

CHAPTER 2

Load Characteristics

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1

Load Characteristics

The load characteristic plays an important role in

- determining the total power and energy requirements of the system
- planning the installed capacity of a power plant
- selection of suitable generating capacity for each unit of the plant..

Some of the terms in connection with the load characteristics are explained below

Demand

The demand of a system is the load at the receiving terminals (usually in kW or kVA) averaged over a suitable specific interval of time of short duration.

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2

Demand Interval

It is the period over which the load is averaged.

Load Curves of a Generating Station

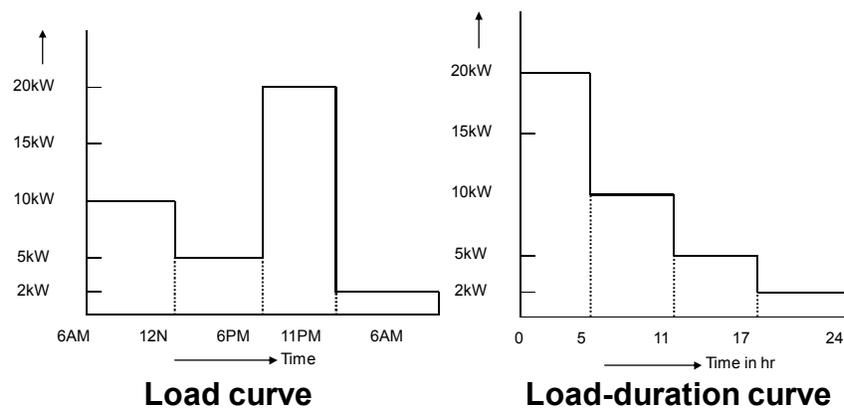
The total power requirement of a generation station can be estimated using this curves

Load Curve (or Chronological Load Curve)

It represents the load in its time sequence. As shown this curve is obtained by plotting the station load along Y-axis and the time when it occurs along X-axis. Usually, it is plotted for one day by taking average load based on the time interval Δt , which is usually an hour. The area under the curve represents the total energy consumed by the load in one day.

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3



Load-Duration Curve

It represents the same data (*i.e.* load *versus* time) but the ordinates are rearranged in *magnitude* sequence (not time sequence). Here, the greatest load is plotted on the left, lesser load towards the right and the least load on the extreme right, as Shown.

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4

The areas under the load curve and load duration curve are equal and each represents the total units consumed during a day of 24 hours. The load – duration curves can be daily, weekly, monthly and annual. Sometimes the plots are done in per unit values.

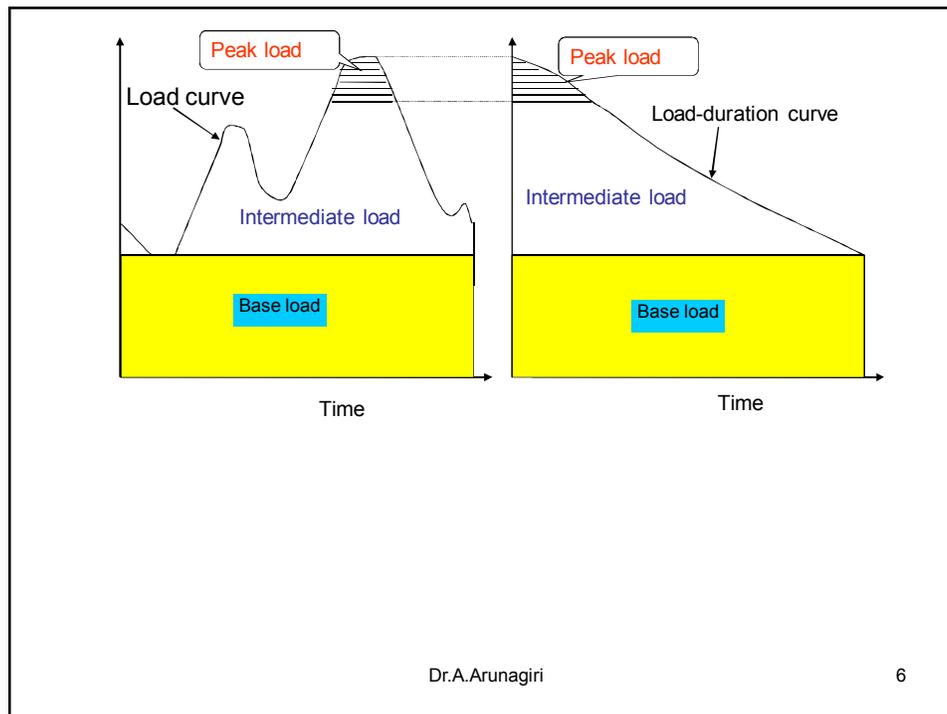
The total load supplied by a generating station is normally divided into three parts:

- Base load
- Intermediate load
- Peak load

The base load is the load below which the demand never falls and is supplied 100% of the time. The peak load occurs for about 15% of the time. The intermediate load represents the remaining load region in the load curve. These types of loads are shown in the next figure.

