Palestine Technical University - Kadoorie

Electrical Engineering Department

Power System Planning and design

Chapter (1): The power system (an Overview)
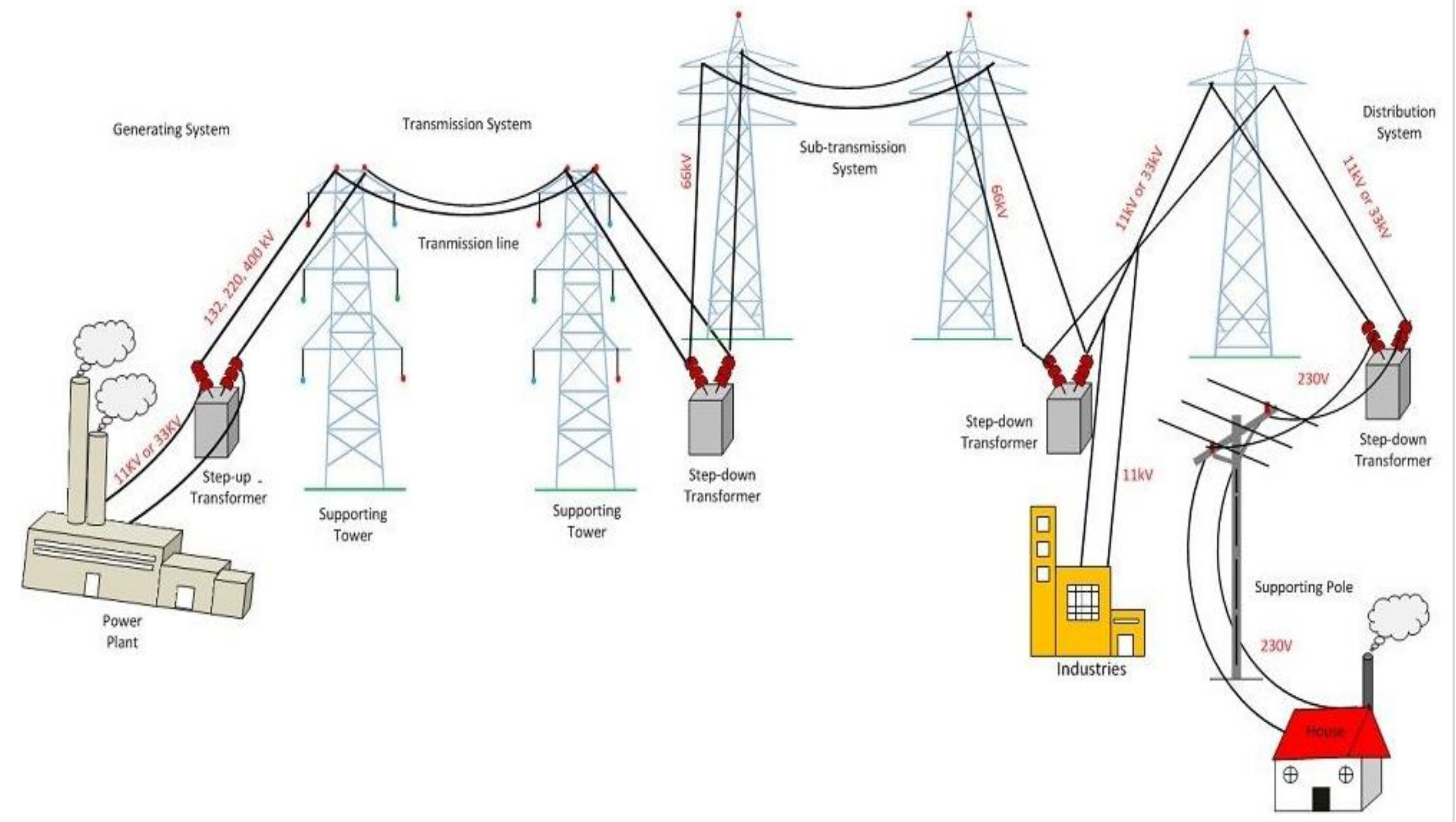
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Prof. Samer Alsadi

Modern Power System

A power system can be subdivided into four major parts:

- Generators
- Transmission and subtransmission
- Distribution
- Loads

Generators

Generators — One of the essential components of power systems is the three- phase ac generator known as synchronous generator or alternator. Synchronous generators have two synchronously rotating fields:
- One field is produced by the rotor driven at synchronous speed and excited by dc current.
- The other field is produced in the stator windings by the three-phase armature currents.

