EEE210:
Energy Conversion and Power Systems

Necessary power system components and concepts-Part II

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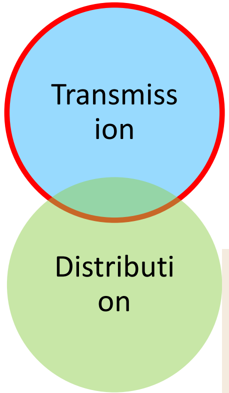
Highlights

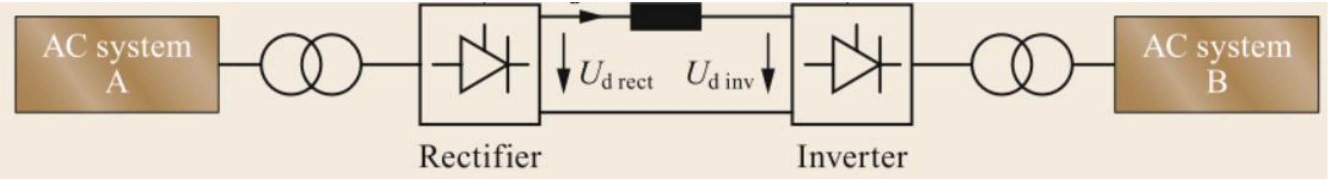
- Generation mixes
- **Delivery systems and consumptions**
- **Essence of the power system control**
- **Smart Grids**

Delivery systems and consumptions

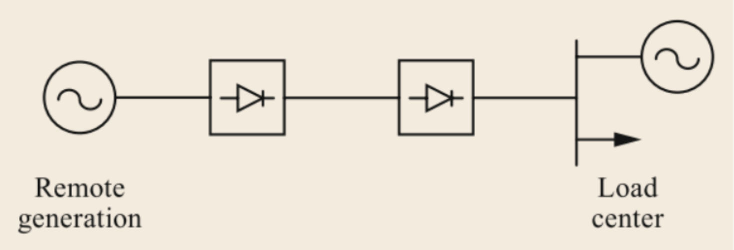
*** Extra knowledge -- HVDC



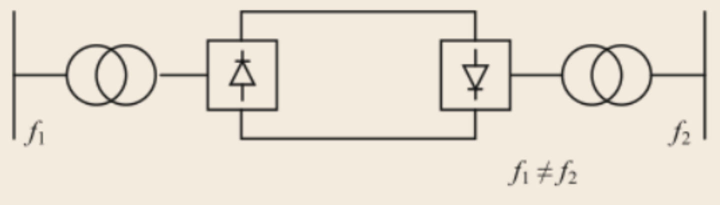
Network structure of a HVDC system

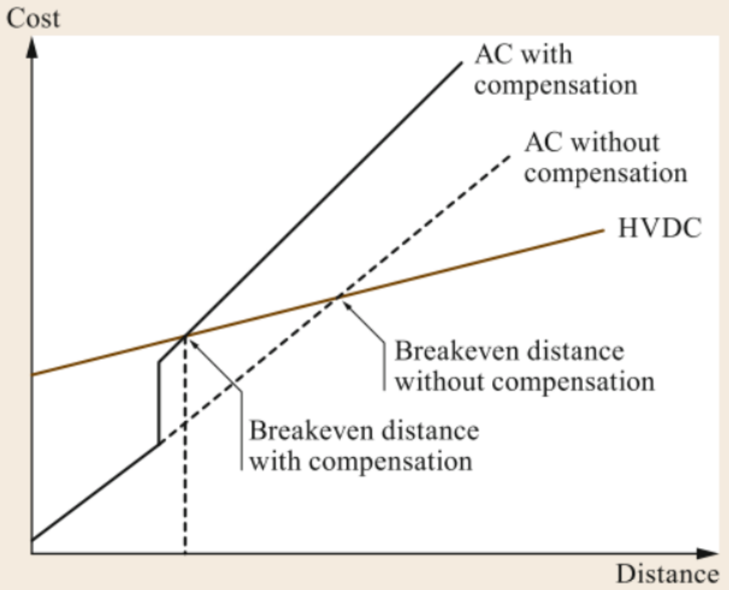


Point-to-point transmission



Connecting systems with different frequencies

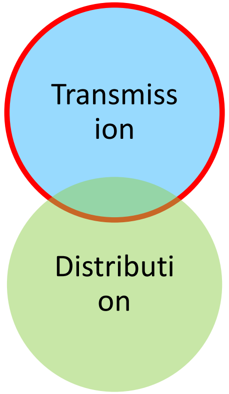




Delivery systems and consumptions

*** Extra knowledge -- HVDC

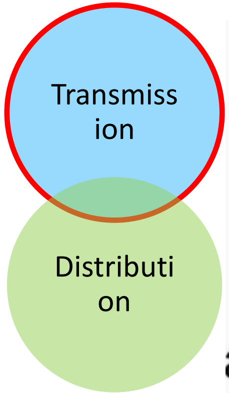
Compared to HVAC systems



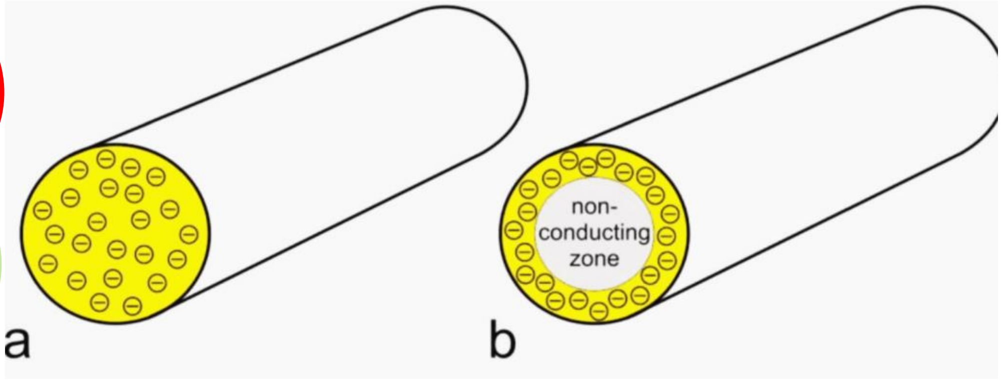
- Very fast control of power flow, which allows improvements in system stability;
- The direction of power flow can be changed very quickly (bidirectionality);
- An HVDC link does not increase the short-circuit currents at the connecting points. This means that it will not be necessary to change the circuit breakers in the existing network;
- HVDC can carry more power than HVAC for a given size of conductor;
- No technical limits in transmitted distance; increasing losses provide an economic limit;
- The need for right-of-way is much smaller for HVDC than for HVAC, for the same transmitted power.

Delivery systems and consumptions

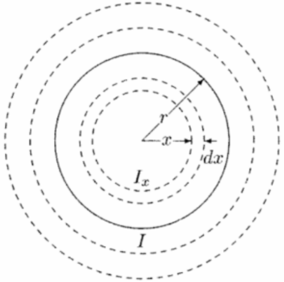
*** Extra knowledge -- HVDC



Skin effect www.youtube.com/watch?v=fvIe9fcYAkE



The concentration of charge is more near the surface as compared to the core of the conductor



Internal inductance

Two examples of HVAC and HVDC cable losses

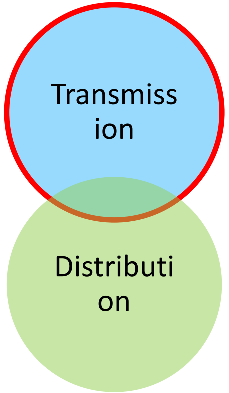
	Length (km)	Power (MW)	Voltage (kV)	Losses (%)
AC	1000/2000	3000	800	6.7/10
DC	1000/2000	6400	800	3.5/5

The current density is maximum at the surface of the conductor and minimum at the center of the conductor. The effect is equivalent to a reduction of the cross-section area of the conductor and, therefore the effective resistance of the conductor is increased.

No internal inductance for conductor under DC current

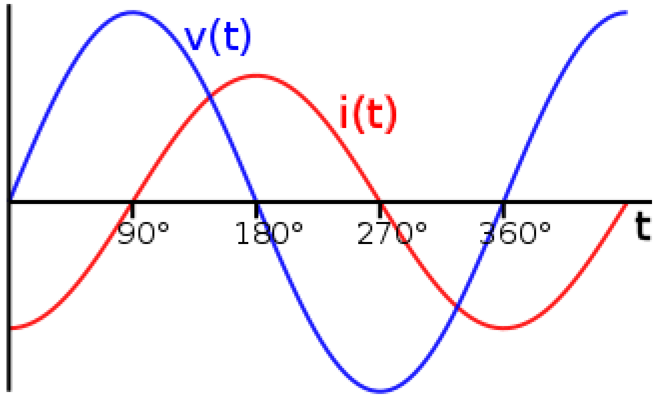
Delivery systems and consumptions

*** Extra knowledge -- HVDC

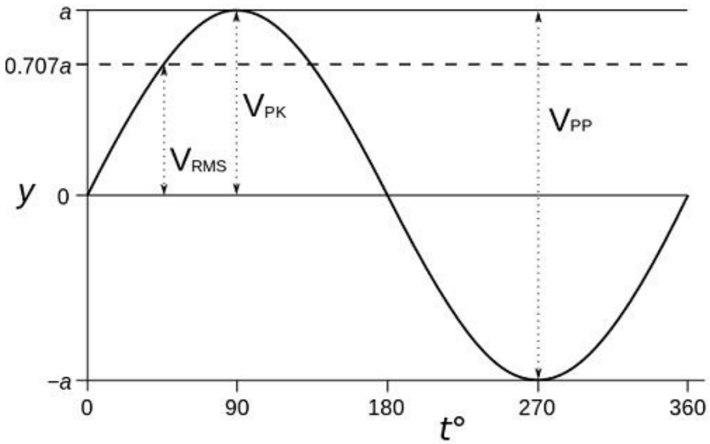


Removing inductance

When a sinusoidal alternating current (AC) is passing through a linear inductance, the induced back-EMF is also sinusoidal.