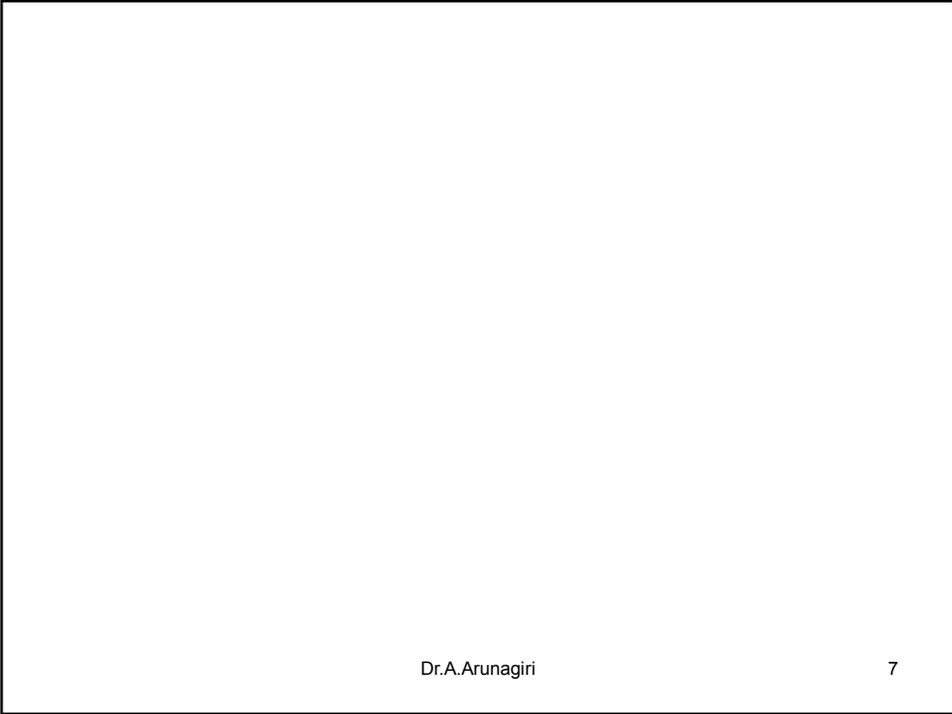
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5



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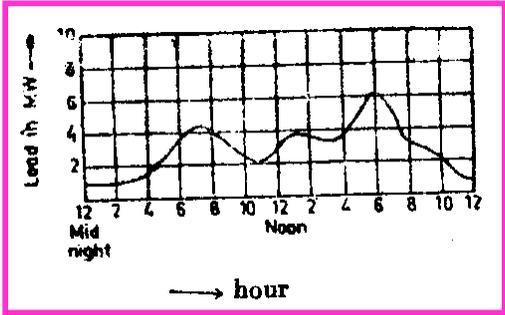
6



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7

Actual Load Curve



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8

Connected load

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

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9

Maximum Demand

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

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10

Demand Factor

It is the ratio of maximum demand on the power station to its connected load

$$\text{Demand Factor} = \frac{\text{Maximum Demand}}{\text{Connected Load}}$$

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11

The value of demand factor is usually less than 1. It is expected because maximum demand on the power station is generally less than the connected load. If the maximum demand on the power station is 80 MW and the connected load is 100 MW,

then demand factor = $80/100 = 0.8$. The knowledge of demand factor is vital in determining the capacity of the plant equipment.