The dc current for the rotor windings is provided by **excitation systems**. In the older units, the exciters are dc generators mounted on the same shaft, providing excitation through slip rings. Today's systems use ac generators with rotating rectifiers, known as brushless excitation systems. The generator excitation system maintains generator voltage and controls the reactive power flow. Because they lack the commutator, ac generators can generate high power at high voltage, typically 30 kV. In a power plant, the size of generators can vary from 50 MW to 1500 MW.

Generators

The source of the mechanical power, commonly known as the **prime mover**, may be hydraulic turbines at waterfalls, steam turbines whose energy comes from the burning of coal, gas and nuclear fuel, gas turbines, or occasionally internal combustion engines burning oil. The estimated installed generation capacity in 1998 for the United States is presented in Table 1.1.

Table 1.1 Installed Generation Capacity

Type	Capacity, MW	Percent	Fuel
Steam Plant	478,800	63	Coal, gas, petroleum
Nuclear	106,400	14	Uranium
Hydro and pumped storage	91,200	12	Water
Gas Turbine	60,800	8	Gas, petroleum
Combined cycle	15,200	2	Gas, petroleum
Internal Combustion	4,940	0.65	Gas, petroleum
Others	2,660	0.35	Geothermal, solar, wind
Total	760,000	100.00	

Generators

Steam turbines operate at relatively high speeds of 3600 or 1800 rpm. The generators to which they are coupled are **cylindrical rotor**, two-pole for 3600 rpm or four-pole for 1800 rpm operation. Hydraulic turbines, particularly those operating with a low pressure, operate at low speed. Their generators are usually a **salient type rotor** with many poles. In a power station several generators are operated in parallel in the power grid to provide the total power needed. They are connected at a common point called a bus.

With today's emphasis on environmental consideration and conservation of fossil fuels, many alternate sources are considered for employing the untapped energy sources of the sun and the earth for generation of power. Some of these alternate sources which are being used to some extent are **solar power**, **geothermal power**, **wind power**, **tidal power**, and **biomass**. The aspiration for bulk generation of power in the future is the nuclear fusion. If nuclear fusion is harnessed economically, it would provide clean energy from an abundant source of fuel, namely water.

Transformers

Transformers — Another major component of a power system is the transformer. **It transfers power with very high efficiency from one level of voltage to another level**. The power transferred to the secondary is almost the same as the primary, except for losses in the transformer, and the product VI on the secondary side is approximately the same as the primary side. Therefore, using a step-up transformer of turns ratio a will reduce the secondary current by a ratio of 1/a. **This will reduce losses in the line, which makes the transmission of power over long distances possible.**

The insulation requirements and other practical design problems limit the generated voltage to low values, usually 30 kV. Thus, step-up transformers are used for transmission of power. At the receiving end of the transmission lines step-down transformers are used to reduce the voltage to suitable values for distribution or utilization. In a modern utility system, the power may undergo four or five transformations between generator and ultimate user.

Transmission and Subtransmission

High voltage transmission lines are terminated in substations, which are called **high-voltage substations**, **receiving substations**, or **primary substations**. The function of some substations is **switching circuits in and out of service**; they are referred to as **switching stations**. At the primary substations, the voltage is stepped down to a value more suitable for the next part of the journey toward the load. Very large industrial customers may be served from the transmission system.

The portion of the transmission system that connects the high-voltage substations through step-down transformers to the distribution substations are called the **subtransmission network**. There is no clear delineation between transmission and subtransmission voltage levels. Typically, the subtransmission voltage level ranges from 69 to 138 kV. Some large industrial customers may be served from the subtransmission system. Capacitor banks and reactor banks are usually installed in the substations for maintaining the transmission line voltage.

Distribution

The distribution system **is that part which connects the distribution substations to the consumers' service-entrance equipment.** The primary distribution lines are usually in the range of 4 to 34.5 kV and supply the load in a well-defined geographical area. Some small industrial customers are served directly by the primary feeders. The secondary distribution network reduces the voltage for utilization by commercial and residential consumers. Lines and cables not exceeding a few hundred feet in length then deliver power to the individual consumers.

The secondary distribution serves most of the customers at levels of 240/120 V, single-phase, Three wire; 208Y/120 V, three-phase, four-wire; or 480Y/277 V, three-phase, four wire. The power for a typical home is derived from a transformer that reduces the primary feeder voltage to 240/120 V using a three-wire line.

Distribution systems are both overhead and underground. The growth of under ground distribution has been extremely rapid and as much as **70 percent** of new residential construction is served underground.