Delivery more power at the same voltage

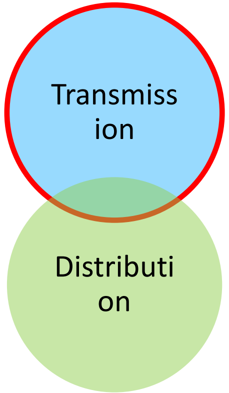


The RMS voltage (= 0.707*Peak voltage) is also known as the equivalent DC voltage because the RMS value gives the amount of AC power drawn by a resistor similar to the power drawn by a DC source

The instantaneous value of an AC signal varies continuously with respect to time. We use the rms value in power system calculations.

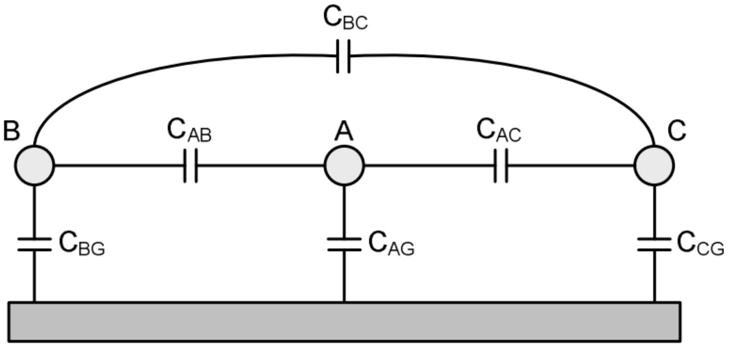
Delivery systems and consumptions

*** Extra knowledge -- HVDC

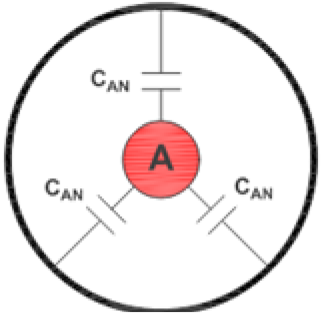


Charging current

The self- and mutual capacitances of a three-phase overhead line



The self- capacitances for a cable



Charging current can limit the length of an HVAC (High Voltage Alternating Current) transmission line. When an AC voltage is applied to a transmission line, the capacitance between the conductors of the line and the ground results in the flow of charging current. This current does not contribute to the power being transmitted but instead charges the capacitance of the line.

As the length of the transmission line increases, the capacitance between the conductors and ground also increases, which results in a larger charging current. This can lead to an increase in the losses and voltage drop across the line, which can limit the distance over which power can be transmitted.

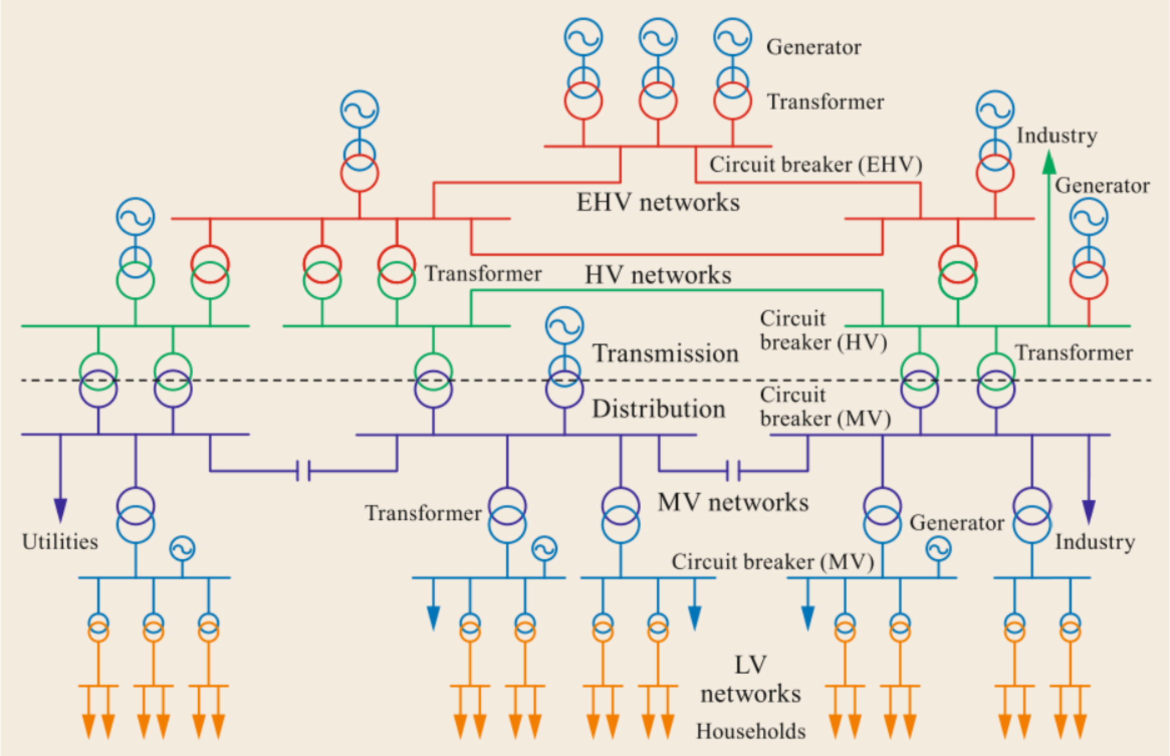
[1] Charging Current in Long Lines and High-Voltage Cables – Protection Application Considerations, 2013.
[2] https://voltage-disturbance.com/power-engineering/charging-current-in-high-voltage-cable/#:~:text=When%20AC%20voltage%20is%20applied%2C%20this%20distributed%20cable,current%20is%20also%20known%20as%20cable%20charging%20current.

Delivery systems and consumptions

Could you find the differences between transmission and distribution networks?

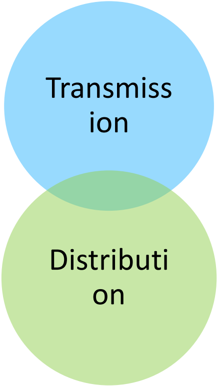
Transmission

Distribution



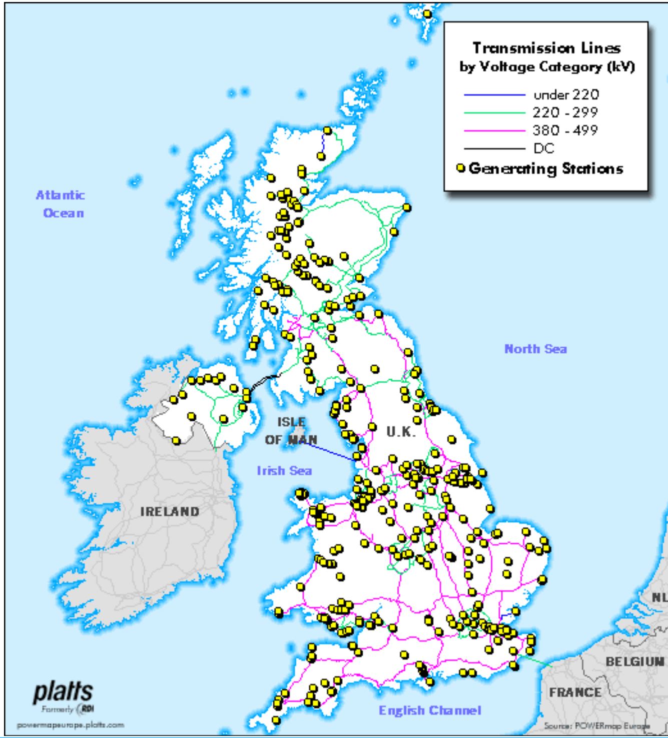
Delivery systems and consumptions

Could you find the differences between transmission and distribution networks?