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12

Average Load

It is the average of loads occurring on the power station in a given period (day or month or year) is known as average load or average demand.

$$\text{Daily average load} = \frac{\text{No. of units (kWh) generated in a day}}{24 \text{ hours}}$$

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13

$$\text{Monthly average load} = \frac{\text{No. of units (kWh) generated in a month}}{\text{Number of hours in a month}}$$

$$\text{Yearly average load} = \frac{\text{No. of units (kWh) generated in a year}}{8760 \text{ hours}}$$

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14

Load Factor

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

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}}$$

If the plant is in operation for T hours,

$$\text{Load factor} = \frac{\text{Average load} \times T}{\text{Max. demand} \times T}$$

$$= \frac{\text{Units generated in T hours}}{\text{Max. demand} \times T}$$

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15

Diversity Factor

It is the ratio of sum of individual maximum demands to the maximum demand on the power station

$$\text{Diversity factor} = \frac{\text{Sum of individual max. demands}}{\text{Max. demand on power station}}$$

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16

Capacity Factor

It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period.

$$\text{Capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}}$$

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17

$$= \frac{\text{Average demand} \times T^*}{\text{Max. demand} \times T}$$

$$= \frac{\text{Average demand}}{\text{Plant capacity}}$$

Thus if the considered period is one year,

$$\text{Annual capacity factor} = \frac{\text{Annual kWh output}}{\text{Plant capacity} \times 8760}$$

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18

Plant Use Factor

It is the ratio of KWhr generated to the product of plant capacity and the number of hours for which the plant was in operation

$$\text{Plant use factor} = \frac{\text{Station output in kWh}}{\text{Plant capacity} \times \text{Hours of use}}$$

Suppose a plant having installed capacity of 20 MW produces annual output of 7.35×10^6 kWh and remains in operation for 2190 hours in year. Then

$$\text{Plant use factor} = \frac{7.35 \times 10^6}{(20 \times 10^3) \times 2190} = 0.167 = 16.7\%$$

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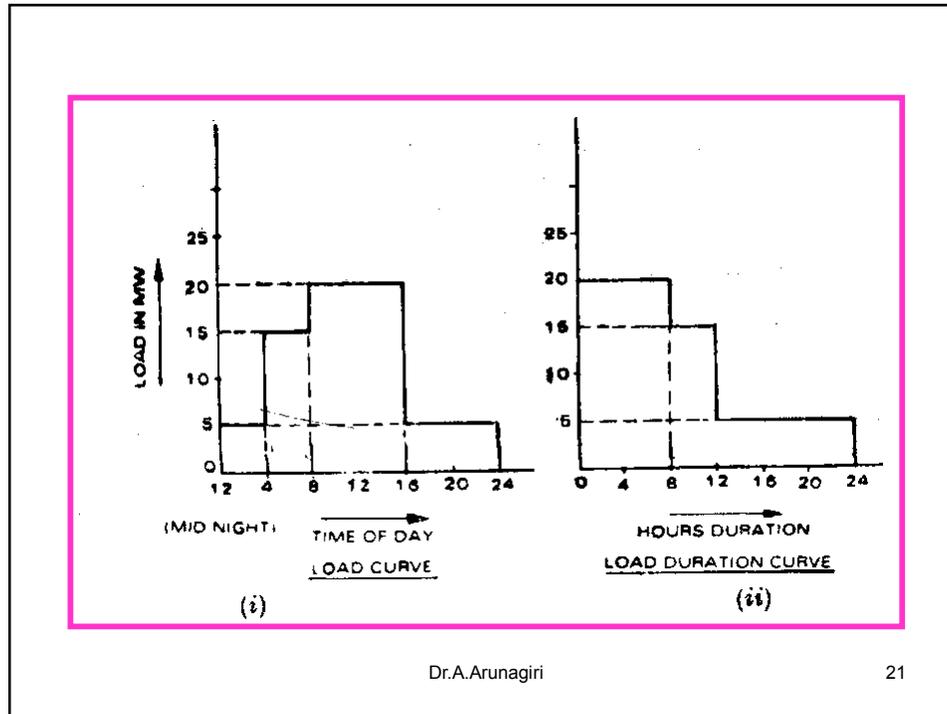
19

Load Duration Curve

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

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20



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21

Problem:

1. The maximum demand on power station is 100 MW . If the annual load factor is 40%, calculate the total energy generated in a year.
(Ans: $3504 \times 10^5 \text{ kWhr}$)

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22

2 A generating station has a connected load of 43MW and a maximum demand of 20 MW, the units generated being 61500000KWhr per annum. Calculate the

- (i) the demand factor (0.465)
(ii) the load factor(35.1%)

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23

The daily demands of three consumers are given below

| Time | Consumer1 | Consumer2 | Consumer3 |
|----------------------|-----------|-----------|-----------|
| 12 midnight to 8 A.M | No load | 200W | No load |
| 8 A.M to 2 P.M | 600W | No load | 200W |
| 2 P.M to 4 P.M | 200W | 1000W | 1200W |
| 4 P.M to 10 P.M | 800W | No load | No load |
| 10 P.M to midnight | No load | 200W | 200W |

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24

Plot the load curve and find

- (i) load factor of individual consumer
45.8%, 16.7%, 13.8%**
- (ii) diversity factor (1.25)**
- (iii) load factor of the station (29.1%)**

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25

The power station has the following daily load cycle:

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

Plot the load curve and load duration curve also calculate the energy generated perday (840000kwhr)

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26

High value of diversity factor means that more consumers can be supplied for a given station maximum demand and so lower prices can be offered to consumer. Usually, domestic load gives higher value of diversity factor than industrial load.

