The Load Curve and Load Duration Curves in Generation Planning

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Abstract

Planning for the future energy supply mix is a very challenging undertaking which requires planners to consider various drivers and decision criteria. This study addresses the multi-period energy planning problem with carbon dioxide (CO_2) emission constraints and cost constraints with energy sources ranked in the order of sustainability. The load curve and duration curve are the primary tool used in analysis of electric power utility operations and for the purpose of planning new power plants.

Keywords
Load curve, load duration curve.

1. Introduction
The technoeconomic analysis of power systems solutions for customers is generally based on the peak demand, average power demands and actual energy consumption. Power demand and supply varies over the time of the day which pauses challenges to utility operators, suppliers and even consumers of electricity. Customer electricity profiles can be applied for improved techno-economic analyses of energy solutions (Poulin, and Dostie 2008).

The load curve is a primary tool used for economic analysis of electric utility operations and planning new energy systems and generation. Piecewise linear approximations to the load duration curve is needed in general equilibrium models and also in other models using linear programming.

1.1. Problem Statement
The main challenge with power generation is predicting demand and selection of the best fit mix of power plants to supply particular electricity demand. The challenge with load profiles and load curves is that complete profiles are often measured by utilities for their own internal use in planning and dispatch (Poulin and Dostie, 2008).

Electricity demand and supply is ever changing which places extreme pressure on the grid to balance generation and consumption. As a result of ever-increasing demand and increased electrification of transport and other operations more generation is needed and more electricity storage. The challenges the grids are facing include;

i.) Growing amount of renewable energy sources

By 2050, it is expected 62 % of electricity generated will come from renewable sources of energy compared to about 27 % of the worldwide generation in 2019. Renewable energy sources are unstable energy sources and their operation can cause serious grid imbalances unless advanced management and control systems used.

ii.) Electricity transmission and distribution losses

Power transmission and distribution over long distances increases losses which have to be paid for by the end-users. The average losses are about 4-5% in Europe and much more in many developing countries e.g. 19% in India and about 50 % in Haiti.

iii.) Frequent power outages

Power outages are mainly caused by extreme weather conditions and time-worn power lines affecting millions of people and damages worth billions of dollars especially in countries like Australia and the United States. Blackouts heavily affect manufacturing and damage products like electronic devices and important data loss

iv.) Electro.mobility

Charging millions of Electric vehicles (EV) consumes significant amount of electricity. Supercharger consumes immense amount of energy can cause instant change in power demand is a huge problem for the grid.

v.) Grid modernization

The traditional grid has the challenge of handling increasing share of variable renewables. The transformation from the traditional grid to the smart grid is a new down being undertaken by several.

vi.) Threat of cyber attacks

With digitalisation of the energy sector has is associated with been cases of hackers infiltrating systems of power companies and exposing thousands of households to a controlled blackout.

vii.) Threat of terrorist attacks

The danger of terrorist attack is real leading to real damage to the physical infrastructure of the power systems like transformers and power lines.

1.2. Rationale of the study

Electricity is an integral part the economy as it directly supports a wide range of services including health care, banking to transportation which makes power supply of paramount importance. The energy and power sector are undergoing a wide range of fundamental changes like decarbonisation with growing share of variable renewables , growth in digitalisation which expands the surface cyberattacks. As a response, there is need for stakeholders to improve their frameworks for power security through updated policies, market design , and regulations.

2. Types of Electric Loads

3. Types of Load

A load refers to any device that taps **electricity** from the power system. Load can be resistive like a lamp or heater, inductive as an induction motor, capacitive and in some case a combination of them. Power system loads can be classified as follows:

3.1. **Domestic load**

Domestic load consists of lights, fans, refrigerators, heaters, television, small motors for pumping water etc. Most of the residential load occurs only for some hours during the day (i.e., 24 hours) e.g., lighting load occurs during night time and domestic appliance load occurs for only a few hours. For this reason, the load factor is low (10% to 12%).

Residential Load

Residential load includes domestic lights, power for domestic appliances like radios, washing machines, television, fridges, water heaters, electric cookers and water pumping.

3.2. Commercial load

This *type of load* consists of lighting for shops, fans and electric appliances used in restaurants etc. This class of load occurs for more hours during the day as compared to the domestic load. The commercial load has seasonal variations due to the extensive use of air conditioners and space heaters.

i.) Commercial Load

Commercial load include lighting for malls and shops, advertisements and electrical appliances in restaurants and shops normally for commercial applications.

3.3. Industrial load

ii.) *Industrial load* consists of load demand by industries. The magnitude of industrial load depends upon the type of industry.Thus small scale industry requires load upto 25 kW, medium scale industry between 25kW and 100 kW and large-scale industry requires load above 500 kW. Industrial loads are generally not weather dependent. **Industrial Load**

This load consists of load demand of various industries or factories.

3.4. Municipal load

Municipal load consists of street lighting, power required for water supply and drainage purposes.Street lighting load is practically constant throughout the hours of the night.For water supply, water is pumped to overhead tanks by pumps driven by electric motors.Pumping is carried out during the off-peak period, usually occurring during the night.This helps to improve the load factor of the power system.

i.) Municipal Load

Municipal load consists of loads like street lighting, power for pumping water supply and drainage purposes.

3.5. Irrigation load

This *type of load* is the electric power needed for pumps driven by motors to supply water to fields.Generally this type of load is supplied for 12 hours during night.

i.) Irrigation Load

Irrigation load is electric load used pumping irrigation water, driven by electric motors to supply water to fields or farmlands.

3.6. **Traction load**

This **type of load** includes tram cars, trolley buses, railways etc.This class of load has wide variation.During the morning hour, it reaches peak value because people have to go to their work place.After morning hours, the load starts decreasing and again rises during evening as since the people start coming to their homes.

iii.) Traction Load

Traction load is load for applications like electric, cars, trolley, electric buses and trains.

3.7. Fixed and Variable load

Types of loads – Load curves – Load duration curve

December 28, 2014

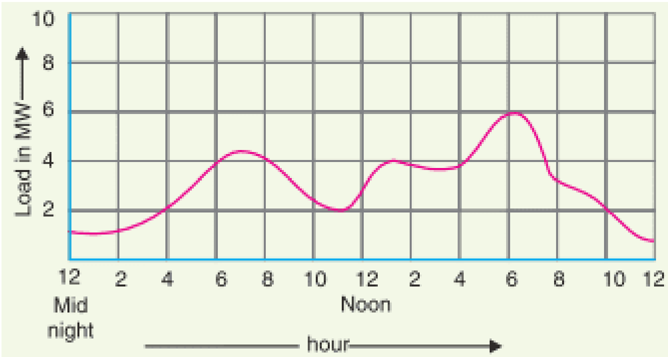


Figure 1. Types of loads – Load curves

Variable load on power stations:

Here I am going to explain you how the load connected to a power station is varied and what are terms used to describe the factors responsible for *variable load*.First of all, lets us know what is a **variable load (Figure 1)**.Generally, in the house, we switch on lights, fan, TV and all other appliances only when we are at home.But when we are out of home all are switched off.So now the load is varied.Like this in every home, it happens and not only at home but many schools, hospitals, buildings, factories, offices.

The **load on a power station** varies from time to time due to uncertain demands of the consumers and is known as the variable load on the station. A power station is designed to meet the load requirements of the consumers. An ideal load on the station, from the standpoint of equipment needed and operating routine, would be one of constant magnitude and steady duration. However, such a steady load on the station is never realised in actual practice.The consumers require their small or large block of power in accordance with the demands of their activities. Thus the load demand of one consumer at any time may be different from that of the other consumer. The result is that load on the power station varies from time to time.

Effects of variable load:

The **variable load on a power station** introduces many perplexities in its operation. Some of the important effects of variable load on a power station are :

(i) Need of additional equipment: The variable load on a power station necessitates to have additional equipment. By way of illustration, consider a station. Air, coal, and water are the raw materials for this plant. In order to produce variable power, the supply of these materials will be required to be varied correspondingly. For instance, if the power demand on the plant increases, it must be followed by the increased flow of coal, air and water to the boiler in order to meet the increased demand.Therefore, additional equipment has to be installed to accomplish this job.As a matter of fact, in a modern power plant, there is much equipment devoted entirely to adjust the rates of supply of raw materials in accordance with the power demand made on the plant.

(ii) Increase in production cost: The **variable load on the plant** increases the cost of the production of electrical energy.An alternator operates at maximum efficiency near its rated capacity.If a single alternator is used, it will have poor efficiency during periods of light loads on the plant.

Therefore, in actual practice, a number of alternators of different capacities are installed so that most of the alternators can be operated at nearly full load capacity.However, the use of a number of generating units increases the initial cost per kW of the plant capacity as well as floor area required.This leads to the increase in production cost of energy.

4. Load Curve

The load curve which is also called the load graph is a graphic record indicating electricity demands for every instant over a given time interval. The graph or record may be for 1 hour, hence an hourly load graph; a day or 24 hours which is becomes a daily load graph; a month in which makes it a monthly load graph; or an annual or yearly which is equivalent to 7860 hours, which would be a yearly load graph/curve. The load curve is therefore a graphical plot indicating the variation in energy demand for consumers on a power plant or energy source.

Curves provide information and help to planners to make decision on the size of installed capacity of the power station as well as well as the economical size of the various generating units within a power plants or power system. Load curves enable the estimation of generating cost and decision making on the operating schedule or sequence of operation of the of the power station terms of which units should run and for how long.