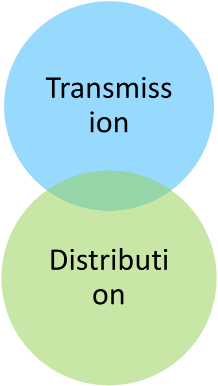
Transmission networks are normally interconnected

- Sharing of generation reserves thereby reducing the overall amount of generating capacity and capital investment needed;
- Providing the ability to buy and sell electricity to take advantage of differences in production costs;
- Facilitating operations by allowing more optimum maintenance scheduling;
- Providing the ability to jointly construct and own power plants;
- Providing local load support at or near the company boundaries

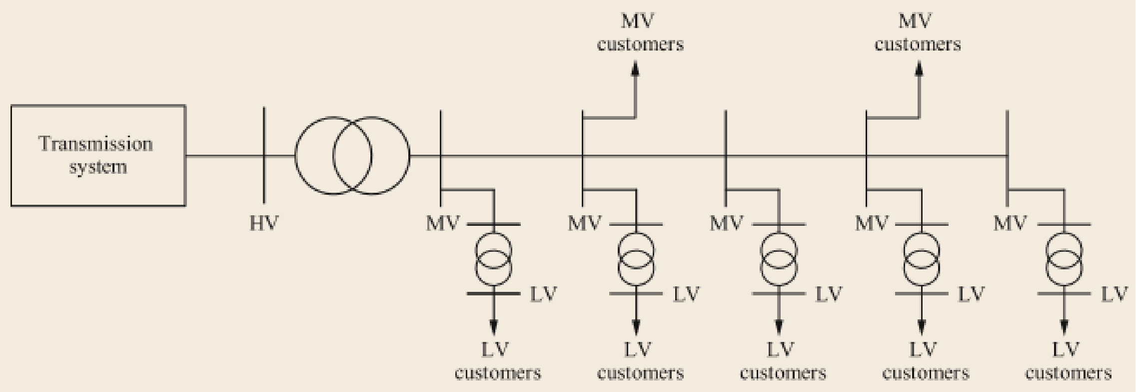


Delivery systems and consumptions

Could you find the differences between transmission and distribution networks?



Distribution networks are commonly in a radial design

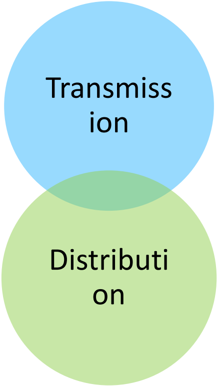


Only one path from the distribution substation to each end customer

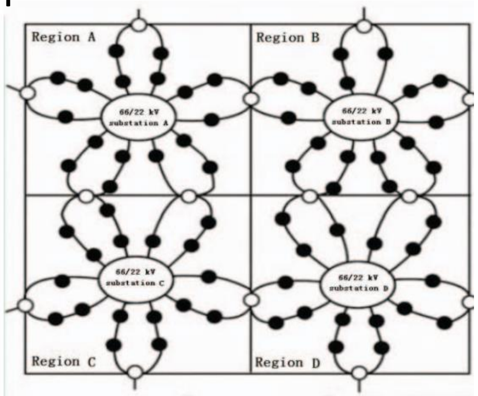
- Network planning is easier and with lower investment cost.
- Network operation, which includes voltage control and power flow management, is less complex.
- Protection coordination is simpler
- Short circuit currents are lower

Delivery systems and consumptions

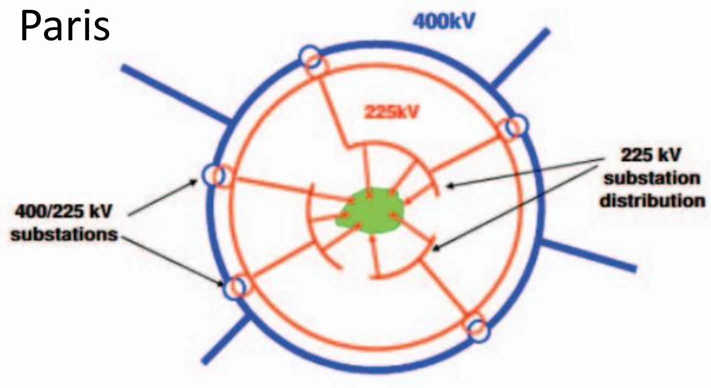
Distribution networks in the interconnected design



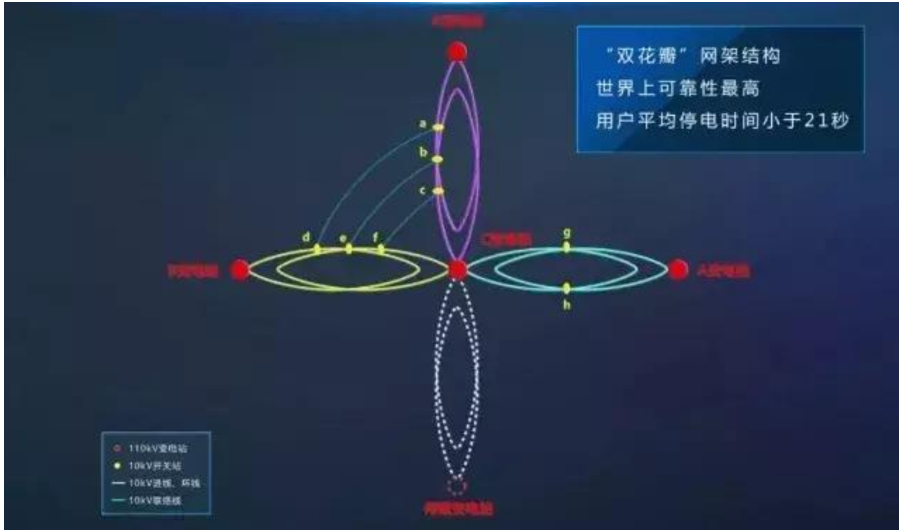
Singapore



Paris



Beijing



Reliability:

Could achieve 99.9999% with annual outage period less than 21 seconds

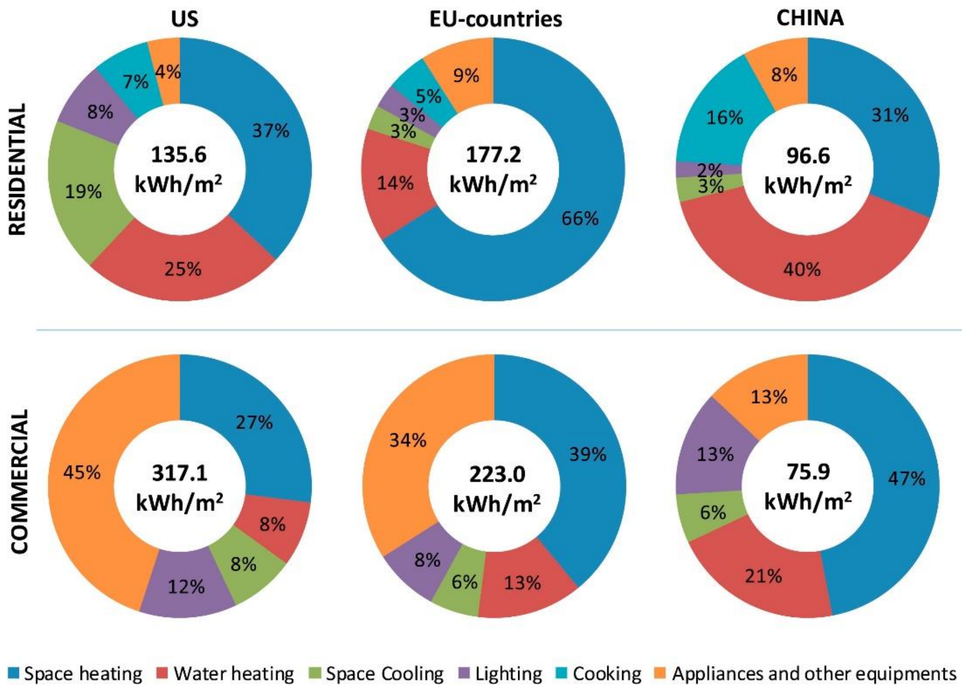
Consumptions

No customers no suppliers

Typically these customer groups (or classes) are:

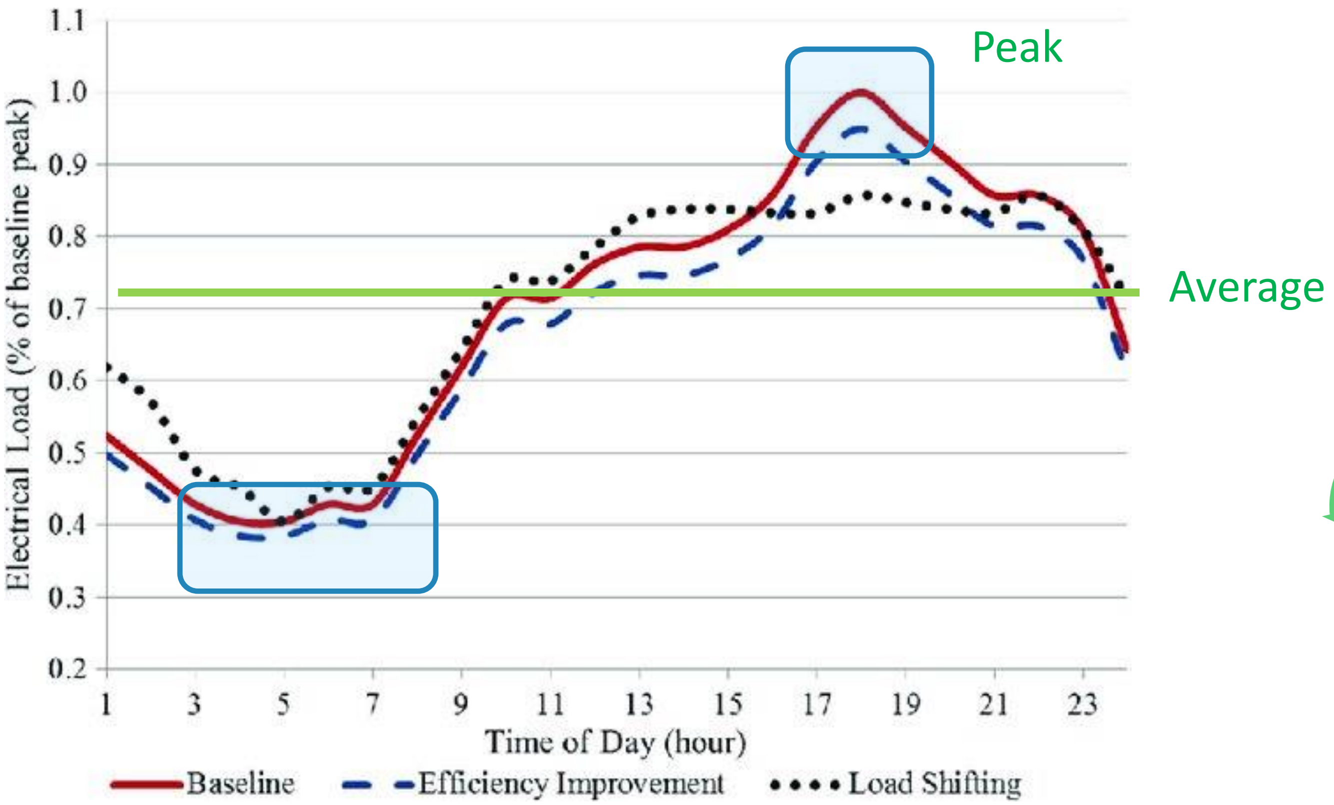
- Residential;
- Commercial;
- Industrial;
- Governmental;
- Traction/railroad.

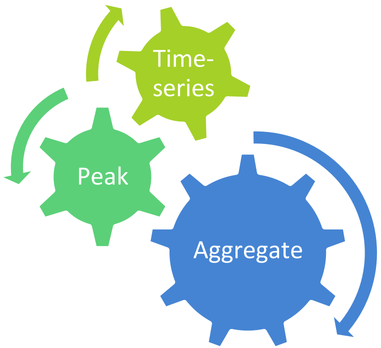
To recognize the costs that each customer class causes in the provision of electric service since different customer classes have different usage patterns with differing impacts on the capital and operating costs. In a regulated environment, where customers are charged for their usage of electricity based on the cost of that supply, these classifications allow different menus of charges (rates) to be developed for each customer class.



LorenzoBelussi, etc. A review of performance of zero energy buildings and energy efficiency solutions, Journal of Building Engineering, 2019

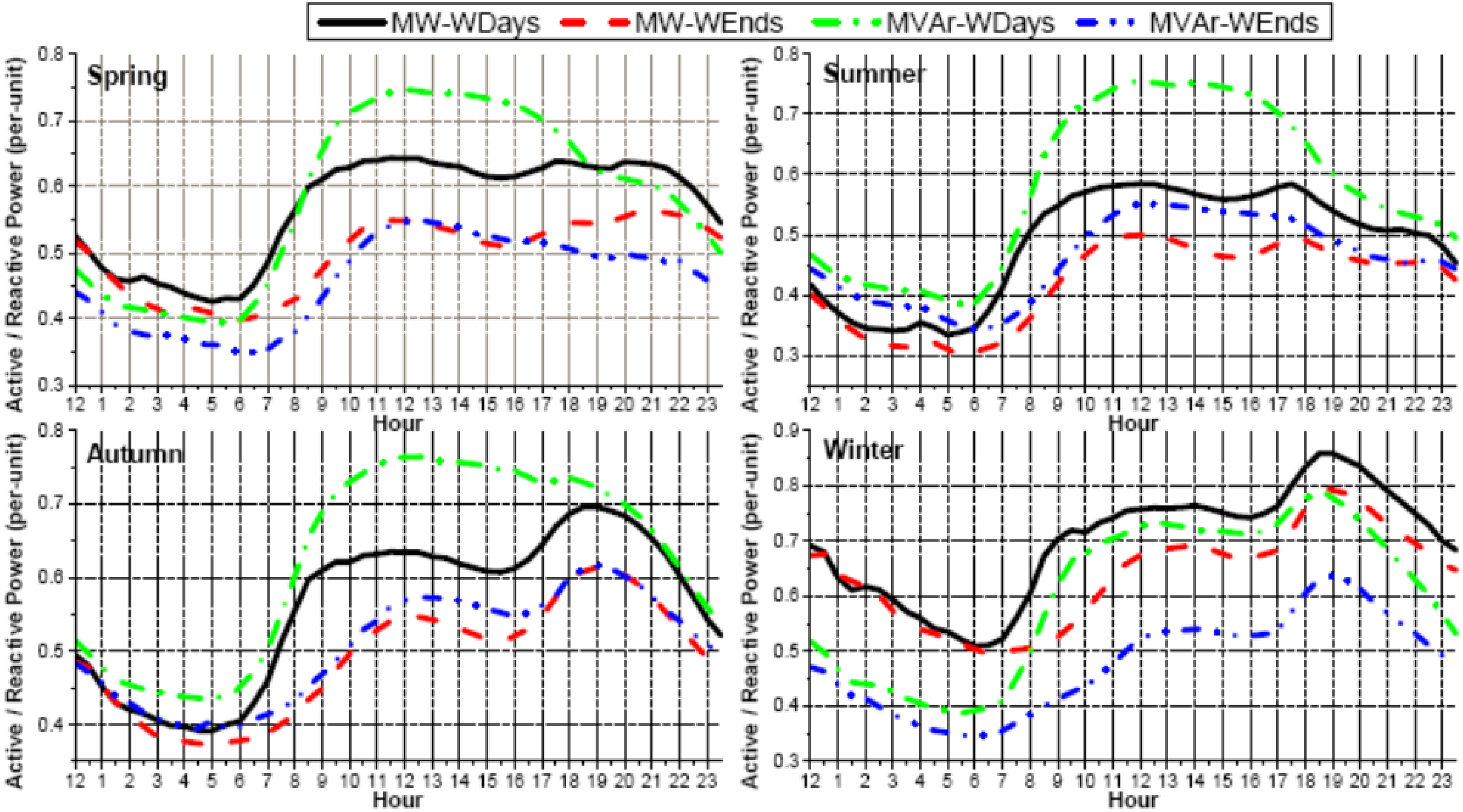
Consumptions





Consumptions

Seasonal variations represented as "average days" (daily load curves)



Consumptions

For individual loading

Average demand:

$$Demand_{average} = \frac{E_i}{H_i}\ (kW)$$

$$i = day, month, year$$

Load factor

$$LF = \frac{Demand_{average}}{Demand_{maximum}}$$

From the utility's standpoint, the optimal load factor would be 1.00, because the system has to be designed to handle the maximum demand. Sometimes, utility companies will encourage industrial customers to improve their load factor. One method of encouragement is to penalize the customer on the electric bill for having a low load factor.

USA electricity tariff

BILL COMPONENT	HOW IT IS BILLED	HOW TO LOWER THIS CHARGE
Energy charges	•Based on amount of electricity (kWh) consumed •Cost can vary by time of use and by season	•Reduce overall consumption •Shift usage from high- to low-cost periods
Demand charges	•Based on maximum demand (kW) during a given period, typically each month	•Curtail usage during peak demand period •Shift usage to different period
Fixed charges	•Fixed cost billed monthly •Determined by rate schedule, not consumption	•Usually not possible

Consumptions

For transformer-side loading

If there are four customers connected at the transformer

	Customer #1	Customer #2	Customer #3	Customer #4
Energy usage (kWh)	58.57	36.46	95.64	42.75
Maximum kW demand	6.18	6.82	4.93	7.05
Time of maximum kW demand	13:15	11:30	6:45	20:30
Average kW demand	2.44	1.52	3.98	1.78
Load factor	0.40	0.22	0.81	0.25

The Maximum Noncoincident Demand is the sum of the individual customer 15-min maximum kW demands, as given by:

$$Demand_{max-nonc} = \sum_{i \in \{1,2,3,4\}} Demand_{i,max}$$

$$= 6.18 + 6.82 + 4.93 + 7.05 = 24.98\ kW$$

Consumptions

For transformer-side loading

The Maximum Noncoincident Demand is $24.98\ kW$

If the transformer's maximum demand would be 16.16 kW

The diversity factor = $\frac{Demand_{max-nonc}}{Demand_{transformer.max}} = \frac{24.98}{16.15} = 1.5458$