Example 1

Assume that there are 6 residential consumers connected to a distribution transformer. The connected load per consumer is 9.0 kW. The demand factor and diversity factor of the group of 6 residential consumers are 0.65 and 1.1 respectively. Calculate the (coincident) maximum demand on the transformer.

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27

Solution

Demand factor of each consumer, $DF_i =$

$$\frac{\text{maximum demand of each consumer}}{\text{total connected load}}$$

Therefore, maximum demand of each consumer is $9 \times DF_i$
 $= 9 \times 0.65 = 5.85 \text{ kW}$

$$\text{Diversity factor} = \frac{\text{sum of individual maximum demands}}{\text{maximum demand of the whole load}}$$

$$1.1 = \frac{5.85 \times 6}{\text{maximum demand of the whole load}}$$

Therefore, the maximum demand on the transformer is
 $5.85 \times 6 / 1.1 = 31.9 \text{ kW}$

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28

Significance of Load Factor

Load factor is, in fact, an index to the proportion of the whole time a generator plant or system is being worked to its **full capacity**. The generating equipment has to be selected on the basis of the maximum power demand that is likely to be imposed on it. However, it seldom happens that the generating equipment is loaded to its maximum load during all the 8,760 hours of a year. But whether the equipment is being worked to its full capacity or not, there are certain charges (like interest, depreciation, taxes, insurance, part of staff salaries etc.) which are adding up continuously. In other word, the equipment is costing money to its owner whether working or idle. The equipment earns profit only during those hours when it is fully loaded and the more it is fully loaded the more is the profit to the owner.

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29

Hence, from the point view of economics it is desirable to obtain high load factors. If the load factor is poor i.e. kWh of electrical 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 fixed charges are distributed over a large number of units of energy.

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30

Connected load Factor

This factor relates only to the receiving equipment and is defined as the ratio of the average power input to the connected load.

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

$$\begin{aligned} \text{Connected load factor} &= \frac{\text{average power input}}{\text{max. demand}} \times \frac{\text{max. demand}}{\text{connected load}} \\ &= (\text{Load factor}) \times (\text{Demand factor}) \end{aligned}$$

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31

Example 3

A consumer has the following load-schedule for a day:

From midnight to 6.00a.m. = 200W

From 6.00a.m to 12.00 noon = 3000W

From 12.00 noon to 1.00p.m = 100W

From 1.00p.m to 4.00p.m = 4000W

From 4.00p.m to 9.00p.m = 2000W

From 9.00p.m to midnight = 1000W

Find the load factor.

Solution

32

Example 4

A generating station has a connected load of 43 MW and a maximum demand of 20 MW. The total annual energy generated by the station is 61,500,000 kWh (Units). Calculate the load factor, demand factor and connected load factor.

Solution

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33

Example 5

A power station has a load cycle as under::
260MW for 6hr; 200MW for 8hr; 160MW for 4hr; 100MW for 6hr.
If the power station is equipped with 4 generating sets of 75MW each, calculate the load factor and the capacity factor from the above data.

Solution

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34

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35

Economics of Power Generation

The art Of determining the per unit (i.e. one kWh) cost of production of electrical energy is known as economics of power generation

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36

The economics of power generation has assumed a great importance in this fast developing power plant engineering. A consumer will use electric power only if it is supplied at reasonable rate. Therefore, power engineers have to find convenient methods to produce electric power as cheap as possible so that consumers are tempted to use electrical methods

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37

Definition Of Terms

(i) Interest. *The Cost Of Use of money is known as interest*

A power station is constructed by investing a huge capital. This money is generally borrowed from banks or other financial institutions and the supply company has to pay the annual interest .

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38

Therefore, while calculating the cost of production of electrical energy, the interest payable on the capital investment must be included. The rate of interest depends upon market position and other factors, and may vary from 4% to 8% per annum.

