

Load Characteristics and Load management

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What do you mean by Electrical load?

An electrical load is a device which consumes certain amount of power/energy to accomplish certain task.

Load demand or Rated load

- Electrical loads are usually rated or measured by the amount of power they need, in units of real volt-amperes, called watts. Large loads are measured in kilowatts (thousands of watts) or megawatts (millions of watts).
- For example, if there are five lamps each rated of 100 W in a room, the load demand of the room is 500 W.
- Note that, the Power ratings of loads refer to the device at a specific *nominal voltage*.

Different types of loads based on the dependency of voltage

- ▶ Constant power load (demand is constant regardless of voltage),
Ex., Electric motors
- ▶ Constant current load demand is proportional to voltage),
Ex., Welding units, smelting, and electroplating processes etc.
- ▶ Constant impedance load (power is proportional to voltage squared).
Ex., Incandescent lighting, resistive water heaters etc.

Different types of loads based on the dependency of voltage

- Given a feeder with a 7.5% voltage drop from substation to feeder end, a constant impedance load will vary by up to 14.5% depending on where it is located on the feeder.
- The same constant impedance load that creates 1 kW of demand at the feeder head would produce only 0.855 kW at the feeder end.
- By contrast, a 1 kW constant power load will produce 1 kW of demand anywhere on the feeder.

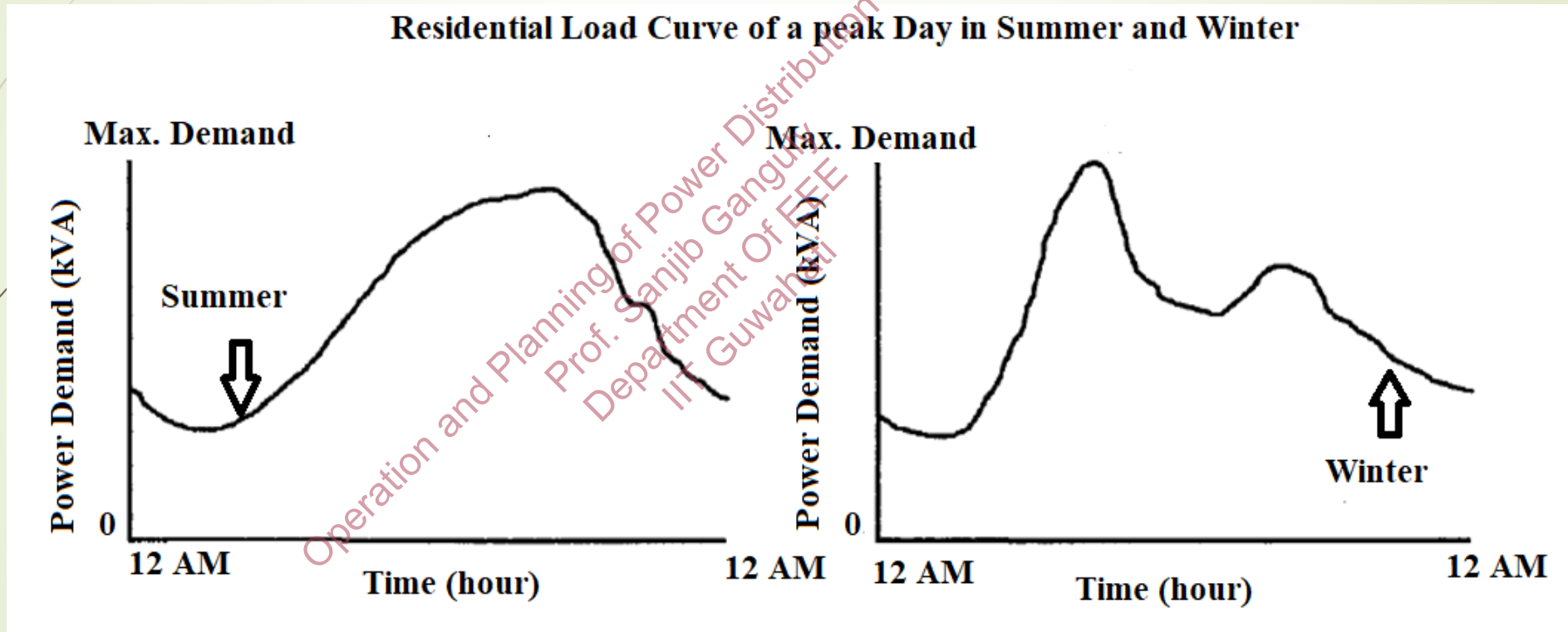
Different types of loads based on different types customers

- Residential
- Commercial
- Industrial
- Agricultural

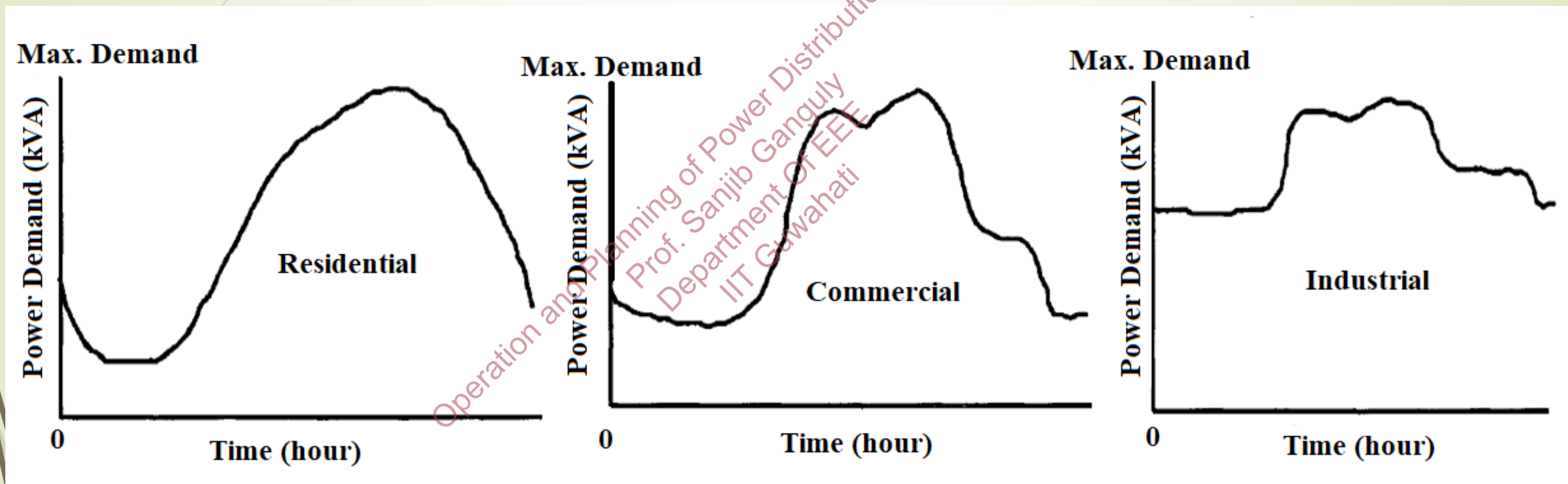
Load Curve and Load-duration curve

- Electrical load demand varies with time. The plot of the load demand with respect to time is known as 'Load curve'.
- Load duration curve is a reordered form of load curve based on descending order of load magnitude