Loads

Loads of power systems are divided into **industrial**, **commercial**, and **residential**. Very large industrial loads may be served from the transmission system. Large industrial loads are served directly from the **subtransmission network**, and small industrial loads are served from the **primary distribution network**. The industrial loads are composite loads, and induction motors form a high proportion of these load. These composite loads are functions of voltage and frequency and form a major part of the system load. Commercial and residential loads consist largely of lighting, heating, and cooling. These loads are independent of frequency and consume negligibly small reactive power.

The real power of loads are expressed in terms of kilowatts or megawatts. **The magnitude of load varies throughout the day**, and power must be available to consumers on demand.

Load Curve

The daily-load curve of a utility is **a composite of demands made by various classes of users**. **The greatest value of load during a 24-hr period is called the peak or maximum demand**. Smaller peaking generators may be commissioned to meet the peak load that occurs for only a few hours. In order to assess the usefulness of the generating plant the load factor is defined. **The load factor is the ratio of average load over a designated period of time to the peak load occurring in that period**. Load factors may be given for a day, a month, or a year. The yearly, or annual load factor is the most useful since a year represents a full cycle of time.

The daily load factor is   or:

$$\text{Daily L.F.} = \frac{\text{average load}}{\text{peak load}}$$

$$\text{Daily L.F.} = \frac{\text{average load} \times 24\,\text{hr}}{\text{peak load} \times 24\,\text{hr}} = \frac{\text{energy consumed during 24 hr}}{\text{peak load} \times 24\,\text{hr}}$$

Load Curve

The annual load factor is:

$$\text{Annual L.F.} = \frac{\text{total annual energy}}{\text{peak load} \times 8760 \text{ hr}}$$

Generally there is diversity in the peak load between different classes of loads, which improves the overall system load factor. In order for a power plant to operate economically, **it must have a high system load factor**. Today's typical system load factors are in the range of 55 to 70 percent.

There are a few other factors used by utilities. **Utilization factor is the ratio of maximum demand to the installed capacity**, and **plant factor is the ratio of annual energy generation to the plant capacity x 8760 hr**. These factors indicate how well the system capacity is utilized and operated.

Computer Analysis

For a power system to be practical it must be safe, reliable, and economical. Thus many analyses must be performed to design and operate an electrical system. However, before going into system analysis we have to model all components of electrical power systems. Therefore, in this course, after reviewing the concepts of power and three-phase circuits, we will calculate the parameters of a multi circuit transmission line. Then, we will model the transmission line and look at the performance of the transmission line. Since transformers and generators are a part of the system, we will model these devices. Design of a power system, its operation and expansion requires much analysis. This course presents methods of power system analysis with the aid of a personal computer and the use of MATLAB. The MATLAB environment permits a nearly direct transition from mathematical expression to simulation.

Computer Analysis

Some of the basic analysis covered in this course are:
- Evaluation of transmission line parameters
- Transmission line performance and compensation
- Power flow analysis
- Economic scheduling of generation

Many MATLAB functions are developed for the above studies thus allowing the student to concentrate on analysis and design of practical systems and spend less time on programming.

Example (1): (Load Curve)

The daily load on a power system varies as shown in Table 1.2.
1. Use the barcycle function to obtain a plot of the daily load curve.
2. Using the given data compute the average load and the daily load factor.

A MATL4B function **barcycle(data)** is developed which **obtains a plot of the load cycle for a given interval**. The demand interval and the load must be defined by the variable data in a **three-column matrix**. The <u>first two columns</u> are **'the demand interval** and the <u>third column</u> is the **load value**. The demand interval may be minutes, hours, or months, in ascending order. Hourly intervals must be expressed in military time.

