Chapter 1

Structure of Power Systems

1.1 Power Systems

Generation, Transmission and Distribution systems are the main components of an electric power system. Generating stations and distribution systems are connected through transmission lines. Normally, transmission lines imply the bulk transfer of power by high-voltage links between main load centers. On the other hand, distribution system is mainly responsible for the conveyance of this power to the consumers by means of lower voltage networks. Electric power is generated in the range of 11 kV to 25 kV, which is increased by stepped up transformers to the main transmission voltage. At sub-stations, the connections between various components are made, for example, lines and transformers and switching of these components is carried out. Transmission level voltages are in the range of 66 kV to 400 kV (or higher). Large amounts of power are transmitted from the generating stations to the load centers at 220 kV or higher. In USA it is at 345 kV, 500 kV and 765 kV, in Britain, it is at 275 kV and 400 kV and in Egypt it is at 500 kV and 750 kV. The network formed by these very high
voltage lines is sometimes called as the super grid. This grid, in turn, feeds a sub-transmission network operating at 132 kV or less. In Egypt, networks operate at 132 kV, 66 kV, 33 kV, 11 kV or 6.6 kV and supply the final consumer feeders at 380 volt three phase, giving 220 volt per phase.

Figure 1.1 and Figure 1.2 shows the schematic diagram of a power supply network. The power supply network can be divided into two parts, i.e., transmission and distribution systems. The transmission system may be divided into primary and secondary (sub-transmission) transmission system. Distribution system can be divided into primary and secondary distribution system. Most of the distribution networks operate radially for less short circuit current and better protective coordination. Distribution networks are different than transmission networks in many ways, quite apart from voltage magnitude. The general structure or topology of the distribution system is different and the number of branches and sources is much higher. A typical distribution system consists of a step-down transformer (e.g., 132/11 kV or 66/11 kV or 33/11 kV) at a bulk supply point feeding a number of lines with varying length from a few hundred meters to several kilometers. Several three-phase step-down transformers, e.g., 11 kV/400 V are spaced along the feeders and from these, three-phase four-wire
networks of consumers are supplied which give 220 volt single-phase supply to houses and similar loads. Figure 1.3 shows part of a typical power system.

Figure 1.1 Schematic diagram of a power supply system.
Figure 1.2 One-line diagram of a simple electric power system.
1.2 Reasons for Interconnection

Generating stations and distribution systems are connected through transmission lines. The transmission system of a particular area (e.g., state) is known as a grid. Different grids are interconnected through tie-lines to form a regional grid (also called power pools). Different regional grids are further connected to form a national grid. Cooperative assistance is one of the planned benefits of interconnected operation.
Interconnected operation is always economical and reliable. Generating stations having large MW capacity are available to provide base or intermediate load. These generating stations must be interconnected so that they feed into the general system but not into a particular load. Economic advantage of interconnection is to reduce the reserve generation capacity in each area. If there is sudden increase of load or loss of generation in one area, it is possible to borrow power from adjoining interconnected areas. To meet sudden increases in load, a certain amount of generating capacity (in each area) known as the "spinning reserve" is required. This consists of generators running at normal speed and ready to supply power instantaneously.

It is always better to keep gas turbines and hydro generators as "spinning reserve". Gas turbines can be started and loaded in 3 minutes or less. Hydro units can be even quicker. It is more economical to have certain generating stations serving only this function than to have each station carrying its own spinning reserve. Interconnected operation also gives the flexibility to meet unexpected emergency loads.

1.3 Load Types

Total load demand of an area depends upon its population and the living standards of people. General nature of load is characterized by the load factor, demand factor, diversity
factor, power factor and utilization factor. In general, the types of load can be divided into the following categories: (1) Domestic (2) Commercial (3) Industrial (4) Agriculture.

**Domestic Load:** Domestic load mainly consists of lights, fans, refrigerators, air-conditioners, mixer, grinders, heaters, ovens, small pumping motors etc.

**Commercial Load:** Commercial load mainly consists of lighting for shops, offices, advertisements etc., fans, heating, air-conditioning and many other electrical appliances used in commercial establishments such as market places, restaurants etc.

**Industrial Loads:** Industrial loads consist of small-scale industries, medium-scale industries, large-scale industries, heavy industries and cottage industries.

**Agriculture Loads:** This type of load is mainly motor pump-sets load for irrigation purposes. Load factor for this load is very small, e.g., 0.15-0.20.

### 1.4 Load Curves

The curve showing the variation of load on the power station with reference 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 graph. The curve thus obtained is
known as *daily load curve* as it shows the variations of load with reference to time during the day. Fig. 1.4 shows a typical daily load curve of a power station. It is clear that load on the power station is varying, being maximum at 6 P.M. in this case. It may be seen that load curve indicates at a glance the general character of the load that is being imposed on the plant. Such a clear representation cannot be obtained from tabulated figures.

![Daily Load Curve](image)

*Fig. 1.4 daily load curve*

The *monthly load curve* can be obtained from the daily load curves of that month. For this purpose, average values of power over a month at different times of the day are calculated and then plotted on the graph. The monthly load curve is generally used to fix the rates of energy. The load curve is obtained by considering the monthly load curves of that particular year. The *yearly load curve* is generally used to
determine the annual load factor.