Typical load curves in different seasons



Typical load curves of different customers



Typical Indian load curve

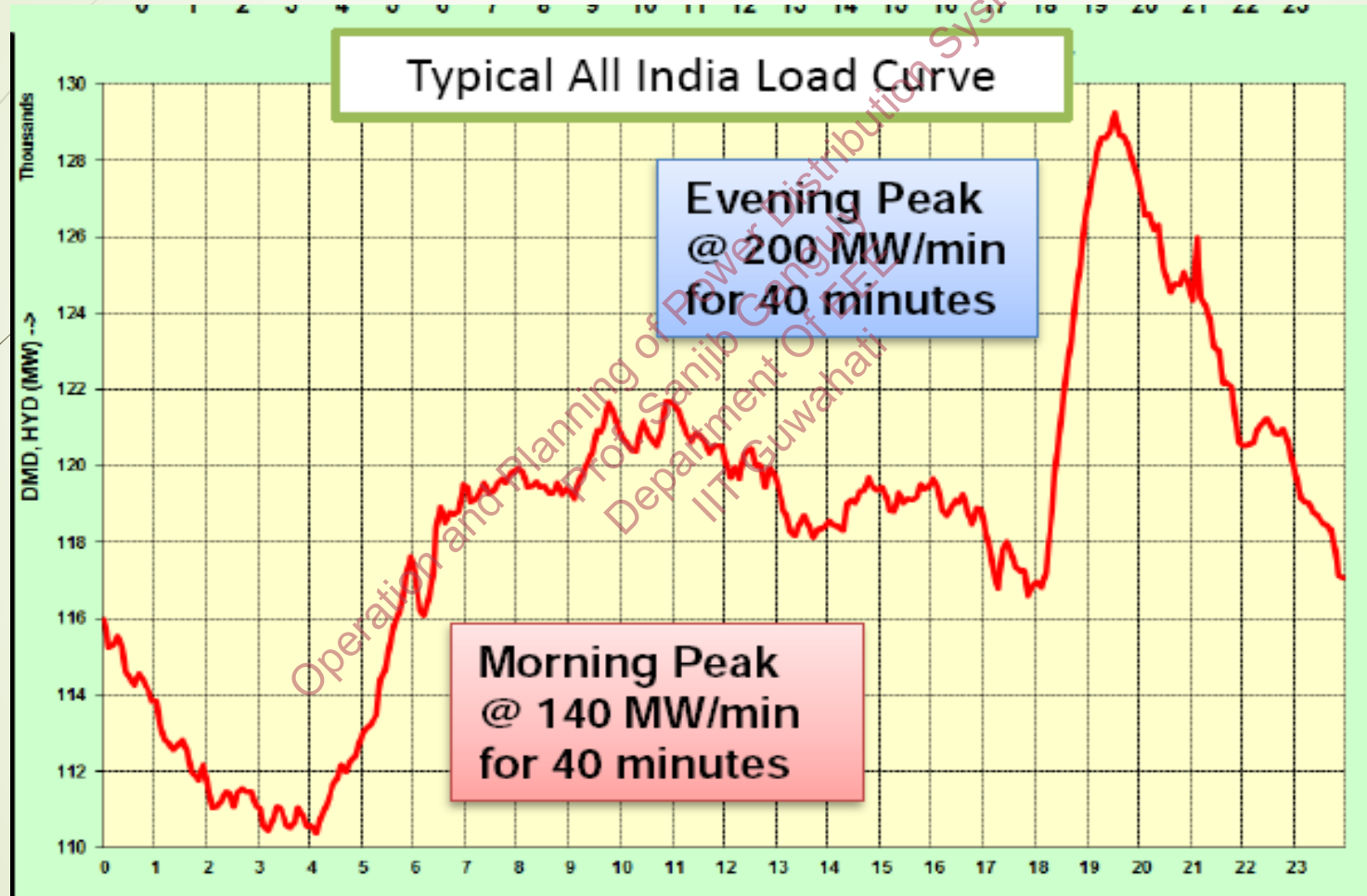


Figure curtesy: POSOCO, India

Seasonal load demand met

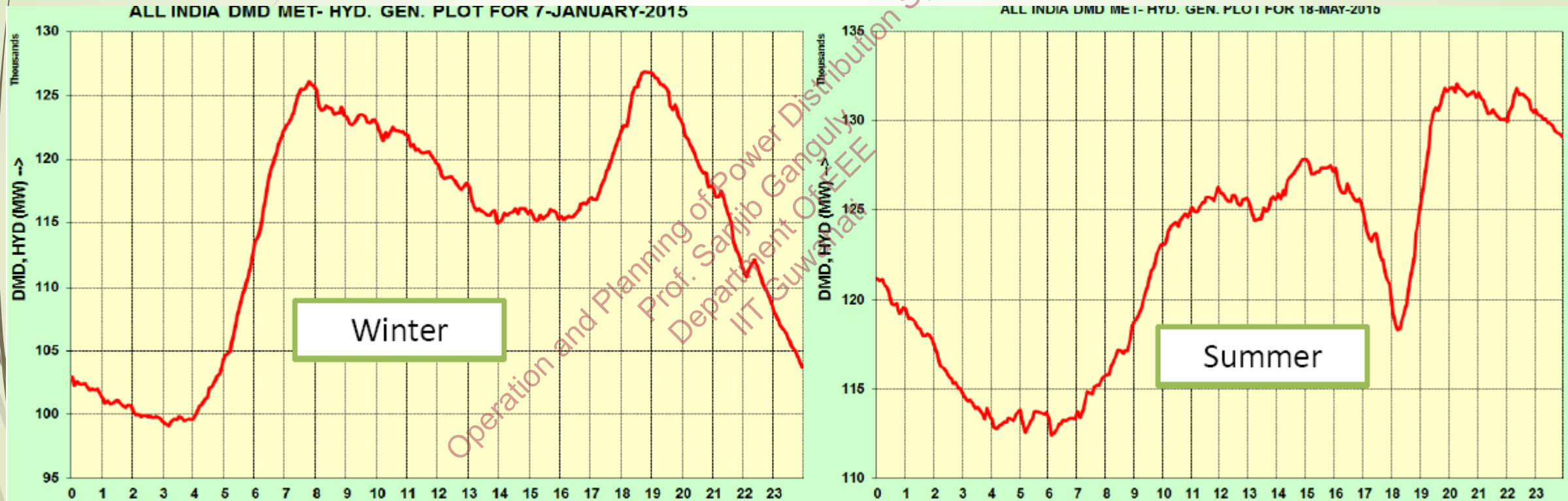
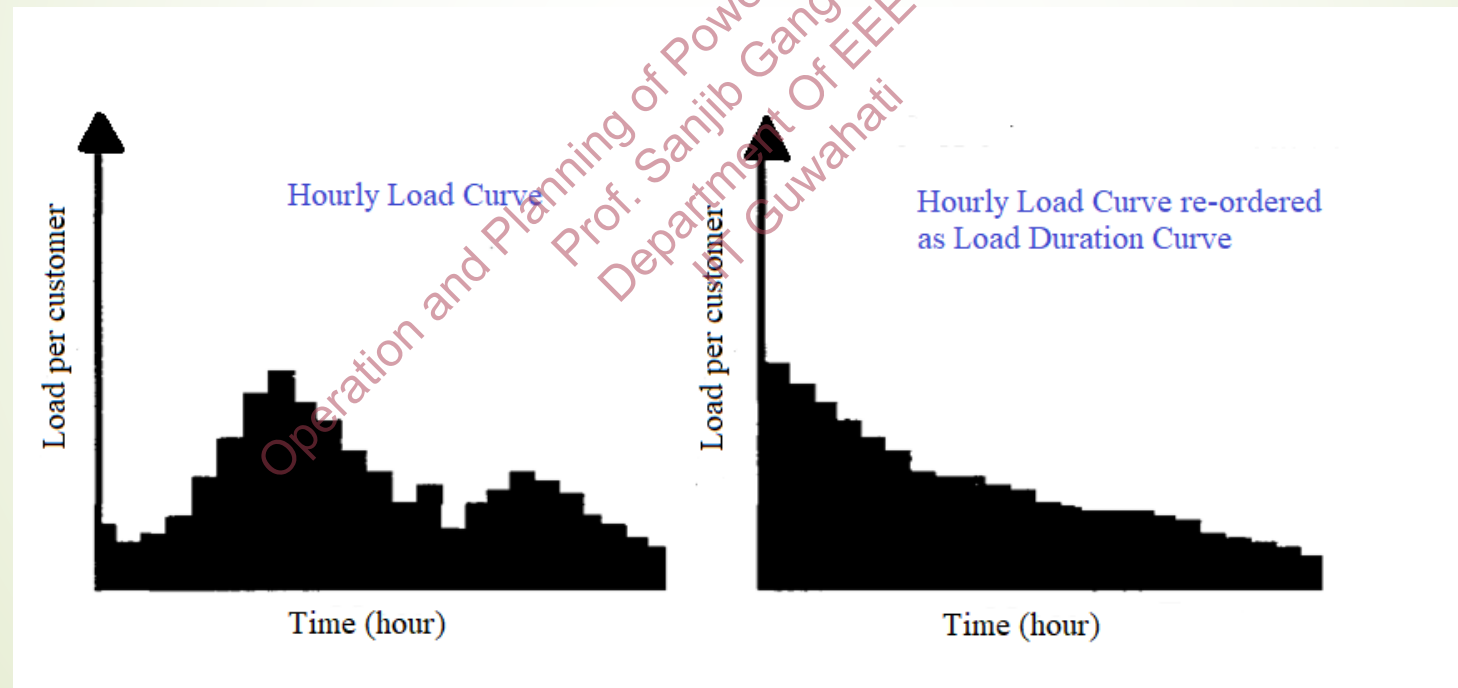


Figure curtsey: POSOCO, India

Load duration curve

- Load duration curve is a reordered form of load curve based on descending order of load magnitude



Maximum and average load demand

- The maximum demand is the highest demand occurred during the specified period of time.
- The average demand is the mean value of demand occurred during the specified period of time.

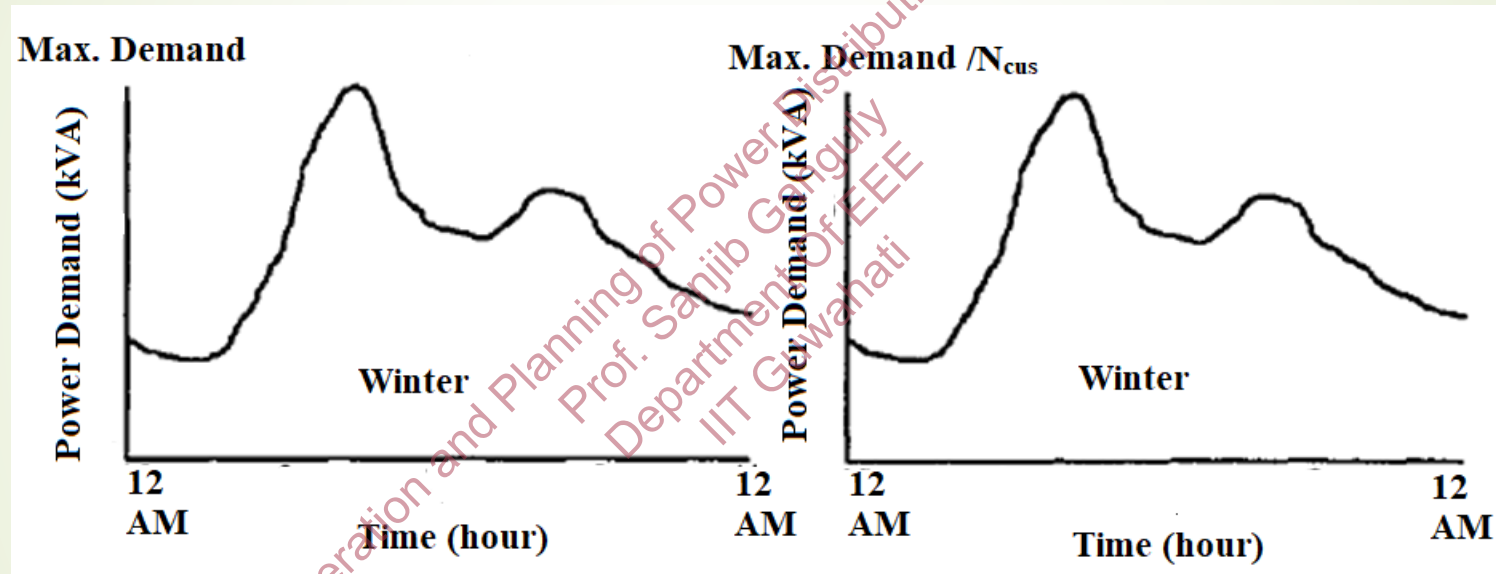
Load Factor

- The load factor is defined as the ratio of the average load demand to the peak load demand
- Load factor is always less than one.

