p}, B = \frac{-RT_p}{R + k_p}$$

$$\Delta F(s) = \frac{-\Delta P_D k_p}{T_p}\left[\frac{RT_p}{R + k_p}\left[\frac{1}{s} + \frac{1}{s + \left[\frac{R+k_p}{RT_p}\right]}\right]\right]$$

$$\Delta f(t) = LT^{-1}\Delta F(s)$$

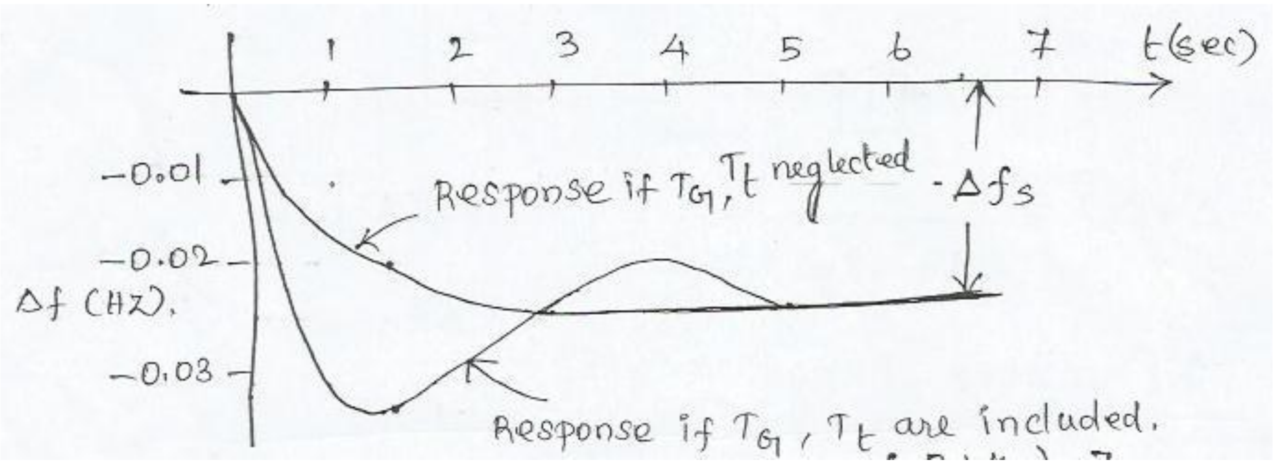


Figure 3.3 Response if T_G, T_t are included and neglected

$$\Delta f(t) = \frac{-\Delta P_D k_p R}{R + k_p}\left[1 - e^{\left(\frac{R+k_p}{RT_p}\right)t}\right]$$

$$\Delta f(t) = \frac{-Mk_p R}{R + k_p}\left[1 - e^{-\left(\frac{R+k_p}{RT_p}\right)t}\right]$$

Above $\Delta f(t)$ = Dynamic response to a step load.

3. Develop a linear mathematical model of two area system and also explain the tie line bias control of two area system (11) (Apr 2015)

Develop the block diagram model of a two area LFC system (11) (Nov 2014)

Explain the principle involved in tie line frequency control in case of two area system(5) (Apr 2013)

Draw the block diagram of Two area load frequency control system and explain the uncontrolled static analysis(11) (Nov 2012)

Describe LFC control of two area system (11) (Nov 2010)

TWO AREA LOAD FREQUENCY CONTROL SYSTEM MODELLING

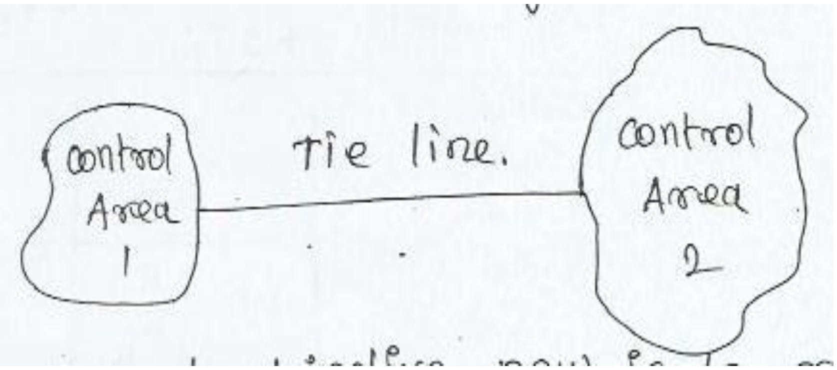


Figure 3.4 Two area load frequency control system modelling

1.The control objective now is to regulate the frequency of each area and to simultaneously regulate the tie line power as per inter area power contracts.

2.As in the case of frequency, proportional plus integral controller will be installed so as to give zero steady state error in the tie line flow as compared to the contracted power.

STATIC ANALYSIS OF UNCONTROLLED CASE

$$\Delta P_c(1) = \Delta P_c(2) = 0$$

ie, No need to change the position of speed changer suppose there is a sudden increase in load demand in the areas by incremental steps$\Delta P_D(1)\&\Delta P_D(2)$. Frequency drops in the steady state and these drops will be equal.

$$\Delta f_{1stat} = \Delta f_{2stat} = \Delta f_{stat}$$

At steady state condition, we will have incremental tie line power,

$$\Delta P_{G1,stat} = \frac{-1}{R_1}\Delta f_{stat}$$

$$\Delta P_{G2,stat} = \frac{-1}{R_2}\Delta f_{stat} ----------- (1)$$

$$\Delta P_{G1,stat} - \Delta P_{D1} - \Delta P_{tie1,stat} \times \left[\frac{k_{p1}}{1 + sT_{p1}}\right] = \Delta f_{stat}$$

$$\Delta P_{G1,stat} - \Delta P_{D1} - \Delta P_{tie1,stat} \times \left[\frac{\frac{1}{B}}{1 + \frac{2Hs}{f^0 B}}\right] = \Delta f_{stat}$$

$$\Delta P_{G1,stat} - \Delta P_{D1} - \Delta P_{tie1,stat} \times \left[\frac{\frac{1}{B}}{1 + \frac{2Hs}{f^0 B}}\right] = \Delta f_{stat}$$

$$\Delta P_{G1,stat} - \Delta P_{D1} - \Delta P_{tie1,stat} = \left[B + \frac{2Hs}{f^0}\right]\Delta f_{stat}$$

$$\Delta P_{G1,stat} - \Delta P_{D1} - \Delta P_{tie1,stat} = B\Delta f_{stat} + \frac{2H}{f^0}\frac{d}{dt}\Delta f_{stat}$$

Put $\frac{d}{dt}\Delta f_{stat} = 0\, forarea\ 1, weget,$

$$\Delta P_{G1,stat} - \Delta P_{D1} - \Delta P_{tie1,stat} = B_1\Delta f_{stat} ------- (2)$$

Similarly for area 2

$$\Delta P_{G2,stat} - \Delta P_{D2} = B_2\Delta f_{stat} + \Delta P_{tie2,stat}$$

$$\Delta P_{G2,stat} - \Delta P_{D2} = B_2\Delta f_{stat} - a_{12}\Delta P_{tie1,stat}$$

$$\Delta P_{G2,stat} - \Delta P_{D2} = B_2\Delta f_{stat} - a_{12}\left[\Delta P_{G1,stat} - \Delta P_{D1} - B_1\Delta f_{stat}\right] ---------- (3)$$

Sub. equation (1) in equation (3) we get

$$\frac{-1}{R_2}\Delta f_{stat} - \Delta P_{D2} = B_2\Delta f_{stat} + \frac{a_{12}}{R_1}\Delta f_{stat} - a_{12}\Delta P_{D1} + a_{12}B_1\Delta f_{stat}$$

$$\Delta f_{stat}\left[\frac{-1}{R_2} - B_2 - \frac{a_{12}}{R_1} - a_{12}B_1\right] = -a_{12}\Delta P_{D1} + \Delta P_{D2}$$

$$\Delta f_{stat} = \frac{-[a_{12}\Delta P_{D1} + \Delta P_{D2}]}{\left[B_2 + \frac{1}{R_2}\right] + a_{12}\left[B_1 + \frac{1}{R_1}\right]} - - - - - - - - (4)$$

$$\Delta P_{tie1,stat} = \Delta P_{G1,stat} - \Delta P_{D1} - B_1\Delta f_{stat}$$

$$= \frac{-1}{R_1}\Delta f_{stat} - \Delta P_{D1} - B_1\Delta f_{stat}$$

$$= -\Delta f_{stat}\left[B_1 + \frac{1}{R_1}\right] - \Delta P_{D1} - - - - - - - (5)$$

Sub. equation (4) in equation (5)

$$\Delta P_{tie1,stat} = \frac{[a_{12}\Delta P_{D1} + \Delta P_{D2}]}{\left[B_2 + \frac{1}{R_2}\right] + a_{12}\left[B_1 + \frac{1}{R_1}\right]}\left[B_1 + \frac{1}{R_1}\right] - \Delta P_{D1}$$

$$= \frac{[a_{12}\Delta P_{D1} + \Delta P_{D2}]\left[B_1 + \frac{1}{R_1}\right] - \Delta P_{D1}\left[B_2 + \frac{1}{R_2}\right] - a_{12}\Delta P_{D1}\left[B_1 + \frac{1}{R_1}\right]}{\left[B_2 + \frac{1}{R_2}\right] + a_{12}\left[B_1 + \frac{1}{R_1}\right]}$$

$$= \frac{[\Delta P_{D2}]\left[B_1 + \frac{1}{R_1}\right] - \Delta P_{D1}\left[B_2 + \frac{1}{R_2}\right]}{\left[B_2 + \frac{1}{R_2}\right] + a_{12}\left[B_1 + \frac{1}{R_1}\right]}$$

Let $\beta_1 = B_1 + \frac{1}{R_1} \& \beta_2 = B_2 + \frac{1}{R_2}$

$$\Delta P_{tie1,stat} = \frac{[\Delta P_{D2}]\beta_1 - [\Delta P_{D1}]\beta_2}{\beta_2 + a_{12}\beta_1}$$

$$\Delta f_{stat} = \frac{-[a_{12}\Delta P_{D1} + \Delta P_{D2}]}{\beta_2 + a_{12}\beta_1}$$

For two identical areas,

$$\beta_1 = \beta_2 = \beta.$$

$$R_1 = R_2 = R.$$

$$B_1 = B_2 = B.$$

$$a_{12} = \frac{P_{r1}}{P_{r2}} = 1.$$

$$\Delta f_{stat} = \frac{-[\Delta P_{D1} + \Delta P_{D2}]}{2\beta}$$

$$\Delta P_{tie1,stat} = -\Delta P_{tie2,stat} = \frac{[\Delta P_{D2}] - [\Delta P_{D1}]}{2}$$

Suppose a step load change occurs at area (1)

$$\Delta P_{D2} = 0$$

$$\Delta f_{stat} = \frac{-\Delta P_{D1}}{2\beta}$$

$$\Delta P_{tie1,stat} = \frac{-[\Delta P_{D1}]}{2}.$$

For interconnected power system the steady state frequency error is reduced by 50% and the change in tie line power is also reduced by 50 % .

DYNAMIC RESPONSE OF UNCONTROLLED CASE

Let us now turn our attention during the transient period for the sake of simplicity.

We shall assume the two areas to be identical further; we shall be neglecting the time constants of generators and turbines as they are negligible as compared to the time constants of power system.

$T_{p1} >> T_{t1}, T_{G1}$; $T_{p2} >> T_{t2}, T_{G2}$

For uncontrolled case ($\Delta P_{c1} = \Delta P_{C2} = 0$)

We can write the following conditions or equation from the block diagram depicted

$$\Delta f_1(s) = \frac{-k_{p1}}{1 + sT_p}\left[\frac{\Delta f_1(s)}{R_1} + \Delta P_{D1}(s) + \Delta P_{tie1}(s)\right] - - - - - - - - (1)$$

$$\Delta f_2(s) = \frac{-k_{p2}}{1 + sT_p}\left[\frac{\Delta f_2(s)}{R_2} + \Delta P_{D2}(s) + \Delta P_{tie2}(s)\right] - - - - - - - - (2)$$

$$\Delta P_{tie}(s) = \frac{2\pi T_{12}}{s}[\Delta f_1(s) - \Delta f_2(s)] - - - - - - - - (3)$$

For identical case

$$\Delta P_{tie,2} = -\Delta P_{tie,1}$$

$$a_{12} = 1$$

$$R_1 = R_2 = 1.$$

$$k_{p1} = k_{p2} = k_p$$

From equation (1)

$$\Delta f_1(s)\left[1 + \frac{k_p}{R(1 + sT_p)}\right] = \frac{-k_p}{1 + sT_p}[\Delta P_{D1}(s) + \Delta P_{tie1}(s)]$$

$$\Delta f_1(s)\left[\frac{(R + sRT_p) + k_p}{R(1 + sT_p)}\right] = \frac{-k_p}{1 + sT_p}[\Delta P_{D1}(s) + \Delta P_{tie1}(s)]$$

$$\Delta f_1(s) = \frac{-k_pR}{R + sRT_p + k_p}[\Delta P_{D1}(s) + \Delta P_{tie1}(s)]$$

From equation (2)

$$\Delta f_2(s) = \frac{-k_pR}{R + sRT_p + k_p}[\Delta P_{D2}(s) + \Delta P_{tie1}(s)]$$

Substituting $\Delta f_1(s)\&\Delta f_2(s) inequation$ (3)

$$\Delta P_{tie1}(s) = \frac{2\pi T_{12}}{s}\left[\frac{-k_pR}{R + sRT_p + k_p}\right] \times [\Delta P_{D1}(s) - \Delta P_{D2}(s) + 2\Delta P_{tie1}(s)]$$

$$\Delta P_{tie1}(s)\left[1 + \frac{4\pi T_{12}k_pR}{R + sRT_p + k_p}\right] = \frac{-2\pi T_{12}k_pR}{s\left(R + sRT_p + k_p\right)}[\Delta P_{D1}(s) - \Delta P_{D2}(s)]$$

$$\Delta P_{tie1}(s)\frac{\left[s^2RT_p + s\left(R + sk_p\right) + 4\pi T_{12}k_pR\right]}{s\left[sRT_p + (R + k_p\right]} = \frac{2\pi T_{12}}{s}\left[\frac{-k_pR}{R + sRT_p + k_p}\right][\Delta P_{D1}(s) - \Delta P_{D2}(s)]$$

$$\Delta P_{tie1}(s) = \frac{-2\pi T_{12}k_p}{T_p\left[s^2 + \left(\frac{R+k_p}{RT_p}\right)s + \frac{4\pi T_{12}k_p}{T_p}\right]}[\Delta P_{D1}(s) - \Delta P_{D2}(s)]$$

We know $k_p = \frac{1}{B}$

$$\Delta P_{tie1}(s) = \frac{-2\pi T_{12}[\Delta P_{D1}(s) - \Delta P_{D2}(s)]}{T_pB\left[s^2 + \left(\frac{R+\frac{1}{B}}{RT_p}\right)s + \frac{4\pi T_{12}}{BT_p}\right]}$$

Power system time constant

$$T_p = \frac{2H}{Bf_o}$$

$$\Delta P_{tie1}(s) = \frac{2\pi T_{12}[\Delta P_{D2}(s) - \Delta P_{D1}(s)]}{\frac{2H}{f_o}\left[s^2 + \left(\frac{RB+1}{\frac{2HR}{f_o}}\right)s + \frac{4\pi T_{12}}{\frac{2H}{Bf_o}}\right]}$$

$$\Delta P_{tie1}(s) = \frac{2\pi T_{12}f_o[\Delta P_{D2}(s) - \Delta P_{D1}(s)]}{2H\left[s^2 + \frac{f_o}{2H}\left(B + \frac{1}{R}\right)s + \frac{2\pi T_{12}f_o}{H}\right]}$$

The denominator is in the form of

$$s^2 + 2 \propto s + \omega^2 = (s{+}\propto)^2 + \omega^2 - \propto^2$$

Where,

$$\propto = \frac{f_o}{4H}\left(B + \frac{1}{R}\right)$$

$$\omega^2 = \frac{2\pi T_{12}f_o}{H}$$

Since $\propto$ &$\omega^2$are positive, therefore, the system is stable & damped.

The roots of the characteristic equation are

$$S_{1,2} = \frac{-2 \propto \pm\sqrt{(2 \propto)^2 - 4\omega^2}}{2} = -\propto \pm\sqrt{\propto^2 - \omega^2}$$

We have three conditions.

1.If$\propto = \omega$the system is critically damped, the roots becomes,$S_{1,2} = \omega$.

2.If$\propto > \omega$ the system becomes under damped, the roots becomes, $S_{1,2} = -\propto \pm\sqrt{\propto^2 - \omega^2}$

3. If $\propto < \omega$ the system becomes over damped, the roots becomes,$S_{1,2} = -\propto \pm j\sqrt{\omega^2 - \propto^2}$

$$S_{1,2} = -\propto \pm j\omega_d$$

Where,

$$\propto = Dampingfactor.$$

$$\omega_d = Dampedangularfrequency.$$

$$\omega_d = \sqrt{\omega^2 - \propto^2}$$

$$= \sqrt{\frac{2\pi T_{12} f_o}{H} - \left[\frac{f_o}{4H}\left(B + \frac{1}{R}\right)\right]^2}$$

Assume the load not varying with frequency

$$B = 0$$

$$\therefore \propto = \frac{f_o}{4HR}$$

The system damping is strongly dependent upon the$\propto$ parameter. sincef_o and H = constant.

The damping will be a function of R.

Low value of R will give strong damping.

High value of R will give weak damping.

If R =$\propto$, ω_d= ω

where ,ω = natural angular frequency (ie) there is not speed governor action.

∴ The system will perform undamped oscillation.

Dynamic response of two identical area systems.

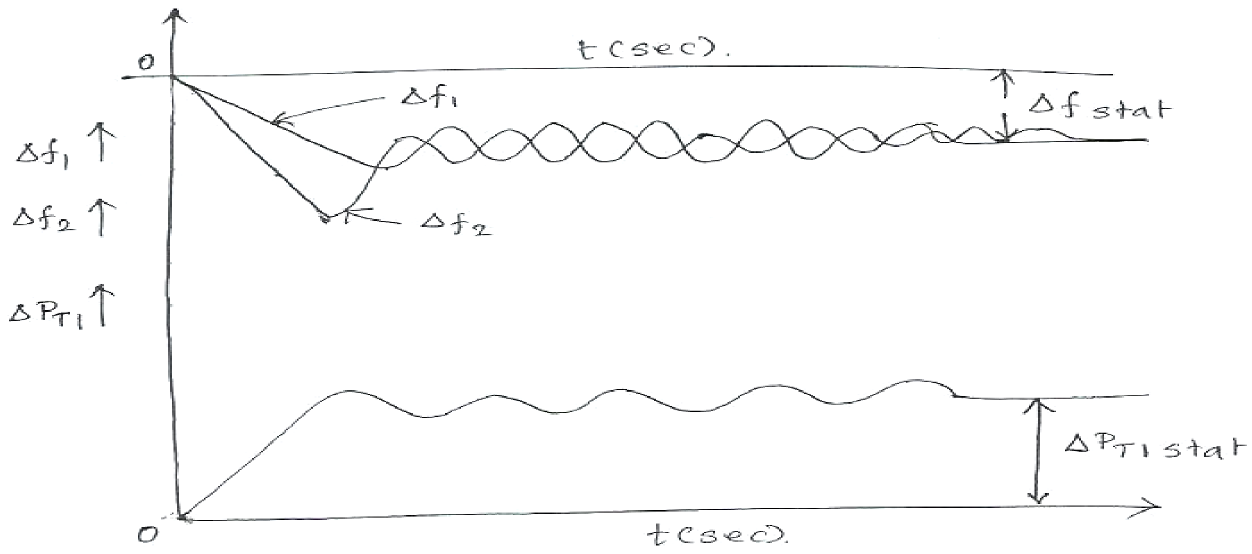


Figure 3.5 Dynamic response of two identical area systems.

TIE LINE WITH FREQUENCY BIAS CONTROL OF TWO AREA SYSTEM

The persistent static frequency error is into liable in the single control area case.

A persistent static error in the line power flow called “inadvertent exchange” would mean that one area would have to support the other on a steady state basic,.

In two area system, we could conceive of the arrangement that area “1” be responsible for frequency for frequency reset and area “2” take care for tie line power.

$$ACE_1 \triangleq \Delta f_1$$

$$ACE_2 \triangleq \Delta P_{tie2}$$

The ACE’s would be fixed via slow integrators or to the respective speed changers. But this arrangement is not so good.

The control strategy is termed as Tie line bias control, and is based upon the principle that all operating pool members must contribute their share to frequency control, in addition to taking care of their own net inter change.

DETERMINATION OF TIE LINE WITH FREQUENCY BIAS CONTROL OF TWO SYSTEM.

Principle :

All operating pool members must contribute their share to frequency control in addition to taking care of their own net interchange.

From the block diagram of two area system ACE is the change in area frequency which, when used in integral control loop forced the steady frequency error to zero.

In order to make the steady state tie line power error to zero, another integral control loop (One for each area) must be introduced to integral control loop (one for each area

) must be introduce to integrate the incremental, tie line power signal and feed it back to the speed changer.

$$ACE_1 = \Delta P_{tie1} + b_1 \Delta_{f1} \text{-------------} (1)$$

Where,

$$b_1 = Area_1 frequencyBias.$$

$$ACE_2 = \Delta P_{tie2} + b_2 \Delta_{f2} \text{-------------} (2)$$

L.T of equation (1) & (2) we get

$$ACE_1 (s) = \Delta P_{tie1}(s) + b_1 \Delta_{f1}(s)$$

$$ACE_2(s) = \Delta P_{tie2}(s) + b_2 \Delta_{f2}(s)$$

speed changer commands are,

$$\Delta P_{c1} = -k_{I1} \int (\Delta P_{tie1} + b_1 \Delta_{f1}) dt - - - - - (3)$$

$$\Delta P_{c2} = -k_{I2} \int (\Delta P_{tie2} + b_2 \Delta_{f2}) dt - - - - - (4)$$

The constant k_{I1}&$k_{I2}$are integrator gains, and constant b_1& b_2 are the frequency bias parameters.

The minus sign must be included, since each area should included since each area should increased its generation if either its frequency error or tie line power increment is negative.

