

ME 419

POWER PLANT ENGINEERING

(Lecture 6: Variable Load Problem)

Variable Load Problems

Variable load refers to the fluctuating demand on a power plant, driven by the varying demands of consumers – these demands are very uncertain in nature.

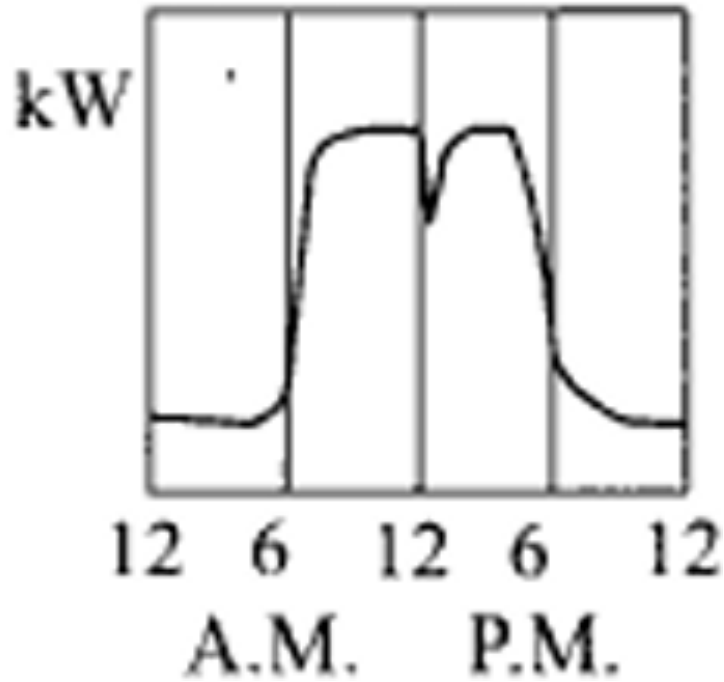
- Ideally, a power station would experience a consistent load, both in magnitude and duration.
- In reality, The load on the power station depends on the activities of the consumers connected to that station

Load Curves

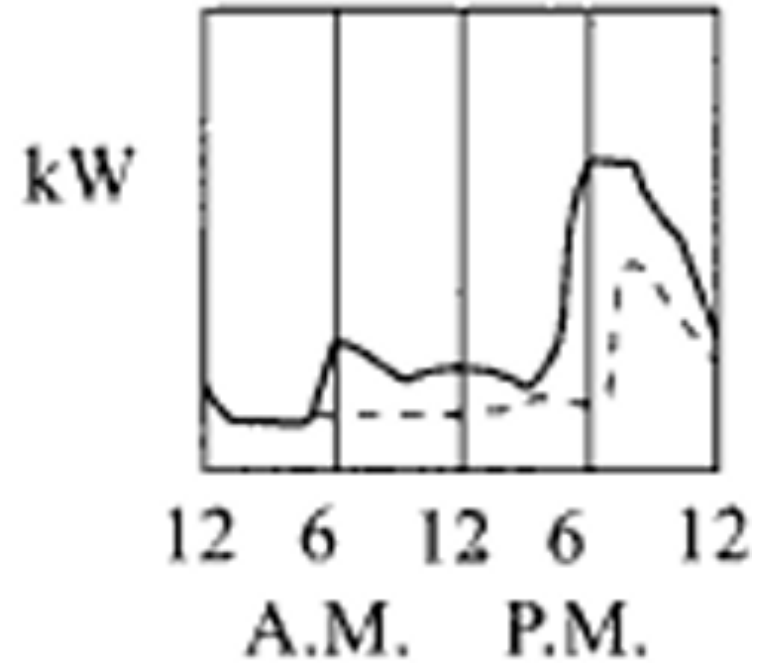
The load curve represents the variation in load on a power station over time.

- **For a daily load curve**, the variations in load during a 24-hour period are recorded at half-hourly or hourly intervals and then plotted against time on a graph. **Time is hours.**
- A **monthly load curve** is obtained by calculating and plotting the average power values at different times of the day over a month. **Time is days.**
- Similarly, a **yearly load curve** is obtained and is commonly used to calculate the annual load factor. **Time is months.**