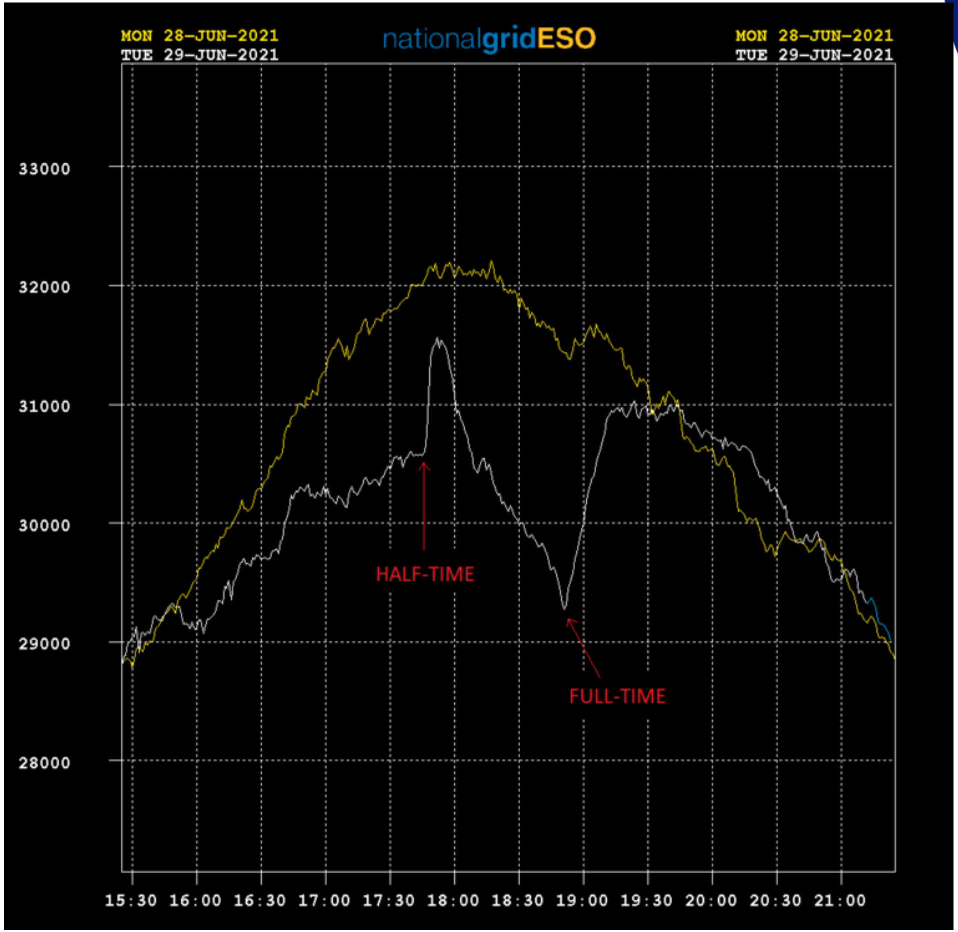
The idea behind the diversity factor is that when the maximum demands of the customers are known, then the maximum transformer-side demand can be computed.

Consumptions

One case study for load variation

TV-induced demand fluctuation: England’s victory over Germany during their UEFA EURO 2020

Our national control room saw around a 1GW pick-up in electricity demand at half-time in the match, and around a 1.6GW pick-up after full-time (that’s equivalent power to around 320 million light bulbs and 888,000 kettles).



Essence of the power system control

Voltage

- the voltage level must be maintained within a specified range to ensure the safe and reliable operation of electrical equipment
- Voltage fluctuations can cause damage to equipment, reduce efficiency, and even lead to power outages

Frequency

- the measure of the number of cycles per second of an alternating current (AC) waveform
- the frequency must be maintained at a constant level to ensure that the equipment operates at the correct speed and synchronizes with other equipment
- deviations in frequency can cause equipment to operate outside of its designed range, leading to equipment failure or power outages

Power angle

- the phase angle difference between the voltage and current waveforms
- a critical parameter in the analysis of power system stability, as it affects the transfer of power between generators and transmission lines
- deviations in power angle can cause a loss of synchronism between generators and transmission lines, leading to instability and even power outages

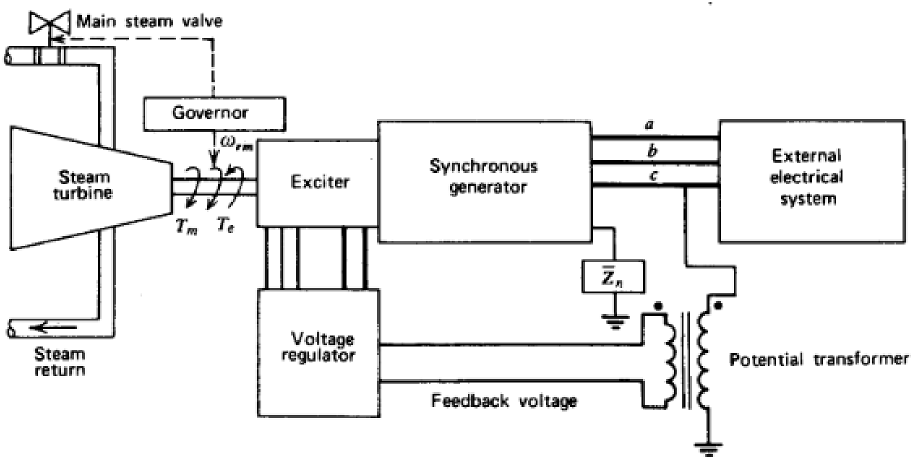
Essence of the power system control

Frequency regulation and power balance

$$n = \frac{120f}{p}$$

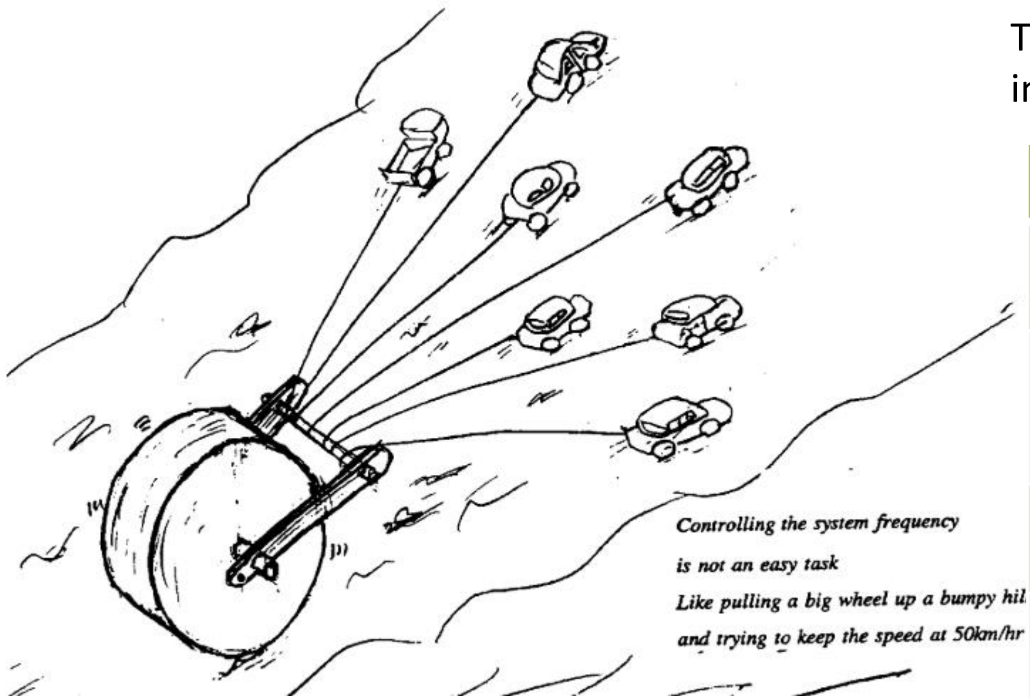
N is the rotating speed for a turbine generator; p if the number of poles of the generator; f is the frequency

the measure of the number of cycles per second of an alternating current (AC) waveform
-- the rotating speed of a turbine generator



Essence of the power system control

Frequency regulation and power balance



Ramp-up rate:
The maximum rate at which a generator can increase its output power to meet the demand.