STEADY STATE RESPONSE

Let the step changes in loads Pd1 and Pd2 be simultaneously applied in area 1 &2 respectively

When steady state conditions area reached, the output signals of all integrating blocks will become constant and their input signals must become zero.

$$\Delta P_{tie1} + b_1 \Delta_{f1} = 0 - - - - - - - - - (1)$$

$$\Delta P_{tie2} + b_2 \Delta_{f2} = 0 - - - - - - - - - (2)$$

$$\Delta_{f1} - \Delta_{f2} = 0$$

$$\frac{\Delta P_{tie1}}{\Delta P_{tie2}} = -a_{12} = constant.$$

equation (1) & (2) satisfied only for,

$$\Delta P_{tie1} = \Delta P_{tie1} = 0 \, \& \Delta_{f1} = \Delta_{f2} = 0$$

Under steady state conditions, change in the tie line power and frequency of each area is zero.

TIE LINE BIAS CONTROL OF MULTI AREA SYSTEM

A control area is interconnected not only with one Tie line to one neighbouring area, in the power pool.

$$ACE = \sum_{j=1}^{m} \Delta P_{ij} \quad + b_i \Delta f_i$$

The net interchange $\sum_{j=1}^{m} \Delta P_{ij}$

The reset control is implemented by sampled data techniques. At sampling intervals of one second, all Tie line power data are fed into the central energy control area, where they are added and compared with predetermined power.

ADVANTAGES OF TWO AREA CONTROL OF MUTIAREA SYSTEM

1. Under normal operating conditions besides meeting respective area loads, scheduled interchange between areas can take place.
2. Under abnormal conditions, such as loss of generation in area, power can flow from other areas, through the interconnection.
3. Such pool operation where mutual assistance is possible which reduces the reserve capacity need.
4. For a large with many areas, the kinetic energy of the rotator inertia is high. A sudden load change may not cause any considerable transient frequency deviation.

Problems:

1. **Two 750 KW alternators operates in parallel. The Speed regulation of 1 set 100% to 103% from full load to no load and that of other is 100% to 104 %. How will the two alternators share a load of 1000 KW and at what load will one machine cease to supply any portion of the load.**

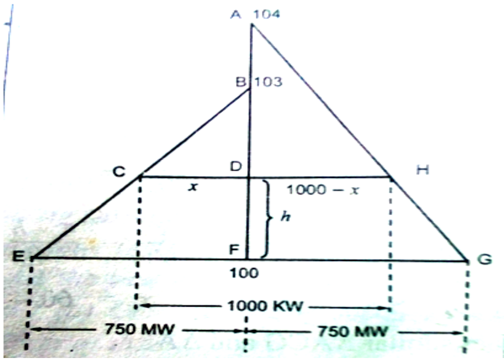


Fig 1

Solution:

Total load = 1000 KW

Unit I = 3% droop

Unit II = 4% droop

Let x be the power generation of unit I.

From similar Δ BCD and Δ BEF,

$$\frac{CD}{EF} = \frac{BD}{BF}$$

$$\frac{x}{750} = \frac{3-h}{3}$$

$$x = 750 - 250\,h \qquad \ldots\ldots\ldots\ldots(1)$$

From similar Δ ADH and Δ AFG shown in fig1,

$$\frac{DH}{FG} = \frac{AD}{AF}$$

$$\frac{1000-x}{750} = \frac{4-h}{4}$$

$$1000 - x = 750 - 187.5\,h$$

$$x = 250 + 187.5h$$

Equating (1) and (2)

$$250 + 187.5h = 750 - 250h$$

$$187.5h + 250h = 750 - 250$$

$$h = 1.142$$

Substituting hin (1), $x = 750-1.142 \times 250$

$$P_{G1} = 464.28KW$$

$$P_{G2} = 1000 - x = 535.7 \text{ KW}$$

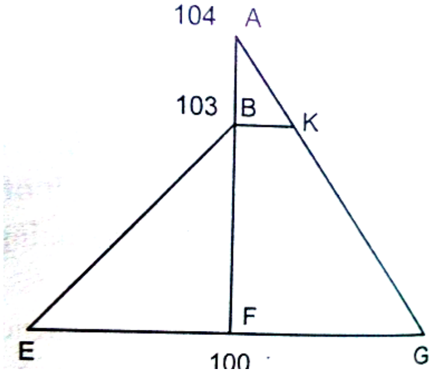


Fig 1.1

Machine 1 cease to supply any load when the line DH is shifted to point B. At this point, machine 2 will supply load equal to BK.

From Δ ABK and Δ AFG shown in fig 1.1,

$$\frac{BK}{FG} = \frac{AB}{AF}$$

$$BK = 750 \times \frac{1}{4} = 187.5 \text{ KW}$$

2. Two identical 60 MW synchronous machine operate in parallel, the governor settings on the machines are such that they have 4% and 3% droops no load to full load % speed drops. Determine (a) the load taken by each machine for a total load of 100 MW. (b) The % no- load speed to be made by the speeder motor if the machines are to share the load equally.

Solution:

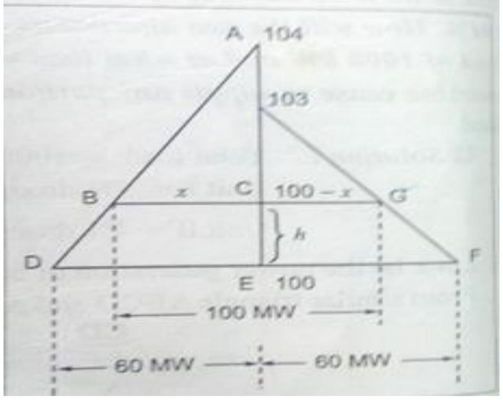


Fig 2

From similar Δ ABC and Δ ADE, shown in fig 2,

$$\frac{BC}{DE} = \frac{AC}{AE}$$

$$\frac{x}{60} = \frac{4-h}{4}$$

$$x = 60 - 15h \qquad \text{.........(1)}$$

From similar Δ ACG and Δ AEF, shown in fig 2,

$$\frac{100-x}{60} = \frac{3-h}{3}$$

$$100 - x = 60 - 20h$$

$$x = 40 + 20h \qquad \text{.......(2)}$$

Equating (1) and (2)

$$60 - 15h = 40 + 20h$$

$$35h = 20$$

$$h = 4/7$$

Substituting h in (1),

$$x = 60 - 15h = 60 - 15 \times (4/7) = 51.42 \text{ MW}$$

Machine 1 delivers 51.42 MW.

Machine 2 delivers = 100 -51.42 = 48.58 MW

(ii) If both machines have share equally,

$P_{G1} = P_{G2} = P_D / 2 = 50MW$

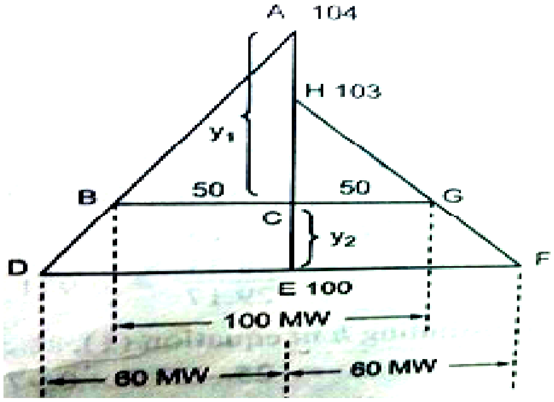


Fig 2.1

From similar Δ ABC and Δ ADE, shown in fig 2.1,

$$\frac{BC}{DE} = \frac{AC}{AE}$$

$$\frac{50}{60} = \frac{y_1}{4}$$

$$y_1 = \frac{4 X 50}{60} = 3.33\%$$

From similar Δ HCG and Δ HEF, shown in fig 2.1,

$$\frac{CG}{EF} = \frac{HC}{HE} = \frac{3 - CE}{HE}$$

$$\frac{50}{60} = \frac{3 - CE}{3}$$

$$3 - CE = \frac{50 X 3}{60}$$

$$CE = 3 - \frac{50 X 3}{60} = 0.5$$

Speed of operation is 100.5%

$y_1 + y_2 = 3.33 + 100.5 = 103.83\%$

Percentage no load speed in the 4% droop machine is 103.83%

3. **Determine the primary ALFC loop parameters for a control area having the following data:**

Total rated area capacity, P_r = 2000 MW

Normal operating Load, P_d = 1000 MW

InertiaconstantH=5.0sec, Regulation=2.0Hz/p.u.MW

Assume that the load-frequency dependency is linear, meaning that the load wouldincreaseonepercentforonepercentfrequencyincrease.Obtainthepowersystemtransferfunction.

Solution:

Assume frequency = 60Hz

Rate of change of load with respect to frequency,

B or D $=\frac{\partial P_D}{\partial f}=\frac{\frac{1}{100}X1000}{\frac{1}{100}X60}$ =16.667 MW/Hz

= 16.667/P_rp.u MW/Hz =16.667/2000 =8.333 X 10^{-3}p.u MW/Hz

Power System gain K_P = 1/B =1/(8.333 X 10^{-3}) =120 Hz/p.u MW

Power time Constant T_p = 2H/Bf_o = (2 x5)/(8.333 x 10^{-3} x 60) = 20 sec

Powersystemtransferfunction = $K_P/(1 + sT_P)$ = 120/(1+20s)

4. **The load frequency dynamics of single area power system whose data are given below:**

Rated Capacity of the area (P_r) =1500 MW

Nominal operating load = 750 MW

Nominal frequency = 50 Hz

Inertia constant of the area = 5.0 s

Speed regulation (governor droop) of all regulating generators = 3 %

Governor time constant = 0 sec

Turbine time constant = 0 sec

Assume linear load frequency characteristics which means, the connected system load increases by 1% if the frequency increases by 1% percent.

The area has a governor control, but not a load frequency controller. The area is subjected to a load increase of 30 MW.

a) **Simulate the load frequency dynamics of this area and determine stead – state frequency deviation in Hz using Area Frequency Response Coefficient (AFRC)**

Solution:

Simulate the load frequency dynamics involving the "Single Area Load Frequency Control"

B or D = $\frac{\left(\frac{1}{100}\right) X\ 750}{\left(\frac{1}{100}\right) X\ 50}$ MW/Hz

= 15 MW/Hz =15/1500 =0.01 p.u MW/Hz

R= 3%

R = (3/100) x (f/P_r) Hz/MW

=(3/100) x (50/1500) =0.001 Hz/MW

R =0.001 x 1500 =1.5 Hz/p.u MW

β = AFRC = [B + (1/R)] = 0.01 +(1/1.5) = 0.68 p.u MW /Hz

Δf_{stat} = (-M/β) [where M = ΔP_D MW = ΔP_D /P_rp.u MW]

= -(30/1500)/0.68 = -0.0294 Hz

5. **A single area consists of two generating units with the following characteristics.**

Unit	**Rating**	**Speed Regulation inp.u**
1	**700MVA**	**7%**
2	**500MVA**	**4%**

The units are operating in parallel, sharing 1000MW at the nominal frequency. Unit 1 supplies 600 MW and unit 2 supplies 400MW at 50 Hz. The load is increased by 100 MW.

a) **Assume there is no frequency dependent load. Find the steady state frequency deviation and the new generation on each unit.**

b) The load varies1.5 percent for every 1 percent change in frequency. Find the steady state frequency deviation and the new generation on each unit.

Solution:

a) There is no frequency dependent load.

Assume base MVA = 1000, B = 0

R_1 = (7/100) x (f_r/P_r) Hz /MW

= (7/100) x (50/1000) =3.5 x10^{-3} Hz/MW

= 3.5x10^{-3} x 1000 = 3.5 Hz/p.u MW

R_2 = (4/100) x (f_r/P_r) Hz /MW

= (4/100) x (50/1000) =2 x10^{-3} Hz/MW

= 2 x10^{-3} x 1000 = 2 Hz/p.u MW

ΔP_D = 100/1000 =0.1 p.u

$\Delta f_{stat} = \frac{-\Delta P_D}{\frac{1}{R_1}+\frac{1}{R_2}} = \frac{-0.1}{\frac{1}{3.5}+\frac{1}{2}}$ = -0.127 Hz

New frequency f = f_0 +Δf = 50+(-0.127) =49.873 Hz

The change in generation for unit 1 is

ΔP_{G1} = -Δf/R_1 = 0.127/3.5 =0.0365 p.u MW

= 0.365 x 1000 = 36.5 MW

ΔP_{G2} = -Δf/R_2 = 0.127/2 =0.0635 p.u MW

= 0.635 x 1000 = 63.5 MW

Unit- I supplies 600+36.5 =636.5 MW

Unit -2 supplies 400+63.5 = 463.5 MW

At the new operating frequency of 49.873 Hz

b) Load varies 1.5% for every 1% change in frequency.

i.e., Rate of change of load with respect to frequency, B or D $=\frac{\partial P_D}{\partial f}=\frac{\frac{1.5}{100}X1000}{\frac{1}{100}X50}$ =30 MW/Hz

= 30/P_rp.u MW/Hz =30/1000 =0.03p.u MW/Hz

Δf = $\frac{-\Delta P_D}{\frac{1}{R_1}+\frac{1}{R_2}+B}$ $=\frac{-0.1}{\frac{1}{3.5}+\frac{1}{2}+\frac{1}{2}}$= -0.1226 Hz

New frequency f = f_0 +Δf = 50+(-0.1226) =49.877 Hz

The Change in generation for unit I is :

ΔP_{G1} = -Δf/R_1 = 0.1226/3.5 =0.035 p.u MW

= 0.035 x 1000 =35 MW

ΔP_{G2} = -Δf/R_2 = 0.1226/2 =0.0613 p.u MW

= 0.0613 x 1000 =61.3 MW

Unit- I supplies 600+35 =635 MW

Unit -2 supplies 400+61.3= 461.3 MW

At the new operating frequency of 49.8774 Hz

Total change in generation = ΔP_{G1}+ΔP_{G2} =35 + 61.3 = 96.3 MW

Which (100-96.3= 3.7 MW) less than the 100 MW load change.

6. **For the p-f control of a single area system have the following data: k_p =120 Hz/p.u MW; T_P =10sec ; T_g = T_t=0; R = 2.5 Hz/p.u MW; K_1 =0.1; ΔP_D = 0.1 p.u MW**

   Compute the time error and the steady state frequency caused by a step disturbance of magnitude given in the data. Express the error in seconds and cycles if the system frequency is 50 Hz

   Solution:

$$\Delta F(s) = \frac{-k_P \Delta P_D}{T_P[s^2+s\left(\frac{R+k_P}{RT_P}\right)+\frac{k_P k_I}{T_P}]}$$

$$= \frac{-120\ X\ 0.1}{10[s^2+s\left(\frac{2.5+120}{2.5X10}\right)+\frac{120\ X0.1}{10}]} = \frac{-1.2}{[s^2+4.9s+1.2]}$$

Roots of $s^2+4.9s+1.2$ =0 are

S = $\frac{-4.9 \pm \sqrt{(4.9)^2 - 4\ X 1.2}}{2}$ = -0.258 or -4.641

ΔF(s) = $\frac{-1.2}{(s+0.258)(s+4.641)}$

Using partial fraction method,

ΔF(s) = $\frac{A}{s+0.258} + \frac{B}{s+4.641}$

A(s+4.641) +B(s+0.258) =-1.2

Equating the coefficients,

A+B =0; 4.641A+0.258B =-1.2

A =-0.274; B=0.274

ΔF(s) = $\frac{-0.274}{s+0.258} + \frac{0.274}{s+4.641}$

Taking inverse Laplace transform,

$\Delta f(t) = 0.274[e^{-4.641t} - e^{-0.258t}]$

Time error $= \int_0^\infty \Delta f(t)dt = \int_0^\infty 0.274[e^{-4.641t} - e^{-0.258t}]dt$

$= 0.274\left[\frac{e^{-4.641t}}{-4.641} - \frac{e^{-0.258t}}{-0.258}\right]_0^\infty$

= -1.002 cycles =-1.002/50 =-0.02 sec

We lose 0.02 sec

$\Delta f_{stat} = Lt_{s\to 0}\ sF(s) = Lt_{s\to 0}\ s\left[\frac{-0.274}{s+0.258} + \frac{0.274}{s+4.64}\right] = 0$

Pondicherry University Questions

2 Marks

1. What are the functions of ALFC? (Apr 2011) (Apr 2013)
2. Howis the realpower in a power system controlled? (Nov 2012)
3. What is the use of secondary loop? (Nov 2011)
4. What are the functions of ALFC? (Nov 2013) (Nov 2014)
5. How is the real power in a power system controlled? (Nov 2010)

11Marks

1. What are the components of speed governing mechanism of an alternator derive the transfer function with an aid of block diagram (11) (Nov 2011) (Nov 2014)(Ref.Pg.No.7,Qn.No.1)
2. Describe speed governing mechanism which control the real power system derive the transfer function (11) (Apr 2014)(Apr 2011)(Ref.Pg.No.7,Qn.No.1)
3. Using Schematic diagram explain operating features of speed governing mechanism(11) (Nov 2013)(Ref.Pg.No.7,Qn.No.1)
4. Explain the speed governing mechanism in a power system derive the transfer function (11) (Apr 2013)(Ref.Pg.No.7,Qn.No.1)
5. Describe the speed governing mechanism of a power system and develop the mathematical model for the same (11) (Nov 2012) (Ref.Pg.No.7,Qn.No.1)
6. Explain the mathematical model of speed governing mechanism (11) (Nov 2010)
7. With a block diagram explain the proportional and integral load frequency control of single area system. Describe the dynamic response of load frequency control (11) (Apr2014)(Ref.Pg.No.7,Qn.No.1)
8. Develop a transfer function model of single area system and evaluate its closed loop servo and regulatory response (11) (Apr 2013)(Ref.Pg.No.12,Qn.No.2)
9. Develop a linear mathematical model of two area system and also explain the tie line bias control of two area system (11) (Apr 2015)(Ref.Pg.No.12,Qn.No.2)
10. Develop the block diagram model of a two area LFC system (11) (Nov 2014) (Ref.Pg.No.18,Qn.No.3)
11. Explain the principle involved in tie line frequency control in case of two area system (5) (Apr 2013)(Ref.Pg.No.18,Qn.No.3)
12. Draw the block diagram of Two area load frequency control system and explain theuncontrolled static analysis (11) (Nov 2012)(Ref.Pg.No.18,Qn.No.3)
13. Describe LFC control of two area system (11) (Nov 2010)(Ref.Pg.No.18,Qn.No.3)

REFERENCES

1. Olle I. Elgerad, “Electric Energy System Theory and Introduction”, Tata Mc Graw Hill publishing company, New Delhi, 2nd edition, 2004.
2. Allen J.Wood, Bruce F. Wollenbarg, “Power Generation, operation and control”,2nd edition, John Wiley and sons, 2008.
3. D.P.Kothari and I.J.Nagrath, " Modern Power System Analysis” Tata Mc Graw Hill publishing company Ltd., 2003.
4. P.S.R. Murty, "Operation and Control in Power Systems" BS Publications, 2005.

UNIT IV: DISPATCH SCHEDULE

Incremental cost curve, co-ordination equations with losses neglected - solution by iteration; co-ordination equations with loss included (No derivation of Bmn co-efficient); solution of co-ordination equations using Bmn co-efficient by iteration method., Base point and participation factors; Economic dispatch controller added to LFC.

TWO MARK QUESTIONS AND ANSWERS

1.Define the state of optimal dispatch?

This is the state that the power system is in prior to any contingency. It is optimal with respect to economic operation but may not be secure.

2. Define economic dispatch problem? /

State the objective of the economic dispatch problem (April 2013)

The objective of economic dispatch problem is to minimize the operating cost of active power generation.

3.Define incremental cost? (Dec 2013)

The rate of change of fuel cost with active power generation is called incrementalcost.

4.Define base point? (Dec 2013)

The present operating point of the system is called base point.

5.Define participation factor? (Nov 2013,April 2013,Nov/Dec 2014)

The change in generation required to meet power demand is called as participation

6.What are the advantages of using participation factor?

The advantages of using participation factor are:

a) computer implementation of economic dispatch is straight forward.
b) Execution time for economic dispatch is short.
c) It will always give consistent answers when units reach limits.
d) It gives linear incremental cost functions or have non-convex cost curves.

7.What is Lagrangian multiplier?

The necessary condition for the existence of a minimum cost operating condition is that the incremental cost rates of all the units be equal to some undetermined value called Lagrangian multiplier.

$\lambda = dF_i/dP_{Gi}$

8.Write the quadratic expression for fuel cost.

$C_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + C_i$ (Rs/Hr)

where,

a_i, b_i, C_i = constants

P_{Gi}=power generation

9.Explain the penalty factor.

The exact coordination equation is given by

$\lambda=(IC)_i / 1-(ITL)_i = (IC)_i L_i$

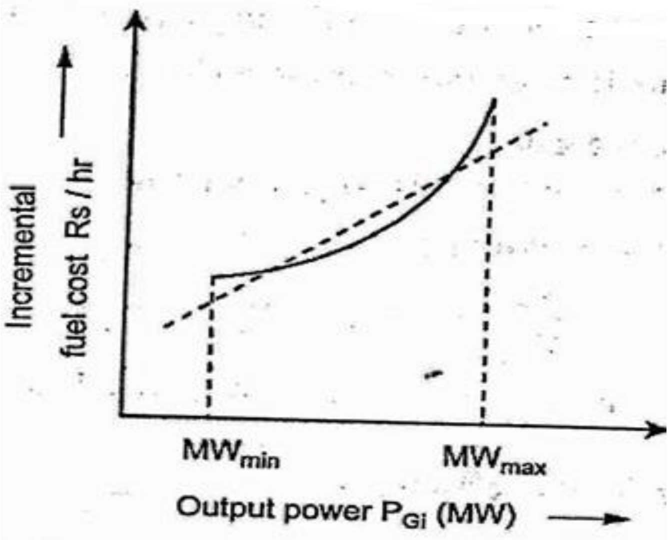
L_i=penalty factor, $(ITL)_i$=incremental transmission loss.

10.Compare with unit commitment and economic load dispatch.

Unit commitment	Economic Load Dispatch
- optimum allocation of number of units to be operated to determine the units of a plant that should operate for a given load is the problem of unit commitment	- Optimum allocation of generation to each station. (At each generating station at various station load level)
- There are number of subsets of the complete set of 'n' units that would satisfy the expected demand.	- The problem assumes that there are 'n' units already connected to the system.
- Purpose of unit commitment is to find the optimal subset among the subsets which provide the minimum operating cost.	- Purpose of economic dispatch problem is to find the optimum operating policy for these 'n' units.

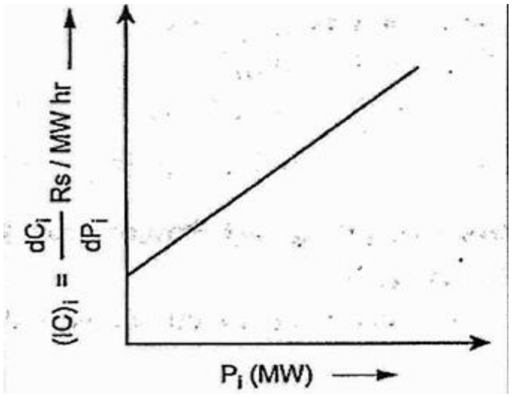
11. Draw incremental cost curve./ what is meant by incremental fuel cost?