The load on a power station is not constant, instead it continuously based on customer demand. The load curve is a is a graphical representation of load on a generating station normally recorded at half-hour or hour intervals against the time chronological order as shown in Figure 2.

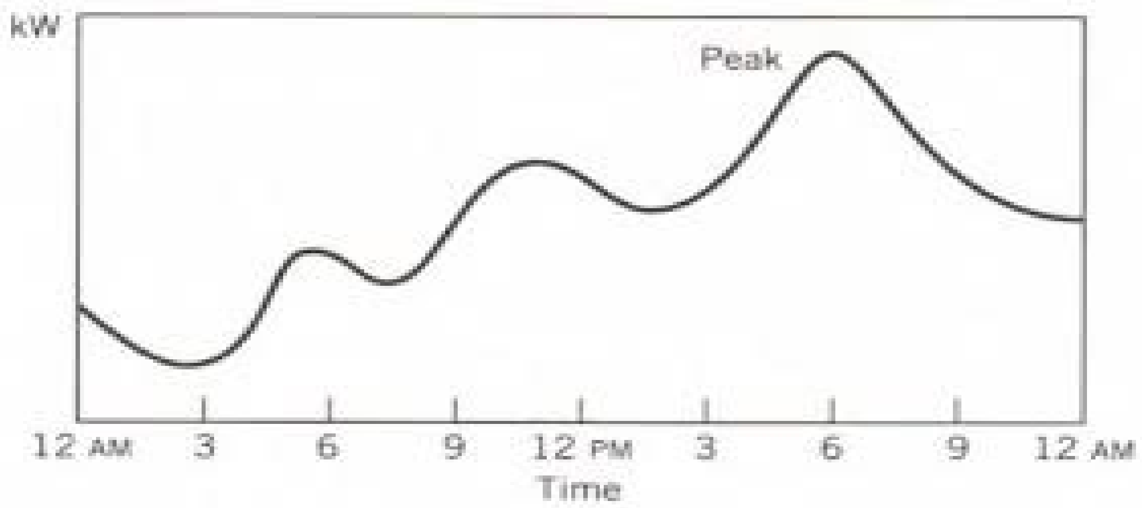


Figure 2. The load curve.

Figure 2 demonstrates a typical daily load curve. From the load curve, the following information can be generated.

i.) The area under the load curve is the total energy generated by a power plant. Therefore, units generated/day = Area (in kWh) under daily load curve.

ii.) Dividing the area load curve, by the rectangle in which is contained give the load factor of the power plant.

iii.) The maximum or peak value on the load curve is the simultaneous maximum demand on the power station.

iv.) Average demand on a power station is the area under the curve divided by hours of the day.

v.) The load curve can be used to establish the minimum load on a power station.

vi.) Load curves can be used to compute the minimum, maximum and average load as well as average annual load factor.

Load Factor = Avg. Load / maximum Load = Avg. Load x24 / 24xmaximum Load

vii.) The daily, weekly and monthly load curve for a power station is unique, hence it differs every day, week, month and year.

The load duration curve accurately reflects the activity consumers in terms of electricity consumption over a given time period.

4.1. Daily Industrial Load Curve.

A closer look and industrial load demand start rising around after 5 hours in morning as machines start preparation for the plant to running perhaps for warming prior to operation of a few departments having to start early to synchronise the overall working of the plant in proper manner. By 8 hours in morning, the industrial load comes is fully loaded but starts dropping shortly before noon, when it begins to fall off a bit because of lunch period. The shape of the curve is restored from around 14 hrs and remains like that till about 18 hrs. The demand falls to minimum again by 21 to 22 hours in night and remains the same till 5 hours in morning next day. This cycle is repeated is repeated over a period of 24 hours.

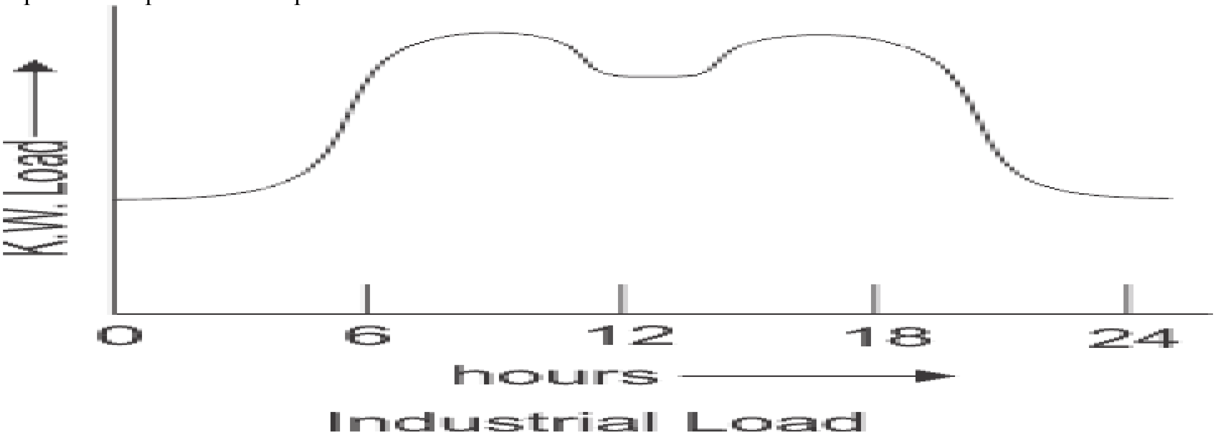


Figure 3. Industrial load curve

Figure 3 shows the industrial load curve which has peaks between 8 and 12 and 14 hours and 20 hrs.

4.2. Daily Residential Load Curve.

For residential loads, the minimum load is reached at about 2 to 3 hours at morning, at a time when most people are asleep and during 12 noon, when most people are out at work. The peak for residential load demand starts at around 17 hrs and lasts to 21 to 22 hrs at night, then the load starts to rapidly, as many people go to sleep. Load demand in summer tends to be higher values during the winter season in countries like India (Figure 4).

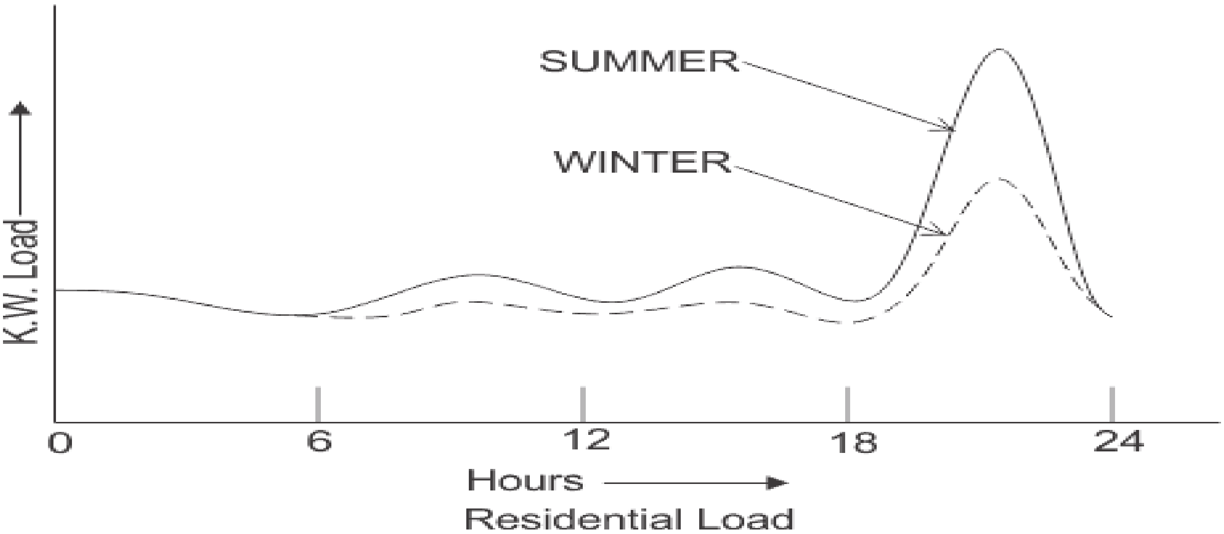


Figure 4. Domestic/residential load curve

From the above to examples we see, that the load duration curve, gives us a graphical representation, of the demand that the supply stations are required to meet throughout the day. And hence they are helpful in deciding the total installed capacity of the plant required, which should be capable of meeting the peak load demand, and the most economical size of various generating units. Most importantly it helps us decide the operating schedule of the power plant, i.e. how, when and in what sequence, the various units should be started, run and shut down. During, the valley period (at lower load demand) the question of shutting down some generator sets and restarting them later on, when more load comes on is to be decided by economic considerations.

