POWER GENERATION ECONOMICS

ECONOMICS OF GENERATION

Multiple Choice Type Questions

1. The unit for speed regulation in governing system is [WBUT 2008]
   a) Hz b) Hz/ MVA c) Hz/ MW d) none of these

Answer: (d)

2. Which of the following power plants has the highest initial cost? [WBUT 2008]
   a) Steam power plant b) Diesel power plant
   c) Hydro-electric power plant d) Gas power plant

Answer: (c)

3. A generating station which has high investment cost and low operating cost are usually operated as [WBUT 2008]
   a) peak load station b) base load station
   c) medium load station d) none of these

Answer: (b)

4. Load factor of a consumer is 35% and monthly consumption is 504kWh. Maximum demand is [WBUT 2008]
   a) 1.75 kW b) 176.4kW c) 5.88 kW d) none of these

Answer: (d)

5. Diversity of demand [WBUT 2008]
   a) increases installation cost b) decreases installation cost
   c) decreases operation cost d) both (a) and (c)

Answer: (d)

6. A thermal power plant is suitable for supplying [WBUT 2008]
   a) fixed load b) variable load c) peak load d) all of these

Answer: (a)

7. If the load factor increases, the cost of generation per kWh [WBUT 2009, 2010]
   a) increases b) decreases
   c) remains unaffected d) may increase factor

Answer: (a)

8. Low diversity factor [WBUT 2009, 2010]
   a) increases system installation cost
   b) reduces system installation cost
   c) does not affect system installation cost
   d) may increase or decrease the installation cost

Answer: (a)

9. Annual depreciation cost of a plant may be calculated by [WBUT 2009, 2010, 2011, 2017]

a) straight line method
b) sinking fund method
c) diminishing value method
d) all of these

Answer: (d)

10. Electrostatic precipitator is installed in a steam power plant between [WBUT 2009]

a) induced fan and chimney
b) air preheater and induced fan
c) economizer and air preheater
d) boiler furnace and economiser

Answer: (d)

11. The unit of heat rate is [WBUT 2010]

a) kW
b) kcal/hour
c) kcal/kWh
d) kWh/kcal

Answer: (c)

12. A generating station which has a high investment cost is usually operated as [WBUT 2010]

a) peak load station
b) base load station
c) off load station
d) none of these

Answer: (a)

13. A system has 5 generators each having a capacity of 400 MW. If 4 of the generators are running while the system load is 1300 MW, the spinning resource is [WBUT 2010]

a) 700 MW
b) 300 MW
c) 1600 MW
d) 1300 MW

Answer: (b)

14. A generating station has the following data: [WBUT 2010]
Installed capacity = 500 MW, capacity factor = 45%, load factor = 60%
Then the maximum demand of the system is

a) 225 MW
b) 300 MW
c) 375 MW
d) 135 MW

Answer: (c)

15. Which of the following is not a storage type power plant? [WBUT 2011]

a) Pumped hydro
b) Solar thermal
c) Gas turbine
d) Geothermal

Answer: (c)

16. Which of the following power plants has the longer life? [WBUT 2011]

a) Thermal
b) Hydel
c) Nuclear
d) Gas turbine combined cycle

Answer: (b)

17. Which of the following power plants can be operated both as base load and a peak load plant? [WBUT 2011]

a) Nuclear plant
b) Hydro power plant
c) Diesel power plant
d) Solar power plant

Answer: (b)

18. Which of the following power plants has the highest initial cost? [WBUT 2011]
   a) Steam power plant
   b) Diesel power plant
   c) Gas power plant
   d) Nuclear power plant

Answer: (d)

19. A generating station with high fuel cost is preferred to be operated as [WBUT 2011, 2015]
   a) base load station
   b) peak load station
   c) both (a) and (b)
   d) none of these

Answer: (a)

20. If the load factor increases, the fuel cost per unit kWh of generated electrical power [WBUT 2011]
   a) increases
   b) decreases
   c) remains unchanged
   d) first increases and then decreases with load factor

Answer: (c)

21. A power plant connected to grid has a maximum demand of 20 MW. The annual load factor is 50% while the plant capacity factor is 40%. The operating reserve of the plant is [WBUT 2011]
   a) 3.75 MW
   b) 5 MW
   c) 6.5 MW
   d) 8 MW

Answer: (a)

22. Load factor for a peak load plant is [WBUT 2012]
   a) 0
   b) 1
   c) low
   d) high

Answer: (c)

23. Hydel power plant can be used as [WBUT 2012]
   a) peak load plant
   b) base load plant
   c) both (a) and (b)
   d) none of these

Answer: (c)

24. Demand factor is [WBUT 2012]
   a) always greater than 1
   b) always less than 1
   c) of any value
   d) depends upon the system

Answer: (b)

25. Efficiency of a thermal power plant is [WBUT 2012]
   a) 40%
   b) 60%
   c) 80%
   d) 30%

Answer: (d)

26. Running cost is high for .... power plant. [WBUT 2012]
   a) thermal
   b) hydel
   c) nuclear
   d) non-conventional

Answer: (a)

27. Initial cost is higher for .... power plant. [WBUT 2012]
a) thermal b) hydel c) nuclear d) diesel
Answer: (b)

28. Diversity factor .... is good for power generation economics. [WBUT 2012]
a) less than 1 b) greater than 1 c) zero d) equals to 1
Answer: (b)

29. In load duration curve loads are arranged in [WBUT 2012]
a) ascending order b) descending order
c) any order d) a way that depends upon the load curve
Answer: (b)

30. A load curve is a plot of [WBUT 2013]
a) load versus generation capacity b) load versus current
c) load versus time d) load versus cost of power
Answer: (c)

31. Which of the following categories of consumers can provide highest load factor? [WBUT 2013]
a) a domestic consumer b) a continuous process plant
c) a steel melting unit using arc furnace d) a cold storage plant
Answer: (a)

32. Load factor during a period is [WBUT 2013]
a) average load / installed capacity b) average load / maximum load
c) maximum load / average load d) maximum load / installed capacity
Answer: (b)

33. Demand factor is the [WBUT 2013]
a) maximum demand / average demand
b) maximum demand / connected load
c) average demand / maximum demand
d) connected load / maximum demand
Answer: (b)

34. Nuclear power station is normally used for [WBUT 2014]
a) peak load b) base load c) average load d) any load
Answer: (b)

35. Which plant can never have 100% load factor? [WBUT 2014, 2015]
a) hydro b) coal-fired c) base load d) peak load
Answer: (c)

36. A system has 5 generators each having a capacity of 400 MW. If 4 of the generators are running while the system load is 1300 MW. The spinning source is [WBUT 2015]

a) 700 MW b) 300 MW c) 400 MW d) 1600 MW

Answer: (b)

37. A generating unit has an incremental production cost of Rs. 60 per MWh. If the penalty factor for this unit is 1.2, the incremental cost of power delivered is [WBUT 2015]

a) Rs. 50 per MWh
b) Rs. 72 per MWh
c) Rs. 61.20 per MWh
d) Rs. 48 per MWh

Answer: (a)

38. Load factor for a base load plant is [WBUT 2015]

a) 0 b) 1 c) low d) high

Answer: (d)

39. Gas turbine can be brought to the bus-bar from cold in about [WBUT 2017]

a) 2-minutes b) 30-minutes c) 1-hour d) 2-hours

Answer: (a)

40. A synchronous generator has higher capacity for [WBUT 2017]

a) Leading p.f.
b) Lagging p.f.
c) Unity p.f.
d) It does not depend on p.f.

Answer: (a)

41. An alternator having induced *emf* of 1.6 p.u. is connected to an infinite bus of 1.0 p.u. voltage. If bus-bar reactance of 0.6 p. u. and alternator has reactance of 0.2 p.u., the maximum power that can be transferred is given by [WBUT 2017]

a) 8 p.u. b) 2 p.u. c) 2.67 p.u. d) 5.0 p.u.

Answer: (b)

42. The cost of generation is theoretically minimum if [WBUT 2017]

a) The system constraints are considered
b) The operational constraints are considered
c) both (a) and (b)
d) the constraints are not considered

Answer: (d)

43. The most appropriate operating speeds n r.p.m. of generators used in Thermal, Nuclear and Hydro power plants would respectively be [WBUT 2017]

a) 3000, 300, 1500
b) 3000, 3000, 300
c) 1500, 1500, 3000
d) 1000, 900, 750

Answer: (b)

44. The maximum demand of a consumer is 2kw and his daily energy consumption is 20 units. His load factor is **[WBUT 2017]**

a) 10% b) 41.6% c) 50% d) none of these

Answer: (b)

Short Answer Type Questions

1. Explain briefly various cost components of generations of electrical energy. **[WBUT 2008, 2009]**

OR,

Briefly explain the various cost components of energy generation. **[WBUT 2015]**

Answer:

In general the cost of electrical energy generated can be roughly divided into the following two portions:

(i) ***Fixed cost:*** These do not vary with the operation of the plant i.e. these are independent of the number of units of electrical energy produced and mainly consist of (a) interest on capital investment (b) allowance for depreciation (c) taxes and insurance (d) most of the salaries and wages (e) small portion of the fuel cost.

(ii) ***Running or operating cost:*** These vary with the operation of the plant i.e. these are proportional to the number of units of electric energy generated and are mostly made up of (a) most of the fuel cost (b) small portion of salaries and wages (c) repair and maintenance.

2. Discuss the start-up and shut down costs associated with thermal generating stations. **[WBUT 2008]**

Answer:

In a thermal power stations unit efficiencies and fuel costs are major factors in the cost of power production. The operational scheduling of power generation involves determining the start up and shutdown (ON/OFF) schedules of generating units to be used to meet forecasted demand over a short span (24 – 168 hours) period. The objective is to minimize total production cost to meet system demand and reserve requirements while observing large set of operating constraints.

The total production cost consists of fuel cost, starting up cost and shutdown cost. Fuel cost is calculated by using heat rate and fuel price information start up cost is expressed as a function of the number of hours the unit has been down (exponential when cooling and linear when banking). The shutdown cost is given by fixed amount for each unit shutdown.

3. Explain the terms 'operating load factor' and 'connected load factor'. How does Diversity factor influence of cost of generation? **[WBUT 2008]**

Answer:

To define operating load factor, it is essential to mention first the term load factor which signifies the ratio of the average power to the maximum demand. It is an index to the proportion of the whole time a generator plant or system is being worked to its full capacity. From the stand point of economics it is desirable to keep the equipment loaded as much time as possible at operating load factor. If the load factor is poor i.e. kWh of electric energy produced is small then charge per kWh would obviously be high. But if load factor is high i.e. the number of kWh, generated is large, then cost of production and hence charge per kWh are reduced because now the standing charges are distributed over a large number of units of energy.

Now reverting to connected load factor it may be mentioned that factor relates only to the receiving equipment and is defined as the ratio of the average power input to the connected load. To render the above value specific it is essential (i) to define the period during which average is taken and (ii) to state the bases on which the connected load is computed.

$$\text{Connected load factor} = \frac{\text{Average power input}}{\text{Connected load}}$$

The connected load factor of a receiving equipment is equal to the product of its demand factor and its load factor.

Diversity factor → The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor.

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand on power station}}$$

A power station supplies load to various types of consumers whose maximum demand generally do not occur at the same time. Therefore, the maximum demand on the power station is always less than the sum of individual maximum demands of the consumers. Diversity factor will always be greater than 1. The greater the diversity factor, the lesser is the cost of generation of power.

4. What are the considerations on which location of a power plant depends?
[WBUT 2009]

Answer:

A. *Centre of Electrical Load* – The plant should be located where there are industries and other important consumption places of electricity. There will be considerable advantage in placing the power station nearer to the centre of the load.

- → There will be saving in the cost of Cu used for transmitting electricity as the distance of transmission line is reduced.
- → The cross-section of the transmission line directly depends upon the maximum current to be carried. In case of alternating current the voltage to be transmitted can be increased thus reducing the current and hence the cross section of the transmission line can be reduced. This will save the amount of Cu.
- → It is desirable to have a national grid connecting all power stations. This provides for selecting a site, which has other advantages such as nearer to fuel supply, condensing water availability.

B. *Nearness to the Fuel Source* – The cost of transportation of fuel may be quite high if the distance of location of the power plant is considerable. It may be advisable to locate big thermal power plants at the mouth of the coalmines. Lignite coalmines should have centralized thermal power station located in the mines itself as this type of coal cannot be transported. Such type of power stations could be located near oil fields of oil is to be used as a fuel and near gas wells where natural gas is available in abundance. In any case it has been seen that it is cheaper to transmit electricity than to transport fuel. Hence the power plant should be located nearer the fuel supply source.

C. *Availability of Water* – The availability of water is of greater importance than all other factors governing station location. Water is required for a thermal power station using turbines for the following two purposes.

i) To supply the make-up water which should be reasonably pure water.
ii) To cool the exhaust stream. This cooling purpose is done in case of diesel engines too. For bigger power station the quantity of this cooling water is tremendous and requires some natural source of water such as lake, river or even sea. Cooling towers could be used economically as the same cooling water could be use again and again. Only a part of make-up-water for cooling will then be required. For small plants spray pounds could sometimes be used. It is economical to limit the rise in cooling water temperature to a small value (between 6° and 12°C) and to gain is cycle efficiency at the extense of increased cooling water pumping requirement.

D. *Type of Soil Available and Land Cost* – While selecting a site for a power plant it is important to know about the character of the soil. If the soil is loose having low bearing power the pile foundation have to be used. Boring should be made at most of the projected site to have an idea of the character of the various strata as well as of the bearing power of the soil. The best location is that for which costly and special foundation is not required.

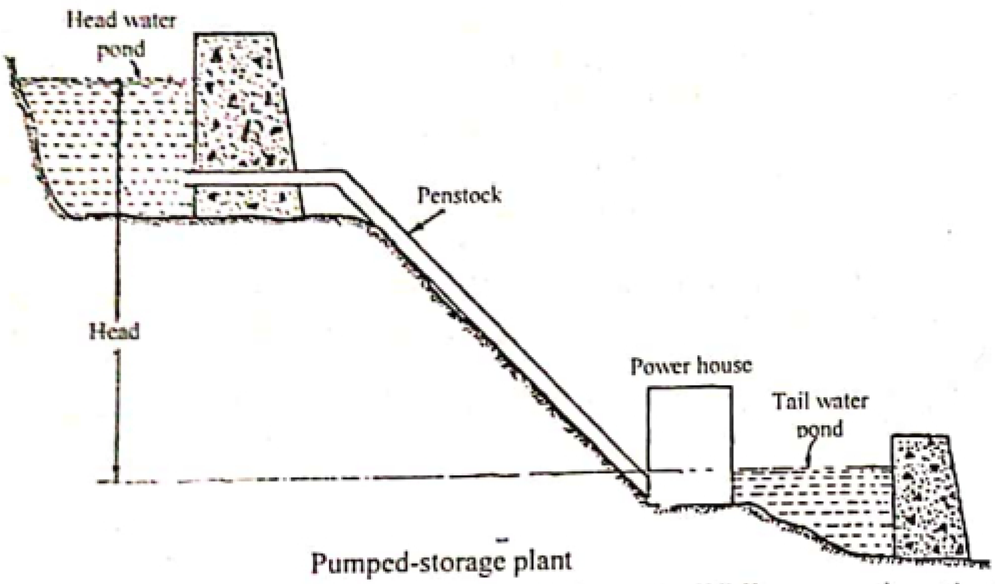
In case of power plants being situated near metropolitan load centers, the land there will be very costly as compared to the land at a distance from the city

5. Discuss the economic justification of pumped storage plants. [WBUT 2010]

Answer:

Pumped storage plants are a special type of power plants which work as ordinary hydropower plants for part of the time and when such plants are not producing power, they can be used as pumping stations which pump water from tail race to the head race. During this time, these plants utilize power available from the grid to run the pumping set. Thus, pumped storage plants can operate only if these plants are interconnected in a large grid.

The pumped storage plant thus consists of two ponds, one at a high level and the other at a low level with powerhouse near the low level pond. The two ponds are connected through a penstock as shown in figure below. It is an ingenious way of conserving the limited water resources on the one hand and balancing the load on the distribution system, on the other hand. The plant operates as a source of electric energy during system peak hours and as a sink during off-peak hours.



Pumped-storage plant

The modern trend is to use a reversible pump turbine unit. While generating, the turbine drives the electric generator and in the reverse operation, the generator runs as a motor driving the turbine, which, now acts as a pump. The following are the advantages of a pumped storage plant:

i) Free from environmental pollution.
ii) Readily adaptable to automatic and remote controls.
iii) Greater flexibility in the operational schedules of the system.
iv) Economical as a peaking power station.
v) Improves load factor of the overall plant as it works as a load during off-peak periods of the system.

6. State the factors that are taken into consideration for selection of the site of a thermal power plant and hydel power plant. **[WBUT 2010]**

Answer:

Thermal Power Plant:

A few important factors for the selection of site for thermal power plant are discussed below:

1. **Supply of Fuel:** The power station should be located as close as possible to the coalmines. In that case, the power will have to be transmitted to the load centres. It is, therefore, a problem of economics to find a suitable location so that the cost per unit of received energy is minimum taking both the transmission and transportation charges into account.
2. **Ash Disposal Facility:** The ash content of coal should be as low as possible. Unfortunately, Indian coal has ash content of 20 to 40%. This creates problems of air pollution and non-effective operation of boiler if it is not removed regularly and effectively. A large space should be available near the plant for ash disposal. Presently the ash from the plant is used for many industrial processes (e.g., cement etc.) and therefore, its disposal to sea or river is not desired but sufficient space should be available for storage.

3. **Availability of Water:** Huge quantities of water are required for condenser, for disposal of ash and as feed water to the boiler and drinking water for the working staff. It is, therefore, desirable to locate the plant near the bank of a river or a canal so as to have continuous supply of water.
4. **Land Requirement:** The average land requirement is 3 to 4 acres per MW capacity. The cost of land adds to the total cost of the plant and therefore, it should be available at a cheap rate which means it should be away from the load centre or heart of the city. The selected site should have good bearing capacity so as to withstand the dead load of the plant and forces transmitted to the foundation due to the plant operation.
5. **Transport Facilities:** As mentioned earlier, the present practice is to go in for pithead super thermal power station so as to avoid the transportation of huge quantities of coal required everyday. However, if the plant is to be located away from the pithead, then rail and road transport facilities should be available.

Hydel Power Plant:

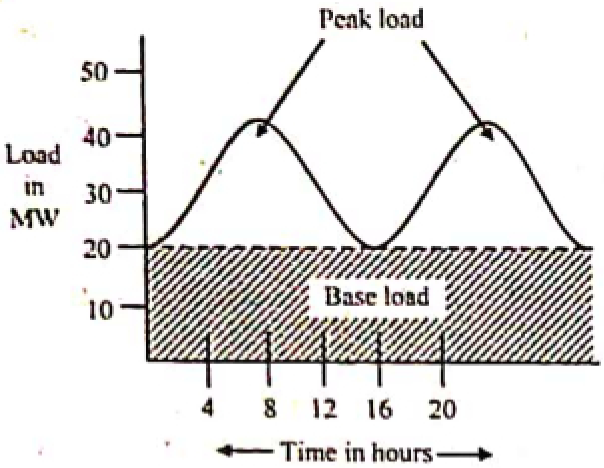
1. **Location of Dam:** From the cost point of view smaller the length of dam; the lower will be the cost of construction. Therefore, the site has to be where the river valley has a neck formation. In order to have capacity, a valley which has a large storage capacity on the upstream side of the proposed dam site is probably the best. It is desirable to locate a dam after the confluence of two rivers so that advantage of both the valleys to provide larger storage capacity is available.
2. **Choice of Dam:** The most important consideration in the choice of the dam is safety and economy. Failure of a dam may result in substantial loss of life and property. The proposed dam must satisfy the test of stability for: (i) shock loads which may be due to earthquakes or sudden changes in reservoir levels and (ii) unusually high floods.
   The dam should, as far as possible, be close to the turbines and should have the shortest length of conduit.
3. **Quantity of Water Available:** This can be estimated on the basis of measurements of steam flow over as long a period as possible.
   Storage of water is necessary for maintaining continuity of power supply throughout the year. Sufficient storage of water should be available since rainfall is not uniform throughout the year and from one year to another.
4. **Accessibility of Site:** The site should be accessible from the view point of transportations of man and material, so that the overall cost for construction, of project is kept low.
5. **Distance from the Load Centre:** The distance should be as small as possible so that the cost of transmission of power is minimum.
   Availability of construction material and general knowledge, should also be considered in site selection.

7. What are base load and peak load plants? **[WBUT 2010]**

Answer:

The changing load on the power station makes its load curve of variable nature. Fig. shows typical load curve of a power station. It is clear that load on the power station varies from time to time.

Base load plants: 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 20MW is the base load of the station. At base load on the station is almost of constant nature, therefore, it can be suitably supplied.



Peak load Plants: The various peak demands of the load over and above the base load of the station, is known as peak load. Referring to the load curve, 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 & may occur throughout the day.

8. Write down the salient requirements for a site to install a thermal power plant. **[WBUT 2011]**

Answer:

Refer to Question No. 4 of Short Answer Type Questions.

9. Discuss the economic justification of the thermal power plants. **[WBUT 2012]**

Answer:

So far the economical aspect of thermal power plant is concerned, it may be mentioned that it is considerably cheaper to transport bulk electric energy over extra high voltage (EHV) transmission lines than to transport equivalent quantities of coal over rail road, the recent trends in India (as well as abrad) is to build super (large) thermal power stations near coal-mines. Bulk power can be transmitted to fairly long distances over transmission lines of 400/765 kV and above. However, the country's coal resources are located mainly in the eastern belt and some coal-fired stations will continue to be sited in distant western and southern regions.

Economical benefits of thermal power plant:

i) **Efficient transportation:** The transmission of electricity through high-voltage power lines is more efficient than transporting coal or petroleum over the same distance. Therefore, many thermal power plants are set up near coal or oil fields.

ii) **Economical:** It is very economical to produce electricity using thermal power plants near coal or oil fields.

10. The yearly load duration curve of a power plant is a straight line. The maximum load is 500 MW and the minimum load is 400 MW. The capacity of the plant is 750 MW. Find:

a) plant capacity factor **b) load factor**
c) utilization factor **d) reserve capacity.** **[WBUT 2013]**

Answer:

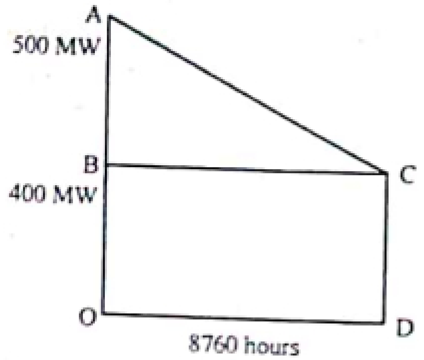
No. of units generated per year

$= \text{area } OACD = \text{area } OBCD + \text{area } BAC$

$= 400 \times 8760 + \frac{1}{2}(500 - 400) \times 8760$

$= 8760\left[400 + \frac{1}{2} \times 100\right]$

$= 8760[400 + 50] = 8760 \times 450$



Average annual load $= \frac{8760 \times 450}{8760} = 450\ MW$

a) $\therefore$ plant capacity factor $= \frac{\text{average annual load}}{\text{rated plant capacity}} = \frac{450}{750} = \frac{3}{5} = 0.6$

b) $\therefore$ Load factor $= \frac{450}{500} = \frac{0}{10} = 0.9$

c) Utilization factor $= \frac{\text{maximum demand}}{\text{rated capacity}} = \frac{500}{750} = .666$

d) Reserve capacity = Plant capacity – Maximum demand = 750 – 500 = 250 MW

11. A generating station has a maximum demand of 25 MW, a load factor of 60%, a plant capacity factor of 50% and a plant use factor of 72%. Find (a) the daily energy produced (b) the reserve capacity of plant. **[WBUT 2014]**

Answer:

$\text{Load factor} = \frac{\text{average demand}}{\text{maximum demand}}$

or, $0.60 = \frac{\text{average demand}}{25}$

$\therefore$ Average demand = 15 MW

$\text{Plant capacity factor} = \frac{\text{average demand}}{\text{installed capacity}}$

or, $0.50 = \frac{15}{\text{installed capacity}}$

$\therefore$ Installed capacity $= \frac{15}{0.5} = 30\,\text{MW}$

$\therefore$ Reserve capacity of the plant = installed capacity – maximum demand

$= 30 - 25 = 5$ MW

Daily energy produced = average demand × 24 = 15 × 24 = 360 MWh

12. Classify the different expenditures of a power utility having generation transmission and distribution in three categories i.e., fixed, semi fixed and running charges. **[WBUT 2015]**

Answer:

The different expenditures of a power utility having generation, transmission and distribution can be divided into three categories viz.:

i) **Fixed cost:** It is the cost, which is independent of maximum demand and units generated and salaries of high officials. The annual expenditure on the central organisation and salaries of high officials is fixed since it has to be met whether the plant has high or low maximum demand or it generates less or more units. Further, the capital investment on the land is fixed and hence the amount of interest is also fixed.

ii) **Semi-fixed cost:** It is the cost, which depends upon maximum demand but is independent of units generated.
The semi-fixed cost is directly proportional to the maximum demand on power station and is on account of annual interest and depreciation of capital investment of building and equipment, taxes, salaries of management and electrical staff. The maximum demand on the power station determines its size and cost of installation. The greater the maximum demand on a power station, the greater is the size and cost of installation. Further, the taxes and clerical staff depend uon the size of the plant and hence upon maximum demand.

iii) **Running cost:** It is the cost, which depends only upon the number of units generated. The running cost is an account of annual cost of fuel, lubricating oil maintenance repairs and salaries of operating staff. Since these charges depend upon the energy output, the running cost is directly proportional to the number of units generated by the station. In other words, if the power station generates more units, it will have higher running cost and vice versa.

13. Explain Cold–Reserve, Hot-Reserve, Spinning-Reserve with example of each. Explain their significance. **[WBUT 2017]**

Answer:

- **Cold Reserve:** Cold reserve in a power system is that reserve capacity which is available for service but normally not ready for immediate loading. A Cold reserve is ensured by special reserve units with small start-up and spin-up time. Period of the cold reserve start-up is varies from 2 to 24 hours and more. Units with small start-up time usually have a power-on reserve. For example, we have an idle generator that can be taken into service if demand increases.
- **Hot Reserve:** Hot Reserve in a power system is that reserve capacity which can be made available quickly. For example, we have a hydroelectric generator of rating say 100 MVA but currently supplies only 70 MVA. In this case we have 30 MVA hot reserve than can be loaded immediately by simply opening the valve to the hydro turbine.

- **Spinning Reserve:** Spinning reserve of active capacity is capacity reserve located at operating units and units with the start-up time of up to 5 minutes. Thus, a fast-start reserve is also a Spinning Reserve.

14. What is load-curve and load-duration curve? Explain their significance in power generation economics. **[WBUT 2017]**

Answer:

1st Part:

Load-Curve: ***Refer to Question No. 2(b)(i) of Long Answer Type Questions.***

Load duration curve: The load duration curve is defined as the curve between the load and time in which the ordinates representing the load, plotted in the order of decreasing magnitude, i.e., with the greatest load at the left, lesser loads towards the rights and the lowest loads at the time extreme right. The load duration curve is shown in the figure below.

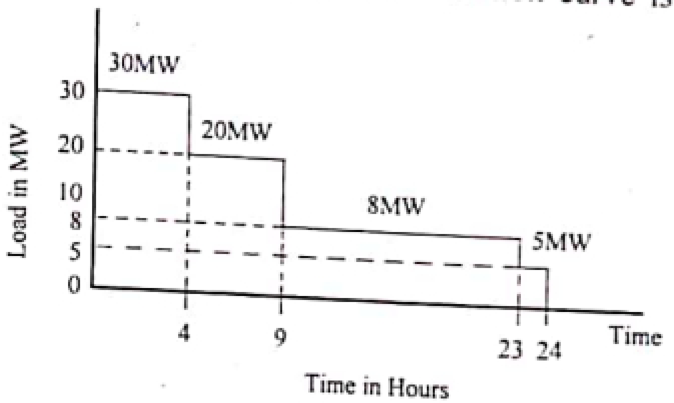


Fig: Load Duration Curve

This curve represents the same data as that of the load curve. The load duration curve is constructed by selecting the maximum peak points and connecting them by a curve. The load duration curve plotting for 24 hours of a day is called the daily load duration curve. Similarly, the load duration curve plotted for a year is called the annual load curve.

$$\text{Average Demand} = \frac{\text{kWh (or MWh) consumed in a given period of time}}{\text{hours in the time period}}$$

$$\text{Average Demand} = \frac{\text{area under the load duration curve}}{\text{base of the load duratin curve}}$$

2nd Part:

1) From the daily load curve we can have insight of load at different time for a day.

2) The area under the daily load curve gives the total units of electric energy generated.

Units Generated / day = Area under the daily Load Curve in kW

3) The peak point on the daily load curve gives the highest demand on the Power Station for that day.

Long Answer Type Questions

1. A generating station has a maximum demand of 50 MW. Calculate **[WBUT 2008]**
- **i) Fixed cost**
- **ii) Running cost**
- **iii) No. of units consumed per year**
- **iv) The cost per kWh from the following data:**
  - **Annual cost of fuel = Rs. 9 × 10^6**
  - **Taxes, wages and salaries factor = Rs. 6 ×10^6**
  - **Interest and depreciation factor = 10%**
  - **Annual load factor = 50%**

Answer:

Units generated / annum = maximum demand × load factor × hours in a year

$$= 500 \times 0.5 \times 8790\,\text{kWh} = 2190000\,\text{kWh} = 2.19 \times 10^6\ \text{kWh}$$

Annual fixed charges

Annual interest and depreciation $= 10\%$ of capital cost

Since capital cost is not provided here, so we assume the capital cost is Rs. 50×10^6 then

Annual interest and depreciation=10%of 50×10^6 = Rs. 5×10^6

Annual running charges

Total annual running charges

= Annual cost of fuel and oil + Taxes, salaries and wages etc.

$= \text{Rs.}\left(9 \times 10^6 + 6 \times 10^6\right) = \text{Rs.}15 \times 10^6$.

2. a) Discuss the effects of 'Load factor' and 'Diversity factor' on power Generation Economics. **[WBUT 2008]**

OR,

Define the terms "load factor" & "diversity factor" and explain the economic implications of these factors on the energy generations. **[WBUT 2009]**

OR,

Define the terms 'load factor' and 'diversity factor' and explain the economic implication of these factors on the cost of energy generation. **[WBUT 2010, 2012]**

Answer:

Load factor → The ratio of average load to the maximum demand during a given period is known as load factor.

i.e. $\text{Load Factor} = \dfrac{\text{Average load}}{\text{Maximum demand}}$

If the plant is in operation for T hours

$$\text{Load Factor} = \frac{\text{Average Load} \times T}{\text{Maximum Demand} \times T} = \frac{\text{Units generated in T hours}}{\text{Maximum demand} \times \text{T hours}}$$

The load factor may be daily load factor, monthly load factor or annual load factor if the time period considered is a day or month or year. Load factor is always less than 1 because average load is smaller than the maximum demand. The load factor plays key role in determining the overall cost per unit generated. Higher the load factor of the power station lesser will be the cost per unit generated.

Diversity factor → The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor.

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand on power station}}$$

A power station supplies load to various types of consumers whose maximum demand generally do not occur at the same time. Therefore, the maximum demand on the power station is always less than the sum of individual maximum demands of the consumers. Diversity factor will always be greater than 1. The greater the diversity factor, the lesser is the cost of generation of power.

b) i) What is a 'Load Curve'? **[WBUT 2008]**
ii) How does 'Load Curve' differ from 'Load duration curve'? **[WBUT 2008]**

OR,

Difference between Load curve Load duration curve. **[WBUT 2009]**

OR,

Write short note on Difference between load curve and load duration curve **[WBUT 2010]**

OR,

Differentiate between Load Curve and Load Duration Curve. **[WBUT 2013]**

Answer:

1st Part:

Load curve → The curve showing the variation of load on the power station with respect to time is known as a load curve.

The load on a power station is never constant, it varies from time to time. These load variations during the whole day (i.e. 24 hours) are recorded half hourly or hourly and are plotted against time on the curve. The curve thus obtained is known as daily load curve as it shows the variations of load with respect to time during the day.

The monthly load curve can be obtained from the daily load curves of that mouth. For this purpose, average values of power over a mouth at different times of the day are calculated and then plotted on the curve. The monthly i.e. is generally used to fix the rates of energy.

The yearly i.e. is obtained by considered the monthly load curves of that particular year. The yearly load curve is generally used to determine the average load factor.

2nd Part:

Difference between Load Curve & Load Duration Curve:

Load Curve	Load Duration Curve
1. The area under the load curve represents the energy generated in the period considered.	1. The area under the load duration curve and the corresponding chronological load curve is equal and represents total energy delivered by the generating station.

Load Curve	Load Duration Curve
2. The area under the curve divided by the total number hours gives the average load on the power station.	2. Load duration curve gives a clear analysis of generating power economically.
3. The peak load indicated by the load curve represents the maximum demand of the power station.	3. Proper selection of base load power plants and peak load power plants becomes easier.

c) A power station has to meet the following demand: **[WBUT 2008]**
Group A: 200 kW between 8 AM and 6 PM
Group B: 100 kW between 6 AM and 10 AM
Group C: 50 kW between 6 AM and 6 AM
Group D: 100 kW between 10 AM and 6 PM and between and 6 AM
plot the daily load curve and determine
i) Diversity factor **ii) Units generated per day**
iii) Load factor.

Answer:
The given load cycle can be tabulated as under

Time (hours)	0 – 6	6 – 8	8 – 10	10 – 18	18 – 24
Group A	—	—	200 kW	200 kW	—
Group B	—	100 kW	100 kW	—	—
Group C	—	50 kW	50 kW	—	—
Group D	100 kW	—	—	100 kW	100 kW
Total load on power station	100 kW	150 kW	350 kW	300 kW	100 kW

From this table, if is clear that total load on power station is 100 kW for 0 – 6 hours 150 kW for 6 – 8 hours, 350 kW for 8 – 10 hours 300 kW for 10 – 18 hours and 100 kW for 18 – 24 hours the load.

It is clear from the curve that maximum demand on the station is 350 kW and occurs from 8 A.M. to 10 A.M. i.e. maximum demand = 350 kW

Sum of individual maximum demands of groups $= 200 + 100 + 50 + 100 = 450\text{ kW}$

i) Diversity Factor $= \dfrac{\text{Sum of individual maximum demands}}{\text{Maximum demand on station}} = \dfrac{450}{350} = 1.286$

ii) Unity generated / day = / rea (in kWh) under load curve
$= 100 \times 6 + 150 \times 2 + 350 \times 2 + 300 \times 8 + 100 \times 6$
$= 4600\text{ kWh.}$

iii) Average load $= 4600/24 = 191.7\text{ kW}$

Load factor $= \dfrac{191.7}{350} \times 100 = 54.8\%$.

3. A power station has to meet the following load demand: **[WBUT 2009]**

Load X: 50 kW between 10 AM and 6 PM
Load Y: 30 kW between 6 PM and 10 PM
Load Z: 20 KW between 4 PM and 10 PM

Plot the daily load curve and determine:
i) diversity factor
ii) load factor.