**Important Notes:**

The daily load curves have attained a great importance in generation as they supply the following information readily:

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

ii. The area under the load curve gives the number of units generated in the day.

\[
\text{Units generated/day} = \text{Area (in kWh) under daily load curve.}
\]

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

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

\[
\text{Average load} = \frac{\text{Area (in kWh) under daily load curve}}{24 \text{ hours}}
\]

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

\[
\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{\text{Average load} \times 24}{\text{Max. demand} \times 24}
\]

vi. The load curve helps in selecting the size number of generating units.
1.5 Units Generated per Annum

It is often required to find the kWh generated per annum from maximum demand and load factor.

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

\[
\text{Average load} = \text{Max. demand} \times \text{L.F.}
\]

\[
\text{Units generated/annum} = \text{Average load (in kW)} \times \text{Hours in a year} = \text{Max. demand (in kW)} \times \text{L.F.} \times 8760
\]

1.6. Base Load and Peak Load on Power Station

The changing load on the power station makes its load curve of variable nature. Figure 1.4 shows the typical load curve of a power station. It is clear that load on the power station varies from time to time. The load curve shows that load on the power station can be considered in two parts, namely;  

(i) Base load  
(ii) Peak load

➢ **Base load:** The unvarying load which occurs almost the whole day on the station. Referring to the load curve of Fig. 1.5, it is clear that 20 MW of load has to be supplied by the station at all times of day and night i.e. throughout 24 hours. Therefore, 20 MW is the base load of the station. As base load on the station is almost of constant nature, therefore, it can be suitably supplied (as discussed in the next Article) without facing the problems of variable load.
- **Peak load**: The various peak demands of load over and above the base load of the station. Referring to the load curve of Fig. 1.5, it is clear that there are peak demands of load excluding base load. These peak demands of the station generally form a small part of the total load and may occur throughout the day.

![Load curve diagram](image)

**Fig. 1.5**

1.7. **Method of Meeting the Load**

The total load on a power station consists of two parts: base load and peak load. In order to achieve overall economy, the best method to meet load is to interconnect different power stations. The more efficient plants are used to supply the base load and are known as **base load power stations**. The less efficient plants are used to supply the peak loads and is known
as *peak load power stations*. There is no hard and fast rule for selection of base load and peak load stations as it would depend upon the particular situation. For example, both hydro-electric and steam power stations are quite efficient and can be used as base load as well as peak load station to meet a particular load requirement.

**Illustration:** The interconnection of steam and hydro plants is a beautiful illustration to meet the load. When water is available in sufficient quantity as in summer and rainy season, the hydroelectric plant is used to carry the base load and the steam plant supplies the peak load as shown in Fig 1.6 (i). However, when the water is not available in sufficient quantity as in winter, the steam plant carries the base load, whereas the hydro-electric plant carries the peak load as shown in Fig. 1,6 (ii)

*Fig. 1.6 Load division on Hydro-steam system*
1.8 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.

The load duration curve is obtained from the same data as the load curve but the ordinates are arranged in the order of descending magnitudes. In other words, the maximum load is represented to the left and decreasing loads are represented to the right in the descending order. Hence the area under the load duration curve and the area under the load curve are equal. Fig. 1.7 (i) shows the daily load curve. The daily load duration curve can be readily obtained from it.

![Fig. 1.7 Daily load duration curve](image)

It is clear from daily load curve [See Fig. 1.7. (i)], that load elements in order of descending magnitude are: 20 MW for 8 hours; 15 MW for 4 hours and 5 MW for 12 hours. Plotting
these loads in order of descending magnitude, we get the daily load duration curve as shown in Fig. 1.7 (ii).

Here are some important points about load duration curve:

- The load duration curve gives the data in a more presentable form. In other words, it readily shows the number of hours during which the given load has prevailed.

- The area under the load duration curve is equal to that of the corresponding load curve. Obviously, area under daily load duration curve. Obviously, area under daily load duration curve (in kWh) will give the units generated on that day.

- The duration curve can be extended to include any period of time. By laying out the abscissa from 0 hour to 8760 hours, the variation and distribution of demand for an entire year can be summarized in one curve. The obtained curve is called the annual load duration curve.

1.9 Basic Definitions of Commonly Used Terms

Electrical engineers use the following terms and factors to describe energy flow in power systems:

- **Connected load**: It is the sum of continuous ratings of all the equipment connected to supply system.

  A power station supplies load to thousands of consumers.
Each consumer has certain equipment installed in his premises. The sum of the continuous ratings of all the equipments in the consumer’s premises is the “connected load” of the consumer. For instance, if a consumer has connections of five 100-watt lamps and a power point of 500 watts, then connected load of the consumer is 5 x 100 + 500 = 1000 watts. The sum of the connected loads of all the consumers is the connected load to the power station.

➢ **Maximum demand:** It is the greatest demand of load on the power station during a given period.

The load on the power station varies from time to time. The maximum of all the demands that have occurred during a given period (say a day) is the maximum demand. Thus referring back to the load curve of Fig. 1.4 the maximum demand on the power station during the day is 6 MW and it occurs at 6 P.M. Maximum demand is generally less than the connected load because all the consumers do not switch on their connected load to the system at a time. The knowledge of maximum demand is very important as it helps in determining the installed capacity of the station. The station must be capable of meeting the maximum demand.
➢ **Demand factor.** *It is the ratio of maximum demand on the power station to its connected load i.e.*

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

The value of demand factor is usually less than 1. It is expected because maximum demand on the power station 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 = \( \frac{80}{100} = 0.8 \). The knowledge of demand factor is vital in determining the capacity of the plant equipment.