Load Curves

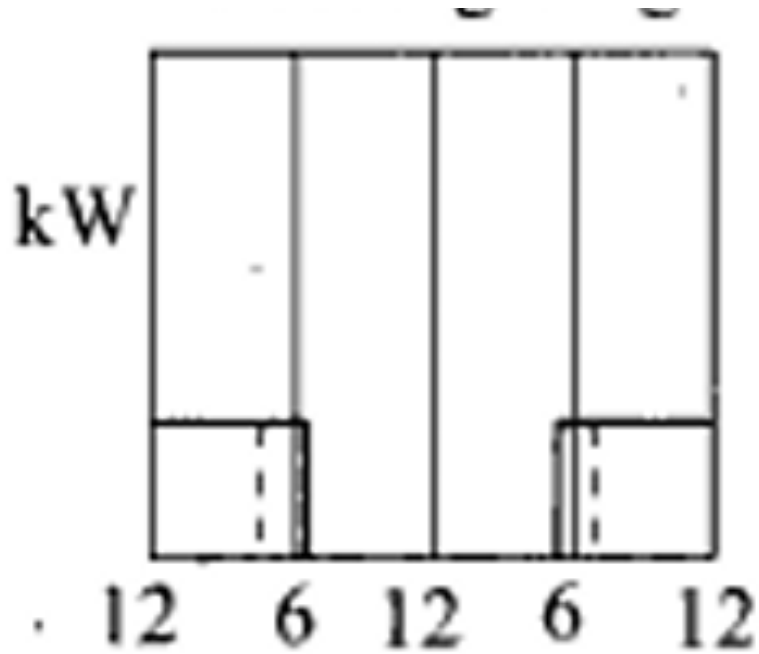


Industrial Load Curve

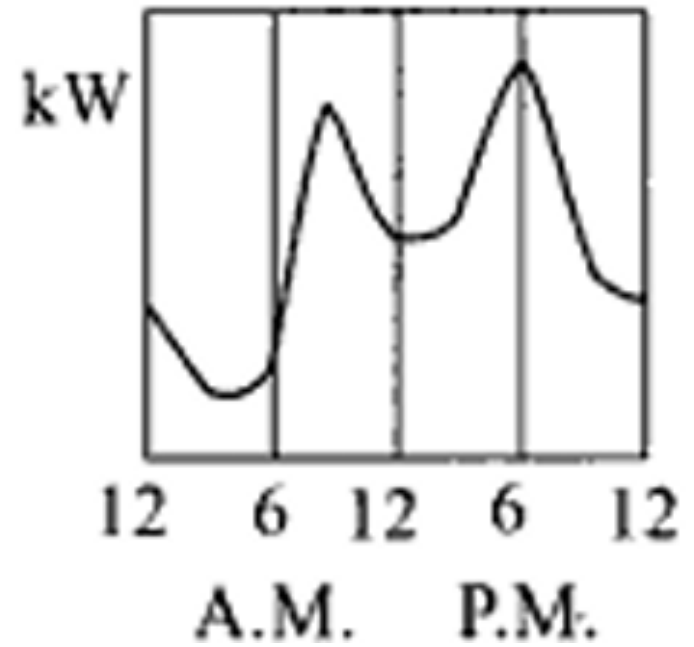


Residential Load Curve

Load Curves

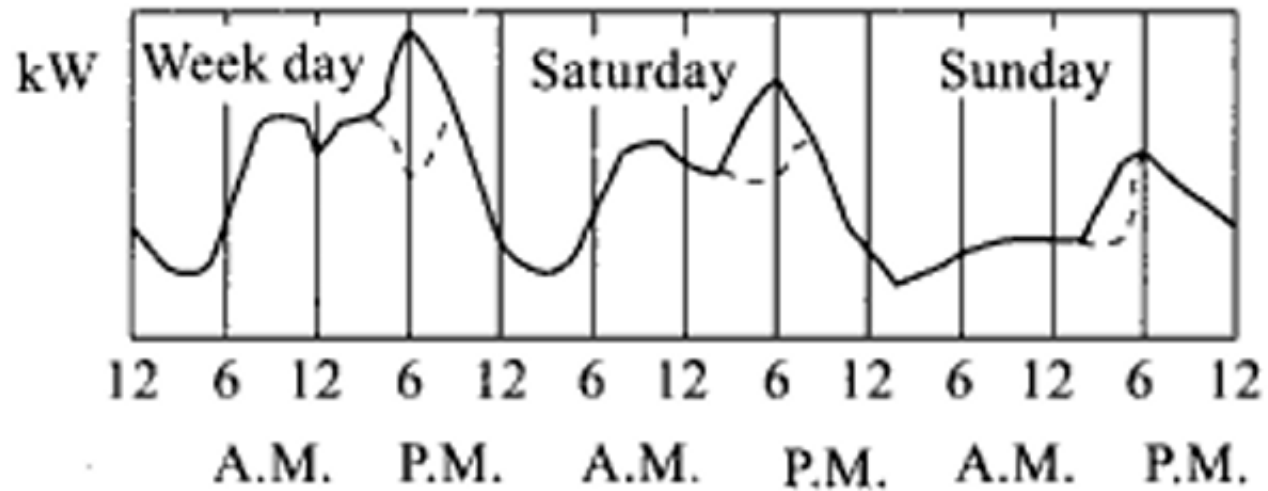


Street Lighting



Urban Traction load

Load Curves



Metropolitan area load

Load Curves

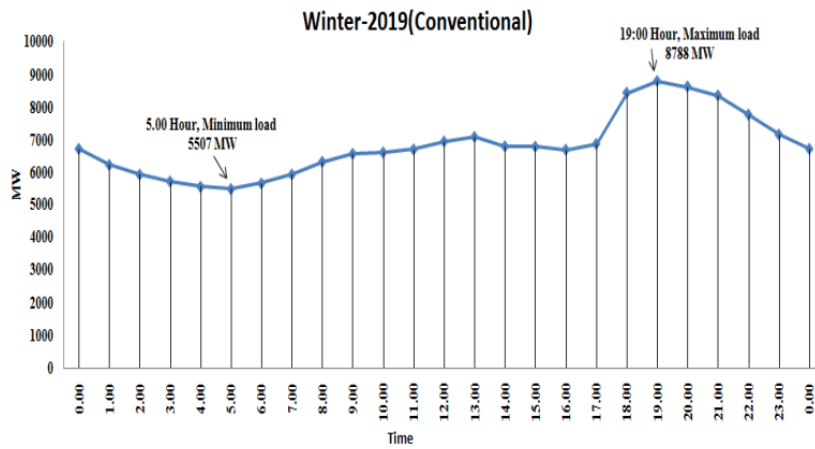


Figure 2.6 Load curve random days (winter'2019)