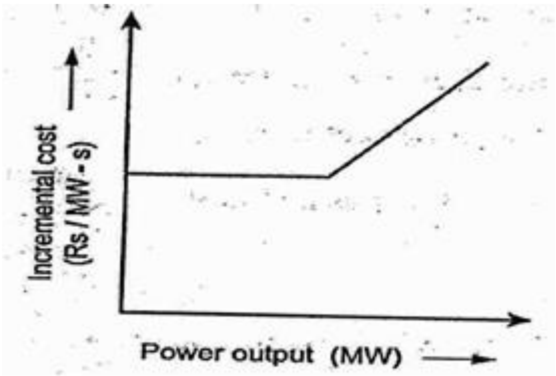
(Nov 2013, April 2015)



12. Draw the incremental cost curve of thermal power plant and hydro power plant.

(April 2013)





Incremental cost curve of thermal power plant   Incremental cost curve of hydro power plant

13. Write the transmission loss formula using B-co-efficient.(April/May 2014)

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{Gi}B_{ij}P_{Gj}\, for N bus system$$

11 MARKS

1.Derive the coordination equation of a power system neglecting line losses.

(or)

Derive the coordination equation for economic dispatch neglecting losses in the power system. Give steps for economic dispatch calculation neglecting losses. (April 2013)

CO-ORDINATION EQUATIONS WITH LOSSES NEGLECTED. SOLUTION BY ITERATION

F_t -Total fuel input of the system

F_n -Fuel input to the nth unit

P_d -Total load demand

P_n -Generation of n unit

The economic dispatch problem is defined as

$$\min F_t = \sum_{n=1}^{n} F_n ---------(1)$$

Subjected to $P_d = \sum_{n=1}^{n} P_n ---------(2)$

Use of lagrangian multiplier the auxiliary function is obtained as

$$F = F_t + \lambda H -------- (3)$$

Where,

$$\lambda = \text{lagrangian multiplier}$$

$$H = P_d - \sum_{n=1}^{n} P_n$$

$$F = F_t + \lambda\left(P_d - \sum_{n=1}^{n} P_n\right) -------- (4)$$

Differentiating F w.r.t generation P_n and equating to zero gives the condition for optimal operation of the system.

$$\frac{rF_n}{rP_n} = \frac{rF_t}{rP_n} + \lambda(0-1) = 0$$

$$But F_t = F_1 + F_2 + \cdots + F_n$$

$$\therefore \frac{rF_t}{rP_n} = \frac{rF_n}{rP_n}$$

$$\frac{df_n}{dp_n} = \lambda ----(6)$$

And the condition for optimum operation is

$$\frac{df_1}{dp_1} = \frac{df_2}{dp_2} = \frac{df_3}{dp_3} \ldots = \frac{df_n}{dp_n} = \lambda ----(7)$$

Where,

$$\frac{df_n}{dp_n} = incremental production cost of plant in Rs/MWhr$$

Equation (7) is called the co-ordination equation neglecting losses.

Analytical solution for (no generation limit)

Cost function C = $a_i {P_{Gi}}^2 + b_i P_{Gi} + c_i$

Using incremental cost

$2a_i P_{Gi} + b_i = \lambda$

$$P_{Gi} = \frac{\lambda - b_i}{2a_i} i = 1,2, \ldots N$$

From power balance equation

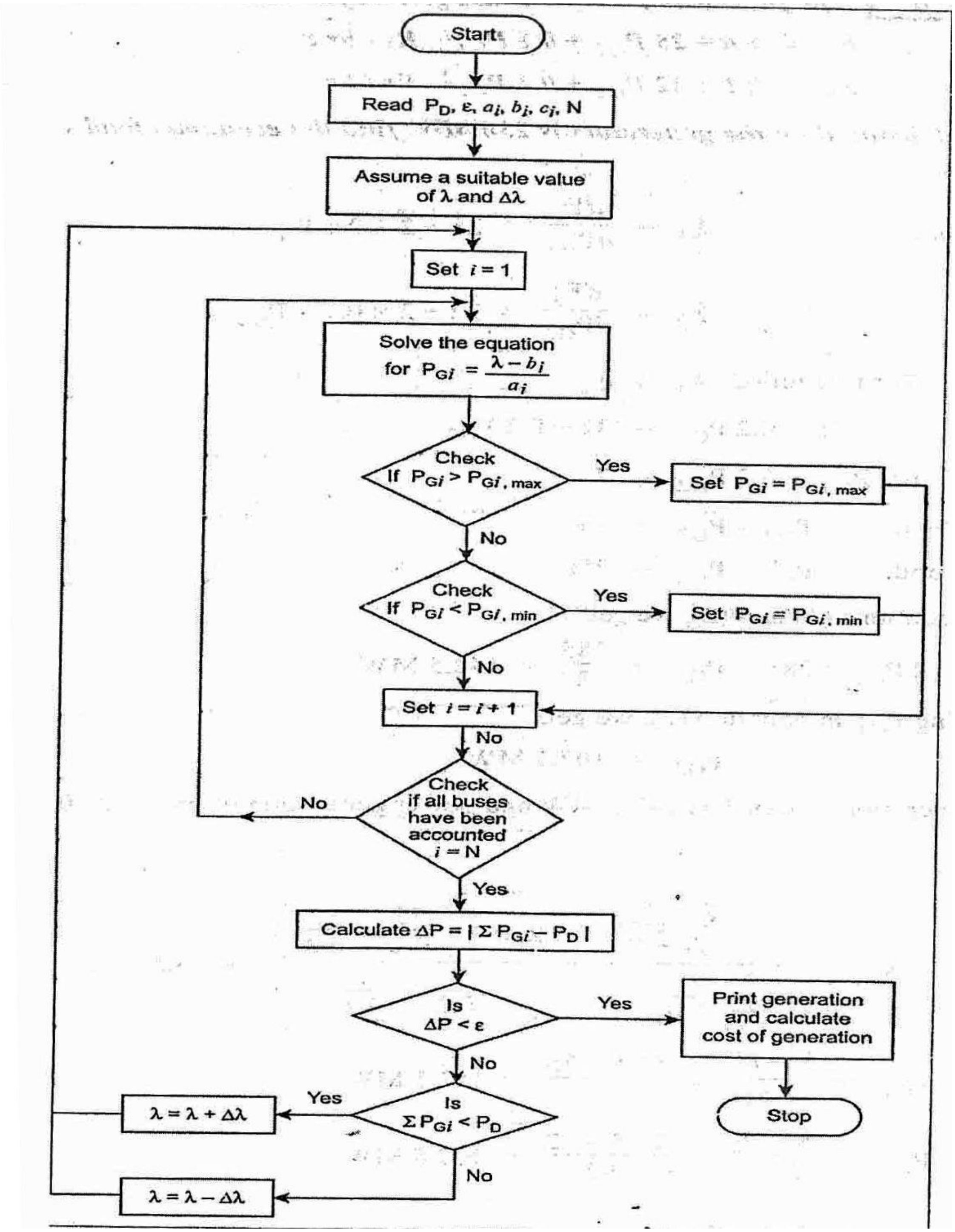


Figure Flow chart for economic dispatch neglecting losses.

$$\sum_{i=1}^{N} P_{Gi} - P_D = 0$$

$$\lambda \sum_{i=1}^{N} \frac{1}{2a_i} - \sum_{i=1}^{N} \frac{b_i}{2a_i} = P_D$$

$$\lambda = \frac{P_D + \sum_{i=1}^{N} \frac{b_i}{2a_i}}{\sum_{i=1}^{N} \frac{1}{2a_i}}$$

Procedure (losses neglected)

Step 1: compute λ using the equation

$$\lambda = \frac{P_D + \sum_{i=1}^{N} \frac{b_i}{2a_i}}{\sum_{i=1}^{N} \frac{1}{2a_i}}$$

Step 2: compute P_{Gi} using equal Incremental cost basis.

The economic schedules $P_{Gi} = \frac{\lambda - b_i}{2a_i} i = 1,2, \ldots N$

Step 3: if the computed P_{Gi} satisfy the operating limits

$$P_{Gi,min} \leq P_{Gi} \leq P_{Gi,max} i = 1,2, \ldots N$$

Then the optimum solution is obtained, otherwise go to next step

Step 4: if P_{Gi} violates the operating limit, then fix the generation at the respective limit

$$P_{Gi} < P_{Gi,min} Fix P_{Gi} = P_{Gi,min}$$

$$P_{Gi} > P_{Gi,min} Fix P_{Gi} = P_{Gi,max}$$

Step 5: redistribute the remaining system load

$$P_{Dnew} = P_{Dold} - sum of the fixed generations to the remaining units.$$

Step 6: compute λ_{new} using $P_{D\,new}$ and compute the remaining generations using

$$P_{Gi} = \frac{\lambda_{\text{new}} - b_i}{2a_i}$$

Step 7: check whether the optimality condition is satisfied

$$\frac{df_i(P_{Gi})}{dp_{Gi}} = \lambda_{\text{new}} for P_{Gi,min} \leq P_{Gi} \leq P_{Gi,max}$$

$$\frac{df_i(P_{Gi})}{dp_{Gi}} \leq \lambda_{\text{new}} for P_{Gi} = P_{Gi,max}$$

$$\frac{df_i(P_{Gi})}{dp_{Gi}} \geq \lambda_{\text{new}} for P_{Gi} = P_{Gi,min}$$

If the condition is satisfied, then stop. Otherwise release the generation schedule fixed at $P_{Gi,min} or P_{Gi,max}$ Of these units not satisfying optimality condition. Include these units in the remaining units and modify the new power demand P_{Dnew}

$$P_{Dnew\,1} = P_{Dnew} + \{sum of the fixed generators not satisfying optimality condition\}$$

And go to step 6.

2. Derive the coordination equation for a power system consisting of n- generating plants supplying several loads interconnected through a transmission network with losses.(Nov 2013)

(or)

Develop an iterative algorithm for solving the optimum dispatch equation of an n-bus power system taking into account the effects of system losses. (April 2015)

CO-ORDINATION EQUATION WITH LOSS OR EXACT CO-ORDINATION EQUATION:

Let

F_t-Total fuel input of the system

F_n-Fuel input to n unit

P_d-Total load demand

P_n-Generation of n unit

P_L -Total system loss

The optimal load dispatch problem including transmission losses is defined as

$$\min F_t = \sum_{n=1}^{n} F_n - - - - - - - - (1)$$

Subjected to $P_D + P_L = \sum_{n=1}^{n} P_n$

$$P_D + P_L - \sum_{n=1}^{n} P_n = 0 - - - - - - - - (2)$$

Use of lagrangian multiplier, the augmented cost function is

$$F = F_t + \lambda\left(P_D + P_L - \sum_{n=1}^{n} P_n = 0\right) - - - - - - (3)$$

Differentiating F w.r.t to generation P_n and equating to 0 gives the condition for optimal operation of the system

$$\frac{rf}{rP_n} = \frac{rF_t}{rP_n} + \lambda\left(\frac{rP_d}{rP_n} + \frac{rP_L}{rP_n} - 1\right) = 0$$

$$\frac{rF_t}{rP_n} + \lambda\left(\frac{rP_L}{rP_n} - 1\right) = 0$$

$$\frac{rF_t}{rP_n} + \lambda\frac{rP_L}{rP_n} - \lambda = 0$$

$$\frac{dF_n}{dP_n} + \lambda\frac{dP_L}{dP_n} = \lambda - - - - - - (4)$$

$$\frac{dF_n}{dP_n} = \left(1 - \frac{dP_L}{dP_n}\right)\lambda - - - - - - (5)$$

Where,

$$\frac{dF_n}{dP_n} = IC = Incrementalfuelcost.$$

$$\frac{dP_L}{dP_n} = ITL = Incrementaltransmissionlinecost.$$

$$\therefore \lambda = \frac{IC}{1-ITL} = L_i\,(IC)$$

Where,

$$L_i = Penaltyfactorofplant = \frac{1}{1-ITL}$$

Equation (5) is called an exact coordination equation when transmission losses are considered or modified Incremental cost.

3. Discuss how to solve co-ordination equations using BMN coefficient by iteration method.(April 2015)

   (or)

   Explain using a flow chart, the solution procedure of coordination equation using B_{mn} coefficient.(April 2013)

   (or)

   Explain with a flow chart the computational procedure for the solution of economic dispatch problem including transmission losses and generator limits. (April / May 2014)

SOLUTION OF COORDINATION EQUATION USING B_{MN} COEFFICIENT BY ITERATION METHOD

Consider a two bus system

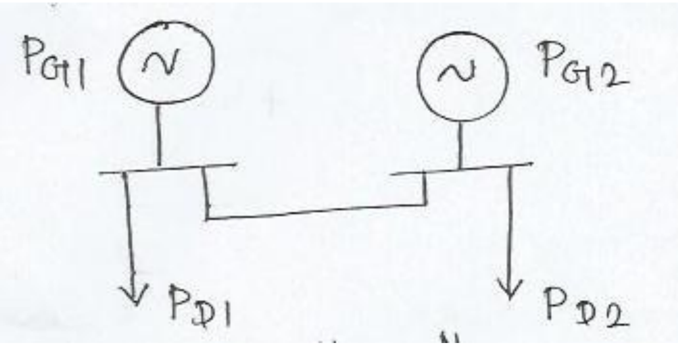


Figure 4.8 Two bus system

Transmission loss

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{Gi}B_{ij}P_{Gj}\; forNbussystem$$

$$P_L = \sum_{i=1}^{2}\sum_{j=1}^{2} P_{Gi}B_{ij}P_{Gj}\; for\ 2\ bussystem ------(1)$$

$$= {P_G}^T B_{ij} P_G$$

$$= [P_{G1} P_{G2}] \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} P_{G1} \\ P_{G2} \end{bmatrix}$$

$$= [P_{G1} B_{11} + P_{G2} B_{21} + P_{G1} B_{12} + P_{G2} B_{22}] \begin{bmatrix} P_{G1} \\ P_{G2} \end{bmatrix}$$

$$P_L = {P_{G1}}^2 B_{11} + P_{G2} B_{21} P_{G1} + P_{G1} B_{12} + {P_{G2}}^2 B_{22}$$

Since B_{ij} matrix is symmetrical $B_{12} = B_{21}$

$$P_L = {P_{G1}}^2 B_{11} + 2\, P_{G1} B_{12}\, P_{G2} + {P_{G2}}^2 B_{22} ------(2)$$

Let the cost function be

$$C_1 = a_1\, {P_{G1}}^2 + b_1\, P_{G1} + c_1$$
$$C_2 = a_2\, {P_{G2}}^2 + b_2\, P_{G2} + c_2$$
$$Incrementalfuelcost(IC)_1 = \frac{dC_1}{dP_{G1}} = 2\, a_1\, P_{G1} + b_1$$

$$Incrementalfuelcost(IC)_2 = \frac{dC_2}{dP_{G2}} = 2\, a_2 P_{G2} + b_2 \; ---- (3)$$

Incremental transmission loss differentiate equation (2) by P_{G1} &P_{G2}

Incremental transmission loss $(ITL)_1 = \frac{dP_L}{dP_{G1}} = 2(B_{11} P_{G1} + B_{12}\, P_{G2})$

Incremental transmission loss $(ITL)_2 = \frac{dP_L}{dP_{G2}} = 2(B_{22} P_{G2} + B_{12}\, P_{G1}) ----- (4)$

For optimum operating conditions, coordination equation is

$$\lambda_1 = \lambda_2$$

$$[IC_1] L_1 = [IC_2] L_2$$

$$IC_1 \times \frac{1}{1 - (ITL)_1} = IC_2 \times \frac{1}{1 - (ITL)_2}$$

$$\frac{2\, a_1\, P_{G1} + b_1}{1 - 2(B_{11} P_{G1} + B_{12}\, P_{G2})} = \frac{2\, a_2 P_{G2} + b_2}{1 - 2(B_{22} P_{G2} + B_{12}\, P_{G1})} -------- (5)$$

Further, we have equality constraints

$$\sum_{i=1}^{2} P_{Gi} = P_D + P_L$$

$$P_{G1} + P_{G2} = P_D + \left({P_{G1}}^2 B_{11} + 2\, P_{G1} B_{12}\, P_{G2} + {P_{G2}}^2 B_{22}\right)$$

$$P_{G1} + P_{G2} - P_D - {P_{G1}}^2 B_{11} - 2\, P_{G1} B_{12}\, P_{G2} - {P_{G2}}^2 B_{22} = 0 ----- (6)$$

Solving equation (5) & (6) , we get P_{G1}&P_{G2}

For N bus system,

$$\lambda_i = \frac{2\, a_1\, P_{G1} + b_1}{1 - 2\sum_{i=1}^{N} B_{1i} P_{Gi}} = \frac{2\, a_2 P_{G2} + b_2}{1 - 2\sum_{i=1}^{N} B_{2i} P_{Gi}}$$

Equality constraint is $P_D + P_L - \sum_{i=1}^{N} P_{Gi} = 0$

$$\sum_{i=1}^{N} P_{Gi} - P_D - \sum_{i=1}^{N}\sum_{j=1}^{N} P_{Gi} B_{ij} P_{Gj} = 0 ------(7)$$

We have N non-linear equation, the solution of which gives the optimum generations

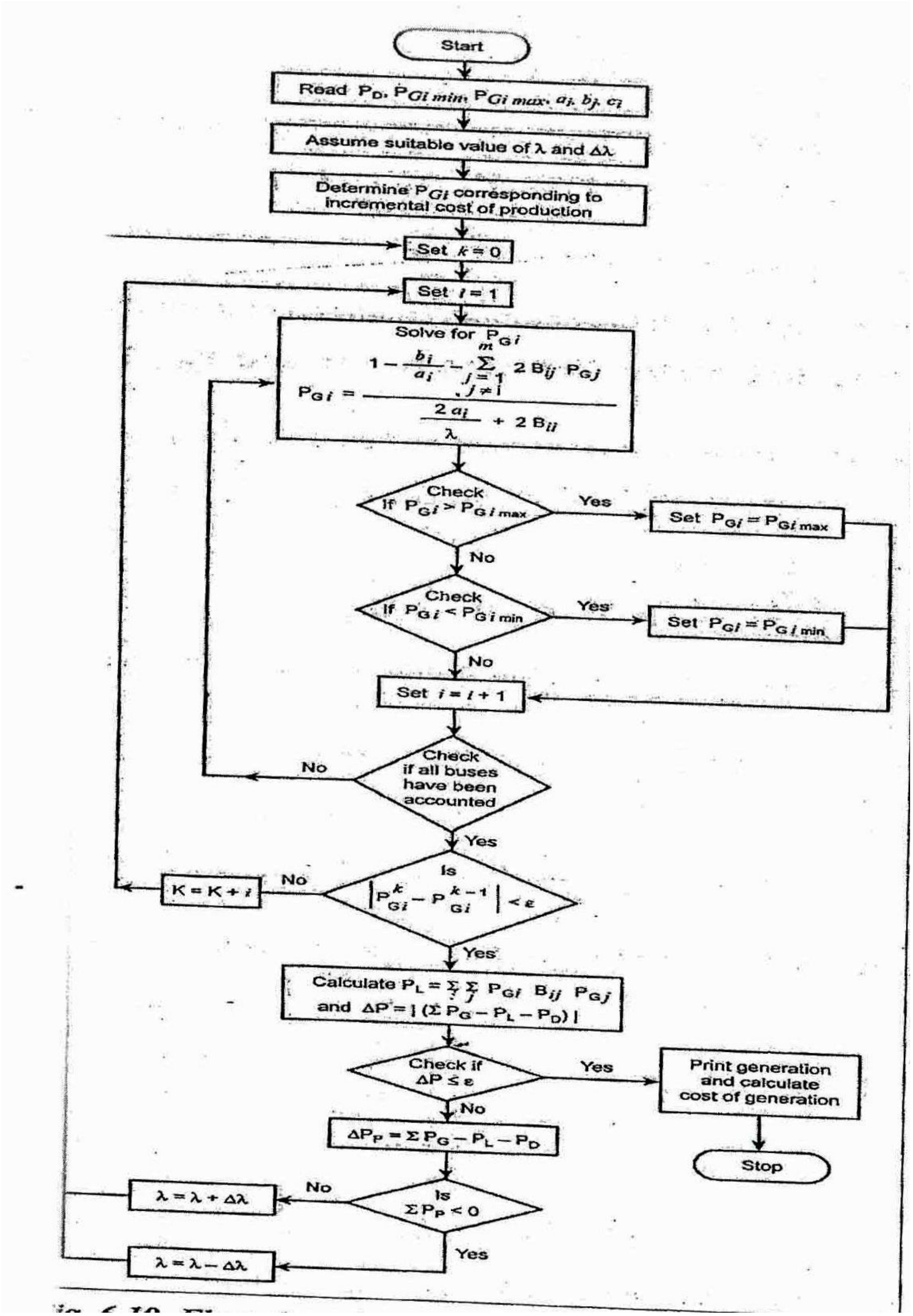


Figure . Flow chart for economic dispatch including losses.

SOLUTION OF λ ITERATION METHOD WITH LOSS

Step 1: Choose lagrange multiplier $\lambda as \lambda^0 or (IC)^0$

Compute $\lambda^0 using \lambda = \frac{P_D + \sum_{i=1}^{N} \frac{b_i}{2a_i}}{\sum_{i=1}^{N} \frac{1}{2a_i}}$

Step 2: Assume $P_{Gi} = 0$ i=1,2,….N

Step 3: Solve for P_{Gi} using

$$P_{Gi} = \frac{1 - \frac{b_i}{\lambda} - 2\sum_{j=1}^{N} B_{ij} P_{Gj}}{\frac{2a_i}{\lambda} + 2B_{ii}}$$

Where,

C = $a_i {P_{Gi}}^2 + b_i P_{Gi} + c_i$

Step 4: check if any P_{Gi} is beyond or below the inequality constraint

$$P_{Gi,min} \le P_{Gi} \le P_{Gi,max}$$

$$P_{Gi} < P_{Gi,min} Fix P_{Gi} = P_{Gi,min}$$

$$P_{Gi} > P_{Gi,min} Fix P_{Gi} = P_{Gi,max}$$

Step 5: calculate transmission loss

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{Gi} B_{ij} P_{Gj}$$

Step 6: check for power balance equation

$$\left| P_D + P_L - \sum_{i=1}^{N} P_{Gi} \right| = 0$$

Value of P_{Gi} gives the optimum generation. Otherwise go to next step

Step 7:

$$Increase \lambda^0 by \Delta\lambda\, , if \left| P_D + P_L - \sum_{i=1}^{N} P_{Gi} \right| < 0$$

$$Decrease \lambda^0 by \Delta\lambda\, , if \left| P_D + P_L - \sum_{i=1}^{N} P_{Gi} \right| > 0$$

Repeat from step 3 till the optimum solution is achieved.