➢ **Average load.** *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.*

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

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

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

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

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

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If the plant is in operation for \( T \) hours,

\[
\text{Load factor} = \frac{\text{Average load} \times T}{\text{Max. demand} \times T} = \frac{\text{Units generated in } T \text{ hours}}{\text{Max. demand} \times T \text{ hours}}
\]

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 (It is because higher load factor means lesser maximum demand. The station capacity is so selected that it must meet the maximum demand. Now, lower maximum demand means lower capacity of the plant which, therefore, reduces the cost of the plant).

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

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

A power station supplies load to various types of consumers whose maximum demands generally do not occur at the same time. Therefore, the maximum demand on the
A power station is always less than the sum of individual maximum demands of the consumers. Obviously, diversity factor will always be greater than 1. The greater the diversity factor, the lesser is the cost of generation of power (Greater diversity factor means lesser maximum demand. This in turn means that lesser plant capacity is required. Thus, the capital investment on the plant is reduced).

➢ **Capacity factor.** *It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period i.e.*

\[
\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}}
\]

Suppose the period is T hours then:

\[
\text{Plant capacity factor} = \frac{\text{Average demand } \times T}{\text{Plant capacity } \times T} = \frac{\text{Average demand}}{\text{Plant capacity}}
\]

Thus if the considered period is one year,

\[
\text{Annual plant capacity factor} = \frac{\text{Annual kWh output}}{\text{Plant capacity } \times 8760}
\]

The plant capacity factor is an indication of the reserve capacity of the plant. A power station is so designed that it has some reserve capacity for meeting the increased load demand in future.
Therefore, the installed capacity of the plant is always somewhat greater than the maximum demand on the plant.

**Reserve capacity = Plant capacity - Max. demand.**

It is interesting to note that difference between load factor and capacity factor is an indication of reserve capacity. If the maximum demand on the plant is equal to the plant capacity, then load factor and plant capacity factor will have the same value. In such a case, the plant will have no reserve capacity.

**Plant use factor.** It is the ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation i.e.

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

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

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

**Example 1.1:** A diesel station supplies the following loads to various consumers:

- Industrial consumer = 1500 kW; Commercial establishment = 750 kW
- Domestic power = 100 kW; Domestic light = 450 kW

*If the maximum demand on the station is 2500 kW and the number of kWh generated per year is $45 \times 10^5$, determine (i) the diversity factor and (ii) annual load factor.*

**Solution:**

(i) Diversity factor $= \frac{1500 + 750 + 100 + 450}{2500} = 1.12$

(ii) Average demand $= \frac{\text{yearly kWh generated}}{\text{Hours in a year}} = \frac{45 \times 10^5}{8760} = 513.7$ kW

Load factor $= \frac{\text{Average load}}{\text{Max. demand}} = \frac{513.7}{2500}$

$= 0.205 = 20.5\%$

**Example 1.2:** A power station supplies the following load

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Load (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 AM — 8 AM</td>
<td>1.2</td>
</tr>
<tr>
<td>8 AM — 9 AM</td>
<td>2.0</td>
</tr>
<tr>
<td>9 AM — 12 Noon</td>
<td>3.0</td>
</tr>
<tr>
<td>12 Noon — 2 PM</td>
<td>1.50</td>
</tr>
<tr>
<td>2 PM — 6 PM</td>
<td>2.50</td>
</tr>
<tr>
<td>6 PM — 8 PM</td>
<td>1.80</td>
</tr>
<tr>
<td>8 PM — 9 PM</td>
<td>2.0</td>
</tr>
<tr>
<td>9 PM — 11 PM</td>
<td>1.0</td>
</tr>
<tr>
<td>11 PM — 5 AM</td>
<td>0.50</td>
</tr>
<tr>
<td>5 AM — 6 AM</td>
<td>0.80</td>
</tr>
</tbody>
</table>
(a) Plot the load curve and find out the load factor.
(b) Determine the proper number and size of generating units to supply this load.
(c) Find the reserve capacity of the plant and capacity factor.
(d) Find out the operating schedule of the generating units selected.

**Solution:**

(a) The following figure shows the plot of load curve

Units generated during 24 hours = (2x1.2 + 1x2 + 3x3 + 2x1.5 + 4x2.5 + 2x1.8 + 1x2 + 2x1 + 6x0.5 + 1x0.8) = 37.80 MWhr

Average load = Units generated / Time in hours
Average load = 37.80 / 24 = 1.575 MW.

Load factor (LF) = Maximum load / Maximum load

Maximum load = 3 MW

\[ \therefore \text{LF} = \frac{1.575}{3} = 0.525 \]

(b) Maximum demand = 3 MW. Therefore, 4 generating units of rating 1.0 MW each may be selected. During the period of
maximum demand 3 units will operate and 1 unit will remain as stand by.