Answer:

Time hours	0 – 6	6 – 8	8 – 10	10 – 18	18 – 24
Load-A	–	–	–	50	–
Load-B	–	30	30	–	–
Load-C	20	20	20	20	
Total	20	50	50	70	–

Maximum demand = 70 kW

Sum of individual maximum demands $(50+30+20)=100\,\text{kW}$

Diversity factor $=\dfrac{100}{70}=1.43$

Units generated/day = Area in kWh under load curve

$$=(20\times6)+(50\times2)+(50\times2)+(70\times8)$$
$$=120+100+100+560=880\,\text{kWh}$$

Average load $=\dfrac{880}{24}=36.66$

Load factor $=\dfrac{36.66}{70}\times100=52.38\%$

4. A power supply is supplying the following loads:

Type of Load	Maximum demand (kW)	Diversity group	Demand factor
Domestic	1500	1.2	0.8
Commercial	2000	1.1	0.9
Industrial	10000	1.25	1

The overall system diversity factor = 1.35
Determine: .

i) **Maximum demand**
ii) **Connected load of each type.** **[WBUT 2010]**

Answer:

i) The sum of maximum demands of three types of loads is

$$=1500+2000+10,000=13,500\,\text{kW}$$

As the system diversity factor is 1.35,

$\therefore$ Maximum demand on the supply system $=13,500/1.35=10,000\,\text{kW}$

ii) Each type of load has its own diversity factor among its consumers.
Sum of maximum demands of different domestic consumers = Maximum domestic demand × diversity factor $=1500\times1.2=1800\,\text{kW}$.

$\therefore$ Connected domestic load $=1800/0.8=2250\,\text{kW}$

Connected commercial load $=2000\times1.1/0.9=2444\,\text{kW}$

Connected industrial load $=10,000\times1.25/1=12,500\,\text{kW}$.

5. The annual load duration curve of a grid is represented by a straight line with maximum demand of 100 MW and minimum demand of 30 MW. The load has to be catered by one base load plant *B* and one peak load plant *P*. The annual operating costs for the two plants are as follows:

$$C_B = 4000 \times L_B + 2.5 \times Q_B \text{ and } C_P = 2500 \times L_P + 3.0 \times Q_P \text{ respectively.}$$

(Here, *L* is the rating of a plant in kW, *Q* is the total annual generation in kWh, and *C* is in Rs.) Find the rating of the two plants so that the annual cost of generation is minimum of the grid. **[WBUT 2011]**

Answer:

Let C_B = Operating cost of base load plant

C_P = Operating cost of peak load plant

P_B = Load (peak) on the base load plant

P_P = Load (peak) on the peak load plant.

The operating costs of base load and peak load plants may be expressed as follows

$$C_B = A_1 \text{ kW} + B_1 \text{ kWh}$$

$$C_P = A_2 \text{ kW} + B_2 \text{ kWh}$$

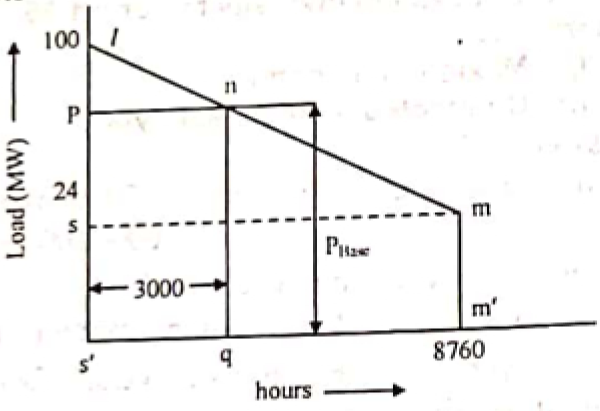
From the given data

$A_1 = 4000 \qquad B_1 = 2.5$

$A_2 = 2500 \qquad B_2 = 3.0$

The time, h hours, for which base load to be operated for minimum overall cost is given by

$$h = \frac{A_1 - A_2}{B_2 - B_1} = \frac{4000 - 2500}{3.0 - 2.5} = \frac{1500}{0.5} = 3000 \text{ hours.}$$



Now $P_B + P_P = 100$

$P_P = 100 - P_B$

Now from Δs lms and lmp

$$\frac{100 - P_B}{100 - 30} = \frac{3000}{8760}$$

or, $$\frac{100 - P_B}{100 - 30} = \frac{3000}{8760}$$

or, $$P_B = 100 - (100 - 30) \times \frac{3000}{8760}$$

$$= 100 - 70 \times \frac{300}{876} = 100 - 23.9726 = 76.0274 \text{ MW} \approx 76 \text{ MW}.$$

$$P_P = 100 - 76.0274 = 23.9726 \text{ MW} \approx 24 \text{ MW}.$$

6. **A residential consumer has 10 lamps of 40 W each connected to his premises. His demand is as follows:**
   i) **From 12 midnight to 5 am — 40 W**
   ii) **From 5 am to 6 pm — no load**
   iii) **From 6 pm to 7 pm — 320 W**
   iv) **From 7 pm to 9 pm — 360 W &**
   v) **From 9 pm to 12 midnight — 160 W.**

Plot the load curve on plain paper taking *X*-axis as time & *Y*-axis as demand. Find the average load, maximum load, load factor and electric energy consumption during the day.
[WBUT 2011, 2014]

OR,

A residential consumer has 20 lamps of 80 W each connected to his premises. His demand is as follows:
   (i) From 12 midnight to 5am – 40W
   (ii) From 5am to 6pm – no load
   (iii) From 6pm to 7pm – 320W
   (iv) From 7pm to 9pm – 360W and
   (v) From 9pm to 12 midnight – 160W

Plot the load curve on plain paper taking X-axis as time & Y-axis as demand. Find the average load, maximum load, load factors and electric energy consumption during the day.
[WBUT 2015]

Answer:

The maximum load is 360 W for 2 hours of the day, from 7 p.m. to 9 p.m. The load curve is plotted in figure 1. It is the plot of the load in watts against the time in hours of the day. The energy consumption during 24 hours the day is

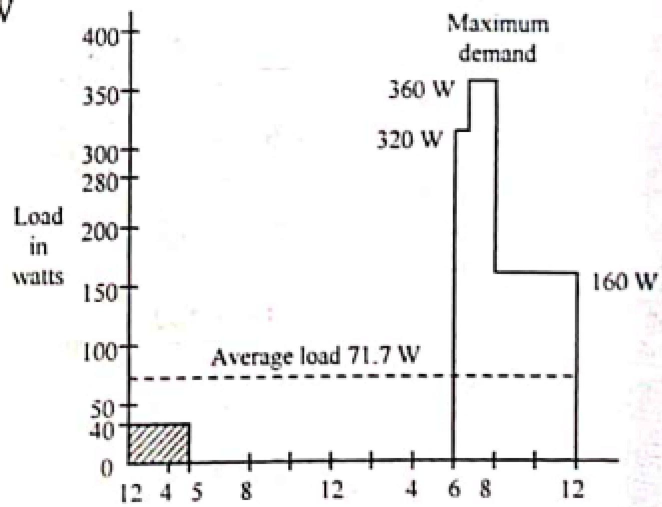
$$(5\times40)+(320\times1)+(360\times2)+(160\times3)=1720 \text{ Wh or } 1.720 \text{ kWh per day.}$$

$$\text{Load factor}=\frac{\text{Energy consumed during 24 hours}}{\text{Maximum demand}\times 24 \text{ hours}}=\frac{1720 \text{ Wh}}{360 \text{ W}\times 24 \text{ h}}=0.199 \text{ or } 19.9\%$$

$$\text{Average load}=\frac{1720 \text{ Wh}}{24 \text{ h}}=71.7 \text{ W}$$

The load factor is also given by the ratio of average load to maximum load i.e.,

$$\text{Load factor}=\frac{71.7 \text{ W}}{360 \text{ W}}=0.199 \text{ or } 19.9\%.$$



7. a) What are the merits of a pumped hydro plant? **[WBUT 2011]**

Answer:

1. There is substantial increase in peak load capacity of the plant at comparatively low capital cost.
2. Due to load comparable to rated load on the plant, the operating efficiency of the plant is high.
3. There is an improvement in the load factor of the plant.
4. The energy available during peak load periods is higher than that of during off peak periods so that in spite of losses incurred in pumping there is overall gain.
5. Load on the hydroelectric plant remains uniform.
6. The hydroelectric plant becomes partly independent of the stream flow conditions.

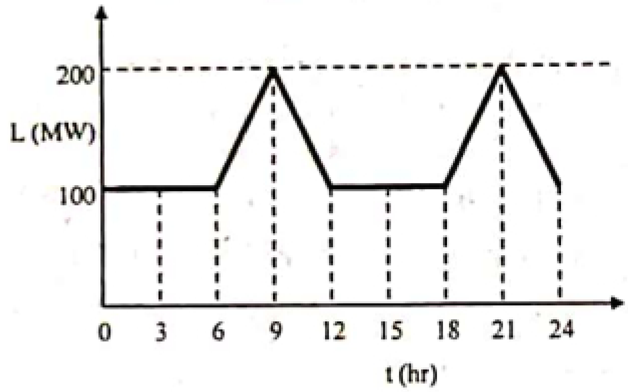
b) The load curve of a grid for a duration of 24 hr is as shown in the figure. Determine

i) the daily energy requirement of the grid **[WBUT 2011]**

ii) the load factor

iii) energy consumed during the pumping in a pumped hydro plant, which may be used to make the load curve of the grid a perfectly flat one. Assume no losses in the pumped hydro plant

iv) the duration for which the pumped hydro plant will run in generating mode.



Answer:

Time(hrs)	Load (MW)
0 – 3	100
3 – 6	100
6 – 9	$\frac{100+200}{2}=150$
9 – 12	$\frac{200+100}{2}=150$
12 – 15	100
15 – 18	100
18 – 21	$\frac{100+200}{2}=150$
21 – 24	$\frac{200+100}{2}=150$

i) The daily energy requirement of the grid

$$=(100\times3)+(100\times3)+(150\times3)+(150\times3)+(100\times3)$$
$$+(100\times3)+(150\times3)+(150\times3)$$
$$=300+300+450+450+300+300+450+450$$
$$=3000\text{ MWhr.}$$

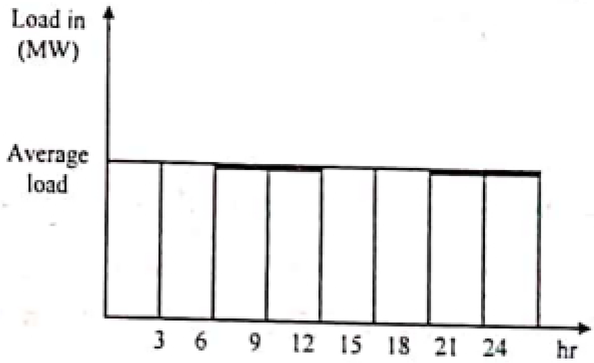
ii) Average load $\dfrac{\text{Units generated}}{\text{Times in hrs.}}=\dfrac{3000}{24}=125\text{ MW}$

Maximum demand = 200 MW.

Load factor $=\dfrac{125}{200}=0.625$

iii) Energy consumed during the pumping in a pumped hydro-plant, which may be used to make the load curve of the grid a perfectly flat one is = Average load×L.F×8760
$=125\times.625\times8760=684375\text{ MWh}$

iv) The duration for which the pumped hydro-plant will run in generating mode is 6 hr.



8. An industrial consumer has a choice between low and high voltage supply available at the following rates:
For high voltage — Rs.50 per kW per year + paise 4 per kWh
For low voltage — Rs.55 per kW per year + paise 5 per kWh
In order to have high voltage supply, consumer has to install his own transformer which costs Rs.110 per kW. The losses in the transformer are 4% of full load. Determine the number of working hours per week above which high voltage supply will be economical.
Assume interest and depreciation 12% of capital, working weeks per year 50 and load of consumer as 1.5 MW. **[WBUT 2011]**

Answer:

Consumer load = 1.5 MW = 1500 kW

Required rating of transformer $=\dfrac{1500}{(1-0.4)}=\dfrac{1500}{0.96}=1562.5\text{kW}$

Cost of the transformer to the consumer $=1562.5\times110=$ Rs. 171875

Annual interest and depreciation $=\dfrac{12}{100}\times171875=$ Rs. 20625

Let the number of hours for which power is required by the consumer $= x$ hours/week

$\therefore$ Number of hours for which power is used during the year $= 50x$ hours

i) Number of units consumed from low voltage side if the load is connected to low voltage $= 1500 \times 50x = 75000x$ kWh/year

ii) Number of units consumed from high voltage side if the load is connected to high voltage $= 1562.5 \times 50x = 78125x$ kWh/year

$$\text{Total cost from low voltage supply in rupees} = 1500 \times 55 + 75000x \times \frac{5}{100}$$

$$= 82500 + 3750x \qquad \text{.... (1)}$$

$$\text{Total cost from high voltage supply in rupees} = 1562.5 \times 50 + 78125x \times \frac{4}{100} + 20625$$

$$= 78125 + 20625 + 3125x \qquad \text{.... (2)}$$

If both the systems cost the same to the consumer, then equating (1) and (2) we get

$$82500 + 3750x = 78125 + 20625 + 3125x$$

$$\Rightarrow \quad 3750x - 3125x = 78125 + 20625 - 82500$$

$$\Rightarrow \quad 3750x - 3125x = 98750 - 82500$$

$$\Rightarrow \quad 625x = 16250$$

$$\Rightarrow \quad x = \frac{16250}{625} = 26 \text{ hours}$$

i.e., Hence the number of working hours above which the high voltage supply will be economical = 26 hours.

9. a) How can high diversity be achieved? Explain whether it is desirable or not. **[WBUT 2012]**

Answer:

A high diversity factor implied that with a smaller maximum demand on the station, it is possible to cater to the needs of several consumers with varying maximum demands occurring at different hours of the day. The lesser the maximum demand, the lesser will be the capital investment on the generation. This helps reduce the overall cost of the unit (kwh) generated.

A higher diversity factor and higher load factor are the desirable characteristics of the load on a power station. The load factor can be improved by encouraging of the consumers to use power during off-peak hours with certain incentives such as offering a reduction in the cost of energy consumed during off-peak hours.

High diversity factor is always beneficial for economic operation of the system, which can be achieved by

1) giving incentives to users to use power in light load period.
2) using day-light saving
3) staggering office time
4) using two parts tariffs both maximum demand and energy consumption.

b) There are three consumers of electricity having different load requirements at different times. Consumer *A* has a maximum demand of 5 kW at 6 p.m. and a demand of 3 kW at 7 p.m. and daily load factor of 20%. Consumer *B* has a maximum demand of 5 kW at 11 a.m., a load of 2 kW at 7 p.m. and an average load of 1.20 kW. Consumer *C* has an average load of 1 kW and his maximum demand is 3 kW at 7 p.m. Determine

i) the diversity factor

ii) the load factor and average load of each consumer

iii) the average load and load factor of the combined load. [WBUT 2012]

Answer:

	i) Maximum Demand		Load Factor
Consumer 1	5 kW at 6 p.m	3 kW at 7 p.m	20%
Consumer 2	MD 5 kW at 11 a.m	2 kW at 7 p.m	Average load 1.2 kW
Consumer 3	MD 3 kW at 7 p.m		Average load 1 kW

i) Maximum demand of the system 8 kW at 7 p.m sum of the individual maximum demands = 5 + 5 + 3 = 13 kW.

$\therefore$ Diversity factor $=\frac{13}{8}=1.625$

ii)

Consumer 1,	Average load $.2\times5=1$ kW LF = 20%
Consumer 2,	Average load 1.2 kW $LF=\frac{1.2}{5}\times100=24\%$
Consumer 3,	Average load 1 kW $LF=\frac{1}{3}\times100=33.33\%$

iii) Combined average load = 1 + 1.2 + 1 = 3.2 kW

Combined load factor $=\frac{3.2}{8}\times100=40\%$

10. a) Define and explain the significance of the following terms:

(i) Demand factor

(ii) Diversity factor

(iii) Plant used factor.

b) Find the total number of units generated per year, fuel cost per year, total annual cost and generation cost per kWh from the following data:

Installed capacity = 200 MW, Capital cost = Rs. 3,000 per kW, Interest and depreciation = 12%, Fuel consumption = 0.9 kg/kWh, Fuel cost = Rs. 70 per 1,000 kg, other operating cost = 30% fuel cost, Load factor = 80%, Peak load = 170 MW.

[WBUT 2013]

Answer:

a) ***Demand Factor*** – The demand factor of any system, or part of a system, is the ratio of maximum demand of the system, a part of the system, to the total connected load of the system, or of the part of the system, under consideration. Expressing the definition mathematically.

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

Diversity Factor – The diversity factor of any system, or part of a system, is the ratio of the maximum power demands of the subdivisions of the system, part of a system, to the maximum demand of the whole system, or part of the system, under consideration, measured at the point of supply. Expressing the definition mathematically,

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand of entire group}}$$

Plant User Factor – It is defined as the ratio of energy produced in a given time to the maximum possible energy that could have been produced during the actual number of hours the plant was in operation. Expressing the definition mathematically,

$$\text{Plant use factor} = \frac{E}{C \times t'}$$

where, t' = Actual number of hours the plant has been in operation.

b) Units generated = Max. Demand × L.F × Hours in a year

Annum $= 170 \times 10^3 = .8 \times 8760$ KWh $= 1,191,360,000$

Annual fuel consumption = $.9 \times 191.360,000 = 1,072,224,000$

Annual cost of fuel $= 1,072.224,000 \times 70 =$ Rs. 75,055,680,000

Other operating cost = 30% of fuel cost = $.3 \times 1,261,440 \times 70 = 22,516,704,000$

Capital cost = 3000×170 $= 510.000$

Annual cost of interest & depreciation = 12% × 510,000 = Rs. 61,200

Total annual charges

= Rs. [75,055,680.000+22,516,704,000+510,000+61,200] = Rs. 97,572,955,200

11. a) A total fixed load *p* is to be delivered by a generating station having two generators *A* and *B* running in parallel. Establish how the generators will share the load, so that total input becomes minimum, when both have same fuel costs and different fuel costs.

b) Two generating plants *A* and *B* are interconnected by a transmission line. Plant *A* is supplying its local load from its Bus, as well as also supplying some power to plant *B* through the interconnected transmission line, so that plant *B* can meet up its local load demand at its Bus. Establish how the incremental production cost at Bus-bar of plant *B* can be estimated?

c) The fuel input per hour of plant *A* and Plant *B* are given as:

$F_A = 0.2P_A^2 + 40P_A + 120$ **Rs. per hour**

$F_B = 0.2P_B^2 + 30P_B + 200$ **Rs. per hour**

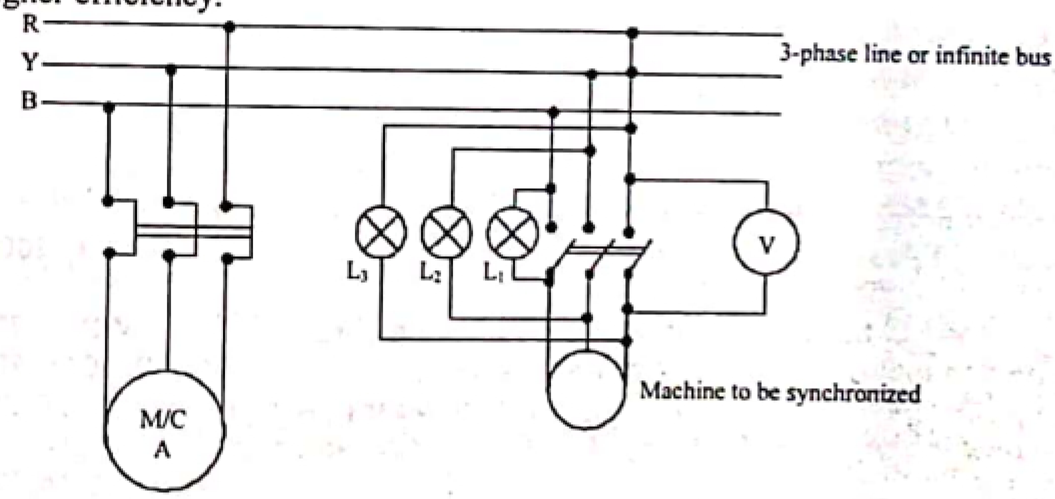
Determine the economic operating schedule and the corresponding cost of generation, if the maximum and minimum loading on each limit is 100 MW and 25 MW. The demand is 180 MW and transmission losses are neglected. If the load is equally shared by both the units determine the saving obtained by loading the units as per equal incremental production cost. **[WBUT 2017]**

Answer:

a) Here total fixed load p is to be delivered by a generating station having two generators A and B running in parallel. **Interconnection** of the electric power systems is essential from the economical point of view and also for reliable and **Parallel Operation.** Interconnection of AC power systems requires synchronous generators to operate in **parallel** with each other. In generating stations, two or more generators are connected in parallel. The alternators are located at different locations forming a **grid** connected system.

They are connected parallel by means of transformer and transmission lines. Under normal operating conditions all the generators and synchronous motors in an interconnected system operate in **synchronism** with each other. A machine has to be adjusted for optimum operating efficiency and greater reliability if the generators are connected in parallel.

As the load increases beyond the generated capacity of the connected units, additional generators are parallel to carry the load. Similarly, if the load demand decreases, one or more machines are taken off the line as per the requirement. It allows the units to operate at a higher efficiency.



b) ***Similar to Question No. 11(a) of Long Answer Type Questions.***

c) $P_{max} = 100\,\text{MW}$

$P_{min} = 25\ \text{MW}$

$P_{load} = 180$ MW

and $F_A = 0.2P_A^2 + 40P_A + 120$ Rs./hr.

$F_B = 0.2_B^2 + 30P_B + 200$ Rs./hr.

The incremental cost characteristics are obtained as.

$IF_A = 0.4P_A + 40$ Rs./MWh

$IF_B = 0.4P_B + 30$ Rs./MWh

Using incremental cost Rule

$0.4P_A + 40 = \lambda;\ 0.4P_B + 30 = \lambda$

Since, $P_A + P_B = 180$

$$\frac{\lambda - 40}{0.4} + \frac{\lambda - 30}{0.4} = 180$$

$$\lambda - 40 + \lambda - 30 = \frac{180 \times 4}{10}$$

$$\lambda = \frac{2 + 70}{2} = \frac{142}{2} = 71 \text{ MWh}$$

Thus, $P_A = \frac{71 - 40}{0.4} = \frac{31 \times 10}{4} = 77.5$

$$P_B = \frac{71 - 30}{0.4} = \frac{41 \times 10}{4} = 102.5$$

It should be noted that $P_B > P_{max}$

Therefore P_2 is set at the maximum value at 100 MW.

Thus, the economic scheduling i.e.,

$P_A = 77.5$ MW

$P_B = 100$ MW

12. Write short notes on the following:

a) Base load and Peak load stations **[WBUT 2009]**

OR,

Economic aspect of base load and peak load power plant **[WBUT 2011]**

b) Heat rate and incremental rate of power plants **[WBUT 2011, 2013]**

c) Cost of power generation for thermal, hydro, nuclear power plants **[WBUT 2012]**

d) Cost of power generation for thermal, hydro, nuclear and diesel power plant **[WBUT 2014, 2015]**

e) Constraints of power plants **[WBUT 2015]**

f) Site selection of nuclear power plant **[WBUT 2015]**

g) How to reduce power generation cost? **[WBUT 2017]**

h) Factors Affecting Economics of Generation and Distribution of Power **[WBUT 2017]**

Answer:

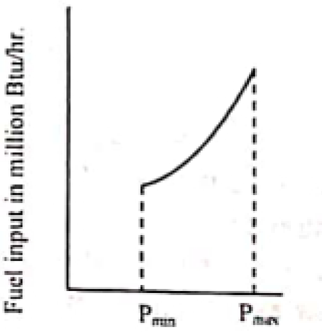
a) Base load and Peak load stations:

Refer to Question No. 7 of Short Answer Type Questions.

b) Heat rate and incremental rate of power plants:

A simplified performance curve of a boiler turbine generator unit is given in figure below. From the curve heat rate is defined as the ratio of fuel input to the corresponding power output and hence the units are million Btu per MWhr. From the heat rate curve incremental heat rate is defined as Incremental heat rate $= \frac{\Delta \text{ input}}{\Delta \text{ output}}$ which means it is a ratio equal to a small change in input to the corresponding small charge in output. As the incremental quantities tend to zero, incremental fuel rate tends to

Incremental heat rate $= \frac{d(\text{input})}{d(\text{output})} = \frac{dF}{dP}$ where F is the fuel input in million Btu/hr and P is the power output in MW.



c) Cost of power generation for thermal, hydro, nuclear power plants:

	Thermal	Hydro	Nuclear
1. Site	Such plants are located at a place where ample supply of water and coal is available transportation facilities are adequate.	Such plants are located at any place because they require less space and small quantity of water.	These plants are located away from thickly populated areas to avoid radioactive pollution.
2. Initial Running Cost	Initial cost is lower than those of hydroelectric and nuclear power plants.	Initial cost is very high because of dam construction and excavation work.	Initial cost is highest because of huge investment on building a nuclear reactor.
3. Running	Higher than hydroelectric and	Practically nil because no fuel is	Except the hydroelectric plant, it has the minimum

	Thermal	Hydro	Nuclear
Cost	nuclear power plant because of the requirement of huge amount of coal.	required.	running cost because small amount of fuel can produce relatively large amount of power.

d) Cost of power generation for thermal, hydro, nuclear and diesel power plant:

Diesel power plant:

	Diesel
1. Site	Such plants can be located at any place because they require less space and small quantity of water.
2. Initial Running Cost	Initial cost is less compared to other plants.
3. Running Cost	Highest among all plants because of high price of diesel..

Rest Part: ***Refer to Question No. 12(c) of Long Answer Type Questions.***

e) Constraints of Power Plants:

Thermal power plants:

i) It pollutes the atmosphere due to production of large amount of smoke and fumes. Ash handling in thermal power plant is a great constraint and needs to be install / arrange ash handling plant.

ii) It is costlier in running cost as compared to hydroelectric plant.

iii) The overall efficiency is low as huge amount of heat is lost in the condenser and secondly heat losses occur at various stages of the plant. The availability of good quality of coal in the country is day by day decreasing.

Hydroelectric power plant:

i) There is uncertainty about the availability of huge amount of water due to dependence of weather conditions.

ii) Wild life and destruction of plants / trees at the time of construction of dam which is also high capital cost create environmental imbalance.

iii) Cost of transmission of power is high as the plant is located in hilly areas.

Nuclear power plant:

i) The disposal of the bye-products, which are radioactive, is a big problem. They have either to be disposed off in a deep trench or in a sea away from the seashore.

ii) These plants are not well suited for varying loads as the reactor does not respond to the load fluctuations efficiently.

iii) The fission by products are generally radioactive and may cause a dangerous amount of radioactive pollution.

iv) The fuel used is expensive and is difficult to recover.

v) Capital cost is very high as compared to other types of plants.

Diesel power plant:

i) The plant has high running charges as the fuel (i.e., diesel) used is costly.
ii) The plant can only generate small power.
iii) The plant does not work satisfactorily under over load conditions for a longer period.

Gas turbine power plant:

i) Since a greater part of power developed by the turbine is used in driving the compressor. The net output is low.
ii) The temperature of combustion chamber is quite high (300°F) so that its life is comparatively reduced.
iii) The over all efficiency is about 20% because the exhaust gases from the turbine contain sufficient heat.

f) Site Selection of Nuclear Power Plants

i) **Availability of water:** As sufficient water is required for cooling purposes, therefore, the plant site should be located where ample quantity of water is available, e.g., across a river or by seaside.
ii) **Disposal of waste:** The site selected for such a plant should have adequate arrangement for the disposal of radioactive waste.
iii) **Distance from populated areas:** The site for such type of power station should be quite away from the populated areas as there is a danger of presence of radioactivity in atmosphere near the plant.
iv) **Transportation facilities:** The site selected for a nuclear power station should have adequate facilities in order to transport the heavy equipment during erection and to facilitate the movement of the worker employed in the plant.

g) How to reduce power generation cost?
Here are the non specific methodologies:

1. Reduce support downtime - Build the gadgets better in any case, keep up them painstakingly and do prescient examination which permit the most practical upkeep cycles. This is extensively utilized in utility-scale age today, however predicative investigation and enhancement of upkeep still have some power use to bring.

2. Reduce work necessities - Automate the hell out of all that you can, ideally so no human needs to try and visit the gadgets aside from upkeep. This is critical on the fuel extraction cycle for those things with fuel that must be extricated, handled and transported. What's more, it's essential on the task and upkeep side. Heaps of Instrument of Things innovation has been set up there and enhancing for quite a long time.

3. Put them near their fuel source, or where better fuel exists - Lots of coal age plants are worked adjacent to coal mines. Wind turbines are constructed where the breeze blows generally emphatically. Sunlight based boards are put where the sun sparkles for the most hours of the year. Hydro plants are put where there's a major watershed with a major vertical drop.

4. Forecast better - Whether it's better breeze gauging, better sunlight based anticipating, better dry season/surge forecast, long range cost of items expectation, a lot of precious stone ball looking with expansive datasets - or if nothing else extensive spreadsheets - goes into making sense of what will be generally productive. Showing signs of improvement at any of the hidden expectations - dry spell in the US southwest making warm age and hydro exceptionally dangerous anybody? - will influence the subsequent to type of age more ready to convey power productively.

5. Use markets - Build a great deal of business sectors. There's a long range showcase, spot markets, auxiliary markets, transmission markets. Get the greater part of the providers put resources into making it conceivable to offer their power at the most elevated net revenue on business sectors. They will be spurred to make their plants and advancements as proficient as would be prudent, and ready to exploit however many markets as could be allowed in the most wise way.

h) Factors Affecting Economics of Generation and Distribution of Power:

All the electrical energy generated in a power station must be consumed immediately as it cannot be stored. So the electrical energy generated in a power station must be regulated according to the demand. The demand of electrical energy or load will also vary with the time and a power station must be capable of meeting the maximum load at any time. Certain definitions related to power station practice are given below:

- **Load curve:** Load curve is plot of load in kilowatts versus time usually for a day or a year.
- **Load duration curve:** Load duration curve is the plot of load in kilowatts versus time duration for which it occurs.
- **Maximum demand:** Maximum demand is the greatest of all demands which have occurred during a given period of time.
- **Average load:** Average load is the average load on the power station in a given period (day/month or year)
- **Base load:** Base load is the minimum load over a given period of time.
- **Connected load:** Connected load of a system is the sum of the continuous ratings of the load consuming apparatus connected to the system.
- **Peak load:** Peak load is the maximum load consumed or produced by a unit or group of units in a stated period of time. It may be the maximum instantaneous load or the maximum average load over a designated interval of time.

- **Demand facto:** Demand factor is the ratio of maximum demand to the connected load of a consumer.
- **Diversity factor:** Diversity factor is the ratio of sum of individual maximum demands to the combined maximum demand on power stations
- **Load factor:** Load factor is the ratio of average load during a specified period to the maximum load occurring during the period.

  Load factor = Average Load / Maximum demand
- **Station load factor:** Station load factor is the ratio of net power generated to the net maximum demand on a power station.
- **Plant factor:** Plant factor is the ratio of the average load on the plant for the period of time considered, to the aggregate rating of the generating equipment installed in the plant.
- **Capacity factor:** Capacity factor is the ratio of the average load on the machine for a period of time considered, to the rating of the machine.
- **Demand factor:** Demand factor is the ratio of maximum demand of system or part of system, to the total connected load of the system, or part of system, under consideration.

ELECTRICITY TARIFF

Multiple Choice Type Questions

1. Domestic consumers are usually charged [WBUT 2017]
   a) Flat demand tariff
   b) Block-rate tariff
   c) Flat rate tariff
   d) Off-peak tariff

Answer: (b)

Short Answer Type Questions

1. What are the objectives of consumer tariff fixed by the power supply undertaking? [WBUT 2008]

The following two tariffs are offered:

a) Rs. 100 plus 10 paise per unit

b) A flat rate of 40 paise per unit.

At what consumption is the first tariff economical?

Answer:

1st Part

1. Recovery of cost of producing electrical energy at the power station.
2. Recovery of cost on the capital investment in transmission and distribution system.
3. Recovery of cost of operation and maintenance of supply of electrical energy e.g. metering equipment, billing etc.
4. A suitable profit on the capital investment.

2nd Part

Let x be the number of units at which charges due to both tariffs become equal.

Then $100+0.1x=0.4x$

or, $0.3x=100$

or, $x=100/0.3=1000/3=333.33$ units.

Therefore tariff (a) is economical if consumption is more than 333.33 units.

2. Enumerate the methods used to calculate depreciation. [WBUT 2009]

Answer:

The following are the commonly used methods for determining the annual depreciation charge:

1) Straight line method
2) Diminishing value method
3) Sinking fund method.

1) Straight Line Method → In this method, a constant depreciation charge is made every year on the basis of total depreciation and the useful life of the properly. In generals annual depreciation charge on the straight line method may be expressed as

annual depreciation charge $=\dfrac{P-S}{n}$.

P = Initial cost of equipment, n = Useful life of equipment in years, S = Scrap or salvage value after the useful life of the plant. The straight line method is extremely simple and is easy to apply as the annual depreciation charge can be readily calculated from the total depreciation and useful life of the equipment. However this method suffers from two defects. Firstly, the assumption of constant depreciation charge every year is not correct. Secondly it does not account for the interest, which may be drawn during accumulation.

2) Diminishing value method → Depreciation charge is made every year at a fixed ration the diminished value of the equipment. In other wards, charge is first applied to the initial cost of equipment and then to its diminished value.

Mathematical Treatment:

P = Capital cost of equipment, n = Useful life of equipment in years, S = Scrap value after useful life. Suppose the annual unit depreciation is x. It is desired to find the value of x in terms of P, n and S.

Value of equipment after one year = $P - P_x = P(1-x)$

Value of equipment after 2 years = Diminished value – Annual depreciation

$$= [P(1-x)] - [(P - P_x)x]$$

$$= P(x^2 - 2x - 1) = P(1-x)^2$$

Value of equipment after n years = $P(1-x)^n$

But the equipment after n years is equal to the scrap value S

$$S = P(1-x)^n \text{ or } (1-x)^n = S/P \text{ or } 1-x = (S/P)^{1/n} \text{ or } x = 1-(S/P)^{1/n} \text{ .... (1)}$$

From equation (1) the annual depreciation can be easily found. This method has two drawbacks. Firstly, low depreciation charges are made in the late years when the maintenance and repair charges are quite heavy. Secondly the depreciation charge is independent of the rate of interest which if may draw during accumulation. Such interest moneys, if earned, are to be treated as income.

3) Sinking fund method → In this method, a fixed depreciation charge is made every year and interest compounded on it annually. The constant depreciation charge is such that total of annual installments plus the interest accumulations equal to the cost of replacement of equipment after its useful life. Let P = Initial value of equipment, n = Useful life of equipment, S = Scrap value after useful life, r = Annual rate of interest expressed as a decimal, Cost of replacement = $P - S$.

Let us suppose that an amount of q is set aside as depreciation charge every year and interest compounded on it so that an amount of $P - S$ is available after n years. An amount q at annual interest rate of r will become $q(1+r)^n$ at the end of n years. The amount q deposited at the end of first year will earn compound interest for $n-1$ years and shall become $q(1+r)^{n-1}$.

Amount q deposited at the end of first year becomes $= q(1+r)^{n-1}$

Amount q deposited at the end of 2nd year becomes $= q(1+r)^{n-2}$

Amount q deposited at the end of 3rd year becomes $= q(1+r)^{n-3}$

Similarly amount q deposited at the end of $n-1$ year becomes $= q(1+r)^{n-(n-1)}$
$$= q(1+r)$$

$$\text{Total fund after } n \text{ years} = q(1+r)^{n-1} + q(1+r)^{n-2} + \cdots + q(1+r)$$
$$= q\left[(1+r)^{n-1} + (1+r)^{n-2} + \cdots + (1+r)\right]$$

This is a G.P. series and its sum is given by: Total fund $= \dfrac{q(1+r)^n - 1}{r}$

This total must be equal to the cost of replacement of equipments i.e. $P-S$.

$$\therefore \quad P - S = q\frac{(1+r)^n - 1}{r}$$

$$\text{Sinking fund} \quad q = (P-S)\left[\frac{r}{(1+r)^n - 1}\right] \qquad \text{.... (2)}$$

The value of q gives the uniform annual depreciation charge. The parenthetical term in equation (2) is frequently referred to as the "sinking fund factor".

$$\therefore \text{Sinking fund factor} = \frac{r}{(1+r)^n - 1}$$

Though this method does not fund very frequent application in practical depreciation accounting it is the fundamental method in making economy studies.