Source: Study Team

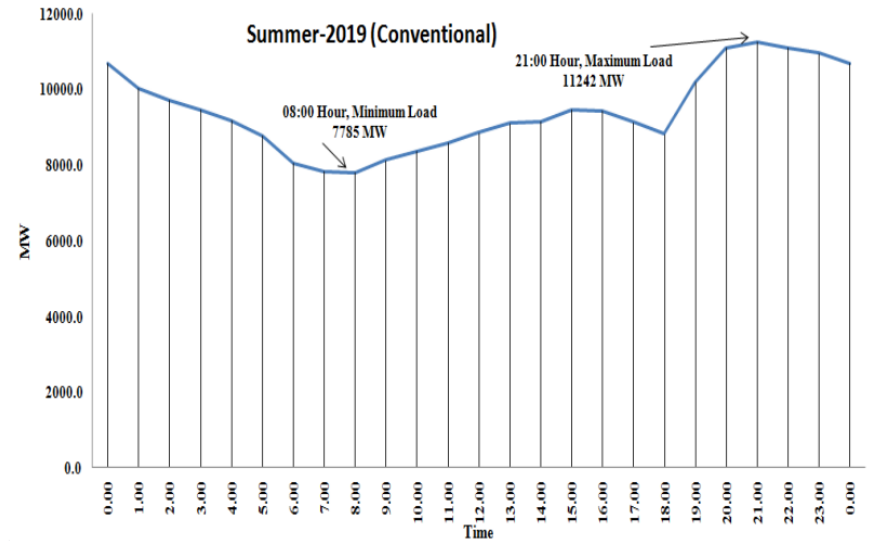
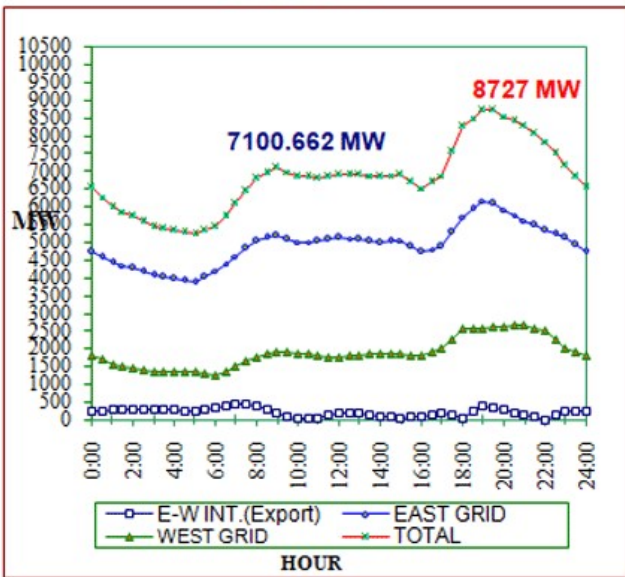


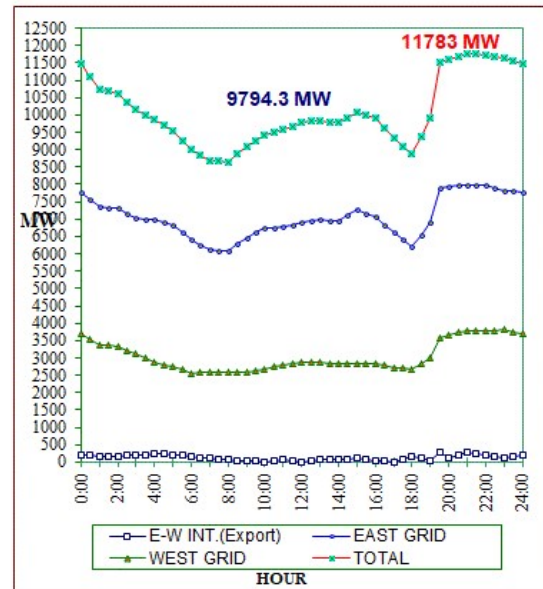
Figure 2.5 Load curve random days (summer'2019)