To shut down the generator sets and to restart them later involves certain losses on one hand and on the other hand to allow the sets to run at partial loads also involve losses due to loss of efficiency of operation which depends upon the time duration for which the sets are run at reduced load. The decision on whether to shut down certain sets or continue their operation at reduced load is to be made in the light of minimum losses. These analyses are done by power sector engineers taking the load duration curve of their supply targets into consideration. Hence it is important that the raw data be taken in form of a load curve and implemented, to optimize the power generating units, in the most efficient manner possible (Figure 5)

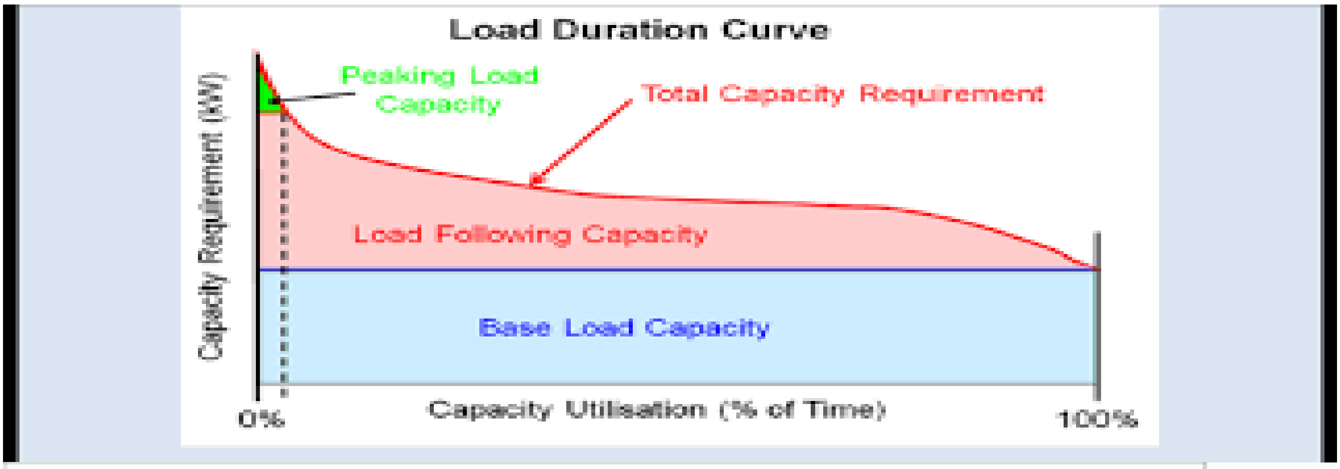
Importance of Load Curve:

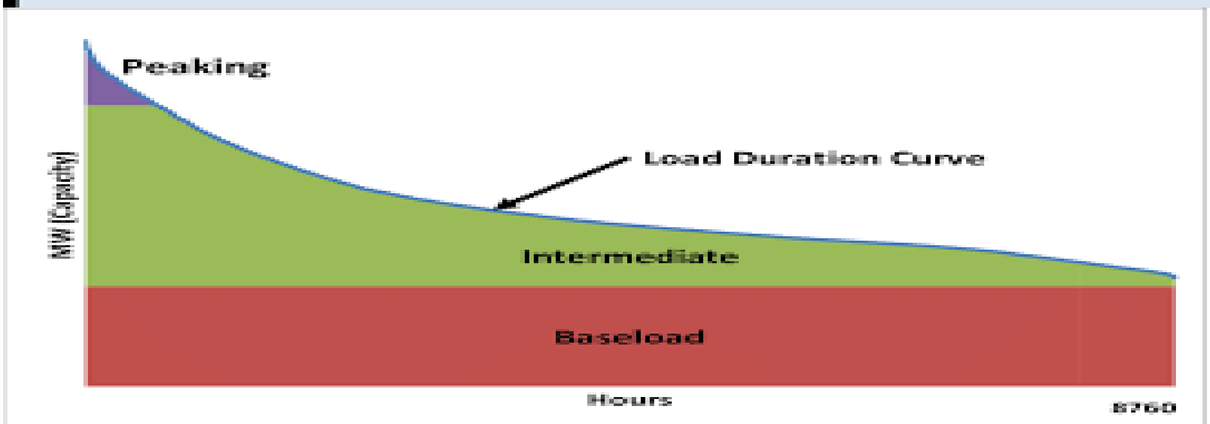
- From the daily load curve, we can have insight of load at different time for a day.
- The area under the daily load curve gives the total units of electric energy generated.

  Units Generated / day = Area under the daily Load Curve in kW
- The peak point on the daily load curve gives the highest demand on the Power Station for that day.
- The average load per day on the Power Station can be calculated using the daily load curve.
- **Average load = Area under the daily Load Curve (kWh)/ 24 hrs.**
- Load curve helps in deciding the size and number of Generating Units.

  = Area under daily Load Curve/Area of Rectangle having Daily Load Curve

Load duration curve





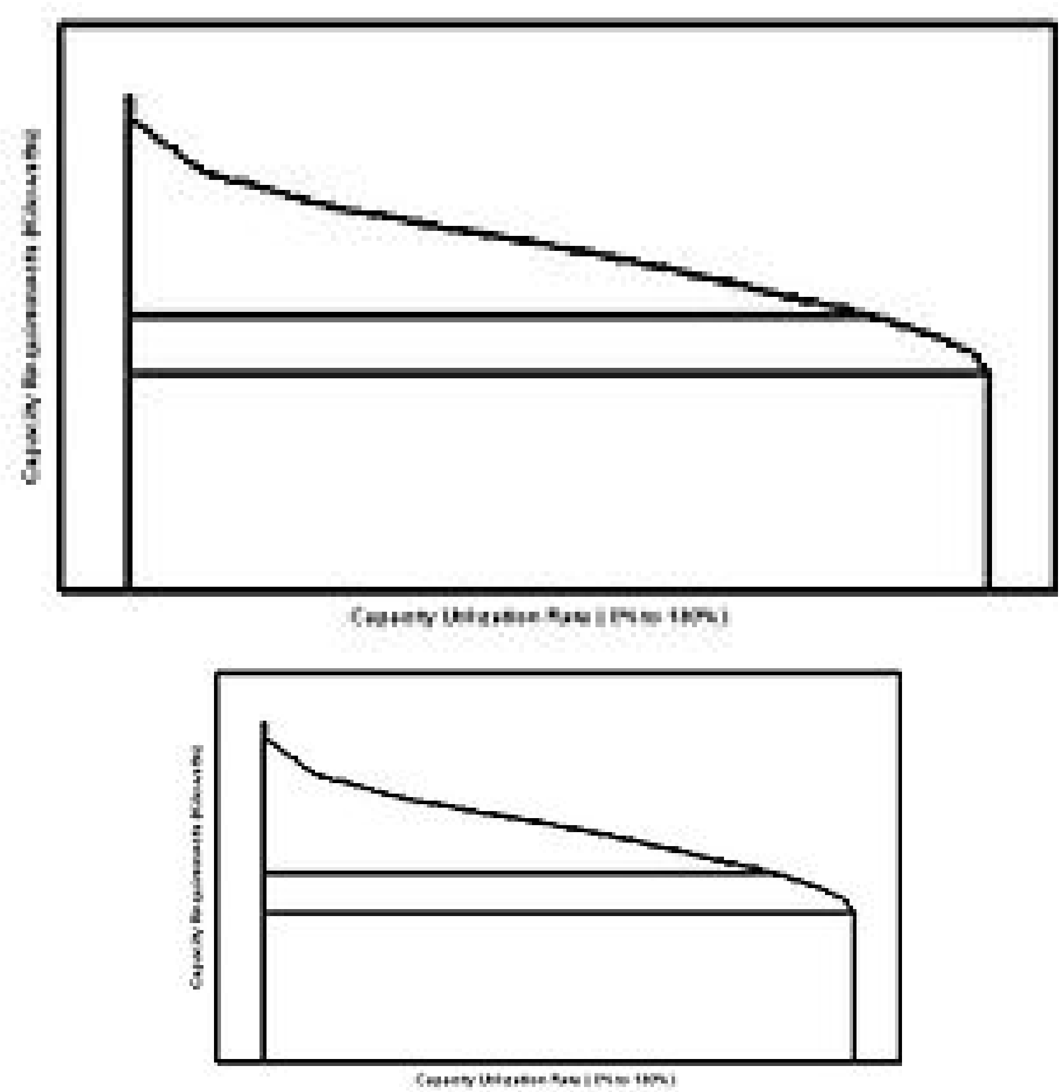


Figure 5. Load duration curve

5. Typical Load Duration Curve

The load duration curve provides information on the amount electricity consumed over given period. The load duration curve is a graphical presentation of the load on power plants and energy produced in in kilowatts with area under the curve in LDC providing an indication of energy demanded. Loads in the LDC are arranged in sliding order of their magnitude. The LDC chart provides an indication on the efficiency of power grid. In power generation, the LDC shows the relationship between generating capacity requirements and capacity utilization of a power system with demand data presented in the descending order of magnitude.

The load duration curve (LDC) refers to a chart that provides an overview of energy required by an electricity system. The LDC is applied in determining the kind of technological mix to supply specific load demand. The LDC demonstrates the relationship between generating capacity requirements and generation capacity utilization. Although the load duration curve (LDC) is similar to a load curve the data, ordered in descending order of magnitude, instead of the chronologically as in the load curve. The height of each slice in the duration curve (LDC) shows capacity utilization requirements for each increment of load. The height shows demand and the width of slices measures utilization rate or capacity factor while the product of the height and width is electrical energy (e.g. kilowatthours) (Figure 6 and Figure 7).