(c) Plant capacity = 4 x 1.0 = 4.0 MW

Reserve capacity = 4 - 3 = 1 MW

From eqn. (1.3),

\[
\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}}
\]

Actual energy produced = 37.80 MWhr

Maximum plant rating = 4 MW

Time duration T = 24 hours

\[
\therefore \quad \text{Plant Capacity Factor} = \frac{37.80}{4 \times 24} = 0.39375.
\]

(d) Operating schedule will be as follows:

One generating unit of 1 MW: — 24 hours

Second generating unit of 1 MW: — 6 AM — 9 PM
(15 hours)

Third generating unit of 1 MW: — 9 AM — 12 Noon
  2 PM — 6 PM
(7 hours)

Example 1.3: A generating station has the following daily load cycle:

<table>
<thead>
<tr>
<th>Time (Hours)</th>
<th>0 — 6</th>
<th>6 — 10</th>
<th>10 — 12</th>
<th>12 — 16</th>
<th>16 — 20</th>
<th>20 — 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load (MW)</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>50</td>
<td>70</td>
<td>40</td>
</tr>
</tbody>
</table>

Draw the load curve and find (i) maximum demand (ii) units generated per day (iii) average load and (iv) load factor.
**Solution:**

Daily curve is drawn by taking the load along $Y$-axis and time along $X$-axis and is shown in Figure.

![Load Curve](image)

(i) It is clear from the load curve that maximum demand on the power station is 70 MW and occurs during the period 16-20 hours. $\therefore$ Maximum demand = 70 MW

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

\[ = 10^3 [40 \times 6 + 50 \times 4 + 60 \times 2 + 50 \times 4 + 70 \times 4 + 40 \times 4] \]

\[ = 12 \times 10^5 \text{ kWh} \]

(iii) Average load = Units generated per day/24 hours

\[ = \frac{12 \times 10^5}{24} = 50,000 \text{ kW} \]

(iv) Load factor = Average load/Max. demand = $\frac{50 \, 000}{70 \times 10^3}$

\[ = 0.714 \]

**Example 1.4:** A power station has to meet the following demand:

*Group A*: 200 kW between 8 A.M. and 6 P.M.

*Group B*: 100 kW between 6 A.M. and 10 A.M.

*Group C*: 50 kW between 6 A.M. and 10 A.M.

*Group D*: 100 kW between 10 A.M. and 6 P.M. and then between 6 P.M. and 6 A.M.
Plot the daily load curve and determine (i) diversity factor (ii) units generated per day (iii) load factor

Solution:

The given load cycle can be tabulated as under:

<table>
<thead>
<tr>
<th>Time (Hours)</th>
<th>0—6</th>
<th>6—8</th>
<th>8—10</th>
<th>10—18</th>
<th>18—24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>—</td>
<td>—</td>
<td>200 kW</td>
<td>200 kW</td>
<td>—</td>
</tr>
<tr>
<td>Group B</td>
<td>—</td>
<td>100 kW</td>
<td>100 kW</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Group C</td>
<td>—</td>
<td>50 kW</td>
<td>50 kW</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Group D</td>
<td>100 kW</td>
<td>—</td>
<td>—</td>
<td>100 kW</td>
<td>100 kW</td>
</tr>
</tbody>
</table>

Total load on power station: 100 kW 150 kW 350 kW 300 kW 100 kW

Plotting the load on power station versus time, we get the daily load curve as shown in Figure. 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 = 450/350 = 1.286

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

\[ = 100\times6 + 150\times2 + 350\times2 + 300\times8 + 100\times6 = 4600 \text{ kWh} \]

(iii) Average load = 4600/24 = 191.7 kW

\[ \therefore \text{ Load factor} = 191.7/350 = 0.548 \]
EXERCISE-1

1. A generating station has a maximum demand of 25MW, a load factor of 60%, a plant capacity factor of 50% and a plant use factor of 72%. Find (i) the reserve capacity of the plant (ii) the daily energy produced and (iii) maximum energy that could be produced daily if the plant while running as per schedule, were fully loaded.

   Ans.: 5 MW, 360 MWh, 500 MWh/day

2. A power supply is having the following loads:

<table>
<thead>
<tr>
<th>Type of load</th>
<th>Max. demand(kW)</th>
<th>Diversity of group</th>
<th>Demand factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>1500</td>
<td>1.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Commercial</td>
<td>2000</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Industrial</td>
<td>10,000</td>
<td>1.25</td>
<td>1</td>
</tr>
</tbody>
</table>

   If the overall system diversity factor is 1.35, determine (i) the maximum demand and (ii) connected load of each type.

   Ans.: 10,000, 2250, 2444, 12,500 kW

3. The daily demands of three consumers are given below:

<table>
<thead>
<tr>
<th>Time</th>
<th>Consumer 1</th>
<th>Consumer 2</th>
<th>Consumer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 midnight to 8 A.M.</td>
<td>No load</td>
<td>200 W</td>
<td>No load</td>
</tr>
<tr>
<td>8 A.M. to 2 P.M.</td>
<td>600 W</td>
<td>No load</td>
<td>200 W</td>
</tr>
<tr>
<td>2 P.M. to 4 P.M.</td>
<td>200 W</td>
<td>1000 W</td>
<td>1200 W</td>
</tr>
<tr>
<td>4 P.M. to 10 P.M.</td>
<td>800 W</td>
<td>No load</td>
<td>No load</td>
</tr>
<tr>
<td>10 P.M. to midnight</td>
<td>No load</td>
<td>200 W</td>
<td>200 W</td>
</tr>
</tbody>
</table>
Plot the load curve and find (i) maximum demand of individual consumer (ii) load factor of individual consumer (iii) diversity factor and (iv) load factor of the station.

\[ \text{Ans.}: \ DF = 1.25, \ LF = 29.1\% \]