Source: Study Team

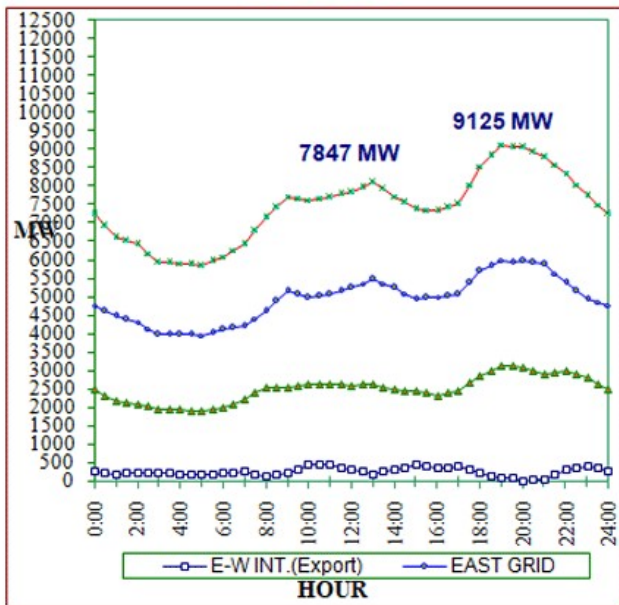
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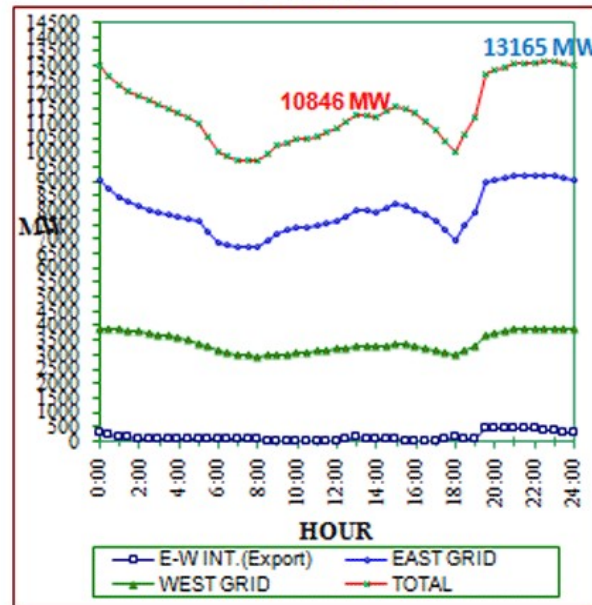
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Important parameters before a PP installation

When planning a power plant, the two basic parameters to be decided are: i. Total power output to be installed, ii. Size of the generating units.

The total installed capacity required can be determined from:

1. First demand (KW_{max}) estimated.
2. Growth of demand anticipated.
3. Reserved capacity required.

The size of generating units depends on:

1. Load curve during 24 hrs (summer, winter, week-days, holidays).
2. Total capacity of units connected to the electric grid.
3. Minimum start-up and shut-down periods of the units.
4. Maintenance program planned.
5. Plant efficiency vs size of unit.
6. Price and space demand per KW vs size of unit.

Important Terms and Factors

- **Connected Load** – is the sum of continuous ratings of all the equipment connected to the supply system
- **Maximum Demand** – is the greatest demand of load on the power station during a given period
 - The knowledge of maximum demand is very important as its helps in determining the installed capacity of the station
- **Demand Factor** – is the ratio of maximum demand on the power station to its connected load, i.e.,

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

Important Terms and Factors

- Average Load or Average Demand – is the average of loads occurring on the power station in a given period (day or month or year), e.g.,

Daily average load = No. of units (kWh) generated in a day / 24 h

- Load Factor (LF) – is the ratio of average load to the maximum demand during a given period, i.e.,
Load factor = Average load / Maximum demand
 - If the plant is in operation for T hours then
Load factor = (average load x T) / (maximum demand x T)
 - The LF plays key role in determining the overall cost per unit generated

Typical Demand Factors

General Category of Consumers	Consumer capacity/type	Demand Factors
Residential Lighting	0.25 kW	1.0
	0.50 kW	0.6
	1 kW and above	0.5
Commercial lighting	Restaurants	0.70
	Stores and offices	0.70
	Theatres	0.60
	Small Industries	0.60
	Schools and Churches	0.55
	Hotels	0.50
General Power Services	0-10 hp	0.75
	10-20 hp	0.65
	20-100 hp	0.55
	Over 100 hp	0.50

Important Terms and Factors

- **Diversity Factor** – is the ratio of the sum of individual maximum demand to the maximum demand on power station/a group of consumers, i.e.,

$$\text{Diversity factor} = \frac{\sum \text{Individual Maximum Demands}}{\text{Maximum Demand on a group}}$$

- Diversity factor is always greater than 1
- The maximum demands of individual consumers do not occur simultaneously but are spread out over a period time. Diversity factor is a measure of the distribution of maximum demands.