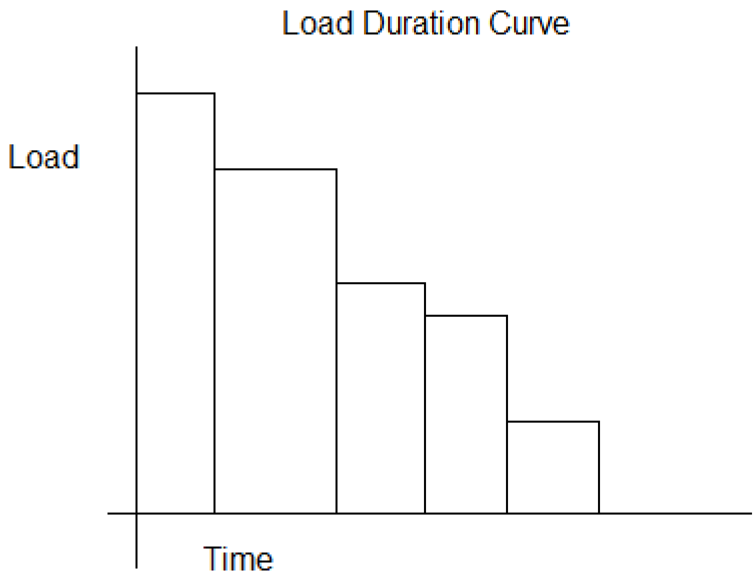


Figure 6. Load duration curve

Price Duration Curve

A price duration curve shows the proportion of time for which the price exceeded a certain value.
Together, the price duration curve and load duration curve enable the analyst to understand the behaviour of the electricity market, for example, the likelihood of peaking power plant being required for service, and the impact that this might have on price.
Mathematically, it is a complementary cumulative distribution function.

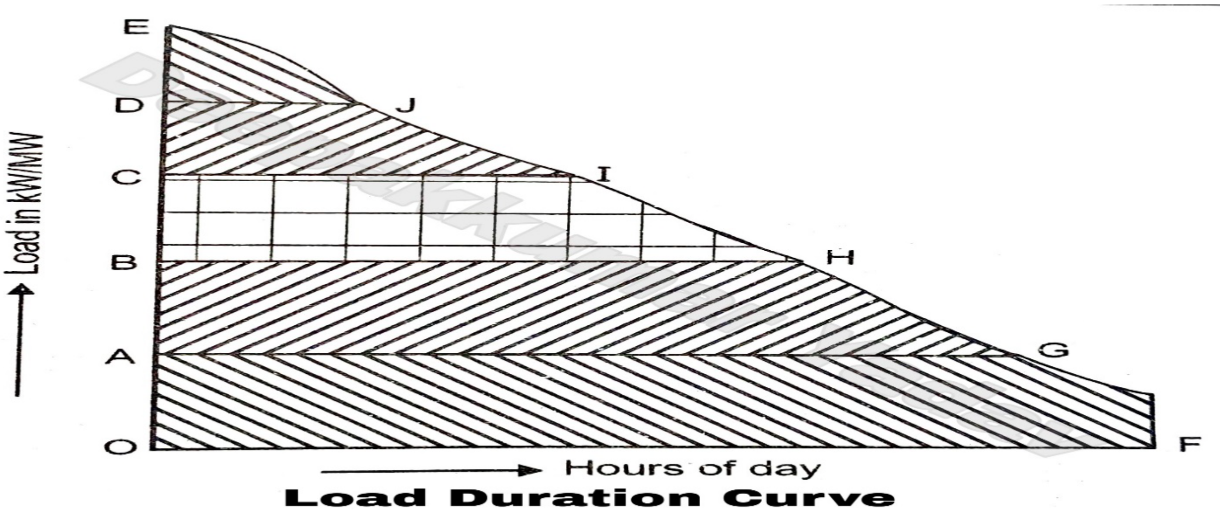


Figure 7. Load duration curve

- The total load supplied during a day is divided into number of sections, may be equal to number of generators used in the plant.
- Suppose that 5 generators are used in the plant. The generator which supplies load OA works almost for 24 hours and supplying its full load and has a load factor of nearly 90 to 95% . Hence, it is a generator supplying the base load on the plant.
- When the load on the station increases and becomes OB, second alternator (generator) will work in addition to first and it works on nearly 50-55% of load factor.
- When the load increases to that represented by OC, third generator works in addition to the previous two, and its load factor may be 30 to 35%.
- Similarly, fourth and fifth generators will start depending upon load requirement and may have load factor of about 10 to 15% and 5 to 10% respectively.

- The area under the load duration curve represents the total number of units consumed in that time. Also the load factor of the station can be determined from it. From this curve it is possible to distribute the load between different units installed in a station or decide the size of different units to be installed in a station.

A load duration curve (LDC) is suited for application in probabilistic technico-economic analysis like Monte Carlo simulations (Figure 8).

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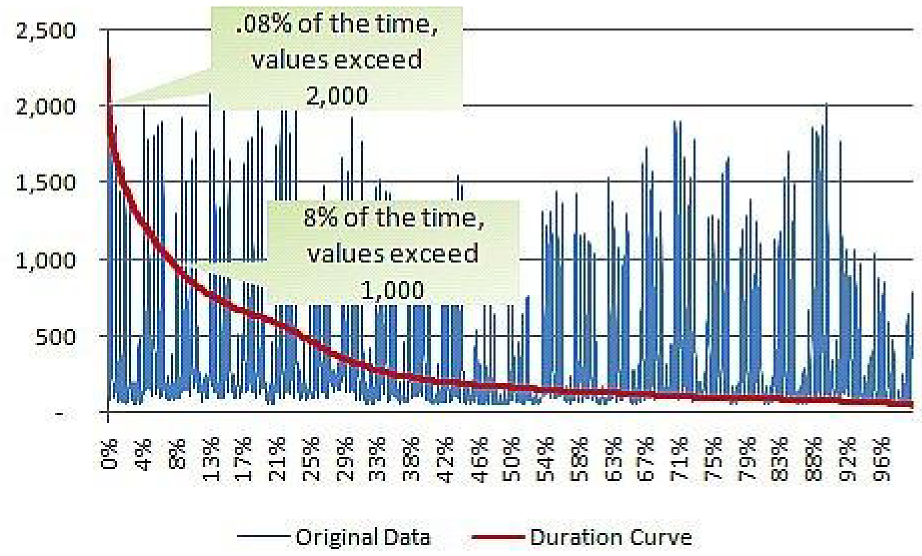


Figure 8. Load duration curve. Source: pua.edu.eg

5.1. How the Shape of The LDC Affects Technology Mix

The shape of the load duration curve (LDC) has direct influence on the mix of power generation technology. Reduction in peak demand reduces the demand for thermal power plants hence less gas, oil or coal consumption. When the load duration curve flattens, the base load thermal plants operate more efficiently. Peak load power systems are found at the highest magnitudes followed by the intermediate load and then at the bottom of the load curve is the base load hence the load demand curve assists in evaluation of system reliability. It also assists in economic dispatch and planning (Figure 9).

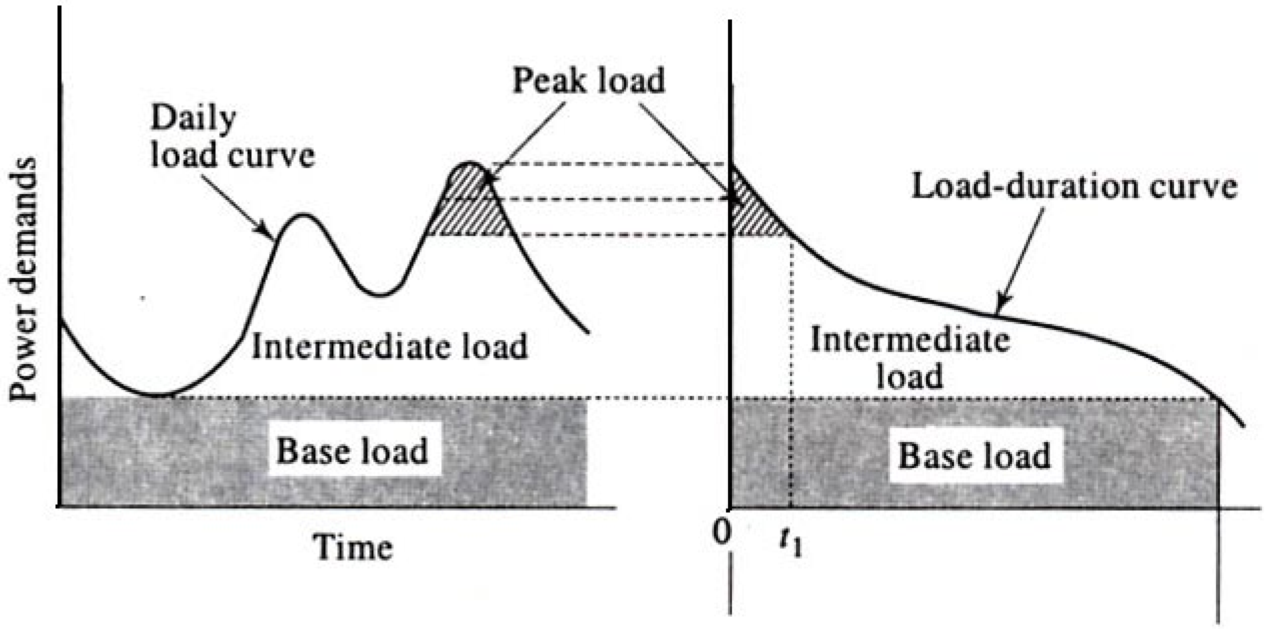
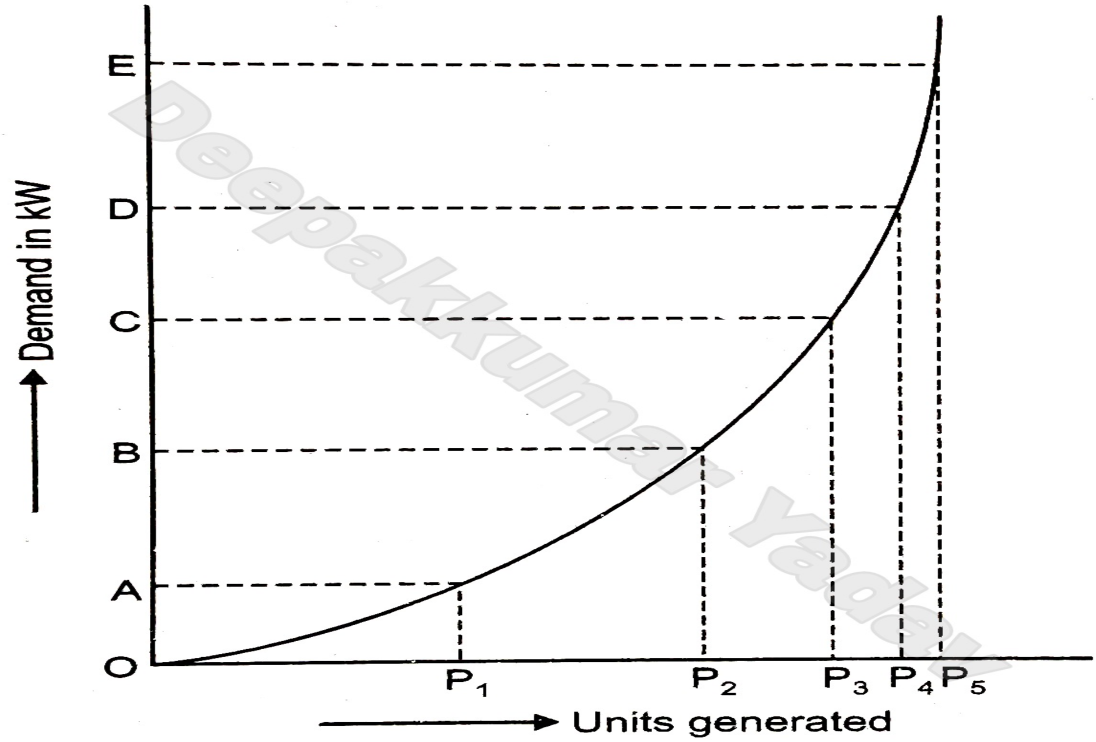