3. What are the components of two part tariff? State how it differs from the three part tariff. [WBUT 2011]

Answer:

Two-part tariff: When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part-tariff.

In two-part-tariff, the total charge to be made from the consumer is split into two components viz. fixed charges and running charges. The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer. Thus the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed i.e.

$$\text{Total charges} = Rs\left(b \times kW + c \times kWh\right)$$

Where, $b =$ Charges per kW of maximum demand
$c =$ Charge per kWh of energy consumed

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

Three-part tariff:

When the total charge to be made from the consumer is split into three parts viz. fixed charge, semi fixed charge and running charge, it is known as a three-part tariff i.e.,

$$\text{total charge} = Rs.(a + b \times kW + c \times kWh)$$

where a = fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labour cost of collecting revenues.

b = charge per kW of maximum demand,

c = charge per kWh of energy consumed.

The principal objection of this type of tariff is that the charges are split into three components. This type is applied to big consumers.

If we add fixed charge made during each billing period with two part tariff, then we get the three part tariff. Three part tariff is applicable to big consumers.

4. A consumer has a maximum demand of 200 kW at 40% load factor. If the tariff is Rs. 100/kW of maximum demand plus 10 paise/kWh, find the overall cost/kWh.

[WBUT 2014]

Answer:

Units consumed / year = Maximum demand × Load Factor × Hours in a year

= 200×(0.4)×8760 = 7,00,800 kWh

Annual charges = Annual maximum demand charges + Annual energy charges

= Rs. (100×200+0.1×700800) = Rs. 90,080

$$\text{Overall cost / kWh} = Rs.\frac{90,080}{7,00,800} = Re.0.1285 = 12.85 \text{ paise}$$

5. Discuss about the ABT tariff.

[WBUT 2014]

Answer: ***Refer to Question No. 1(a) of Long Answer type Questions.***

Long Answer Type Questions

1. a) What are Availability Base Tariff (ABT)? What is the advantage of ABT over normal bulk tariff?

[WBUT 2008]

Answer:

1st Part:

It is performance-based tariff for the supply of electricity by generators owned and controlled by the central government. It is also a new system of scheduling and dispatch, which requires both generators and beneficiaries to commit to day-ahead schedules.

It is a system of rewards and penalties seeking to enforce day ahead pre-committed schedules, though variations are permitted if notified one and one half hours in advance.

The order emphasizes prompt payment of dues. Non-payment of prescribed changes will be liable for appropriate action under sections 44 and 45 of the ERC Act.

It has three parts.

- A fixed charge (FC) payable every month by each beneficiary to the generator for making capacity available for use. The FC is not the same for each beneficiary. It varies with the share of a beneficiary in a generators capacity. The FC, payable by each beneficiary, will also vary with the level of availability achieved by a generator.
- In the case of thermal stations like those of NLC, where the fixed charge has not already been defined separately by GOI notification, it will comprise interest on loan, depreciation, O & M expenses, ROE, Income Tax and Interest on working capital.
- In the case of hydro stations it will be the residual cost after deducting the variable cost calculated as being 90% of the lowest variable cost of thermal stations in a region.
- An energy charge (defined as per the prevailing operational cost norms) per kWh of energy supplied as per a pre-committed schedule of supply drawn upon a daily basis.
- A charge Unscheduled Interchange (UI charge) for the supply and consumption of energy in variation from the pre-committed daily schedule. This charge varies nversely with the system frequency prevailing at the time of supply/consumption. Hence it reflects the marginal value of energy at the time of supply.

2nd Part:

Advantages of ABT over normal bulk tariff

- ABT brings about enhanced grid discipline
- Economically viable power with right pricing
- Promote competition and efficiency and also
- Encourage use of Merit Order Dispatch / Economic Dispatch in India.

b) How TOD tariff has helped the supplier of electricity to the industrial consumer? What are the schedules of time applicable for a day in TOD tariff? [WBUT 2008]

Answer:

The Energy and Resources Institute (TERI), along with the GoNCTD (Government of National Capital Territory of Delhi) initiated a programme called DEEP (Delhi Energy Efficiency Programme) with an objective to make Delhi an energy efficient city. An important part of this effort is to structure tariffs in a manner that would provide an incentive to shift consumption from peak to off-peak periods and to encourage use of more efficient appliances. The aim is to design and demonstrate the impact of ToD (time-of-day) pricing and use of energy efficient appliances on consumer and the utilities. For this purpose three areas have been selected for pilot demonstrations for implementation in select areas of the city.

The above task is being jointly undertaken along with the EE&REM (Energy Efficiency and Renewable Energy Management) Centre of Delhi Transco Ltd, a GoNCTD undertaking. Some of the phases of the programme include area identification, selection of DSM (Demand Side Management) measures based on cost-benefit analysis, sample survey to establish baseline parameters, preparation of implementation plan and monitoring and evaluation. These tasks are being accompanied by extensive awareness campaigns, education outreach programmes etc. The learning from this programme would provide successful cases to be replicated in other parts of the Delhi and elsewhere. One of the problems facing the electricity sector in India has been its growing demand-supply imbalance. Power demand has been growing rapidly. In the last decade (1995-96 to 2005-26), the city's demand grew at an average growth rate of around 6% annually. Delhi has already recorded a peak demand of 3900 MW during the summer, which is expected to rise even further.

Power requirement is met by generation capacity within Delhi, allocations from Central Generating Stations (CGS) and other banking and bilateral arrangements.

Overtime, there has been a consistent gap between energy requirement and availability and between peak demand and peak met in the city.

In India, residential consumers dominate the electricity consumption profile not only in terms of numbers but also in terms of load and consumption.

2. a) What is a tariff? Discuss and compare various tariffs commonly practiced by utilities. **[WBUT 2009]**

OR,

a) What are the objectives and requirements of tariff? **[WBUT 2014]**

OR,

What are the objectives and requirements of a power utility tariff system? **[WBUT 2015]**

b) Mention the different types of tariff. **[WBUT 2014]**

Answer:

1st Part:

The rate at which electrical energy is supplied to a consumer is known as tariff. The supply company has to ensure that the tariff is such that it not only recovers the total cost of producing electrical energy but also earns profit against the capital investment.

Tariff structures may be such as to influence the load curve and to improve the load factor.

The tariff must have the following objectives:

(a) Recovery cost of producing electrical energy at the power station
(b) Recovery of cost on the capital investment in transmission and distribution systems.
(c) Recovery of cost of operation and maintenance of supply of electrical energy i.e. metering equipment, billing etc.
(d) Reasonable profit against capital investment.

2nd Part:

Various types of tariff:

1. ***Simple tariff:*** When there is a fixed rate per unit of energy consumed, it is called a simple or uniform rate tariff.
2. ***Flat rate tariff:*** When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.
3. ***Block rate tariff:*** When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate tariff.
   For example. the first 30 units may be charged at the rate of 55 paise per unit, the next 25 units at the rate of 50 paisa per unit.
4. ***Two part tariff:*** When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part-tariff.
   In two-part-tariff, the total charge to be made from the consumer is split into two components viz. fixed charges and running charges. The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer. Thus the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed i.e
   Total charges $= Rs(b \times kW + c \times kWh)$
   where, $b =$ Charges per kW of maximum demand
   $c =$ Charge per kWh of energy consumed
   This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.
   Advantages
   (i) It is understood by the consumers,
   (ii) It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.
   Disadvantages
   (i) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.
   (ii) There is always error in assessing the maximum demand of the consumer.
5. ***Maximum demand tariff:*** It is similar to two-part with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer. This removes the objection of two-part tariff where the maximum demand is assumed merely on the basis of the ratable value. This type of tariff is mostly applied to big consumers. However, it is not suitable for a small consumer (e.g. residential consumer) as a separate maximum demand meter is required.

6. ***Power factor tariff:*** The tariff in which power factor of the consumer's load is taken into consideration is known as power factor tariff.
In an a.c system, power factor plays an important role. A low power factor increases the rating of station equipment and line losses. Therefore, a consumer having low power factor must be penalized. The following are the important types of power factor tariff:
   (i) ***kVA maximum demand tariff:*** it is a modified form of two-part tariff. In this case, the fixed charges are made on the basis of maximum demand in kVA and not in kW. As kVA is inversely proportional to power factor, therefore, a consumer having low power has to contribute more towards the fixed charges. This type of tariff has the advantage that it encourages the consumers to operate their applications and machinery at improved power factor.
   (ii) ***Sliding scale tariff:*** This also known as average power tariff. In this case, an average power factor say 0.8 lagging, is known as the reference. If the power factor of the consumer falls below this factor, suitable additional charges are made. On the other hand, if the power factor is above the reference, a discount is allowed to the consumer.
   (iii) ***kW and kVAR tariff:*** In this type, both active power (kW) and reactive power (kVAR) supplied are charged separately. A consumer having low power factor will draw more reactive power and hence shall have to pay more charges.

7. ***Three – part tariff:*** When the total charge to be made from the consumer is split into three parts viz. fixed charge, semi fixed charge and running charge, it is known as a three-part tariff i.e.,

$$\text{Total charge} = Rs.(a + b \times kW + c \times kWh)$$

where $a =$ fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labour cost of collecting revenues.

$b =$ charge per kW of maximum demand,

$c =$ charge per kWh of energy consumed.

The principal objection of this type of tariff is that the charges are split into three components. This type is applied to big consumers.

b) A small scale industry has a maximum demand of 50 kW and maintains a monthly load factor of 60%. A power utility offers the following alternative tariff:
i) Standing change of Rs. 30 per kW of maximum demand plus Rs. 1.20 per kWhr.
ii) First 500 units at Rs. 2.00 per unit, next 500 units at 1.50 per unit and additional energy at Rs. 1.10 per unit.
Which of the two tariffs is economical and what is the corresponding monthly bill?
[WBUT 2009]

Answer:

Unit consumed per month = Maximum demand × Load factor × Hours in a month

$= 50 \times 0.60 \times 720 = 21{,}600\,\text{kWh}$

1st case monthly charges = Rs.30 × 50 + Rs.1.20 × 21,600 = 1500 + 25920 = Rs.27,420

2nd case monthly charges $= 500 \times 2 + 500 \times 1.50 + 20{,}600 \times 1.10$

$= 1000 + 750 + 22{,}600 = \text{Rs.}24{,}410$

Second tariff is more economical.

3. Two systems of tariff are available for a factory working eight hours a day for 300 working days in a year.
a) High voltage supply at Rs. 75 per month per kVA of maximum demand plus Rs. 1.15 per kWh consumed.
b) Low voltage supply at Rs. 80 per month per kVA plus Rs. 1.43 per kWh consumed.
The factory has an average load of 400 kW at 0.8 power factor and a maximum demand of 500 kW at the same power factor. The cost of high voltage equipment is Rs. 900 per kVA of maximum demand and the losses can be taken as 4%. The interest and depreciation charges on high voltage equipment are 15%. Calculate the annual bill for both the system. **[WBUT 2010]**

Answer:

a) High voltage supply:

Maximum demand in $\text{kVA} = 500/0.8 = 625\,\text{kVA}$

As the losses in h.v. equipment are 4% therefore capacity of h.v. equipment $625/0.96\,\text{kVA} = 651.0416\,\text{kVA}$

Capital investment on h.v. equipment = Rs.900 × 651.0416 = Rs.585937.5

Annual interest and depreciation $= 585937.5 \times 0.15 = 87890.625$

Annual charge due to m ximum kVA demand = Rs.625×75×12= Rs.562500

$$\text{Unit consumed / year} = \frac{400 \times 0.8 \times 300}{0.96} = 1000000\,\text{kWh}$$

Annual charge due to kWh consumption = Rs.1.15×1000000= Rs.1150000

Total annual cost = Rs.(1150000+87890.625+562500) = Rs.1800390.625

b) Low voltage supply:

There is no loss of energy as no equipment is used:

Maximum demand in $\text{kVA} = 500/0.8 = 625\,\text{kVA}$

Annual charge due to maximum kVA demand=Rs.625×80×12=Rs.600000

Units consumed / year $= 400 \times 8 \times 300 = 960000\,\text{kWh}$

Annual charge due to kWh consumption=Rs.1.43×960000=Rs.1372800

Total annual cost $= \text{Rs.}(600000 + 1372800) = \text{Rs.}1972800$.

4. A factory to be set up is to have a fixed load of 760 kW at 0.8 pf. The electricity board offers to supply energy at the following alternate rates:

i) LV supply at Rs.32/kVA max demand/annum +10 paise/kWh

ii) HV supply at Rs.30/kVA max demand/annum +10 paise/kWh

The HV switchgear costs Rs.60/kVA and switchgear losses at full load amount to 5%. Interest, depreciation charges for the switchgear are 12% of the capital cost. If the factory is to work for 48 hours/week, determine the more economical tariff.

Answer: [WBUT 2012]

Maximum demand	$=\frac{760}{0.8}\ 950\,KVA$
Loss in switchgear	= 5%
Input demand	$=\frac{950}{.95}=1000\,KVA$
Cost in switchgear	= 60 × 1000 = Rs. 60,000

Annual charges on depreciation
= 0.12 × 60,000 = Rs. 7,200

Annual fixed charges due to maximum demand corresponding to tariff (b) = 30×1000
= Rs. 30,000

Annual running charges due to kWh consumed
= 1000 × 48 × 52 × 0.10 = 1,99,680

Total charges / annum = (1,99,680 + 30,000 + 7,200) = Rs. 2,36,880

Maximum demand corresponding to tariff (a) = 950 KVA

Annual fixed charges = 32 × 950 = Rs. 30,400

Annual running charges for kWh consumed
= 950 × .8 [illegible] 52 × 0.10 = Rs. 1,89,696

Total = (1,89,696 + 30,400) = 2,20,096

5. A factory has an average load of 400 kW at 0.8 p.f. and maximum demand of 500 kW at the same p.f. The factory is working for 8 hour a day for 300 working days in a year. Two system of tariff is offered

i) High voltage supply at Rs 75 per month per kVA of maximum demand plus Rs 1.15 per kWh consumed

ii) low voltage supply at Rs 80 per month per kVA of maximum demand plus Rs 1.43 per kWh consumed.

Cost of HV equipment is Rs 900 kVA, losses can be taken as 4% and interest and depreciation of the HV equipment is 15%. Calculate the annual expenditure for both the systems to find out the cheaper tariff. [WBUT 2014]

Answer:

i) High voltage supply

Maximum demand in kVA $= \dfrac{500}{0.8} = 625\text{kVA}$

As the losses in h.v equipment are 4% therefore capacity of h.v equipment

$$= \frac{625}{0.96} = 651.041\text{kVA}$$

Capital investment on h.v equipment = Rs. 900 ×651.041
= Rs. 585,936.9

Annual interest and depreciation = Rs. 585,936.9 × 0.15
= Rs. 87,890.535

Annual charge due to maximum kVA demand
= Rs. 651.041 × 75 × 12
= Rs. 585,936.9

Units consumed / year $= \dfrac{400 \times 8 \times 300}{0.96} = 1,000,000\text{kWh}$

Annual charge due to kWh consumption $= 0.115 \times 1,000,000 = 115,000$

Total annual cost $= \text{Rs}(87,890.535 + 585,936.9 + 115,000) = 788,827.435$

ii) Low voltage supply

There is no loss of energy as no equipment is used.

Maximum demand in kVA $= \dfrac{500}{0.8} = 625\text{kVA}$

Annual charge due to maximum KVA demand = Rs. 625 × 80 × 12
= Rs. 600,000

Unit consumed / year = 400 × 8 × 300 = 960,000 kWh

Annual charge due to kWh consumption
= Rs. 0.143 × 960,000 = Rs. 137,280

Difference in the annual cost of two systems
= Rs. (788.827.435 – 737,280) = Rs. 51,547.435

Hence low voltage supply is cheaper than high voltage supply by Rs. 51, 547.435.
Therefore tariff (a) is economical.

6. a) Briefly discuss TOD tariff and ABT.
b) The following data are related to a power generating station
(i) Max demand 50 MW
(ii) Capital Cost Rs. 150 × 10^6
(iii) Taxes, wages and salaries – Rs. 6 × 10^6
(iv) Interest and depreciation – 10%
(v) Annual fuel cost is Rs. 8 × 10^6 when annual Load Factor is 50% and the fuel cost is Rs. 9 × 10^6 when the Load Factor is 60%.
Compare the generation cost per unit with improved Load Factor. [WBUT 2015]

Answer:

a) *Refer to Question No. 7(b) of Long Answer Type Questions.*

b) Maximum demand 50 MW

Capital cost $=₹150\times10^6$

Taxes, wages and salaries $=₹6\times10^6$

Interest and depreciation $=10\%$

Annual fuel cost $=₹8\times10^6$

Load factor is 50%

Units generated / annum = maximum demand × load factor × hours in a year

$$=50\times0.5\times8760\times10^3\,\text{kWh}$$
$$=219\times10^3\times10^3\,\text{kWh}$$
$$=219\times10^6\,\text{kWh}$$

Annual fixed charges

Annual interest and depreciation $=10\%$ of capital cost $=10\%\times150\times10^6=₹15\times10^6$

Annual running charges

Total annual running charges = Annual cost of fuel + Taxes & wages and salaries

$$=8\times10^6+6\times10^6$$
$$=₹14\times10^6$$

When the load factor is 60%

Units generated / annum = maximum demand × load factor × hours in a year

$$=50\times0.6\times8760\times10^3\,\text{kWh}$$
$$=30\times8760\times10^3\,\text{kWh}$$
$$=262800\times10^3\,\text{kWh}$$
$$=262.8\times10^6\,\text{kWh}$$

Annual fixed charges

Annual interest and depreciation $= 10\%$ of capital cost $= 10\% \times 150 \times 10^6 =$ ₹15×10^6

Annual running charges

Total annual running charges = Annual cost of fuel + Taxes wages & salaries

$= 9 \times 10^6 + 6 \times 10^6 =$ ₹15×10^6

7. Write short notes on the following: **[WBUT 2009]**

a) Cross-subsidization **[WBUT 2009, 2010, 2011, 2012, 2013]**

b) Availability based tariff **[WBUT 2010, 2011]**

c) Pool tariff in transmission system **[WBUT 2013]**

d) Types of consumers and their tariffs **[WBUT 2017]**

e) Availability tariff and Availability Based tariff

Answer:

a) Cross-subsidization:

Cross subsidization is the practice of charging higher prices to one group of consumers in order to subsidize lower prices for another group. State trading enterprises with monopoly control over marketing agricultural exports are sometimes alleged to cross subsidize, but lack of transparency in their operations makes it difficult if not impossible to determine if that is the case.

In the ICT sector, it is common for firms to supply a number of services. Network operators generally sell services in both competitive and non-competitive markets.

A firm with market power in one area may charge a high price for non-competitive services and use the proceeds to subsidize low prices for competitive services.

If the firm breaks even overall, a given service receives a subsidy if it does not generate sufficient revenue to cover its total service long run incremental cost (TSLRIC).

For example take an incumbent firm with market power in the provision of long distance calls. The incumbent could use its market power to charge high prices to long distance customers, and use the excess revenue to support low prices for internet access and undercut competing internet access providers.

By cross-subsidizing competitive services, a telecommunications firm can:

- Ensure that it covers its overall costs, including fixed costs, and
- Strengthen the firm's competitive position where it matters most, namely in the supply of its more competitive products.

Cross-subsidization will only maximize the firm's profitability if the resulting gain in market share in the competitive market outweighs the loss in revenue from the reduced price. This is because the firm could still increase prices for the non-competitive service, even if it did not subsidize the competitive service. So its next best option would be to increase the non-competitive price and keep the resulting revenue.

b) Availability based tariff:

This tariff scheme, applicable to central sector generators and power utilities, has been approved by central regulatory commission. It is based on the rotational of correcting the grid frequency to bring it within the permissible band. There is a provision for fixed charge when power is available (peak and non-peak separately) and a separate energy charge when power is delivered. State power utilities need to pay a fixed price for the generation capacity allocated to them a day earlier irrespective of their consumption. However, variable cost will be paid only if energy is drawn. The tariff is linked to unscheduled interchange (UI) charges will be paid or received under four conditions.

i) When a generator generates more than the schedule, increasing the system frequency.

ii) When the beneficiary state overdraws power, decreasing the frequency.

iii) When the beneficiary underdraws power, increasing frequency.

The UI charge accruse to the party adversely affect on account of grid indiscipline. In all the instances, there is sufficient incentive for both the generator and the beneficiary states to maintained system frequency close to 50 Hz. UI charge also offers greater incentive to hydropower capacity in the system. On the supply side, there is a strict penalty for wrongly declaring availability. If the power utilities are saddled with surplus power, they will be forced to look for buyers. This will encourage power trading and better rates for the consumer.

c) Pool tariff in transmission system:

Electricity pool is not a physical location. It is a set of rules and procedures managed by the load dispatch centre. The power pool operates the wholesale market under mandatory trading arrangements, bidding and settlement procedures. It is not possible to distinguish which generator produces the electricity consumed by a particular consumer. Hence, this is the concept of a central pool of generation to supply total consumer demand. Typically, pool rules require generating and supply companies to submit a day-ahead bid package and demand reservations for each half-hour period during the next seven days. The pool administration uses this to prepare a seven-day generating unit commitment plan, ranking bids in the order of merit to determine the system marginal price at which offers match demand. The pool price paid to generating companies generally comprise:

1. The system marginal cost
2. Start up and no-load adjustment and
3. Ancillary services payment, back start capability and spinning reserve.

The pool price, paid by the supplier, needs to be hedged or capped. It generally comprises

1. Price paid to generating companies
2. An adjustment for transmission losses
3. Pool administration charges and
4. Uplift (e.g., for constrained on units).

x) There is some disincentive for non-performance of dispatch instruction.
xi) There is an explicit clearing price that is visible to participants.
xii) Demand is generally drawn from the grid without contract rather than having to make a commitment in advance.

d) Types of consumers and their tariffs:
There are different types of consumers who consume electricity for different purposes. They can be classified into four subgroups:

1. Domestic consumers use electricity for domestic purpose.
2. Agricultural consumers use electricity of agricultural purposes such as irrigation, trashing, etc.
3. Industrial consumers use electricity for industrial production such as heavy industries, manufacturing companies, etc.
4. Commercial consumers are electricity for commercial purposes such as municipalities, hospitals, etc.

For tariff part: ***Refer to Question No. 2(a) of Long Answer Type Questions.***

e) Availability tariff and Availability Based tariff:
Availability tariff: With a view to promote overall economic operation of the power sector and to achieve improvement in operational parameter GOI felt that the existing tariff structure in power sector needs to be rationalized. Accordingly GOI proposed, for sale of electricity by generating companies to the beneficiaries, a three part tariff structure in viz. Capacity charge, Energy charge, Unscheduled interchanges (UI)

$$\text{TOTAL PAYMENT} = (a) + (b) \pm (c)$$

where,

(a) = CAPACITY CHARGE
(b) = ENERGY CHARGE
(c) = ADJUSTMENT FOR DEVIATIONS (UI CHARGE)

(a) = a function of Ex-bus MW availability of power plant for the day declared before the day starts × SEB's % share
(b) = MWh for the day as per ex-bus drawl schedule for the SEB finalized before the day starts × Energy charge rate
(c) = Σ(Actual energy interchange in a 15 min time block – scheduled energy interchange for the time block) × UI rate for the time block

Advantages:

- Improved frequency and voltage
- Economic dispatch
- Autonomy to the utility

- Incentive for high plant availability, but no incentive to over generation during off-peak hours
- Technically and commercially right
- Immediate solution for IPPs and Captives
- True free market; market forces decide the pool price
- Pool price known on-line
- Total transparency; No regulator required
- Simple practicable; Meters already developed and installed

Availability Based tariff:
Refer to Question No. 7(b) of Long Answer Type Questions.

UNIT COMMITMENT

Multiple Choice Type Questions

1. Five 200 MW plants are connected to a grid having a peak demand of 1000 VA. If the generators are operating at a lagging *pf* of 0.85, the spinning reserve is [WBUT 2011]

a) 0 MW b) 50 MW c) 150 MW d) 250 MW

Answer: (c)

2. A storage type power plant is essential for betterment of a grid that suffers from [WBUT 2011]

a) very low peak demand
b) very high peak demand but high load factor
c) very high peak demand but low load factor
d) very low peak demand but high load factor

Answer: (b)

3. Unit commitment is [WBUT 2014]

a) a must before we solve economic operation problem
b) a short term problem of maintenance scheduling
c) more meaningful for thermal units
d) all of these

Answer: (d)

4. For long term hydrothermal problem [WBUT 2014]

a) A head variation can be ignored
b) transmission loss cannot be ignored
c) unit commitment should be taken into account
d) all of these

Answer: (d)

Short Answer Type Questions

1. What do you mean by unit commitment problem? Discuss the Importance of 'Spinning Reserve' as related to unit commitment problem. [WBUT 2008]

OR,

Discuss briefly about unit commitment and spinning reserve. [WBUT 2009]

Answer:

Unit Commitment (UC)

It is not economical to run all the units available all the time. To determine the nits of a plant that should operate for a particular load is the problem of unit commitment (UC). This problem is of importance for thermal plants as for other types of generation such as hydro; their operating cost and start-up times are negligible so that their on-off status is not important.

A simple but sub-optimal approach to the problem is to impose priority ordering; wherein the most efficient unit is loaded first to be followed by the less efficient units in order as the load increases.

A straightforward but highly time-consuming way of finding the most economical combination of units to meet a particular load demand, is to try all possible combinations of units that can supply this load; to divide the load optimally among the units of each combination by use of the coordination equations, so as to find the most economical operating cost of the combination; then, to determine the combination, which has the least operating cost among all these. Considerable computational saving can be achieved by using branch and bound or a dynamic programming method for comparing the economics of combinations as certain combinations need not be tried at all.

Spinning Reserve

The liberalisation of the electricity supply industry and the introduction of competitive markets for electrical energy have required the definition of ancillary services. The purpose of these ancillary services is to help maintain the security and the quality of the supply of electricity. In particular, control of the frequency requires that a certain amount of active power be kept in reserve to be able to re-establish the balance between load and generation at all times. In general, reserve can thus be defined as the amount of generation capacity that can be used to produce active power over a given period of time and which has not yet been committed to the production of energy during this period. In practice, different types of reserve services are required to respond to different types of events over different time frames. In particular, while the term "spinning reserve" is widely used in literature, this service can be defined in different ways. This may lead to some confusion.

To help reduce this confusion, this document proposes a definition of spinning reserve. It then provides the amount of spinning reserve required in several jurisdictions according to this definition.

2. Discuss the various constraints related to unit commitment problem.

[WBUT 2010]

Answer:

Constraints in Unit Commitment:

1. Thermal Unit Constraints: Thermal units require a trained lot of crew to operate the units. A thermal power plant undergoes a gradual temperature change and this needs some time intervals to bring the unit on line. As a result, the following constraints arise:

i. **Minimum up time:** It states that there should be a minimum time of operation when the unit runs. It is not desired to turn off immediately after it is brought on-line.

ii. **Minimum down time:** Once the thermal unit is decommissioned, there would be a minimum time before it can be recommissioned.

iii. **Crew constraints:** If a plant consists of more than one unit, both the units cannot be turned on simultaneously as there is usually not enough staff to attend both the units.

iv. **Operational constraints:** In operation of thermal units, a certain amount of energy must be consumed to bring the unit on-line. This energy does not result in any effective power generation and in unit commitment problem, it has been treated as Start up cost.

2. Spinning Reserve: Spinning reserve is defined as follows:

Spinning reserve $= \sum P_i - P_{Load} - P_i$, at any interval of time.

Spinning reserve must be maintained so that the loss of one or more units does not cause unacceptable decline in frequency, i.e., there must be sufficient reserve such that if one unit is lost, other unit can make up for the loss in a specified time period.

3. Hydro-constraints: As we pointed out that unit commitment problem is of much importance for the scheduling of thermal units it is not the meaning of unit commitment that cannot be completely separated from the scheduling of a hydro-unit.
The operation of hydro-thermal system having both hydro and thermal plants, however for more complex as hydro-plants have negligible operation costs, but are required to operate. Under constraints of water available for hydro-generation in a given period of time.
The problem of minimizing the operating cost of a hydrothermal system can be viewed as one of minimizing the fuel cost of thermal plants. Under the constraint of water availability for hydro-generation over a given period of operation.

4. Fuel Constraints: A system in which some units have limited fuel on else have constraint that require them to burn a specified amount of fuel in a given time presents a most challenging unit commitment problem.

3. What are the importance of unit commitments in a grid? Discuss the basis of economic load scheduling of power plants in a connected grid. **[WBUT 2011]**

Answer:

1st Part:

Unit commitment involves determining the start up and shut down (ON/OFF) schedules of generating units to be used to meet forecasted demand over a short-term (24 – 168 hours) period. The objective is to minimize total production cost to meet system demand and reserve requirements while observing a large set of operating constraints.
Optimum allocation (commitment) of generators (Units) at each generating stations at various station load levels (including sharing among committed generators) are the unit commitment problems and optimum allocation of generation to each station for various system load levels may be called as load scheduling problem.

2nd Part:

The factors that govern the economic operation of hydrothermal plants are incremental fuel costs of steam plants, hydro generation as a function of head and discharge, water intake losses, incremental transmission losses. To find the schedules for hydrothermal plants for time duration during the operating period, it is presumed that:

i) a desired amount of water is used over the given period of time producing the maximum amount of energy and
ii) the fuel input and hence the generation cost of the thermal units will be minimum.

With the above end in view, there will be two sets of co-ordination equations which will be solved for optimum scheduling – one set for the thermal units and the other set for the hydro units.

Let us consider that out of n-controllable generators m are steam plants and the remaining $(n-m)$ are hydro generator units. Then the co-ordination equations are·

$$\frac{dc_i}{dP_{Si}} + \lambda \frac{\delta P_L}{\delta P_{Si}} - \lambda = 0 \qquad i = 1, 2, \ldots\ldots, m \qquad \ldots.(1)$$

$$R_j \frac{dW_j}{dP_{Hj}} + \lambda \frac{\delta P_L}{\delta P_{Hj}} - \lambda = 0 \qquad j = m+1, m+2, \ldots., n \qquad \ldots.(2)$$

Here

P_{Si} = output in MW of the *i*th steam unit

P_{Hj} = output in MW of *j*th hydroelectric unit.

$\frac{\delta P_L}{\delta P_{Si}}$ = Incremental transmission loss associated with the *i*th steam unit.

$\frac{\delta P_L}{\delta P_{Hj}}$ = Incremental transmission loss associated with the *j*th hydropower unit.

$\frac{d c_i}{dP_{Si}}$ = Incremental cost for the *i*th thermal unit in Rs/M Wh.

$\frac{dW_j}{dP_{Hj}}$ = Incremental water rate of *j*th hydro unit in $m^3 / MW - \text{sec}$.

R_j = Constant which converts the incremental water rate of the *j*th hydro plant into an incremental cost. It has a unit of Rs per hour/ m^3 per sec.

If the transmission losses are neglected, Eqns. (1) and (2) become.

$$\frac{dc_i}{dP_{Si}} - \lambda = 0$$

$$R_j \frac{dW_j}{dP_{Hj}} - \lambda = 0$$

The incremental cost $\left(\frac{dc_i}{dP_{Si}}\right)$ for the thermal units and incremental water rate $\left(\frac{dW_j}{dP_{Hj}}\right)$ for the hydroelectric units are both non-linear but for simplified computation, both of these can be represented by linear equations.

4. What is spinning reserve? Why is it important to keep a spinning reserve in the grid? What is the downside of keeping a high spinning reserve? [WBUT 2011]

Answer:

1st Part:

Spinning reserve is the reserve generating capacity which is connected to the bus and ready to take load.

2nd Part:

The total spinning-reserve from all the generating units must be greater than or equal to the spinning-reserve requirement of the system. This can be either a fixed requirement in MegaWatts (MW) or a specified percentage of the largest on-load output of any generating unit. Again, the user can choose how strongly to enforce this constraint. The purpose of the spinning-reserve requirement is to ensure that there is enough spare capacity from the units on-load or 'spinning' at any time to cover the accidental loss of any individual generating unit, or to satisfy demands that are higher than their forecast values. Precisely it may be told that spinning-reserve requirement of the system will indicate how much spinning-reserve a particular unit supplies can be customised to the user's requirements. It is possible to impose several different spinning reserve requirements simultaneously, with each reserve requirement being over a different time-scale.

3rd Part:

The downside of keeping a spinning-reserve in the grid will ensure that there are sufficient generating units running above their Minimum Stable Generation levels at all times to allow the total output to be quickly reduced by a specified number of MW. (There may be a variety of reasons for such a requirement – for example to cover the possibility of demands being lower than their forecast values.)

5. Discuss the various types of Unit Commitment method. [WBUT 2012, 2015]

Answer:

The major available method for unit commitment can be grouped as follows:

- Deterministic techniques
- Meta-heuristic techniques
- Hydrothermal coordination

Deterministic approach includes priority list, inter/mixed-integer programming method, dynamic and linear programming, branch-and-bound method, decomposition technique, and colony system and Lagrangian relaxation.

Meta-heuristic approaches include expert system, fuzzy logic, artificial neural networks, genetic algorithm, evolutionary programming, simulated annealing, tabu search and memetic algorithm (hybrid technique).
Large scale UCP can also be solved using "equivalencing" like method comprising three steps: aggregation, solution and disaggregation.

Hydrothermal Coordination
The problem of short-term hydro scheduling is to determine the optimum hourly generation production of hydro units, water flows through generating stations, reservoir releases and storage levels. The objective is to maximize the energy production from hydro resources.
In a hydrothermal system, short-term hydro scheduling is to be done as part of hydrothermal coordination. The hydrothermal coordination problem requires the solution for the thermal unit commitments and generation dispatch as well as the hydro schedules. The objective here is to minimize the thermal production cost subject to meeting the load and other generation requirements. Most of the methods for solving the hydrothermal coordination problem are based on decomposition methods involving the unit commitment and hydro scheduling sub problems. The coordination procedure depends on the decomposition method used like heuristic decomposition, combined Lagrangian relaxation and network flow programming, genetic algorithm etc.

6. Develop a simple Computational method in economic load scheduling. **[WBUT 2012]**

Answer:
Plant Scheduling:
The total cost of production of electric energy in an n-machine controllable system will be given by:

$$C=\sum_{i=1}^{n}C_i=\sum_{i=1}^{n}f_i(P_G)\text{Rs/hour}$$
$$=f_1(P_{G1})+f_2(P_{G2})+...+f_n(P_{Gn})\text{Rs/hour} \quad \text{.... (1)}$$

Our problem is to select n variables $P_{G1}(i=1,2,....,n)$, so that C is minimized provided certain equality and inequality constraints are simultaneously satisfied. As we have already observed that the reactive power does not affect fuel cost, there will be only one equality constraint to be satisfied. This is given by:

$\sum_{i=1}^{n}P_{Gi}$ = total power demand on the system – total power supplied by base load units.

= Power demanded from the controllable group of generators

$= P_D$

i.e., $$\sum_{i=1}^{n}P_{Gi}-P_D=0 \quad \text{.... (2)}$$

i.e., $$g(P_{G1},P_{G2},.....P_{Gn})=0 \quad \text{.... (3)}$$

where, g is a function.