Coincidence of load

- Load behavior at the distribution level is dominated by individual appliance characteristics
- All customers do not have their peak demand of electricity at precisely the same time.
- This needs accurate load studies with utmost care.
- Proper measurement and modeling of distribution loads is a challenging task.

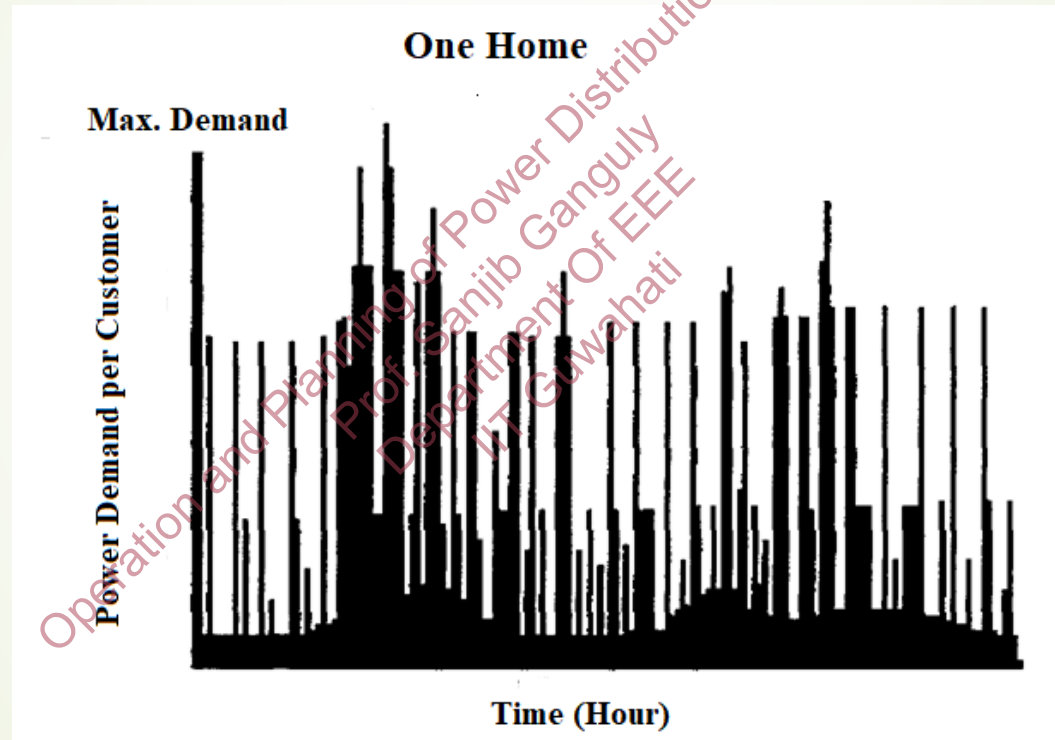
“Customer class” load curves derived from the aggregated load curve



Power demand of the entire residential area with N_{cus} residential consumers.

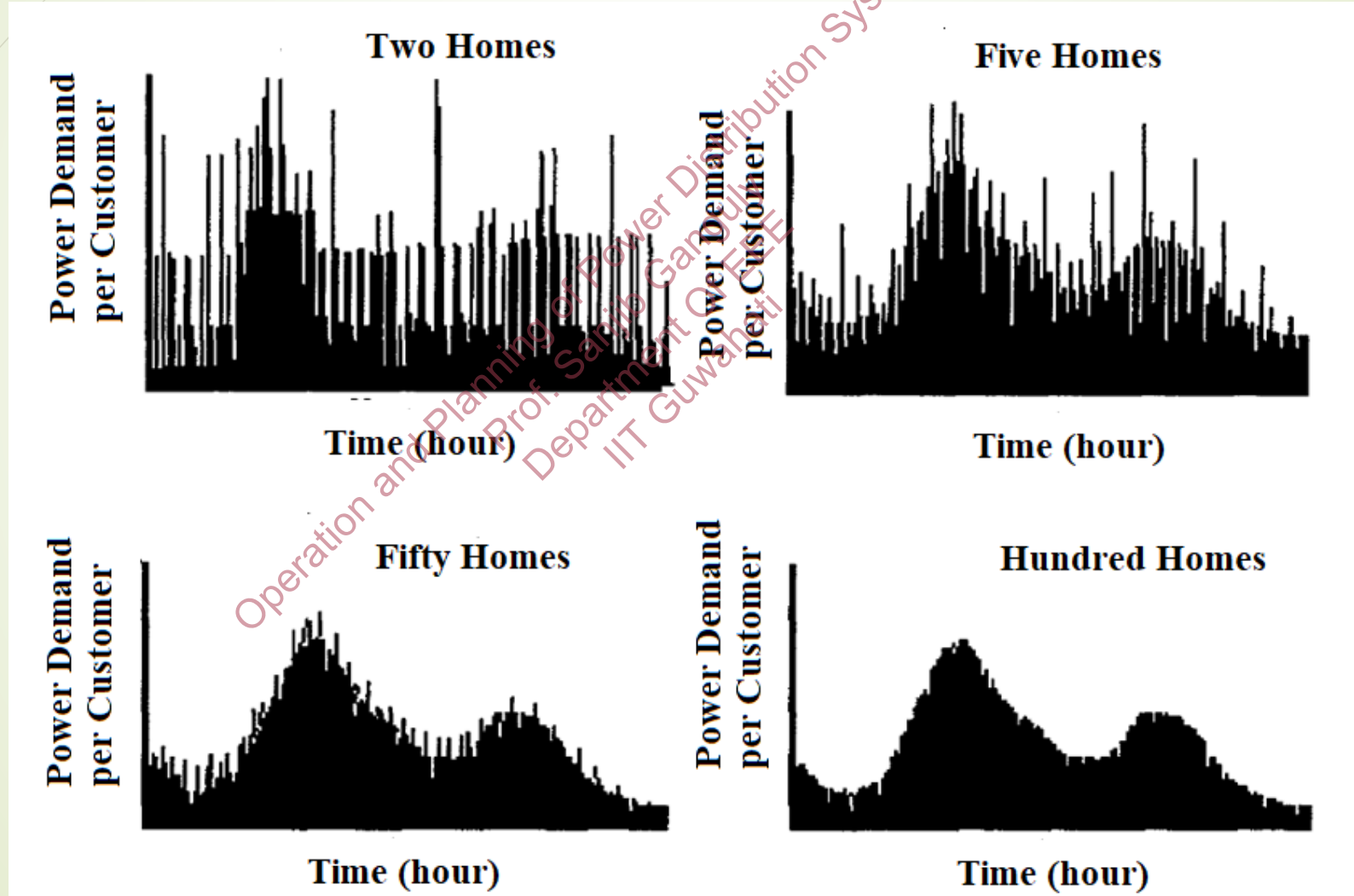
Can the load curve of individual customer be drawn by scaling down?

Actual load curve of a customer looks like.....



An individual household looks like this, dominated by high "needle peaks" caused by the joint operation of major appliances.