4. A power station has a daily load cycle as under:

260 MW for 6 hours; 200 MW for 8 hours; 160 MW for 4 hours; and 100 MW for 6 hours.

If the power station is equipped with 4 sets of 75 MW each, calculate (i) daily load factor (ii) plant capacity factor and (iii) daily requirement if the calorific value of oil used were 10,000 kcal/kg and the average heat rate of station were 2860 kcal/kWh.

\[ \text{Ans.}: 70.5\%, 61.1\%, 1258.4 \text{ tons} \]

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

Annual standby station output = \( 7.35 \times 10^6 \) kWh
Annual base load station output = \( 101.35 \times 10^6 \) kWh
Peak load on standby station = 12 MW
Hours of use by standby station/year = 2190 hours

\[ \text{Ans.}: 28\%, 4.2\%, 64.2\% \]
Chapter 2

Economics of Power Generation

Introduction
A power station is required to deliver power to a large number of consumers to meet their requirements. While designing and building a power station, efforts should be made to achieve overall economy so that the per unit cost of production is as low as possible. This will enable the electric supply company to sell electrical energy at a profit and ensure reliable service. The problem of determining the cost of production of electrical energy is highly complex and poses a challenge to power engineers. There are several factors which influence the production cost such as cost of land and equipment, depreciation of equipment, interest on capital investment etc. Therefore, a careful study has to be made to calculate the cost of production. In this chapter, we shall focus our attention on the various aspects of economics of power generation.

2.1 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

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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. Before passing on to the subject further, it is desirable that the readers get themselves acquainted with the following terms much used in the economics of power generation:

(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 on this amount. Even if company has spent out of its reserve funds, the interest must be still allowed for, since this amount could have earned interest if deposited in a bank. 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.

(ii) **Depreciation.** The decrease in the value of the power plant equipment and building due to constant use is known as depreciation.
If the power station equipment were to last forever, then interest on the capital investment would have been the only charge to be made. However, 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. It becomes obvious that while determining the cost of production, annual depreciation charges must be included. There are several methods of finding the annual depreciation charges and are discussed in sec. 2.4.

2.2 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.
(i) **Fixed cost.** It is the cost which is independent of maximum demand and units generated.

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.

(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 on capital investment of building and equipment, taxes, salaries of management and clerical 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 its size and cost of installation. Further, the taxes and clerical staff depend upon 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 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 and vice-versa.

2.3 Expressions for Cost of Electrical Energy

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

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

\[
\text{Total annual cost of energy} = \text{Fixed cost} + \text{Semi-fixed cost} + \text{Running cost} \\
= \text{Constant} + \text{Proportional to max. demand} + \text{Proportional to kWh generated.} \\
= \text{LE} \ (a + b \ kW + c \ kWh)
\]

where

a = annual fixed cost independent of maximum demand and energy output. It is on account of the costs mentioned in sec. 2.2.

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

c = a constant which when multiplied by kWh output per annum gives the annual running cost.
(ii) 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 viz., 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:

\[
\text{Total annual cost of energy} = \text{LE} (A \ kW + B \ kWh)
\]

where

\[
A = \text{a constant which when multiplied by maximum kW demand on the station gives the annual cost of the first part}
\]

\[
B = \text{a constant which when multiplied by the annual kWh generated gives the annual running cost.}
\]

It is interesting to see here that two-part form is a simplification of three-part form. A little reflection shows that constant “a” of the three part form has been merged in fixed sum per kW maximum demand (i.e. constant A) in the two-part form.

2.4 Methods of Determining Depreciation

There is reduction in the value of the equipment and other property of the plant every year due to depreciation. Therefore, a suitable amount (known as depreciation charge) must be set aside annually so that by the time the life span of the plant is over, the collected amount equals the cost of replacement of the plant.

The most commonly used methods for determining the annual depreciation charge are: Straight line method; and Diminishing value method;
(i) **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 property. Obviously, annual depreciation charge will be equal to the total depreciation divided by the useful life of the property. Thus, if the initial cost of equipment is LE 1,00,000 and its scrap value is LE 10,000 after a useful life of 20 years, then,

$$\text{Annual depreciation charge} = \frac{\text{Total depreciation}}{\text{Useful life}}$$

$$= \frac{1,00,000 - 10,000}{20} = \text{LE 4,500}$$

In general, the annual depreciation charge on the straight line method may be expressed as:

$$\text{Annual depreciation charge} = \frac{P - S}{n}$$

Where

- $P$ = 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. Fig. 2.1 shows the graphical representation of the method. It is clear that initial value $P$ of the equipment reduces uniformly, through
depreciation, to the scrap value $S$ in the useful life of the equipment.

![Depreciation Curve](image)

**Fig. 2.1**

The depreciation curve (PA) follows a straight line path, indicating constant annual depreciation charge. 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.

(ii) **Diminishing value method.** In this method, depreciation charge is made every year at a fixed rate on the diminished value of the equipment. In other words, depreciation charge is first applied to the initial cost of equipment and then to its diminished value. As an example, suppose the initial cost of equipment is LE
10,000 and its scrap value after the useful life is zero. If the annual rate of depreciation is 10%, then depreciation charge for the first year will be \(0.1 \times 10,000 = \text{LE} \, 1,000\). The value of the equipment is diminished by \(\text{LE} \, 1,000\) and becomes \(\text{LE} \, 9,000\). For the second year, the depreciation charge will be made on the diminished value (i.e. \(\text{LE} \, 9,000\)) and becomes \(0.1 \times 9,000 = \text{LE} \, 900\). The value of the equipment now becomes \(9000 - 900 = \text{LE} \, 8100\). For the third year, the depreciation charge will be \(0.1 \times 8100 = \text{LE} \, 810\) and so on.