Between	Residential lighting	Commercial lighting	General power services
Consumers	3-4	1.5	1.5
Transformers	1.3	1.3	1.3
Feeders	1.2	1.2	1.2
Substations	1.1	1.1	1.1

Important Terms and Factors

- **Plant Capacity Factor** – is the ratio of actual energy produced to the maximum possible energy that could have been produced during a period, i.e.,

$$\text{Plant Capacity Factor} = \frac{\text{Actual Energy Produced in a given period of time}}{\text{Maximum possible energy that could have been produced in that period}}$$

- The plant capacity factor is an indication of the reserve capacity of the plant
 $\text{Reserve capacity} = \text{Plant capacity} - \text{maximum demand}$

- **Plant Use Factor** – is the ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation:

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

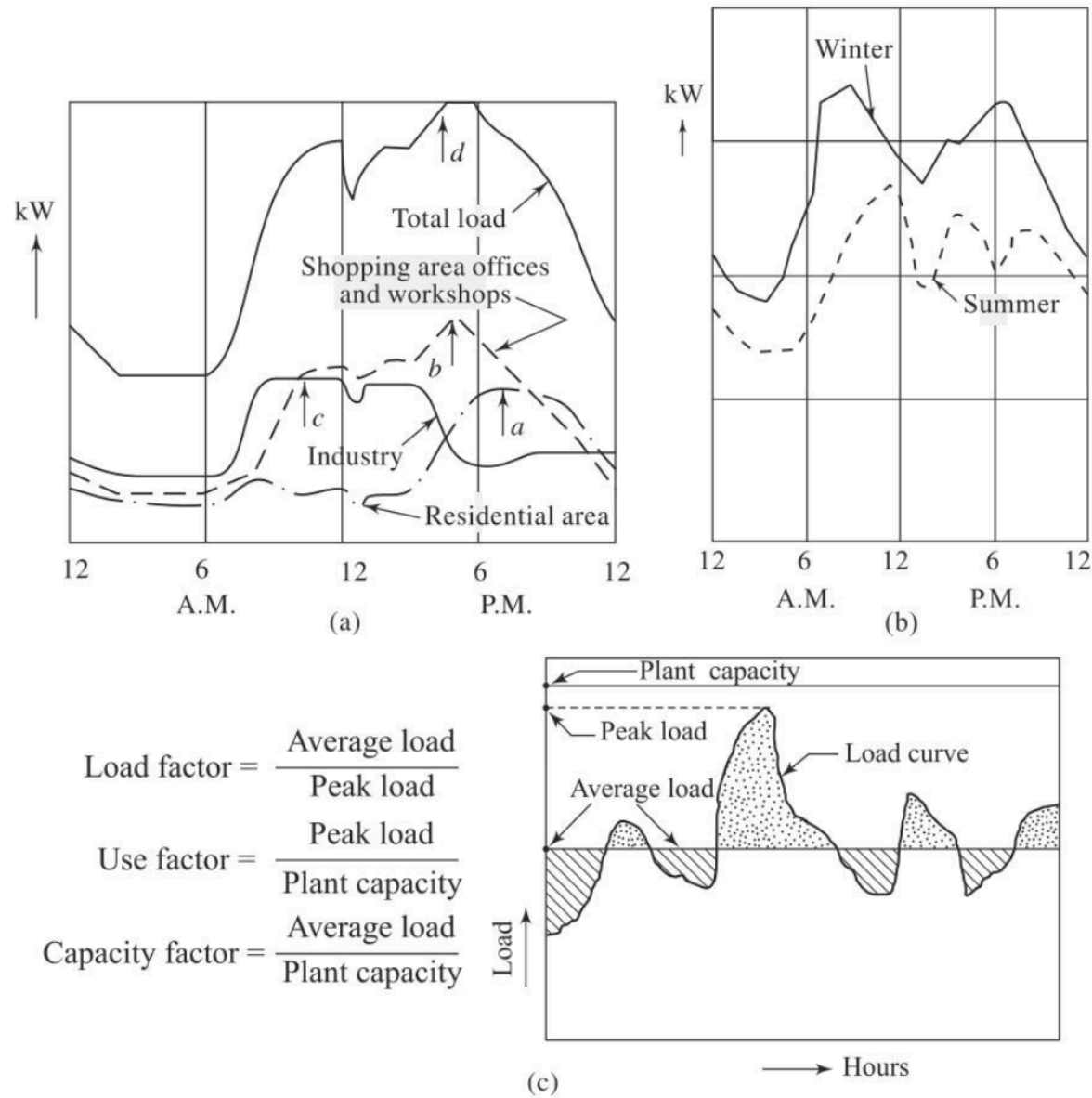


Fig (a) Diversity of loads of consumer groups (b) Load curves of an industrialized country on typical winter and summer week-days (c) Representation of different factors