4. Explain the base point and participation factor. Briefly.

BASE POINT AND PARTICIPATION FACTOR

The economic dispatch problem has to be solved repeatedly by moving the generators from one economically schedule to another as the load changes by a reasonably small amount we start from a schedule obtained from equal Incremental cost as base point. Next, the scheduler assumes a load change and investigates how much each generating unit needs to be moved. i.e. participate in the load change in order that the new load be served at the most economic operating cost. Assume that both the first and second derivatives in the cost versus power output function are available. i.e. both F_i^1 and F_i^{11} exist. The incremental cost curve for the ith unit is given in fig.4.10

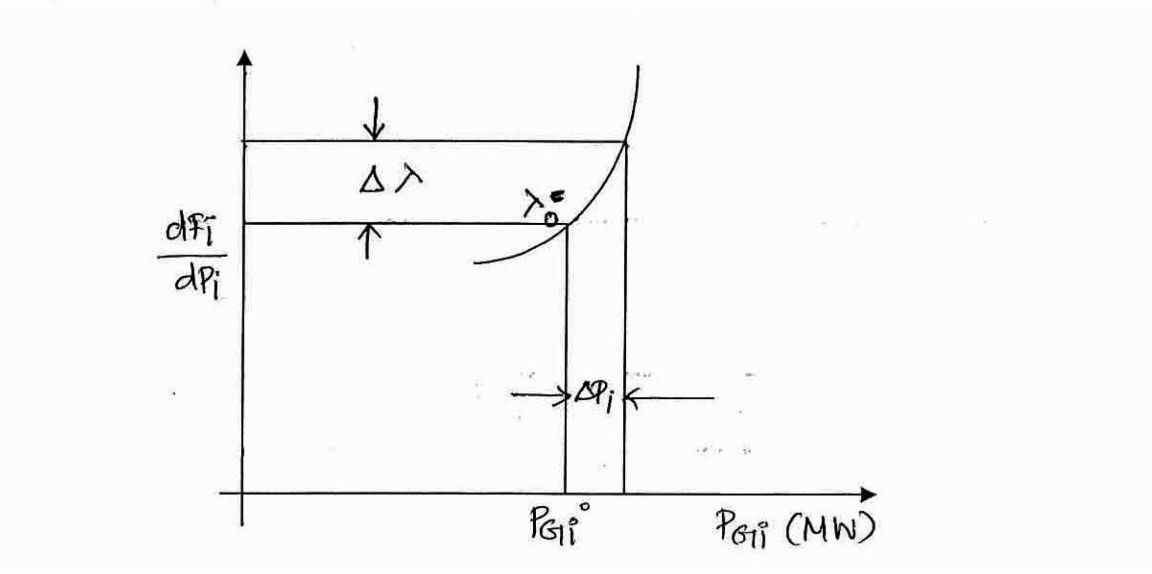


Figure . The incremental cost curve for the ith unit

As the unit load is changed by an amount ΔP_i the system Incremental cost moves from λ^0 to $\lambda^0 + \Delta\lambda$

For a small change in power output on the single unit

$$F_i = a_i {P_{Gi}}^2 + b_i P_{Gi} + c_i$$

$$\lambda_i = \frac{\Delta F_i}{\Delta P_{Gi}} = 2a_i P_{Gi} + b_i = F_i'$$

$$\frac{\Delta\lambda_i}{\Delta P_{Gi}} = F_i'' = 2a_i$$

$$\Delta\lambda_i = \Delta\lambda \cong F_i'' \Delta P_{Gi} - - - - - (1)$$

This is true for each of the N units on the system, so that

$$\Delta P_{G1} = \frac{\Delta\lambda}{F_1''}$$

$$\Delta P_{G2} = \frac{\Delta\lambda}{F_2''}$$

$$\Delta P_{GN} = \frac{\Delta\lambda}{F_N''}$$

Let P_D be the total demand on the generation

The total change in generation=change in total system demand

$$P_D = P_{load} + P_L$$

$$Changeindemand \Delta P_D = \Delta P_{G1} + \Delta P_{G2} + \cdots + \Delta P_{GN} .$$

$$\Delta P_D = \frac{\Delta\lambda}{F_1''} + \frac{\Delta\lambda}{F_2''} + \cdots + \frac{\Delta\lambda}{F_N''}$$

$$\Delta P_D = \Delta\lambda \sum_{\mathrm{i=1}}^{\mathrm{N}} \frac{1}{F_i''} ----(2)$$

Participation factor for each unit

Divide (1) by (2)

$$\frac{\Delta P_{Gi}}{\Delta P_D} = \frac{\frac{1}{F_i''}}{\sum_{\mathrm{i=1}}^{\mathrm{N}} \frac{1}{F_i''}} ------(3)$$

Suppose P_D increases to ${P_D}^0 + \Delta P_D$

The new value of generation is calculated

$$P_{new,i} = P_{base,i} + \left[\frac{\Delta P_{Gi}}{\Delta P_D}\right] \Delta P_D i = 1,2 \ldots N$$

Where,

$$\Delta P_D = changeinloaddemand.$$

4ADVANTAGES OF USING PARTICIPATION FACTOR

- ✓ Computer implementation of economic dispatch is straight forward
- ✓ Execution time for the economic dispatch is short
- ✓ It will always give consistent answers when units reach limits.
- ✓ It gives linear incremental cost functions or have non- convex cost curves.

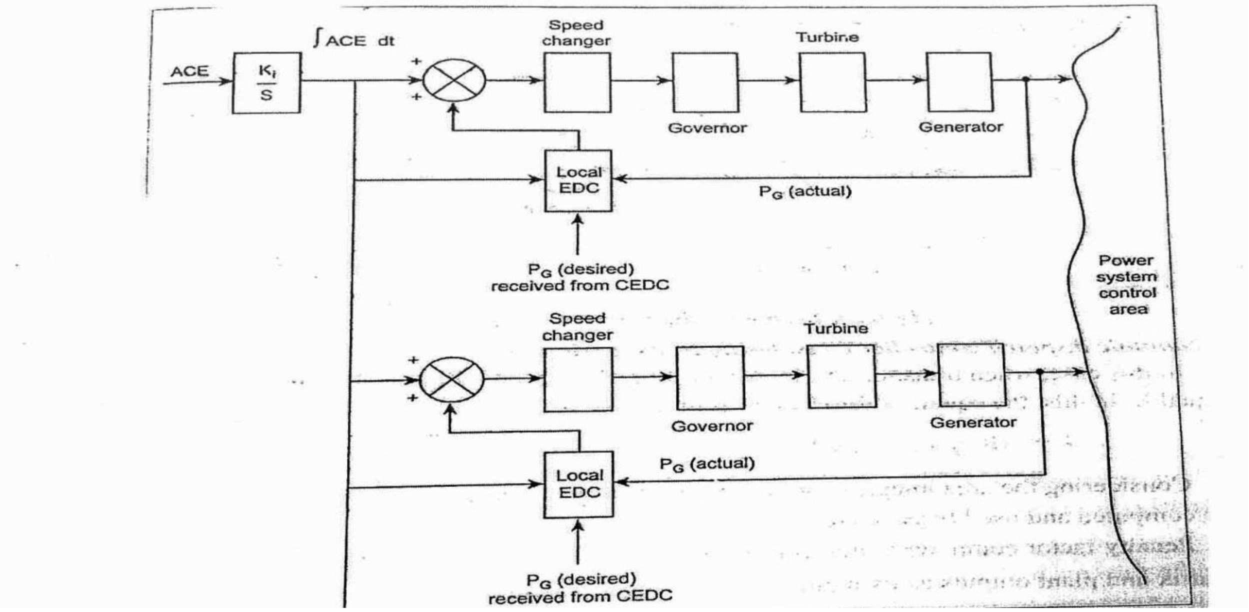
5. Explain in detail the combined economic dispatch and load frequency control.

(Nov/ Dec 2014)

ECONOMIC DISPATCH CONTROLLER ADDED TO LFC

Load frequency with integral controller achieves zero steady state frequency error and a fast dynamic response, but it exercises no control over the relative loadings of various generating stations of the control size. The economic controller added to LFC is as shown in fig.4.11

If a sudden small increase in load in the control area, the LFC changes the speed changer settings of the governors of all generating units. These units match the load and the frequency returns to be scheduled value. However, the loading of generating units is independent of economic loading considerations. Some units may get overloaded. Some control over this can be done by adjusting the gain factor (k_i). However, this cannot be satisfactory.



EDC-Economic dispatch controller.

CEDC-Central Economic dispatch controller.

Figure . Combined economic dispatch and load frequency control.

A best solution is obtained by using independent controls for load frequency and economic dispatch. The load frequency controller is a fast acting control and the economic dispatch controller is a slow acting control. LFC adjust the speed changer setting every minute in accordance with a command signal generated by the central economic dispatch computer.

The signal P_G (desired) is computed by the central economic dispatch computer and is transmitted to the local economic dispatch centre. The economic dispatch error $P_{G(des)} - P_{G(act)}$ is modified by the integral ACE at that instant of time. The system operates with economic dispatch error only for every short periods of time, before it is readjusted.

Through the operation of integral controller, primary control is exercised to alter the position of speed changers so that the generating stations of the area produce outputs conforming to the demand. But by this control alone, it may not be ensured that all the participating station of area operate at equal incremental cost of generation. For this purpose, the secondary control i.e. economic dispatch control is fitted into the system.

Integral controller output is a common input signal to the stations of the area. With $\lambda=(IC)_1 =(IC)_2 =\ldots\ldots$,we get the desired generation for the plants. The same way, then compared with the actual generation to determine the economic error.

The economic dispatch control equipments as shown, comprises of a function generator to find desired generation from λ, comparator to detect the error by comparing desired generation with actual MW generation. Low gain integral controller provided at energy control centre to send the correct signal for readjustment of speed changer position. This low gain of the integral controller ensures slow action of the secondary control. This economic controller can be added to LFC control.

It may be extended to two area system as well. In that case only change that has to be made is in the formulation of area control error. In that case, the change in tie-line power is to be considered over and above the frequency deviation.

ECONOMIC DISPATCH CONTROLLER CONSIDERING TRANSMISSION LOSSES

In this case, when transmission losses are significant, optimum economy is obtained from equal λ . in this equation for i^{th} plant is given by

$$\lambda = (\mathrm{IC})_i L_i \,, (\mathrm{IC})_i = \frac{\lambda}{L_i}$$

Considering the area integral controller output as λ,with the help of penalty factor L_i may be computed and used to yield$(\mathrm{IC})_i$.

Penalty factor which computes which computers.

$L_i = \frac{1}{1-(\mathrm{ITL})_i}$ Requires storage of B-matrix and plant output as its input.

Two area system with AGC as well as EDC considering transmission losses as shown in fig 4.12

Where,

AGC = Automatic generation control.

EDC = Economic dispatch control centre.

IC = Incremental cost.

ITL = Incremental transmission loss.

When transmission losses are included, the incremental production cost at each plant I must be multiplied by a factor

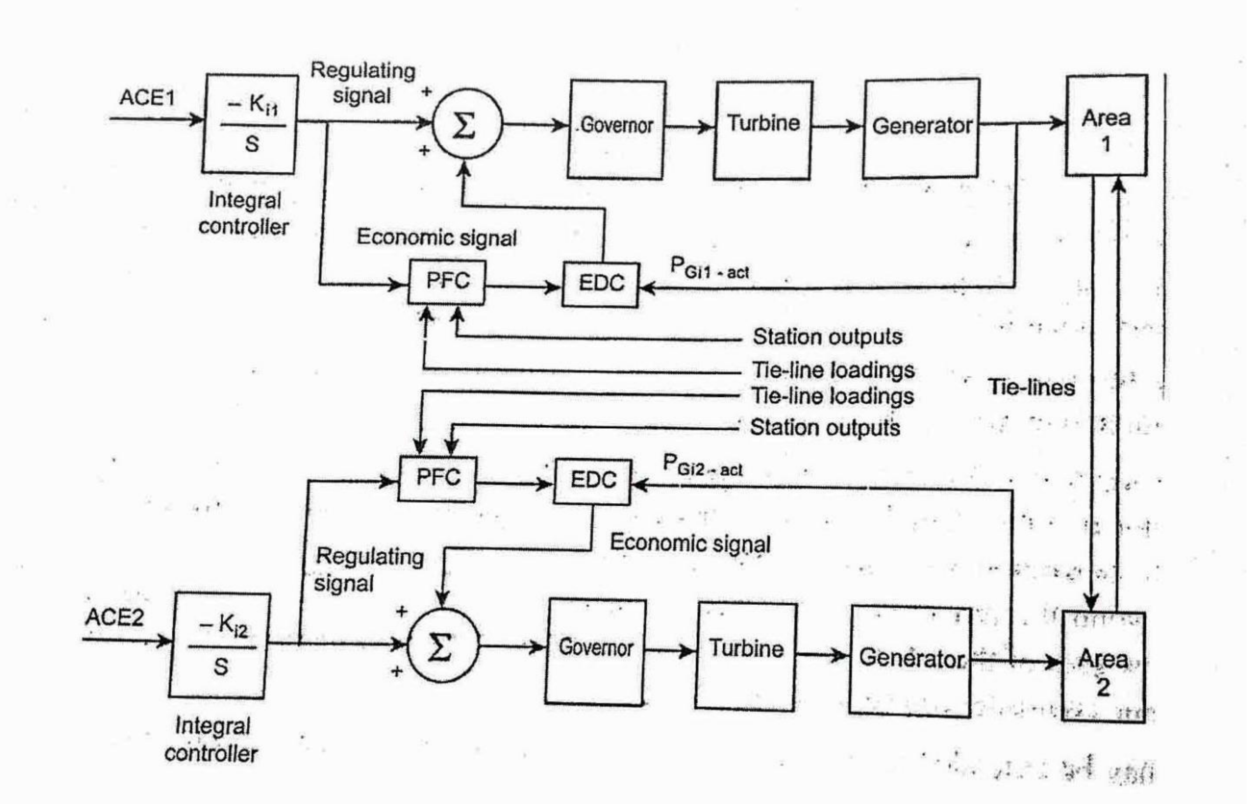


Figure 4.12 Two area system with AGC as well as EDC considering transmission losses

Which then will be equal to the incremental cost of power delivered. Hence, the factor is called penalty factor.

6. Briefly explain the incremental cost curve of thermal and hydro power plant.

INCREMENTAL COST CURVE

The input/output curve of generating units of a plant is important to describe the efficiency of the plant. Such a curve for thermal power plant is shown. The input/output curve for a hydro plant is also similar except that the input will correspond to water discharge.

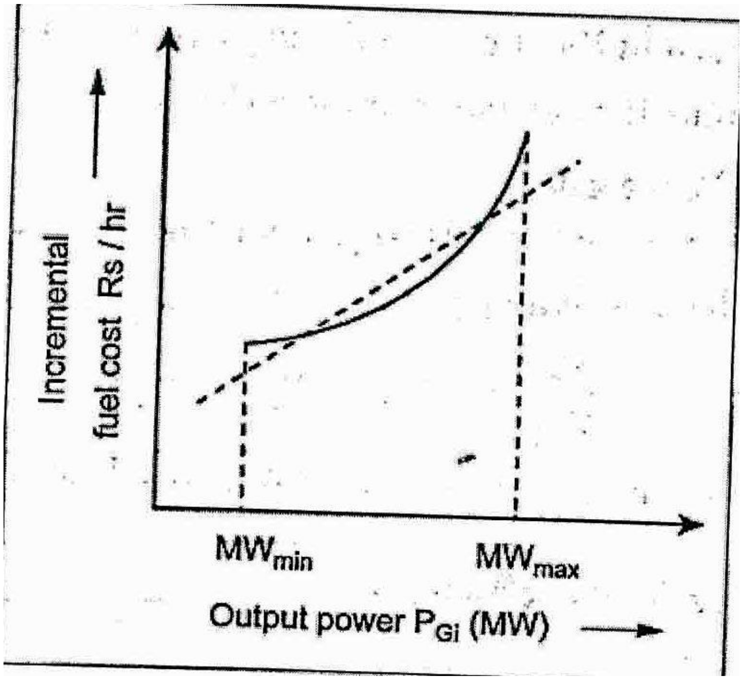


Figure 4.1 Incremental fuel cost curve

Where,

$$H = HeatinputtotheUnit.\frac{Btu}{hour}orkcal/hour$$

$$B = FuelcostcurveinRs/hour.$$

The empirical equation of the fuel cost curve is

$$F_i = a_iP_i{}^2 + b_iP_i + c_i$$

Where,

$$a_i\ ,b_i,c_i = costcoefficient.$$

Incremental fuel cost $IC = \frac{dF_i}{dP_i}$

$$IC = \frac{dF_i}{dP_i} = 2a_iP_i + b_iRs/MWhour.$$

Incremental cost is the slope of cost curve. Incremental cost curve for a typical thermal plant is shown.

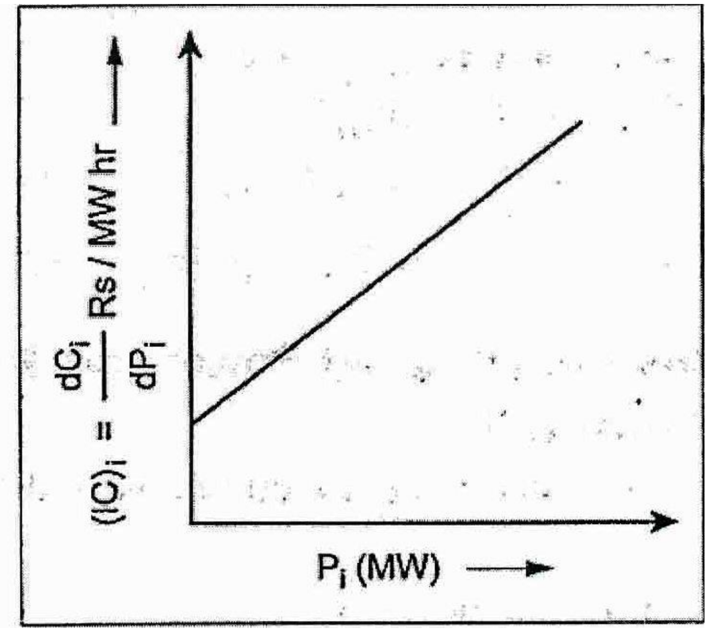


Figure 4.2 Incremental cost curve for the thermal power plant

The following assumptions are made for incremental rate theory

1. Input – output curves are continuous
2. First derivations of the input-output curves are linear
3. The value of Incremental rate increase with the increase in output

The Input-output curve and Incremental cost curve for a hydro power plant is shown.

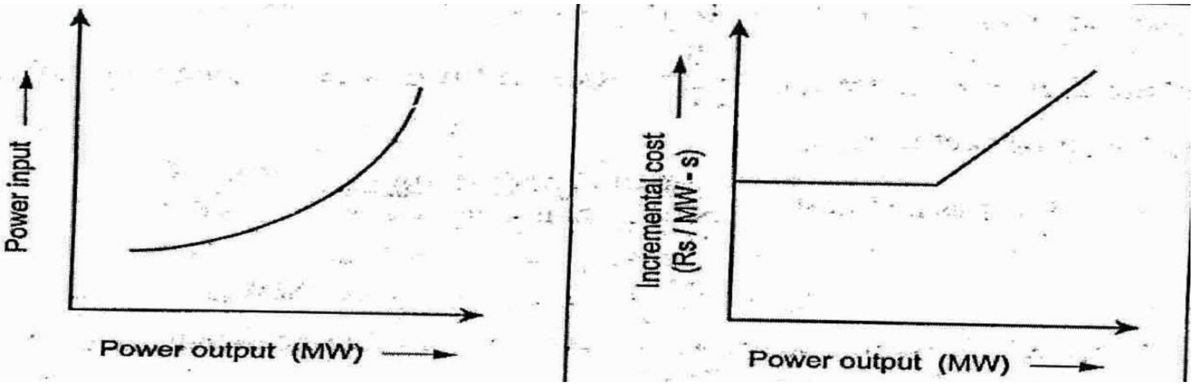


Figure 4.3 Incremental cost curve for a hydro power plant

The incremental fuel cost of all the generating units must be the same. The common value of incremental fuel cost is called the system Incremental cost. In same case, some of the units operate at their upper or lower limits. The IC of all other machines which have not hit their limit must be equal to λ is called as system λ or Incremental cost of received power.

The fuel cost curve and the Incremental cost curve may have a number of discontinuous as shown.

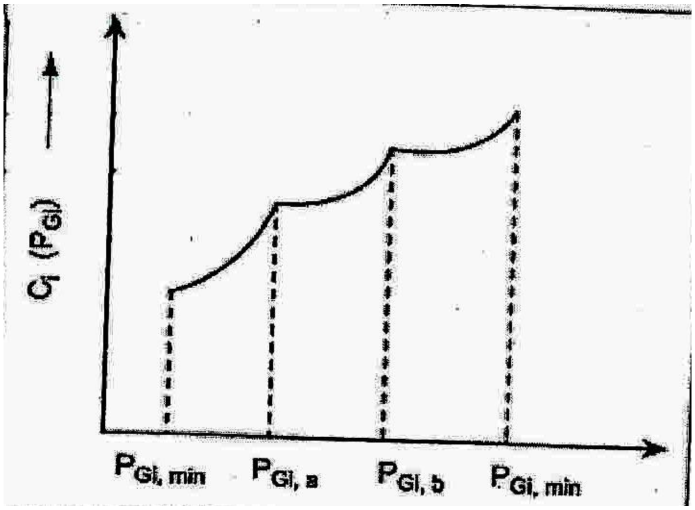


Figure 4.4 Fuel cost curve.

The discontinuous occur when the output power has to be extended by using additional boilers, steam condenser or other equipments.

Discontinuous also appear is the cost represent the operation of an entire power station. So that cost has discontinuous on paralleling of generators.

Real power generation as

$$P_{Gi} = \propto_i + \beta_i (IC)_i + r_i (IC)_i^{\ 2} + \cdots MW$$

The discontinuous of fuel cost curve may be approximated as straight line as shown.

