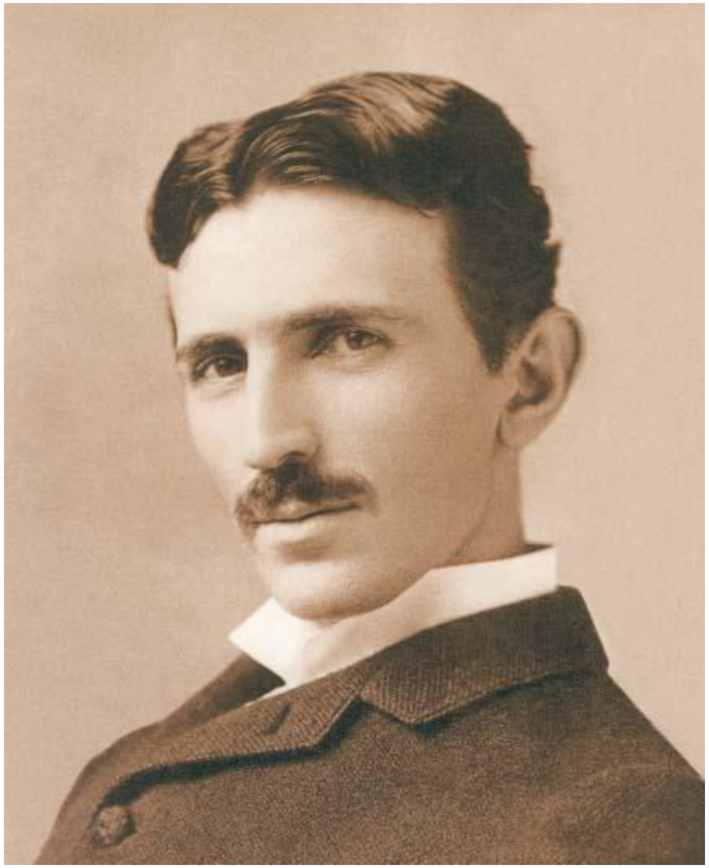
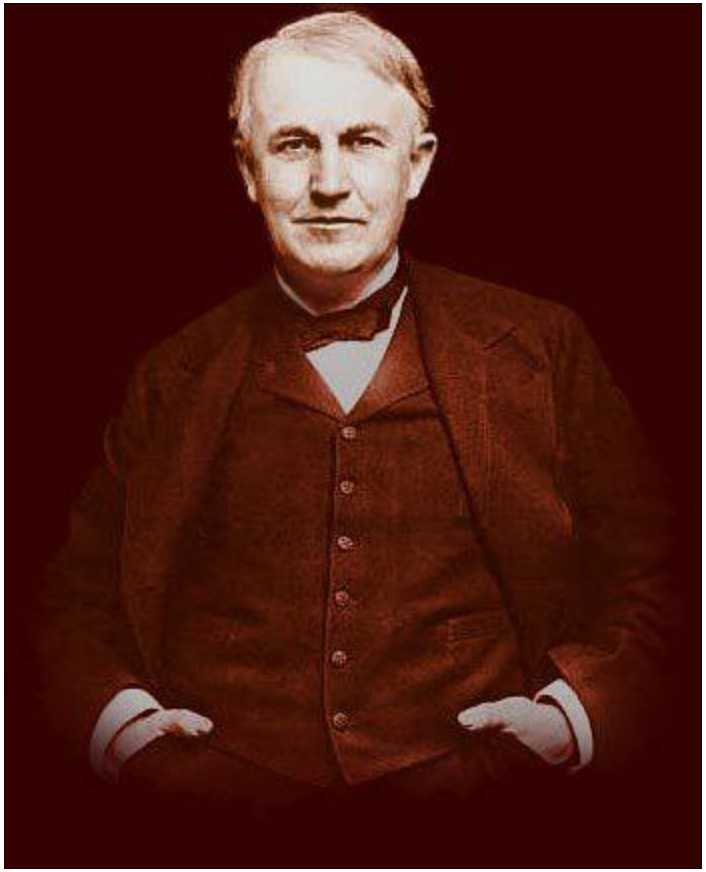
AC/DC - History and Differences