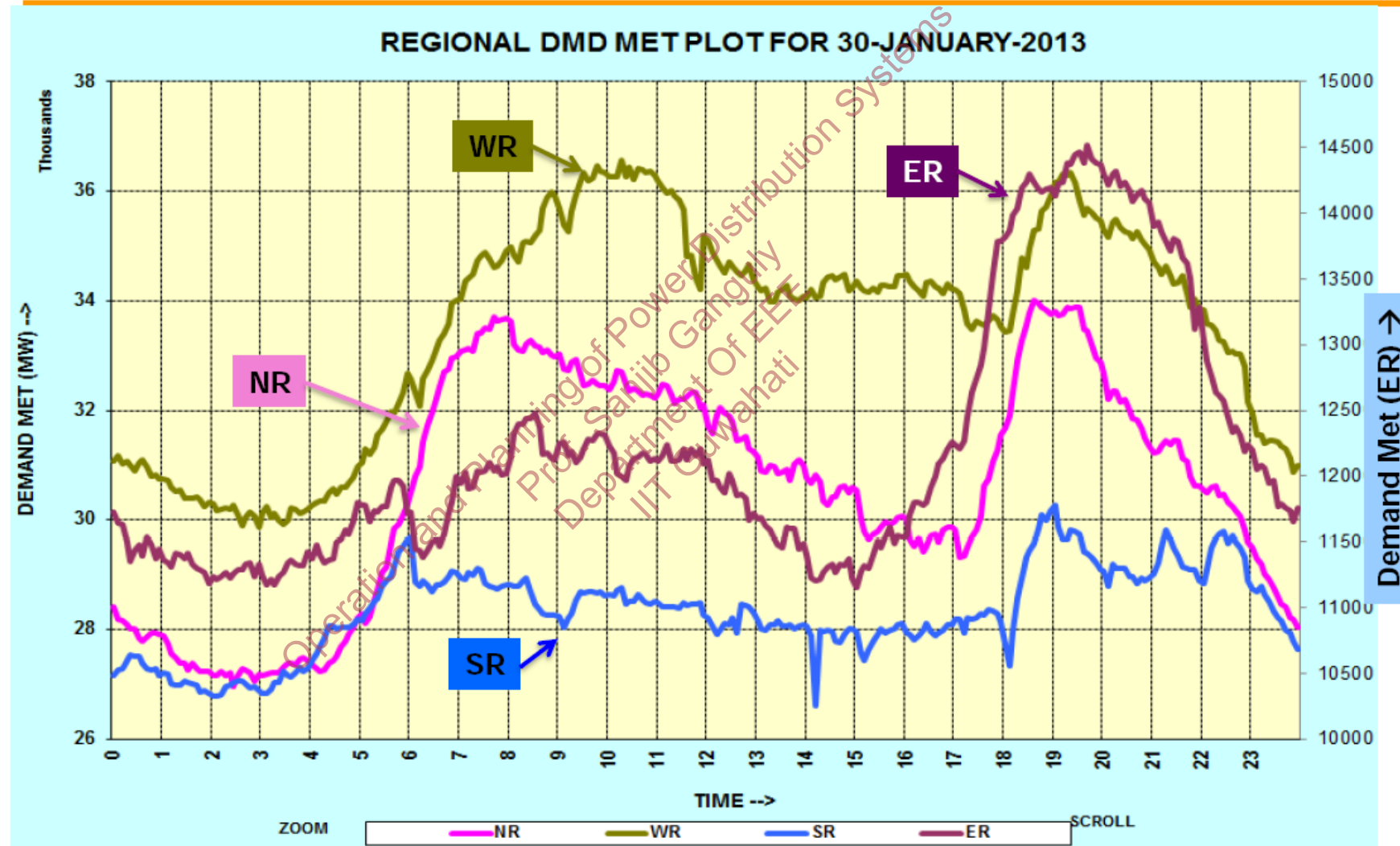
Coincident Load Behavior



Diversified demand and Non-coincident demand

- Diversified demand is the demand of the composite group, as a whole, of somewhat unrelated loads over a specified period of time.
- Non-coincident demand is the sum of the demands of a group of loads with no restrictions on the interval to which each demand is applicable.

Regional Geographical Diversity



Diversity on account of geographical location, seasons, time of day, load, etc.

Figure courtesy: POSOCO, India

Demand factor

- It is the ratio of the maximum demand of the system to the total connected load of the system.

$$\text{Demand factor } DF = \frac{\max(D_j)}{TCD}$$

- TCD is the total connected demand

Diversity factor and Coincident Factor

- Diversity factor is the ratio of the sum of the individual maximum demands (i.e., non coincident demand) a system to the maximum demand of the whole system.
- If there are n different groups of loads, the diversity factor is computed as:

$$DVF = \frac{\sum_{i=1}^n D_i^{max}}{D_{gr}}$$

where, D_i^{max} is the peak/maximum demand of the load i
 D_{gr} is the coincident maximum demand of the group
(also called diversified demand of the group).

Utilization factor

- It is the ratio of the maximum demand to the rated capacity of a system
- It is same as the demand factor.

Diversity factor contu....

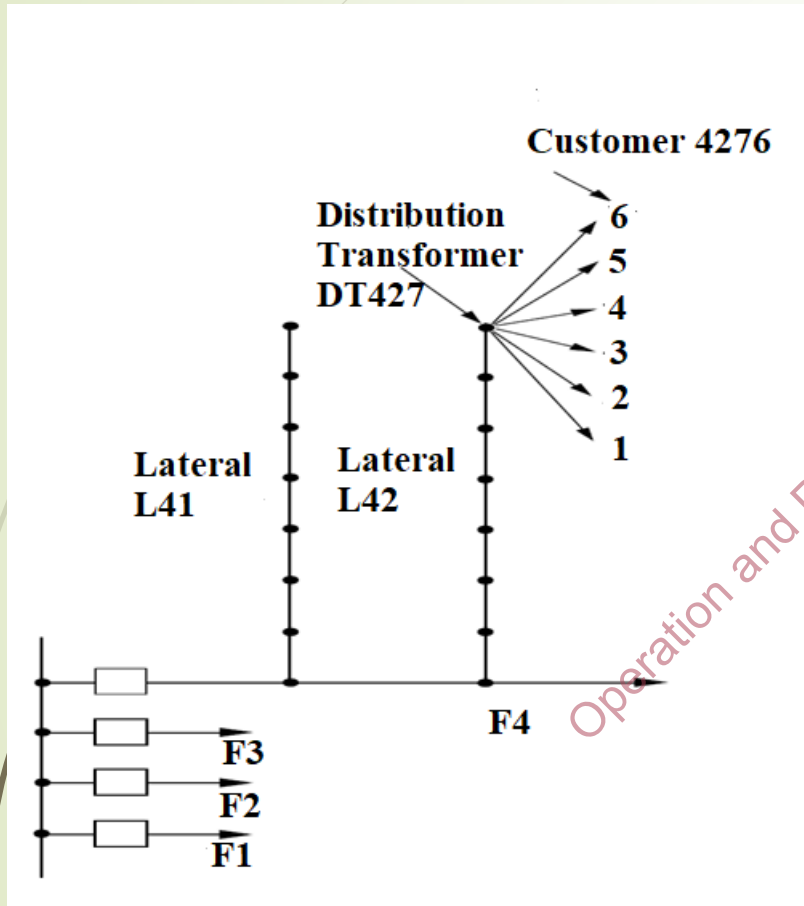
- In terms of the demand factor, the diversity factor can be written as,

$$DVF = \frac{\sum_{i=1}^n D_i^{max}}{D_{gr}} = \frac{\sum_{i=1}^n DF_i * TCD_i}{D_{gr}}$$

Where, DF_i is the demand factor of the group i

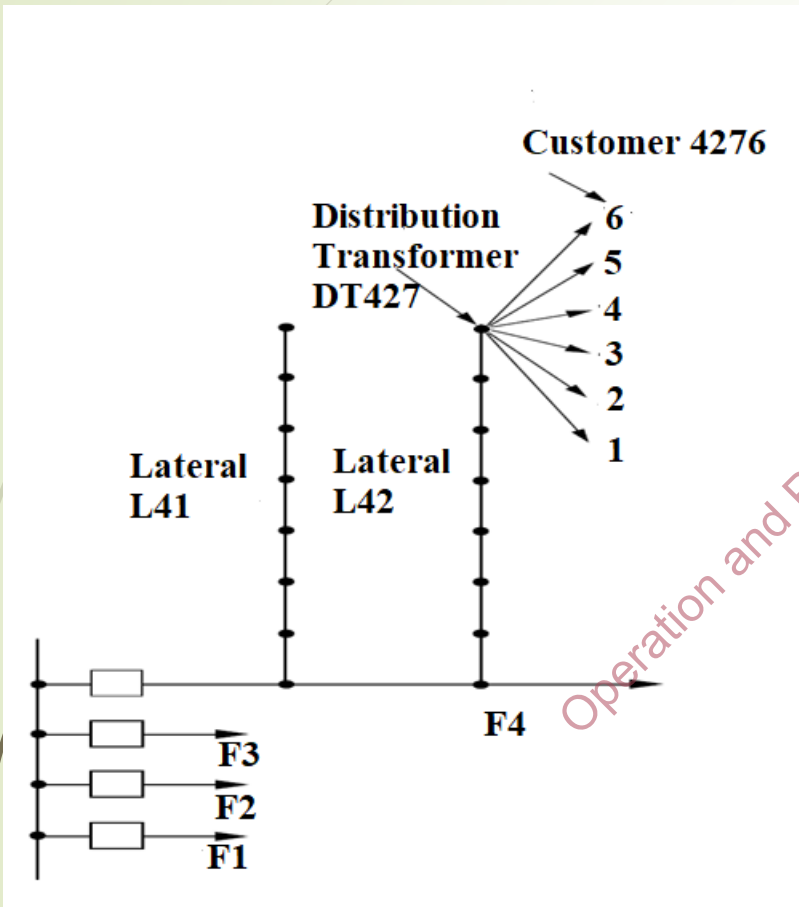
TCD_i is the connected load in group i

Example...



- There are six residential customers connected to a distribution transformer (DT), as shown in the Figure. Notice the code in the customer account number, for example, 4276; the first digit, 4, stands for feeder F4; the second digit, 2, indicates the lateral number connected to the F4 feeder; the third digit, 7, is for the DT on that lateral; and finally the last digit, 6, is for the house number connected to that DT. Assume that the connected load is 10 kW per house and that the demand factor and diversity factor for the group of six houses, have been decided as 0.65 and 1.10, respectively. Determine the diversified demand of the group of six houses on the distribution transformer DT427.

Solution



- The diversified demand of a group can be determined by:

$$D_{gr} = \frac{\sum_{i=1}^n DF_i * TCD_i}{DVF}$$

- Given that: $n=6$

$$DF_1 = DF_2 = \dots = DF_6 = 0.65$$

$$DVF = 1.10$$

$$TCD_1 = TCD_2 = \dots = TCD_6 = 10 \text{ kW}$$

- Hence, we can compute

$$D_{gr} = \frac{6 * 0.65 * 10}{1.1} = 35.45 \text{ kW}$$

Example...