Table 1.2 Daily System Load

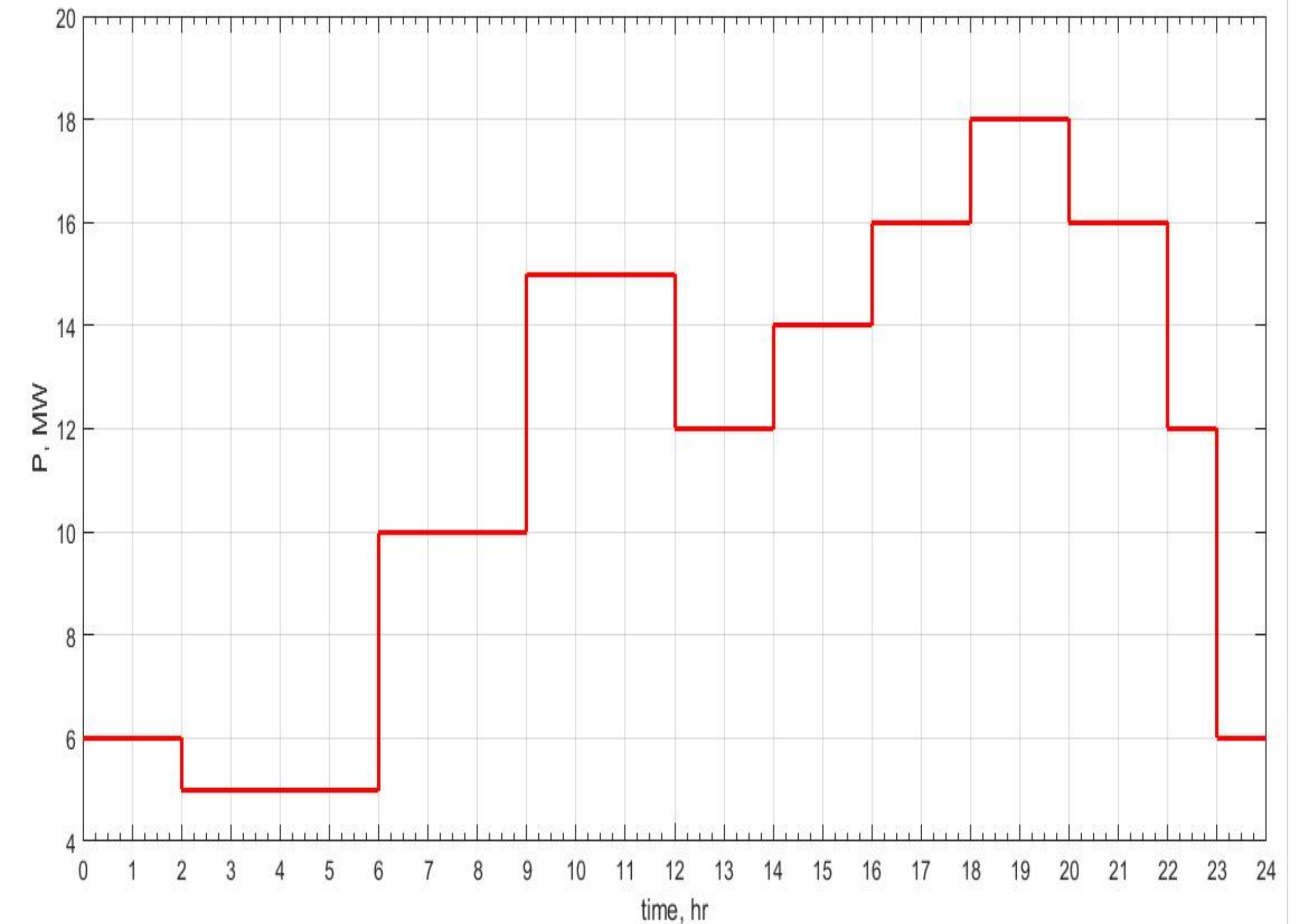| Interval, hr		Load, MW
12 A.M. –	2 A.M.	6
2 –	6	5
6 –	9	10
9 –	12	15
12 P.M. –	2 P.M.	12
2 –	4	14
4 –	6	16
6 –	8	18
8 –	10	16
10 –	11	12
11 –	12 A.M.	6

Example (1): (Load Curve)

```matlab
data = [0 2 6 ; 2 6 5 ; 6 9 10 ; 9 12 15 ; 12 14 12 ; 14 16 14 ; 16 18 16 ;
18 20 18 ; 20 22 16 ; 22 23 12 ; 23 24 6];
%plot load curve
barcycle(data)
xlabel('time , hr')
ylabel ('p , MW')
grid
%find load factor
p = data(:,3);
Dt=data(:,2)-data(:,1);
W=p'*Dt;
Pave = W / sum(Dt)
Peak = max(p)
LF = (Pave/Peak) * 100
```

Pavg = 11.5417
Peak = 18
LF   = 64.12

Example (2):

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 curves 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. Assume the peak power demand in the United States in 1984 is 480 GW with an average growth rate of 3.4 percent.

Using MATLAB:
1. Plot the predicated peak demand in GW from 1984 to 1999.
2. Estimate the peak power demand for the year 1999.

Example (2):

```
t0 = 84;
P0 = 480;
a =0.034;
t =(84:1:99);
P =P0*exp(a*(t-t0));
disp('Predicted Peak Demand - GW')
disp([t, P])
plot(t, P), grid
xlabel('Year'), ylabel('Peak power demand GW')
P99 =P0*exp(a*(99 - t0))
```

```
P99 =

   799.3398
```