PROBLEM-1

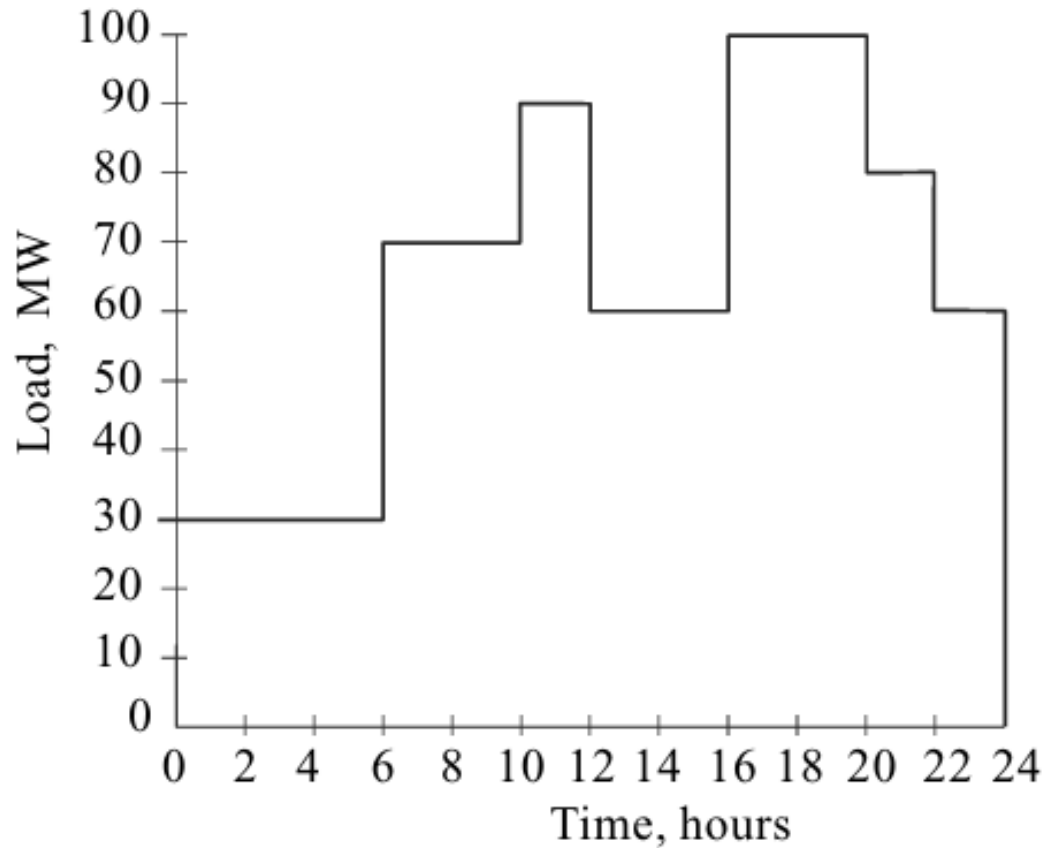
A power station supplies the following loads to the consumers:

Time in hours	0–6	6–10	10–12	12–16	16–20	20–22	22–24
Load in MW	30	70	90	60	100	80	60

- i. Draw the load curve and estimate the load factor of the plant.
- ii. What is the load factor of a standby equipment of 30 MW capacity if it takes up all loads above 70 MW? What is its use factor?

SOLUTION

Time in hours	0-6	6-10	10-12	12-16	16-20	20-22	22-24
Load in MW	30	70	90	60	100	80	60



Energy generated = area under the load curve

$$\begin{aligned} &= 30 \times 6 + 70 \times 4 + 90 \times 2 + 60 \times 4 + 100 \times 4 + 80 \times 2 + 60 \times 2 \\ &= 180 + 280 + 180 + 240 + 400 + 160 + 120 = \mathbf{1560 \text{ MWh}} \end{aligned}$$

SOLUTION

$$\text{Average load} = \frac{1560 \text{ MWh}}{24 \text{ h}} = 65 \text{ MW}$$

$$\text{Load factor} = \frac{\text{average load}}{\text{peak load}} = \frac{65}{100} = 0.65$$

If the load above 70 MW is supplied by a standby unit of 30 MW capacity, the energy generated by it-

$$\begin{aligned} &= 20 \times 2 + 30 \times 4 + 10 \times 2 \\ &= 40 + 120 + 20 = 180 \text{ MWh} \end{aligned}$$

Time during which the standby unit remains in operation
 $= 2 + 4 + 2 = 8 \text{ h}$

$$\text{Average load} = 180 \text{ MWh}/8\text{h} = 22.5 \text{ MW}$$

$$\text{Load factor} = 22.5/30 = 0.75$$

$$\text{Use factor} = \frac{\text{energy generated}}{\text{plant capacity} \times \text{operating hours}}$$

$$= \frac{180 \times 10^3 \text{ kWh}}{30 \times 10^3 \text{ kW} \times 8 \text{ h}} = 0.75$$

PROBLEM-2

A power plant has the following annual factors: load factor = 0.75, capacity factor = 0.6, use factor = 0.65. Maximum demand is 60 MW. Estimate (a) the annual energy production, (b) the reserve capacity over and above the peak load, and (c) the hours during which the plants not in service per year.

Solution

$$(a) \quad \text{Load factor} = \frac{\text{average load}}{\text{peak load}}$$

$$\text{Average load} = 0.75 \times 60 = 45 \text{ MW}$$

$$\begin{aligned} \text{Annual energy production} &= 45,000 \times 8760 = 394,200,000 \text{ kWh} \\ &= 394.2 \times 10^6 \text{ kWh} \end{aligned}$$

Ans.

$$(b) \quad \text{Capacity factor} = \frac{\text{average load}}{\text{plant capacity}}$$

$$\text{Plant capacity} = 45/0.6 = 75 \text{ MW}$$

$$\begin{aligned} \text{Reserve capacity over and above the peak load} \\ &= 75 - 60 = 15 \text{ MW} \end{aligned}$$

Ans.