Mathematical treatment

Let:

- \(P\) = Capital cost of equipment
- \(n\) = Useful life of equipment in years
- \(S\) = Scrap value after useful life

It is desired to find the value of \(x\) in terms of \(P\), \(n\) and \(S\). Suppose the annual unit depreciation is \(x\) (If annual depreciation is 10%, then we can say that annual unit depreciation is 0.1).

Value of equipment after one year

\[
= P - Px = P(1 - x)
\]

Value of equipment after 2 years

\[
= \text{Diminished value} - \text{Annual depreciation}
= [P - Px] - [(P - Px)x]
= P - Px - Px + Px^2
= P(x^2 - 2x + 1)
= P(1 - x)^2
\]

\[
\therefore \text{Value of equipment after } n \text{ years}
= P(1 - x)^n
\]
But the value of equipment after n years (i.e., useful life) is equal to the scrap value S.

\[ S = P(1 - x)^n \]

or

\[ (1 - x)^n = \frac{S}{P} \]

or

\[ 1 - x = (\frac{S}{P})^{1/n} \]

or

\[ x = 1 - (\frac{S}{P})^{1/n} \]

From the last equation, the annual depreciation can be easily found. For the first year the depreciation is given by:

\[ \text{Depreciation for the first year} = xP \]

\[ = P[1 - (\frac{S}{P})^{1/n}] \]

Similarly, annual depreciation charge for the subsequent years can be calculated.

This method is more rational than the straight line method. Fig. 2.2 shows the graphical representation of diminishing value method. The initial value P of the equipment reduces, through depreciation, to the scrap value S over the useful life of the equipment. The depreciation curve follows the path PA. It is clear from the curve that depreciation charges are heavy in the early years but decrease to a low value in the later years.

The main advantage of this method lies in that the low depreciation charges are made in the late years when the maintenance and repair charges are quite heavy. Whereas the disadvantage of it is that the depreciation charge is independent of
the rate of interest which it may draw during accumulation. Such interest moneys, if earned, are to be treated as income.

**Example 2.1:** A transformer costing LE 90,000 has a useful life of 20 years. Determine the annual depreciation charge using straight line method. Assume the salvage value of the equipment to be LE 10,000.

**Solution:**

Initial cost of transformer, $P = LE\ 90,000$; Useful life $n = 20$ years; Salvage value $S = LE\ 10,000$

Using straight line method:

Annual depreciation charge $= (P - S)/n = LE\ 4000$
Example 2.2: The equipment in a power station costs LE 15,60,000 and has a salvage value of LE 60,000 at the end of 25 years. Determine the depreciated value of the equipment at the end of 20 years on the following methods:

(i) Straight line method (ii) Diminishing value method.

Solution:

Initial cost of equipment \( P \) = LE 15,60,000; Salvage value of equipment \( S \) = LE 60,000; Useful life, \( n \) = 25 years

(i) Straight line method

Annual depreciation = \( \frac{P - S}{n} \) = LE 60,000

Value of equipment after 20 years = \( P - \text{Annual depreciation} \times 20 \)

= 15,60,000 - 60,000 \times 20 = LE 3,60,000

(ii) Diminishing value method

Annual unit depreciation, \( x = 1 - \frac{S}{P} \) \(^{1/n} = 1 - 0.878 = 0.122 \)

Value of equipment after 20 years = \( P(1 - x)^{20} \)

= 15,60,000 \( (1 - 0.122)^{20} \) = LE 1,15,615

2.5 Importance of High Load Factor

The load factor plays a vital role in determining the cost of energy. Some important advantages of high load factor are listed below:

(i) Reduces cost per unit generated: A high load factor reduces the overall cost per unit generated. The higher the load factor, the
lower is the generation cost. It is because higher load factor means that for a given maximum demand, the number of units generated is more. This reduces the cost of generation.

(ii) Reduces variable load problems: A high load factor reduces the variable load problems on the power station. A higher load factor means comparatively less variations in the load demands at various times. This avoids the frequent use of regulating devices installed to meet the variable load on the station.

Example 2.3: A generating station has a maximum demand of 50,000 kW. Calculate the cost per unit generated from the following data:

Capital cost = LE 95 × 10^6; Annual load factor = 40%; Annual cost of fuel and oil = LE 9 × 10^6; Taxes, wages and salaries etc. = LE 7.5 × 10^6; Interest and depreciation = 12%

Solution:

Units generated/annum = max. demand × L.F. × hours in a year

= (50,000) × (0.4) × (8760) kWh = 17.52 × 10^7 kWh

Annual fixed charges

Annual interest and depreciation = 12% of capital cost

= LE 0.12 × 95 × 10^6 = LE 11.4 × 10^6

Annual Running Charges

Total annual running charges = Annual cost of fuel and oil + Taxes, wages etc.
= LE \( (9 \times 10^6 + 7.5 \times 10^6) = LE \ 16.5 \times 10^6 \)

Total annual charges = \( 11.4\times10^6 + 16.5\times10^6 = LE \ 27.9 \times 10^6 \)

\[ \therefore \text{Cost per unit} = \left( \frac{27.9\times10^6}{17.52\times10^7} \right) = LE \ 0.16 \]

**Example 2.4:** A generating plant has a maximum capacity of 100 kW and costs LE 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%.