Figure 9. Load duration curve and its relation to generation technologies. Source: pua.edu.eg
Key features of each of the following

5.2. Integrated curve

A plot that represents the number of units generated (kWh) for a given demand (kW) is referred to as integration load duration curve. Electricity load or demand is presented on the Y-axis, in kW or MW while on the horizontal axis is corresponding number of units generated. The integrated curve corresponds to the load duration curve. This is represented in Figure shown in Figure 10.



Integrated Duration Curve

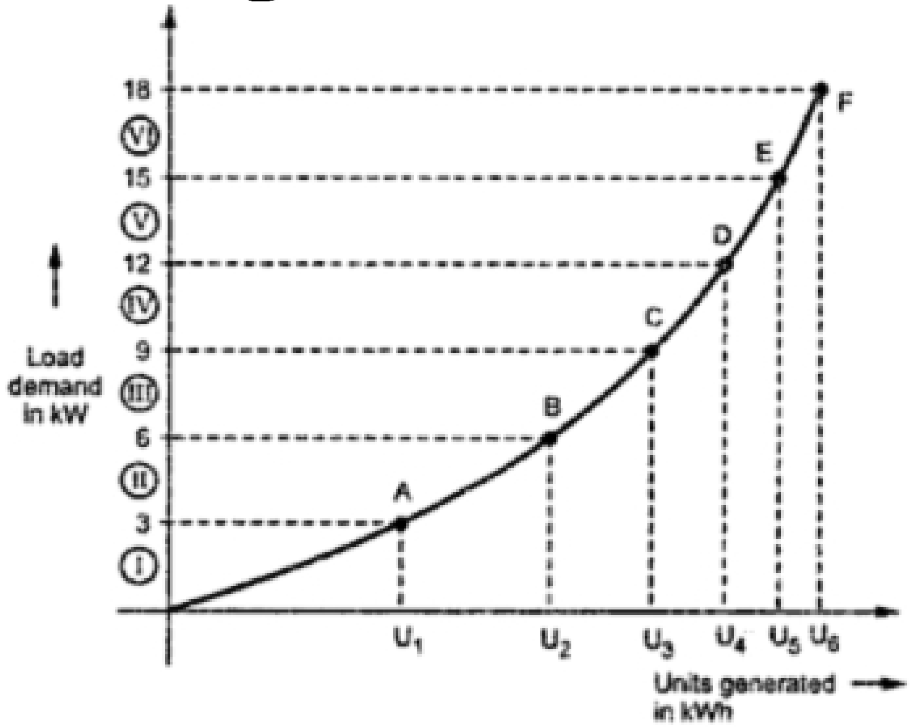


Figure 10: Integrated duration curve

- The curve representing total number of units generated for the given demand in kW is called as Integrated duration curve. The ordinate represents the the demand in kW and the abscissa represents units generated in kWH. Such a curve can be drawn from the load duration curve.

- Consider Figure 11, let the load demand be represented by a point A and it corresponds to line AG on the load duration curve.
- The number of units generated (P_1) corresponding to this load demand are represented by the area OAGF, it corresponds to point P_1, on the integrated duration curve. Similarly, point P_2 on this curve corresponds to load demand B and kWH generated (P_2) area given by the area OBHF.

This curve is obtained from load duration curve. Let the load demand be 3 kW from the load duration curve in section I. The number of units generated corresponding to this demand will be area under section I which is shown as U_1 in integrated load duration curve. Similarly the other pints are also obtained to get a total curve.

The number of units consumed by a load upto a particular time of a day can also be shown on a curve which is called as mass curve.

Electricity demand forecast

A load duration curve is often used to help plan for electrical utilities, and a typical curve is presented in Figure 11 (Murphy, *et al.*, 1982). From Figure 11, *h* is the number of hours in a year during which the demand is greater than or equal to a given load *L* (MW). The area under the curve represents the amount of energy, given in megawatt-hours, for a given period of time.

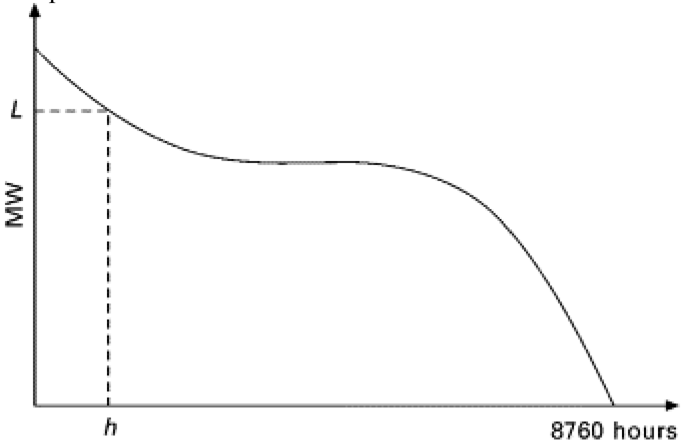


Figure 11. Various electricity demand

Various electricity demand forecasts for Ontario have been published. In 2005, Independent Electricity System Operator (IESO) forecast the energy and peak-load demand for Ontario for the ten-year period from 2006–2015. The results show that the energy demand is predicted to grow by 0.9 % annually over the forecast period. Total energy demand is expected to increase from 157 TWh to 170 TWh by 2015. IESO predicts an increase in the normal weather peak from 24 200 MW in 2006 to 25 700 MW in 2015, while the normal weather summer peak is expected to increase from 24 000 MW to 26 900 MW over the same time period. Furthermore, the forecast shows an average annual increase of 0.7 % for the winter peak and an average annual growth rate of 1.3 % for the summer peak.

Navigant Consulting Ltd used IESO's 2005 forecast to extrapolate electricity demand to 2025. In this forecast, annual hourly data was extracted from IESO's forecast for the period 2006–2015. For the remaining analysis period 2016–2025, the 2015 typical week profile was extrapolated and fit to the annual energy and peak demand forecast (Navigant Consulting, 2005). The Ontario peak demand and energy consumption forecasts from Navigant Consulting Ltd are shown in Table 1.

Table 1. Forecasted peak demand (MW) and energy demand (TWh) from Navigant Consulting Ltd.

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Annual energy (TWh)	156.8	158.3	160.3	161.2	162.6	164.2	166.0	167.0	168.4	169.7
Peak demand (MW)	24 205	24 374	24 627	25 045	25 228	25 534	25 840	26 461	26 461	26 874

	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Annual energy (TWh)	171.2	172.7	174.3	175.8	177.4	178.9	180.5	182.1	183.7	185.3
Peak demand (MW)	27 211	27 552	27 898	28 248	28 602	28 961	29 692	29 692	30 064	30 441

Chui *et al.* (2006) used a stochastic model to forecast Ontario's electricity demand from 2006–2020. In this model, employment forecasts from the Ontario Ministry of Finance and various weather scenarios were used to predict electricity demand. This forecast contains a lower, median and upper bound. The lower bound uses a low employment growth rate and mild weather conditions, while the median bound uses median employment growth rate and median weather scenarios. Finally, the upper bound uses high employment growth rate and extreme weather scenarios. The forecast annual energy demand, annual peak-load demand and annual base-load demand from Chui *et al.* (2006) are shown in Figures 12 -14 respectively (Figure 12 and Figure 13).

