Load Curves and Factors

In choosing the type of generation (thermal, hydro-electric and nuclear), and to select the size and number of generating units, there are number of points must be considered:

i. Kinds of fuels which are available.
ii. Costs suitable of site for hydro station.
iii. Nature of loads to be supplied.

The load which a power system has to supply is never constant because of variable demands at different time of the day. The variations can be seen from the predication load curve.

Load curve:

It is a graphic record showing the demand of the power for every instant during the hour, the day, the month or the year. The Figure below represent the daily load curve.

Important terms and factors:

The variable load problem has introduction the following terms and factors in power plant generating:

1. Connected load: It is the sum of continuous ratings of all the equipment’s connected in supply system.

2. Demand: Demand of an installation or system is the load that is drawn from the supply at a specified interval of time; it is expressed in KWs, KVA or Amperes.

3. Maximum demand (max; or peak load):
   It is the greatest demand of load on the power station during a given period. Max; demand is very important to determine the installed capacity of the station. The station must be capable meeting the max; demand.

   \[
   \text{Power generation} = \text{power load} + \text{loss of lines} \\
   P_G = P_L \text{ (when losses of T.L } = 0) 
   \]

4. Demand factor = \( \frac{\text{Max Demand}}{\text{Connected load}} \)

Demand factor < 1. It is used to determine the capacity of the plant equipment. And may indicate the degree to which the total connected load is operated simultaneously.
5. **Average load:** The average of load occurring on the power station in a given period (day or month or year) is known as *average load* or *average demand*.

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

\[
= \frac{\text{Total energy generated during a day KWh}}{24 \text{hours}}
\]

\[
= \frac{\text{Area under the daily curve}}{24 \text{ hours}}
\]

Also:

\[
\text{Monthly average load} = \frac{\text{Total energy generated during a month KWh}}{\text{No. of hours in a month}}
\]

\[
\text{Yearly average load} = \frac{\text{Total energy generated during a year KWh}}{\text{No. of hours in a year (8760 h)}}
\]

\[
\text{In general average load} = \frac{\text{Total energy generated during a } T \text{ period}}{\text{No. of hours in } T \text{ period}}
\]

6- **Load factor (L.F.)**

\[
\text{Load factor (L.F.)} = \frac{\text{Average (Load or demand)}}{\text{Max. demand (load)}}
\]

during a certain period.

\[
= \left( \frac{\text{Total energy generated during a } T \text{ period}}{\text{Max. demand} \times \text{No. of hours in } T \text{ period}} \right)
\]

\[
= \frac{\text{Total energy generated during a } T \text{ period}}{\text{Max. demand} \times \text{No. of hours in } T \text{ period}} \times \frac{\text{Units generated in } T}{\text{Max. Demand} \times T}
\]

**Note:** Load factor may be daily, monthly or annual. If \( T = 24 \text{ hours} \), the L.F is called daily load factor.

\[\text{L.F} < 1; \text{L.F} \propto \frac{1}{\text{Max. demand}}\]

Cost Plant \( \propto \) Capacity of station \( \propto \) Max. Demand.

\[\therefore \text{ Cost of plant } \propto \frac{1}{\text{LF of power station}}\]

\(i.e.\) Load factor is plays key role in to determining the overall cost of plant. And it indicates the degree to which the peak load is sustained during the period.

7 – **Diversity factor (D.F)**

\[
\text{Diversity factor (D.F)} = \frac{\text{Sum of individual max. demands}}{\text{Max. Demand on power station}}
\]

Diversity factor will always be greater than 1.
Fig (a)  
1. 14-16  →  100 KW = y1 
2. 14-16  →  100 KW = y2 
3. 14-16  →  100 KW = y3 

D. F = \frac{y1 + y2 + y3}{Y} = \frac{3y}{300} = 1 \text{ (Very bad D.F)} 

Fig (b) 
D.F = \frac{300}{100} = 3 \text{ (Very good D.F)} 

\text{DF} \geq 1; \text{DF} \propto \frac{1}{\text{Max. demand}} 
\therefore \text{Cost of plant} \propto \frac{1}{\text{DF}} 

8- \text{Plant Capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}} 
= \frac{\text{Average load (demand) \times T}}{\text{Max. Demand \times T}} 
= \frac{\text{Average demand}}{\text{Plant Capacity}} 

\text{If the period is one year,} 
\text{Annual Capacity factor} = \frac{\text{Annual KWh output}}{\text{Plant Capacity} \times 8760} 

\text{The plant capacity factor is an indication of the reserve capacity of the plant.} 

9- \text{Reserve Capacity} = \text{Plant Capacity} - \text{Max. Demand} 

10- \text{Plant use factor} = \frac{\text{Station output in KWh}}{\text{Plant Capacity} \times \text{hours of use}} 

\text{Ex.} 20 \text{ MW power station, produces annual output of (7.35 \times 10^6) KWh and remains in operation for 2190 hours in year, find the plant use factor.} 

\text{Sol.:} 
\text{Plant use factor} = \frac{7.35 \times 10^6 \times 10^3}{(20 \times 10^6) \times 2190} = 0.16 = 16.7\%
Base Load and Peak Load on Power Station

The changing load on the power station makes its load curve of variable nature. The Fig; shows load curve of power station.