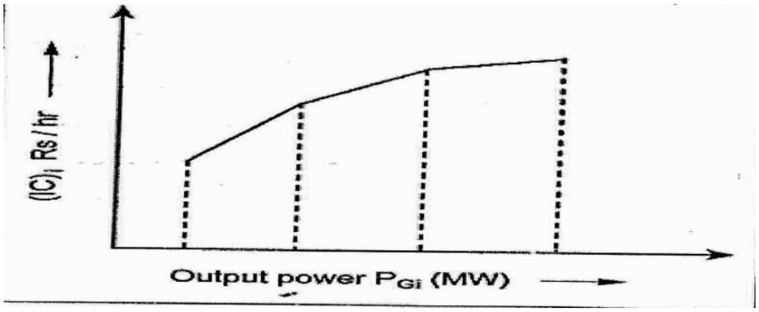


Figure 4.5 Incremental cost curve

When the economical load distribution between a number of generator units is considered. The optimum generating schedule is effected when an Incremental cost increase at one of the units replace a compensating decrease at every other unit in turn at the same Incremental cost. The economic optimum load distribution is obtained when all the generator units operate at the equal Incremental rate.

When two areas are operating at different Incremental costs, there is a possibility to improve the overall economy. Consider the two area system shown.

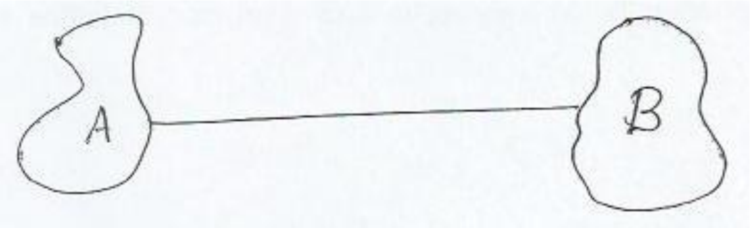


Figure 4.6 Two area system.

Three possible cases are

1. The area A is generating power at a lower Incremental cost than area B and possesses extra spinning reserve.
2. Area B will save money simply by purchasing extra MW from area A which is generating power at a lower cost than area B.
3. Area A would benefit economically from selling power to area B as long as area B is selling in pay a price.

Problems:

Type 1: without loss and without limits

The fuel cost of 2 unit given by F1=1.6 + 25PG$_1$ + 0.1G$^2{}_1$, F1=2.1 + 32PG$_2$ + 0.1 G$^2{}_1$, if the total demand on the generator is 250mw. Find to economic load scheduling of 2 units.

Solution:

$$\lambda = \frac{P_D + \sum_{i=1}^{2} \frac{b_i}{2a_i}}{\sum_{i=1}^{2} \frac{1}{2ai}}$$

$$\lambda = \frac{P_D + \left[\frac{b_1}{2a_1} + \frac{b_2}{2a_2}\right]}{\frac{1}{0.2} + \frac{1}{0.2}}$$

$$\lambda = \frac{250 + \left[\frac{25}{0.2} + \frac{32}{0.2}\right]}{\frac{1}{0.2} + \frac{1}{0.2}}$$

λ=53.5

$$PG_1 = \frac{\lambda - b_1}{2a_1}$$

$$PG_1 = \frac{53.5 - 25}{0.2} = 142.5\text{MW}$$

$$PG_2 = \frac{\lambda - b_2}{2a_2}$$

$$PG_1 = \frac{53.5 - 32}{0.2} = 107.5\text{MW}$$

$$\sum PG_i - P_D = 0$$

$$\sum PG_i = P_D$$

$$\sum PG_i = 142.5 + 107.5$$

$$\sum PG_i = 250\text{Mw} = P_D$$

2:Without loss and with limit.

Determine the economic load scheduling generating units in a power system to meet the system load of 925MW. The operating limits and cost function are given below.

Cost function	Operating limit
F_1=0.0045PG_1^2 + 5.2PG_1+580	250 ≤ PG_1 < 450
F_1=0.0056PG_2^2 + 4.5PG_2+640	200 ≤ PG_1 < 350
F_1=0.0079PG_3^2 + 5.8PG_3+580	125 ≤ PG_3 < 225

$$\lambda = \frac{P_D + \sum_{i=1}^{3} \frac{b_i}{2a_i}}{\sum_{i=1}^{2} \frac{1}{2ai}}$$

$$\lambda = \frac{P_D + \left[\frac{b_1}{2a_1} + \frac{b_2}{2a_2} + \frac{b_3}{2a_2}\right]}{\frac{1}{2a_1} + \frac{1}{2a_2} + \frac{1}{2a_3}}$$

$$\lambda = \frac{P_D + \left[\frac{5.2}{9*10^{-3}} + \frac{4.5}{0.0112} + \frac{5.8}{0.0158}\right]}{\frac{1}{9*10^{-3}} + \frac{1}{0.0112} + \frac{1}{0.0158}} = 8.61$$

i) To find the generations using λ = 8.6149:

$$\frac{dF_1 P_{G1}}{dP_{G1}} = \lambda_1$$

$= 2 \text{ x } 0.0045P_{G1} + 5.2$

$$\frac{dF_2 P_{G2}}{dP_{G2}} = \lambda_2$$

$= 2 \text{ x } 0.0056P_{G2} + 4.5$

$$\frac{dF_3 P_{G3}}{dP_{G3}} = \lambda_3$$

$= 2 \text{ x } 0.0079P_{G1} + 5.8$

$$PG_1 = \frac{\lambda - B_1}{2a_1}$$

$$PG_1 = \frac{8.61 - 5.2}{2 * 0.0045} = 378.88\text{MW}$$

$$PG_2 = \frac{\lambda - B_2}{2a_2}$$

$$PG_2 = \frac{8.61 - 4.5}{2 * 0.0086} = 366.964\text{MW}$$

$$PG_3 = \frac{\lambda - B_3}{2a_3}$$

$$PG_1 = \frac{8.61 - 5.8}{2 * 0.0078} = 177.848\text{MW}$$

PG_1 and PG_2 within the limits while PG_2 exceeds the limits. Therefore PG_2=350MW (Fixed)

$$\lambda_2 = 2 \text{ x } 0.0056\ P_{G2} + 4.5 = 2\text{x}0.0056(350) + 4.5 = 8.42 < 8.6149$$

The incremental cost for unit 2< λ, so limit2 should be at max

P_D(new) = P_D(old) –(sum of fixed)

=925-350=575MW

Now share the load $P_{G1} + P_{G3}$ =575 MW between units 1 and 3 using incremental cost rule

$$\lambda_1 = \lambda_3$$

$$2 \text{ x } 0.0045P_{G1} + 5.2 = 2 \text{ x } 0.0079P_{G1} + 5.8$$

$$0.009\ P_{G1} - 0.0158\ P_{G3} = 0.6 \quad \ldots(1)$$

$$P_{G1} + P_{G3} = 575 \quad \ldots.(2)$$

Multiplying equation (2) by 0.0158,

$$0.0158\ P_{G1} + 0.0158P_{G3} = 9.085 \quad \ldots..(3)$$

Adding (1) and (3)

$$0.0248\ P_{G1} = 9.685$$

$$P_{G1} = 390.524 \text{ MW}$$

$$P_{G3} = 575 - 390.524 = 184.476 \text{ MW}$$

$$\lambda_{new} = 2\text{x}0.0045\text{x}390.524 + 5.2 = 8.7147$$

Now λ_1 =8.7147 Rs/MWhr

λ_2 =8.42 Rs/MWhr

λ_1 =8.7147 Rs/MWhr

$\lambda_2 < \lambda_{new}$ i.e, we are fixing $P_{G2} = P_{G2,\ max}$

The optimum schedule is P_{G1} = 390.524 MW

P_{G2} = 350 MW

P_{G3} = 184.47 MW

Example 3 A system consists of two units to meet the daily load cycle as shown in Fig.

The cost curves of the two units are:

$C_1 = 0.15P_{G_1}^2 + 60P_{G_1} + 135$ Rs./hr

$C_2 = 0.25P_{G_2}^2 + 40P_{G_2} + 110$ Rs./hr

The maximum and minimum loads on a unit are to be 220 and 30 MW, respectively.

Find out:

(i) The economical distribution of a load during the light-load period of 7 hr and during the heavy-load periods of 17 hr. In addition, find the operation cost for this 24-hr period operation of two units.

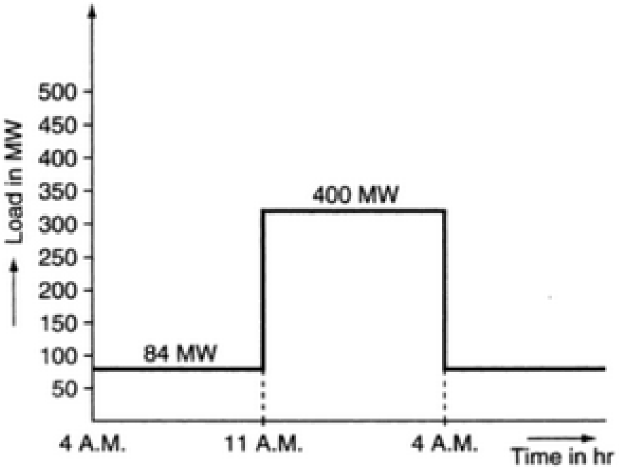
(ii) The operation cost when removing one of the units from service during 7 hr of light-load period.
Assume that a cost of Rs. 525 is incurred in taking a unit off the line and returning it to service after 7 hr.

(iii) Comment on the results.

Solution:

(i) When both units are operating throughout a 24-hr period,

Total time = 24 hr



Total load = 84 MW for 7 hr (from 4 A.M. to 11 A.M.) + 400 MW for 17 hr (from 11 A.M. to 4 A.M.)

For a heavy load of 400 MW:

Heavy-load period, $t_h = 17$ hr

load, $P_{D_h} = 400$ MW

We have to find the optimal scheduling of two units with this load.

We have the cost curves of two units:

For Unit 1:

$$C_1 = 0.15\,P_{G_1}^2 + 60\,P_{G_1} + 135 \text{ Rs./hr}$$

Incremental fuel cost, $\dfrac{dC_1}{dP_{G_1}} = 0.15 \times 2\,P_{G_1} + 60$

$$= 0.3\,P_{G_1} + 60 \text{ Rs./MWh}$$

For Unit 2:

$$C_2 = 0.25P_{G_2}^2 + 40P_{G_2} + 110 \text{ Rs./hr}$$

$$\Rightarrow \frac{dC_2}{dP_{G_2}} = 0.25 \times 2P_{G_2} + 40$$

$$= 0.5\,P_{G_2} + 40 \text{ Rs./MWh}$$

For the optimal distribution of a load,

$$\frac{dC_1}{dP_{G_1}} = \frac{dC_2}{dP_{G_2}} = \lambda$$

$$0.3P_{G_1} + 60 = 0.5P_{G_2} + 40$$

$$0.3P_{G_1} - 0.5P_{G_2} = -20 \qquad (1)$$

$$P_{G_1} + P_{G_2} = 400 \text{ (given)} \qquad (2)$$

From Equations (1) and (2), we have

$$\begin{array}{ll} 0.3P_{G_1} - 0.5P_{G_2} & = -20 \\ \underline{0.5P_{G_1} + 0.5P_{G_2}} & = 200 \\ 0.8P_{G_1} & = 180 \end{array}$$

$$\therefore P_{G_1} = 225 \text{ MW}$$

Substituting the P_{G_1} value in Equation (2), we get

$P_{G_2} = 175$ MW

Here, $P_{G_1} = 225$ MW and $P_{G_1} > P_{G_{\max}}$; hence, set P_{G_1} at its maximum generation limit

i.e., $P_{G_1} = 220$ MW

$\therefore P_{G_2} = 400 - 220 = 180$ MW

The operation cost for a heavy-load period (i.e., from 11 A.M. to 4 A.M.) with this optimal distribution is

$$\begin{aligned} C &= (C_1 + C_2) \times t_h \\ &= [(0.15 \times 220^2 + 60 \times 220 + 135) + (0.25 \times 180^2 + 40 \times 180 + 110)] \times 17 \\ &= \text{Rs. } 6{,}12{,}085 \end{aligned}$$

For a light load of 84 MW:

Period, $t_l = 7$ hr

load, $P_D = 84$ MW

For optimal load sharing,

i.e., $0.3\,P_{G_1} + 60 = 0.5\,P_{G_2} + 40$

$$0.3\,P_{G_1} - 0.5\,P_{G_2} = -20 \qquad (3)$$

$$P_{G_1} + P_{G_2} = 84 \qquad (4)$$

By solving Equations (3) and (4), we get

$P_{G_1} = 27.5$ MW; $P_{G_2} = 56.5$ MW

Here, $P_{G_1} = 27.5 \text{ MW} < P_{G_{\min}} = 30$ MW

Therefore, the load shared by Unit-1 is set to $P_{G_1} = 30$ MW and $P_{G_2} = 84 - 30 = 54$ MW.

The operation cost for a light-load period (i.e., from 4 A.M. to 11 A.M.) with this optimal distribution:

$= [(0.15) \times (30)^2 + 60 \times 30 + 135) + (0.25 \times 54^2 + 40 \times 54 + 110)] \times 7$
$=$ Rs. 35,483

Hence, the total fuel cost when both the units are operating throughout the 24-hr period

$=$ Rs. $(6{,}12{,}085 + 35{,}483)$
$=$ Rs. 6,47,568

(ii) If only one of the units is run during the light-load period,
i.e., Period, $t_l = 7$ hr
load, $P_D = 84$ MW

When Unit-1 is to be run,

Cost of operation $= C_1 \times t_1$
$= [0.15 \times 84^2 + 60 \times 84 + 135] \times 7$
$=$ Rs. 43,633.80

When Unit-2 is to be run,

Cost of operation $= C_2 \times t_l$
$= [0.25 \times 84^2 + 40 \times 84 + 110] \times 7$
$=$ Rs. 36,638

From the above, it is verified that it is economical to run Unit-2 during a light-load period and to put off Unit-1 from service.

The operating cost with only Unit-2 in operation $=$ Rs. 36,638

The operating cost for the operation of both units in a heavy-load period and Unit-2 only in a light-load period $=$ Rs. $(6{,}47{,}568 + 36{,}638) =$ Rs. 6,48,723

In addition, given that a cost of Rs. 525 is incurred in taking a unit off the line and returning it to service after 7 hr,

Total operating cost $=$ operating cost $+$ start-up cost $=$ Rs. $(6{,}48{,}723 + 525) =$ Rs. 6,49,248.

(iii) Total operating cost for (i) $=$ Rs. 6,47,568
Total operating cost for (ii) $=$ Rs. 6,49,248

It is concluded that the total operating cost when both units running throughout 24-hr periods is less than the operating cost when one of the units is put off from the line and returned to the service after a light-load period. Hence, it is economical to run both units throughout 24 hr.

Example A constant load of 400 MW is supplied by two 210-MW generators 1 and 2, for which the fuel cost characteristics are given as below:

$$C_1 = 0.05\, P_{G_1}^2 + 20\, P_{G_1} + 30.0 \text{ Rs./hr}$$

$$C_2 = 0.06\, P_{G_2}^2 + 15\, P_{G_1} + 40.0 \text{ Rs./hr}$$

The real-power generations of units P_{G_1} and P_{G_2} are in MW. Determine: (i) the most economical load sharing between the generators. (ii) The saving in Rs./day thereby obtained compared to the equal load sharing between two generators.

Solution:

The IFCs are

$$\frac{dC_1}{dP_{G_1}} = 0.10 P_{G_1} + 20.0$$

$$\frac{dC_2}{dP_{G_2}} = 0.12 P_{G_2} + 15.0$$

(i) For optimal sharing of load, the condition is

$$\frac{dC_1}{dP_{G_1}} = \frac{dC_2}{dP_{G_2}}$$

$$0.10 P_{G_1} + 20.0 = 0.12\, P_{G_1} + 15.0$$

$$\text{or} \quad 0.10 P_{G_1} - 0.12\, P_{G_1} = 15.0 - 20.0$$

$$\text{or} \quad 0.10 P_{G_1} - 0.12\, P_{G_1} = -5.0 \tag{2.19}$$

$$\text{Given:} \quad P_{G_1} + P_{G_2} = 400 \tag{2.20}$$

Solving Equations (2.19) and (2.20), we have

$$\begin{array}{rr} & 0.10\, P_{G_1} - 0.12\, P_{G_2} = -5.0 \\ \text{Equation (2.20)} \times 0.12 \Rightarrow & 0.12\, P_{G_1} + 0.12\, P_{G_2} = 48.0 \\ \hline & 0.22\, P_{G_1} = 43.0 \\ & \therefore\ P_{G_1} = 195.45 \text{ MW} \end{array}$$

Substituting $P_{G_1} = 195.45$ MW in Equation (2.20), we get

$$P_{G_2} = 400 - 195.45 = 204.55 \text{ MW}$$

The load of 400 MW is economically shared by the two generators with $P_{G_1} =$ 195.45 MW and $P_{G_2} = 204.55$ MW.

Example Three power plants of a total capacity of 500 MW are scheduled for operation to supply a total system load of 350 MW. Find the optimum load scheduling if the plants have the following incremental cost characteristics and the generator constraints:

$$\frac{dC_1}{dP_{G_1}} = 40 + 0.25P_{G_1}, \quad 30 \leq P_{G_1} \leq 150$$

$$\frac{dC_2}{dP_{G_2}} = 50 + 0.30P_{G_2}, \quad 40 \leq P_{G_3} \leq 125$$

$$\frac{dC_3}{dP_{G_3}} = 20 + 0.20P_{G_3}, \quad 50 \leq P_{G_3} \leq 225$$

Solution:

For economic load scheduling among the power plants, the necessary condition is

$$\frac{dC_i}{dP_{G_i}} = \lambda$$

For three plants,

$$\frac{dC_1}{dP_{G_1}} = \frac{dC_2}{dP_{G_2}} = \frac{dC_3}{dP_{G_3}} = \lambda$$

Given total load $= P_{G_1} + P_{G_2} + P_{G_3} = 350$ MW **(2.34)**

$$40 + 0.25P_{G_1} = 50 + 0.30P_{G_2} = 20 + 0.20P_{G_3} = \lambda \qquad \textbf{(2.35)}$$

$$\frac{dC_1}{dP_{G_1}} = \frac{dC_3}{dP_{G_3}}$$

or $0.25P_{G_1} - 0.30P_{G_2} = 50 - 40 = 10$ **(2.36)**

and $40 + 0.25P_{G_1} = 20 + 0.2P_{G_3}$

or $0.25P_{G_1} - 0.2P_{G_3} = 20 - 40 = -20$ **(2.37)**

From Equation (2.36), we have

$$0.25P_{G_1} - 10 = 0.30P_{G_2}$$

$$\therefore P_{G_2} = \frac{0.25P_{G_1} - 10}{0.3} = 0.833P_{G_1} - 33.33 \quad \textbf{(2.38)}$$

Substituting Equation (2.38) in Equation (2.34)

$$P_{G_1} + 0.833P_{G_1} - 33.33 + P_{G_3} = 350$$

or $1.833P_{G_1} + P_{G_3} = 383.33$ **(2.39)**

Solving Equations (2.37) and (2.39)

$$0.25P_{G_1} - 0.2P_{G_3} = -20$$

Equation (2.39) × 0.2 ⇒ $\underline{0.366P_{G_1} + 0.2P_{G_3} = 76.66}$

$$0.616P_{G_1} = 56.66$$

or $P_{G_1} = 91.98$ MW

Substituting the value of P_{G_1} in Equation (2.39),

$$1.833 \times 91.98 + P_{G_3} = 383.33$$

or $P_{G_3} = 214.73$ MW

Substituting the values of P_{G_1} and P_{G_2} in Equation (2.34), we get

$$91.98 + P_{G_2} + 214.73 = 350$$

or $P_{G_2} = 43.29$ MW

∴ For economic scheduling of the load, the generations of three plants must be

$P_{G_1} = 91.98$ MW, $P_{G_2} = 43.29$ MW, and $P_{G_3} = 214.73$ MW

Example A 2-bus system consists of two power plants connected by a transmission line as shown in Fig. 3.6.

The cost-curve characteristics of the two plants are:

$$C_1 = 0.015P_{G_1}{}^2 + 18P_{G_1} + 20 \text{ Rs./hr}$$
$$C_1 = 0.03P_{G_2}{}^2 + 33P_{G_2} + 40 \text{ Rs./hr}$$

When a power of 120 MW is transmitted from Plant-1 to the load, a loss of 16.425 MW is incurred. Determine the optimal scheduling of plants and the load demand if the cost of received power is Rs. 26/MWh. Solve the problem using co-ordination equations and the penalty factor method approach.

Solution:

For two units, $P_L = P_{G_1}B_{11}P_{G_1} + 2P_{G_1}B_{12}P_{G_2} + P_{G_2}B_{21}P_{G_1}$.

Since the load is located at Bus-2 alone, the losses in the transmission line will not be affected by the generator of Plant-2.

i.e., $B_{12} = B_{21} = 0$ and $B_{22} = 0$

$$\therefore\ P_L = B_{11}P_{G_1}^2 \tag{3.25}$$

$$16.425 = B_{11} \times 120^2$$

$$B_{11} = 0.00114 \text{ MW}^{-1}$$

Using the co-ordination equation method:

The co-ordination equation for Plant-1 is

$$\frac{dC_1}{dP_{G_1}} + \lambda\frac{\partial P_L}{\partial P_{G_1}} = \lambda \tag{3.26}$$

FIG. 3.6 *Illustration for Example 3.9*

$$P_L = 0.00114P_{G_1}^2$$

$$\Rightarrow \frac{\partial P_L}{\partial P_{G_1}} = 0.00228P_{G_1} \tag{3.27}$$

$$\frac{dC_1}{dP_{G_1}} = 0.03P_{G_1} + 18 \tag{3.28}$$

Substitute Equations (3.27) and (3.28) in Equation (3.26); then the equation for Plant-1 becomes

$$0.03P_{G_1} + 18 + \lambda(0.00228P_{G_1}) = \lambda$$

$$0.03P_{G_1} + 18 + 26(0.00228P_{G_1}) = 26$$

$$0.03P_{G_1} + 0.0593P_{G_1} + 18 = 26$$

$$0.0893P_{G_1} = 8$$

$$\therefore\ P_{G_1} = \frac{8}{0.0893} = 89.6\ \text{MW}$$

The co-ordination equation for Plant-2 is

$$\frac{dC_2}{dP_{G_2}} + \lambda\frac{\partial P_L}{\partial P_{G_2}} = \lambda \tag{3.29}$$

$$\frac{dC_2}{dP_{G_2}} + \lambda(0) = \lambda$$

$$\frac{dC_2}{dP_{G_2}} = 0.06P_{G_2} + 22$$

$\therefore$ Equation (3.29) becomes

$$0.06P_{G_2} + 22 + 26(0) = 22$$

$$P_{G_2} = \frac{26-22}{0.06} = 66.67\ \text{MW}$$

$\therefore$ The transmission loss, $P_L = B_{11}P_{G_1}^2$

$$= 0.00114 \times (89.6)^2$$

$$= 9.15\ \text{MW}$$

$\therefore$ The load, $P_D = P_{G_1} + P_{G_2} - P_L$

$$= 89.6 + 66.67 - 9.15 = 147.12\ \text{MW}$$

3. The input and output curve characteristics of three units are

$F_1 = 940+5.46P_{G1} +0.0016\, P^2_{G1}$

$F_2 = 820+5.35P_{G2} +0.0019\, P^2_{G2}$

$F_3 = 99+5.65P_{G2} +0.0032\, P^2_{G3}$

Total load is 600MW. Use the Participation factor method to calculate the dispatch for aload is reduced to 550 MW?