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39

(ii) Depreciation

The decrease in the value of the *power plant equipment and building* due to constant use is known as depreciation.

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40

In actual practice, every power station has a useful life ranging from fifty to sixty years. From the time the power station is installed, its equipment steadily deteriorates due to wear and tear so that there is a gradual reduction in the value of the plant. This reduction in the value of plant every year is known as annual depreciation. Due to depreciation, the plant has to be replaced by the new one after its useful life. Therefore, suitable amount must be set aside every year so that by the time the plant retires, the collected amount by way of depreciation equals the cost of replacement.

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41

Cost of Electrical Energy

The total cost of electrical energy generated can be divided into three parts, namely;

- (i) Fixed cost;
- (ii) Semi-fixed cost;
- (iii) Running or operating cost.

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42

Fixed Cost

It is the cost which is independent of maximum demand and units generated.

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43

The fixed cost is due to the annual cost of central organization, interest on capital cost of land and salaries of high officials. The annual expenditure on the central organization 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.

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44

Semi-fixed cost

It is the cost which depends upon maximum demand, but is independent of units generated.

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45

Running cost

It is the cost which depends only upon the number of units generated.

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46

The running cost is on 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

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47

Expressions for Cost of Electrical Energy

The overall annual cost of electrical energy generated by a power station can be expressed in two forms *ie three part form and two part form*.

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48

Three part form

In this method, the overall annual cost of electrical energy generated is divided into three parts i.e. fixed cost, semi-fixed cost and running cost

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49

Total annual cost of energy =
Fixed cost + Semi fixed cost + Running cost

Constant + Proportional to max. demand + Proportional to kWh generated.

$RM(a + b \text{ kW} + c \text{ kWh})$

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50

where a = annual fixed cost independent of maximum demand and energy output

b = a constant which when multiplied by maximum demand on the station gives annual semi fixed cost

c = a constant which when multiplied by KWhr output per annum gives the annual running cost

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51

Two part form

It is sometimes convenient to give the annual cost of energy in two part form. In this case, the annual cost of energy is divided into two parts ie a fixed sum per kW of maximum demand *plus* a running charge per unit of energy. The expression for the annual cost of energy then becomes

Total annual cost of energy
= RM(A kW+B kWh)

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52

where A = a constant which when multiplied by maximum kW, demand on the station gives the annual cost of the first part.

B = a constant which when multiplied by KWhr output per annum gives the annual running cost

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53

PROBLEM

A generating station has a maximum demand of 50,000 kW. Calculate the cost per unit generated from the following data :

Capital cost = SR 95×10^6 ;

Annual load factor = 40%

Annual cost of fuel and oil = SR 9×10^6

Taxes, wages and salaries etc. = SR 7.5×10^6

Interest and depreciation = 12% (16 Halala)

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54

Problem

A generating station has an installed capacity of 50,000 kW and delivers 220×10^6 units per annum. If the annual fixed charges are SR 160 per kW installed capacity and running charges are 4 halala per kWh, determine the cost per unit generated.(7.64)

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55

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56

Problem

A generating plant has a maximum capacity of 100 kW and costs SR 1,60,000. The annual fixed charges are 12% consisting of 5% interest, 5% depreciation and 2% taxes. Find the fixed charges per kWh if the load factor is

(i) 100% and (ii) 50%. (HALALA 2.19,4.38)

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57

Problem

Estimate the generating cost per kWh delivered from a generating station from the following data :

Plant capacity = 50 MW ;Annual load factor = 40%

Capital cost = 12 millions;

annual cost of wages, taxation etc. = Rs 0.4 Imillion;

cost of fuel,lubrication, maintenance etc. = 1·0

halala/kWh generated.

Interest 5% per annum, depreciation 6%per annum of initial value. (2)

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58

Problem

The annual working cost of a power station is represented by the formula Rs $(a + b kW + c kWh)$ where the various terms have their usual meaning. Determine the values of a , b and c for a 60 MW station operating at annual load factor of 50% from the following data :

- (i) capital cost of building and equipment is Rs 5×10^6
- (ii) the annual cost of fuel, oil, taxation and wages of operating staff is Rs 9,00,000
- (iii) the interest and depreciation on building and equipment are 10% per annum
- (iv) annual cost of organisation and interest on cost of site etc. is Rs 5,00,000.

Load and Loss Factor Relationship

While calculating the energy cost the cost of power loss also must be taken into account.