Along with this equality constraint, n number of inequality constraints need to be satisfied. These are:

$$P_{Gi\min} < P_{Gi} < P_{Gi\max}, \qquad i = 1,2,....n \qquad .... (4)$$

Referring back to Eqn. (1) we observe that we are to optimize C. a function of n variables, by independently selecting $(n-1)$ variables, the other variable gets automatically fixed by the equality constraint Eqn. (2).

The mathematical procedure to find constrained optimum i.e. optimization technique is given below for ready reference.

Let us consider a scalar cost function given by

$$C = f(x_1, x_2 ... x_n) \qquad .... (5)$$

$x_1, x_2 ..... x_n$ are n independent variables. The problem is to find out the maximum or minimum value of C.

The total differential dc may be expressed as:

$$dc = \frac{\delta f}{\delta x_1} dx_1 + \frac{\delta f}{\delta x_2} dx_2 + ... + \frac{\delta f}{\delta x_n} dx_n \qquad .... (6)$$

For an optimal value of C, the total differential must be zero. This condition demands that all the partial derivatives in $x_i (i = 1, 2, ...n)$ must be zero because the variables are independent of each other and there is no constraint in their variation. So, the condition for optimization is: -

$$\frac{\delta f}{\delta x_1} = 0 \text{ for } i = 1,\ 2,\ ....n \qquad .... (7)$$

If the problem is now modified by stating that C is to be optimized subject to the condition (constraint) that the equation below be satisfied.

$$g(x_1, x_2 ...... x_n) = 0 \qquad .... (8)$$

The above equation is an equality constrain equation. On partial differentiation of the above equation, it is obtained

$$\frac{\delta g}{\delta x_1} dx_1 + \frac{\delta g}{\delta x_2} dx_2 + ... + \frac{\delta g}{\delta x_n} dx_n = 0 \qquad .... (9)$$

With the constraint of this equation to be satisfied along with the Eqn. (6), there is no liberty of choosing all the n differentials $dx_1, ..., dx_n$ independently. As such one degree of freedom is lost in the sense that only $(n-1)$ of the differential may be chosen independently and the remaining one is fixed by Eqn. (9). If both sides of Eqn. (9) is multiplied by λ and then subtracted from Eqn. (6), the result is: -

$$dc = \left(\frac{\delta f}{\delta x_1} - \lambda \frac{\delta g}{\delta x_1}\right) dx_1 + \left(\frac{\delta f}{\delta x_2} \lambda \frac{\delta g}{\delta x_2}\right) dx_2 + ... + \left(\frac{\delta f}{\delta x_n} - \lambda \frac{\delta g}{\delta x_n}\right) dx_n \qquad .... (10)$$

If dc has to be zero, then all the n terms within parentheses are to be zero. The optimum conditions are then: -

$$\frac{\delta f}{\delta x_i} - \lambda \frac{\delta g}{\delta x_i} = 0 \text{ for } i = 1, 2, \ldots n \quad \ldots (11)$$

These n equations and the constraint Eqn. (8) will yield $(n + 1)$ variables i.e. $x_1, x_2 \ldots x_n$ and λ.

So definition of a lag-range cost function f^* now be given by

$$f^* = f - \lambda g \quad \ldots (12)$$

Then the n Eqn. (11) can be written as

$$\frac{\delta f^*}{\delta x_i} = \frac{\delta f}{\delta x_i} - \lambda \frac{\delta g}{\delta x_i} = \partial \text{ for } i = 1, 2, \ldots n \quad \ldots (13)$$

It can therefore be construed that the problem of optimizing the function f with the equality constraint $g = 0$ is tantamount to obtain the unconstrained optimization of f^*.

The constant λ is called the lag-range multiplier.

Now reverting to the problem, which is to be optimized

$$C = f(P_{G1}, P_{G2}, \ldots, P_{Gn}) \quad \ldots (14)$$

with the equality constraint

$g(P_{G1}, P_{G2}, P_{G2}, \ldots P_{Gn}) = 0$ being satisfied

The augmented cost function

$$f^* = f - \lambda g \quad \ldots (15)$$

where, λ is the Lag-range multiplier.

Now,

$$\frac{\delta f^*}{\delta P_{Gi}} = \frac{\delta f}{\delta P_{Gi}} - \lambda \frac{\delta g}{\delta P_{Gi}} = 0 \text{ (for } i = 1, 2, \ldots, n) \quad \ldots (16)$$

$$\frac{\delta f}{\delta P_{Gi}} = \frac{\delta}{\delta P_{Gi}} \left[f_1(P_{G1}) + f_2(P_{G2}) + \ldots + f_n(P_{Gi}) + \ldots + f_n(P_{Gi}) \right]$$

$$= \frac{\delta f_i(P_{Gi})}{\delta P_{Gi}} = \frac{\delta C_i}{\delta P_{Gi}} = (IC)_i \quad \ldots (17)$$

where, $(IC)_i$ is the incremental cost of the ith generator.

Also $$\frac{\delta g}{\delta P_{Gi}} = \frac{\delta}{\delta P_{Gi}} \left[P_{G1} + P_{G2} + \ldots + P_{Gi} + \ldots + P_{Gn} - P_D \right] = 1 \quad \ldots (18)$$

So, from Eqn. (16)

$$(IC)_i = \lambda \quad i = 1, 2, \ldots n$$

i.e., $$(IC)_1 = (IC)_2 = (IC)_n = \lambda \quad \ldots (19)$$

The optimum condition, therefore, is obtained when we make sure that all the individual controllable generators operate at equal incremental production costs and at the same time, the generated powers add up to the power demanded from the controllable group. The condition can be graphically depicted on the incremental cost curve as shown in Fig. 1. The optimum condition to be satisfied for a certain IC value λ, such that $P_{G1} + P_{G2} + ... + P_{Gi} + ... + P_{Gn} = P_D$.

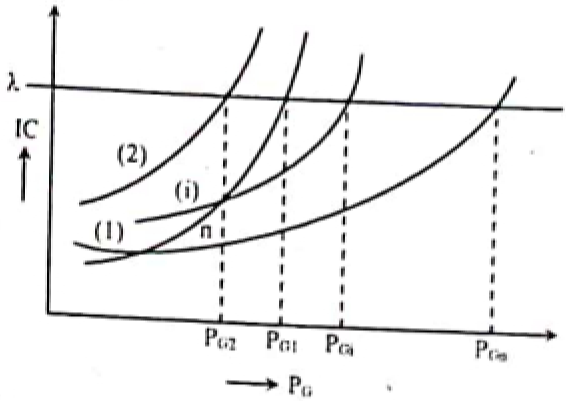


Fig: 1 Graphical depiction of optimum condition incremental curve

P_{Gi} is the real power at the point where the horizontal line drawn form the IC axis at a distance λ from the origin, cuts the ith incremental curve.

We have not yet taken any cognizance to the n inequality constraints of Eqn. (4). The operating strategy should be that if one or several generators reach their limits, these will be operated at those limits and the rest of the generators should satisfy equal incremental cost rule.

If we use a quadratic cost function given by Eqn. (1) the condition for optimum scheduling or optimum dispatch is: -

$$\beta + 2\gamma_i,\ P_{Gi} = \lambda \quad \text{for } i = 1, 2, ...n \qquad .... (20)$$

So,

$$P_{Gi} = \frac{\lambda - \beta_i}{2\gamma_i} \qquad .... (21)$$

From the equality constraint of Eqn. (2)

$$\sum_{i=1}^{n} P_{Gi} = P_D$$

or,

$$\sum_{i=1}^{n} \frac{\lambda - \beta_i}{2\gamma_i} = P_D$$

or,

$$\lambda = \frac{P_D + \sum_{i=1}^{n} \frac{\beta_i}{2\gamma_i}}{\sum_{i=1}^{n} \frac{1}{2\gamma_i}} \qquad .... (22)$$

The value of λ obtained in Eqn. (22) is substituted in Eqn. (21) to obtain the scheduling of generation.

7. Discuss the importance of spinning reserve requirements in the solution of unit commitment problem. **[WBUT 2013]**

Answer:

Spinning reserve is the term used to describe the total amount of generation available from all synchronized units on the system minus the present load and losses being supplied. Here, the synchronized units on the system may be named units spinning on the system.

$$\text{Spinning reserve} = \begin{bmatrix} \text{Total generation output of all} \\ \text{synchronized units at} \\ \text{a particular time} \end{bmatrix} - \begin{bmatrix} \text{Load at that time} + \\ \text{Losses at that time} \end{bmatrix}$$

Let $P_{G_{sr}}$ be the spinning reserve, P_{G_i} the power generation of the i^{th} synchronized unit, P_D the total load on the system and P_L the total loss of the system:

$$\therefore \quad P_{G_{sr}} = \sum_{i=1}^{n} P_{G_i} - (P_D + P_L)$$

The spinning reserve must be maintained so that the failure of one or more units does not cause too far a drop in system frequency. Simply, if one unit fails, there must be an ample reserve on the other units to make up for the loss in a specified time period.

The spinning reserve must be a given a percentage of forecasted peak load demand, or it must be capable of taking up the loss of the most heavily loaded unit in a given period of time.

It can also be calculated as a function of the probability of not having sufficient generation to meet the load.

The reserves must be properly allocated among fast-responding units and slow-responding units such that this allows the automatic generation control system to restore frequency and quickly interchange the time of outage of a generating unit.

- Beyond the spinning reserve, the UC problem may consider various classes of 'scheduled reserves' or offline reserves. These include quick-start diesel or gas-turbine units as well as most hydro-units and pumped storage hydro-units that can be brought online, synchronized and brought upto maximum capacity quickly. As such, these units can be counted in the overall reserve assessment as long as their time to come up to maximum capacity is taken into consideration.
- Reserves should be spread well around the entire power system to avoid transmission system limitations (often called 'bottling' of reserves) and to allow different parts of the system to run as 'islands', should they become electrically disconnected.

8. What is unit commitment? **[WBUT 2013, 2014]**

Compare an optimal unit commitment problem with an economical load dispatch problem. **[WBUT 2013]**

Answer:

1st Part:

In operational scheduling of electric power generation, the most important problems is the unit commitment. It involves determining the start up and shut down (ON/OFF) schedules of generating units to be used to meet forecasted demand over a short-term (24 – 168 hours) period. The aim is to minimize total production cost to meet system demand and reserve requirements while observing a large set of operating constraints. In fact it is a complex mathematical optimization problem having both integer and continuous variables. Prior to solve the economic dispatch problem, unit commitment problem should be solved because only those units which were allocated to generating duties by the unit commitment solution can be considered for power generation.

2nd Part:

Economic load dispatch economically distributes the actual system.
Load as it rises to the various units already online. But the UC problem plans for the best set of units to be available to supply the predicted or forecast load of the system over future time periods.

9. Explain Thermal Unit constraints with emphases to Minimum Up Time, Minimum Down Time and Crew Constraints. What is 'cooling' and 'Banking' of Boilers? [WBUT 2017]

Answer:

1st Part: *Refer to Question No. 2 of Short Answer Type Questions.*

2nd part:

- **Cooling:** Open evaporative cooling systems are an essential part of most commercial HVAC or industrial processes, however these well aerated water systems essentially scrub dust and organic material from the cooling air stream, setting up a perfect environment for corrosion, fouling, scaling, microbial activity and bio-film formation. Accordingly a good water treatment program is not only essential for regulatory compliance, but also to extend asset longevity, optimize plant efficiency, minimize operating costs and mitigate pathogen related public health risks.
- **Banking of boilers:** Boiler Bank Tubes are Bent to Shape Tubes or Steam Generating Tubes where Water is converted to Steam. Boiler Bank Tubes carry a mixture of water and steam. Fabricated from Tubes in various sizes and shapes, bending of these tubes is generally to larger Radius hence they need some Tube Bending Expertise to avoid wrinkles, surface cracking, irregularities, ensuring long life of tube resulting in smooth and efficient operation of the Boiler.

Long Answer Type Questions

1. a) Discuss the priority order approach for the solution of the unit commitment problem. **[WBUT 2008]**

Answer:

It is not economical to run all the units available all the time. To determine the units of a plant that should operate for a particular load is the problem of unit-commitment. This problem is of importance for thermal plants as for other types of generation such as hydro, the operating cost and start uptime are negligible so that their On-Off status is not important. A simple but sub-optimal approach to the problem is to impose priority ordering, where in the most efficient unit is loaded first to be followed by the less efficient units in order as the load increases. A straight-forward but highly time consuming way of finding the most economical combination of units to meet a particular load demand, is to try all possible combinations of units that can supply the load, to divide the load optimally among the units of each combination by use of the co-ordination equations so as to find the most economical operating cost of the combination. Then to determine the combination which has the least operating cost among all these.

b) Explain the shut down algorithm to be followed while using the merit order approach. **[WBUT 2008]**

Answer:

When this method is applied to economic scheduling of power plants, it assumes that the incremental cost of all the generators is constant over the full range or over successive discrete portions within the range.

The economical way of meeting a load will be to load the machines in order of highest incremental efficiency. This method, therefore, needs forming of a table which could be looked into, for any load condition and does not need any complicated calculations. Normally the incremental cost curves are not constant, therefore this method is not used.

2. a) Explain the difference between the Unit Commitment and the Economic Dispatch problem. **[WBUT 2009]**

Answer:

The optimal system operation, in general, involved the consideration of economy of operation, system security, emissions at certain fossil-fuel plants, optimal releases of water at hydro generation, etc. All these considerations may make for conflicting requirements and usually a compromise has to be made for optimal system operation. We consider the economy of operation only, also called the economic dispatch problem.

The main aim in the economic dispatch problem is to minimize the total cost of generating real power (production cost) at various stations while satisfying the loads and the losses in the transmission links. For simplicity we consider the presence of thermal plants only in the beginning. We will consider the presence of hydro plants, which operate in conjunction with thermal plants. While there is negligible operating cost at a hydro plant, there is a limitation of availability of water over a period of time, which must be used to save maximum fuel at the thermal plants.

The specified variables are real and reactive powers at PQ buses, real powers and voltage magnitudes at PV buses and voltage magnitude and angle at the slack bus. The additional variables to be specified for load flow solution are the tap settings of regulating transformers. If the specified variables are allowed to vary in a region constrained by practical considerations (upper and lower limits on active and reactive generations bus voltage limits and range of transformer tap settings), there results an infinite number of load flow solutions, each pertaining to one set of values of specified variables. The 'best' choice in some sense of the values of specified variables leads to the 'best' load flow solution. Economy of operation is naturally predominant in determining allocation of generation to each station for various system load levels. The first problem in power system parlance is called the 'unit commitment' (UC) problem and the second is called the 'load scheduling' (LS) problem. One must first solve the UC problem before proceeding with the LS problem.

b) What are the various costs to be considered in the Unit Commitment problem?

Answer: **[WBUT 2009]**

The various costs that are considered in the unit commitment problem include the loading of generating equipment particularly of thermal plants, where unit efficiencies and fuel costs are major factors in the cost of power production. The proper operation of hydro-plants can also affect generation cost where at times of the year the availability of water is high and at other times must be conserved. Purchase power availability, co[illegible] and the scheduling of overhaul of generating unit all affect operating cost.

c) Why are minimum ON time and minimum OFF time constraints important?

Answer: **[WBUT 2009]**

The minimum ON time and minimum OFF time constraints are important to meet forecasted demand over a short-term (24 – 168 hours) period. The objective is to minimize total production cost to meet system demand and reserve requirements while observing a large set of operating constraints.

d) Discuss the basic principle of the dynamic programming method in solving the Unit Commitment Problem. **[WBUT 2009]**

Answer:

In a practical problem, the Unit Commitment (UC) table is to be arrived at for the complete load cycle. If the load is assumed to increase in small but finite size steps, dynamic programming (DP) can be used to advantage for computing the UC table, wherein it is not necessary to solve the coordination equations; while at the same time the

unit combinations to be tried are much reduced in number. For these reasons, only the DP approach will be advanced here.
The total number of units available, their individual cost characteristics and the load cycle on the station are assumed to be known a priori, further, it shall be assumed that the load on each unit of combination of units changes in suitably small but uniform steps of size ΔMW (e.g. 1 MW).
Starting arbitrarily with any two units, the most economical combination is determined for all the discrete load levels of the combined output of the two units. At each load level the most economic answer may be to run either unit or both units with a certain load sharing between the two. The most economical cost curve in discrete form for the two units thus obtained, can be viewed as the cost curve of a single equivalent unit. The third unit is now added and the procedure repeated to find the cost curve of the three combined units. It may be noted that in this procedure the operating combinations of third and first, also third and second are not required to be worked out resulting in considerable saving in computational effort. The process is repeated, till all available units are exhausted. The advantage of this approach is that having obtained the optimal way of loading k units, it is quite easy to determine the optimal manner of loading $(k+1)$ units.

Let a cost function $F_N(x)$ be defined as follows:

$F_N(x)$ = the minimum cost in Rs/hr of generating x MW by N units,

$f_N(y)$ = cost of generating y MW by the Nth unit

$F_{N-1}(x-y)$ = the minimum cost of generating $(x-y)$ MW by the remaining $(N-1)$ units.

Now the application of DP results in the following recursive relation

$$F_N(x) = \min_{y}\{f_N(y) + F_{N-1}(x-y)\}$$

Using the above recursive relation, we can easily determine the combination of units, yielding minimum operating costs for loads ranging in convenient steps from the minimum permissible load of the smallest unit to the sum of the capacities of all available units. In this process the total minimum operating cost and the load shared by each unit of the optimal combination are automatically determined for each load level.

3. Discuss the concept of reserves and constraints in the Unit Commitment problem. **[WBUT 2013]**

Answer:

Spinning Reserve

Spinning reserve is defined as follows:

Spinning reserve = $\sum_{i=1}^{NG} P_i - P_{Load} - P_1$, at any interval of time.

Spinning reserve must be maintained so that the loss of one or more units does not cause unacceptable decline in frequency, i.e., there must be sufficient reserve such that if one unit is lost, other unit can make up for the loss in a specified time period.

Constraints of Unit Commitment Problems

UCP is a practical problem and must take into account a large number of practical constraints. These constraints are system, device/operational and environmental type. Again, these are broadly categorized as equality and inequality constraints.

Equality constraint is described by the system power balance (demand plus loss and export) also known as demand constraint i.e.,

$$\sum_{i}^{N} P_i = P_D$$

where P_D = Load demand

N = Number of units committed at a particular hour

Inequality constraints are:

- Minimum up-time and down-time
- Unit generation capability (upper/lower) limits
- Ramp rate limits
- System reserve requirement
- Plant crew constraint.
- Unit status restrictions (must-run, fixed-MW, unavailable/ available).

The most non-linear constraints are the units minimum up-time and down-time restriction. A unit is to be started up only if it will run for a minimum number of continuous hours. By contrast, minimum down-time is the number of hours a unit must be off-time before it can be brought on-line again. Violation of down-time constraint may be alleviated by banking the units.

The upper and lower limits of generation on the generating units force them to operate within their boundaries of operations.

The rate of increasing or decreasing electrical output from the unit is restricted by the ramp rate limit.

System reserve requirement pertains to supply the load throughout the scheduling period with certain degree of reliability even during outage of some committed units.

Plant crew constraint pertains to the number of units that can be started at the same time in a particular plant due to the limited personnel (crew) available.

4. a) For which type of power plant it is applicable and why? **[WBUT 2014]**

Answer:

The unit commitment decisions are coupled or iteratively solved in conjunction with coordinating the use of hydro including pumped storage capabilities and ensuring system reliability using probabilistic measures. The function may also include labour constraints due to crew policy and costs, which is the normal times that a full operating crew will be available without committing overtime costs. A foremost consideration is to adequately adopt environmental controls, such as fuel switching.

b) Describe the following in connection with unit commitment: **[WBUT 2014]**

i) spinning reserve

ii) must run and must out units

iii) maximum up time and minimum down time

iv) maximum up and down rate

v) Start-up cost.

Answer:

i) *Refer to Question No. 1, 2 & 4 of Short Answer Type Questions.*

ii) Must Run Units

These units are continuously committed during the scheduling period. This is due to economic and system reliability considerations.

These units are always online due to high efficiency or operational reliability or high initial capital cost such as nuclear units.

These units are out of service because of maintenance and forced outage and are unavailable for commitment.

iii) The most non-linear constraints are the units minimum up-time and down-time restriction. A unit is to be started up only if it will run for a minimum number of continuous hours. By contrast, minimum down-time is the number of hours a unit must be off-time before it can be brought on-line again. Violation of down-time constraint may be alleviated by banking the units.

iv) These rates outline the region of the dispatch of a unit.

v) Start-up Cost: When a unit is brought online, a certain amount of energy is spent which does not result into output power. The cost of the spent up energy is called the start-up cost. This may be high in case of a 'cold start' where the unit is practically at room temperature condition. The start-up cost may be low in case the unit being switched on was switched off very recently and is very close to the operating temperature.

The start-up cost depends on how a thermal unit is treated during the shutdown period. If the unit boiler is allowed to cool down and then heated back to operating temperature is time for a scheduled turn on, the start-up cost is given by:

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

α = Thermal time constant

t = Time in hours the unit was cooled

C_c = Cold-start fuel energy in kcal/hr

F = Fuel cost

C_f = Fixed cost

In case, the boiler is allowed to maintain operating temperature by supplying sufficient energy (called 'banking'), the cost of start-up is given by:
Start-up cost when banking $= C_t \times t \times F + C_f$

C_t = Heat energy/hr for maintaining unit at operating temperature.

t = Time the plant is shutdown

information. Start-up cost is expressed as a function of the number of hours the unit has been down (exponential when cooling and linear when banking). The shut-down cost is given by fixed amount for each unit shut down.

5. Discuss the solutions of unit commitment problem. **[WBUT 2015]**

Answer:

It is fact that to run the units available all the time is not economical. To determine the units of a plant that should operate for a particular load is the problem of Unit Commitment (UC). This problem is of importance for thermal plants as the other type of generation such as, hydro, the operating cost and start up times are negligible so that their on-off status is not important.

A simple but sub-optimal solution to the problem is to impose priority ordering where in the most efficient unit is loaded first to be followed by the less efficient units in order as the load increases.

A straight forward but highly time consuming way of finding the most economical combination of units to meet a particular load demand, is to try all possible combinations of units that can supply this load, to divide the load optimally among the units of each combination by use of the coordination equations so as to find the most economical operating cost of the combination, then to determine the combination, which has the least operating cost among all these. Considerable computational saving can be achieved by using branch and bound or a dynamic programming method for comparing the economics of combinations as certain combinations need not be tried at all.

6. a) What is unit commitment? What is optimal unit commitment? How optional unit commitment problem can be solved by Dynamic Programming Method?
b) A power system has four generating units listed in the Table below.

Table: Generating unit parameters for the system

Unit No.	Capacity (MW)		Cost curve parameters (d = 0)	
	Min	Max	a (Rs/MW^2)	b (Rs/MW)
1	1.0	12	0.77	23.5
2	1.0	12	1.60	26.5
3	1.0	12	2.00	30.0
4	1.0	12	2.50	32.0

d is the fixed cost. It is required to determine the most economical units to be committed for a load of 9 MW. Let the load change in steps of 1 MW. Find also the minimum cost of operation of the committed units. **[WBUT 2017]**

Answer:

a) 1st Part: ***Refer to Question No. 8(1st Part) of Short Answer Type Questions.***

2nd Part:

As is evident, it is not economical to run all the units available all the time. To determine the units of a plant that should operate for a particular load is the problem of unit commitment (UC). This problem is of importance for thermal plants as for other types of generation such as hydro; their operating cost and start-up times are negligible so that their on-off status is not important.

A simple but sub-optimal approach to the problem is to impose priority ordering, wherein the most efficient unit is loaded first to be followed by the less efficient units in order as the load increases.

A straightforward but highly time-consuming way of finding the most economical combination of units to meet a particular load demand, is to try all possible combinations of units that can supply this load; to divide the load optimally among the units of each combination by use of the coordination equations, so as to find the most economical operating cost of the combination; then, to determine the combination which has the least operating cost among all these. Considerable computational saving can be achieved by using branch and bound or a dynamic programming method for comparing the economics of combinations as certain combinations need not be tried at all.

3rd Part: ***Refer to Question No. 2(d) of Long Answer Type Questions***

b) ***Similar to Question No.6 of Short Answer Type Questions.***

7. Write short notes on the following:
a) Unit commitment **[WBUT 2012]**
b) Spinning reserve **[WBUT 2012, 2015]**
c) Lagrangian Multiplier (λ) and its Physical significance

Answer:

a) Unit commitment:

In operational scheduling of electric power generation, the most important problems is the unit commitment. It involves determining the start up and shut down (ON/OFF) schedules of generating units to be used to meet forecasted demand over a short-term (24 – 168 hours) period. The aim is to minimize total production cost to meet system demand and reserve requirements while observing a large set of operating constraints. In fact it is a complex mathematical optimization problem having both integer and continuous variables. Prior to solve the economic dispatch problem, unit commitment problem should be solved because only those units which were allocated to generating duties by the unit commitment solution can be considered for power generation.

Constraints of Unit Commitment Problems

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where P_D = Load demand

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Inequality constraints are:

- Minimum up-time and down-time
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- Unit status restrictions (must-run, fixed-MW, unavailable/ available).

The most non-linear constraints are the units minimum up-time and down-time restriction. A unit is to be started up only if it will run for a minimum number of continuous hours. By contrast, minimum down-time is the number of hours a unit must be off-time before it can be brought on-line again. Violation of down-time constraint may be alleviated by banking the units.

The upper and lower limits of generation on the generating units force them to operate within their boundaries of operations.

The rate of increasing or decreasing electrical output from the unit is restricted by the ramp rate limit.

System reserve requirement pertains to supply the load throughout the scheduling period with certain degree of reliability even during outage of some committed units.

Plant crew constraint pertains to the number of units that can be started at the same time in a particular plant due to the limited personnel (crew) available.

b) Spinning reserve:
To meet contingencies, the capacity of units on line (running) must have a definite márgin over the load requirements at all times. This margin is called spinning reserve. It ensures continuity by meeting the load demand upto a certain extent of probable loss of generation capacity. While rules of thumb are used, based on past experience, Patton's analytical approach to this problem is the most promising.
Since the probability of unit outrage increases with operating time and since a unit which is to provide the spinning reserve at a particular time has to be started several hours ahead, the problem of security of supply has to be treated in totality over a period of one day. Furthermore, the loads are never known with complete certainty. Also, the spinning reserve has to be provided at suitable generating stations of the system and not necessarily at every generating station.

c) Lagrangian Multiplier (λ) and its Physical significance:
For an extremum of f to exist on g, the gradient of f must line up with the gradient of g. The gradient is a horizontal vector (i.e., it has no z-component) that shows the direction that the function increases; for g it is perpendicular to the curve, which is a straight line in this case. If the two gradients are in the same direction, then one is a multiple $(-\lambda)$ of the other, so

$$\nabla f = -\lambda \nabla g$$

The two vectors are equal, so all of their components are as well, giving

$$\frac{\partial f}{\partial x_k} + \lambda \frac{\partial g}{\partial x_k} = 0$$

For all $k = 1.\cdots n,$ where the constant λ is called the language multiplier.
The extremum is then found by solving the $n+1$ equations in $n+1$ unknowns, which is done without inverting g, which is why language multipliers can be so useful.
For multiple constraints $g1 = 0, g2 = 0.\cdots,$

$$\nabla f + \lambda_1 \nabla_{g1} + \lambda_2 \nabla_{g2} + \cdots = 0$$

Physical Significance:
When you want to maximize (or minimize) a multivariable function $f(x, y, \cdots)$ subject to the constraint that another multivariable function equals a constant, $g(x, y, \cdots) = c$, follow these steps:
Step 1: Introduce a new variable λ, and define a new function L as follows:

$$L(x, y, \ldots, \lambda) = f(x, y, \ldots) - \lambda(g(x, y, \ldots) - c)$$

This function L is called the "Lagrangian", and the new variable λ is referred to as a "Lagrange multiplier".

Step 2: Set the gradient of L equal to the zero vector.

$$\nabla L(x, y, \ldots \lambda) = 0 \leftarrow \text{Zero vector}$$

In other words, find the critical points of L.

Step 3: Consider each solution, which will look something like $(x_0, y_0, \ldots, \lambda_0)$. Plug each one into f. Or rather, first remove the λ_0 component, then plug it into f, since f does not have λ as an input. Whichever one gives the greatest (or smallest) value is the maximum (or minimum) point your are seeking.

ECONOMIC LOAD DISPATCH

Multiple Choice Type Questions

1. A 3-phase balanced system working at 0.9 power factor (lag) has a line loss of 3600 kW, If the power factor is reduced to 0.6, the line loss would be [WBUT 2008]
   a) 8100 kW
   b) 1600 kW
   c) 5400 kW
   d) 7200 kW

Answer: (d)

2. Which of the following are the advantages of interconnected operation of power system? [WBUT 2008]
   a) Less reserve capacity requirement
   b) More reliability
   c) High power factor
   d) Reduction in short-circuit level

Answer: (a)

3. Smooth supply of reactive power output can be obtained from [WBUT 2008]
   a) shunt capacitor
   b) synchronous condenser
   c) static var compensator
   d) both (b) and (c)

Answer: (d)

4. For a lumped inductive load, with increase in supply frequency [WBUT 2008]
   a) *P* & *Q* decrease
   b) *P* & *Q* increase
   c) *P* decreases but *Q* increases
   d) *P* increases but *Q* decreases

where *P* is the active component and Q is the reactive component of load

Answer: (c)

5. Load frequency control is achieved by properly matching the individual machines [WBUT 2008, 2014]
   a) Reactive power
   b) Generated voltage
   c) Turbine input
   d) Turbine and Generator ratings

Answer: (d)

6. The power generated by two plants are P_1 = 50 MW. P_2 = 40 MW. If the loss co- efficient are B_{11} = 0.001, B_{22} = 0.0025 and B_{12} = – 0.0005, then the power loss will be [WBUT 2009, 2014]
   a) 5.5 MW
   b) 6.5 MW
   c) 4.5 MW
   d) 8.5 MW

Answer: (c)

7. Penalty factor in economic operations of the power system is to be considered when [WBUT 2009, 2010, 2011]
   a) generator losses are considered
   b) turbine losses are considered
   c) transmission losses are considered
   d) none of these

Answer: (c)

8. The incremental transmission loss of a plant is [WBUT 2010]
a) always positive
b) always negative
c) may be positive or negative
d) none of these

Answer: (c)

9. Reactive power is delivered in a system by [WBUT 2010]
a) capacitor bank
b) reactor
c) induction machine
d) all of these

Answer: (d)

10. Load flow solution is done to calculate [WBUT 2012]
a) generated power by slack bus
b) system parameter
c) bus voltage & active power loss
d) bus voltage & phase angle of each and every bus

Answer: (d)

11. The incremental transmission loss of a plant is [WBUT 2013]
a) positive always
b) negative always
c) can be positive or negative
d) zero always

Answer: (c)

12. If for a given alternator in economic operation mode the incremental cost is given by $(0.012p + 8) Rs/MWh. \frac{dp_l}{dp} = 0.2$ and plant $\lambda = 25$ then the power generation is [WBUT 2013]
a) 1000 MW
b) 1250 MW
c) 750 MW
d) 1500 MW

Answer: (b)

13. The cost function of a 50 MW generator is given by $F(p) = 225 + 53p + 0.02p^2$. When 100% loading is applied, the IFC will be [WBUT 2013]
a) Rs. 55 per MWh
b) Rs. 55 per MW
c) Rs. 33 per MWh
d) Rs. 33 per MW

Answer: (c)

14. In terms of plant powers p_n and p_m and loss coefficients B_{mn} the total transmission loss p_l is [WBUT 2013]
a) $\sum_{m=1}^{N} \sum_{n=1}^{N} B_{mn} p_n$
b) $\sum_{m=1}^{N} \sum_{n=1}^{N} B_{mn} p_m$
c) $\sum_{m=1}^{N} \sum_{n=1}^{N} B_{mn} p_n p_m$
d) $\sum_{m=1}^{N} \sum_{n=1}^{N} 2B_{mn} p_m$

Answer: (c)

15. At stack bus, which one of the following combinations of variable is specified? [WBUT 2013]
a) $|v|, \delta$
b) P, Q
c) $p, |v|$
d) $Q, |v|$

Answer: (a)

16. Normally Z_{bus} matrix is a [WBUT 2013]

a) null matrix
b) sparse matrix
c) full matrix
d) unity matrix

Answer: (c)

17. The incremental cost characteristics of the two units in a plant are
$Ic_1 = 0.1p_1 + 8.0\ Rs/MWh,\ Ic_2 = 0.15p_2 + 3.0\ Rs/MWh$.
When the total load is 100 MW, the optimum sharing of the load is [WBUT 2013]

	p_1	p_2
a)	40 MW	60 MW
b)	33.3 MW	66.7 MW
c)	60 MW	40 MW
d)	66.7 MW	33.3 MW

Answer: (a)

18. If the penalty factor of a plant is unity, its incremental transmission loss is [WBUT 2013, 2014, 2017]

a) 1.0
b) –1.0
c) zero
d) none of these

Answer: (c)

19. If the speed regulation is 5.1 and the rated frequency is 60Hz then change in frequency is [WBUT 2014, 2015]

a) 3 Hz
b) 6 Hz
c) 5 Hz
d) none of these

Answer: (a)

20. Economic operation of power system is carried out on the basis of [WBUT 2014]

a) equal incremental fuel cost
b) equal area criterion
c) equal fuel cost criterion
d) all units sharing equal power

Answer: (a)

21. In transmission loss representation, the loss depend upon [WBUT 2015]

a) generation
b) load
c) transmission parameters
d) total power system

Answer: (c)

23. For economic operation, the generator with highest positive incremental transmission loss will operate at [WBUT 2017]

a) The lowest positive incremental cost of production
b) The lowest negative incremental cost of production
c) The highest positive incremental cost of production
d) None of these

Answer: (a)

24. In a two plant system, the load is connected to plant 2. The loss coefficients [WBUT 2017]

a) B_{11}, B_{12}, B_{22} are non zero
b) B_{11} and B_{22} are non zero but B_{12} is zero

c) B_{11} and B_{12} are non zero but B_{22} is zero

d) B_{11} is non zero but B_{12} and B_{22} are zero

Answer: (d)

25. In the optimum generator scheduling of different plants, the minimum fuel cost is obtained when **[WBUT 2017]**

a) Only the incremental fuel cost of each plant is the same
b) The penalty factor of each plant is the same
c) The ratio of the incremental fuel cost to the penalty factor of each plant is the same
d) The incremental fuel cost of each plant multiplied by its penalty factor is the same

Answer: (a)

Short Answer Type Questions

1. The economic dispatches of the plants of a power system are 393 MW, 335 MW and 122 MW and the incremental cost are
$IC_1 = 7.92 + 0.003125 P_1$
$IC_2 = 7.85 + 0.00388 P_2$
$IC_3 = 7.97 + 0.00964 P_3$ respectively. The load increases by 50 MW. Find the modified schedules using the method of participation factor.