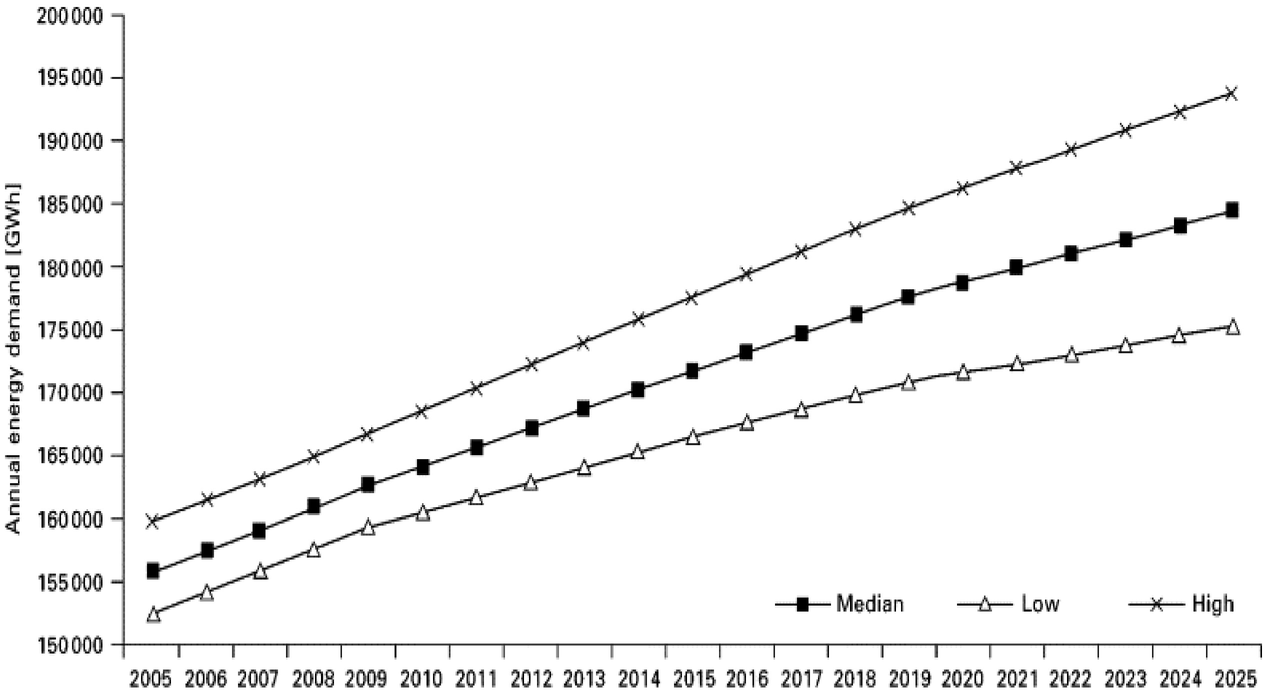


Figure 12. Ontario's forecasted annual energy demand (GWh) for low, median, and upper bound (Chui *et al.*, 2006)

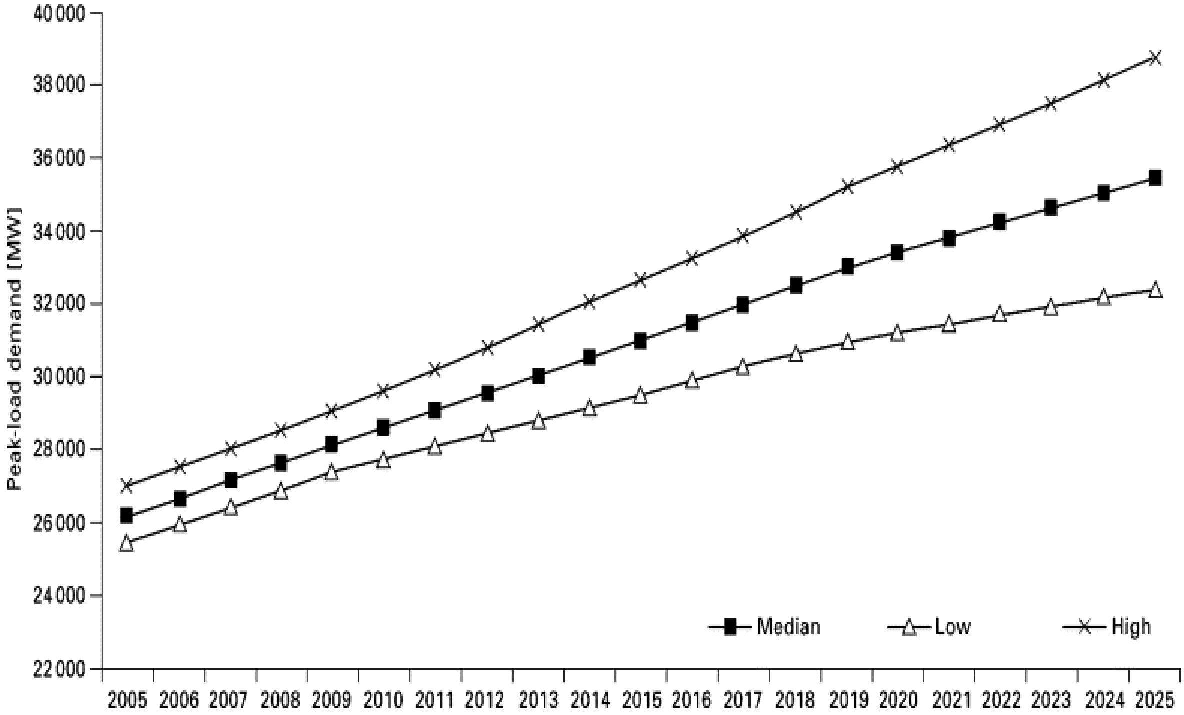


Figure 13. Ontario's forecasted annual peak-load demand (MW) for low, median, and upper bound (Chui *et al.*, 2006).

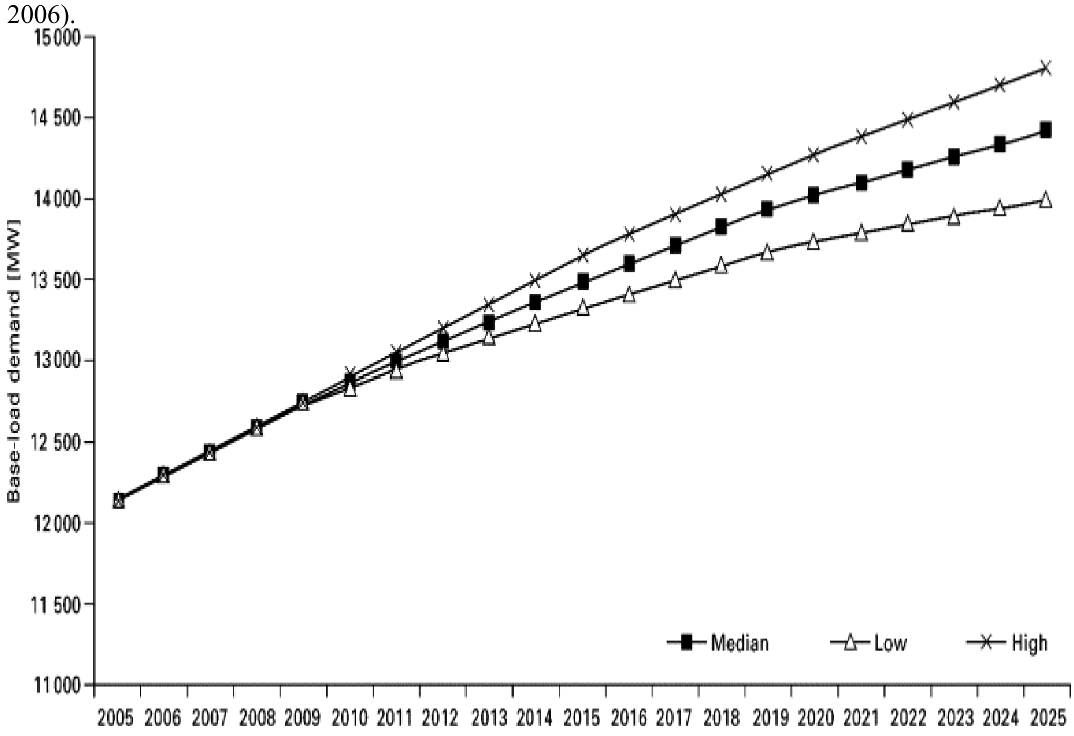


Figure 14. Ontario's forecasted annual base-load demand (MW) for low, median, and upper bound (Chui *et al.*, 2006).