Time	Load demand under transformer#1 in kW				Total load demand	Load demand under transformer#2 in kW				Total load demand
	Cust. 1	Cust. 2	Cust. 3	Cust. 4		Cust. 1	Cust. 2	Cust. 3	Cust. 4	
12-12:30	10	5	10	5	30	15	20	50	30	115
12:30-1	20	25	15	25	85	50	20	30	40	140
1-1:30	5	40	40	20	105	15	30	10	10	65
1:30-2	10	10	20	20	60	15	30	40	50	135
2-2:30	10	20	30	40	100	30	40	20	5	95
2:30-3	25	30	25	10	90	40	30	25	10	105
3-3:30	5	25	50	15	95	20	25	20	40	105
3:30-4	10	50	15	10	85	15	5	10	20	50

Answer: For Transformer#1: (i) 105 kW/0.8, (ii) 165 kW, (iii) 0.77, (iv) 1.57, (v) 100, (vi) 131/100, (vii) 325 kWh
 For Transformer#2: (i) 140 kW/0.8, (ii) 190 kW, (iii) 0.72, (iv) 1.35, (v) 150, (vi) 175/150, (vii) 405 kWh

For each transformer, determine the following:

- (i) 30-min maximum kVA demand
- (ii) Non-coincident maximum demand
- (iii) Load factor
- (iv) Diversity factor
- (v) suggested transformer rating (75, 100, 150, 200 kVA)
- (vi) utilization factor
- (vii) Energy demand

Assume p.f.=0.8

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Coincidence factor

- It is the ratio of the maximum coincident total demand of a group of consumers to the sum of the maximum power demands of the group (i.e., sum of non-coincident demand).
- Coincident factor is the reciprocal of the diversity factor.
- Coincidence factor, $CF(n)$, is a measure of the simultaneity of peak demands of a group of N customers.
- Peak load for the group equals n x individual peak demand x $CF(n)$.
- Typical values of $CF(n)$ for $n > 100$ are in the range of 0.2 to 0.5.

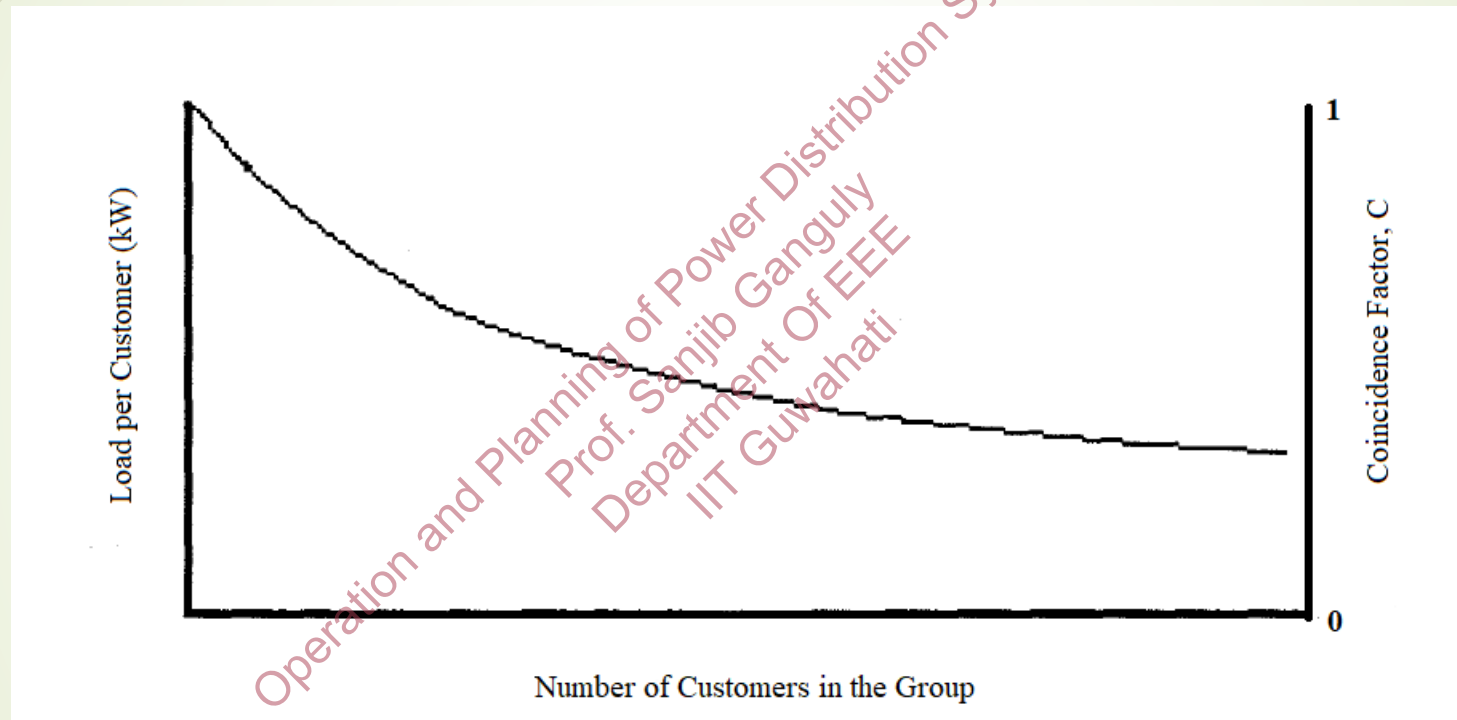
Estimation of Peak/maximum demand

- Estimates of equipment loads are often based on load data from coincidence curves.
- Very often, T&D equipment sizes are determined by using such coincidence curves.
- For example, the "coincident peak" for a group of customers served by a feeder segment, transformer, or secondary line can be estimated from individual peak load data as:

Group peak for n customers = $CF(n) \times n \times$ (average individual peak load)

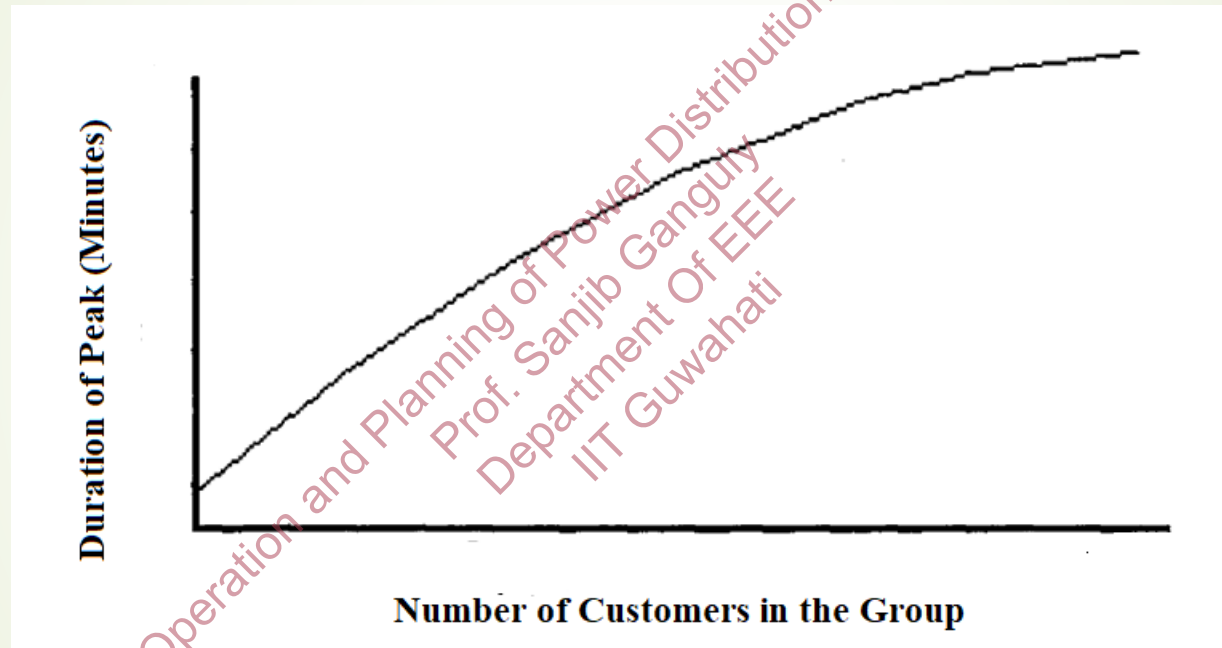
- The peak load for a transformer serving ten houses, each with an estimated individual peak load of 25 kW would be = $CF(10) \times 10 \times 25$ kW
- Using a typical value of $CF(10)$, which is about 0.6, gives 150 kW as the estimated peak load for the transformer.

Estimation of Peak/maximum demand



The peak load per customer drops as a function of the number of customers in a group.

Estimation of the duration of the peak demand time



The peak period as a function of the number of customers in a group. Larger groups generally have longer peak load periods.

Contribution factor

- The contribution factor (c_i) is defined as the contribution of the i -th load to the peak/maximum demand of the group.

- The peak demand of the group can be determined as:

$$D_{gr} = c_1 D_1^{max} + c_2 D_2^{max} + \dots + c_n D_n^{max}$$

- The coincidence factor can be computed as:

$$CF = \frac{\sum_{i=1}^n c_i * D_i^{max}}{\sum_{i=1}^n D_i^{max}}$$

Contribution factor

- If the peak demand of each load is equal, i.e., $D_1^{max} = D_2^{max} = \dots = D_n^{max} = D$, the coincidence factor would be:

$$CF = \frac{D \sum_{i=1}^n c_i}{nD} = \frac{\sum_{i=1}^n c_i}{n}$$

The coincidence factor is equal to the average contribution factor.

- If the contribution factor of each load is equal, i.e., $c_1 = c_2 = \dots = c_n = c$, the

the coincidence factor would be:

$$CF = \frac{c \sum_{i=1}^n D_i^{max}}{\sum_{i=1}^n D_i^{max}} = c$$

The coincidence factor is equal to the contribution factor.

Loss Factor

- The loss factor is defined as the ratio of the average power loss to the peak load power loss during a specified period of time.
- It is an important parameter used in power distribution system planning to determine the power loss of the planned network, since the planning is mostly carried out considering the peak load demand.