Answer: **[WBUT 2008, 2015]**

Total power demand on the system $= 392 + 335 + 122 + 50 = 899\text{MW}$

Cost coefficients:

$\beta_1 = 7.92 \quad \gamma_1 = 0.003125$

$\beta_2 = 7.85 \quad \gamma_2 = 0.00388$

$\beta_3 = 7.97 \quad \gamma_3 = 0.00964$

The incremental fuel cost is given by the equation

$$\lambda = \frac{P_D + \left(\frac{\beta_1}{2\gamma_1} + \frac{\beta_2}{2\gamma_2} + \frac{\beta_3}{2\gamma_3}\right)}{\frac{1}{2\gamma_1} + \frac{1}{2\gamma_2} + \frac{1}{2\gamma_3}} = \frac{899 + \left(\frac{7.92}{2\times.003125} + \frac{7.85}{2\times.00388} + \frac{7.97}{2\times.00964}\right)}{\frac{1}{2\times.003125} + \frac{1}{2\times.00388} + \frac{1}{2\times.00964}}$$

$$= \frac{899 + (7.92\times160 + 7.85\times128.865 + 7.97\times51.867)}{160 + 128.865 + 51.867}$$

$$= \frac{899 + 1267.2 + 1011.59025 + 413.37999}{340.732} = \frac{3591.17024}{340.732} = 10.5395$$

From the condition for optimum scheduling or optimum dispatch

$$P_{G1} = \frac{\lambda - \beta_1}{2\gamma_1} = \frac{10.5395 - 7.92}{2 \times .003125} = \frac{2.6195}{2 \times .003125} = 2.6195 \times 160 = 419.12\,\text{MW}$$

$$P_{G2} = \frac{\lambda - \beta_2}{2\gamma_2} = \frac{10.5395 - 7.85}{2 \times .00388} = \frac{2.6895}{2 \times .00388} = 2.6895 \times 128.865 = 346.5824\,\text{MW}$$

$$P_{G3} = \frac{\lambda - \beta_3}{2\gamma_3} = \frac{10.5395 - 7.97}{2 \times .00964} = \frac{2.5695}{2 \times .00964} = 2.5695 \times 51.867 = 133.2722\,\text{MW}$$

2. A constant load of 300 MW is supplied by two 200MW generators, 1 and 2, for which the respective incremental fuel cost are

$$\frac{dC_1}{dP_{G_1}} = 0.2P_{G_1} + 40$$

$$\frac{dC_2}{dP_{G_2}} = 0.2P_{G_2} + 30$$

Calculate the extra cost incurred in Rs/h if a load of 220 MW is scheduled as $P_{G_1} = P_{G_2} = 110$ MW. **[WBUT 2014]**

Answer:

$$\frac{dC_1}{dP_{G_1}} = 0.2P_{G_1} + 40$$

$$\frac{dC_2}{dP_{G_2}} = 0.2P_{G_2} + 30$$

Now for economic operation of the units

$$\frac{dC_1}{dP_{G_1}} = \frac{dC_2}{dP_{G_2}}$$

$$0.2P_{G_1} + 40 = 0.2P_{G_2} + 30$$

or, $$0.2\left(P_{G_1} - P_{G_2}\right) = -10$$

or, $$P_{G_1} - P_{G_2} = \frac{-10}{2} = -50$$

$$P_{G_1} + P_{G_2} = 300$$

$$P_{G_1} - P_{G_2} = -50$$

$$2P_{G_1} = 250$$

$\Rightarrow$ $$P_{G_1} = 125\,\text{MW}$$

$$P_{G_2} = 175\,\text{MW}$$

P_1	P_2	Plant output $(P_1 + P_2)$
30	20	50
30	25	55
30	40	70
40	45	85
50	50	100
100	75	175
100	120	220

For a total load of 220 MW unit 1 should take up to 100 MW and unit 2 should supply 120 MW. For equal distribution each unit supplies 110 MW.
The cost of generation for each unit are

$$C_1 = \int (dC_1 / dP_{G_1})\, dP_{G_1} = \int IC_1\, dP_{G_1} = \int (0.2P_{G_1} + 40)\, dP_{G_1} = 0.2P_{G_1}^2 + 40P_{G_1} + k_1 \text{ Rs./h}$$

$$C_2 = \int (dC_2 / dP_{G_2})\, dP_{G_2} = \int IC_2\, dP_{G_2} = \int (0.2P_{G_2} + 30)\, dP_{G_2} = 0.2P_{G_2}^2 + 30P_{G_2} + k_2 \text{ Rs./h}$$

where k_1 and k_2 are constants.
The increase in cost for unit 1

$$C_1(110) - C_1(100) = 0.2(110^2 - 100^2) + 40(110 - 100)$$
$$= 0.2 \times 210 \times 10 + 400 = 420 + 400 = 820 \text{ Rs./h}$$

The increase in cost for unit 2

$$C_2(110) - C_2(100) = 0.2(110^2 - 100^2) + 30(110 - 120)$$
$$= 0.2 \times 230 \times (-10) - 30 \times 10 = -460 - 300 = -760 \text{ Rs./h}$$

Net saving caused by optimum scheduling is
$$-760 + 820 = 60 \text{ Rs/h}$$

This saving justifies the need for optimal load sharing and the devices to be installed for controlling the unit loadings automatically.

3. Develop the condition of economic operation of a power system considering transmission line loss. **[WBUT 2014]**

Answer: ***Refer to Question No. 1(a) of Long Answer Type Questions.***

4. The fuel costs in Rs/hr for the three thermal units are given by.

$$F_1(P_1) = 300 + 7P_1 + 0.004P_1^2 \, Rs./hr.$$

$$F_2(P_2) = 450 + 7.3P_2 + 0.0025P_2^2 \, Rs./hr.$$

$$F_3(P_3) = 600 + 6.6P_3 + 0.003P_3^2 \, Rs./hr.$$

P_1, P_2, P_3 are in MW. Find the optimum schedule and compare the cost of this to the case when the generators share the load equally if the demand is 500 MW. Neglect losses. **[WBUT 2015]**

Answer:

$$F_1 = 30 + 7P_1 + 0.004P_1^2 \text{ Rs/hr.}$$
$$F_2 = 450 + 7.3P_2 + 0.0025P_2^2 \text{ Rs/hr.}$$
$$F_3 = 600 + 6.6P_3 + 0.003P_3^2 \text{ Rs/hr.}$$

Here power demand

$$P_D = 500\,\text{MW}$$

Cost coefficients:

$$\beta_1 = 7 \qquad \gamma_1 = 0.004$$
$$\beta_2 = 7.3 \qquad \gamma_2 = 0.0025$$
$$\beta_3 = 3.6 \qquad \gamma_3 = 0.003$$

The incremental fuel cost is given by the equation

$$\lambda = \frac{P_D + \left(\frac{\beta_1}{2\gamma_1} + \frac{\beta_2}{2\gamma_2} + \frac{\beta_3}{2\gamma_3}\right)}{\frac{1}{2\gamma_1} + \frac{1}{2\gamma_2} + \frac{1}{2\gamma_3}} = \frac{500 + \left(\frac{7}{2\times0.004} + \frac{7.3}{2\times0.0025} + \frac{6.6}{2\times0.003}\right)}{\frac{1}{2\times0.004} + \frac{1}{2\times0.0025} + \frac{1}{2\times0.003}}$$

$$= \frac{500 + (7\times125 + 7.3\times200 + 6.6\times166.66)}{125 + 200 + 166.66} = \frac{500 + (875 + 1460 + 1099.956)}{491.66}$$

$$= \frac{500 + 3434.956}{491.66} = \frac{3934.956}{491.66} = 8.003$$

From the condition for optimum scheduling or optimum dispatch

$$P_{a1} = \frac{\lambda - \beta_1}{2\gamma_1} = \frac{8-7}{2\times0.004} = 125\,\text{MW}$$

$$P_{a2} = \frac{\lambda - \beta_2}{2\gamma_2} = \frac{8-7.3}{2\times0.0025} = 0.7\times200 = 140\,\text{MW}$$

$$P_{a3} = \frac{\lambda - \beta_3}{2\gamma_3} = \frac{8-6.6}{2\times0.003} = 1.4\times166.66 = 233.324\,\text{MW}$$

Total fuel cost

$$C = C_1 + C_2 + C_3$$

$$C_1 = \left(300 + 7\times125 + 0.004\times125^2\right) = (300 + 875 + 62.5) = ₹1237.5\,/\,\text{hr.}$$

$$C_2 = \left(450 + 7.3\times140 + 0.0025\times140^2\right) = (450 + 1022 + 49) = ₹1521\,/\,\text{hr.}$$

$$C_3 = \left(600 + 6.6\times233.324 + 0.003\times233.324^2\right)$$

$$= (1539.9384 + 163.320) = ₹2303.2584\,/\,\text{hr.}$$

$$C = ₹(1237.5 + 1521 + 2303.2584)\,/\,\text{hr.} = ₹5061.7584\,/\,\text{hr.}$$

5. Explain the problems of economic load dispatch. How the problems can be settled?

Answer: **[WBUT 2017]**

1st Part: ***Refer to Question No. 8(b) of Long Answer Type Questions.***
2nd Part: ***Refer to Question No. 3(a) of Long Answer Type Questions.***

6. What are the advantages of interconnected power System? What is the name of Indian interconnected power system? How many Zones are interconnected in Indian power System? What are the names of those zones? In which zone West Bengal has been included?

Answer: **[WBUT 2017]**

1st part:

The connection of several generating stations in parallel is known as interconnected grid system. The advantages are as follows:

Exchange of Peak Loads:

An important advantage of interconnected system is that the peak load of the power station can be exchanged. If the load curve of a power station shows a peak demand that is greater than the rated capacity of the plant, then the excess load can be shared by other stations interconnected with it.

Use of Older Plant:

The interconnected system makes it possible to use the older and less efficient plants to carry peak loads of short durations. Although such plants may be inadequate when used alone, yet they have sufficient capacity to carry short peaks of loads when interconnected with other modern plants. Therefore, interconnected system gives a direct key to the use of obsolete plants.

Increases Diversity Factor:

The load curves of different interconnected stations are generally different. The result is that the maximum demand on the system is much reduced as compared to the sum of individual maximum demands on different stations. In other words, the diversity factor of the system is improved, thereby increasing the effective capacity of the system.

2nd part: Power Grid Corporation of India – Its original name was the 'National Power Transmission Corporation Limited'.

3rd part: 5 zones are inter-connected.

4th part: The grids were the Northern, Eastern, Western, North Eastern and Southern Grids.

5th part: west Bengal is included in eastern zone.

Long Answer Type Questions

1. a) Derive the co-ordination equation for optimum load dispatch for a power system including transmission losses and hence an expression for penalty factor. What is the significance of penalty factor in economic operation of the generating plant? [WBUT 2008]

OR,

Show that transmission loss of a power system can be expressed as a function of the active power outputs of the generators in the system. State the assumptions you make. [WBUT 2009]

OR,

Derive the expression for transmission loss as a function of plant generation. [WBUT 2013, 2015]

Answer:

The objective is to minimize the overall cost of generation at any time under equality constraint of meeting the load demand with transmission loss, i.e.

$$C=\sum_{i=1}^{k} C_i\left(P_{Gi}\right) \quad \text{.... (1)}$$

$$\sum_{i=1}^{k} P_{Gi}-P_D-P_L=0 \quad \text{.... (2)}$$

where k = total number of generating plants

P_{Gi} = generation of ith plant

P_D = sum of load demand at all buses (system load demand)

P_L = total system transmission loss.

To solve the problem, we write the Lagrangian as

$$£=\sum_{i=1}^{5} C_i\left(P_{Gi}\right)-\lambda\left[\sum_{i=1}^{k} P_{Gi}-P_D-P_L\right] \quad \text{.... (3)}$$

It will be shown later in this section that, if the power factor of load at each bus is assumed to remain constant, the system loss P_L can be shown to be a function of active power generation at each plant, i.e.

$$P_L=P_L\left(P_{G1}, P_{G2}, \cdots, P_{Gk}\right) \quad \text{.... (4)}$$

Thus in the optimization problem posed above, $P_{Gi}\left(i=1,2, \cdots, k\right)$ are the only control variables.

For optimum real power dispatch,

$$\frac{\partial £}{\partial P_{Gi}}=\frac{dC_i}{dP_{Gi}}-\lambda+\lambda \frac{\partial P_L}{\partial P_{Gi}}=0, \quad i=1,2, \ldots, k \quad \text{.... (5)}$$

Rearranging Eqn. (5) and recognizing that changing the output of only one plant can affect the cost at only that plant, we have

$$\frac{\dfrac{dC_i}{dP_{Gi}}}{\left(1-\dfrac{\partial P_L}{\partial P_{Gi}}\right)}=\lambda \quad \text{or,} \quad \frac{dC_i}{dP_{Gi}}L_i=\lambda,\ i=1,2,\cdots,k \qquad \text{.... (6)}$$

where $L_i=\dfrac{1}{(1-\partial P_L/\partial P_{Gi})}$ .... (7)

is called the penalty factor of the ith plant.

The Lagrangian multiplier λ is in rupees per megawatt-hour, when fuel cost is in rupees per hour. Eqn. (6) implies that minimum fuel cost is obtained, when the incremental fuel cost of each plant multiplied by its penalty factor is the same for all the plants.

The $(k+1)$ variables $(P_{G1}, P_{G2}, ...P_{Gk}, \lambda)$ can be obtained from k potential dispatch Eqn.(6) together with the power balance Eqn.(2). The partial derivative $\dfrac{\partial P_L}{\partial P_{Gi}}$ is referred to as the incremental transmission loss $(ITL)_i$, associated with the ith generating plant.

Eqn.(6) can be written in the alternative form

$(IC)_i=\lambda[1-(ITL)_i] \quad i=1,2,3,\cdots\cdots\cdots k$ .... (8)

This Eqn.(8) is referred to as the exact Co-ordination equation.

b) A power system consists of two 100 MW units whose input cost data are represented by the equations:

$C_1=0.05P_1^2+20P_1+800$ **Rupees / hour**

$C_2=0.06P_2^2+15P_2+1000$ **Rupees / hour**

Total received power P_R = 150 MW. **[WBUT 2008]**

Answer:

The incremental production costs of both the units are

$$\frac{dC_1}{dP_1}=(0.05\times 2)P_1+20 \text{ Rs. per MWhr}$$

$$\frac{dC_2}{dP_2}=(0.06\times 2)P_2+15 \text{ Rs. per MWhr}$$

Now for economic operation of the units

$$\frac{dC_1}{dP_1}=\frac{dC_2}{dP_2}$$

i.e., $0.1P_1+20=0.12P_2+15$ .... (1)

and $P_1+P_2=150\text{ MW}$ .... (2)

Solution of these equations

$P_1=59.1\text{ MW}$

$P_2=90.90\text{ MW}$

Now cost of generation $= C_1 + C_2$

$C_1 = 0.05P_1^2 + 20P_1 + 800 = 0.05 \times 59.1^2 + 20 \times 59.1 + 800 = 2156.6405$ Rs./hr.

$C_2 = 0.06P_2^2 + 15P_2 + 1000 = 0.06 \times 90.90^2 + 15 \times 90.90 + 1000 = 2859.2686$ Rs./hr.

Total cost $= 2156.6405 + 2859.2686 = 5015.909$ Rs./hr.

2. The loss coefficients for a system with plants are **[WBUT 2009]**

$B_{11} = 0.001$ $B_{12} = 0.0007$ $B_{22} = 0.0015$

If the power outputs are 200 MW and 150 MW respectively, determine the load on the system. Also calculate the penalty factors of the plants.

If the system λ is Rs. 130 per MWh, calculate the incremental fuel costs of the plants.

Answer:

Total losses on the system

$$P_L = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2 = .001 \times 200^2 + 2 \times .0007 \times 200 \times 150 + .0015 \times 150^2$$

$$= .001 \times 40000 + 2 \times .0007 \times 30000 + .0015 \times 22500 = 40 + 42 + 33.75$$

$$= 234.25\text{MW}$$

$\therefore$ Load on the system $= (200 + 150 - 115.75)\text{MW} = (350 - 115.75)\text{MW} = 234.25\text{MW}$

Penalty factor of the plant 1

$$L_1 = \frac{1}{1 - \frac{\partial P_L}{\partial P_{G1}}} = \frac{1}{1 - \frac{115.75}{200}} = \frac{1}{1 - .578} = 2.369$$

Penalty factor of the plant 2

$$L_2 = \frac{1}{1 - \frac{\partial P_2}{\partial P_{G2}}} = \frac{1}{1 - \frac{115.75}{150}} = \frac{1}{1 - .7716} = 4.378$$

$\lambda =$ Rs 130 per MWh

Incremental fuel cost of plant 1 is $\dfrac{\frac{dC_1}{dP_{G1}}}{\left(1 - \frac{\partial P_L}{\partial P_{G1}}\right)} = \lambda = 130 \times 2.369 = 308.0568$ Rs/MWhr

Incremental fuel cost of plant 2 is $\dfrac{\frac{dC_2}{dP_{G1}}}{\left(1 - \frac{\partial P_L}{\partial G_2}\right)} = \lambda$

$$\frac{dC_2}{dP_{G2}} = \lambda . L_2 = 130 \times 4.378 = 569.14$$

Total incremental fuel cost is, $(308.0568 + 569.14) = 877.1968$ Rs/MWh.

3. a) Develop a simple computer approach for solving the economic dispatch problem. **[WBUT 2010]**

Answer:

Economic Load Dispatch by Newton-Raphson Method:

The economic load dispatch problem can be defined by equation

$$F = f(x,u)$$

$$g(x,u) = 0 \quad \text{.... (1a)}$$

$$h(x,u) \le 0 \quad \text{.... (1b)}$$

$$u_{\min} \le u \le u_{\max} \quad \text{.... (1c)}$$

$$x_{\min} \le x \le x_{\max}$$

subjected to the power balance equation (2) and the power limit constraint,

$$\text{Minimize } F_c\left(P_{g_i}\right) = \sum_{i=1}^{NG}\left(\alpha_i P_{g_i}^2 + \beta_i P_{g_i} + \gamma_i\right) \quad \text{.... (2)}$$

Subjected to

(i) the power balance equation $\sum_{i=1}^{NG} P_{g_i} = P_{\text{load}_T} + P_l$ and

(ii) the inequality constraints $P_{g_i}^{\min} \le P_{g_i} \le P_{g_i}^{\max}$ for $i = 1, 2, 3, \ldots, NG$ where,

α_i, β_i and γ_i are the cost coefficients,

P_{load_T} = total load demand of the system,

P_{g_i} = real power generation at ith generator bus,

NG = total number of generators,

P_l = active power loss in the transmission lines.

Transmission line loss can be expressed as

$$P_l = B_{00} + \sum_{i=1}^{NG} B_{i0} P_{g_i} + \sum_{i=1}^{NG}\sum_{j=1}^{NG} P_{g_i} B_{ij} P_{g_j} \quad \text{.... (3)}$$

The Lagrange function to obtain optimal power generation being given by

$$L\left(P_g, \lambda\right) = \sum_{i=1}^{NG} F_{c_i}\left(P_{g_i}\right) + \lambda\left[P_{\text{load}_T} + P_l - \sum_{i=1}^{NG} P_{g_i}\right] \quad \text{.... (4)}$$

The necessary condition for optimization is given by

$$\frac{\partial L\left(P_g, \lambda\right)}{\partial P_{g_i}} = \frac{\partial F_{c_i}\left(P_{g_i}\right)}{\partial P_{g_i}} + \lambda\left(\frac{\partial P_l}{\partial P_{g_i}} - 1\right) = 0 \quad \text{.... (5)}$$

and

$$\frac{\partial L\left(P_{g_i}, \lambda\right)}{\partial \lambda} = P_{\text{load}_T} + P_l - \sum_{i=1}^{NG} P_{g_i} = 0 \quad \text{.... (6)}$$

The solution of a non-linear equation can be obtained using Newton-Raphson method in which any change in control variables, about their initial values, can be obtained using Taylor's expansion. Taylor's expansion of second order of equations (5) and (6) can be written as

$$\frac{\partial^2 L}{\partial P_{g_i}^2}\Delta P_{g_i} + \sum_{\substack{k=1\\k\neq i}}^{NG}\frac{\partial^2 L}{\partial P_{g_i}\partial P_{g_k}}\Delta P_{g_k} + \frac{\partial^2 L}{\partial P_{g_i}\partial \lambda}\Delta\lambda = -\frac{\partial K}{\partial P_{g_i}} \quad \text{.... (7a)}$$

and
$$\sum_{k=1}^{NG}\frac{\partial^2 L}{\partial \lambda \partial P_{g_k}}\Delta P_{g_k} + \frac{\partial^2 L}{\partial \lambda^2}\Delta\lambda = -\frac{\partial L}{\partial \lambda} \quad \text{.... (7b)}$$

for $i = 1, 2, 3, \ldots, NG$

Equations (7a) and (7b) can then be written in a matrix form as

$$\begin{bmatrix} \dfrac{\partial^2 L}{\partial P_{g_i}\partial P_{g_k}} & \dfrac{\partial^2 L}{\partial P_{g_i}\partial \lambda} \\ \dfrac{\partial^2 L}{\partial \lambda \partial P_{g_k}} & \dfrac{\partial^2 L}{\partial \lambda^2} \end{bmatrix} \begin{bmatrix} \Delta P_{g_k} \\ \Delta\lambda \end{bmatrix} = -\begin{bmatrix} \dfrac{\partial L}{\partial P_{g_i}} \\ \dfrac{\partial L}{\partial \lambda} \end{bmatrix} \quad \text{.... (8a)}$$

for $i = 1, 2, 3, \ldots, NG$ and $k = 1, 2, 3, \ldots, NG$

or,
$$\underbrace{\begin{bmatrix} H_{P_g P_g} & H_{P_g\lambda} \\ H_{\lambda P_g} & H_{\lambda\lambda} \end{bmatrix}}_{[H]} \begin{bmatrix} \Delta P_g \\ \Delta\lambda \end{bmatrix} = -\underbrace{\begin{bmatrix} J_{P_g} \\ J_{\lambda} \end{bmatrix}}_{[J]}$$

or,
$$[H][\text{Change in control variables}] = [J] \quad \text{.... (8b)}$$

where $[H]$ and $[J]$ are called Hessian and Jacobian matrix, respectively. The order of different submatrices of $[H]$ matrix and their interrelationships are given below:

Order of $[H_{P_g P_g}] = NG \times NG$

Order of $[H_{P_g\lambda}] = NG \times 1$ and $[H_{\lambda P_g}] = [H_{P_g\lambda}]^T$

Order of $[H_{\lambda\lambda}] = 1 \times 1$

The order of different sub-matrices of $[J]$ matrix are given below:

Order of $[J_{P_g}] = NG \times 1$

Order of $[J_{\lambda}] = N \times 1$

The first order derivatives required for equations (7a) and (7b) are given below:

$$\frac{\partial L(P_{g_i}, \lambda)}{\partial P_{g_i}} = \frac{\partial F_c(P_{g_i})}{\partial P_{g_i}} + \lambda\left(\frac{\partial P_l}{\partial P_{g_i}} - 1\right)$$

$$= \left(2\alpha_i P_{g_i} + \beta_i\right) + \lambda\left\{\left(B_{i0} + \sum_{k=1}^{NG} 2B_{ik} P_{g_k}\right) - 1\right\} \quad .... (9a)$$

for $i = 1, 2, 3, \ldots, NG$

$$\frac{\partial L\left(P_{g_i}, \lambda\right)}{\partial \lambda} = P_{\text{load}_r} + P_l - \sum_{i=1}^{NG} P_{g_i} \quad .... (9b)$$

The second order derivatives of equation (9a) with respect to P_{g_i} are obtained as:

$$\frac{\partial^2 L}{\partial P_{g_i}^2} = \frac{\partial^2 F_{c_i}}{\partial P_{g_i}^2} + \lambda \frac{\partial^2 P_l}{\partial P_{g_i}^2} = 2\alpha_i + 2\lambda B_{ii} \qquad \text{for } i = 1, 2, 3, \ldots, NG \quad .... (10a)$$

$$\frac{\partial^2 L}{\partial P_{g_i} \partial P_{g_k}} = \lambda \frac{\partial^2 P_l}{\partial P_{g_i} \partial P_{g_k}} = 2\lambda B_{ik} \quad .... (10b)$$

for $i = 1, 2, 3, \ldots, NG$; $k = 1, 2, 3, \ldots, NG$ but $i \neq k$

The second order derivatives of equation (9a) with respect to *l* are given in equation (10c)

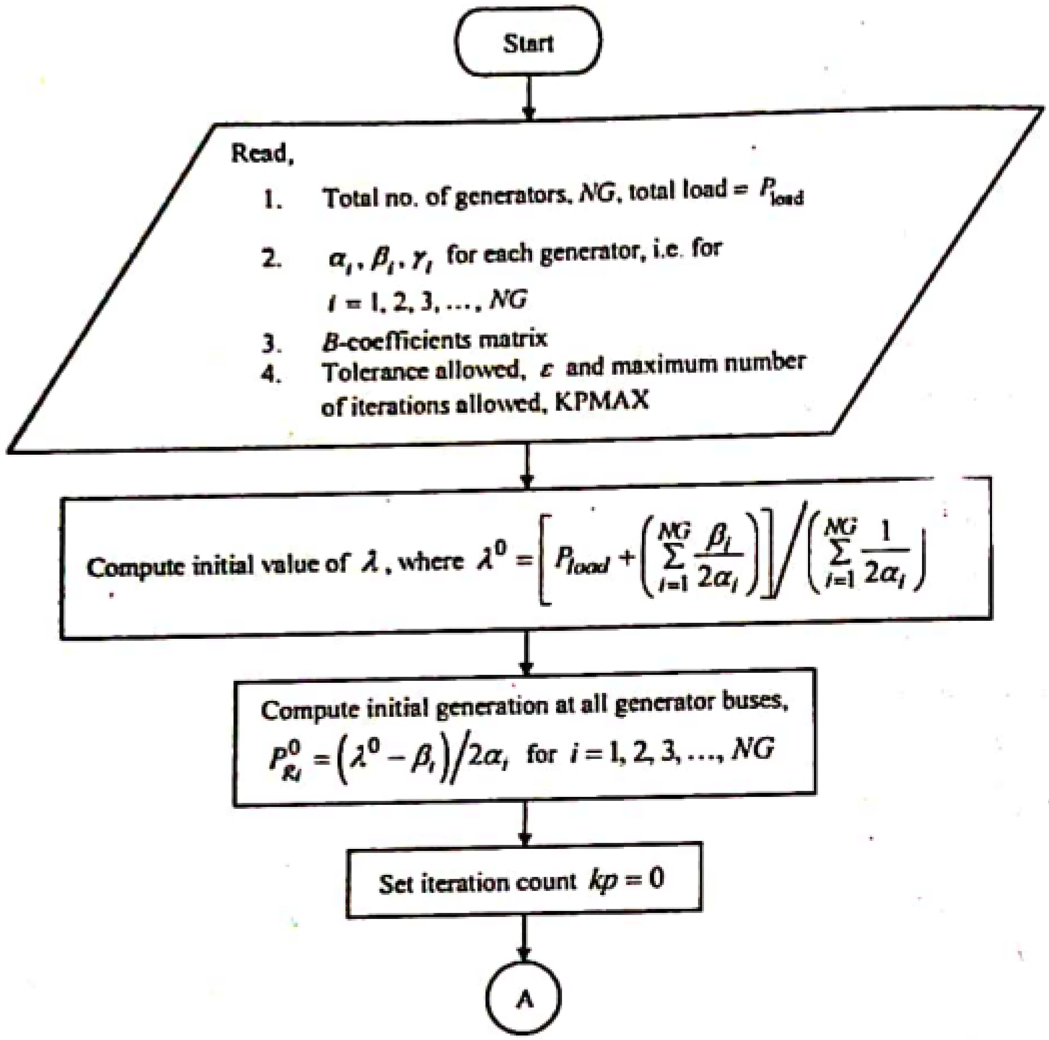
$$\frac{\partial^2 L}{\partial P_{g_i} \partial \lambda} = \frac{\partial^2 L}{\partial \lambda \partial P_{g_i}} = \frac{\partial P_l}{\partial P_{g_i}} - 1 = B_{i0} + \sum_{k=1}^{NG} 2B_{ik} P_{g_k} - 1 \quad .... (10c)$$

for $i = 1, 2, 3, \ldots, NG$

The second order derivatives of equation (9b) with respect to *l* are obtained as:

$$\frac{\partial^2 L}{\partial \lambda^2} = 0 \quad .... (10d)$$

Economic load dispatch problem may be solved by solving equation (8a) or (8b) using equations (9a) – (10d). The flowchart, in order to find economic generation schedule using Newton-Raphson method, is shown in figure 1.


Start
Read,
1. Total no. of generators, NG, total load = P_{load}
2. $\alpha_i, \beta_i, \gamma_i$ for each generator, i.e. for $i = 1, 2, 3, \ldots, NG$
3. B-coefficients matrix
4. Tolerance allowed, ε and maximum number of iterations allowed, KPMAX
Compute initial value of λ, where $\lambda^0 = \left[P_{load} + \left(\sum_{i=1}^{NG} \frac{\beta_i}{2\alpha_i} \right) \right] \Big/ \left(\sum_{i=1}^{NG} \frac{1}{2\alpha_i} \right)$
Compute initial generation at all generator buses, $P_{g_i}^0 = \left(\lambda^0 - \beta_i \right) / 2\alpha_i$ for $i = 1, 2, 3, \ldots, NG$
Set iteration count $kp = 0$
A

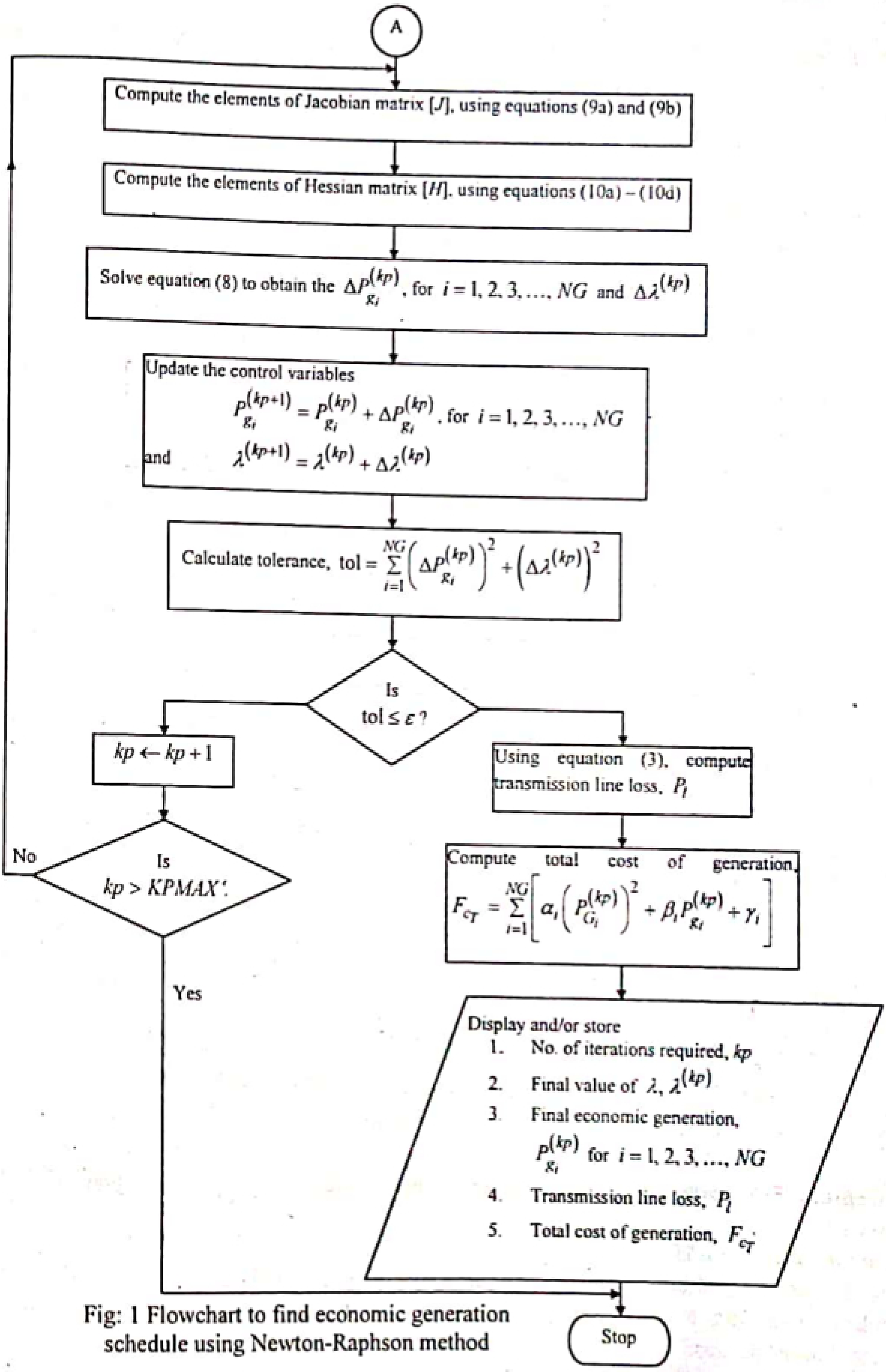


Fig: 1 Flowchart to find economic generation schedule using Newton-Raphson method

b) In a tree plant system the cost functions are given by **[WBUT 2010, 2013]**

$$F_1(P_1) = 500 + 7P_1 + 0.002P_1^2$$

$$F_2(P_2) = 400 + 6.5P_2 + 0.003P_2^2$$

$$F_3(P_3) = 200 + 7.2P_3 + 0.006P_3^2$$

The transmission loss is expressed as

$$P_l = 0.00002P_1^2 + 0.00005P_2^2 + 0.00001P_3^2$$

Assume total load to be 900 MW. Find the economic dispatch schedule.

Answer:

$$(IC)_A = 7 + 0.002 \times 2P_1$$

$$(IC)_B = 6.5 + 0.003 \times 2P_2$$

$$(IC)_C = 7.2 + 0.006 \times 2P_3$$

$$(IC)_A = (IC)_B = (IC)_C = \lambda$$

$$P_1 + P_2 + P_3 = 900\,\text{MW}$$

$$\lambda = \frac{900 + \left(\frac{7}{2\times 0.002} + \frac{6.5}{2\times 0.003} + \frac{7.2}{2\times 0.006}\right)}{\left(\frac{1}{2\times 0.002} + \frac{1}{2\times 0.003} + \frac{1}{2\times 0.006}\right)}$$

$$= \frac{900 + (7\times 250 + 6.5\times 166.67 + 7.2\times 83.33)}{(250 + 166.67 + 83.33)}$$

$$= \frac{900 + (1750 + 1083.355 + 600)}{500} = \frac{4333.355}{500} = 8.6667$$

$$P_1 = \frac{\lambda - \beta_1}{2\gamma_1} = \frac{8.6671 - 7}{2\times 0.002} = 1.6671 \times 250 = 416.775\,\text{MW}$$

$$P_2 = \frac{\lambda - \beta_2}{2\gamma_2} = \frac{8.6671 - 6.5}{2\times 0.003} = 361.19\,\text{MW}$$

$$P_3 = \frac{\lambda - \beta_3}{2\gamma_3} = \frac{8.6671 - 7.2}{2\times 0.006} = 122.25\,\text{MW}$$

$$P_l = 0.00002P_1^2 + 0.00005P_2^2 + 0.00001P_3^2$$

$$P_l = 0.00002 \times 416.775^2 + 0.00005 \times 361.190^2 + 0.0001 \times 122.25^2$$

$$= 3.474 + 6.52291 + 1.4945 = 11.4914\,\text{MW}.$$

4. Explain 'Flow only algorithm' with required equations. **[WBUT 2012]**

Answer:

Newton - Raphson Method

Newton-Raphson method is a practical and powerful method of solving non-linear algebric equations. It works faster, and is sure to converge in most cases as compared to Gauss-Siedel method. The only drawback is the large requirement of computer memory, which can be overcome through a compact storage scheme. Convergence can be considerably speeded up by performing the first iteration through the G.S. method, and using the values so obtained for solving N.R. iterations.