Solution:

$F_1 = 940+5.46\, P_{G1}+0.0016\, P^2_{G1}$

$F_2 = 820+5.35P_{G2} +0.0019\, P^2_{G2}$

$F_3 = 99+5.65P_{G2} +0.0032\, P^2_{G3}$

Total load P_D =600MW

Power reduced P_G = 550MW

We know that, $P_{G1} + P_{G2} +P_{G3} =600$ ….(I)

$$F_1' = \frac{dF_1}{dP_{G1}}$$

$= 5.46 +0.0032\, P_{G1} = \lambda$ ….(1)

$$F_2' = \frac{dF_2}{dP_{G2}}$$

$= 5.35 +0.0038\, P_{G2} = \lambda$ ….(2)

$$F_3' = \frac{dF_3}{dP_{G3}}$$

$= 5.65 +0.0064\, P_{G3} = \lambda$ ….(3)

Solving (1) and (2),

$5.46 +0.0032P_{G1} = 5.35 +0.0038\, P_{G2}$

$P_{G1} = -34.375 +1.1875\, P_{G2}$ …..(4)

solving (2) and (3)

$5.35 +0.0038\, P_{G2} = 5.65 +0.0064\, P_{G3}$ ….(5)

$P_{G3} = -46.875+0.594\, P_{G2}$

Sub(4) and (5) in Eqn (I)

$-34.375+1.1875\, P_{G2}+P_{G2}+(-46.875)+0.594\, P_{G2} =600$

P_{G2} =244.92MW

Sub the value of P_{G2} in eqn (5) we get P_{G3}

P_{G3} =98.60MW

Sub the value of P_{G2}, P_{G3} in eqn (2) we get P_{G1}

P_{G1} =256.47MW

$$F_1'' = 0.0032\ ;\ F_2'' = 0.0032\ ;\ F_3'' = 0.0032$$

$$\frac{\Delta P_i}{\Delta P_D} = \frac{\frac{1}{F_i''}}{\sum_{i=1}^{3}\frac{1}{F_i''}}$$

$$\frac{\Delta P_{G1}}{\Delta P_D} = \frac{\frac{1}{F_1''}}{\sum_{i=1}^{3}\frac{1}{F_i''}} = \frac{\frac{1}{F_1''}}{\frac{1}{F_1''}+\frac{1}{F_2''}+\frac{1}{F_3''}}$$

$$= \frac{\frac{1}{0.0032}}{\frac{1}{0.0032}+\frac{1}{0.0038}+\frac{1}{0.0064}} = 0.43$$

$$\frac{\Delta P_{G2}}{\Delta P_D} = \frac{\frac{1}{F_2''}}{\sum_{i=1}^{3}\frac{1}{F_i''}} = \frac{\frac{1}{F_2''}}{\frac{1}{F_1''}+\frac{1}{F_2''}+\frac{1}{F_3''}}$$

$$= \frac{\frac{1}{0.0038}}{\frac{1}{0.0032}+\frac{1}{0.0038}+\frac{1}{0.0064}} = 0.3595$$

$$\frac{\Delta P_{G3}}{\Delta P_D} = \frac{\frac{1}{F_3''}}{\sum_{i=1}^{3}\frac{1}{F_i''}} = \frac{\frac{1}{F_3''}}{\frac{1}{F_1''}+\frac{1}{F_2''}+\frac{1}{F_3''}}$$

$$= \frac{\frac{1}{0.0064}}{\frac{1}{0.0032}+\frac{1}{0.0038}+\frac{1}{0.0064}} = 0.2135$$

ΔP_D = 550 -600 = -50MW

The new values of generations are given by,

$P_{new,1}$ =$P_{base,1}$ +$\left(\frac{\Delta P_{G1}}{\Delta P_D}\right)$ ΔP_D =256.47 +0.43 (-50) =234.97 MW

$P_{new,2}$ =$P_{base,2}$ +$\left(\frac{\Delta P_{G2}}{\Delta P_D}\right)$ ΔP_D =244.92 +(0.3595)(-50) =226.945 MW

$P_{new,3}$ =$P_{base,3}$ +$\left(\frac{\Delta P_{G3}}{\Delta P_D}\right)$ ΔP_D =98.6+0.2135(-50) = 87.925 MW

Pondicherry University Questions

2 Marks

1. Define the state of optimal dispatch?

2. Define economic dispatch problem.

State the objective of the economic dispatch problem (April 2013)

3. Define incremental cost?(Dec 2013)

4. Define base point?(Dec 2013)

5. Define participation factor?(Nov 2013,April 2013,Nov/Dec 2014)

6. What are the advantages of using participation factor?

7.What is Lagrangian multiplier?

8. Write the quadratic expression for fuel cost.

9. Explain the penalty factor.

10. Compare with unit commitment and economic load dispatch.

11. Draw incremental cost curve./ what is meant by incremental fuel cost?

(Nov 2013, April 2015)

12. Draw the incremental cost curve of thermal power plant and hydro power plant.

(April 2013)

13. Write the transmission loss formula using B-co-efficient.(April/May 2014)

11Marks

1. Derive the coordination equation of a power system neglecting line losses.

(or)

Derive the coordination equation for economic dispatch neglecting losses in the power system. Give steps for economic dispatch calculation neglecting losses. (April 2013)

2. Derive the coordination equation for a power system consisting of n- generating plants supplying several loads interconnected through a transmission network with losses.(Nov 2013)

(or)

Develop an iterative algorithm for solving the optimum dispatch equation of an n-bus power system taking into account the effects of system losses. (April 2015)

3. Discuss how to solve co-ordination equations using BMN coefficient by iteration method.(April 2015)

(or)

Explain using a flow chart, the solution procedure of coordination equation using B_{mn} coefficient.(April 2013)

(or)

Explain with a flow chart the computational procedure for the solution of economic dispatch problem including transmission losses and generator limits. (April / May 2014)

4. Explain the base point and participation factor. Briefly.

5. Explain in detail the combined economic dispatch and load frequency control.(Nov/ Dec 2014)

REFERENCE BOOKS

1. Olle I. Elgerad, “Electric Energy System Theory and Introduction”, Tata Mc Graw Hill publishing company, New Delhi, 2nd edition, 2004.
2. Allen J.Wood, Bruce F. Wollenbarg, “Power Generation, operation and control”,2nd edition, John Wiley and sons, 2008.
3. D.P.Kothari and I.J.Nagrath, " Modern Power System Analysis” Tata Mc Graw Hill publishing company Ltd., 2003.
4.A.K.Mahalanbias, D.P.Kothari & S.I.Ahson, "Computer Aided Power System Analysis and Control" Tata Mc Graw Hill publishing company, New Delhi, 1990.
5. P.S.R. Murty, "Operation and Control in Power Systems" BS Publications, 2005.
6. M. Geraldin Ahila, “Power System Operation and Control” ARS Publications,2008.

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ASPIRE TO EXCEL

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UNIT V

VOLTAGE CONTROL

Fundamental characteristics of excitation system; Block diagram model of exciter system; Generation and absorption of reactive power; methods of voltage control; static shunt capacitor/inductor VAR compensator; tap changing transformer; comparisons of different types of compensating equipment for transmission systems.

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2 Marks

1. **What is excitation?** **(April/May 2014)**

   The excitation system is the power system and its ancillary equipment supplied to excitation current for synchronous generator. Excitation Systems includes excitation power and excitation device.

2. **What are the various functions of excitation system?** **(Nov\Dec 2014)(Nov 2012)(April 2013)**

   The basic function of an excitation system is to provide direct current to the synchronous machine. In addition, the excitation system performs control and protective functions. The control function includes the control of voltage and reactive power flow and the enhancement of system stability.

3. **What are the types of excitation system?**
   - DC excitation system
   - AC excitation system
   - Static excitation system

4. **What are the types of tap changing transformer?**
   - Off load tap changing
   - On load tap changing

5. **Distinguish between on load and off load tap changing transformer.** **(April 2015)**

   Off load tap changing: Theoff load tap changing transformer which requires the disconnection of transformer when the tap setting is to be changed.

   On load tap changing: Inthis type, the voltage is a maximum value and since the currents are divided equally and flow in opposition through the coils, the resultant flux is zero and hence the minimum impedance.

6. **What are static shunt compensators?** **(Nov 2012)**

   Static shunt compensators fall into the class of active compensators. They have no moving parts. They are used for surge impedance compensation and for compensation by sectioning in long distance, high voltage transmission systems.

7. **What are the methods of voltage control?** **(April 2015)(Nov 2013)**

   The methods of voltage control are

   1. Excitation system
   2. Static shunt capacitors
   3. Static series capacitors
   4. Static shunt reactors
   5. Synchronous condensers

8. What is asynchronous condenser?

A synchronous motor running at no load feeds positive VARs into the line under over excited conditions and feeds negative VARs when under excited. A machine thus running is called a synchronous condenser.

9. Compare shunt and series capacitors.

Sl. No	Shunt capacitors	Series capacitors
1	The function of shunt capacitor applied as the single unit or in groups of units is to supply lagging KVAR to the system at the point where they are connected	Series capacitors are connected in series with the line and are used to reduce inductive reactance between supply point and load.
2.	It si mainly used for power factor correction at the load terminal of low voltage	It is mainly used to compensate the effect of series reactance
3.	If the load VAR requirement is small, shunt capacitors are of high use.	If the load VAR requirement is small, series capacitors are of small use.
4.	If the total line reactance is high, shunt capacitors are not effective	If the total line reactance is high, series capacitors are very effective and stability is improved

10. What are the advantages and disadvantages of synchronous condenser?

Advantages:

1. Flexibility of operation for all load conditions
2. As the losses are considerable compared with static capacitors and the power factor is not zero

Disadvantages:

1. The cost of installation is high
2. Losses of synchronous condensers are much higher compared to those of capacitors.

11. What is use of static VAR compensators? **(April/May 2014)**

1. Maintain voltage at or near a constant level
2. Improve power system stability
3. Improve power factor.
4. Correct phase unbalance

12. What is SVC? Why it is used?

Static VAR compensators are used for compensation of reactive power injected into line by shunt capacitors and shunt reactors.

It is used to maintain voltage and frequency under disturbances. The transient stability can be improved and the system transmission capacity can be increased both under operating and fault conditions.

13. What are the different types of static VAR compensators?

1. Reactors with direct current controlled saturation
2. Thyristor controlled shunt reactors
3. Thyristor controlled high impedance transformer
4. Thyristor controlled reactor compensator

14. List the various compensating devices?/ What are the different compensating devices for transmission systems? **(April 2015)(Nov 2013)**

i. Series compensation-TCSR,TCSC
ii. Shunt compensation-TCR, STATCOM
iii. Shunt capacitive compensation
iv. Shunt inductive compensation

15. What is static VAR compensator? **(Nov\Dec 2014)(April\May 2014)**

Static VAR compensators are shunt connected static generators and or absorbers whose outputs are varied so as to control specific parameters of the electric power system.

16. Mention the effect of connecting a static capacitor in series with the line? (April\May 2014)

They are connected in series with the line conductors to compensate for the inductive reactance of the line. This reduces the transfer reactance between the buses to which the line is connected, increases maximum power that can be transferred and reduces the reactive power losses. Series capacitors are not usually installed for voltage control as such, they do contribute to improved voltage control and reactive power balance. The reactive power produced by as series capacitor increases with increasing power transfer.

17. What is the need of power system stabilizer in an excitation system? **(April 2015)**

It provides an additional input signal to the regulator to damp power system oscillations. Some commonly used input signals are rotor speed deviation, accelerating power and frequency deviation.

18. What is the need of using power system compensatorsin a power system?(April 2013)

The reactive power absorbed/supplied by the power system compensators are automatically adjusted so as to maintain voltages of the buses to which they are connected.

19. What are the advantages of static VAR compensators? **(Nov 2013)**

They are, in general, cheaper, higher-capacity, faster and more reliable than synchronous condensers.

11 Marks

1. Explain about the excitation system?

When the load on the power system changes, the terminal voltage of the generator changes, therefore to maintain the terminal voltage with permissible standards. The excitation of the generator must be decreased or increased depending upon the situation prevailing to protect the devices or apparatus which is operating in the power system. This can be achieved by employing automatic voltage regular.

The basic function of an excitation system is to provide direct current to the synchronous machine. In addition the excitation system performs control and protective functions essentially to the satisfactory performance of the power system to controlling the field voltage, thereby the field current.

The control functions include the control of voltage and reactive power flow and the enhancement of system stability. The protective function ensures that the capability limits of the synchronous machine, excitation system and other equipment are not exceeded.

In addition to voltage regulators at generator buses static shunt capacitors, synchronous compensators, static VAR systems, tap changing transformers are also used in the power system for rapid voltage control.

EXCITATION SYSTEM DEFINTIONS:

a) **Exciter ceiling Voltage:**
It is the maximum voltage that may be attained by an exciter under specific conditions.

b) **Excitation system Ceiling Voltage:**
It is the maximum D.C. component system output voltage that is able to attain by an excitation system under specified conditions.

c) **Exciter nominal ceiling voltage:**
It is the ceiling voltage of an exciter loaded with a resistor having an ohmic value the resistance of the field winding to be excited and with the field winding at a temperature.

d) **Excitation system Voltage response time:**
It is the time in seconds for the excitation voltage to reach 95% of ceiling voltage under specified conditions.

e) **Excitation system voltage time response :**

It is the excitation system output voltage expressed as a function of time under specified conditions.

EXCITATION SYSTEM REQUIREMENTS

The excitation system must satisfy the following requirements.
1. Meet specified response criteria.
2. Must be able to prevent damage to itself, generation and its associated equipments.
3. It should have good operating flexibility.

TYPES OF EXCITATION SYSTEM

Based on excitation power source used, the excitation system can be classified as

D.C. Excitation systems:

- ✓ This excitation system utilizes D.C generators as source of excitation power and provides current to the rotor of the synchronous machine through slip rings.

- ✓ The D.C. excitation systems were used in the earlier days. Now it has been superseded by A.C.exciters.

Disadvantage: Large time constant (about 3 sec) and commutation difficulties.

A.C. EXCITATION SYSTEM

- ✓ An A.C. excitation system consists of and A.C generator and thyristorrectifier bridge directly connected to the alternator shaft.
- ✓ The advantage of this method of excitation is that the moving contacts such as slip lings and brushes are completely eliminated thus offering smooth and maintenance free operation such a system is known as brushless excitation system.
- ✓ The A.C output or the exciter is rectifier by either controlled (or) uncontrolled rectifier to provide the direct current for the generator field.

2. Draw the block diagram of a static excitation system and explain its operation.

(April/May 2014)

STATIC EXCITATION SYSTEMS:

The components in these systems are static or stationary. The static rectifier either controlled or un-controlled supply the excitation current directly to the field of the main synchronous generator through slip rings. The main source of power to the rectifiers is from the main generator through a transformer to step down the voltage to a required level. At the time of starting the field is supplied through battery power.

Advantage:

1. By eliminating rotating exciters, the noise level in the plant is reduced.
2. The equipment of static excitation may be mounted or placed separately at aconvenient place.
3. Compared to rotating exciters, the static devices are more reliable.

TYPICAL EXCITATION SYSTEM

(OR)

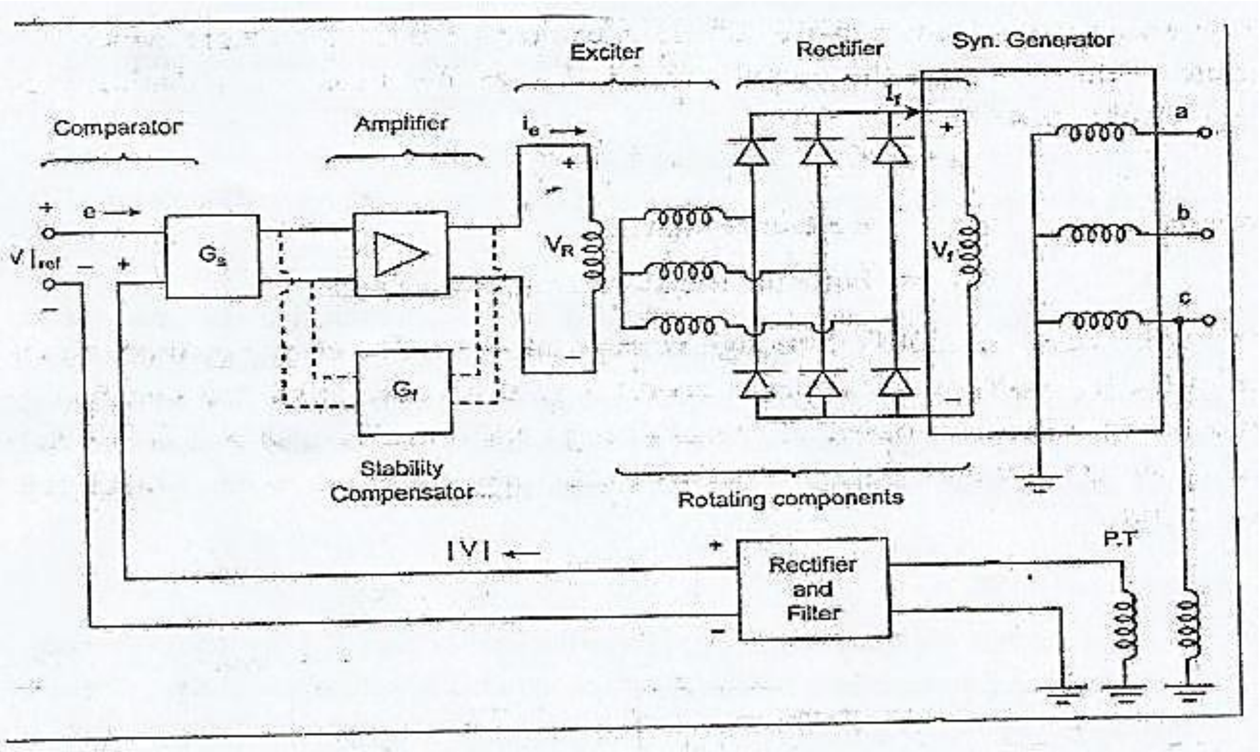
BRUSHLESS AUTOMATIC VOLTAGE REGULATOR

Synchronous generator:

It is a machine which generates A.C three phase power. It may be a turbo-alternator-run by steam turbine at a very high speed or be a low speed A.C., Generator run by water – turbine. The terminal voltage of the generator is maintained constant during is varying load conditions with the help of excitation system.

Exciter:

The purpose of the exciter is to supply field current to the rotor field of the synchronous generator. It may be a A.C generator driver by either the steam turbine or an induction motor. But in the modern systems of excitation, the exciters are solid state system consisting of some form of rectifier or thyristor system supplied from the A.C. bus or from an alternator – exciter.



Voltage Regulator: (Hear of the excitation system)

Voltage regulator working in conjunction with the exciter is to maintain terminal voltage of alternator constant. Voltage regulators are generally classified three categories namely rheostat type, non-continuously acting and continuously acting regulator.

In fact voltage regulator couples the output variables of the synchronous generator to the input of the exciter through feedback and forwarding elements for the purpose of regulating the synchronous machine output variables.

Thus the regulator may be assumed to consist of an error-detector, preamplifier, power amplifier, stabilizers, compensators, auxiliary inputs and limiters.

The exciter consists of D.C generator driven by the main generator shaft. This type of excitation uses rings and brushes for the transfer of D.C power to the rotor of alternator.

Out of the three types of excitation systems, the modern excitation system tends to be either brushless or static design. Here the exciter consists of an 3ᶲ alternator with rotating armature type and stationary field (ie) the 3ᶲ armature on the rotor and the field on the stator. The A.C armature Voltage is rectified by diode bridge mounted on rotating shaft and then fed directly into the main generator field. The design eliminates the need for slip rings and burses.

3. **Derive the transfer function of the exciter and draw the block diagram model of exciter system./ Develop the transfer function model of excitation system/ Draw the typical automatic voltage regulator and develop its block diagram representation/ Develop a mathematical model of an exciter system and brief on its control action.**

(April/May 2014)(Nov 2012)(April 2015)(April 2013)

MODELLING OF AVR

Assume that for some reasons generator terminal voltage |V| has been decreased. This results in an increased error voltage (e) which in turn, causes increased values of V_r, i_e, $V_f$and i_f. The direct axis generator flux increases as a result of increase in i_f, thus raising the magnitude of the terminal voltage to the required level.

Potential Transformer & Rectifier:

Using potential transformer, the terminal voltage of the generator is stepped down to the valve required for control signal and then rectified to get D.C. Voltage proportional to the r.m.s. valve of terminal voltage.