Loss Factor Computation

- From the figure, the load factor,

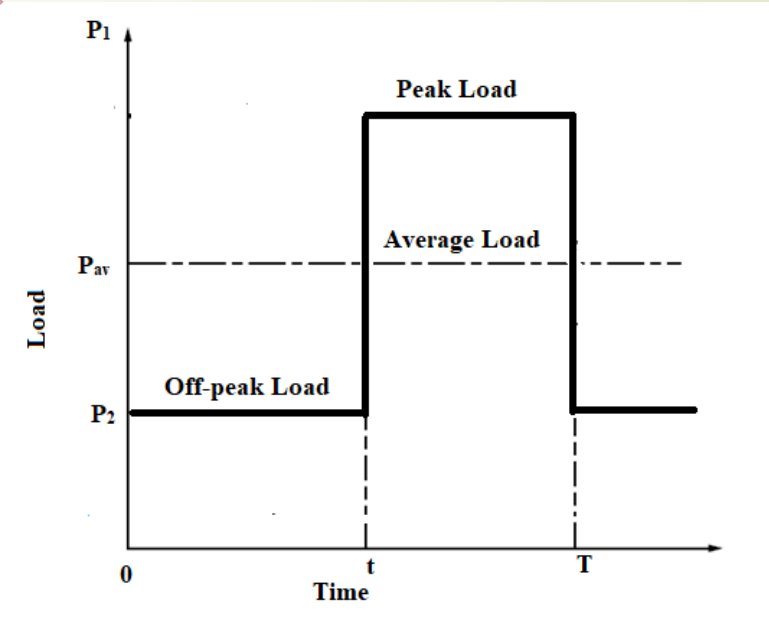
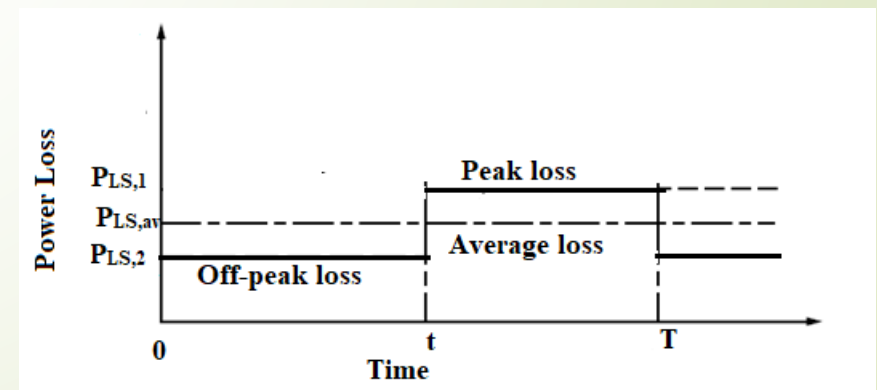
$$LF = \frac{P_{av}}{P_{max}} = \frac{P_{av}}{P_1}$$

- The average power:

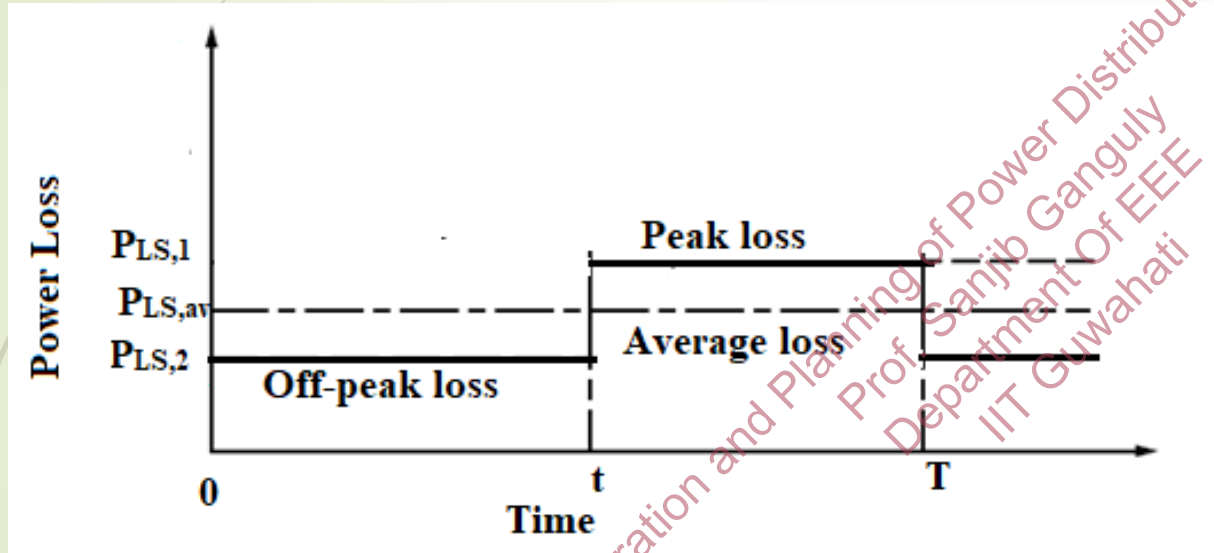
$$P_{av} = \frac{P_2 t + P_1 (T - t)}{T}$$

- Hence, we can write

$$LF = \frac{P_2}{P_1} \left(\frac{t}{T} \right) + \frac{(T - t)}{T}$$



Loss Factor Computation



- From the figure, the loss factor,

$$LSF = \frac{P_{LS,av}}{P_{LS1}}$$

- The average loss:

$$P_{av} = \frac{P_{LS,2}t + P_{LS,1}(T-t)}{T}$$

- Hence, we can write

$$LSF = \frac{P_{LS,2}}{P_{LS,1}} \left(\frac{t}{T} \right) + \frac{(T-t)}{T}$$

Where, $P_{LS,av}$ is average power loss; $P_{LS,1}$ is the power loss at peak demand; $P_{LS,2}$ is the power loss at the off-peak load demand

Loss Factor Computation

- Since power loss is proportional to the square of the associated load, the power loss corresponding to the peak and off-peak load demand can be computed as:

$$P_{LS,2} = kP_2^2 \quad \text{and} \quad P_{LS,1} = kP_1^2 \quad [k: \text{constant}]$$

- The loss factor can be expressed by:

$$LSF = \frac{kP_2^2 t + kP_1^2 (T-t)}{kP_1^2 T} = \frac{t}{T} \left(\frac{P_2}{P_1} \right)^2 + \frac{(T-t)}{T}$$

Loss Factor Computation: Case study

- ▶ The peak demand sustains very short time, i.e., $(T - t) \rightarrow 0$, hence,

this yields, $LSF \approx (LF^2)$,

The loss factor equals to the square of the load factor

- ▶ Steady load, i.e., $t \rightarrow 0$ or, $P_1 \approx P_2$ which means that the difference between the peak load and off-peak load is negligible. This results in,

$$LSF \approx (LF)$$

The loss factor equals to the of the load factor

The relationship between loss factor and load factor

In general, the value of the loss factor is:

$$(LF)^2 < LSF < (LF)$$

However, Buller and Woodrow* developed an approximate formula to relate the loss factor to the load factor as:

$$LSF = k_1(LF) + k_2(LF)^2$$

where, $k_1 = 0.3, k_2 = 0.7$

*Buller, F. H. and C. A. Woodrow: Load factor-equivalent hour values compared, *Electr. World*, 92(2), July 14, 1928, 59–60.

Example...

- Assume that one of the distribution transformers of a substation supplies three primary feeders. The 30 min annual maximum demands per feeder are listed in the following table, together with the power factor (PF) at the time of annual peak load. Assume a diversity factor of 1.15 among the three feeders for both real power (P) and reactive power (Q).
 - Calculate the 30 min annual maximum demand on the substation transformer in kilowatts and in kVA.
 - Find the load diversity in kilowatts.

Feeder	Demand (kW)	Power factor
1	1800	0.95
2	2000	0.85
3	2200	0.9

Solution...

- We know that, the diversity factor can be computed as:

$$DVF = \frac{\sum_{i=1}^n P_i^{max}}{P_{gr}} = \frac{(1800+2000+2200)}{P_{gr}} = 1.15$$

Hence, maximum active power demand of the group is $P_{gr} = 5217$ kW

- The kVA demand corresponding to each active power demand and power factor can be computed as: $S = P / \cos \phi$ [ϕ : phase angle]
- Thus, the diversified demand of the reactive power can be written as:

$$DVF = \frac{\sum_{i=1}^n P_i^{max} / \cos \phi_i}{S_{gr}} = \frac{1895+2353+2444}{S_{gr}} = 1.15$$

- Hence, maximum kVA demand of the group is $S_{gr} = 5819$ kVA
- The load diversity can be computed as:

$$P_{LD} = \sum_{i=1}^3 P_i - P_{gr} = 6000 - 5217 = 783 \text{ kW}$$

Exercise...

- A room consists of 20 tube lights, 10 ceiling fans, and 20 personal computers. The ratings of each tube light, fan, and computer are 40 W, 100 W, and 200 W, respectively. There is a smart electric meter in the room to display and record the instantaneous power demand of the room. The maximum/peak reading of the meter in a year is found to be 4000 W. What is the demand factor of this room?

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Exercise...

- In an office building there are 20 such rooms, as mentioned. There is also a smart electric meter to display and record the instantaneous power demand of the whole building. The maximum/peak reading of the meter in a year is found to be 66666.66 W. Assuming that the maximum reading of the meter placed in each room is same, i.e., 4000 W. Determine the diversity factor of the building's load.

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Load Forecasting

- The load growth of the geographical area served by a utility company is the most important factor influencing the expansion of the distribution system.
- The traditional way to estimate the future load, also called the *growth equation*, since it is often used to explain the phenomenon of growth through time as follows:

$$P_n = P_0(1 + g)^n$$

- where P_n is the load at the end of the n th year; P_0 is the initial load; g is the annual growth rate; n is the number of years
- This equation is applicable, if the load growth rate is known.