Set of n non-linear algebric equations is considered

$$f_i(x_1, x_2, \ldots, x_n) = 0 \text{ where } i = 1, 2, \ldots, n \qquad \ldots (1)$$

It is assumed that initial values of unknowns are as $x_1^0, x_2^0, \ldots, x_n^0$. Let $\Delta x_1^0, \Delta x_2^0, \ldots, \Delta x_n^0$ be the corrections to be found out, which on being added to the initial values, give the actual solution. Therefore,

$$f_i\left(x_1^0 + \Delta x_1^0, \ldots, x_n^0 + \Delta x_n^0\right) = 0; \; i = 1, 2, \ldots, n \qquad \ldots (2)$$

Expanding these equations around the initial values by Taylor series,

$$f_1^0\left(x_i^0, \ldots, x_n^0\right) + \left[\left(\frac{\delta f_i}{\delta x_1}\right)^0 \Delta x_1^0 + \ldots + \left(\frac{\delta f_i}{\delta x_n}\right)^0 \Delta x_n^0\right]$$

$$+\text{higher order terms} = 0 \qquad \ldots (3)$$

where $\left(\frac{\delta f_i}{\delta x_1}\right)^0 \ldots \left(\frac{\delta f_i}{\delta x_n}\right)^0$ are the derivatives of f_i w.r.t. $(x_1, x_2, \ldots, x_n)$ evaluated at $x_0^1 \ldots x_n^0$.

Neglecting the higher order terms, Eqn. (3) can be written in matrix form as: -

$$\begin{bmatrix} f_1^0 \\ \vdots \\ \vdots \\ f_n^0 \end{bmatrix} + \begin{vmatrix} \left(\frac{\delta f_1}{\delta x_1}\right)^0 & \cdots & \cdots & \left(\frac{\delta f_1}{\delta x_n}\right)^0 \\ \vdots & & & \vdots \\ \vdots & & & \vdots \\ \left(\frac{\delta f_n}{\delta x_1}\right)^0 & \cdots & \cdots & \left(\frac{\delta f_n}{\delta x_n}\right)^0 \end{vmatrix} \begin{bmatrix} \Delta x_1^0 \\ \vdots \\ \vdots \\ \Delta x_n^0 \end{bmatrix} \cong \begin{bmatrix} 0 \\ \vdots \\ \vdots \\ 0 \end{bmatrix} \qquad \ldots (4)$$

or in vector matrix form

$$f^0 + J^0 \Delta x^0 = 0 \qquad \ldots (5)$$

where J^0 is the Jacobian Matrix evaluated at x^0.

In compact notation,

$$J^0 = \left(\frac{\delta f(x)}{\delta x}\right)^0 \qquad \ldots (6)$$

In eqn. (5) Δx^0 is the vector of approximate correction.

This can be written in the form

$$\Delta x^0 = \left(-J^0\right)^{-1} f^0 \qquad \ldots (7)$$

Thus Δx^0 can be evaluated by calculating inverse of J^0. But in practice, evaluation of inverse matrix is not done, as it is computationally expensive and not really needed. Also inverse has to be found for every iteration. So eqn. (5) can be written in the form: -

$$J^0 \Delta x^0 \cong -f^0 \quad \dots (8)$$

These being a set of linear algebric equations, can be solved for Δx^0 efficiently by triangularization and back substitution. Up dated values of x are then,

$$x^1 = x^0 + \Delta x^0$$

In general, for the $(r+1)$ th iteration

$$\left(j\left(x^r\right)\right)\Delta x^r = -f\left(x^r\right)$$

or, $$\left(-J\left(x^r\right)\right)\Delta x^r = f\left(x^r\right) \quad \dots (9)$$

or, $$\left(-J^r\right)\Delta x^r = f^r$$

and $$x^{(r+1)} = x^r + \Delta x^r \quad \dots (10)$$

Iterations are continued till Eqn. (1) is satisfied to any desired accuracy i.e.

$$\left| f_i\left(x^r\right) \right| < \varepsilon \ \text{(a specified value)}, i = 1, 2, \dots, n$$

Thus each iteration involves the evaluation of $f\left(x^r\right)$, $j\left(x^r\right)$ and the correction Δx^r. It indicates that time taken for each iteration by NR method is more compared to the GS method, but the method converges in only a few iterations and the total computation time is much less than by the GS method.

5. a) How the transmission loss formula is expressed? Draw the flow chart for the solution of coordination equation considering transmission loss.
[WBUT 2012, 2014]

Answer:
In general form, the transmission loss can be expressed as

$$P_l = P^T BP + P^T B_0 + B_{00} \quad \dots. (1)$$

Eqn. (1) is the generalised transmission loss formula.
Flow chart for the solution of coordination equation considering transmission loss.

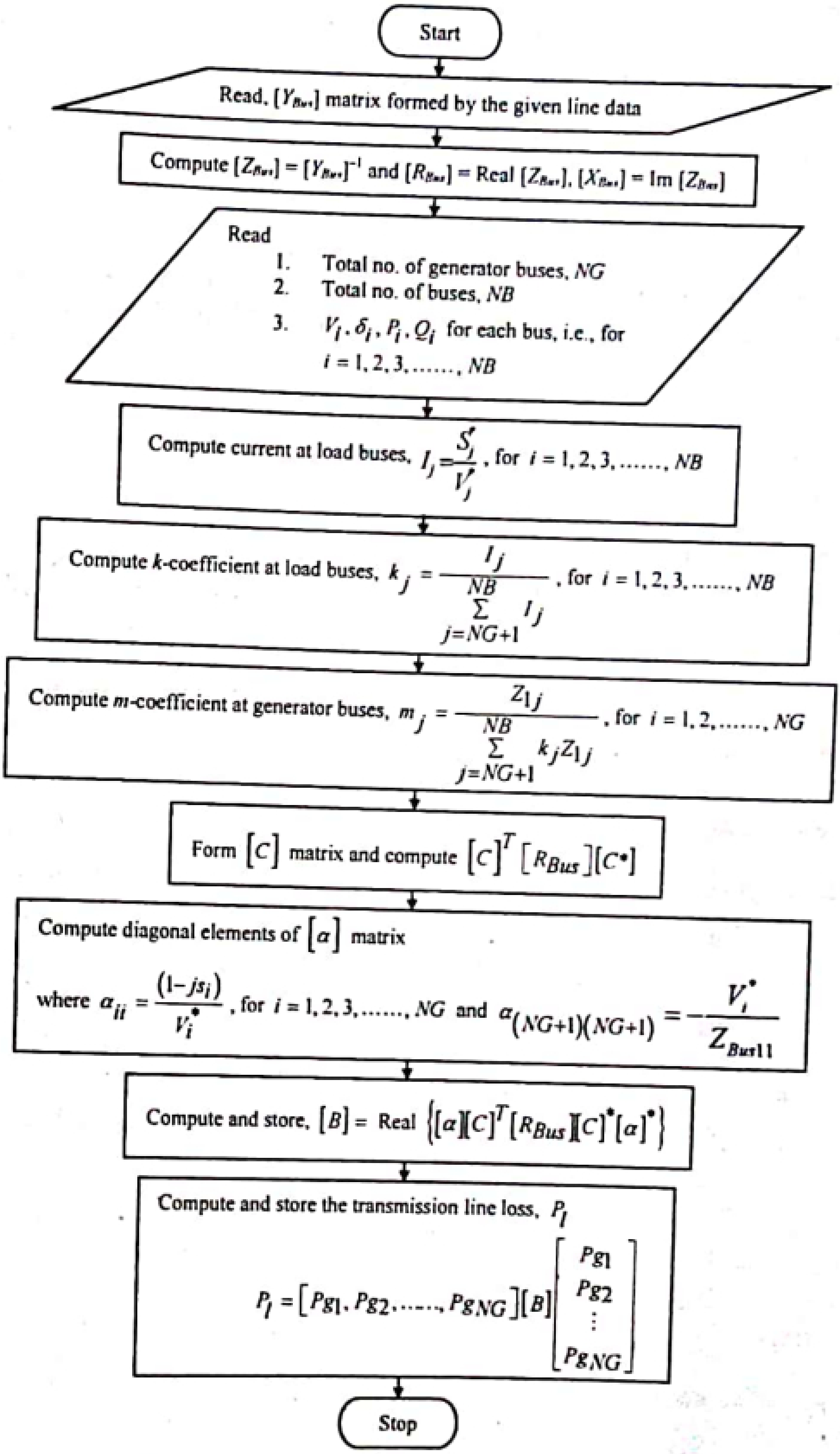


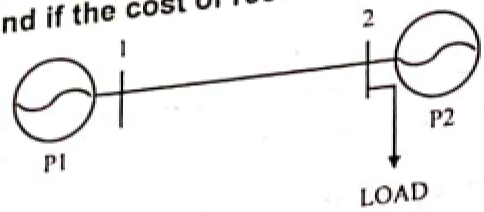
Fig: 1 Flowchart to find out loss coefficients (i.e., [B} matrix) and transmission line loss

In a system of N sources,

$$P_l = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{i0} P_i + B_{00}$$

where B terms are called loss coefficients or B-coefficients ($N \times N$ matrix) and is always symmetrical.

b) A two-bus system is shown in given figure. If a load of 125 MW is transmitted from plant 1 to the load, a loss of 15.625 MW is incurred. Determine the generation schedule and load demand if the cost of received power is Rs.24/MWhr.



The incremental production cost of the plants are **[WBUT 2012]**

$$\frac{dF_1}{dP_1} = 0.025P_1 + 15, \quad \frac{dF_2}{dP_2} = 0.05P_2 + 20$$

Answer:

Since the load is at bus 2 alone, therefore the losses in the line will not be affected by generator of plant 2.

$$P_L = B_{11}P_1^2 \text{ as } B_{12} = B_{21} = 0 \text{ and } B_{22} = 0$$

$$\therefore \quad 15.625 = B_{11} \times 125^2$$

$$B_{11} = .001$$

Now coordination equation $\frac{dF_1}{dP_1} + \lambda \frac{\partial P_L}{\partial P_1} = \lambda$

where $P_L = .001P_1^2$ or $\frac{dP_L}{dP_1} = .002P_1$

Substituting in the coordination equation for plant 1 we get

$$0.025P_1 + 15 + \lambda \times .002P_1 = \lambda$$

or, $$0.025P_1 + 0.048P_1 + 15 = 24$$

or, $$.073P_1 = 9$$

or, $$P_1 = 123.28 \text{ MW}$$

and from the coordination equation for plant 2

$$0.05P_2 + 20 = 24$$

or, $$P_2 = \frac{4}{.05} = 80 \text{ MW}$$

$\therefore$ The transmission loss $P_L = .001 \times 123.28^2 = 15.19$ MW

$\therefore$ The load $P_D = 123.28 + 80 - 15.19 = 188.1$ MW

6. Describe how a "Predicted load curve" helps a load dispatch engineer planning daily generation schedule for an interconnected system. **[WBUT 2013]**

Answer:

The most important planning aspect of the control centre is load forecasting and generation scheduling. Usually, short-term load forecasting is preferred where the forecasting is done on a daily basis. The forecasting mechanism ensures the prediction of the load curve as accurately as possible with reference to the load curves of the previous day, the corresponding day in the previous week and year and also taking into account weather conditions. A forecasting program includes some allowances in order to cope with special events, if any. An attempt is made to make forecasting method effective by incorporating the objective of economic operation in the forecasting program.

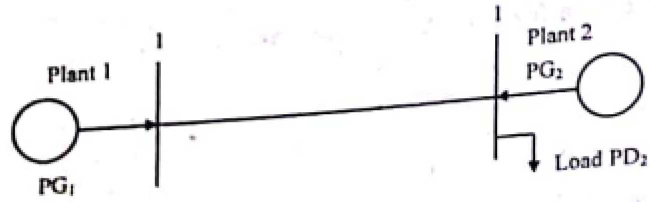
In some forecasting programs, sometimes the skill of a human operator and his/her experience is included, but usually load forecasting is attempted following automatic computer algorithms based on extrapolation methods. Implementation of forecasting programs based on artificial neural networks (ANN) is more effective and takes into account the role of weather, labour problem possibilities, disputes and contingencies.

The next planning aspect is to determine the power reserve in the system. A certain amount of power reserve is usually maintained in the interconnected system in excess of the load demand in order to provide the scope for maintenance of units and to have some spare capacity to meet minor contingencies. It also covers the errors in the estimation of the load demands. However, the capacity of reserve depends on the number and size of the generating units, maintenance requirements, characteristics of plants, security aspect, load level, seasonal factors etc. though active power reserve determination is more customary, still it is preferred to maintain some reserve of reactive power.

Plant scheduling and unit commitment are also very important planning aspects. Usually, scheduling is done in such a way that the major hydro-plants and the thermal plants serve as base load plants. Some low-merit thermal plants, captive plants and pumped storage plants serve as peak load plant. The base load plants operate for full time while the peak load plants are pressed into service for the required intervals of time only.

Maintenance of line loadability is also an important aspect of planning in control centres. The control centre should plan the routing of power flow through designated lines in order to avoid any overloading.

In proper system planning, the role of reactive power is very important. Proper reactive power flow can only maintain the voltage level at different load bus within specified values. Reactive generation at strategic locations is very important. Proper reactive power scheduling should also include adequate security margins. The reactive power flow control is also an important aspect. During light load period the system encounters reactive power surplus and the long lines may suffer from Ferranti effect. Shunt inductive reactors are then to be pressed into service to control the voltage at the remote ends of the lines. On the other hand, during heavy load period, the system voltage drops and it needs to inject capacitive reactive power into the system. Capacitive reactive compensators are then pressed into service.

7. 

A two bus system is shown in figure. If 100 MW is transmitted from plant 1 to the load, a transmission loss of 10 MW is incurred. Find the required generation for each plant and the power received by the load when the system is Rs. 25/MWH
The incremental fuel cost of the two plants are given below:

$$\frac{dC_1}{dP_{G_1}} = 0.02P_{G_1} + 16.0 \text{ Rs/MWH}$$

[WBUT 2014]

$$\frac{dC_2}{dP_{G_2}} = 0.04P_{G_2} + 20.0 \text{ Rs/MWH}$$

Answer:
Since the load is at bus 2 alone, P_2 will not have any effect on P_L, Therefore,

$$B_{22} = 0 \text{ and } B_{12} = 0 = B_{21}$$

Hence, $P_L = B_{11}P_1^2$

Since, $P_{D1} = 0,\ P_{G1} = P_1$

For, $P_{G1} = 100\text{MW},\ P_L = 10\text{MW}$

i.e., $10 = B_{11}(100)^2$ or, $B_{11} = 0.001(\text{MW})^{-1}$

For plant 1

$$\frac{\partial P_L}{\partial P_{G1}} = \frac{\partial P_L}{\partial P_1}$$

$$0.02P_{G1} + 16.00 = \lambda\left(1 - \frac{\partial P_L}{\partial P_1}\right) = \lambda(1 - B_{11}P_1)$$

$$= \lambda(1 - 2B_{11}P_{G1}) \quad \text{.... (1)}$$

and for plant 2 becomes

$$0.04P_{G2} + 20.00 = \lambda\left(1 - \frac{\partial P_L}{\partial P_2}\right)$$

Substituting the value of B_{11} and $\lambda = 25$, we get

$$P_{G1} = 128.57\text{MW}$$

$$P_{G2} = 125.00\text{MW}$$

The transmission power loss is

$$P_L = B_{11}P_1^2 = 0.001 \times (128.57)^2 = 16.53\text{MW}$$

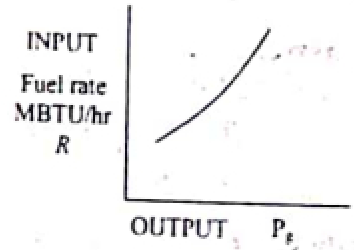
and the load is

$$P_{D2} = P_{G1} + P_{G2} - P_L = 128.57 + 125 - 16.53 = 237.04\,\text{MW}$$

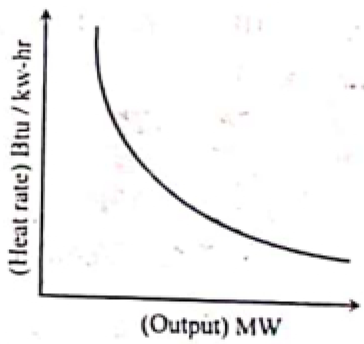
8. a) How input-output curve of a generator can be represented? Explain the efficiency and Heat-rate (H.R.) curve.
b) If *n*-number of generators are running in parallel, then under what conditions, cost of generation will be minimum?
c) The input-output curve of a 10 MW station is expressed as follows:
$I = 4\times10^6\left(10+8L+0.4L^2\right)$ **where *I* is the input KJ/hour and *L* is the output in MW.**
(i) Without plotting any curve find the load at which the minimum efficiency occurs?
(ii) Find the increase in input required to increase the station output from 3 to 5 MW by means of input-output curve and also by incremental rate curve.

Answer: **[WBUT 2017]**

a) The energy input can be obtained by measuring the coal tonnage used during the hour and then multiplying by the coal energy content in MBTU/ton. The plot the fuel input can be plotted in MBTU/hr as a function of the power output P_g in MW. Such a plot is called an input-output curve.



Heat-rate Curve: The heat rate curve plots the heat energy required per MWH of generated electrical output for the generator as a function of the generator's MW output. Thus, the heat rate curve indicates the efficiency of the unit over its operating range. Generally, units are least efficient at the minimum and maximum portions of their MW output capability and most efficient somewhere in the middle of their operating range. The vertical axis is plotted in MBTU/MWH and the horizontal axis is plotted in MW. You may interpret the heat rate for a generator producing X MW as follows: the heat rate indicates the amount of heat input energy per MWH of generation required to produce X MW of power.



The lower this number, the less input energy is required to produce each MWH of electricity.

b) The easiest way to setup n-number of generator parallel system is to use generators that are exactly alike, or at least have the same output rating and alternator pitch. Another flexible approach to backing up your power requirements is to have two or more generators of variable output. In either scenario, these can be connected in parallel with paralleling switchgear to achieve maximum output during peak requirement or the desired minimal output during other times.

Individual units operating in parallel are typically of smaller capacities. The engines used in these generators are usually industrial, on-road or high-volume engines designed with advanced manufacturing technology that gives them a high degree of reliability and low cost of generation per unit of power.

c) i) Load at which maximum efficiency occurs:

$$I = 4\times10^6\left(10+8L+0.4L^2\right)$$

or, $$\frac{I}{L} = 4\times10^6\left(\frac{10}{L}+8+0.4L\right)$$

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{L}{T}$$

$$\therefore \text{Efficiency, } \eta = \frac{1}{4\times10^6\left(\frac{10}{L}+8+0.4L\right)}$$

The efficiency will be maximum when $\left(\frac{10}{L}+8+0.4L\right)$ is minimum

$$\frac{d}{dL}\left(\frac{10}{L}+8+0.4L\right)=0$$

$$\therefore \frac{10}{L^2}+0.4=0$$

or, $$L^2 = \frac{10}{0.4} = 25$$

or, $$L = 5\text{MW}$$

Hence, the load at which the maximum efficiency occurs = 5MW (Ans.)

ii) Increase in input:

By input output curve:

When load, $L = 3\text{MW}$

Input, $I_3 = 4\times10^6\left(10+8\times3+0.4\times3^2\right) = 150.4\times10^6$ kJ/h

When load, $L = 5\text{MW}$

Input, $I_5 = 4\times10^6\left(10+8\times5+0.4\times5^2\right) = 240\times10^6$ kJ/h

Increase in input $= I_5 - I_3 = (240-150.4)\times10^6 = 89.6\times10^6$ kJ/h

9. Write short notes on the following:

a) Reactive power optimization [WBUT 2009, 2010]

b) Economic load dispatch [WBUT 2010, 2011]

c) Algorithm for computer solution of economic operation without considering losses in the system [WBUT 2013]

d) Load sharing between base load and peak load plants [WBUT 2013, 2014]

e) Active and reactive power optimization [WBUT 2014]

f) Predicted load curve [WBUT 2014]

Answer:

a) Reactive power optimization:

The power flow solution calculates power flows and determines bus voltages at an operating point. However, it is left to the engineering judgement of the system planner to determine optimum way of system operation considering operating objectives, operating and equipment constraints. Such an exercise is very tedious and time consuming for a practical system with large number of operating controls and constraints. A properly designed optimal power flow solution provides the best and most optimum practical solution to achieve improvement in a single or multiple hierarchical objectives while respecting various constraints on the system operation. An OPF can determine the most effective subset of controls and their solution for a given operating condition to improve the specified objectives. OPF can consider different objectives for improvement such as transmission loss minimization, voltage stability improvement and minimization of system operating cost.

OPF/RPO analysis module of Power Application is based on the dual LP programming approach and has the following features:

- Newton-Raphson load flow for solution at an operating point.
- OPF/RPO solution of multiple-islanded systems. The solution is available for each of the islands having a reference (slack) node. The reference node is automatically identified by the algorithm as the largest generator node in each island.
- Choice of objectives for the OPF/RPO (Transmission loss minimization, Voltage Stability improvement, Removal of operating violations, Economic dispatch).
- Optimal load flow.
- OPF/RPO control options are active power injections, reactive power injections, shunt compensations, series compensations, phase shifters, transformer taps.
- OPF/RPO sensitivity calculations with respect to the performance objective provides information for suitable location of shunt reactive power compensation and also identifies most effective controllers for optimization.
- No limits on the number of study cases and related reports in a single execution of the program.

b) Economic load dispatch:

Economic load dispatch (ELD) problem is a constrained optimization problem in power systems that have the objective of dividing the total power demand among the online participating generators economically while satisfying the various constraints. Over the year, many efforts have been made to solve the problem, incorporating different kinds of constraints or multiple objectives, through various mathematical programming and optimization techniques. The conventional methods include Lambda iteration method, base point and participation factors method, gradient method, etc. Among these methods, lambda iteration is most common one and owing to its ease of implementation, has been applied through various software packages to solve ELD problems. But for effective implementation of this method, the formulation needs to be continuous. The basic ELD considers the power balance constraint apart from the generating capacity limits.

However, a practical ELD must take ramp rate limits, prohibited operating zones, valve point loading effects and multi fuel options into consideration to provide the completeness for the ELD problem formulation. The resulting ELD is a non-convex optimization problem, which is a challenging one and cannot be solved by the traditional methods. An ELD problem with valve point loading has also been solved by dynamic programming (DP). Though promising results are obtained in small sized power systems while solving it with DP, it unnecessarily raises the length of solution procedure resulting in its vulnerability to solve large size ELD problems in stipulated time frames.

Moreover, evolutionary and behavioural random search algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO) etc, have previously been implemented on the ELD problem at hand. In addition, an integrated parallel GA incorporating ideas form simulated annealing (SA) and Tabu search (TS) techniques was also proposed in utilizing generator's output power as the encoded parameter. Yalcinoz has used a real-coded representation technique along with arithmetic genetic operators and elitistic selection to yield a quality solution. GA has been deployed to solve ELD with various modifications over the years. In a similar attempt, a unit independent encoding scheme has also been proposed based on equal incremental cost criterion. In spite of its successful implementation, GA does posses some weaknesses leading to longer computation time and less guaranteed convergence, particularly in case of epistatic objective function containing highly correlated parameters.

This paper proposes a new optimization approach, to solve the ELD using a hybrid Bacterial Foraging (BF) – Differential Evolution (DE) algorithm, which is a recently emerged stochastic optimization technique. Passion proposed the Bacterial Foraging optimization technique, where the social foraging behaviour of *Escherichia coli* (those living in our intestines) has been studied thoroughly. On the other hand DE is a simple Genetic Algorithm (GA), which implements a differential mutation operator that distinguishes it form traditional GA. In this work the chemotaxis step of bacterial foraging is made adaptive and merged with the DE in order to tackle real world problems in a more elegant way.

c) Algorithm for computer solution of economic operation without considering losses in the system:

The simplest procedure for the economic scheduling of thermal power generating plants, with losses neglected, is conventionally the λ-iteration method, the algorithm being presented below:

Step 1: An initial estimate of λ^0 is to be assigned.

Step 2: To compute P_i^0 corresponding to the following numerical relation.

$$P_i^0 = \alpha_i\left(\lambda_i^0\right)^2 + \beta_i\left(\lambda_i^0\right) + \gamma_i$$

(λ_i^0 being identical to the initial estimate of the λ of the i-th generator)

Step 3: To compute $\sum_{i=1}^{N} P_i^0$

Step 4: To check whether $\sum_{i=1}^{N} P_i^0 = P_{load}$ is satisfied.

[Usually $\sum_{i=1}^{N} P_i^0 - P_{load} = \varepsilon \leq 0.001$ (a tolerance)]

Step 5: If $\sum_{i=1}^{N} P_i^0$ becomes less than P_{load}, it is required to assign a new value of $\lambda^1[=\lambda^0 + \Delta\lambda]$ and go to step 2. Computational loop is continued till $\sum_{i=1}^{N} P_i - P_{load} = \varepsilon$.

Step 6: If $\sum_{i=1}^{N} P_i^0$ becomes greater than P_D in step 4, a new value of $\lambda^1[=\lambda^0 - \Delta\lambda]$ is assigned and then it is required to proceed to step 2. Computational loop is continued till $\sum_{i=1}^{N} P_i - P_{load} = \varepsilon$.

Step 7: To stop, if step 4 is satisfied.

If the effects of power limits are to be considered, a partial modification is needed in the algorithm. As λ is increased or decreased in the iterative process, if a particular generator loading P_i reaches the prescribed limit $\left(P_{i_{max}} \text{ or } P_{i_{min}}\right)$ its loading from now is held fixed at this value and the balance of the load demand is then shared between the remaining generation on equal incremental cost basis. This operation is also said to be optimal.

d) Analysis of Load Sharing between Base Load and Peak Load Stations:

If the combination of two plants/services is to be used, in that case the next problem is sharing of load between the plants. It is not desirable to transfer all the loads to one plant and also depending upon the operating characteristics of the various plants the load between the plants should be so decided that overall economy is achieved. This load sharing can be easily manipulated by viewing the load duration curve of the plants as follows:

Fig. 1 shows a load duration curve.

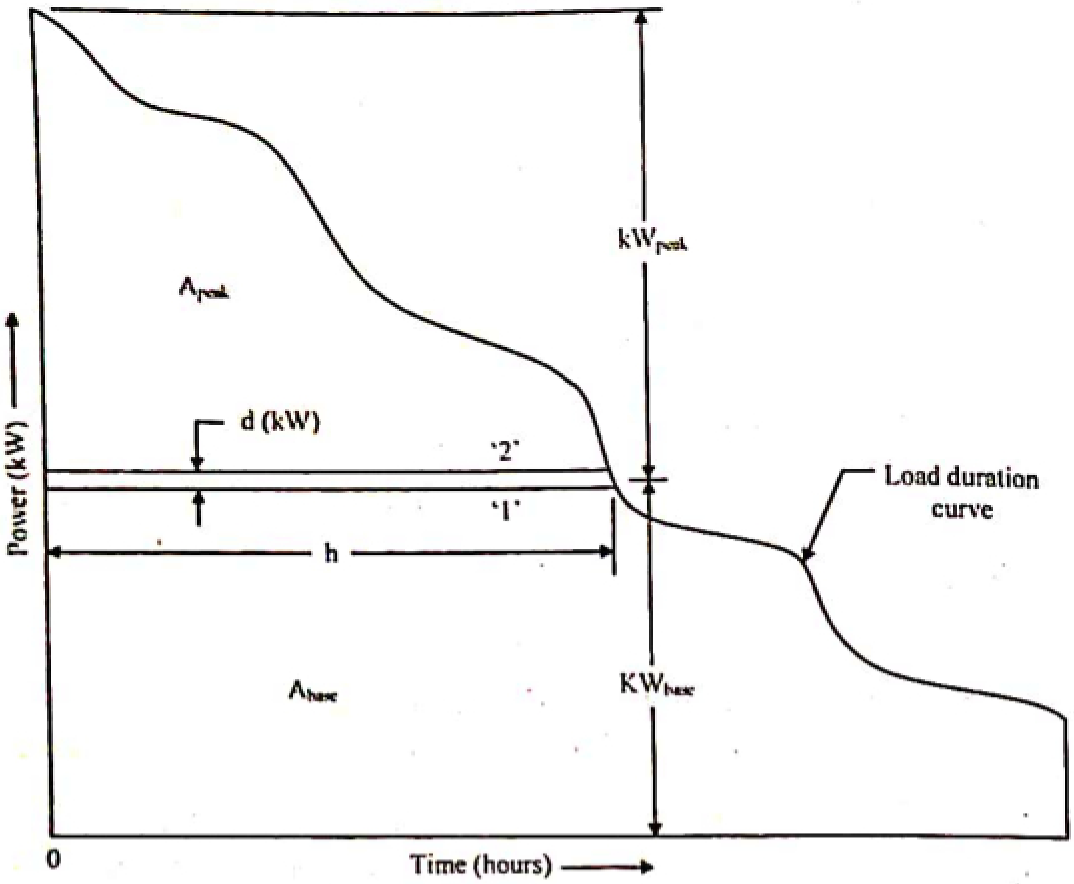


Fig: 1 Load duration curve of the plants

Let, A_{peak} = Area of curve for peak load plant,

A_{base} = Area of curve for base load plant,

kW_{peak} = Load for peak load plant,

kW_{base} = Load for base load plant,

C = Total operating cost of the combination and

h = Hours per year.

Let the base load be supplied by a plant having the annual cost equation as

$$(Rs.)_1 = a_1 + b_1 kW + c_1 kWh \quad \text{.... (1)}$$

For the plant supplying the peak load let the equation be

$$(Rs.)_2 = a_2 + b_2 kW + c_2 kWh \quad \text{.... (2)}$$

Since the base load plant is operated most of the time, therefore, normally a plant having $c_1 < c_2$ us used for meeting the base load.

Let $b_1 > b_2$.

Let the load between the two plants (Fig. 1) be divided by arbitrary line drawn on the load duration curve represented by '1'. Under these conditions let kW_{base} be the kW for base load plant and let kW_{peak} be the load for peak load plant.

In this case the total operating cost of the combination is given as:

$$C_1 = a_1 + a_2 + b_1 \text{kW}_{\text{base}} + b_2 \text{kW}_{\text{peak}} + c_1 A_{\text{base}} + c_2 A_{\text{peak}} \quad \text{.... (3)}$$

Now, if the base power is extended by the amount of $d(\text{kW})$ to line '2', the total operating cost of the combination will modify as follows:

$$C_2 = a_1 + a_2 + b_1\left(\text{kW}_{\text{base}} + d\text{kW}\right) + b_2\left(\text{kW}_{\text{peak}} - d\text{kW}\right)$$
$$+\left(A_{\text{base}} + d\text{kW} \times h\right)c_1 + \left(A_{\text{peak}} - d\text{kW} \times h\right)c_2 \quad \text{.... (4)}$$

The change in cost,

$$C_2 - C_1 = \left(b_1 - b_2\right)d\text{kW} + \left(c_1 - c_2\right)d\text{kW} \times h \quad \text{.... (5)}$$

The optimum condition requirements are that above change must be zero, i.e.,

$$h = \frac{b_1 - b_2}{c_2 - c_1} \quad \text{.... (6)}$$

Thus it is possible to share the load between the plants due to which overall economy in operation is effected.

The method described above for distributing the load among the two power plants in an interconnected system can be used for any type of plants as (i) Thermal and diesel, (ii) Thermal and hydro, (iii) Nuclear and hydro and so on.

e) Active and reactive power optimization:

Reactive power optimization is an important function both in planning for the future and day-to-day operations of power systems. It uses all the reactive power sources judiciously, while planning suitable location and size of VAR compensation in a system. With increasing fuel costs and capital investments, economics of reactive power planning and scheduling have a tremendous effect on the profitable and reliable operation of a power system.

Electric power systems all over the world are moving towards deregulated electricity markets. To control frequency, stability, security and voltage profile of the system and to ensure the generation and transmission, ancillary services like frequency control, network control and system restart are needed. Reactive power and voltage control is one of the ancillary services to maintain voltage profile through injecting or absorbing reactive power in electricity market. A number of optimization techniques have been proposed in the literature to solve the reactive power optimization problems.

To minimize the active power loss and the voltage deviation under some operational constraints, reactive power optimization in power system need find a optimal solution, containing the reactive power output of generators (or voltage of generators V_G), the reactive power compensation capacity (including the capacity of shunt capacitors Q_c and reactance Q_L) and transformer tap-settings (T). It has a significant influence on security and economic operation of power systems.

The augmented objective function is to minimize the active power loss ΔP and the voltage deviation ΔV_i

$$F = \min\left[\Delta P + \lambda \sum_{i=1}^{n} \Delta V_i^2\right] \qquad .... (1)$$

where n is the node number and λ is the equivalent coefficient of nodal voltage deviation ΔV_i. Supposing $V_{i\max}$ is the maximum voltage of node i, $V_{i\min}$ is the minimum voltage of node i, the definition of ΔV_i is given as below:

$$\Delta V_i = \begin{bmatrix} V_i - V_{i\max} & (V_i > V_{i\max}) \\ 0 & (V_{i\min} \le V_i \le V_{i\max}) \\ V_{i\min} - V_i & (V_i < V_{i\min}) \end{bmatrix} \qquad .... (2)$$

Equality constraints contain active and reactive power balance constrains in the following.

$$\Delta P_i = P_{Gi} - P_{Li} - V_i \sum_{j \in i} V_j \left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) = 0 \qquad .... (3)$$

$$\Delta Q_i = Q_{Gi} - Q_{Li} + N_{ci}\Delta Q_{ci} - N_{Li}\Delta Q_{Li} - V_i \sum_{j \in i} V_j \left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) = 0$$

where P_{Gi} and Q_{Gi} are active power and reactive power supply of bus i, P_{Li} and Q_{Li} are active and reactive load of bus i, V_i and V_j is the voltage module of bus i and j, θ_{ij} is the difference angle between bus i and j. ΔQ_{ci} and ΔQ_{Li} are the unit capacity of capacitor and reactance of bus i. N_{ci} and N_{Li} are working span of capacitor and reactance of bus i.

Inequality constraints contain:

$$V_{Gi\min} \le V_{Gi} \le V_{Gi\max}$$
$$N_{ci\min} \le N_{ci} \le N_{ci\max}$$
$$N_{Li\min} \le N_{Li} \le N_{Li\max}$$
$$T_{ij\min} \le T_{ij} \le T_{ij\max}$$
$$Q_{Gi\min} \le Q_{Gi} \le Q_{Gi\max}$$
$$S_{ij} \le S_{ij\max}$$

where V_{Gi}, N_{ci}, N_{Li}, T_{ij} are voltage of generator, working span of capacitor, working span of reactance and transformer tap. All of them are control variables. Q_{Gi} and S_{ij} are reactive power output of generator i and power flow on branch ij and they are state variables.

f) Predictive Load Curve:

Unit commitment refers to committing a generating unit to be online and generating electricity during a specific time slot, so that the generation requirements of the system can be met and other EMS functions can take necessary action. Generating stations such as thermal units require quite an amount of time to come up to the required speed, generate the required voltage and get synchronized to the system. Once the unit is committed, it should be available to supply load; however, to leave the generating unit committed all the time becomes an expensive affair. It makes much more sense to de-commit the units when they are not required. Once the load forecasting is done, depending on the requirement, it is economical to know when each unit is to be committed and de-committed for specific time slots.