Comparator:

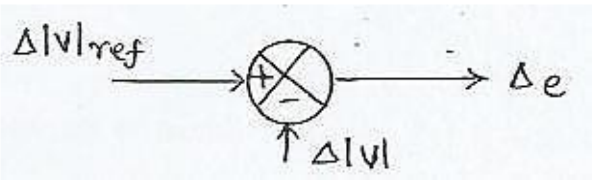
The comparator compares the measured signals IV against the reference D.C signal (V_{ref}). The difference between these two signals produce an error voltage 'V_e' called error signal.
The error signal

$$\Delta e = \Delta|v|_{ref} - \Delta|v| ------------ (1)$$

Taking L.T of equation 1

$$\Delta v_{ref}(s) - \Delta v(s) = \Delta e(s)$$

The model of comparator is shown below



Amplifier:

The amplifier amplifies the input error signal depending on the amplification factor. There are various types of amplifiers used in the excitation system. They are tuned generator, amplildyne and electronic amplifier.

$$\Delta v_R \propto \Delta e$$

$$\Delta v_R = k_A \Delta e -----------(2)$$

$$\Delta v_R = Outputvoltageofanamplifier.$$

$$k_A = Amplifiergain.$$

Taking L.T of equation (2)

$$\Delta v_R(s) = k_A \Delta e(s)$$

Amplifier transfer function

$$G_A = \frac{\Delta v_R(s)}{\Delta e\ (s)} = k_A$$

$$G_A = k_A$$

Where,

$G_A = Amplifiertransferfunction.$

$$k_A = InstantaneousAmplifiergain.$$

The amplifier will have a time delay that can be represented by a time constant T_A as shown in figure and the amplifier transfer function becomes

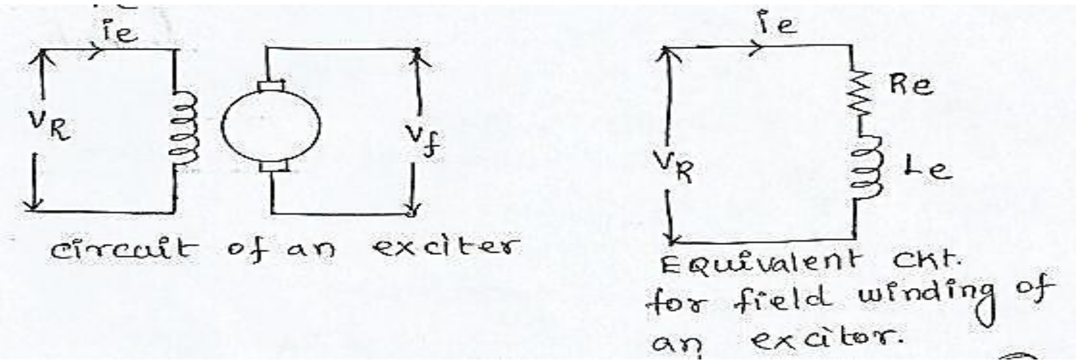
$$G_A = \frac{\Delta v_R(s)}{\Delta e\ (s)} = \frac{k_A}{1 + sT_A}$$

Model of amplifier

Typical value of k_A = 10 to 400;T_A are in the range of 0.02 to 0.1 sec.

Exciter:

The purpose of the exciter is to supply filed current to the rotor field of the synchronous generator.



Let

$$R_e = The exciter field resistor.$$

$$L_e = The exciter field inductance.$$

Input voltage, $\Delta v_R = R_e \Delta i_e + L_e \frac{d}{dt}(\Delta i_e) ------------ (4)$

Output voltage of an exciter (or) field voltage of a generator

$$\Delta v_f \propto \Delta i_e$$

$$\Delta v_f = k_1 \Delta i_e ---------- (5)$$

Taking L.T of equations (4) & (5)

$$\Delta v_R(s) = [R_e + L_e(s)]\Delta i_e(s)$$

$\Delta v_f(s) = k_1 \Delta i_e$(s)

Transfer function of the exciter,

$$G_e = \frac{\Delta v_f(s)}{\Delta v_R(s)} = \frac{k_1}{R_e + L_e(s)} = \frac{k_1}{\left[1 + \left[\frac{L_e}{R_e}\right] s\right] \times R_e}$$

$$G_e = \frac{\frac{k_1}{R_e}}{1 + \left[\frac{L_e}{R_e}\right] s} = \frac{k_e}{1 + sT_e}$$

Where,

$$k_e = \frac{k_1}{R_e} = Gain of the exciter$$

$$T_e = \left[\frac{L_e}{R_e}\right] = Time constant of the exciter\ (sec)$$

$$T_e are ranges from\ 0.5\ to\ 1 sec$$

Model of exciter

Synchronous Generator:

It generates 3 Q AC power at its terminals. It may be driver by steam turbine at a very high speed or by low speed water turbine depending on the energy available at that particular place.

The terminal voltage of the generator is maintained constant during its varying load conditions, with the help of excitation system.

The terminal voltage (V) of the generator equals to difference between induced emf (E) and drop across armature (V_{drop}).

$$\Delta v = \Delta E - v_{drop}$$

The relationship between v_f and v depends on the generator loading.

At no load the drop can be neglected. Hence

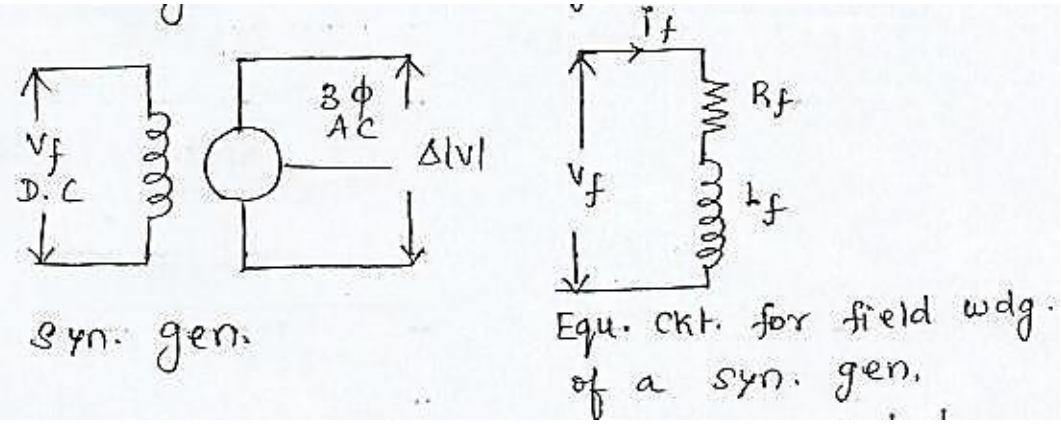
$$v = E$$

Taking L.T,

$$\Delta v(s) = \Delta E(s)$$

Applying KVL to the field winding

$$\Delta v_f = R_f \Delta i_f + L_f \frac{d}{dt}(\Delta i_f) ------------(6)$$



$$E_{max} = I_f x_L = I_f \omega L_{fa}$$

$$E_{rms} = \frac{I_f}{\sqrt{2}} \omega L_{fa}$$

$$I_f = \frac{\sqrt{2}}{\omega L_{fa}}$$

$$E_{rms} = \frac{\sqrt{2}E}{\omega L_{fa}}$$

$$\Delta v_f = \frac{\sqrt{2}}{\omega L_{fa}}\left[R_f \Delta e + L_f \frac{d}{dt}\Delta e\right]$$

Taking L.T

$$\Delta v_f(s) = \frac{\sqrt{2}}{\omega L_{fa}}\left[R_f + sL_F\right]\Delta E(s)$$

Transfer function of the generator

$$\frac{\Delta v(s)}{\Delta v_f(s)} = \frac{\Delta E(S)}{\Delta v_f(s)} = \frac{\Delta E(S)}{\frac{\sqrt{2}}{\omega L_{fa}}\left[R_f + sL_f\right]\Delta E(s)}$$

$$= \frac{\omega L_{fa}}{\sqrt{2}R_f\left[1 + \frac{L_f}{R_f}s\right]}$$

$$= \frac{k_f}{1 + sT'_{do}}$$

Where,

$$k_f = \frac{\omega L_{fa}}{\sqrt{2}R_f}$$

$T'_{do} = \frac{L_f}{R_f} = opencircuitdirectaxistimeconstant.$

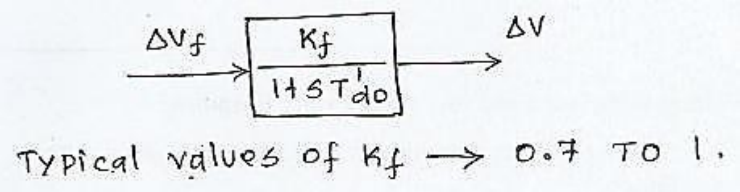
$L_f = selfinductanceoffieldwinding.$

$R_f = Resistanceoffieldwinding.$

$L_{fa} = Mutualinductancecoefficientrotorfield\&ststorarmaturemeasured$

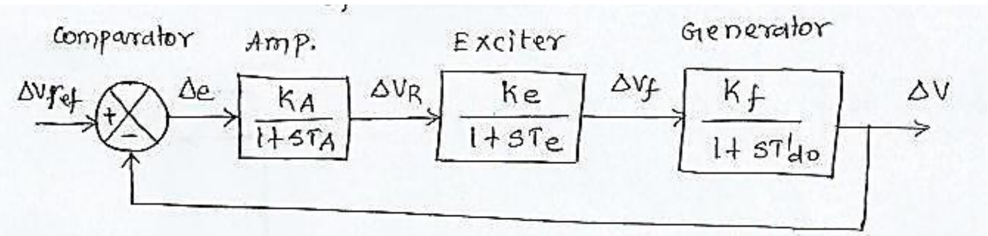
$whenmagneticaxiscoincide.$

Generator model

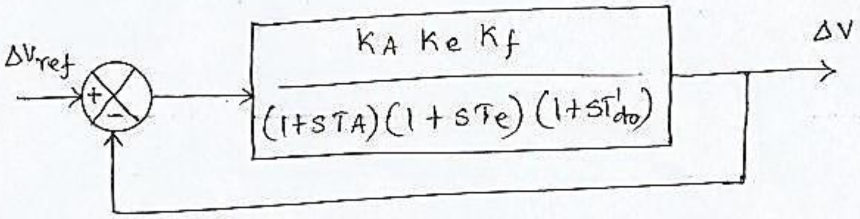


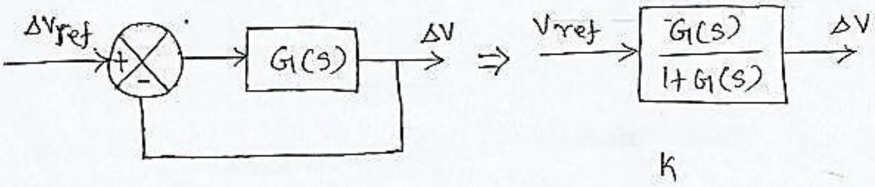
Typical values of k_f = 0.7 to 1. T'_{do} = 1 to 2 sec

Combining all the individual blocks, we get closed loop model of AVR.



Applying Block reduction Technique, the above model is reduced.





Open loop transfer function $= \frac{k}{(HsT_a)(1+sT_e)(1+sT'_{do})}$

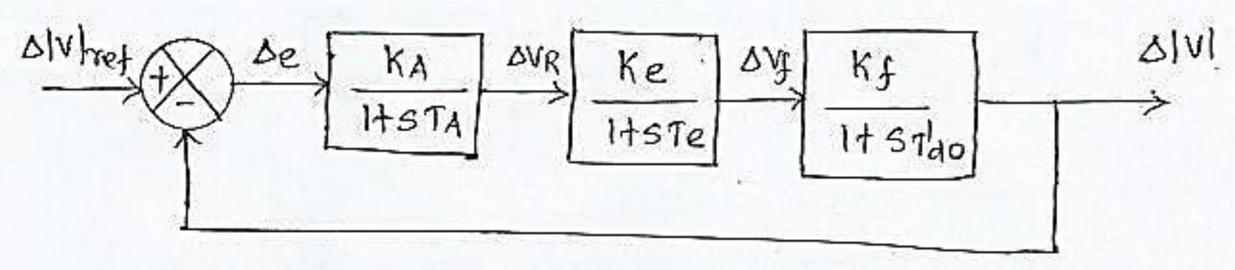
STATIC ANALYSIS OF AUTOMATIC VOLTAGE REGULATOR LOOP (OR) STEADY STATE RESPONSE

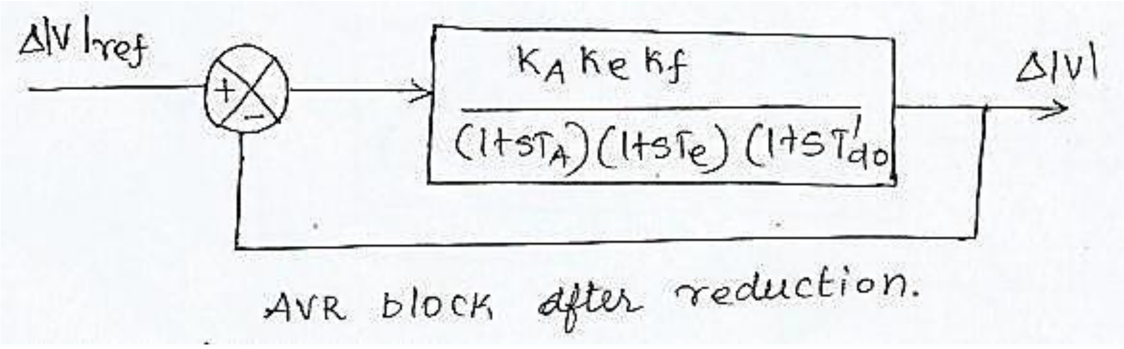
1. The automatic voltage regulator must regulate the terminal voltage (v) within the required static accuracy limit.
2. It must have sufficient speed response.
3. It must be stable.

The block diagram of AVR is

Initial error, $= \Delta e_0 = \Delta|v|_{ref0} - \Delta|v|_o$

Open loop T.F,





$$G(s) = \frac{k_a k_e k_f}{(1+sT_a)(1+sT_e)(1+sT'_{do})}$$

At initial condition,

$$\Delta|v|_0 = \frac{G(s)}{1+G(s)} - - - - - - - - - (1)$$

Δe_0 must be less than some specified % P of ref voltage Δv_{ref0} . The static accuracy specification is

$$\Delta e_0 < \frac{P}{100}\Delta|v|_{ref0} - - - - - - - - - - (2)$$

For a constant input, the transfer function is obtained by setting S=0.

Sub equation (1) in (2) we get

$$\Delta e_0 = \left[\Delta|v|_{ref0}\right] - \left[\frac{G(s)}{1+G(s)}\Delta|v|_{ref0}\right]$$

$$= \Delta|v|_{ref0}\left[\frac{1}{1+G(s)}\right]$$

Putting S=0 $\Delta e_0 = \left[\Delta|v|_{ref0}\right]\left[\frac{1}{1+\lim_{s\to 0} G(s)}\right] = \frac{\Delta v_{ref0}}{1+k_p}$

Position error constant

$$k_p = \lim_{s\to 0} G(s)$$

$$= \lim_{s\to 0} G(s) = \lim_{s\to 0}\frac{k_a k_e k_f}{(1+sT_a)(1+sT_e)(1+sT'_{do})}$$

$$= k_a k_e k_f$$

$$k = k_p = k_a k_e k_f$$

$$\Delta e_0 = \frac{\Delta|v|_{ref0}}{1+k} - - - - - - - - - - - (3)$$

If k increases, Δe_0 decreases therefore static error decreases with an increased loop gain.

To find the value of k

Consider equation (2)

$$\Delta e_0 < \frac{P}{100}\Delta|v|_{ref0}$$

$$\therefore \Delta e_0 = \frac{\Delta|v|_{ref0}}{1+k}$$

$$\frac{\Delta|v|_{ref0}}{1+k} < \frac{P}{100}\Delta|v|_{ref0}$$

$$\frac{1}{1+k} < \frac{P}{100}$$

(or)

$$1+k > \frac{100}{P}$$

$$k > \frac{100}{P} - 1$$

If Δe_0 is less than 1%, k must exceed 99%.

REACTIVE POWER AND VOLTAGE CONTROL

A power system is said to be well designed if it gives a good quality of reliable supply. Voltage level maintained within reasonable limits is referred as good quality. If variation is more than specified valve, the performance of equipment suffers and also the life of equipment is scarified.

When the load on the system increases, the voltage at the consumer terminals falls due to the increased voltage drop in alternator synchronous impedance, transmission line, transformer impedance, feeders and distributors.

Power is supplied to load through transmission line, keeping sending end voltage constant. The higher load we have smaller the power factor. Service voltage are usually specified by a nominal valve.

For examples 220 volt.residential supply circuit, the voltage might normally vary between limits 210 V and 230 V. The picture on a television starts rolling is the voltage is below certain level. While sudden drips or rapid fluctuations of less that 1 or 1.5% produce annoying eight fluctuations, they are called as eight flickers.

The methods for controlling voltage are

Tap changing transformers.

Regulating transformers etc

Synchronous condenser.

Static shunt capacitors,

Shunt reactors are common source of reactive power.

REQUIREMENTS OF VOLTAGE & REACTIVE POWER CONTROL

For efficient & reliable operation of power system should have the following:

a) All the machines and equipments are designed to operate at a certain voltage. Operation above or below the allowable range could damage them.
b) System stability in increase to maximize utilization of the transmission system. Voltage and reactive power control have a significant impact on system stability.
c) The reactive power flow is minimized so as to reduce I^2R and I^2X losses and to operate the transmission system efficiently (IP) mainly for active power transfer.

The reactive power cannot be transmitted over long distance; voltage control has to be affected by using special devices dispersed throughout the system. This is in contrast to the control of frequency which depends on the overall system active power balance. The problem of maintain voltage constant is that the loads keep on changing over a wide range, when the load varies, the power requirement also varies.

IMPORTANCE OF VOLTAGE CONTROL

The variations of Voltage at load will affect the consumer terminals. So , we should maintain the voltage within prescribed limits for the following reasons.

1. In lighting load, the lamp characteristics are very sensitive to change of voltage. If the supply voltage decrease, then the illumes acting power may decrease. If the supply voltage increase, the of the lamp reduces.
2. In induction motors, the voltage variations may cause erratic operation. If the supply voltage increase, the motor may operate with a saturated magnetic circuit and produce heating, thereby low power factor. If the voltage decrease. The starting torque of the motor may reduce.
3. In distribution transformers, the voltage variations may cause excessive heating and thereby rating of transformer.
   Location of voltage control equipment.

The voltage control equipments are connected between the generating station and the consumers. It is used at more than one point in any part of power system because, the power network is very large and there is a considerable voltage drop in transmission distribution load characteristics.

Voltage control equipment is located at .

1. Generating stations
2. Transformer stations
3. Feeders

4. Explain the methods for generating and absorbing the reactive power/ Discuss the components of a power system where the reactive power is generated and absorbed.

(April 2013)(Nov 2013)(Nov/Dec 2014)

GENERATION AND ABSORPTION OF REACTIVE POWER

1. Synchronous generators

It can generate or absorb reactive power. Reactive power (q) is supplied by synchronous generators depending upon the short circuit ratio (SCR).

$$SCR=1/X_S$$

Where X_s = synchronous reactance.

An over excited synchronous machine operating on no load condition, generates reactive power. An under excited synchronous machine absorbs reactive power. It is undesirable to transmit large amount of KVAR over transmission lines as this produces excessive voltage droop.

2. Shunt capacitors:

It offers the cheapest means of reactive power supply.

3. Shunt reactors:

It offers the cheapest means of reactive power absorption and these are connected in the transmission line during light load conditions.

4. Transformers:

It always absorb reactive power regardless of their loading.

At no load – shunt magnetizing reactance effect is predominant.

At full load – series leakage inductance effect is pre-dominant.

$$P.Ureactance, X_T = \frac{ActualX}{Basevalue} = \frac{ActualX}{\frac{V}{I}}$$

$$ActualX = X_T\frac{V}{I} = X_T\frac{KV}{I} \times 1000$$

$$I_{ph} = \frac{KVA}{\sqrt{3}\,KV}$$

$$X = \frac{X_T}{KVA} \times \sqrt{3} \times KV^2 \times 1000$$

$$Reactivepowerabsorbedorloss[Q_T] = 3 \times |I^2| \times VAR$$

$$= 3 \times |I^2| \times \frac{X_T}{KVA} \times \frac{X_T}{KVA} \times 1000$$

$$= \frac{3KVA^2}{3KV^2} \times \frac{X_T}{KVA} \times \sqrt{3} \times KV^2 \times 1000$$

$$= \sqrt{3} \times KVA \times X_T \times KVAR$$

Where,

$$I = Currentinampsflowingthroughthetransformer.$$

$$X = Transformerreactance/phase$$

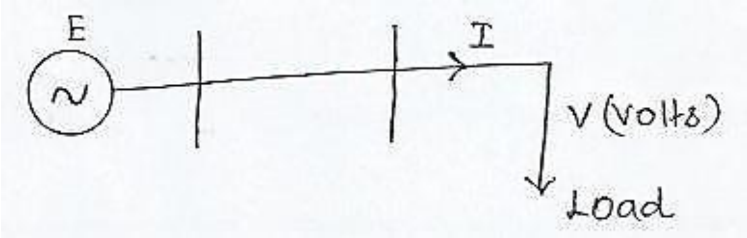
5. Cables:

Cables generate more reactive power than transmission lines because the cables have high capacitance.

6. Overhead lines:

Transmission lines are considered as generating KVAR in their shunt capacitance and consuming KVAR in their series inductance. The inductive KVAR Vary with the line current, where as the capacitive KVAR varies with the system potential.

Consider transmission line be loaded such that load current be 'I' amperes and load voltage 'V' volts as shown in figure.



If we assume the transmission line to be lossless, the reactive power absorbed by the line will be

$$\Delta Q_L = |I|^2 \times X_L$$

$$= |I|^2 \omega L$$

Due to the capacitance of the line, the reactive power generated by the line will be

$$\Delta Q_c = \frac{|V|^2}{X_c} = |V|^2 \omega C$$

Suppose $\Delta Q_L = \Delta Q_c$

$$|V|^2 \omega C = |I|^2 \omega L$$

$$= \left|\frac{V}{I}\right| = \frac{\omega L}{\omega C} = \frac{L}{C}$$

$$Z_n = \frac{V}{I} = \sqrt{\frac{L}{C}}$$

Where Zn is called surge impedance of the line.\

A line is said to be operating as its surge impedance loading when it is terminated by a resistance equal to its surge impedance. The power transmitted under to its impedance. The power transmitted under this condition is called natural or surge power.
In general,

$$P = \frac{|E||V|}{X} sin\delta$$

$$\delta = 90^\circ, \max powercanbetransfered.$$

$$P = \frac{|E||V|}{X} MW$$

By varying X,δ, $|V|$, we can get the control power.

Case (i)

$$\Delta Q_L > \Delta Q_c$$

$$|V|^2 \omega C < |I|^2 \omega L$$

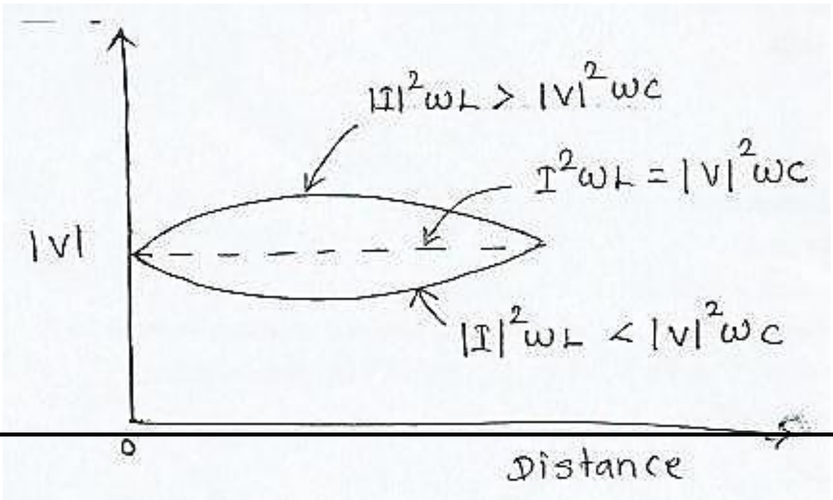
The voltage sags if the voltage at the two ends is maintained constant. The variation of voltage along the line is as shown in fig 2.