The load curve can be considered in to parts, namely:
1. **Base load**: The unvarying load which occurs almost the whole day on the station.
2. **Peak load**: The various peak demand of the load over and above the base load of the station.

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. It gives the data in more presentable form.

Fig. below represents:
- **i)** Daily load curve.
- **ii)** Daily load duration curve.

Area under daily load curve = Area under daily load duration curve.

= Total energy generated (KWh) on the day.

Load curves and selection of the number and sizes of the generation units:

The number and size of generating units are selected in such a way that they correctly fit the station load curve as shown:

<table>
<thead>
<tr>
<th>Time</th>
<th>Units in operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 mid night-----7 A.M.</td>
<td>1</td>
</tr>
<tr>
<td>7 A.M.-----12 noon</td>
<td>1+2</td>
</tr>
<tr>
<td>12 noon -----2 P.M.</td>
<td>1</td>
</tr>
<tr>
<td>2 P.M. -----5 P.M.</td>
<td>1 + 2</td>
</tr>
<tr>
<td>5 P.M.-----10.30 P.M.</td>
<td>1 + 2 + 3</td>
</tr>
<tr>
<td>10.30-----12 mid night</td>
<td>1 + 2</td>
</tr>
</tbody>
</table>

In Fig; **i)**, the annual load curve of the station, it clear a wide variations of the load on the station. Minimum load begin somewhat near 50KW and maximum load reaching 500KW. Fig; **ii)**, illustrated the total plant capacity is divided in to several generating units the different sizes to fit the load curve.
The important points in the selection of generator units are:
» The selection of units should be approximately fit the annual (yearly) load curve of the station.
» The capacity of the plant should be made 15 to 20% more than the maximum demand.
» One unit should be kept as a spare generating unit (standby unit).
» By using identical units (having the same capacity) ensure saving in cost of station, but often do not meet the load requirement.
» The load curve can be fit very accurately if large number and small capacity of units are selected, this is one side, in other side, the investment cost per KW of capacity increases as the size of the units decreases.

Interconnected Grid System:
The connected of several generating station in parallel is known as interconnected system.
Advantages of interconnected system are:
1. Exchange of peak loads: If the load curve of 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.
2. Use older plants: The interconnected system makes it possible to use the older and less efficient plant to carry peak loads of short duration.
3. Ensures economical operation: The interconnected system makes the operation of concerned power stations quite economical, because sharing of load among the stations.
4. Increasing diversity factor: The load curve of different interconnected stations are generally different, the result is that maximum demand on the system is much reduced. The diversity factor of the system is improves there by increasing the effective capacity of the system.
5. Reduced plant reserve capacity:
6. Increases reliability of supply: If a major break down occurs in one station continuity of supply can be maintained by other stations.
A power station is to supply three consumers. The daily demand of three consumers is given below:

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Consumer (1)</th>
<th>Consumer (2)</th>
<th>Consumer (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 6</td>
<td>200 KW</td>
<td>100 KW</td>
<td>No – load</td>
</tr>
<tr>
<td>6 – 14</td>
<td>600 KW</td>
<td>1000 KW</td>
<td>400 KW</td>
</tr>
<tr>
<td>14 – 18</td>
<td>No – load</td>
<td>600 KW</td>
<td>400 KW</td>
</tr>
<tr>
<td>18 – 24</td>
<td>800 KW</td>
<td>No – load</td>
<td>600 KW</td>
</tr>
</tbody>
</table>

Plot the load curve of power station and, find:
1- Load factor of individual consumer.
2- Diversity factor of power station.
3- Load factor of power station.

**Sol.**:

1- Load factor of consumer  = \( \frac{\text{Energy consumed / day}}{\text{Max. demand} \times \text{hours in day}} \times 100 \)

Load factor of consumer (1) = \( \frac{200 \times 6 + 600 \times 8 + 0 \times 4 + 800 \times 6}{800 \times 24} \) = 56.25%

Load factor of consumer (2) = \( \frac{100 \times 6 + 1000 \times 8 + 600 \times 4 + 0 \times 6}{1000 \times 24} \times 100 = 45.8\%

Load factor of consumer (3) = \( \frac{0 \times 6 + 400 \times 8 + 400 \times 4 + 600 \times 6}{600 \times 24} \times 100 = 58.3\%

From load curve, the Max; demand on power station is 2000 KW.