THERE are two type of losses:

- Fixed Loss (No load loss)
- Variable loss (Load losses)

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61

No load losses:

Since these are essentially constant , extra generating equipments must be provided to supply the additional demand at peak hours. Efficient base –load units(from hydro capacity , thermal or nuclear) can supply these losses most of the time. Hence the perunit demand/energy cost for these is low.

Load Losses:

These losses constitute two losses

Demand loss

Energy loss

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62

Load diversity complicates the evaluation of the demand based cost of peak load losses. The distribution system peak loading may not coincide with the total system (generation) peak.

In these losses, the demand cost depends upon peak responsibility factor (k) which is the ratio of distribution systems load at the time of total system peak to its peak load. It generally varies between 0.2 and 0.8 for distribution system and 0.8 and 0.95 for transmission systems.

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63

If a distribution has P kw loss at its peak load, then k^2P will be the loss at the time of total system peak, the cost of which is demand based. Therefore k^2P kw losses demand must be provided by the generating equipments.

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64

For energy based losses the **loss factor** is important. It is the ratio of the energy loss in the system during a given time period to the energy loss that would result if the system peak loss had persisted throughout that period.

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65

Load and losses factors relationship:

One empirical formula is

$$\text{Loss factor} = (\text{Load factor})^{1.732}$$

Or another thumb rule is One empirical formula is

$$\text{Loss factor} = c (\text{Load factor}) + (1-c) (\text{Load factor})^2$$

Where $c = 0.3$ for transmission system and 0.15 for distribution systems. These two relations are considered accurate if the minimum demand during the period does not fall below 0.2 pu of the peak demand.

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66

In case the system load factor L_f is below 0.8 the following relation is more accurate:

$$L_s = L_f^2 + 0.273(L_f - K)^2$$

K is the minimum demand in pu of peak demand

L_s is loss factor

L_f is load factor

**Total losses per annum = Loss factor* Maximum losses
based on continuous peak current**

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67

•In terms of British experience , this the Losses factor fits relationship:

$$L_s = 0.2L_f + 0.8L_f^2$$

•The American experience gives:

For urban areas

$$L_s = 0.3L_f + 0.7L_f^2$$

For rural areas

$$L_s = 0.16L_f + 0.84L_f^2$$

•The Australians use:

$$L_s = 0.2L_f + 0.8L_f^2$$

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68

Example

In a power utility the energy consumption per year is 5000 GWhr with the maximum and minimum demands of 1000 and 100 MW respectively. Find the loss factor and the typical empirical relation.

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69

Solution

Yearly load factor = AD/MD = 0.57

K is the minimum demand in pu of peak demand

$K = 100/1000 = 0.10$

$$L_s = L_f^2 + 0.273(L_f - K)^2$$

$$= 0.3852$$

Loss factor = c (Load factor) + $(1-c)$ (Load factor)²

$0.3852 = c$ (Load factor) + $(1-c)$ (Load factor)²

$C = 0.25$

The empirical relation will be

Loss factor = 0.25 (Load factor) + (0.75) (Load factor)²

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70

Load Growth

The demand estimation is the starting point for planning the future electric power supply. The consistency of demand growth over the years has led to numerous attempts to fit mathematical curves to this trend. One of the simplest method is

$$P = P_0 e^{a(t-t_0)}$$

where a is the average per unit growth rate, P is the demand in year t , and P_0 is the given demand at year t_0 .

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71

Definition of some basic concepts in statistics:

• Mean value

$$\mu = \frac{\sum y_i}{n}$$

• Weighted mean

$$\mu' = \frac{\sum \omega_i y_i}{n}$$

• Variance (standard deviation)

$$\sigma^2 = \frac{\sum (y_i - \mu)^2}{n}$$

• Normal distribution

$$f(y) = \frac{\exp\left[-\frac{1}{2}(y-\mu)^2/\sigma^2\right]}{\sigma\sqrt{2\pi}}$$

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72

Problem

A 2.5MVAR, 11KV, capacitor bank has been commissioned at a 33/11KV, 10MVA transformer substation having the following data: 33KV line length is 35 KM and conductor resistance is $0.584\Omega/\text{KM}$, Load factor = 0.65.

Find saving in losses and sparing of system capacity after installation of the capacitors

| | Without Capacitors | With Capacitors |
|----------------------|--------------------|-----------------|
| Peak load | 8000KW | 8000KW |
| Voltage | 10.4KV | 11.4KV |
| Power Factor | 0.846 | 0.99 |
| Peak current on 11KV | 525A | 409A |
| Peak current on 33KV | 175A | 136.3A |

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73

Solution

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74