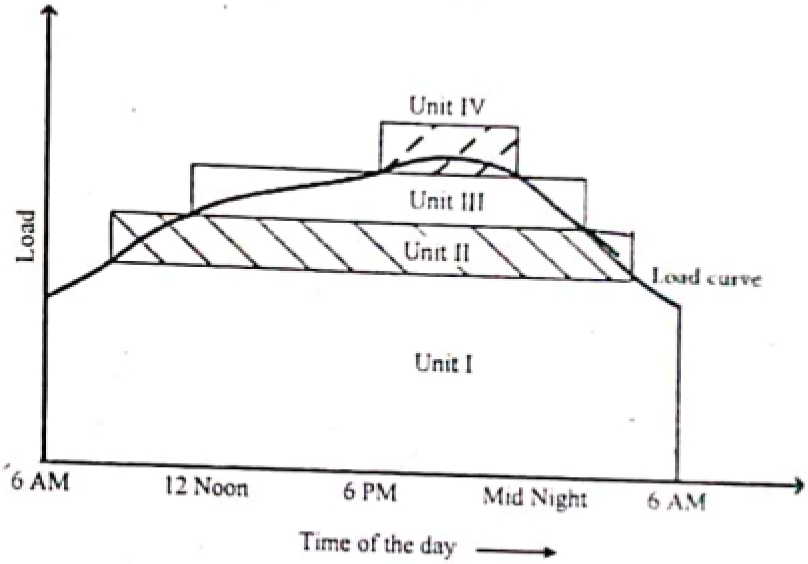


Fig: 1 Unit commitment of four generating stations

Fig. 1 illustrates a simple unit commitment example where four units are supplying the load on the system and the units are committed and made available, de-committed and turned off and when there is a demand as seen from the predicted load curve.

The unit commitment problem is not as simple as discussed above, as each power utility will be working under a large number of constraints and laws and these have to be nuilt into the unit commitment problem, so that an optimal economical schedule is available for the operations.

Keeping ample spinning reserve as per the directive of the regulatory authority in each country is a constraint. Spinning reserve is the difference between the total generation capacity available of all the units online (spinning) and the load supplied including the losses. It gives an indication of how much extra capacity the system possesses to take care of an emergency, whether the sudden loss of a generating unit or a transmission line. Each utility will have norms for the percentage of generation or load as spinning reserve. Typically, the reserve is equivalent to the largest generation unit, so that the sudden loss of any unit can be handled. The spinning reserve could also be a mix of stations that can be quick started with traditional thermal plants. The spinning reserve can also be geographically distributed so that the transmission corridor congestion may not pose a threat.

Other constraints for unit commitment include the maximum uptime and minimum downtime for thermal units, startup and shutdown time and costs, hydro units that may be in a state where they have to run continuously due to rain and flooding of the reservoir and other generating units that may have to conserve fuel. Respective utilities may also have their own constraints to be considered while meeting their unit commitment.

The unit commitment defines a specific number of time intervals and the number of units to commit. The permutations and combinations can be exponentially high; however, once the constraints are set and the actual system loading comes into the picture, the number of feasible solutions diminishes. The usual methods used are Lagrange relation, dynamic programming and priority list schemes that are well established.

STATE ESTIMATION AND LOAD FORECASTING

Multiple Choice Type Questions

1. Frequency variation occurs in power systems due to [WBUT 2009]
   a) unbalance between active power generation and load
   b) unbalance between reactive power generation and load
   c) unbalance between MVA demand and MVA generation
   d) unbalance between the loading at different phases

Answer: (a)

2. Load frequency control is achieved by properly matching the individual machines [WBUT 2009]
   a) reactive power
   b) generated voltage
   c) turbine input
   d) turbine and generator ratings

Answer: (d)

3. State estimation is done to know [WBUT 2012, 2014, 2015]
   a) best estimate of voltage magnitude and phase angle of each and every bus
   b) economic dispatch solution
   c) system power loss
   d) load flow solution

Answer: (a)

4. Short term load forecasting is for [WBUT 2015]
   a) state estimation
   b) planning for generation growth
   c) allocation of spinning reserve
   d) contingency analysis

Answer: (d)

5. Power system state estimation is normally a [WBUT 2015]
   a) linear problem
   b) nonlinear problem
   c) quadratic problem
   d) none of these

Answer: (c)

6. Normally Z bus matrix is a [WBUT 2015]
   a) null matrix
   b) unity matrix
   c) sparse matrix
   d) full matrix

Answer: (d)

Short Answer Type Questions

1. What is state estimation? Why is it important in any power system operation and control? **[WBUT 2010]**

OR,

What is state estimation? How is it relevant to power system operation and control? **[WBUT 2011, 2014, 2015]**

Answer:

State estimation process of a power system is nowadays very much essential. The objective of this process is to obtain the best possible values of bus voltage (magnitudes and angles) by using the available network data. Most state estimation algorithms in practical use are solved as weighted least squared (WLS) problem as the process of state estimation. It estimates true value of the state variables.

In a power system, the state variables are the voltage magnitudes and phase angles at the buses. The inputs to the state estimation process are imperfect power system measurements. The purpose of state estimation is to design the best estimate of the system voltage and phase angles, though there are errors in the measured quantities and there may be redundant measurements in the input. The output data can be used for carrying out several real time studies and security analysis.

2. Write down about the different load forecasting techniques. **[WBUT 2012]**

Answer:

Load forecasting techniques can be classified in two categories:

(i) *Time series based*

(ii) Regression based

In the time series approach, the load pattern is treated as a time series signal with known periodicities. It does not consider weather variables.

In the regression approach, firstly the available weather variables are selected and then functional elements are assumed. Finally, the co-efficients of linear combination are found. Regression approaches are either linear or piecewise linear and hence, do not yield accurate forecast.

Recent advances in the area of artificial neural (ANN) has opened new vistas for such applications like non-linear smoothing and interpolation, ability to learn complex non-linear mappings and adapting themselves to different statistical distribution. ANN can generalize from previous examples to new ones, can learn from experience, abstract essential characteristics from inputs containing irrelevant data, and modify their behavior in response to their environments.

ANN are biologically inspired and try to emulate the functions of a human brain. The basic elements of an ANN is an artificial neuron analogus to a biological neuron. The artificial neurons are then organized in different network structures to form an ANN. There are many ANN structures are available. The accuracy is much better and largely depends upon training set data accuracy. Nowadays ANN based short term load forecasting used exptensively.

3. Explain what do you mean by state estimation of power system. How does it differ from load flow?

Answer: **[WBUT 2013]**

1st Part: ***Refer to Question No. 1 of Short Answer Type Questions.***

2nd Part:

On the face of it, it may appear as if there is not much of a difference between load flow calculations and static-state estimation. But, this is a superficial point of view. In load flow studies, it is taken for granted that the date on which calculations are based are absolutely free from error. On the other hand, in state-estimation method, accuracy of measurement on modeling errors are taken into account by ensuring redundancy of input data. This means that the number of input data 'm' on which calculations are based are much more than the number of unknown variables 'n' whose knowledge completely specifies the system. The more the redundancy, the better it is from an estimation point of view. But redundancy has a price to pay in terms of installation of additional measuring equipment and communication facilities.

Long Answer Type Questions

1. State the different load modellings used in load forecasting techniques. Indicate the limitations of these models.

Answer: **[WBUT 2010]**

Load forecasting is a method to estimate the load for a future time point from the available past data.

1. Estimation of Average and Trend Terms of Deterministic Part of Load

To obtain the simplest possible estimate of deterministic part of load, $d(\sigma)$, we must use the equation of straight line with zero intercept for trend curve fitting. Therefore, we can write, $d_d(\sigma) = \overline{d}_d + \beta\sigma + e(\sigma)$ .... (1)

where, $\overline{d}_d$ = average or the mean value of $d_d(\sigma)$,

$\beta\sigma$ = trend term that grows linearly with time, σ,

$e(\sigma)$ = error in modelling the complete load using the average and the trend terms.

To estimate $d_d(\sigma)$, it is required to find the most accurate estimate of the values of $\overline{d}_d$ and β. The method of LSE is helpful regarding estimating the error term $e(\sigma)$. Let us use LSE method to estimate $\overline{d}_d$ and β. Following earlier discussion in state estimation, the estimation index *f* may be written as

$$f = E\{e^2(\sigma)\} \quad \text{.... (2)}$$

where $E(.)$ represents the expectation operation. The estimation index f must be minimum for best estimation with respect to the state variable to be estimated (here $\bar{d}_d$ and β). This is possible by considering upto first order term in Taylor series expansion. We can write from equation (1).

$$E\{\bar{d}_d - d_d(\sigma) + \beta\sigma\} = 0 \quad \text{.... (3)}$$

$$E\{\beta\sigma^2 - d_d(\sigma)\sigma + \bar{d}_d\sigma\} = 0 \quad \text{.... (4)}$$

Since the expectation operation has no effect on the constant quantities, the above two equations ca be written as

$$\bar{d}_d = E\{d_d(\sigma)\} - \beta E\{\sigma\} \quad \text{.... (5)}$$

$$\beta = E\{d_d(\sigma)\sigma\} - \frac{\bar{d}_d E\{\sigma\}}{E\{\sigma^2\}} \quad \text{.... (6)}$$

Here $\bar{d}_d$ and β may be assumed to be constant with respect to time. Replacement expectation operation by the time averaging formula and assuming total N number of statistical data available, from equations (5) and (6) we can write (using the concepts in statistics).

$$\bar{d}_d = \frac{1}{N}\left[\sum_{\sigma=1}^{N} d_d(\sigma) - \beta\sum_{\sigma=1}^{N}\sigma\right] \quad \text{.... (7)}$$

$$\beta = \frac{\frac{1}{N}\sum_{\sigma=1}^{N}\{d_d(\sigma)\sigma\} - \frac{1}{N}\bar{d}_d\sum_{\sigma=1}^{N}\sigma}{\frac{1}{N}\sum_{\sigma=1}^{N}\sigma^2}$$

or, $$\beta = \frac{\sum_{\sigma=1}^{N}\{d_d(\sigma)\sigma\} - \bar{d}_d\sum_{\sigma=1}^{N}\sigma}{\sum_{\sigma=1}^{N}\sigma^2}$$

or, $$\beta = \frac{\sum_{\sigma=1}^{N} d_d(\sigma)\sigma - \left[\frac{1}{N}\left\{\sum_{\sigma=1}^{N} d_d(\sigma) - \beta\sum_{\sigma=1}^{N}\sigma\right\}\right]\sum_{\sigma=1}^{N}\sigma}{\sum_{\sigma=1}^{N}\sigma^2}$$ [using equation (7)]

or, $$\beta = \frac{N\sum_{\sigma=1}^{N} d_d(\sigma)\sigma - \sum_{\sigma=1}^{N} d_d(\sigma)\sum_{\sigma=1}^{N}\sigma + \beta\left[\sum_{\sigma=1}^{N}\sigma\right]^2}{N\sum_{\sigma=1}^{N}\sigma^2}$$

or, $$\beta N\sum_{\sigma=1}^{N}\sigma^2 = N\sum_{\sigma=1}^{N}d_d(\sigma)\sigma - \sum_{\sigma=1}^{N}d_d(\sigma)\sum_{\sigma=1}^{N}\sigma + \beta\left[\sum_{\sigma=1}^{N}\sigma\right]^2$$

or, $$\beta\left[N\sum_{\sigma=1}^{N}\sigma^2 - \left\{\sum_{\sigma=1}^{N}\sigma\right\}^2\right] = N\sum_{\sigma=1}^{N}d_d(\sigma)\sigma - \sum_{\sigma=1}^{N}d_d(\sigma)\sum_{\sigma=1}^{N}\sigma$$

$$\therefore \quad \beta = \frac{N\sum_{\sigma=1}^{N}d_d(\sigma)\sigma - \sum_{\sigma=1}^{N}d_d(\sigma)\sum_{\sigma=1}^{N}\sigma}{N\sum_{\sigma=1}^{N}\sigma^2 - \left[\sum_{\sigma=1}^{N}\sigma\right]^2} \qquad \text{.... (8)}$$

Equations (7) and (8) can be effectively used to estimate the average and trend coefficient of deterministic part of any load data. It should be noted here that equations (7) and (8) hold good only if $d_d(\sigma)$ is assumed to be stationary (because ergodic hypothesis does not hold good if the data processed is non-stationary (time varying) one. If $d_d(\sigma)$ is non-stationary, then it is also possible to use equations (7) and (8) to estimate $\overline{d}_d$ and β. Provided $d_d(k)$ may be assumed to be stationary for certain time (i.e., certain block of data available) and equations (7) and (8) may be used for each time block separately.

Limitation of the Method

The data processed in equations (7) and (8) may not be adequate for statistical calculations and therefore, the estimate available may be erroneous. In addition to this, the statistical data to be processed for state estimation may be non-stationary, which will induce some error in the estimated values.

2. Generalised Load Modelling

The generalised load model should contain the second and higher order terms on the right-hand side of equation (1) and it can be written as

$$d_d(\sigma) = \sum_{i=1}^{L}\beta_i\sigma_i + e(\sigma) \qquad \text{.... (9)}$$

where the coefficient β_i needs to be computed from previous data available. It is obvious that the load model described in equation (9) is a non-linear function of the time σ and it requires the L coefficients to be estimated.

The exponential form is another approach to non-linear load modeling, which may be written as

$$d_d(\sigma) = \gamma e^{\beta k} + e(\sigma) \qquad \text{.... (10)}$$

Here, there are only two unknown coefficients, γ and β. In addition to this, the exponential model can easily be transformed into a linear form by taking the natural log of the given data. In both the cases, the method of LSE can easily be used to estimate the model parameters from the given historical data.

3. Estimation of Stochastic Part of Load

From equation $d(\sigma)=d_d(\sigma)+d_s(\sigma)$, it may be written that

$$d_s(\sigma)=d(\sigma)-d_d(\sigma) \quad \text{.... (11)}$$

After modelling of the deterministic part, now the task is how to model and estimate the stochastic part of load.

4. Time Series Approach

The auto-regressive model is the simplest form of this stochastic time series models. This model is used to represent the behaviour of a zero mean stationary stochastic sequence. In this method, the data for $d_s(\sigma)$ should ensure a zero mean. The series of data variable must be assumed to be stationary and then only it may be possible to identify a suitable auto-regressive model for this sequence.

Auto-Regressive (AR) Models:

The *n*-th order auto-regressive [AR(*n*)] model of sequence $d_s(\sigma)$ can be expressed as

$$d_s(\sigma)=\sum_{i=1}^{n} a_i d_s(\sigma-i)+w(\sigma) \quad \text{.... (12)}$$

where the coefficients a_i are the model parameters and $w(\sigma)$ is a zero mean. The solution of equation (12) may represent a stationary process if the roots of the characteristics equation given by

$$1-a_1z^{-1}-a_2z^{-2}-\ldots-a_nz^{-1}=0 \quad \text{.... (13)}$$

remain inside the unit circle in the z-plane for the particular values of coefficients a_i. The auto-correlation functions being first computed from the given data and the model order *n* and the parameter vector *a* [i.e., coefficients a_i] being estimated, the next task is to estimate the statistics of the noise process $w(\sigma)$. The best estimate of $w(\sigma)$ may be obtained from the residual $e(\sigma)=d_s(\sigma)-\hat{d}_s(\sigma)$, where the estimate $\hat{d}_s(\sigma)$ is determined from equation (12).

$$\hat{d}_s(\sigma)=-\sum_{i=1}^{n} a_i d_s(\sigma-i) \quad \text{.... (14)}$$

The variance σ^2 of $w(\sigma)$ is then given by

$$\sigma^2=-\frac{1}{n}\sum_{i=1}^{n} e^2(\sigma) \quad \text{.... (15)}$$

Auto-Regressive Moving-Average (ARMA) Models:

The AR model may not be helpful in some cases; the order n of the model is required to be very high to represent the available load behaviour. In such a case, ARMA (n, m) model is used and is given by

$$d_s(k) = -\sum_{i=1}^{n} a_i d_s(\sigma - i) + \sum_{j=1}^{n} \beta_j w(\sigma - j) + w(\sigma) \quad \text{.... (16)}$$

In this case, the task is to estimate two structural parameters (n and m), model parameters (a_i and b_j) and the σ^2 of the noise term $w(\sigma)$.

5. Kalman Filtering Approach

The time series approaches are employed in the load forecasting processes due to its relative simplicity of the model forms. But, the available statistical information about the load data is not utilized properly in these methods. In addition to this, the model identification problem is quite difficult in ARMA model. To avoid these difficulties, the Kalman filtering techniques are used.

2. Estimate two values random variables *x* by weighted LSE method for

$$W = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0.5 & 0 \\ 0 & 0 & 0.1 \end{bmatrix} \qquad H = \begin{bmatrix} 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad y = \begin{bmatrix} 0.5 \\ 0.45 \\ 0.51 \end{bmatrix}$$

[WBUT 2012]

Answer:

Given $H = \begin{bmatrix} 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad \therefore H^T = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}$

$$WH = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0.5 & 0 \\ 0 & 0 & 0.1 \end{bmatrix} \times \begin{bmatrix} 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0.5 & 0 \\ 0 & 0.1 \end{bmatrix}$$

$$H^T WH = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 0.5 & 0 \\ 0 & 0.1 \end{bmatrix} = \begin{bmatrix} 1.5 & 1 \\ 1 & 1.1 \end{bmatrix},$$

$$(H^T WH)^{-1} = \begin{bmatrix} 1.5 & 1 \\ 1 & 1.1 \end{bmatrix}^{-1} = \begin{bmatrix} 1.6923 & -1.5385 \\ -1.5385 & 2.3077 \end{bmatrix}$$

$$\therefore L=(H^TWH)^{-1}H^TW=\begin{bmatrix}1.6923 & -1.5385\\ -1.5385 & 2.3077\end{bmatrix}\begin{bmatrix}1 & 1 & 0\\ 1 & 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0 & 0\\ 0 & 0.5 & 0\\ 0 & 0 & 0.1\end{bmatrix}$$

$$=\begin{bmatrix}1.6923 & -1.5385\\ -1.5385 & 2.3077\end{bmatrix}\begin{bmatrix}1 & 0.5 & 0\\ 1 & 0 & 0.1\end{bmatrix}=\begin{bmatrix}0.1538 & 0.8462 & -0.1538\\ 0.7692 & -0.7692 & 0.2308\end{bmatrix}$$

However, $y=\begin{bmatrix}y_1\\ y_2\\ y_3\end{bmatrix}=\begin{bmatrix}0.5\\ 0.45\\ 0.51\end{bmatrix}$

Hence $\hat{x}=Ly=\begin{bmatrix}0.1538 & 0.8462 & -0.1538\\ 0.7692 & -0.7692 & 0.2308\end{bmatrix}\begin{bmatrix}y_1\\ y_2\\ y_3\end{bmatrix}$

$$=\begin{bmatrix}0.1538y_1+0.8642y_2-0.1538y_3\\ 0.7692y_1-0.7692y_2+0.2308y_3\end{bmatrix}$$

$$=\begin{bmatrix}0.3792\\ 0.1562\end{bmatrix}\quad [\because y_1=0.5,\ y_2=0.45,\ y_3=0.51]$$

Here the weighing matrix W suggests that the estimate of x is more dependent on y_1. Let us justify the estimate by checking the elements of covariance matrix ξ.

Let us assume $R=\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}$

Using $\xi=LRL^T$ we get

$$=\begin{bmatrix}0.1538 & 0.8462 & -0.1538\\ 0.7692 & -0.7692 & 0.2308\end{bmatrix}\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}0.1538 & 0.7692\\ 0.8462 & -0.7692\\ -0.1538 & 0.2308\end{bmatrix}$$

$$=\begin{bmatrix}0.1538 & 0.8462 & -0.1538\\ 0.7692 & -0.7692 & 0.2308\end{bmatrix}\begin{bmatrix}0.1538 & 0.7692\\ 0.8462 & -0.7692\\ -0.1538 & 0.2308\end{bmatrix}=\begin{bmatrix}0.7633 & -0.5680\\ -0.5680 & 1.2367\end{bmatrix}$$

So, the elements of covariance matrix ξ are quite high. Therefore, the above estimate of x is not very accurate.

Next we assume $\qquad W=R^{-1}=\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}$

Then $$L=\begin{bmatrix}0.3333 & 0.6667 & -0.3333\\ 0.3333 & -0.3333 & 0.6667\end{bmatrix}$$

and $$\hat{x}=\begin{bmatrix}0.2967\\ 0.3567\end{bmatrix}$$

$$\xi=\begin{bmatrix}0.6667 & -0.3333\\ -0.3333 & 0.6666\end{bmatrix}$$

Here, the elements of covariance matrix ξ are comparatively lower than the earlier estimate. Therefore, the above estimate of x is acceptable.

3. If measurement vector $M=(Q^T)[R^{-1/2}]M^{meas}$, derive the estimation of state variable quantities X_1^{est} and X_2^{est} in relation to control variables U_{11}, U_{12} and U_{22} for three elements of $M(M_1, M_2, M_3)$. R is the diagonal matrix of the variances in the normal distribution of residual errors. **[WBUT 2013]**

Answer:

If we have a sample of m measurements given by vector z, and n states (voltage magnitude and angle), $n<m$ and e is m dimensional vector of measurement errors. Here h is the m dimensional non-linear function vector relating measurements to the state vector. Then the measurement vector can be written in the matrix form as

$$z=\begin{bmatrix}z_1\\ z_2\\ \vdots\\ z_m\end{bmatrix}=\begin{bmatrix}h_1(x_1,x_2,\dots\dots,x_n)\\ h_2(x_1,x_2,\dots\dots,x_n)\\ \vdots\\ h_m(x_1,x_2,\dots\dots,x_n)\end{bmatrix}+\begin{bmatrix}e_1\\ e_2\\ \vdots\\ e_m\end{bmatrix}=h(x)+e \qquad \dots.(1)$$

The weighted least square estimator will minimize the following objective function:

$$\min J(x)=\sum_{i=1}^{m}(z_i-h_i(x))^2/R_{ii} \qquad \dots.(2)$$

where $$R=\begin{bmatrix}\sigma_1^2 & & & \\ & \sigma_2^2 & & \\ & & \ddots & \\ & & & \sigma_m^2\end{bmatrix} \qquad \dots.(3)$$

where $[R]$ is called the covariance matrix of measurement errors.

Eqn. (2) can be written as

$$\min J(x)=[z-h(x)]^T[R^{-1}][z-h(x)] \qquad \dots.(4)$$

The minimum of $J(x)$ can be obtained when $g(x)=\delta j(x)/\delta x=0$

or, $$-H^T(x)R^{-1}[z-h(x)]=0 \qquad \dots.(5)$$

where $H(x)=\delta h(x)/\delta x$ is the Jacobian matrix of dimension $(m\times n)$ measurement.

Note that (5) is valid only when $m > n$; that is, the number of parameters to be estimated is less than the number of measurements made. If $n > m$ there will be many values of states that will satisfy the above equation. In such cases, pseudo-measurements are added to give a completely determined or over-determined problem.
Pseudo-measurements are not obtained from meters but are typically calculated using historical data or short-term load forecast, or as zero injections.
The most common exact pseudo-measurement ifs the bus injection at a substation that has no generation and serves no load. Here we can say with certainty that real and reactive power injection at this bus is zero.

The non-linear function $h(x)$ can be linearized as

$$h(x+\Delta x) \approx h(x) + H(x)\Delta x \quad \text{.... (6)}$$

If we write $H(x)$ as H, the following iterative procedure is obtained:

$$\left(H^T R^{-1} H\right)\Delta x = H^T R^{-1}\left[z - h(x)\right] \quad \text{.... (7)}$$

or, $$\Delta x = \left(H^T R^{-1} H\right)^{-1} H^T R^{-1}\left[z - h(x)\right] \quad \text{.... (8)}$$

where $x^{k+1} = x^k + \Delta x$.

$$x^{k+1} = x^k + H(x^k)^T R^{-1} H(x^k)^{-1} H(x^k)^T R^{-1}\left[z - h(x^k)\right] \quad \text{.... (9)}$$

The symmetric matrix $\left(H^T R^{-1} H\right) = G(x)$ is called the gain or information matrix and (7) through (9) are known as normal equations.

State Estimation by Orthogonal Decomposition
In the Weighted Least Square method of state estimation, the solution to the system states using normal equation may sometimes have very slow convergence or may fail to converge under certain conditions. Analysis has shown that ill-conditioning may happen when any of the following factors are present:

- Disparity in weighting factor;
- Large number of injection measurements;
- Connection of long and short transmission lines.

The orthogonal transformation method (also known as the Q-R method) performs Q-R decomposition of the Jacobian matrix directly. According to this, any *m-n* matrix of full rank can be decomposed into two matrices of the form

$$A = QR$$

where Q is an orthogonal matrix of size *m-m* and R is an upper triangular matrix of size *m-n*. Since Q is an orthogonal matrix $Q^T Q = I$,

or, $$Q^T A = R \quad \text{.... (10)}$$

If Q and R are partitioned as

$$A=[Q_n \quad Q_0]\begin{bmatrix}U\\0\end{bmatrix}=Q_nU \qquad \text{.... (11)}$$

the orthogonal transformation is therefore more numerically stable. When this algorithm is applied to the WLS state estimation, (8) $\Delta x=\left(H^TR^{-1}H\right)^{-1}H^TR^{-1}\left[z-h(x)\right]$ is solved to eliminate the R^{-1} matrix.

If the R^{-1} matrix is written as

$$R^{-1}=R^{-\frac{1}{2}}R^{-\frac{1}{2}} \qquad \text{.... (12)}$$

$$\text{where} \quad R^{-\frac{1}{2}}=\begin{bmatrix}\frac{1}{\sigma_{m1}} & & \\ & \frac{1}{\sigma_{m2}} & \\ & & \frac{1}{\sigma_{mn}}\end{bmatrix} \qquad \text{.... (13)}$$

$$\text{or,} \quad \left[H^TR^{-1}H\right]^{-1}=H^TR^{-\frac{1}{2}}R^{-\frac{1}{2}}[H]^{-1}=\left[H'^T \quad H'\right] \qquad \text{.... (14)}$$

$$\text{where} \quad [H']=\left[R^{-\frac{1}{2}}\right][H]$$

Eqn. (8) therefore becomes

$$\Delta x=\left(H'^TH'\right)^{-1}(H'T)\left[R^{-\frac{1}{2}}\right]\left[z-h(x)\right] \qquad \text{.... (15)}$$

$$\text{or,} \quad \Delta x=\left(H'^TH'\right)^{-1}\left(H'^T\right)[\Delta z'] \qquad \text{.... (16)}$$

$$\text{where} \quad \Delta z'=\left[R^{-\frac{1}{2}}\right][\Delta z]$$

$$\text{and} \quad \Delta z=\left[z-h(x)\right]$$

The orthogonal decomposition algorithm is used to find an orthogonal matrix $[Q]$ such that

$$[H']=[Q][U] \qquad \text{.... (17)}$$

The matrix $[U]$ has an upper triangular structure. The state estimation equation with these substitutions become

$$\Delta x=\left[U^TQ^TQU\right]^{-1}\left[U^TQ^T\right]\Delta z' \qquad \text{.... (18)}$$

which after rearrangement can be written as

$$\left[U^T\right]\left[U\right]\Delta x=\left[U^T\right]\left[Q^T\right]\Delta z' \quad \text{.... (19)}$$

or, $$\left[U\right]\Delta x=\left[Q^T\right]\Delta z' \quad \text{.... (20)}$$

The orthogonal decomposition algorithm for the power system state estimation can be explained by

- Determining the Q matrix and U matrix. The Q matrix must be orthogonal.
- Performing the factorization $\left[H'\right]=\left[Q\right]\left[U\right]$.
- Computing the vector $\left[Q^T\Delta z'\right]$.
- Computing x from back substitution using $\left[U\right]\Delta x=\left[Q^T\right]\Delta z'$.

4. Explain the process of Short Term Load Forecasting. What information are necessary for the forecasting process? [WBUT 2013]

OR,

Write short note on Short term load forecasting. [WBUT 2014]

Answer:

1st Part:

For day-to-day operation, covering one day or a week, short-term forecasting is needed in order to commit enough generating capacity formatting the forecasting demand and for maintaining the required spinning reserve. Hence, it is usually done 24 hours ahead when the weather forecast for the following day becomes available from the meteorological office. This mostly consists of estimating the weather-dependent component and that due to any special event or festival because the base load for the day is already known.

The power supply authorities can build up a weather load model of the system for this purpose or can consult some tables. The final estimate is obviously done after accounting the transmission and distribution losses of the system. In addition to the prediction of hourly values, a short-term load forecasting (STLF) is also concerned with forecasting of daily peak-system load, system load at certain times of a day, hourly values of system energy, and daily and weekly system energy.

2nd Part:

i. For proper planning of power system;
ii. For proper planning of transmission and distribution facilities;
iii. For proper power system operation;
iv. For proper financing;
v. For proper manpower development;
vi. For proper grid formation;
vii. For proper electrical sales.

(i) ***For Proper Planning of Power System***

- To determine the potential need for additional new generating facilities;
- To determine the location of units;
- To determine the size of plants;
- To determine the year in which they are required;
- To determine that they should provide primary peaking capacity or energy or both;
- To determine whether they should be constructed and owned by the Central Government or State Government or Electricity Boards or by some other autonomous corporations.

(ii) ***For Proper Planning of Transmission and Distribution Facilities:*** For planning the transmission and distribution facilities, the load forecasting is needed so that the right amount of power is available at the right place and at the right time. Wastage due to misplanning like purchase of equipment, which is not immediately required, can be avoided.

(iii) ***For Proper Power System Operation:*** Load forecast based on correct values of demand and diversity factor will prevent overdesigning of conductor size, etc. as well as overloading of distribution transformers and feeders. Thus, they help to correct voltage, power factor, etc. and to reduce the losses in the distribution system.

(iv) ***For Proper Financing:*** The load forecasts help the Boards to estimate the future expenditure, earnings, and returns and to schedule its financing program accordingly.

(v) ***For Proper Manpower Development:*** Accurate load forecasting annually reviewed will come to the aid of the Boards in their personnel and technical manpower planning on a long-term basis. Such a realistic forecast will reduce unnecessary expenditure and put the Boards' finances on a sound and profitable footing.

(vi) ***For Proper Grid Formation:*** Interconnections between various state grids are now becoming more and more common and the aim is to have fully interconnected regional grids and ultimately even a super grid for the whole country. These expensive high-voltage interconnections must be based on reliable load data, otherwise the generators connected to the grid may frequently fall out of step causing power to be shut down.

(vii) ***For Proper Electrical Sales:*** In countries, where spinning reserves are more, proper planning and the execution of electrical sales program are aided by proper load forecasting.

5. a) Explain "Line only algorithm" with required equations. **[WBUT 2014, 2015]**

Answer:

In line flows only algorithm, the data for line flows (both active and reactive) through transmission lines are processed to generate the vector of voltage difference across transmission lines. Let e be that voltage difference vector and this vector can be represented by the following equation,

$$e = Ax + r_e \quad \text{.... (1)}$$

where A is node incidence matrix and r_e is the error vector for errors in voltage data. Eqn. (1) is a linear equation, therefore we can use WLSE to estimate x following equation $\hat{x} = \left(H^T WH\right)^{-1} H^T Wz = G^{-1}H^T Wz$ and is given by

$$\hat{x} = \left(A^T WA\right)^{-1} A^T We \quad \text{.... (2)}$$

The vector e is not directly measurable, but it is required to be generated from line flows data. We can write

$$S_{ij}^* = V_i^*\left(V_i - V_j\right)y_{ij} + V_i^* V_i y_{ij_0}$$

or, $$S_{ij}^* = V_i^* V_{ij} y_{ij} + V_i^* V_i y_{ij_0} \qquad \text{[here, } V_{ij} = V_i - V_j\text{]}$$

or, $$P_{ij} - jQ_{ij} = V_i^* V_{ij} y_{ij} \qquad \text{[assuming i } y_{ij_0} \cong 0\text{]}$$

$$\therefore \quad V_{ij} = \frac{z_{ij}\left(P_{ij} - jQ_{ij}\right)}{V_i^*} \quad \text{.... (3)}$$

where z_{ij} = impedance of line between the buses i and j.

Therefore, vector e has a non-linear relationship with measurement vector z (the line flows) and state vector x and we can write,

$$e = f\left(x, z\right) \quad \text{.... (4)}$$

So, Eqn. (2) may be rewritten as

$$\hat{x} = \left(A^T WA\right)^{-1} A^T Wf\left(\hat{x}, z\right)$$

The above equation being non-linear one, it can only be solved by iterative approach. For j-th iteration, we can write

$$\hat{x}^{j+1} = \left(A^T WA\right)^{-1} A^T Wf\left(\hat{x}^j, z\right) \quad \text{.... (5)}$$

It should be noted here that for a linear problem, the optimal solution may be obtained using Eqn. (2). However, the data e is needed to be generated using non-linear transformation [Eqn. (3)]. This requires the use of iterative algorithm using Eqn. (4). This algorithm is computationally easier than injection only algorithm, because here the gain matrix $\left(A^T W A\right)^{-1} A^T W$ is constant. The concept of decoupling can also be employed in line flows only algorithm to estimate the state vector x.

b) Estimate two values random variable *x* by weighted LSE method.

[WBUT 2014, 2015]

Answer:

This equation is called the 'normal equation' and may be solved explicitly for the LSE of the vector $\hat{x}$ as

$$\hat{x} = \left(H'H\right)^{-1} H'y \quad \text{.... (1)}$$

The estimate given in Eqn. (1) is often referred to as the 'ordinary' least squares estimate and is obtained by minimising the index function that puts equal weightage to the errors of estimation of all components of the vector y. It is often desirable to put different weightages on the different components of y since some of the measurements may be more reliable and accurate than the others and these should be given more importance. To achieve this, we define the estimation index as

$$J = \overline{y}' W \overline{y} \quad \text{.... (2)}$$

where, W is a real symmetric weighting matrix of dimension $m \times m$. This is often chosen as a diagonal matrix for simplicity.

It is relatively straightforward to extend the method of LSE to the weighted form of J and to derive the following form of the normal equation.

$$H'WH\hat{x} - H'Wy = 0 \quad \text{.... (3)}$$

This leads to the desired weighted least squares estimate (WLSE)

$$\hat{x} = \left(H'WH\right)^{-1} H'Wy \quad \text{.... (4)}$$

This pertains to minimisation as the hessian $2H'WH$ is a non-negative definite.

Some Properties:

Rewriting Eqn. (4) as

$$\hat{x} = ky \quad \text{.... (5)}$$

where, $k = \left(H'WH\right)^{-1} H'W$ .... (6)

Here the matrix k depends on the value of H and the choice of W.

Using Eqns. (1) and (6) it is easy to get the relation as follows.

$$\hat{x} = KHx + kr = \left(H'WH\right)^{-1}\left(H'WH\right)x + kr$$

or, $\hat{x} = x + kr$ .... (7)

and $E\{\hat{x}\} = E\{x\}$ .... (8)

In Eqn. (8) it is assumed that the error r is statistically independent of columns of H and the vector r has a zero mean. An estimate that satisfied Eqn. (8) is called an unbiased estimate. This implies that the estimation error is zero on an average.

$$\overline{x} = kr \quad \text{.... (9)}$$

The covariance of the error of estimation is therefore given by

$$P_x = KRK' \quad \text{.... (10)}$$

where R is the covariance of the error vector r. Note that the covariance P_x is a measure of the accuracy of the estimation and a smaller trace of this matrix is to set $W = R^{-1}$. The optimum value of the error covariance matrix is then given by

$$P_x = \left(H'R^{-1}H\right)^{-1} \quad \text{.... (11)}$$

6. a) What does load forecasting mean?
b) How load forecasting can be classified?
c) What are the deciding factors behind load forecasting?
d) What are the different techniques of load forecasting?
e) How load forecasting can be estimated? **[WBUT 2017]**

Answer:

a) Load forecasting is a technique used by power or energy-providing companies to predict the power/energy needed to meet the demand and supply equilibrium. The accuracy of forecasting is of great significance for the operational and managerial loading of a utility company.

b) The load forecasting can be classified as:
1. Demand Forecasting and
2. Energy Forecasting

c) Deciding factors behind load forecasting:
- Time factors such as:
  - Hours of the day (day/night)
  - Day of the week (week day/weekend)
  - Time of the year (season)
- Weather conditions (temperature and humidity)
- Class of customers (residential, commercial, industrial, agricultural, public, etc.)
- Special events (TV programmes, public holidays, etc.)
- Population
- Economic indicators (per capita income, Gross national product (GNP), Gross domestic product (GDP), etc.)
- Trends in using technologies
- Electricity price

d) ***Refer to Question No. 2 of Short Answer Type Questions.***

e) Electrical load forecasting is the estimation for future load by an industry or utility company - it has many applications including energy purchasing and generation, load switching, contract evaluation, and infrastructure development.
Load forecasting load forecasting is a difficult task. First, because the load series is complex and exhibits several levels of seasonality: the load at a given hour is dependent not only on the load at the previous hour, but also on the load at the same hour on the previous day, and on the load at the same hour on the day with the same denomination in the previous week. Secondly, there are many important exogenous variables that must be considered, especially weather- related variables.