2- Diversity factor = \( \frac{\text{Sum of individual max; demands}}{\text{Max; demand on power station}} \) = \( \frac{800 + 1000 + 600}{2000} \) = 1.2

3- Load factor of power station = \( \frac{300 \times 6 + 2000 \times 8 + 1000 \times 4 + 1400 \times 6}{2000 \times 24} \times 100 = 62.9\%

**Ex.:** A proposed station has the following daily load cycle:

<table>
<thead>
<tr>
<th>Time in hours</th>
<th>Load in MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-8</td>
<td>20</td>
</tr>
<tr>
<td>8-11</td>
<td>40</td>
</tr>
<tr>
<td>11-16</td>
<td>50</td>
</tr>
<tr>
<td>16-19</td>
<td>35</td>
</tr>
<tr>
<td>19-22</td>
<td>70</td>
</tr>
<tr>
<td>22-24</td>
<td>40</td>
</tr>
<tr>
<td>24-6</td>
<td>20</td>
</tr>
</tbody>
</table>

Draw the load curve and selected suitable generator units from the 10000, 20000, 25000, 30000KVA. Determine the load factor from the curve.
Sol.:

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

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

\[ = 925 \times 10^3 \text{ kWh.} \]

Average load = \[ \frac{\text{No.of units (KWh) generated in day}}{24 \text{ hours}} \]

\[ = \frac{925 \times 10^3}{24} = 38541.7 \text{ kW} \]

Load factor (L. F) = \[ \frac{\text{Average load}}{\text{Max. Demand}} = \frac{38541.7}{70 \times 10^3} \times 100 = 55.06\% \]

Selection the number and size of units: Assuming P.F = 0.8, output of the generating units available will be 8, 16, 20 and 24 MW.

i. One set of highest capacity should be kept as standby unit.

ii. The units should meet the maximum demand (70 MW).

iii. There should be overall economy.

According to the above conditions, 4 units with 24 MW for each one are choosing. Therefore, three units will meet the maximum demand of 70 MW and one unit will serve as a standby unit.

H.W: A power station supplies the loads as tabulated below:

<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</td>
</tr>
<tr>
<td>9 AM — 12 Noon</td>
<td>3</td>
</tr>
<tr>
<td>12 Noon — 2 PM</td>
<td>1.5</td>
</tr>
<tr>
<td>2 PM — 6 PM</td>
<td>2.5</td>
</tr>
<tr>
<td>6 PM — 8 PM</td>
<td>1.8</td>
</tr>
<tr>
<td>8 PM — 9 PM</td>
<td>2</td>
</tr>
<tr>
<td>9 PM — 11 PM</td>
<td>1</td>
</tr>
<tr>
<td>11 PM — 5 AM</td>
<td>0.5</td>
</tr>
<tr>
<td>5 AM — 6 AM</td>
<td>0.8</td>
</tr>
</tbody>
</table>

a. Plot the load curve and find 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 plant factor.

[Ans.: L.F. = 0.525, 4 unit & 1MW, R.C. = 1MW and P.F. = 0.39375]
Power Transmission

There are two types of transmission system:

**a**- Overhead transmission line.

**b**- Underground cables.

**Overhead transmission line:**
An overhead transmission line consists of conductors, insulators, support structures, and in most cases, shield wire (ground wire).

**Economic choice of transmission voltage:**

\[ P_{\text{1-phase}} = VI \cos \phi \quad \ldots \ldots (1) \]

If \( \cos \phi \) constant

\[ P_{\text{1-phase}} \alpha V^\uparrow I_\downarrow \rightarrow \left\{ \begin{array}{l}
\text{loss} \downarrow, \eta \uparrow \\
\rightarrow \text{C. S. A of conductor } \alpha \text{ cost } \downarrow \\
\rightarrow \text{Voltage regulation (V.R)} \downarrow \\
\rightarrow \text{Cost of transformers, towers, insulators and switchgears } \uparrow
\end{array} \right. \]

The transmission losses may be computed from the approximate formulas:

\[ P_{\text{loss}} \approx R_l \frac{P_{tr}^2 + Q_{tr}^2}{|V_{tr}|^2} \quad \text{Watt} \quad \ldots \ldots (2) \]

\[ Q_{\text{loss}} \approx X_l \frac{P_{tr}^2 + Q_{tr}^2}{|V_{tr}|^2} \quad \text{VAR} \]

Where:  
\( R_l \) - Resistance of line.  
\( X_l \) - Reactance of line.  
\( P_{tr} \) and \( Q_{tr} \) are active and reactive transmission power (power of load).