(c) Use factor = $\frac{\text{energy generated per year}}{\text{plant capacity} \times \text{hours in operation}}$

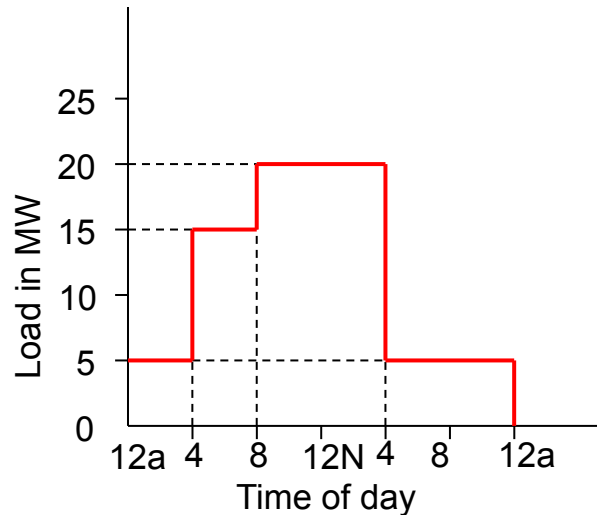
$$\text{Hours in operation} = \frac{394.2 \times 10^6 \text{ kWh}}{75 \times 10^3 \text{ kW} \times 0.65} = 8086 \text{ hrs}$$

$$\text{Hours not in service in a year} = 8760 - 8086 = 674 \text{ hrs}$$

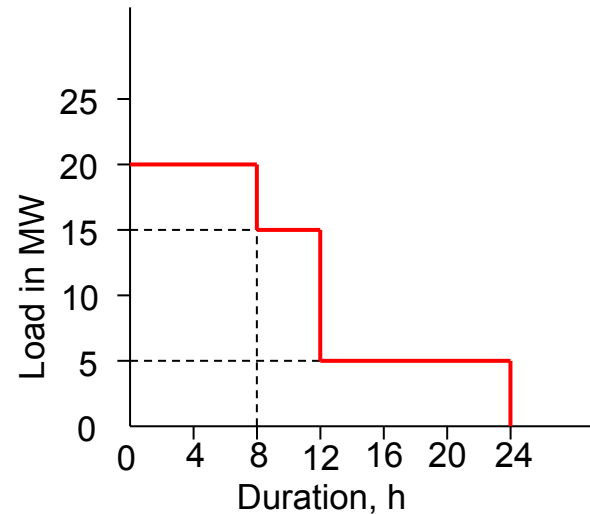
Ans.

Load Duration Curve (LDC)

- 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**



Daily Load curve



Daily Load duration curve

Effects of Variable Load on Power Plants

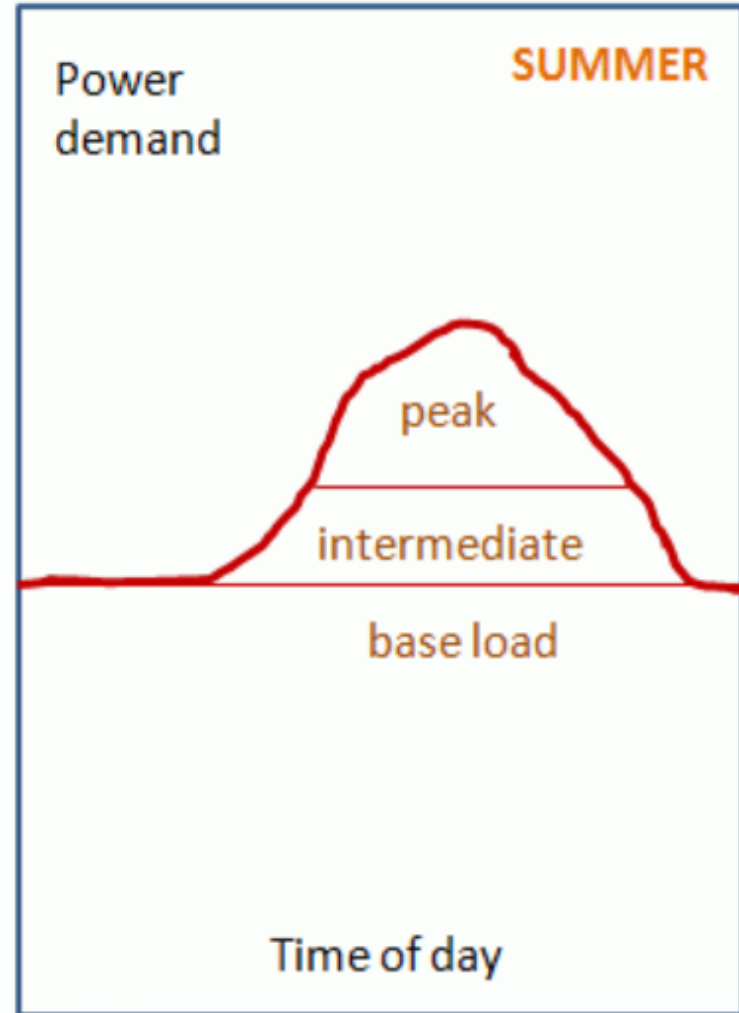
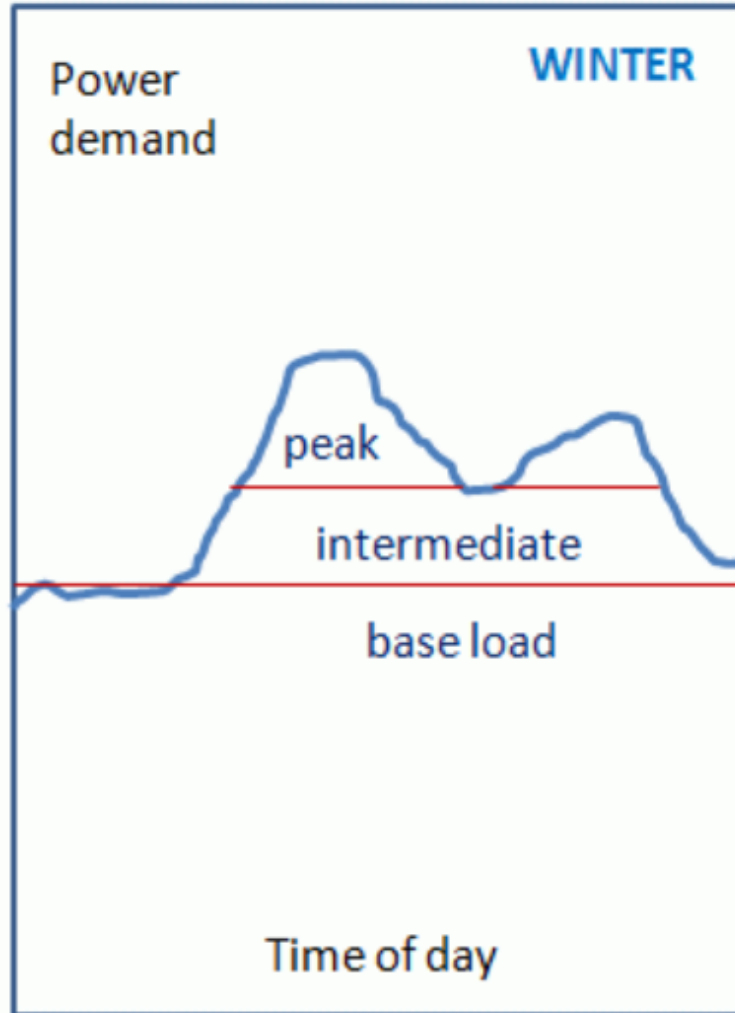
□ Increase in production cost