**Solution:**

Maximum demand = 100 kW

Annual fixed charges = LE 0.12 \times 1,60,000 = LE 19,200

(i) **When load factor is 100%**

Units generated/annum=Max. demand \times L.F. \times Hours in a year

\[ = 100 \times 1 \times 8760 = 8,76,000 \text{ kWh} \]

Fixed charges/kWh = \( \frac{19200}{876000} = LE \ 0.0219 \)

(ii) **When load factor is 50%**

Units generated/annum = 100 \times 0.5 \times 8760 = 4,38,000 kWh

Fixed charges/kWh = \( \frac{19200}{438000} = LE \ 0.0438 \)

It is interesting to note that by decreasing the load factor from 100% to 50%, the fixed charges/kWh have increased two-fold.

Incidentally, this illustrates the utility of high load factor
2.6 Tariff of Electricity

The electrical energy produced by a power station is delivered to a large number of consumers. The consumers can be persuaded to use electrical energy if it is sold at reasonable rates. The tariff i.e., the rate at which electrical energy is sold naturally becomes attention inviting for electric supply company. 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 on the capital investment. However, the profit must be marginal particularly for a country like Egypt where electric supply companies come under public sector and are always subject to criticism. In this section, we shall deal with various types of tariff with special references to their advantages and disadvantages.

2.6.1 Tariff definition and objectives

*The rate at which electrical energy is supplied to a consumer is known as tariff.*

Although tariff should include the total cost of producing and supplying electrical energy plus the profit, yet it cannot be the same for all types of consumers. It is because the cost of producing electrical energy depends to a considerable extent upon the magnitude of electrical energy consumed by the user and his load conditions. Therefore, in all fairness, due consideration has to
be given to different types of consumers (e.g., industrial, domestic and commercial) while fixing the tariff. This makes the problem of suitable rate making highly complicated.

**Objectives of tariff:**

Like other commodities, electrical energy is also sold at such a rate so that it not only returns the cost but also earns reasonable profit. Therefore, a tariff should include the following items:

(i) Recovery of cost of producing electrical energy at the power station.

(ii) Recovery of cost on the capital investment in transmission and distribution systems.

(iii) Recovery of cost of operation and maintenance of supply of electrical energy e.g., metering equipment, billing etc.

(iv) A suitable profit on the capital investment.

**2.6.2 Desirable characteristics of a tariff**

A tariff must have the following desirable characteristics:

*(i) Proper return:* The tariff should be such that it ensures the proper return from each consumer. In other words, the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit. This will enable the electric supply company to ensure continuous and reliable service to the consumers.
(ii) **Fairness:** The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy. Thus a big consumer should be charged at a lower rate than a small consumer. It is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy. Similarly, a consumer whose load conditions do not deviate much from the ideal (i.e., non-variable) should be charged at a lower rate than the one whose load conditions change appreciably from the ideal.

(iii) **Simplicity:** The tariff should be simple so that an ordinary consumer can easily understand it. A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

(iv) **Reasonable profit:** The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of monopoly. Therefore, the investment is relatively safe due to non-competition in the market. This calls for the profit to be restricted to 8% or so per annum.

Efforts should be made to fix the tariff in such a way so that consumers can pay easily.
2.6.3 Types of Tariff

There are several types of tariff. However, the following are the commonly used types of tariff:

1. Simple tariff.
In this type of tariff, the price charged per unit is constant i.e., it does not vary with increase or decrease in number of units consumed. The consumption of electrical energy at the consumer’s terminals is recorded by means of an energy meter. This is the simplest of all tariffs and is readily understood by the consumers.

Disadvantages
(i) There is no discrimination between different types of consumers since every consumer has to pay equitably for the fixed charges.
(ii) The cost per unit delivered is high.
(iii) It does not encourage the use of electricity.

2. Flat rate tariff.
In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate. The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculations.

Disadvantages
(i) Since the flat rate tariff varies according to the way the supply is used, different meters are required for different types of
consumers. This makes the application of such a tariff expensive.

(ii) A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

3. Block rate tariff.
In this type of tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. In some countries the price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy. In other countries which suffer from electricity crisis, the first block is the lowest and it is progressively increased for the succeeding blocks of energy. In the last case, the first 30 units may be charged at the rate of 30 piastres per unit; the next 25 units at the rate of 40 piastres per unit and the remaining additional units may be charged at the rate of 60 piastres per unit.

The advantage of such a tariff is that the utility can control the consumption of electricity. It can encourage the consumers to consume more electrical energy. This increases the load factor of the system and hence reduces the cost of generation. On other hand the weak utilities can discourage the consumers to consume more electrical energy to maintain the utility out of electricity shortage.
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: 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 (or connected load) plus a certain amount per kWh of energy consumed i.e.

\[ \text{Total charges} = \text{LE} (b \times \text{kW} + c \times \text{kWh}) \]

where,

- \( b \) = charge 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 easily 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.

There are other used tariff types, such as:

- Maximum demand tariff.
- Power factor tariff.
- Three-part tariff.

**Example 2.5:** The maximum demand of a consumer is 20 A at 220 V and his total energy consumption is 8760 kWh. If the energy is charged at the rate of 20 piastres per unit for 500 hours use of the maximum demand per annum plus 10 piastres per unit for additional units, calculate:

(i) annual bill (ii) equivalent flat rate.