http://www.youtube.com/watch?v=GpaVgUfi0Xo



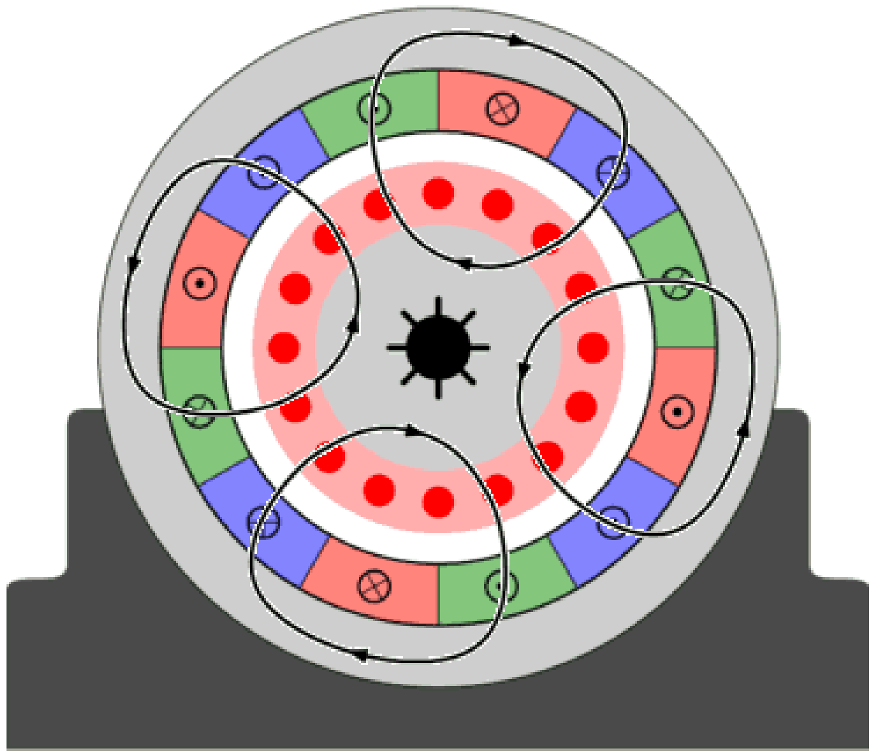
Nikola Tesla (1856 - 1943)



Thomas Alva Edison (1847 - 1931)

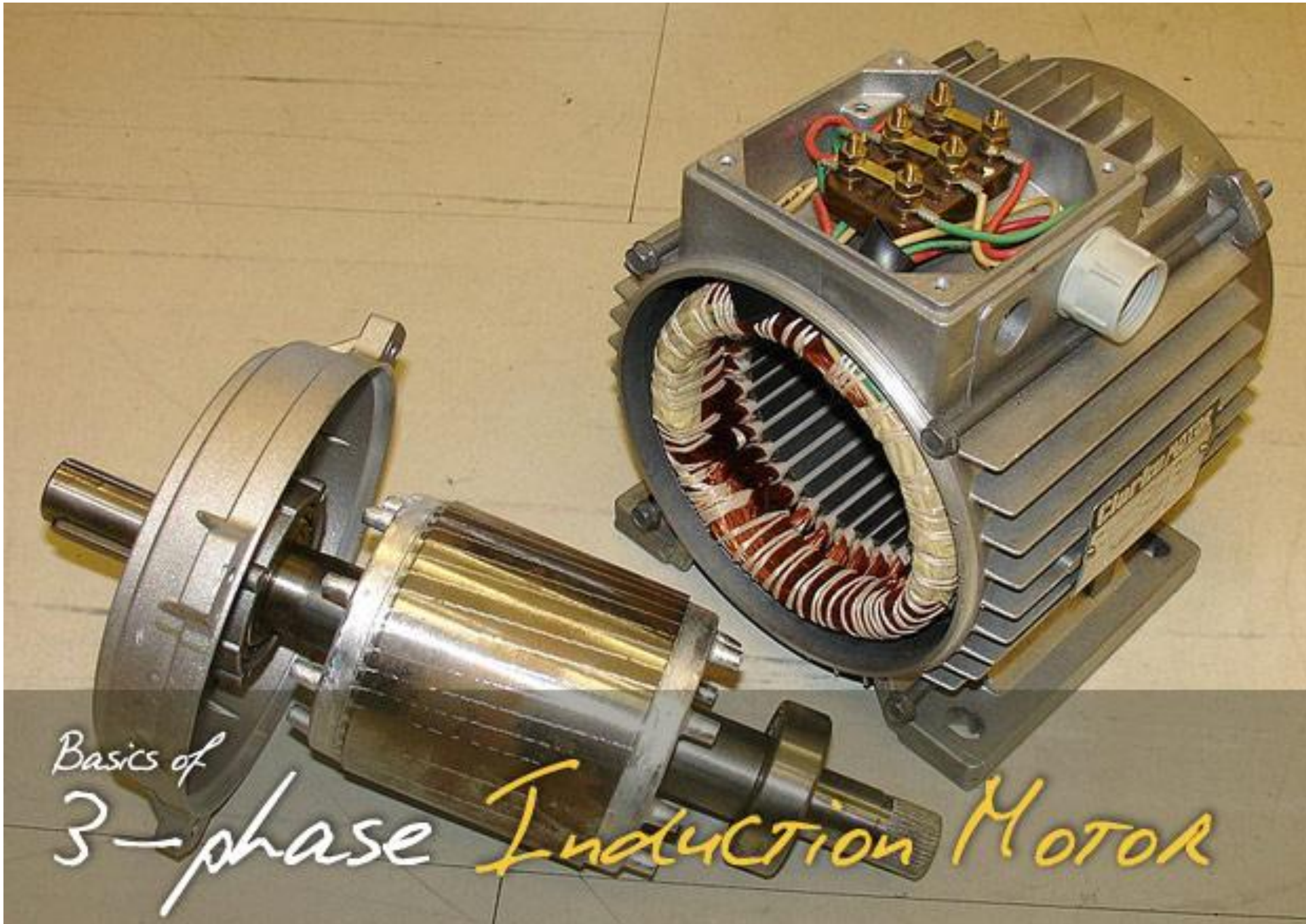
https://www.youtube.com/watch?v=NoKi4coyFw0