	Ramp-up rate
Gas turbines	10% to 15% of the maximum output per minute
Coal-fired steam turbines	5% to 10% of the maximum output per minute
Hydroelectric generators	Per-second control
Nuclear reactors	1% to 2% of the maximum output per hour

Essence of the power system control

Low Frequency Demand Disconnection (LFDD) following Generator Trips and Frequency Excursion on 9 Aug 2019, UK

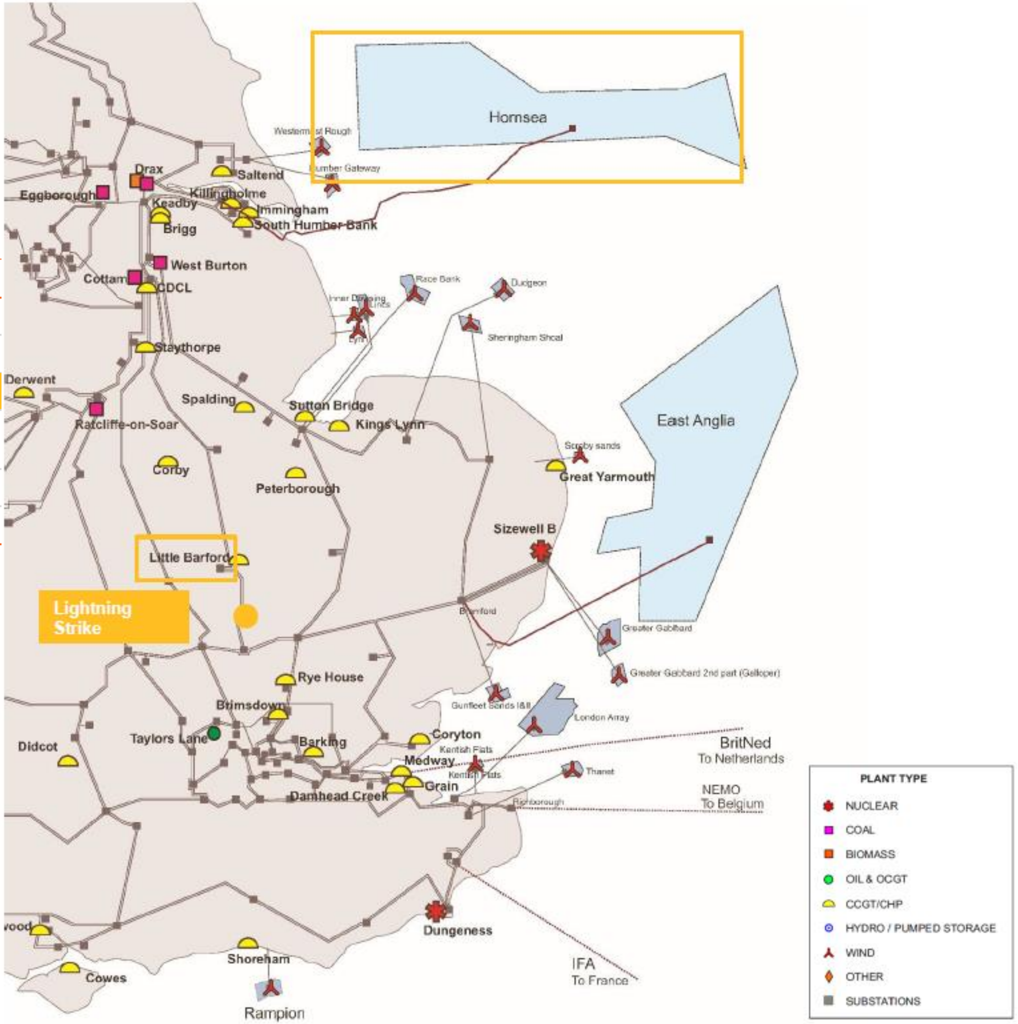
Reporting DNO		MW of disconnected demand by LFDD	Customers Affected	Final Restoration Time of Demand
Scottish Hydro Electric Power Distribution (SHEPD)		0		
Scottish Power (SP)		22	23 117	16:59
Northern Power Grid (NPG)	North East	76	93 081	17:18
	Yorkshire	14	10 571	17:12
Electricity North Limited (ENW)		52	56 613	17:17
SP Manweb		130	74 938	17:15
Western Power Distribution (WPD)	East Midlands	122	150 445	17:25
	West Midlands	160	187 427	17:37
	South Wales	36	29 060	17:11
	South West		110 273	17:22
UK Power Networks (UKPN)	Eastern	69	79 390	16:56
	London	174	239 861	17:37
	Southern	69	81 358	17:15
Scottish Electric Power Distribution (SEPD)		7	16 744	17:07
Totals		**931**	**1 152 878**	**17:37**

Low Frequency Demand Disconnection (LFDD) following Generator Trips and Frequency Excursion on 9 Aug 2019, UK

Below is the detail of the cumulative losses of infeed

Generation Unit	Infeed Loss	Cumulative Infeed Loss
Little Barford ST1C	244 MW	244 MW
Hornsea Offshore Windfarm	737 MW	981 MW
ESO Security Standards and Planning Required an infeed loss 1,000 MW loss to be covered		
Estimated, Embedded generation infeed loss due to Loss of Mains Protection	~500 MW	~1481 MW
Little Barford GT1A	210 MW	~1691 MW
Little Barford GT1B	187 MW	~1878 MW

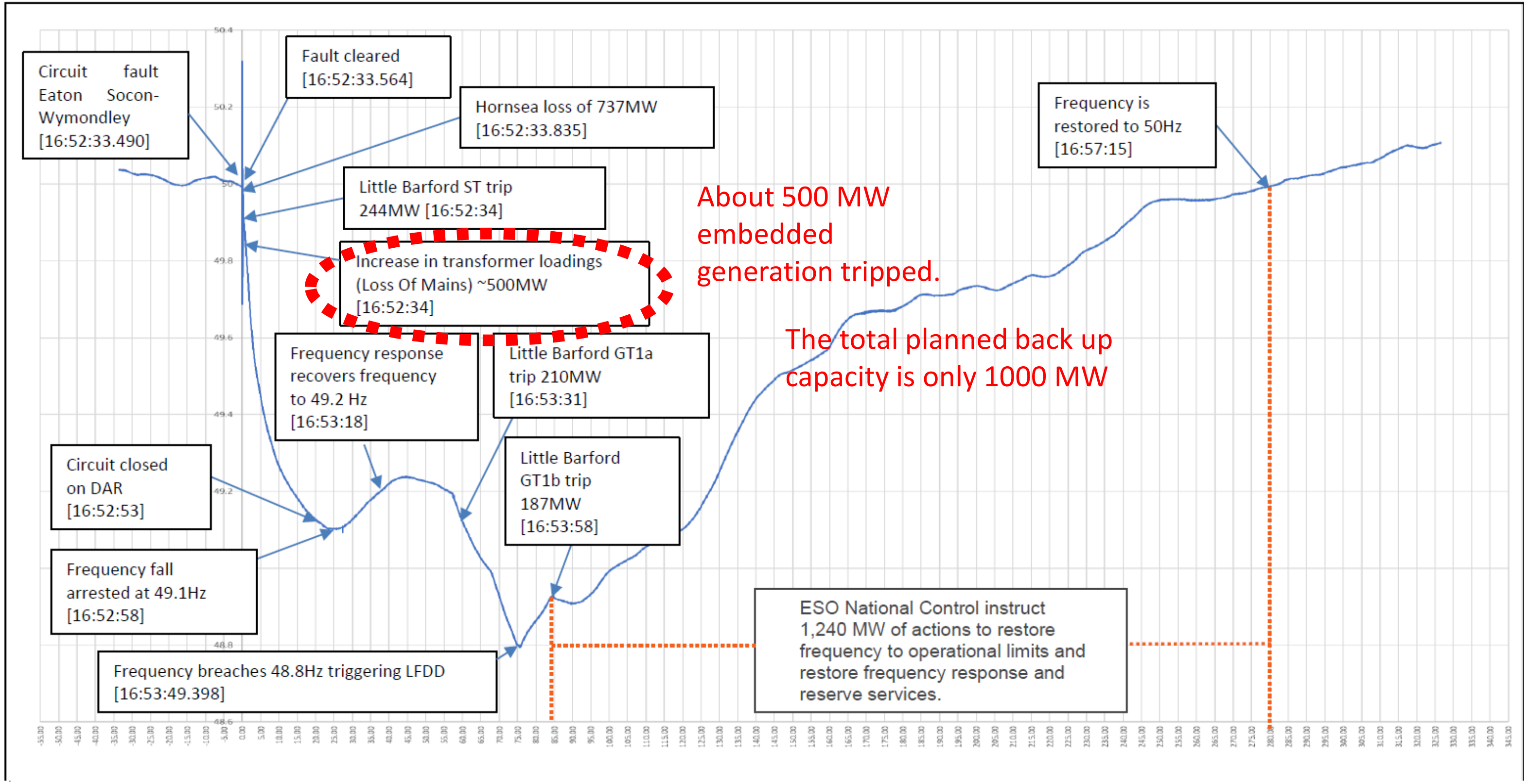
Table 2 – Table of cumulative infeed losses