- An alternator works most efficiently when it is run near its rated capacity
 - ✓ If a single alternator is used, efficiency thus varies with the variation of load
 - ✓ In practice, a number of alternators of different capacities are used in power stations
 - This, in turn, increases initial costs of the power plant and hence, the production costs

Effects of Variable Load on Power Plants

- One of the worst effects of variable loading is the change of frequency when the load increases or decreases
 - For proper operation, the frequency must be within the permissible limits (usually $\pm 3\%$)
 - Any change in frequency would destabilise the power transmission grid
 - Special type of control equipment must be installed to keep the frequency within limits
 - Such equipment increase the cost and complexity of the system

Electricity Demand and Power Plant Choice and Operation



Electricity Demand and Power Plant Choice and Operation

- Base level of demand is met with “baseload” generating units
 - Baseload units can also meet some of the demand above the base, and can reduce output when demand is unusually low
- The greater part of the daily up/down swings in demand are met with “intermediate” units (also referred to as load-following or cycling units)
 - These units can quickly change their output to match the change in demand.
- The highest daily loads are met with peaking units
 - These units are typically the most expensive to operate, but can quickly startup and shutdown to meet brief peaks in demand
 - Peaking units also serve as spinning reserve, and as “quick start” units able to go from shutdown to full load in minutes
 - A peaking unit typically operates for only a few hundred hours a year

Classification of Electric Power Generation Units

- **Base-load units**
 - Nuclear power plant
 - High-performance steam turbine plant
 - Advanced combined gas and steam turbine plant
 - Hydroelectric plant
- **Intermediate (medium-load), load-following or cycling generating units**
 - Simple steam turbine plant
 - Old base-load plant
 - Combined gas and steam turbine plant
- **Peak-load generating units**
 - Gas turbine
 - Diesel engine
 - Hydro pumped storage plant
 - Old simple steam turbine plant

Types of Load

- The various types of loads on the power system are:
 - **Domestic load:** consists of light, fan, refrigerator, heater and cooler, television, small motor for pumping etc
 - Most of the domestic load occurs only for some hours of the day and as a result, the LF is low (10% to 12%)
 - **Commercial load:** Commercial load consists of lighting for shops, fans and electrical appliances used in restaurants, etc
 - This class of load occurs for more hours of the day than the residential load and it has seasonal variations

Types of Load...

Industrial load: The magnitude of industrial load depends upon the type of industry

- These loads are not generally weather dependent

Municipal load: This type of load includes street lighting, power required for water supply and drainage systems

- Both street lighting and water pumping occur during the night thereby improving the LF of the power system

Irrigation load: This is seasonal in nature

Traction load: This type of load includes tram cars, trolley buses, underground/metro rails, etc.

- It has a wide variation – reaches its peaks in the morning and evening on weekdays