**Solution:**

Assume the load factor and power factor to be unity.

\[ \text{Maximum demand} = \frac{220 \times 20 \times 1}{1000} = 4.4 \text{ kW} \]

(i) Units consumed in 500 hrs = 4.4 \times 500 = 2200 kWh

Charges for 2200 kWh = LE 0.2 \times 2200 = LE 440

Remaining units = 8760 – 2200 = 6560 kWh

Charges for 6560 kWh = LE 0.1 \times 6560 = LE 656
∴ Total annual bill = LE (440 + 656) = LE 1096

(ii) Equivalent flat rate = LE 1096/8760 = LE 0.125 = 12.5 piastres

**Example 2.6:** A supply is offered on the basis of fixed charges of LE 30 per annum plus 3 piastres per unit or alternatively, at the rate of 6 piastres per unit for the first 400 units per annum and 5 piastres per unit for all the additional units. Find the number of units taken per annum for which the cost under the two tariffs becomes the same.

**Solution:**

Let \( x (> 400) \) be the number of units taken per annum for which the annual charges due to both tariffs become equal.

Annual charges due to first tariff = LE \((30 + 0.03x)\)

Annual charges due to second tariff = LE \([(0.06 \times 400) + (x - 400) \times 0.05]\) = LE \((4 + 0.05x)\)

As the charges in both cases are equal,

∴ \(30 + 0.03x = 4 + 0.05x\)

Then \(x = 1300\) kWh
Exercise 2

1. A distribution transformer costing LE 50,000 has a useful life of 15 years. Determine the annual depreciation charge using straight line method. Assume the salvage value of the equipment to be LE 5,000.  
   \textit{Ans. LE 3,000}

2. 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 = 1.2 \times 10^6;
   Annual cost of wages, taxation etc. = LE 4 \times 10^5;
   Cost of fuel, lubrication, maintenance etc. = 0.01 LE/kWh
   Interest = 5\% per annum. depreciation 6\% per annum of initial value.  
   \textit{Ans. LE 0.02}

3. A hydro-electric plant costs LE 3000 per kW of installed capacity. The total annual charges consist of 5\% as interest; depreciation at 2\%, operation and maintenance at 2\% and insurance, rent etc. 1.5\%. Determine a suitable two-part tariff if the losses in transmission and distribution are 12.5\% and diversity of load is 1.25. Assume that maximum demand on the station is 80\% of the capacity and annual load factor is 40\%. What is the overall cost of generation per kWh?  
   \textit{Ans. LE (210 \times kW + 0.043 \times kWh), LE 0.128}
4. A power station having a maximum demand of 100 MW has a load factor of 30% and is to be supplied by one of the following schemes:

(i) a steam station in conjunction with a hydro-electric station, the latter supplying $100 \times 10^6$ kWh per annum with a maximum output of 40 MW.
(ii) a steam station capable of supplying the whole load.
(iii) a hydro-station capable of supplying the whole load.

Compare the overall cost per kWh generated, assuming the following data:

<table>
<thead>
<tr>
<th>Item</th>
<th>Steam</th>
<th>Hydro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost/kW installed</td>
<td>LE 1250</td>
<td>LE 2500</td>
</tr>
<tr>
<td>Interest and depreciation on capital investment</td>
<td>12%</td>
<td>10%</td>
</tr>
<tr>
<td>Operating cost /kWh</td>
<td>5 piastre</td>
<td>1.5 piastre</td>
</tr>
<tr>
<td>Transmission cost/kWh</td>
<td>negligible</td>
<td>0.2 piastre</td>
</tr>
</tbody>
</table>

*Ans. 10.97, 10.71, 11.21 piastres*

5. The maximum demand of a consumer is 25A at 220 V and his total energy consumption is 9750 kWh. If energy is charged at the rate of 20 piastres per kWh for 500 hours use of maximum demand plus 5 piastres per unit for all additional units, estimate his annual bill and the equivalent flat rate.

*Ans. LE 900; 9.2 piastres*
6. A consumer has a maximum demand of 200 kW at 40% load factor. If the tariff is LE. 100 per kW of maximum demand plus 10 piastres per kWh, find the overall cost per kWh.

\[ \text{Ans. 12.85 piastres} \]

7. A consumer has an annual consumption of \(2 \times 10^5\) units. The tariff is LE 50 per kW of maximum demand plus 10 piastres per kWh.

(i) Find the annual bill and the overall cost per kWh if the load factor is 35%.
(ii) What is the overall cost per kWh if the consumption were reduced by 25% with the same load factor?
(iii) What is the overall cost per kWh if the load factor were 25% with the same consumption as in (i)?

\[ \text{Ans. (i) LE 23,400; 11.7 pias. (ii) 11.7 pias. (iii) 12.28 pias.} \]

8. Determine the load factor at which the cost of supplying a unit of electricity from a Diesel and from a steam station is the same if the annual fixed and running charges are as follows:

<table>
<thead>
<tr>
<th>Station</th>
<th>Fixed charges</th>
<th>Running charges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>LE 300 per kW</td>
<td>25 piastres /kWh</td>
</tr>
<tr>
<td>Steam</td>
<td>LE 1200 per kW</td>
<td>6.25 piastres /kWh</td>
</tr>
</tbody>
</table>

\[ \text{Ans. 54.72\%} \]