Wind power exceeds over 50% of the generation at that time

Essence of the power system control

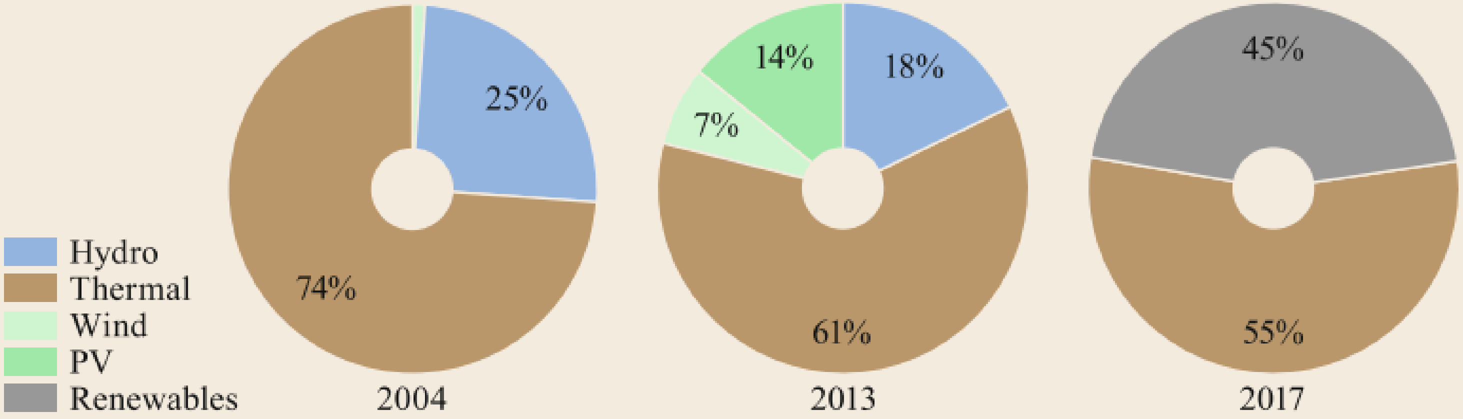
Low Frequency Demand Disconnection (LFDD) following Generator Trips and Frequency Excursion on 9 Aug 2019, UK



Smart Grids

Generation mixes change over time(the Italy example)

Classification	Plants (k)	Power (GW)	Plants (k)	Power (GW)
Hydroelectric	2	21.1	2.9	22.5
Thermal power	1.9	62.2	3.9	76.9
Wind	0.1	1.1	1.4	8.5
PV	0	0	559.4	18.5
Total	4	84.4	567.6	126.4

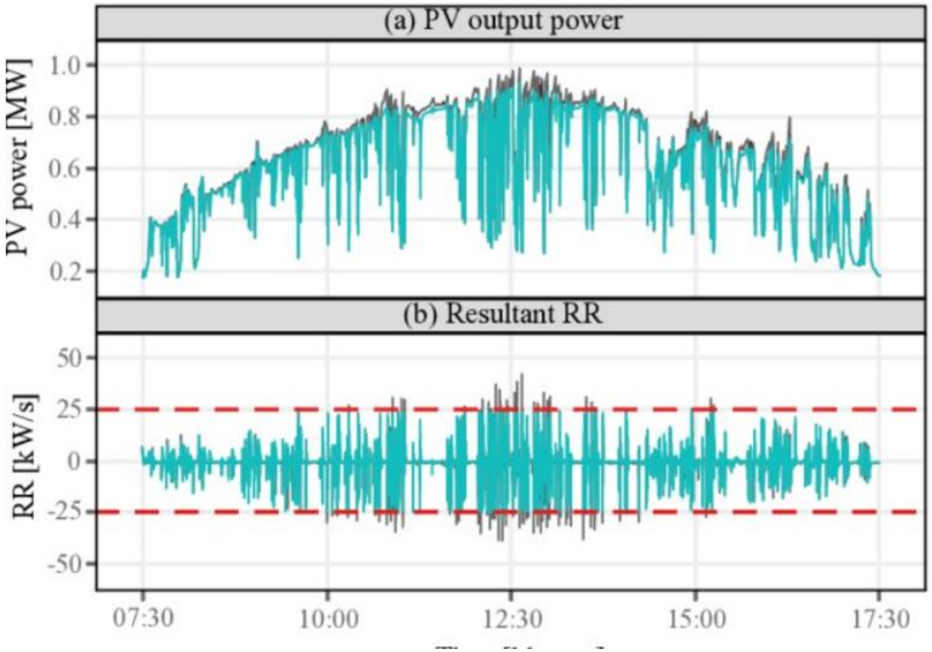


From 2004 to 2013, the share of the total power generated in Italy that is contributed by RES plants increased from 26% to 39%, and this share reached 45% in 2017 (Fig. 5.135).

Smart Grids

Basic problems for renewable generations:

? Reliability over a day, a week, a month or a year



Reference: 国产凌凌漆

Ideally, PV could provide:

- 90% of hot demand in summer

- 25% of hot demand in winter

拜托了小翔哥：“小伙用太阳能做了一道红烧肉……”

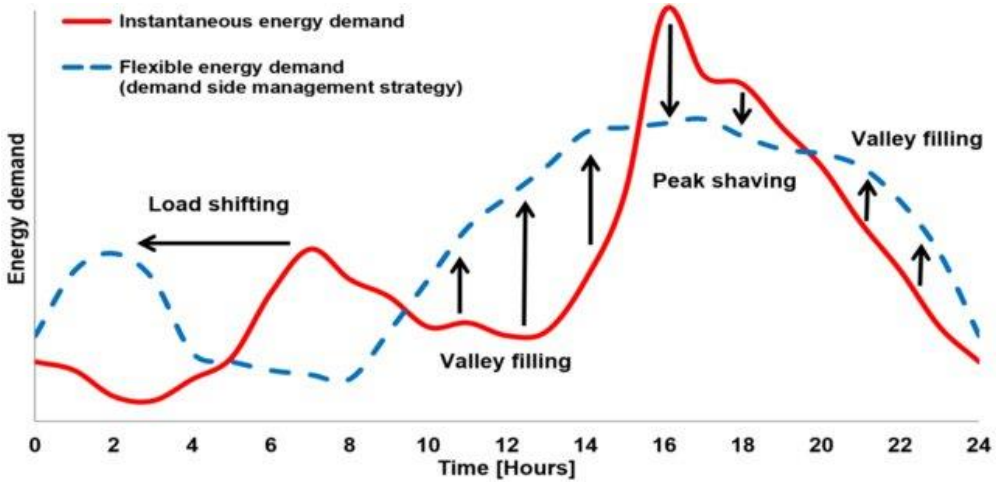
Smart Grids

The concept or objective of a smart grid

A smart grid is an electricity network that can intelligently integrate the behavior and actions of all users connected to it—generators, consumers and those that do both—in order to efficiently ensure sustainable, economic and secure electricity supply.

Flexible generation → Flexible generation + Flexible demand

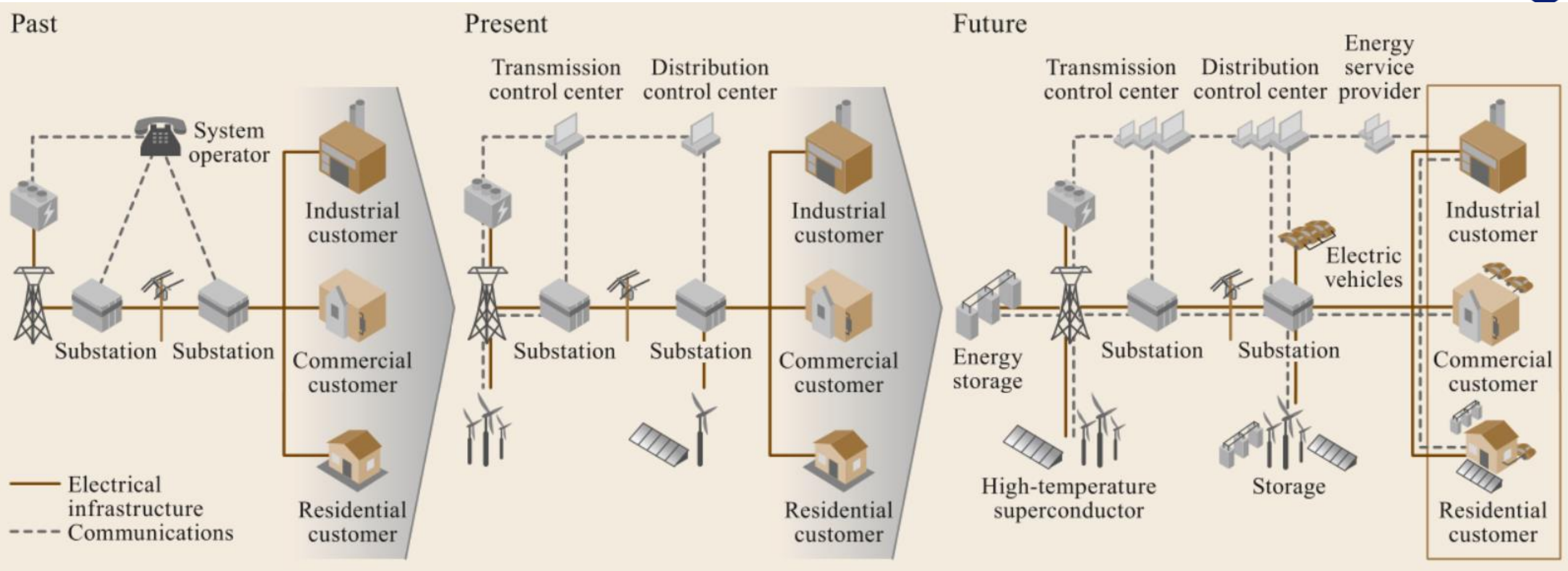
Example flexible demand



Building energy flexibility: a sensitivity analysis and key performance indicator comparison