As can be seen from Figure 14 Ontario's annual energy demand grows by a range of 0.7 % to 0.97 % between 2006 and 2020. Figure shows an annual increase in peak-load demand in the range of 1.21 % to 1.82 % for the same time period. Finally, from Figure 15, it can be seen that the annual base-load demand grows in the range of 0.71 % to 0.99 %. In this chapter, we will use the above electricity forecast for the case study that will be discussed in Section 4.4 (StudyCorgi 2020)

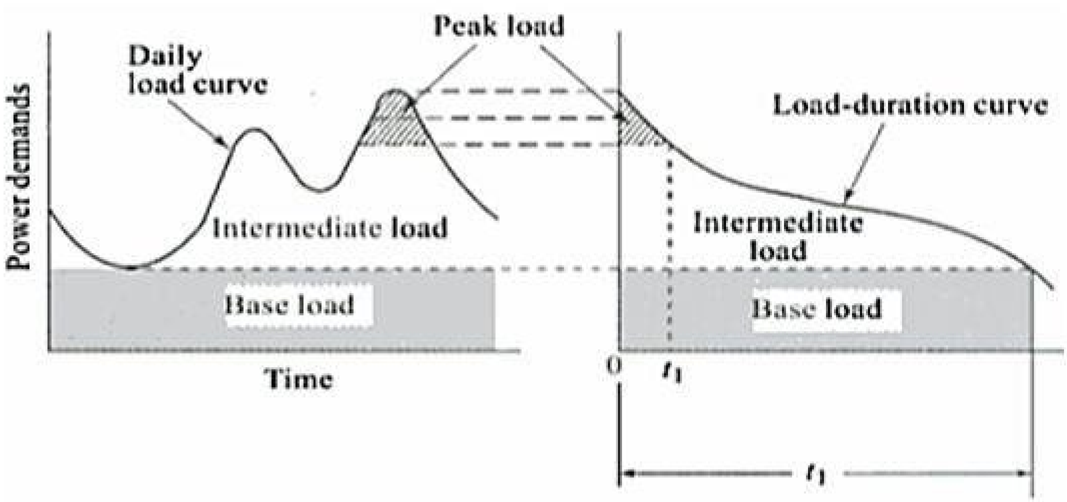


Figure 15. Load curve and Load Duration curve

6. Dispatch

6.1. Types of Power

The following points are worth noting :

(a) The area under the load duration curve and the corresponding chronological load curve is equal and represents total energy delivered by the generating station.

(b) Load duration curve gives a clear analysis of generating power economically. Proper selection of base load power plants and peak load power plants becomes easier.

6.1. Dump Power

This term is used in hydroplants and it shows the power in excess of the load requirements and it is made available by surplus water.

6.2. **Firm Power**

It is the power which should always be available even under emergency conditions.

6.3. **Prime Power**

It is the power which may be mechanical, hydraulic or thermal that is always available for conversion into electric power.

6.4. **Cold Reserve**

It is that reverse generating capacity which is not in operation but can be made available for service.

6.5. **Hot Reserve**

It is that reserve generating capacity which is in operation but not in service.

6.6. **Spinning Reserve**

It is that reserve generating capacity which is connected to the bus and is ready to take the load.

Load Curves:

The curve showing the variation of load on the power station with respect to (w.r.t) time is known as a load curve.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 w.r.t. the time during the day.The figure below 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.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 yearly load curve is obtained by considering the monthly load curves of that particular year. Various electricity is generally used to determine the annual load factor (Figure 16).

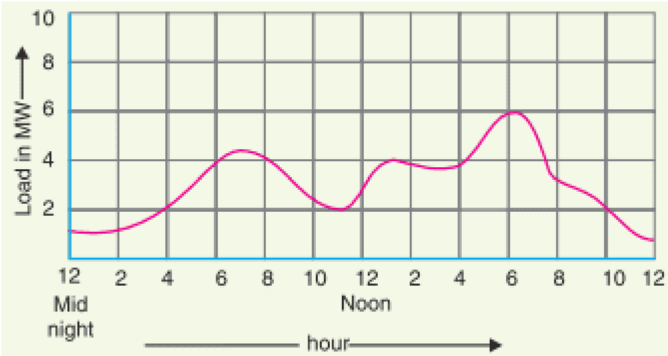


Figure 16. Various electricity

Importance: The **daily load curves** have attained a great importance in a 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.
(iii)The highest point on the *daily load curve* represents the maximum demand on the station on that day.
(iv) The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

Average load =Area (in kWh) under daily load curve/24hours
(v)The ratio of the area under the load curve to the total area of a rectangle in which it is contained gives the load factor.
Load factor=Average load/Max. demand=Average load × 24/Max. demand ×24=Area (in kWh) under daily load curve/Total area of a rectangle in which the load curve is contained.
(vi)The **load curve** helps in selecting the size and number of generating units.
(vii)The load curve helps in preparing the operation schedule of the station.

Important terms and factors:
The **variable load** problem has introduced the following terms and factors in power plant engineering:

6.7. Dispatch Curve

Dispatch curve shows in Figure 17.

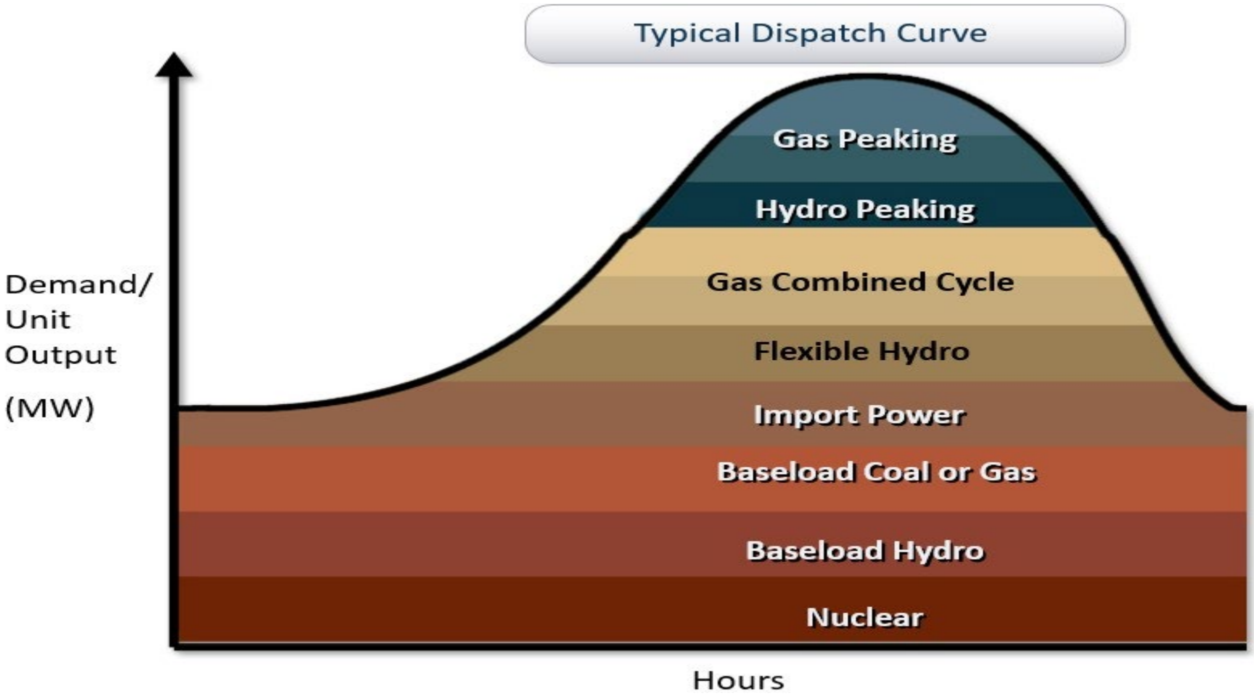


Figure 17. Dispatch curve

7. POWER PLANT PERFORMANCE INDICATORS

7.1. Demand

The demand of an installation or power system refers to the load drawn from the power source at the receiving terminals averaged a reasonable or a suitable and specific time interval expressed as in kilowatts (kW), kilo volt-amperes (kVA), amperes (A), or other suitable units.

7.2. Connected load

Connected load is the sum of sum of continuous ratings of all the equipment or loads connected to the power supply system or the combined continuous rating of power receiving apparatus or devices on consumers' premises, that are connected to the system, or part of the system, being examined. A power plant may deliver load to thousands of consumers each having equipment installed at their premises at the load centres. The total sum of the continuous ratings of all the equipment at the consumer's premises is referred to as "connected load" of the consumers. An important thing to note is that at no point or rather consumer rarely puts into use this equipment at the same time.

7.3. Maximum demand/ Peak

Maximum demand refers to the highest demand of load on the power station for a given specific period under consideration, while noting that load on a power station keeps varying and is not always at its maximum value due to consumer behaviour. The maximum of these varying loads or demands on a power station that occurred for that period e.g. a day, month or year is the maximum demand for that day or period. Therefore, on the load curve, the maximum demand is represented by the peak of the curve and represents the greatest of all the demands recorded over the period of measurement.

The Maximum demand is often less than the connected load since the consumers never switch on their connected load at the same time, and additionally the devices may not be of same capacity and consumption pattern for all consumers. The maximum demand guides planners in establishing the installed capacity of the station and capacity growth planning. So that the power station can meet the current and projected future demand.

7.4. Demand factor

The demand factor of any power system, or part of a power system, is the ratio of maximum demand of the system or part of the system to the total connected load of the system, or of the part of the system being analysed. Demand factor is mathematically expressed as;

Demand factor = Maximum demand / Connected load.

The actual value of demand factor is always less than one (1) since the maximum demand on the power station is generally less low than the connected load. For a typical case where the maximum is 90 MW for 100 MW as connected load, then the demand factor is 90/100 = 0·9. Demand factor is applied in capacity planning for a power system, hence it is an important parameter.