Load forecasting: Few important notes

- **Spatial load forecasting**: This approach includes the *where* aspect of the load growth along with the *how much*.
- **Small area-load forecasting**: Usually, the utility service area is divided into a set of small areas forecasting the load growth in each.

Load forecasting by Trend

- *Trend (or regression analysis)* is the study of the behavior of a time series or a process in the past and its mathematical modeling so that future behavior can be extrapolated from it. Two usual approaches followed for trend analysis are
 - 1. The fitting of continuous mathematical functions through actual data by minimizing error, known as *regression analysis*
 - 2. The fitting of a sequence on discontinuous lines or curves to the data.

Regression analysis

- ▶ The principle of regression theory is that any function $y = f(x)$ can be fitted to a set of points $(x_1, y_1), (x_2, y_2)$ so as to minimize the sum of errors squared to each point, that is,

$$\varepsilon^2 = \sum_{i=1}^n [y_i - f(x_i)]^2 = \text{minimum}$$

- ▶ Typical regression curves used in power system forecasting are given below:
 - Linear
 - Exponential
 - Polynomial

Small area load forecasting

- In this type of forecasting, the utility service area is divided into a set of small areas, and the future load growth in each area is forecasted.
- The more traditional approach was to forecast growth on a substation-by-substation or feeder-by-feeder basis.

Load management

- The *load management* process involves controlling system loads by direct/indirect control of individual customer loads.
- Load management can also be affected by inducing customers to suppress loads during utility-selected daily periods by means of time-of-day rate incentives.
- Such activities are called **demand-side management**.

Demand side management (DSM)

- DSM is the planning, implementation, and evaluation of utility activities designed to encourage customers to modify their electricity consumption patterns with respect to both the timing and level of demand (kW) and energy (kWh).

Need of Demand side management

- For a developing country like India, the major challenge is to meet:
 - Increasing energy demand (MWhr of MU)
 - Increasing peak load demand (MW)

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Month-wise power supply position of India in 2017-18

Year	Peak (MW)				Energy (MU)			
	Peak Demand	Peak Met	Surplus(+) / Deficit(-)	(%) Surplus/ Deficit	Energy requirement	Availability	Surplus(+) / Deficit(-)	(%) Surplus/ Deficit
Apr-17	1,59,307	1,58,393	-914	-0.6	1,02,552	1,01,938	-614	-0.6
May-17	1,59,816	1,56,733	-3,083	-1.9	1,07,304	1,06,517	-787	-0.7
Jun-17	1,55,547	1,53,179	-2,368	-1.5	1,00,230	99,636	-594	-0.6
Jul-17	1,56,750	1,54,302	-2,448	-1.6	1,02,762	1,02,117	-645	-0.6
Aug-17	1,64,066	1,60,752	-3,314	-2.0	1,05,656	1,04,905	-751	-0.7
Sep-17	1,62,452	1,58,550	-3,902	-2.4	1,02,465	1,01,560	-905	-0.9
Oct-17	1,62,027	1,57,394	-4,633	-2.9	1,01,327	1,00,376	-951	-0.9
Nov-17	1,51,406	1,49,036	-2,370	-1.6	95,190	94,506	-684	-0.7
Dec-17	1,52,827	1,51,567	-1,260	-0.8	96,944	96,363	-581	-0.6
Jan-18	1,58,640	1,56,720	-1,920	-1.2	1,00,572	99,942	-630	-0.6
Feb-18	1,58,505	1,57,037	-1,468	-0.9	91,903	91,300	-603	-0.7
Mar-18	1,62,263	1,60,364	-1,899	-1.2	1,06,420	1,05,537	-884	-0.8
Annual	1,64,066	1,60,752	-3,314	-2.0	12,13,325	12,04,697	-8,629	-0.7

Data Courtesy: <http://www.cea.nic.in>

Demand side management (DSM)

- *Category #1: Energy - Saving or Conservation Programs:* These programs are activities designed to encourage the consumers to replace their less energy efficient equipment by less electricity consuming devices producing the same service (quality and quantity) and to change consumer behavior to reduce energy use.
- *Category #2: Load Management Programs:* These programs are designed by utilities to reduce demand peak periods to make more economic use of existing resources through demand displacement over time.

Demand side management (DSM)

- It includes all measures, programs, equipment, and activities that are directed toward improving efficiency and cost-effectiveness of energy usage on the *customer side* of the meter.
- In general, such load control results in a load reduction at time t .

Example...

- Assume that a 5 kW air conditioner would run 80% of the time (80% duty cycle) and, during the peak hour, might be limited by utility remote control to a duty cycle of 70%. Determine the following:
- The number of minutes of operation denied at the end of 1 h of control of the unit
- The amount of reduced power consumption during the peak hour if such control is applied simultaneously to 100,000 air conditioners throughout the system
- The total amount of peak load reduction

Solution...

- ▶ The number of minutes of operation denied is
$$(0.80 - 0.70) \times (60 \text{ min/h}) = 6 \text{ min/h}$$
- ▶ The amount of reduced power consumption during the peak is
$$(0.80 - 0.70) \times (5 \text{ kW}) = 0.5 \text{ kW/h}$$
- ▶ The total amount of peak reduction for 100,000 units is
$$\begin{aligned} &= 5 \times (0.8 - 0.7) \times 100000 = 50000 \text{ kW/h} \\ &= 50 \text{ MW/h} \end{aligned}$$

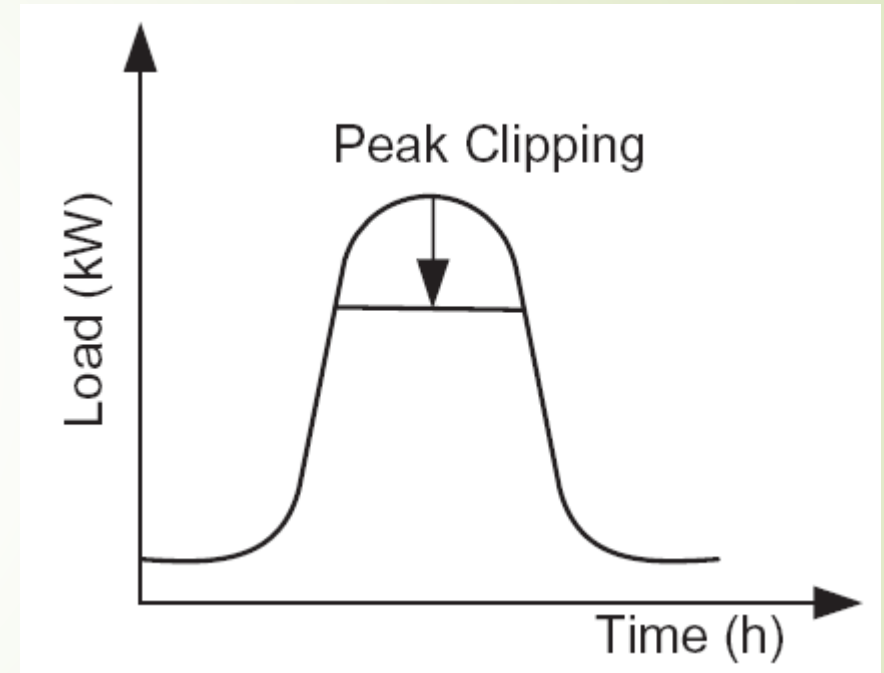
Utilities' benefit on demand side management

- Maximizing utilization of existing distribution system can lead to deferrals of capital expenditures. This is achieved by shaping the daily (monthly, annual) load characteristic in the following manner:
- By suppressing loads at peak times and/or encouraging energy consumption during off-peak times
- By minimizing the requirement for more costly generation or power purchases
- By relieving the consequences of significant loss of generation or similar emergency situations by suppressing loads.
- By reducing cold load pickup

Means of demand side management

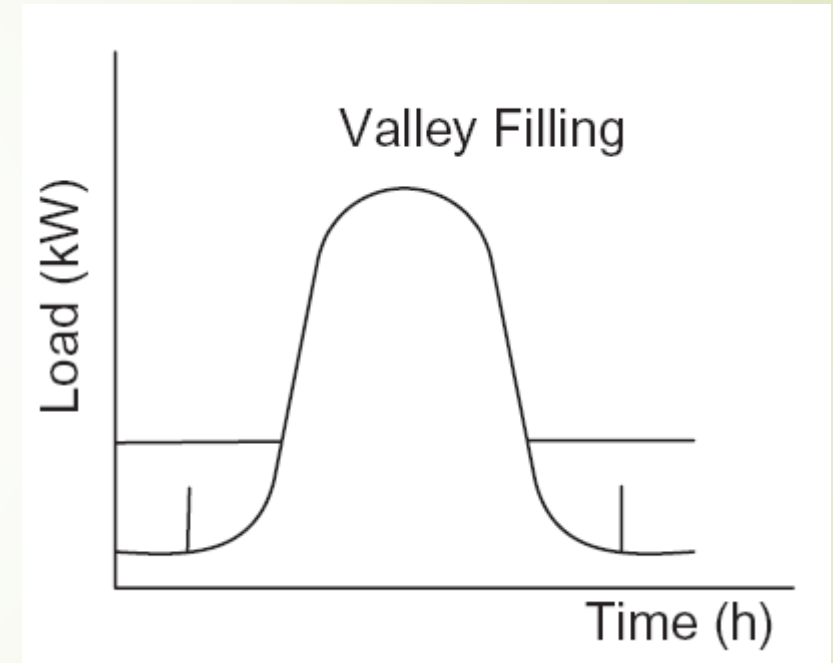
- **Peak Shaving/peak Clipping:**
The load during peak demand period is reduced. This can defer the need for additional generation capacity and result in a reduction in both peak demand and total energy consumption

Example: Efficient control of air conditioner, water heaters.