Smart Grids

Evolution of the utilization of information and communication technology in power systems

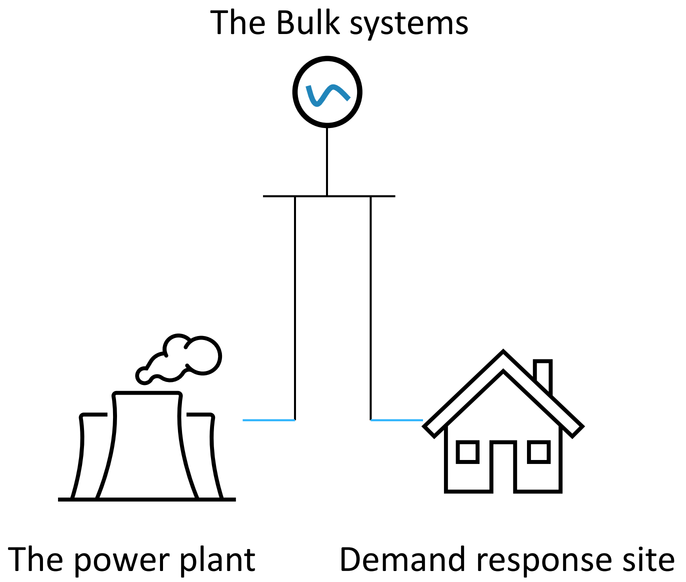


In transmission and distribution networks, the adoption of DG, together with electricity market procedures and the expected sudden growth in electric vehicle deployment yield loads of innovation opportunities.

Smart Grids

Example questions

You are a power grid operator responsible for maintaining power balance in the grid. Right now you have the following data in hand:



Power Plant:
- Capacity: 200 MW
- Ramp rate: 40 MW/hour
- The minimal power: 40 MW
- Incremental cost of generation: $50/MW

Demand response program:
- Capacity: ± 50 MW
- Ramp rate: 50 MW/second
- Cost of demand response: $20/MW

- Cost of power excess and shortage: $100/MW

Smart Grids

Example questions

Questions:

1.If the total demand is 300MW, without considering the demand response capacity, what is the current power balance in the grid? Is there an excess or shortfall of power?

2.Suppose the demand in the grid is 230 MW. Determine the optimal power of the power plants and the demand response program to meet the demand while minimizing costs.

3.Suppose the demand drops to 20 MW and keep consistent for the next 1 hour. Initially the power of the power plant and demand response site are 80 MW and 0 MW, respectively. Determine the optimal power output of the power plant and the demand response program after 1hour at the minimal cost.

Smart Grids

Example questions

Questions:

1.If the total demand is 300MW, without considering the demand response capacity what is the current power balance in the grid? Is there an excess or shortfall of power?

- Given the data:

$$Demand_{grid} = 300MW; P_{G1} = 200MW;$$

$$The\ excess\ power = P_{G1} - Demand_{grid} = 200 - 300 = -100\ MW$$

There is a shortfall of 100 MW in the grid.

Smart Grids

Example questions

Questions:

2. Suppose the current demand in the grid is 230 MW. Determine the optimal power output of the power plants and the demand response program to meet the demand while minimizing costs.

- Define variables:

$$Demand_{grid} = 230\ MW; P_{G1} = 0{\sim}200\ MW;\ P_{dr} = -50{\sim}50\ MW$$

$$C_{in,G1} = \$50/MW;\ C_{in,dr} = \$20/MW$$

- The cost function would be:

$$Total\ cost\ =\ C_{in,G1} * |P_{G1}| + C_{in,dr} * |P_{dr}| + C_{excess} * \left(\left|P_{G1}(t) + P_{dr}(t) - Demand_{grid}\ \right|\right)$$

$$= 50 * P_{G1} + 20 * |P_{dr}|$$

- Considering the demand constraints:

$$40\ MW \leq P_{G1} \leq 200\ MW$$

$$-50\ MW \leq P_{dr} \leq 50\ MW$$

$$P_{G1} + P_{dr} = 230\ MW$$

There is multiple ways to find the solution of a minimal total costs (try it after class):

$$P_{G1} = 180\ MW;\ P_{dr} = 50\ MW$$

The minimal cost is $10,000/hour

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Example questions

Questions:

3. Suppose the demand drops to 20 MW and keep consistent for the next 1 hour. Initially the power of the power plant and demand response site are 80 MW and 0 MW, respectively. Determine the optimal power output of the power plant and the demand response program after 1 hour at the minimal cost.

- Define variables:

$$Demand_{grid} = 20\ MW; P_{G1}(0) = 80\ MW; P_{G1}(1) = 0{\sim}200\ MW; P_{dr} = -50{\sim}50\ MW$$

$$C_{in,G1} = \$50/MW;\ C_{in,dr} = \$20/MW;\ C_{excess} = \$100/MW$$

- The cost function would be:

$$Total\ cost\ (t)$$
$$= C_{in,G1} * |P_{G1}(t)| + C_{in,dr} * |P_{dr}(t)| + C_{excess} * \left(\left|P_{G1}(t) + P_{dr}(t) - Demand_{grid}\right|\right)$$
$$= 50 * P_{G1}(t) + 20 * |P_{dr}(t)| + 100 * \left(\left|P_{G1}(t) + P_{dr}(t) - Demand_{grid}\right|\right)$$

t = 0, 1

Please write the constraints after class

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Example questions

	Time = 0	Time = 0’	Time = 1 hour
Demand (MW)	20	20	20
P1(MW)	80	80	40
Pdr(MW)	0	-50	-20
Excess power(MW)	60	10	0
Cost P1	$ 4000	$ 4000	$ 2000
Cost Pdr	$ 0	$ 1000	$ 400
Cost of excess	$ 6000	$ 1000	$ 0
Total costs	$10,000	$ 6000	$ 2400

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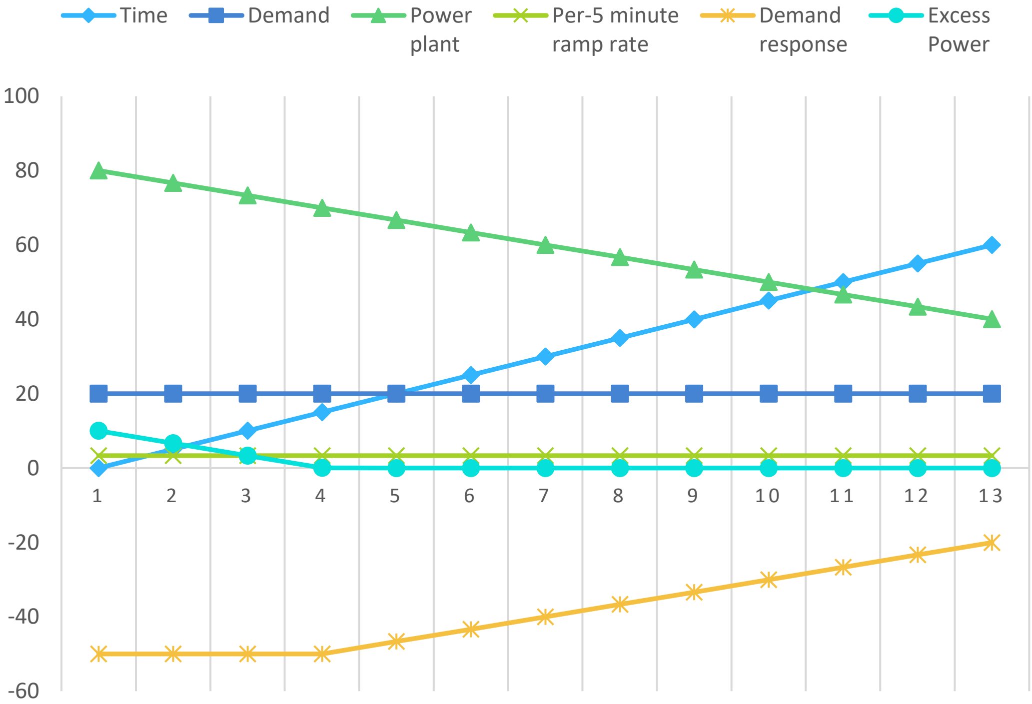
Example questions

In reality

Time	Demand	Power plant	Per-5 minute ramp rate	Demand response	Excess Power
0	20	80	3.33	-50	10
5	20	76.67	3.33	-50	6.67
10	20	73.34	3.33	-50	3.34
15	20	70.01	3.33	-50	0.01
20	20	66.68	3.33	-46.68	0
25	20	63.35	3.33	-43.35	0
30	20	60.02	3.33	-40.02	0
35	20	56.69	3.33	-36.69	0
40	20	53.36	3.33	-33.36	0
45	20	50.03	3.33	-30.03	0
50	20	46.7	3.33	-26.7	0
55	20	43.37	3.33	-23.37	0
60	20	40.04	3.33	-20.04	0



Next Lecture

Basic principles in power system analysis (1)

Thanks for your attendance!