7.5. Average load

Average load of a power station is the power station for a given time period e.g. day, month or year also called average demand is the ratio of actual generation to the length of the period i.e. day (24 hours) month (days * 24 hours) or year 8760 hrs. It is mathematically expressed as;

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

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

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

7.6. Load factor

The load factor is defined as the ratio of average power to the maximum demand on a power plant. The interval of measuring maximum load and duration over average is noted should be specifies e.g. measurement has to be taken every after 30 minutes or half-hourly monthly. The best interval and period are determined by local conditions and the purpose for which the load factor measured and applied. Therefore, load factor of a power station is the average load divided by the maximum demand on the power which is mathematically expressed as;

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

If the plant is in operation for T hours,

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

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

Load factor may be daily load factor, monthly load factor or annual load factor depending on the period under consideration. The value for load factor is always less than because average load is always less than the maximum demand. The load factor is a very important parameter in the determination of the overall cost of power per unit generated. Power stations with higher load factor generally have less cost per unit of power produced.

7.7. Diversity factor

A plant generally supplies power or load to various types of consumers each having own maximum demands which for some reasons may never occur at the same time. For this reason, the maximum demand on a power station is always lower than the sum of maximum demand of individual demands of the different consumers. Therefore, the diversity factor is always greater than unity (Poulin and Dostie, 2008).

Diversity factor is the ratio of the sum of individual maximum demands to the maximum demand on the power station, power system or subsystem. Diversity factor is mathematically expressed as;

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

The lesser greater or higher the diversity factor, the lesser or the lower the cost of power generation.

7.8. Plant capacity factor

The plant capacity factor is the ratio of actual energy generated in kWh or MWh to the maximum possible energy that the power plant could produce during the period under consideration i.e.,

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

$$= \frac{\text{Average demand} \times T^{**}}{\text{Plant capacity} \times T}$$

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

If capacity factor is considered for one year, then

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

Plant capacity factor = (E / C* t), where, E = Energy produced (kWh Plant Economy) in a given period, C = Capacity of the plant in kW, and t = Total number of hours in the given period.

7.9. Reserve Factor

The power plant capacity factor is an indicator of the e reserve capacity of a power station. The design of a power station makes provision for reserve capacity to meet increased load demand for the future as well as for emergency. The he installed capacity of the plant is therefore always higher than the maximum demand on the power plant. Reserve Capacity = Plant capacity − Max. demand

The difference between the load factor and plant capacity factor is an indicator of reserve capacity of a power station. Therefore, a power plant has no reserve capacity if the maximum demand equals to the plant capacity which implies that the load factor and plant capacity factors are equal.

7.10. Plant use factor

Plant use factor is the ratio of energy generated over a given time period to the maximum possible generation during the actual number of hours that the power plant operated. Plant use factor is mathematically expressed as

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

Plant use factor = E / C*t'

where, t' = Actual number of hours the plant has been in operation. C= Power plant capacity.
Therefore, the ratio of kWh generated to the product of the power plant capacity and hours for which the power plant operated.

7.11. Utilization Factor

The utilisation refers to the ratio of the maximum generator demand to the generator capacity.

Must Read:

- Gas turbine power plant

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.The figure below shows the daily load curve.The daily load duration curve can be readily obtained from it.It is clear from *daily load curve*, those 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 Figure 18 below.

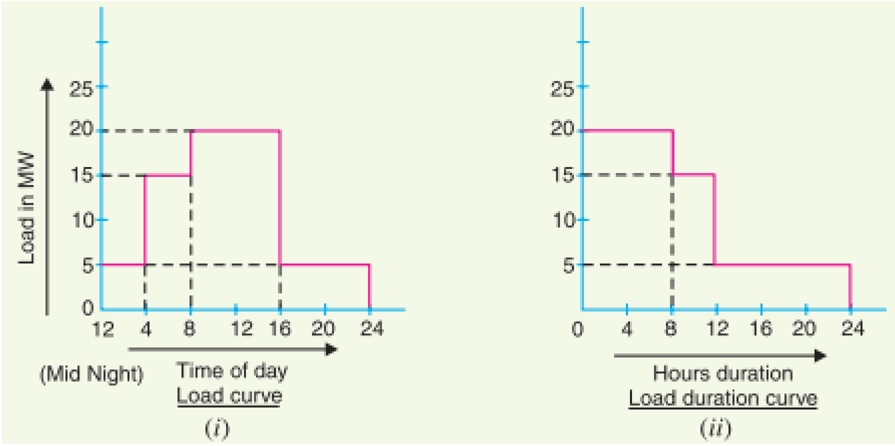


Figure 18. Load duration curve

The following points may be noted about **load duration curve** :
(i) 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.
(ii)The area under the load duration curve is equal to that of the corresponding **load curve**. Obviously, the area under *daily load duration curve* (in kWh) will give the units generated on that day.
(iii) The load duration curve can be extended to include any period of time. By laying out the abscissa from 0 hours to 8760 hours, the variation and distribution of demand for an entire year can be summarised in one curve. The curve thus obtained is called the *annual load duration curve*.

8. Results and Conclusion

A new method is proposed for forecasting electricity load-duration curves. The approach first forecasts the load curve and then uses the resulting predictive densities to forecast the load-duration curve. A virtue of this procedure is that both load curves and load-duration curves can be predicted using the same model, and confidence intervals can be generated for both predictions. The procedure is applied to the problem of predicting New Zealand electricity consumption. A structural time-series model is used to forecast the load curve based on half-hourly data. The model is tailored to handle effects such as daylight savings, holidays and weekends, as well as trend, annual, weekly and daily cycles. Time-series methods, including Kalman filtering, smoothing and prediction, are used to fit the model and to achieve the desired forecasts of the load-duration curve (Maybee and Uri 1979)

Recommended measures to challenges facing the grid

i.) Growing amount of renewables

Electricity accumulation. Batteries or other energy storage systems that can store unused energy and save it for later need. Artificial intelligence can improve prediction systems and thus allow for more accurate weather or energy consumption forecasts. With this approach, utility companies can improve the planning of their clients' electricity needs and smart energy management solutions can turn green energy into a reliable alternative to fossil fuels[4].

ii.) Transmissions losses

Energy decentralization. A shift from electricity production in a few big power plants to a system of small local energy sources that ensure energy is consumed as close as possible to its source, even on the level of individual residential buildings, e.g. prosumers

iii.) Frequent power losses

Increased energy self-sufficiency. Backup sources, such as batteries, can offer long-lasting protection in case of power outages and ensure continuous operation of crucial equipment. When combined with a renewable energy source, a delivery point can stockpile green energy and save it for later use

Electromobility

Solution: Smart grid**.** Online connection of various sources such as solar panels, batteries, EV chargers or other equipment. Through the analysis of collected "Big data" in real-time, it is possible to speed up the reaction time to the changes in the power grid and thus ensure high quality and stable energy supply. Or in other words, devices can dispose of unused energy to benefit other equipment that needs.

iv.) **Grid modernization**

Energy decentralization**.** As mentioned above, local energy production and consumption lowers the amount of electricity distributed through the power grid. Therefore, the transmission losses are lower and less burdened power lines last longer

v.) Cyber attacks

Solution: Blockchain. The potential of distributed databases to eliminate cyber-attacks proved to be so efficient that even international financial institutions e.g. J.P. Morgan and Nasdaq consider its implementation. Similarly, as during energy generation decentralization in which the responsibility for the grid operation is not in the hands of a single supplier, distributed databases mean that an attack on one single point in the grid, e.g. one power plant, cannot interfere with the operation of the entire system.

vi.) Threat of terrorism

Solution: Microgrids. Or, simply said, self-sufficient energy communities. If a terrorist group decided to stop the energy supply on a big scale, an attack on a huge number of microgrids would be needed **(**Štompf 2020, Elkamel 2010, StudyCorgi 2020).

9. Conclusion

The load duration curve is a primary tool used in the economic analysis of electric utility operations and for the purpose of planning new construction. In general equilibrium models and also in other models using linear programming, piecewise linear approximations to the load duration curve are required. A **load duration curve** (**LDC**) is used in electric power generation to illustrate the relationship between generating capacity requirements and capacity utilization. Load duration curves are used in power stations to illustrate the relationship between generating capacity requirements and capacity utilization. A load duration curve (LDC) is similar to a load curve but the demand data is ordered in descending order of magnitude, rather than chronologically.

A LDC is similar to a load curve but the demand data is ordered in descending order of magnitude, rather than chronologically. The LDC curve shows the capacity utilization requirements for each increment of load. The height of each slice is a measure of capacity, and the width of each slice is a measure of the utilization rate or capacity factor. The product of the two is a measure of electrical energy (e.g. kilowatthours).

A price duration curve shows the proportion of time for which the price exceeded a certain value.
Together, the price duration curve and load duration curve enable the analyst to understand the behaviour of the electricity market, for example, the likelihood of peaking power plant being required for service, and the impact that this might have on price. Mathematically, it is a complementary cumulative distribution function.

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Biographies

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Oludolapo Akanni Olanrewaju is currently a Senior Lecturer and Head of Department of Industrial Engineering, Durban University of Technology, South Africa. He earned his BSc in Electrical Electronics Engineering and MSc in Industrial Engineering from the University of Ibadan, Nigeria and his Doctorate in Industrial Engineering from the Tshwane University of Technology, South Africa. He has published journal and conference papers. His research interests are not limited to energy/greenhouse gas analysis/management, life cycle assessment, application of artificial intelligence techniques and 3D Modelling. He is an associate member of the Southern African Institute of Industrial Engineering (SAIIE) and NRF rated researcher in South Africa.