MISCELLANEOUS

Multiple Choice Type Questions

1. One kilogram of natural uranium gives an energy equivalent to [WBUT 2009, 2010]

a) 100 kg of coal
b) 1000 kg of coal
c) 500 kg of coal
d) 10000 kg of coal

Answer: (d)

2. If the speed regulation of the governor is 4% and the rated frequency is 50Hz, then the change in frequency is [WBUT 2009]

a) 2 Hz
b) 2 kHz
c) 0.5 Hz
d) 1.2 Hz

Answer: (a)

3. Low power factor has the drawback(s) of [WBUT 2011]

a) high cost of equipment for a given load
b) increased transmission & distribution losses
c) poor voltage regulation
d) all of these

Answer: (d)

Short Answer Type Questions

1. What are the problems of high VAR loading in a grid? What are the measures adopted in a grid to minimize these problems? [WBUT 2011]

Answer:

The VAR demand of the system varies in wider limits during day and contingent operating conditions, which cannot be supplied by the generators without considerable voltage drop as they are generally located far off from the load centres. During off-peak condition the network experiences over voltages at some location whereas during peak load condition there is a average low voltage problem.

It has been observed that in certain areas in the grid the voltage of 400 kV buses goes down as low as 320 kV and the voltage of 220 kV buses goes as low as 165 kV on account of heavy reactive power drawn by the underlying system. Under such condition loss of any line results in further voltage dip account of increased reactive power losses. This results in the voltage instability and subsequent grid failure. Several much incidents had taken place in recent past especially in the Western Regional grid and Southern Regional grid. This shows the lack of awareness regarding high reactive power demand in the system, which is aggravating the low voltage problem in the grid.

Basically the reactive power demand in any power system can be met in any way if it is available but the same is not true for the reactive power. Indeed, the reactive power demand should be met at the demand point itself rather than transporting it from somewhere else in order to maintain good voltage profile. In fact adequate compensation

in the network at proper voltage level causes erratic behaviour of the grid and consequently would hamper the grid security.
The major techniques available for compensation in EHV network and thereby voltage improvement in the network are transformer tap settings, excitation control of generators, series capacitors, shunt capacitors, static var compensators etc.

Long Answer Type Questions

1. Write short note on Economic running of combined Hydro and Steam Power plants.
Answer: [WBUT 2017]

Economic running of combined Hydro and Steam Power plants:

No country or region is rich in both fuel and hydro resources to generate electricity economically. So it is essential to combine these resources to get the best results. By doing so, the following benefits can be achieved.

Flexibility of operation:
The main drawback of a steam power plant is that long time to start up, synchronies the plant and increase the load. Therefore it is essential for steam power plant to be cope with the rapid rate of increase in load and have necessary margin of safety against breakdown and other dangerous. In addition to that, to reduce the stresses and strains on boiler joints, it is essential to have sufficient boiler plant be hot for whole day and night to meet the peak load requirements. This indicates that there is a continuous loss of energy that can't be eliminated.
On the other hand, in hydro-electric power plant the load can be raised from no load to rated load rapidly because the plant can be run up easily and quickly synchronized. Also the plant can be capable of withstanding sudden variations in load demand and therefore it is suitable for peak load operation. If steam and hydro plant are combined in a system, its operation will be flexible and violent fluctuations of load can be rectified by hydro plant very easily.

Security of supply: As far as security and reliability of operation for electric supply are concerned, there is not much to select between these two power plants. Actually reliability varies for each plant. In case of steam power plant, reliability purely depends on the supply of coal and in later case, it depends on flow of stream. So combining these two plants would be more value to reliability compared to individual system.

Improved utilization of hydro-power: During rainy season flow of stream will be more, so that the hydro plant can be able to generate more power meeting the base load and hence steam power plant may not produce as much energy resulting in great savings of coal. Conversely, during draught periods steam power plant produces more power and hydro power generation is minimum which will result in savings of water in the reservoir.

Spare plant: In any power system, spare plant is necessary to provide for any unforeseen demand due to sudden breakdown or maintenance and repairs of plant takes place. Hydro power plant is best for use it as spare due to less maintenance than a steam power plant. But for a combined system, there is no need of spare plant because one can meet the sudden unavoidable situation. But it is more advantageous to keep up spare plant even in combined power plants.

QUESTION 2012

Group – A

(Multiple Choice Type Questions)

1. Choose the correct alternatives for the following:

i) Load factor for a peak load plant is

a) 0 b) 1

✓c) low d) high

ii) Hydel power plant can be used as

a) peak load plant b) base load plant

✓c) both (a) and (b) d) none of these

iii) Load flow solution is done to calculate

a) generated power by slack bus

b) system parameter

c) bus voltage & active power loss

✓d) bus voltage & phase angle of each and every bus

iv) Demand factor is

a) always greater than 1 ✓b) always less than 1

c) of any value d) depends upon the system

v) Efficiency of a thermal power plant is

a) 40% b) 60%

c) 80% ✓d) 30%

vi) Running cost is high for .... power plant.

✓a) thermal b) hydel

c) nuclear d) non-conventional

vii) Initial cost is higher for .... power plant.

a) thermal ✓b) hydel

c) nuclear d) diesel

viii) Diversity factor .... is good for power generation economics.

a) less than 1
✓b) greater than 1
c) zero
d) equals to 1

ix) In load duration curve loads are arranged in

a) ascending order
✓b) descending order
c) any order
d) a way that depends upon the load curve

x) State estimation is done to know

✓a) best estimate of voltage magnitude and phase angle of each and every bus
b) economic dispatch solution
c) system power loss
d) load flow solution

Group – B

(Short Answer Type Questions)

2. Discuss the economic justification of the thermal power plants.
See Topic: ECONOMICS OF GENERATION, Short Answer Type Question No. 9.

3. Discuss the various types of Unit Commitment method.
See Topic: UNIT COMMITMENT, Short Answer Type Question No. 5.

4. Define the terms 'load factor' and 'diversity factor' and explain the economic implication of these factors on the cost of energy generation.
See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 2(a).

5. Develop a simple Computational method in economic load scheduling.
See Topic: UNIT COMMITMENT, Short Answer Type Question No. 6.

6. Write down about the different load forecasting techniques.
See Topic: STATE ESTIMATION AND LOAD FORECASTING, Short Answer Type Question No. 2.

Group – C

(Long Answer Type Questions)

7. a) Explain 'Flow only algorithm' with required equations.
b) Estimate two values random variables x by weighted LSE method for

$$W = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0.5 & 0 \\ 0 & 0 & 0.1 \end{bmatrix} \qquad H = \begin{bmatrix} 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad y = \begin{bmatrix} 0.5 \\ 0.45 \\ 0.51 \end{bmatrix}$$

a) See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 4.
b) See Topic: STATE ESTIMATION AND LOAD FORECASTING, Long Answer Type Question No. 2.

8. a) Write a short note on 'ABT'.
b) A factory to be set up is to have a fixed load of 760 kW at 0.8 pf. The electricity board offers to supply energy at the following alternate rates:
   i) LV supply at Rs.32/kVA max demand/annum +10 paise/kWh
   ii) HV supply at Rs.30/kVA max demand/annum +10 paise/kWh

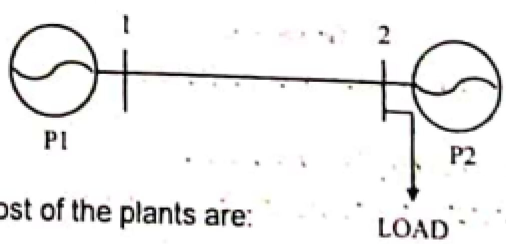
The HV switchgear costs Rs.60/kVA and switchgear losses at full load amount to 5%. Interest, depreciation charges for the switchgear are 12% of the capital cost. If the factory is to work for 48 hours/week, determine the more economical tariff.

a) See Topic: ELECTRICITY TARIFF, Long Answer Type Question No. 6(b).
b) See Topic: ELECTRICITY TARIFF, Long Answer Type Question No. 4.

9. a) How can high diversity be achieved? Explain whether it is desirable or not.
b) There are three consumers of electricity having different load requirements at different times. Consumer *A* has a maximum demand of 5kW at 6p.m. and a demand of 3kW at 7p.m. and daily load factor of 20%. Consumer *B* has a maximum demand of 5kW at 11 a.m., a load of 2kW at 7p.m. and an average load of 1.20 kW. Consumer *C* has an average load of 1kW and his maximum demand is 3kW at 7p.m. Determine
   i) the diversity factor
   ii) the load factor and average load of each consumer
   iii) the average load and load factor of the combined load.

See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 9(a) & (b).

10. a) How the transmission loss formula is expressed? Draw the flow chart for the solution of coordination equation considering transmission loss.
b) A two-bus system is shown in given figure. If a load of 125 MW is transmitted from plant 1 to the load, a loss of 15.625 MW is incurred. Determine the generation schedule and load demand if the cost of received power is Rs.24/MWhr.



The incremental production cost of the plants are:

$$\frac{dF_1}{dP_1} = 0.025P_1 + 15, \quad \frac{dF_2}{dP_2} = 0.05P_2 + 20$$

See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 5(a) & (b).

11. Write short notes on the following:
   a) Unit commitment
   b) Cost of power generation for thermal, hydro, nuclear power plants
   c) Spinning reserve.

a) See Topic: UNIT COMMITMENT, Long Answer Type Question No. 6(a).
b) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 11(c).
c) See Topic: UNIT COMMITMENT, Long Answer Type Question No. 6(b).

QUESTION 2013

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any ten of the following:

i) A load curve is a plot of
   a) load versus generation capacity
   b) load versus current
   ✓c) load versus time
   d) load versus cost of power

ii) Which of the following categories of consumers can provide highest load factor?
   ✓a) a domestic consumer
   b) a continuous process plant
   c) a steel melting unit using arc furnace
   d) a cold storage plant

iii) The incremental transmission loss of a plant is
   a) positive always
   b) negative always
   ✓c) can be positive or negative
   d) zero always

iv) Load factor during a period is
   a) average load / installed capacity
   ✓b) average load / maximum load
   c) maximum load / average load
   d) maximum load / installed capacity

v) Demand factor is the
   a) maximum demand / average demand
   ✓b) maximum demand / connected load
   c) average demand / maximum demand
   d) connected load / maximum demand

vi) If for a given alternator in economic operation mode the incremental cost is given by $(0.012\,p+8) Rs/MWh$. $\frac{dp_l}{dp}=0.2$ and plant $\lambda=25$ then the power generation is

a) 1000 MW
✓b) 1250 MW
c) 750 MW
d) 1500 MW

vii) The cost function of a 50 MW generator is given by $F(p)=225+53p+0.02p^2$. When 100% loading is applied, the IFC will be

a) Rs. 55 per MWh
b) Rs. 55 per MW
✓c) Rs. 33 per MWh
d) Rs. 33 per MW

viii) In terms of plant powers p_n and p_m and loss coefficients B_{mn} the total transmission loss p_l is

a) $\sum_{m=1}^{N}\sum_{n=1}^{N} B_{mn}p_n$
b) $\sum_{m=1}^{N}\sum_{n=1}^{N} B_{mn}p_m$
✓c) $\sum_{m=1}^{N}\sum_{n=1}^{N} B_{mn}p_n p_m$
d) $\sum_{m=1}^{N}\sum_{n=1}^{N} 2B_{mn}p_m$

ix) At stack bus, which one of the following combinations of variable is specified?

✓a) $|v|,\delta$
b) P,Q
c) $p,|v|$
d) $Q,|v|$

x) Normally Z_{bus} matrix is a

a) null matrix
b) sparse matrix
✓c) full matrix
d) unity matrix

xi) The incremental cost characteristics of the two units in a plant are

$$Ic_1=0.1p_1+8.0\ Rs/MWh,\ Ic_2=0.15p_2+3.0\ Rs/MWh.$$

When the total load is 100 MW, the optimum sharing of the load is

	p_1	p_2
✓a)	40 MW	60 MW
b)	33.3 MW	66.7 MW
c)	60 MW	40 MW
d)	66.7 MW	33.3 MW

xii) If the penalty factor of a plant is unity, its incremental transmission loss is

a) 1.0 b) –1.0

✓c) zero d) none of these

Group – B
(Short Answer Type Questions)

2. Derive the expression for transmission loss as a function of plant generation.
See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 1(a).

3. Explain what do you mean by state estimation of power system. How does it differ from load flow?
See Topic: STATE ESTIMATION & LOAD FORECASTING, Short Answer Type Question No. 3.

4. Discuss the importance of spinning reserve requirements in the solution of unit commitment problem.
See Topic: UNIT COMMITMENT, Short Answer Type Question No. 7.

5. What is unit commitment? Compare an optimal unit commitment problem with an economical load dispatch problem.
See Topic: UNIT COMMITMENT, Short Answer Type Question No. 8.

6. The yearly load duration curve of a power plant is a straight line. The maximum load is 500 MW and the minimum load is 400 MW. The capacity of the plant is 750 MW. Find:

a) plant capacity factor b) load factor

c) utilization factor d) reserve capacity.

See Topic: ECONOMICS OF GENERATION, Short Answer Type Question No. 10.

Group – C
(Long Answer Type Questions)

7. a) Discuss the concept of reserves and constraints in the Unit Commitment problem.
b) In a three-plant system the cost functions are given by

$$F_1(P_1) = 500 + 7P_2 + 0.002P_1^2$$
$$F_2(P_2) = 400 + 6.5P_2 + 0.003P_2^2$$
$$F_3(P_3) = 200 + 7.2P_3 + 0.006P_3^2$$

and the transmission loss is expresses as $P_L = 0.00002P_1^2 + 0.00005P_2^2 + 0.0001P_3^3$. Assume total load to be 900 MW. Find the economic dispatch schedule.

a) See Topic: UNIT COMMITMENT, Long Answer Type Question No. 3.
b) See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 3(b).

8. a) Explain the process of Short Term Load Forecasting. What information are necessary for the forecasting process?
b) Describe how a "Predicted load curve" helps a load dispatch engineer planning daily generation schedule for an interconnected system.
a) See Topic: STATE ESTIMATION & LOAD FORECASTING, Long Answer Type Question No. 4.
b) See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 6.

9. a) If measurement vector $M = (Q^T)[R^{-1/2}]M^{meas}$, derive the estimation of state variable quantities X_1^{est} and X_2^{est} in relation to control variables U_{11}, U_{12} and U_{22} for three elements of $M(M_1, M_2, M_3)$.
R is the diagonal matrix of the variances in the normal distribution of residual errors.
b) Differentiate between Load Curve and Load Duration Curve.
a) See Topic: STATE ESTIMATION & LOAD FORECASTING, Long Answer Type Question No. 3.
b) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 2(b).

10. a) Define and explain the significance of the following terms:
(i) Demand factor
(ii) Diversity factor
(iii) Plant used factor.

b) Find the total number of units generated per year, fuel cost per year, total annual cost and generation cost per kWh from the following data:
Installed capacity = 200 MW, Capital cost = Rs. 3,000 per kW, Interest and depreciation = 12%, Fuel consumption = 0.9 kg/kWh, Fuel cost = Rs. 70 per 1,000 kg, other operating cost = 30% fuel cost, Load factor = 80%, Peak load = 170 MW.
See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 10(a) & (b).

11. Write short notes on any three of the following:
a) Heat rate and Incremental fuel cost
b) Availability based tariff (ABT)
c) Types of consumers and their tariffs
d) Algorithm for computer solution of economic operation without considering losses in the system
e) Load sharing between base load and peak load plants.

a) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 12(b).
b) See Topic: ELECTRICITY TARIFF, Long Answer Type Question No. 7(b)
c) See Topic: ELECTRICITY TARIFF, Long Answer Type Question No. 7(d).
d) See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 9(c).
e) See Topic: ECONOMIC Load Dispatch, Long Answer Type Question No. 9(d).

QUESTION 2014

Group – A
(Multiple Choice Type Questions)

1. Answer any ten questions.

i) State estimation is done to know
- ✓a) best estimate of voltage magnitude and phase angle of each and every bus
- b) economic dispatch solution
- c) system power loss
- d) load flow solution

ii) The power generated by two plants are p1 = 50MW, p2 = 40MW. If the loss coefficients are B11 = 0.001 and B22 = 0.0025 and B12 = –0.0005 then power loss will be
- a) 5.5 MW
- b) 6.5 MW
- ✓c) 4.5 MW
- d) 8.5 MW

iii) If the penalty factor of a plant is unity its incremental transmission loss is
- a) 1.0
- ✓b) 0
- c) –1.0
- d) none of these

iv) Load frequency control is achieved by properly matching the individual machine's
- a) reactive power
- b) generated power
- c) turbine input
- ✓d) turbine and generator rating

v) Frequency variation occurs in power systems due to
- ✓a) unbalance between active power generation and load
- b) unbalance between reactive power generation and load
- c) unbalance between mva demand and mva generation
- d) unbalance between the loadings at different phases

vi) If the speed regulation is 5.1 and the rated frequency is 60Hz then change in frequency is
- ✓a) 3 Hz
- b) 6 Hz
- c) 5 Hz
- d) none of these

vii) Economic operation of power system is carried out on the basis of
- ✓a) equal incremental fuel cost
- b) equal area criterion
- c) equal fuel cost criterion
- d) all units sharing equal power

viii) Unit commitment is
- a) a must before we solve economic operation problem
- b) a short term problem of maintenance scheduling
- c) more meaningful for thermal units
- ✓d) all of these

ix) For long term hydrothermal problem
- a) A head variation can be ignored
- b) transmission loss cannot be ignored
- c) unit commitment should be taken into account
- ✓d) all of these

x) For economic operation the generator with highest positive incremental transmission loss will operate at
- a) the highest positive incremental cost of production
- b) the highest negative incremental cost of production
- ✓c) the lowest positive incremental cost of production
- d) the lowest negative incremental cost of production

xi) Nuclear power station is normally used for
- a) peak load
- ✓b) base load
- c) average load
- d) any load

xii) Which plant can never have 100% load factor?
- a) hydro
- b) coal
- ✓c) base load
- d) peak load

Group – B
(Short Answer Type Questions)

2. A consumer has a maximum demand of 200 kW at 40% load factor. If the tariff is Rs. 100/kW of maximum demand plus 10 paise/kWh, find the overall cost/kWh.

See Topic: ELECTRICITY TARIFF, Short Answer Type Question No. 4.

3. A generating station has a maximum demand of 25 MW, a load factor of 60%, a plant capacity factor of 50% and a plant use factor of 72%. Find (a) the daily energy produced (b) the reserve capacity of plant.

See Topic: ECONOMICS OF GENERATION, Short Answer Type Question No. 11.

4. Develop the condition of economic operation of a power system considering transmission line loss.

See Topic: ECONOMIC LOAD DISPATCH, Short Answer Type Question No. 3.

5. Discuss about the ABT tariff.

See Topic: ELECTRICITY TARIFF, Short Answer Type Question No. 5.

6. A constant load of 300 MW is supplied by two 200MW generators, 1 and 2, for which the respective incremental fuel cost are

$$\frac{dC_1}{dP_{G_1}} = 0.2P_{G_1} + 40$$

$$\frac{dC_2}{dP_{G_2}} = 0.2P_{G_2} + 30$$

Calculate the extra cost incurred in Rs/h if a load of 220 MW is scheduled as $P_{G_1} = P_{G_2} = 110$ MW.

See Topic: ECONOMIC LOAD DISPATCH, Short Answer Type Question No. 2.

Group – C
(Long Answer Type Questions)

7. a) A residential consumer has 20 lamps of 80W each connected to his premises. His demand is as follows:

i) From 12 midnight to 5 am – 40W
ii) From 5 am to 6 pm – no load
iii) From 6 pm to 7 pm – 320'
iv) From 7 pm to 9 pm – 360W and
v) From 9 pm to 12 midnight – 160 W

Plot the load curve on plain paper taking x-axis as time and y-axis as demand. Find the average load, maximum load, load factors and electric energy consumption during the day.

See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 6.

b) What is state estimation? How is it relevant to power system operation and control?

See Topic: STATE ESTIMATION & LOAD FORECASTING, Short Answer Type Question No. 1.

8. a) How the transmission loss formula is expressed? Draw the flow chart for the solution of coordination equation considering transmission loss.

See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 5(a).

b)

A two bus system is shown in figure. If 100 MW is transmitted from plant 1 to the load, a transmission loss of 10 MW is incurred. Find the required generation for each plant and the power received by the load when the system is Rs. 25/MWH

The incremental fuel cost of the two plants are given below:

$$\frac{dC_1}{dP_{G_1}} = 0.02P_{G_1} + 16.0 \text{ Rs/MWH}$$

$$\frac{dC_2}{dP_{G_2}} = 0.04P_{G_2} + 20.0 \text{ Rs/MWH}$$

See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 7.

9. a) What are the objectives and requirements of tariff?

See Topic: ELECTRICITY TARIFF, Long Answer Type Question No. 2(a).

b) Mention the different types of tariff.

See Topic: ELECTRICITY TARIFF, Long Answer Type Question No. 2(b).

c) A factory has an average load of 400 kW at 0.8 p.f. and maximum demand of 500 kW at the same p.f. The factory is working for 8 hour a day for 300 working days in a year. Two system of tariff is offered

i) High voltage supply at Rs 75 per month per kVA of maximum demand plus Rs 1.15 per kWh consumed

ii) low voltage supply at Rs 80 per month per kVA of maximum demand plus Rs 1.43 per kWh consumed.

Cost of HV equipment is Rs 900 kVA, losses can be taken as 4% and interest and depreciation of the HV equipment is 15%. Calculate the annual expenditure for both the systems to find out the cheaper tariff.

See Topic: ELECTRICITY TARIFF, Long Answer Type Question No. 5.

10. a) What is unit commitment? For which type of power plant it is applicable and why?

b) Describe the following in connection with unit commitment:

i) spinning reserve

ii) must run and must out units

iii) maximum up time and minimum down time

iv) maximum up and down rate

v) Start-up cost

See Topic: UNIT COMMITMENT, Long Answer Type Question No. 4(a) & (b).

11. a) Explain "Line only algorithm" with required equations.

b) Estimate two values random variable x by weighted LSE method.

See Topic: STATE ESTIMATION & LOAD FORECASTING, Long Answer Type Question No. 5(a) & (b).

12. Write short notes on any three of the following:

a) Load sharing between base load and peak load plants

b) Cost of power generation for thermal, hydro, nuclear and diesel power plant

c) Active and reactive power optimization

d) Short term load forecasting

e) Predicted load curve

a) See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 9(d).

b) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 12(d).

c) See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 9(e).

d) See Topic: STATE ESTIMATION & LOAD FORECASTING, Long Answer Type Question No. 4.

e) See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 9(f).

QUESTION 2015

Group – A

(Multiple Choice Type Questions)

1. Answer any *ten* questions:

i) State estimation is done to know

✓a) best estimate of voltage magnitude and phase angle of each and every bus

b) economic dispatch solution

c) system power loss

d) load flow solution

ii) A generating unit has an incremental production cost of Rs. 60 per MWh. If the penalty factor for this unit is 1.2, the incremental cost of power delivered is

✓a) Rs. 50 per MWh

b) Rs. 72 per MWh

c) Rs. 61.20 per MWh

d) Rs. 48 per MWh

iii) Which plant can never have 100% load factor?

a) hydro
b) coal-fired
✓c) base load
d) peak load

iv) Short term load forecasting is for

a) state estimation
b) planning for generation growth
c) allocation of spinning reserve
✓d) contingency analysis

v) Load factor for a base load plant is

a) 0
b) 1
c) low
✓d) high

vi) In transmission loss representation, the loss depend upon

a) generation
b) load
✓c) transmission parameters
d) total power system

vii) Power system state estimation is normally a

a) linear problem
b) nonlinear problem
✓c) quadratic problem
d) none of these

viii) A generating station which has a high investment cost is usually operated as

✓a) peak load station
b) off load station
c) base load station
d) none of these

ix) A system has 5 generators each having a capacity of 400 MW. If 4 of the generators are running while the system load is 1300 MW. The spinning source is

a) 700 MW
✓b) 300 MW
c) 400 MW
d) 1600 MW

x) If the speed regulation is 5.1 and the rated frequency is 60 c/s, then the change is frequency is

✓a) 3 c/s
b) 6 c/s
c) 5 c/s
d) none of these

xi) Normally Z bus matrix is a

a) null matrix
b) unity matrix
c) sparse matrix
✓d) full matrix

Group – B
(Short Answer Type Questions)

2. Derive the expression for transmission loss as a function of plant generation.
See Topic: ECONMIC LOAD DISPATCH, Long Answer Type Question No. 1(a).

3. Discuss the various types of unit commitment method.
See Topic: UNIT COMMITMENT, Short Answer Type Question No. 5.

4. Briefly explain the various cost components of energy generation.
See Topic: ECONOMICS OF GENERATION, Short Answer Type Question No. 1.

5. What are the objectives and requirements of a power utility tariff system?
See Topic: ELECTRICITY TARIFF, Short Answer Type Question No. 2(a).

6. Classify the different expenditures of a power utility having generation transmission and distribution in three categories i.e., fixed, semi fixed and running charges.
See topic: ECONOMICS OF GENERATION, Short Answer Type Question No. 12.

7. The fuel costs in Rs/hr for the three thermal units are given by.

$$F_1(P_1) = 300 + 7P_1 + 0.004P_1^2 \; Rs./hr.$$
$$F_2(P_2) = 450 + 7.3P_2 + 0.0025P_2^2 \; Rs./hr.$$
$$F_3(P_3) = 600 + 6.6P_3 + 0.003P_3^2 \; Rs./hr.$$

P_1, P_2, P_3 are in MW. Find the optimum schedule and compare the cost of this to the case when the generators share the load equally if the demand is 500 MW. Neglect losses.
See Topic: ECONOMIC LOAD DISPATCH, Short Answer Type Question No. 4.

Group – C
(Long Answer Type Questions)

8. a) A residential consumer has 20 lamps of 80 W each connected to his premises. His demand is as follows:

(i) From 12 midnight to 5am –40W
(ii) From 5am to 6pm – no load
(iii) From 6pm to 7pm –320W
(iv) From 7pm to 9pm –360W and
(v) From 9pm to 12 midnight –160W

Plot the load curve on plain paper taking X-axis as time and Y-axis as demand. Find the average load, maximum load, load factors and electric energy consumption during the day.

(b) What is state estimation? How it is relevant to power system operation and control?

a) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 6.

b) See topic: STATE ESTIMATION AND LOAD FORECASTING, Short Answer Type Question No. 1.

9. a) Briefly discuss TOD tariff and ABT.

b) The following data are related to a power generating station

(i) Max demand 50 MW

(ii) Capital Cost Rs. 150×10^6

(iii) Taxes, wages and salaries – Rs. 6×10^6

(iv) Interest and depreciation – 10%

(v) Annual fuel cost is Rs. 8×10^6 when annual Load Factor is 50% and the fuel cost is Rs. 9×10^6 when the Load Factor is 60%.

Compare the generation cost per unit with improved Load Factor.

See Topic: ELECTRICITY TARIFF, Long Answer Type Question No. 6(a) & (b).

10. a) Discuss the solutions of unit commitment problem.

b) The economic dispatches of the plants of power system are 393 MW, 335 MW and 122 MW. The incremental costs are

$$IC_1 = 7.92 + 0.003125P_1$$
$$IC_2 = 7.85 + 0.00388P_2$$
$$IC_3 = 7.97 + 0.00964P_3$$

The load increases by 50 MW. Find the modified schedules using partition factor.

a) See Topic: UNIT COMMITMENT, Long Answer Type Question No. 5.

b) See Topic: ECONOMIC LOAD DISPATCH, Short Answer Type Question No. 1.

11. a) Explain "Line only algorithm" with required equations.

b) Estimate two values random variables x by weighted LSE method.

See topic: STATE ESTIMATION & LOAD FORECASTING, Long Answer Type Question No. 5(a) & (b).

12. Write short notes on any *two* of the following:

a) Spinning Reserve

b) Cost of power generation for thermal, hydro, nuclear and diesel power plant.

c) Constraints of power plants

d) Site selection of nuclear power plant.

a) See Topic: UNIT COMMITMENT, Long Answer Type Question No. 7(b).
b) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 12(d).
c) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 12(e).
d) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 12(f).

QUESTION 2017

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any *ten* of the following:

i) Gas turbine can be brought to the bus-bar from cold in about
✓a) 2-minutes
b) 30-minutes
c) 1-hour
d) 2-hours

ii) A synchronous generator has higher capacity for
✓a) Leading p.f.
b) Lagging p.f.
c) Unity p.f.
d) It does not depend on p.f.

iii) An alternator having induced *emf* of 1.6 p.u. is connected to an infinite bus of 1.0 p.u. voltage. If bus-bar reactance of 0.6 p. u. and alternator has reactance of 0.2 p.u., the maximum power that can be transferred is given by
a) 8 p.u.
✓b) 2 p.u.
c) 2.67 p.u
d) 5.0 p. u

iv) Annual depreciation cost of a plant may be calculated by
a) straight line method
b) sinking fund method
c) diminishing value method
✓d) any of these

v) Domestic consumers are usually charged
a) Flat demand tariff
✓b) Block-rate tariff
c) Flat rate tariff
d) Off-peak tariff

vi) The cost of generation is theoretically minimum if
a) The system constraints are considered
b) The operational constraints are considered
c) both (a) and (b)
✓d) the constraints are not considered

vii) The most appropriate operating speeds n r.p.m of generators used in Thermal, Nuclear and Hydro power plants would respectively be

a) 3000, 300, 1500
✓b) 3000, 3000, 300
c) 1500, 1500, 3000
d) 1000, 900, 750

viii) If the penalty factor of a plant is unity, its incremental transmission loss is

a) 1.0
b) – 1.0
✓c) zero
d) none of these

ix) For economic operation, the generator with highest positive incremental transmission loss will operate at

✓a) The lowest positive incremental cost of production
b) The lowest negative incremental cost of production
c) The highest positive incremental cost of production
d) None of these

x) The maximum demand of a consumer is 2 kw and his daily energy consumption is 20 units. His load factor is

a) 10%
✓b) 41.6%
c) 50%
d) none of these

xi) In a two plant system, the load is connected to plant 2. The loss coefficients

a) B_{11}, B_{12}, B_{22} are non zero

b) B_{11} and B_{22} are non zero but B_{12} is zero

c) B_{11} and B_{12} are non zero but B_{22} is zero

✓d) B_{11} is non zero but B_{12} and B_{22} are zero

xii) In the optimum generator scheduling of different plants, the minimum fuel cost is obtained when

✓a) Only the incremental fuel cost of each plant is the same
b) The penalty factor of each plant is the same
c) The ratio of the incremental fuel cost to the penalty factor of each plant is the same
d) The incremental fuel cost of each plant multiplied by its penalty factor is the same

Group – B
(Short Answer Type Questions)

2. Explain Thermal Unit constraints with emphases to Minimum Up Time, Minimum Down Time and Crew Constraints. What is 'cooling' and 'Banking' of Boilers?
See Topic: UNIT COMMITMENT, Short Answer Type Question No. 9.

3. Explain Cold–Reserve, Hot-Reserve, Spinning-Reserve with example of each. Explain their significance.
See Topic: ECONOMICS OF GENERATION, Short Answer Type Question No. 13.

4. What is load-curve and load-duration curve? Explain their significance in power generation economics.
See Topic: ECONOMICS OF GENERATION, Short Answer Type Question No. 14.

5. Explain the problems of economic load dispatch. How the problems can be settled?
See Topic: ECONOMIC LOAD DISPATCH, Short Answer Type Question No. 5.

6. What are the advantages of interconnected power System? What is the name of Indian interconnected power system? How many Zones are interconnected in Indian power System? What are the names of those zones? In which zone West Bengal has been included?
See Topic: ECONOMIC LOAD DISPATCH, Short Answer Type Question No. 6.

Group – C
(Long Answer Type Questions)

7. a) What is unit commitment? What is optimal unit commitment? How optional unit commitment problem can be solved by Dynamic Programming Method?
b) A power system has four generating units listed in the Table below.

Table: Generating unit parameters for the system

Unit No.	Capacity (MW)		Cost curve parameters (d=0)	
	Min	Max	a (Rs/MW^2)	b (Rs/MW)
1	1.0	12	0.77	23.5
2	1.0	12	1.60	26.5
3	1.0	12	2.00	30.0
4	1.0	12	2.50	32.0

d is the fixed cost. It is required to determine the most economical units to be committed for a load of 9 MW. Let the load change in steps of 1 MW. Find also the minimum cost of operation of the committed units.

See Topic: UNIT COMMITMENT, Long Answer Type Question No. 6.

8. a) What does load forecasting mean?
b) How load forecasting can be classified?
c) What are the deciding factors behind load forecasting?
d) What are the different techniques of load forecasting?
e) How load forecasting can be estimated?

See Topic: STATE ESTIMATION AND LOAD FORECASTING, Long Answer Type Question No. 6.

9. a) How input-output curve of a generator can be represented? Explain the efficiency and Heat-rate (H.R.) curve.-
b) If *n*-number of generators are running in parallel, then under what conditions, cost of generation will be minimum?
c) The input-output curve of a 10 MW station is expressed as follows:

$I = 4 \times 10^6 \left(10 + 8L + 0.4L^2\right)$ where I is the input KJ/hour and L is the output in MW.

(i) Without plotting any curve find the load at which the minimum efficiency occurs?
(ii) Find the increase in input required to increase the station output from 3 to 5 MW by means of input-output curve and also by incremental rate curve.

See Topic: ECONOMIC LOAD DISPATCH, Long Answer Type Question No. 8.

10. a) A total fixed load p is to be delivered by a generating station having two generators A and B running in parallel. Establish how the generators will share the load, so that total input becomes minimum, when both have same fuel costs and different fuel costs.
b) Two generating plants A and B are interconnected by a transmission line. Plant A is supplying its local load from its Bus, as well as also supplying some power to plant B through the interconnected transmission line, so that plant B can meet up its local load demand at its Bus. Establish how the incremental production cost at Bus-bar of plant B can be estimated?
c) The fuel input per hour of plant A and Plant B are given as:

$F_A = 0.2P_A^2 + 40P_A + 120$ Rs. per hour

$F_B = 0.2P_B^2 + 30P_B + 200$ Rs. per hour

Determine the economic operating schedule and the corresponding cost of generation, if the maximum and minimum loading on each limit is 100 MW and 25 MW. The demand is 180 MW and transmission losses are neglected. If the load is equally shared by both the units determine the saving obtained by loading the units as per equal incremental production cost.

See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 11.

11. Write the short notes any *three* of the following:
   a) How to reduce power generation cost?
   b) Availability tariff and Availability Based tariff
   c) Lagrangian Multiplier (λ) and its Physical significance
   d) Factors Affecting Economics of Generation and Distribution of Power
   e) Economic running of combined Hydro and Steam Power plants.

a) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 12(g).
b) See Topic: ELECTRICITY TARIFF, Long Answer Type Question No. 7(c).
c) See Topic: UNIT COMMITMENT, Long Answer Type Question No. 7(c).
d) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 12(h).
e) See Topic: ECONOMICS OF GENERATION, Long Answer Type Question No. 1.