Here the line is loaded below Zn (ie) light load condition. The net effect of the line will be absorbed reactive power.
Case (ii)

$$\Delta Q_L < \Delta Q_c$$

$$|V|^2 \omega C > |I|^2 \omega L$$

The variation of voltage along the line is as shown in fig below and we find that the voltage rises and maintains constant voltage at the ends. Under light load conditions the effect of shunt capacitors is predominating and the line will generate reactive power.



7. **Loads:**

It absorb reactive power load change occurs depending on the day, season and weather conditions. Both active and reactive power of the composite loads vary as a function of voltage magnitudes load operating at L.P.F give voltage drop in the line and is uneconomical. Industrial consumers improve the p.f. using shunt capacitors.

5. **Explain the different methods of controlling the voltage in a power system.** **(April 2013)**

Explain the injection of reactive power by switched capacitors to maintain acceptable voltage profile and to minimize transmission losses in a power system/Discuss using a phasor diagram the role of static shunt compensator as a reactive power compensator.

(Nov 2013) (Nov 2012)

METHOD OF VOLTAGE CONTROL

Voltage level control is accomplished by controlling the generation, absorption and reactive power flow at all levels in the system.

1. Shunt Capacitors:

Shunt capacitors banks are used to supply reactive power at both transmission and distribution levels, along lines or sub-stations and loads. Capacitors are either directly connected to a bus bar or to the tertiary winding of a main transformer. They may be switched on and off depending on the changes in load having a lagging power factor, the capacitors supply reactive power.

Shunt capacitors are extensively used in industrial and utility systems at all voltage levels. By developing higher power density, lower cast improved capacitors and an increase in energy density by a factor of 100 is possible. These present a constant impedance type of load and the capacitive power output varies with the square of voltage.

$K_{Var},V_2= K_{Var},V_1[V_2/V_1]^2$

Where Kvar, V1 is output at voltage V_1

Kvar, V2 is output at voltage V_2

As the voltage reduces, so does the reactive power output, when it is required the most. This is called the destabilizing effect of power capacitors. Capacitors can be switched in certain discrete steps and do no not provide a stepless control. As a reactive power demand increases voltage falls.

Advantages:

1. These are less costly.
2. Flexibility of installation and operation.
3. Power factor improvement.
4. Efficiency of transmission and distribution of power is high.
5. Single or multiple banks industrial distribution at low and medium voltage substation.
6. Essential elements of SVC & Facts controllers and HVDC transmission.
7. Reactive power compensation

Disadvantages:

1. They cannot be overloaded.

2. The reactive power supplied by static capacitors tends to decrease in case of voltage dip on the bus because KVAR α V^2

Problems Associated with shunt capacitors:

- Switching inrush currents at higher frequencies and switching over voltage.
- Harmonic resonance problems.
- Limited overvoltage withstands capacity.
- Limited of harmonic current loadings
- Possibility of self-excitation of motors when improperly applied as power factor improperly applied as power factor improvement capacitors switched with motor.

Applications:

- improve power factor
- improve feeder voltage control

2. Series capacitors

It is connected in series to compensate the inductive reactance of line. This reduces the transfer reactance between the fuses to which the lines is connected. It increases maximum power that can be transmitted and reduce reactive power loss. The reactive power produced by the series capacitor increases with increase in power transfer, a series capacitor is self regulating in this regard.

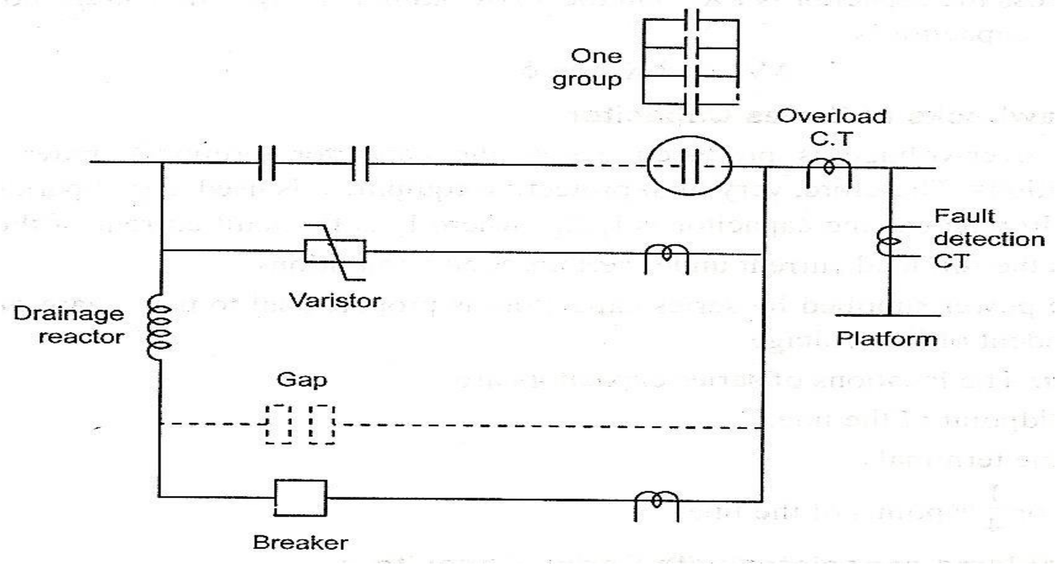
Under fault conditions, the voltage across the capacitor rises and unlike a shunt capacitor, a series capacitor experiences many time its rated voltage due to fault currents.

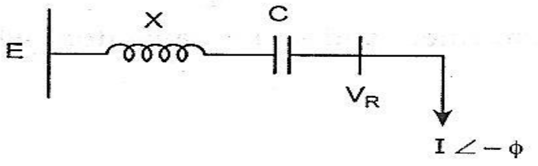
A Zinc oxide varistor in parallel with the capacitor may be adequate to limit this voltage.

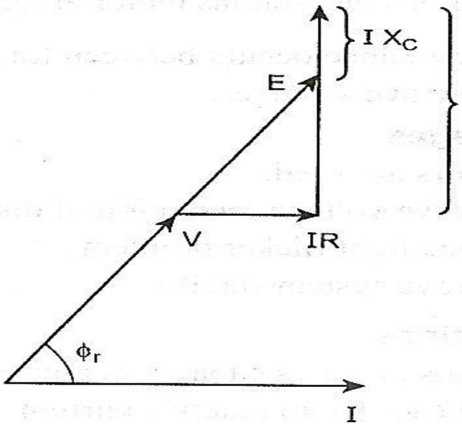
For locations with high fault currents a parallel fast acting triggered gap is introduced which operates for more severe faults. When the spark gap triggers it is followed by closure of the bypass breaker.

The drainage reactor limits the frequency and magnitude of the current through the capacitor when the gap sparks.

The schematic diagram of a series capacitor installation is shown in figure.







The voltage drop across the line is

$$IR\cos\phi_r + I(X_L - X_c)\sin\phi_r$$

It is clear from the vector diagram shown in figure that the voltage drop produced by an inductive load can be reduced particularly when the line has a high X/R ratio.

In practice X_c may be so chosen that the factor $(X_L - X_c)\sin\phi_r$ becomes negative and numerically equal to $R\cos\phi_r$ so that the voltage drop becomes zero. The ratio X_c/X_L pressed as a percentage is usually referred to as the percentage compensation.

If I is the full load current, and X_c is the capacitive reactance of the series capacitor, then the drop across the capacitor is IX_c and the VAR rating is I^2X_c. The voltage boost produced by the series capacitor is $V = IX_c \sin\phi_r$.

Drawbacks of series capacitor:

1. High over-voltage is produced across the capacitor terminals under short curcuit conditions. Therefore, very high protective equipment is used. E.g., spark gap.
2. The drop across the capacitor is if Xc, where if is the fault current of the order of 20 times the full load current under certain circuit conditions. Reactive power supplies capacitor is proportional to the square of line current and independent of line voltage.

Location:

The location of series capacitors au:

1.Midpoint of the line.

2.Line luminal

3.1/3 or ¼ th point of the line.

Problems associated with series capacitors:

- ✓ Locking of synchronous motor during stating.
- ✓ Hunting of synchronous motor at light load due to high R/x ratio
- ✓ Ferro resonance occurs between transformers and series capacitors which produces harmonic over voltages.

Advantages:

Series capacitors are used

- ✓ To improve voltage regulation of distribution and industrial feeders
- ✓ To reduce light flicker problems
- ✓ To improve system stability

Applications:

The applications of series capacitors are

- ✓ Voltage rise due to reactive current
- ✓ By passing the capacitor during faults and reinsertion after fault clearing

3. Shunt reactors:

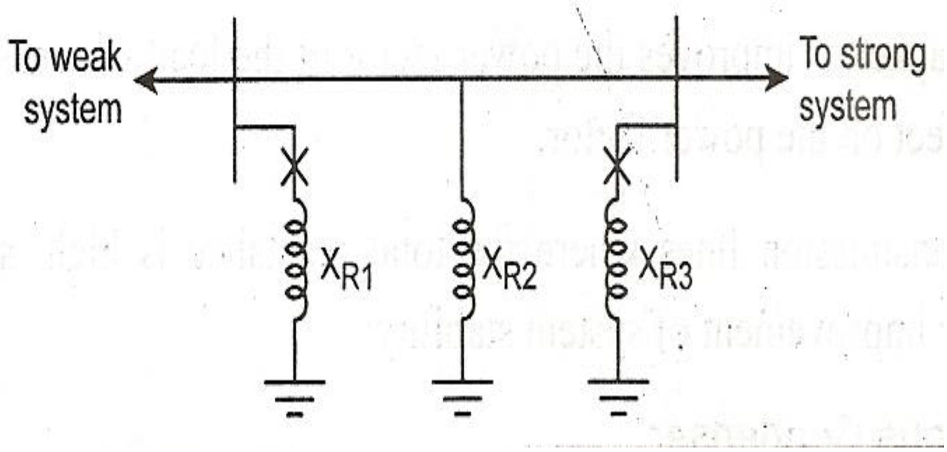
The shunt reactor au used to reduce (or) limit rise due to circuit (or) light load, shunt reactor absorbs reactive power are usually used for EHV lines longer than and when the far end line is opened, the large source inductive reactance will cause a rise in voltage at the receiving end of the line. Ferranti effete will cause a feather rise in receiving end voltage. During heavy loads some of the reactors may have to be disconnected.

Advantages:

- ✓ Shunt reactors of sufficient sixe is permanently connected to the line to limit fundamental. Frequency temporary over voltages
- ✓ To limit switching transients
- ✓ To maintain normal voltage under light load conditions
- ✓ During heavy load conditions, some of the reactors are disconnected by using switching reactors and circuit breakers.

Location:

Shunt reactors added to maintain normal voltage under light load may be connected to EHV bus as shown in fig.

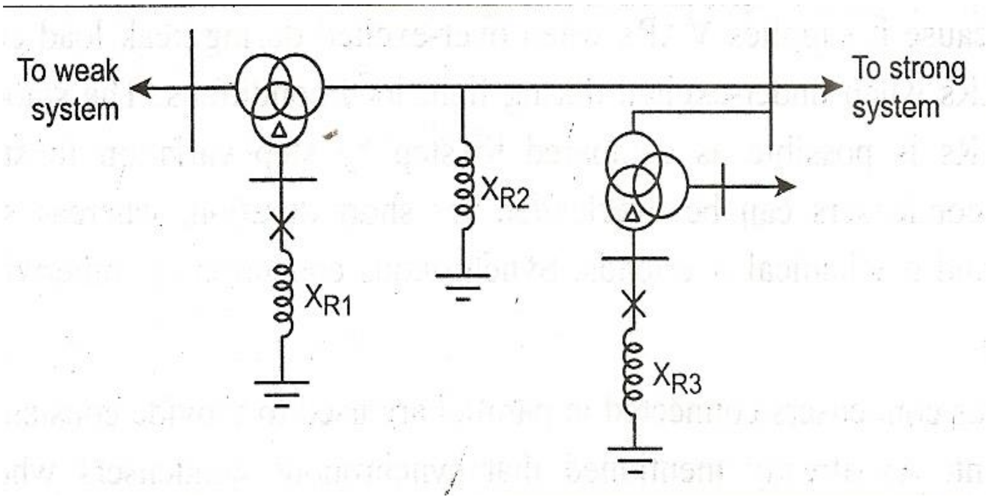


Shunt reactors connected to EHV bus:

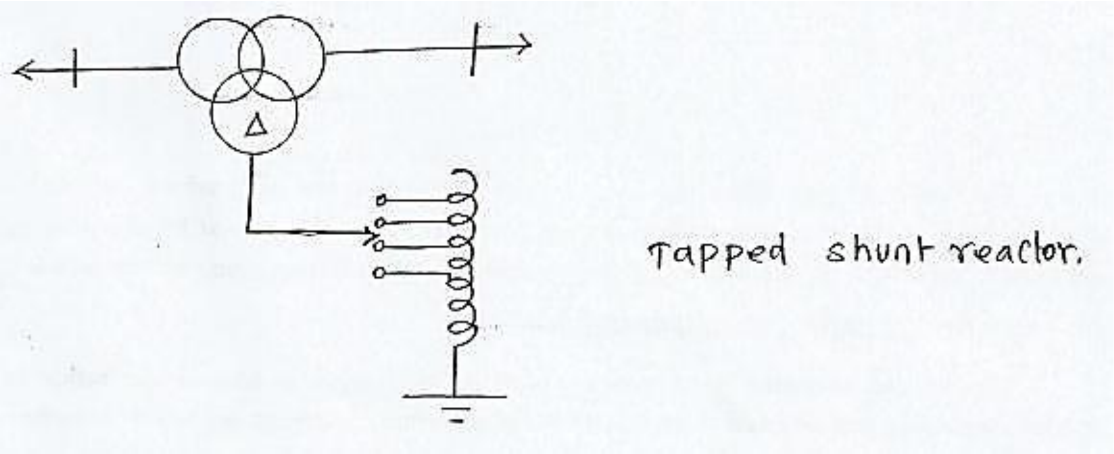
XR_1, XR_3 – switchable reactors.

XR_2 – permanently connected reactor

shunt reactors connected to the tertiary windings of adjacent transformers as shown in fig 5.6



In short transmission lines, no need connecting shunt reactors permanently, so switchable reactors may be connected to EHV bus or tertiary winding of transformers but in some applications, tapped reactors with on load tap changer is used in fig.



Comparison between series & shunt capacitors:

- The voltage boost due to a shunt capacitor is evenly distributed over the transmission line whereas the change in voltage between the two ends of a series capacitor where it is connected in sudden. The voltage drop along the line is unaffected.
- For the same voltage, the reactive power capacity of a shunt capacitor is greater than that of a series capacitor.
- The shunt capacitor improves the power factor of the load whereas the series capacitor has little effect on the power factor.
- For long transmission lines where the total reactance is high, series capacitors are effective for improvement of system stability.

6. What is meant by OLTC? Explain the action of tap changing transformer for controlling the voltage level of the system./Explain the operation of on load tap changing transformer for reactive power control. Also discuss its merits and demerits compared with other control methods./Describe the tap changing transformer method of voltage control. What are the limitations of this method? (April/May 2014)(Nov 2013) (Nov/Dec 2014)

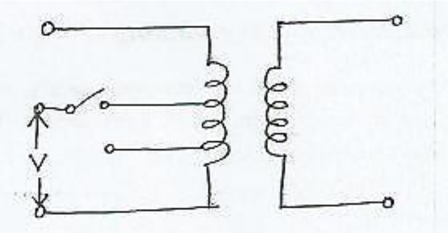
TAP CHANGING TRANSFORMER:

All power transformers on transmission lines an provided with traps for control of secondary voltage. The tap changing transformers do not control voltage by regulating the flow of active VARs but by changing transformation ratio.

There are two types of tap changing transformer:

a) Off-load tap changing transformers.
b) On load (under-load) tap changing transformers.[OLTC]

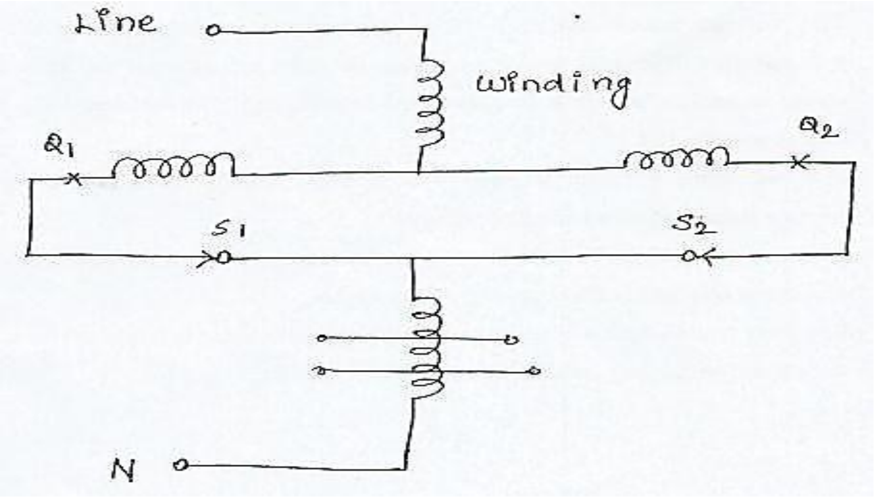
Off-load tap changing transformer:



The off-load tap changing transformer as shown in fig. which requires the disconnection of the transformer when the tap setting is to be changed off load tap changers are used when it is to be operated in frequently due to load growth or some seasonal change.

On load tap changing transformer (OLTC):

On-load tap changing transformer is used when changes in transformer ration to be needed frequently and no need to switch of the transformer to change the top of transformer. It is used on power transformers, auto transformers and bulk distribution transformers and at other points of load service.



The modern practice is to use on load tap changing transformer which is shown in fig.5.9. In the position shown, the voltage is maximum and service the currents divide equally and flow in opposition through the coil between Q_1 and Q2, the resultant flux is zero and hence minimum impedance.

To reduce the voltage the following operations an required in sequence:

i) Open Q_1
ii) Move selector switch S_1 to the next contact
iii) Class Q_1
iv) Open Q_2
v) Move selector switch se to the next contact
vi) Close Q_2

Thus, six operations are required for one change in tap position. The voltage change between taps is often 1.25% of the nominal voltage.

Applications of tap-changing transformers:

Auto transformers used to change voltage from one sup-system to another are often furnished with under-load or on-load tap changing facilities (ULTC). They may be controlled either automatically or manually. These are usually present throughout the network interconnecting transmission systems of different levels. The taps on these transformer provide a convenient means of controlling reactive power flow between subsystems. This in turn can be used to control line voltage profiles and reactive power losses.

The control of single transformer will cause change in voltages at its terminals. In addition, it influences the reactive power flow through the transformer. During high system load conditions, the network voltages are kept at the highest practical level to maximize reactive power requirement and increase the effectiveness of shunt capacitors and line-charging.

During lightly loaded condition, it is usually required to lower the network voltage, to reduce line charging and avoid under excited operation of generators.

Transformers with off-load tap changing facilities can also help to maintain satisfactory voltage profile, while transformers with VLTC can be used to take care of daily, hourly and minute-by-minute variation in system conditions setting of off-load tap changing transformers have to be carefully chosen depending on long term variation due to system expansion, load growth or seasonal changes.

PONDICHERRY UNIVERSITY QUESTIONS

2 MARKS

1. What is excitation? **(April/May 2014)**
2. What are the various functions of excitation system? **(Nov\Dec 2014)(Nov 2012)(April 2013)**
3. Distinguish between on load and off load tap changing transformer. **(April 2015)**
4. What are static shunt compensators? **(Nov 2012)**
5. What are the methods of voltage control? **(April 2015)(Nov 2013)**
6. What is use of static VAR compensators? **(April/May 2014)**
7. List the various compensating devices?/ What are the different compensating devices for transmission systems? **(April 2015)(Nov 2013)**
8. What is static VAR compensator? **(Nov\Dec 2014)(April\May 2014)**
9. Mention the effect of connecting a static capacitor in series with the line? **(April\May 2014)**
10. What is the need of power system stabilizer in an excitation system? **(April 2015)**
11. What is the need of using power system compensators in a power system? **(April 2013)**
12. What are the advantages of static VAR compensators? **(Nov 2013)**

11 MARKS

1. Draw the block diagram of a static excitation system and explain its operation. **(April/May 2014)**
2. Derive the transfer function of the exciter and draw the block diagram model of exciter system./ Develop the transfer function model of excitation system/ Draw the typical automatic voltage regulator and develop its block diagram representation/ Develop a mathematical model of an exciter system and brief on its control action. **(April/May 2014)(Nov 2012)(April 2015)(April 2013)**

3. Explain the methods for generating and absorbing the reactive power/ Discuss the components of a power system where the reactive power is generated and absorbed. **(April 2013)(Nov 2013)(Nov/Dec 2014)**
4. Explain the different methods of controlling the voltage in a power system. **(April 2013)**

   Explain the injection of reactive power by switched capacitors to maintain acceptable voltage profile and to minimize transmission losses in a power system/Discuss using a phasor diagram the role of static shunt compensator as a reactive power compensator. **(Nov 2013) (Nov 2012)**

5. What is meant by OLTC? Explain the action of tap changing transformer for controlling the voltage level of the system./Explain the operation of on load tap changing transformer for reactive power control. Also discuss its merits and demerits compared with other control methods./Describe the tap changing transformer method of voltage control. What are the limitations of this method? **(April/May 2014)(Nov 2013) (Nov/Dec 2014)**

REFERENCE BOOKS

1. Olle I. Elgerad, “Electric Energy System Theory and Introduction”, Tata Mc Graw Hill publishing company, New Delhi, 2nd edition, 2004.
2. Allen J.Wood, Bruce F. Wollenbarg, “Power Generation, operation and control”,2nd edition, John Wiley and sons, 2008.
3. D.P.Kothari and I.J.Nagrath, " Modern Power System Analysis” Tata Mc Graw Hill publishing company Ltd., 2003.
4. A.K.Mahalanbias, D.P.Kothari&S.I.Ahson, "Computer Aided Power System Analysis and Control" Tata Mc Graw Hill publishing company, New Delhi, 1990.
5. P.S.R. Murty, "Operation and Control in Power Systems" BS Publications, 2005.
6. M. GeraldinAhila, “Power System Operation and Control” ARS Publications,2008.