Means of demand side management

- *Valley Filling*: This can be done by adding loads that previously operated on nonelectric fuels (e.g., thermal energy storage, automobile). These loads can be supplied at off - peak load periods.

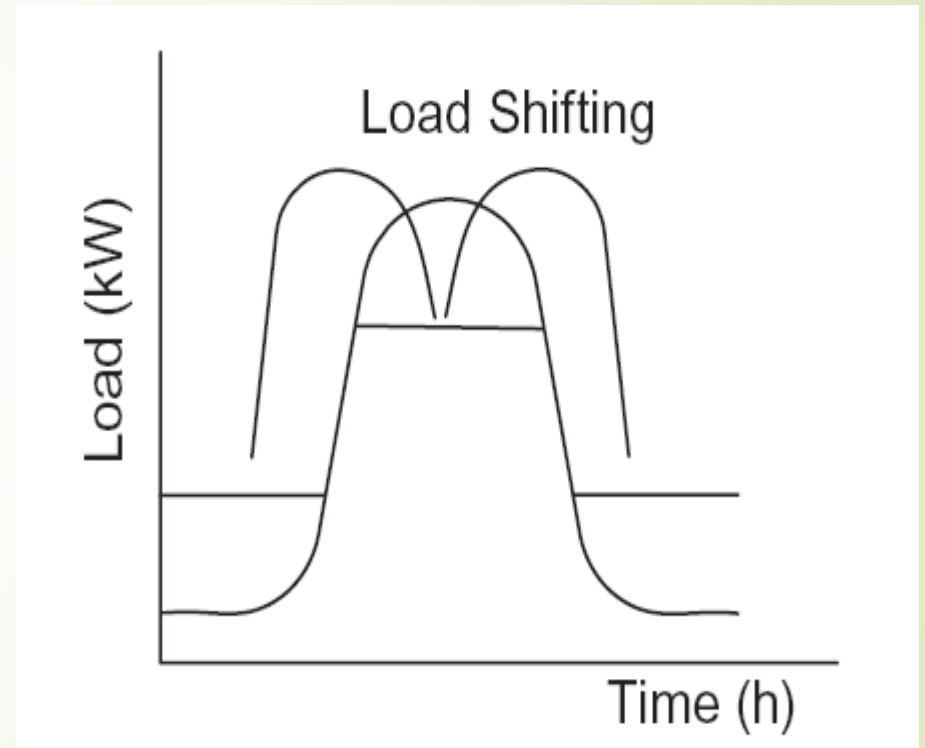


Example: Electric vehicles charging G2V

Means of demand side management

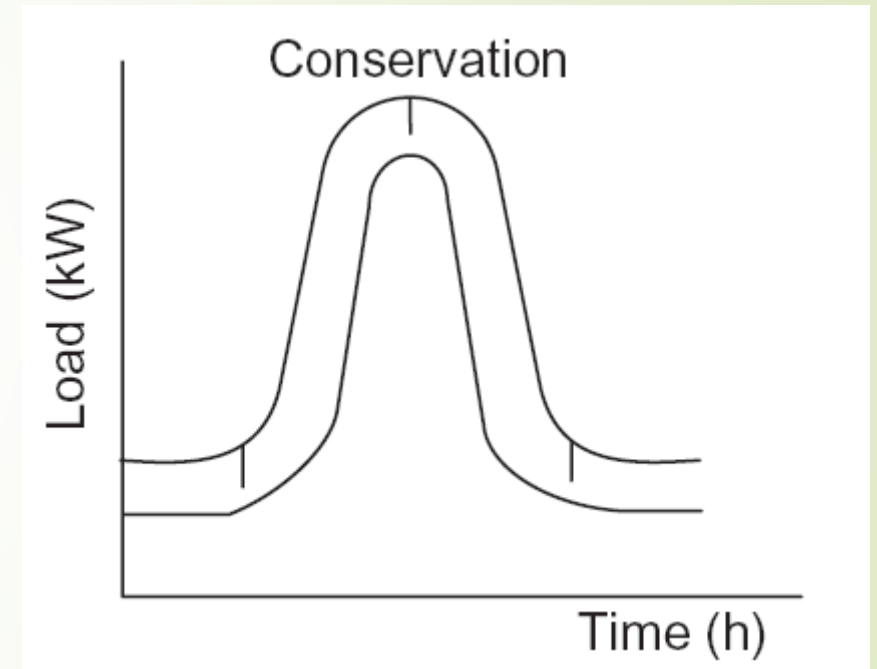
- *Load Shifting*: It involves moving load from on peak to off-peak periods.
- It leads to a reduction in peak demand and no change in total energy consumption.
- Use of storage devices that shift the timing of some conventional electric appliances operation is one of the tools being used for load shifting.

Example: Electric vehicle charging and deferrable loads



Means of demand side management

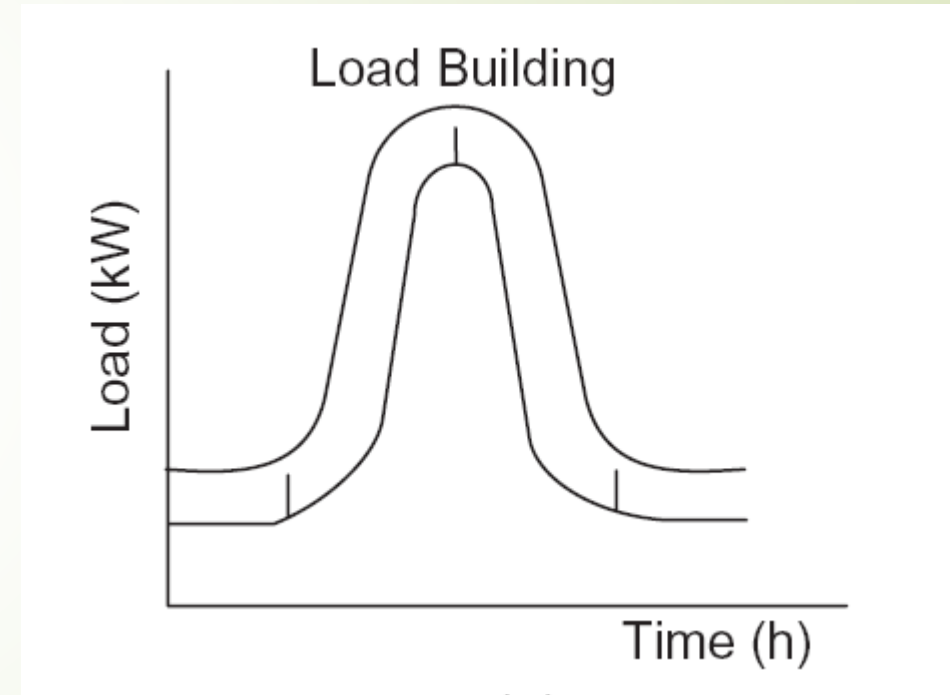
- *Strategic Conservation*: By applying end use efficiency techniques to reduce the end use consumption, a decrease in both peak demand and total energy consumption can be achieved.



Example: Efficient lighting, air conditioning

Means of demand side management

- *Strategic Load Growth (Load Building)*: In the event of new consumers or energy intensity increase, the overall sales are increased. The load is managed to keep the same load shape leading to an increase in both peak demand and total energy consumption.



Example: Efficient planning of power distribution

DSM Program

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DSM programs assist the planners to achieve load reduction or allowing customers to reduce electricity use in response to price signals. These price signals are applied in different ways:

- *Time-of-Use Rates*: The price rate is raised to be two or four times higher than off-peak rates.
- *Real Time Pricing*: The energy tariff is calculated on use time (each hour, each half day, daily, etc.). So, a technique to modify and recalculate the online energy pricing is required.
- *Direct Load Control*: The distribution system operator has the flexibility to shut down some consumer loads at the peak time according to pre-assigned contract.
- *Data Provided by Utilities*: Two types of data are requested from the utilities. The first type is data on each demand side activity, while the second type is data on each supplier's system as a whole.

Concept of 'Negawatt'

- A “negawatt ” (a negative watt) of electricity saved through demand side management is as good as a watt of generation capacity.
- For instance, if a utility manages to reduce electricity demand, it can postpone the construction of expensive new power plants or increase reliability.

This needs new government regulations or directives to ensure that utilities will undertake DSM programs

Energy rate structure/tariff structure

- The total revenue that a utility may collect through the sales of its services should be equal to the company's total cost of the service.

Different tariff structures

- Flat demand rate structure (a constant price per kilowatt-hour)
- Block meter rate structure (lower prices for greater usage)
- Demand rate structure (separate charges for demand and energy)
- Season rate structure (higher prices per kilo-watt-hour used during the season when system peak demand occurs)
- Time-of-day (or peak-load pricing) structure (higher prices per kilo-watt-hour used during the peak period of the day and lower prices during the off-peak period of the day.)

Conversion from consumer to *prosumer*

- With the installation of roof-top photo-voltaic (PV) cell based energy generation unit, a customer can sell its excess energy to the utility.
- This is possible, if the customer is connected with a bi-directional communication link and with appropriate incentives.
- These customers are named as **prosumers**.

References

- H. Lee. Willis. *Power Distribution Planning Reference Book*; CRC press; 2nd Edition, Revised and Expanded, 2004.
- T. Gonen. *Electric Power Distribution System Engineering*; CRC Press, 3rd Edition, 2014.
- A.A. Sallam and O.P. Malik. *Electric Distribution Systems*; IEEE Press, 2011.

Thank You...

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