Above discussion and formulas informs that the cost for lost energy decreases with increased voltage level. However, the fixed costs of (towers, insulators transformers and switchgears) increase with voltage. Therefore, for every transmission line, there is optimum transmission voltage, beyond which there is nothing to be gained in the matter of economy.

The Fig. blows shown that the total transmission costs will therefore be minimized at a certain voltage level.

It is called **economical transmission voltage**.
The *empirical formula* of economical transmission voltage between lines in a 3-phase ac system is:

\[
V = 5.5 \sqrt{0.62 \, l + \frac{3 \, P}{150}} \quad \ldots (3)
\]

Where:  
- \( V \) – Line voltage in KV.  
- \( P \) – Maximum KW per phase to be delivered to single circuit.  
- \( l \) – Length of transmission line in Km (distance of transmission line).

According to *empirical formula*:

If the distance of transmission line increased, the cost of terminal apparatus decreased, resulting in higher economic transmission voltage. Also if power to be transmitted is large, large generating and transforming units can be employed. This reduces the cost per kW of the terminal station equipment.

**Standard voltage levels:**

<table>
<thead>
<tr>
<th>Type</th>
<th>Voltage Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low voltage transmission (KV)</td>
<td>11, 22, 33, 66</td>
</tr>
<tr>
<td>High voltage transmission (KV)</td>
<td>110, 132, 220, 275, 330</td>
</tr>
<tr>
<td>Extra high voltage transmission (KV)</td>
<td>380, 400, 500, 750, 1000</td>
</tr>
<tr>
<td></td>
<td>1100-1500 under research</td>
</tr>
</tbody>
</table>

**Conductor materials:**

Characteristics of materials are:

1. High electrical conductivity.  
2. High tensile strength.  
3. Low cost.  
4. Low specific gravity so that weight per unit volume is small.

*Commonly used conductor materials:* Commonly used conductor materials for overhead lines are copper, aluminum, steel-cored aluminum, galvanized steel and cadmium copper.

1. **Copper (Cu):** Its ideal material for overhead lines owing to its high electrical conductivity and greater tensile strength, but cost of material is high.

2. **Aluminum (Al):**
   
   a. Conductivity of Al is 60% from the Cu.  
   b. Coefficient of linear expansion of Al is high.  
   c. Weak (low) tensile strength.  
   d. Lower cost and lighter weight of an Al conductor compared with a Cu.  
   e. For the same resistance, Al conductor has a large diameter than a Cu conductor, i.e. low effect of *corona*.

Therefore aluminum has replaced copper as the most common conductor metal for overhead transmission.

Symbols identifying different types of Al conductors are as follows:

The most common conductor types is A.C.S.R., which consists of layers aluminum strands surrounding a central core of steel strands as shown in fig. below.

Stranded conductors are easier to manufacture, since larger conductor size can be obtained by simply adding successive layers of strands and also easier to handle and more flexible than solid conductors. The number of strands depends on the number of layers and on whether all the strands are the same diameter. (The strands are uniform diameter):

\[
Total \ No. \ of \ strands \ (N_s) = 1 + 3n (n + 1) \ldots (4)
\]

Where: \( n \) is the number of layers around the central strand.

<table>
<thead>
<tr>
<th>No. of layers (( n ))</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_s ), including the single center strand</td>
<td>1+6=7</td>
<td>1+18=19</td>
<td>1+36=37</td>
<td>1+60=61</td>
<td>1+90=91</td>
</tr>
</tbody>
</table>

Stranded conductors usually have central wire (core) around which are successive layers of (6, 12, 18, 24) wires as shown in above Fig.

The equivalent diameter of stranded conductor is given by:

\[
D = (1 + 2n) d \quad \ldots \ldots (5)
\]

Where: \( d \) is the diameter of the strand.
Ex. Stranded conductor 19/2.9 mm. calculate the equivalent diameter of conductor.

Sol.: The diameter of one strand (d) = 2.9 mm, No. of stranded in conductor ($N_s$) = 19. Therefore for No. of layer = 2, distributed as follow:

Can be calculated by eq. (4) as follow:

\[
\begin{align*}
19 &= 1 + 3n (n + 1) \\
18 &= 3n^2 + 3n \\
n^2 + n - 6 &= 0 \\
(n + 3)(n - 2) &= 0
\end{align*}
\]

\[
\therefore \\
D &= (1 + 2n) d \\
&= (1 + 2 \times 2) \times 2.9 = 14.5 \text{ mm}.
\]