Induction Motor



The AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. The rotating magnetic flux induces currents in the windings of the rotor

Induction Motor



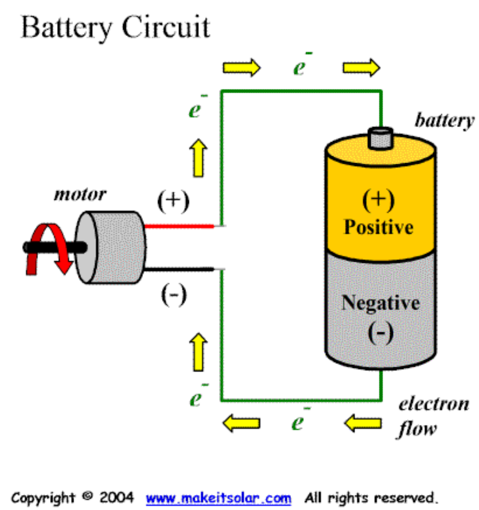
Production of Electricity

Direct vs. Alternating curent

http://www.pbs.org/wgbh/amex/edison/sfeature/acdc.html

Production of Electricity

- **Direct current** (DC)
  - Electrons flow only in one direction in a closed circuit, ie. DC has zero frequency
  - The electrons in the circuit flows from "-" to "+"
  - To get the energy of an electron to the appliance the electron must complete the way from source to the appliance
  - For longer routes (eg. already from 1 km) DC quickly loses its power and leads to huge losses in networks

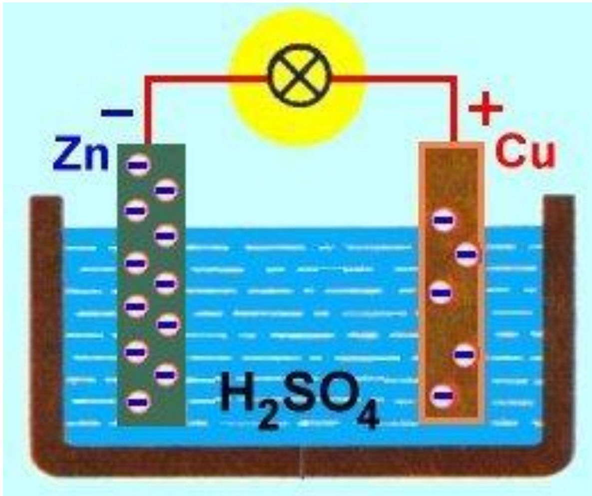


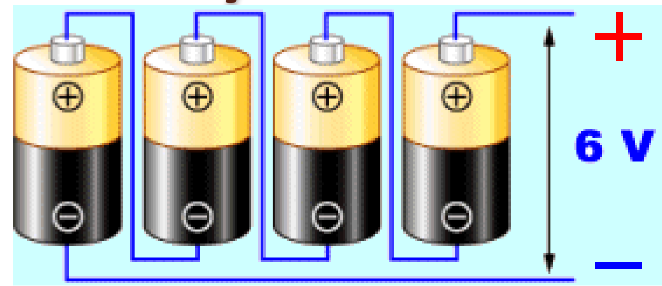
- **What is the use?**

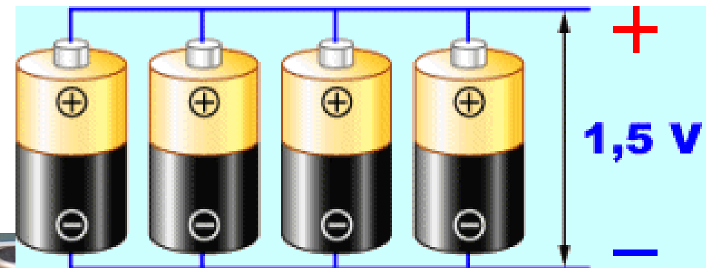
Production of Electricity

- **Direct current** (DC)
  - It is used all around us, for example in batteries, rechargeable batteries, chargers, adapters, thermocouples, solar cells, transistors, etc..
  - But even in trams, trains in the region Decin-Praha-Ostrava, in the train operation in the world, in most of the world's subways, etc..)
  - It is also used by remote transmissions of large volumes of electricity, so called HVDC lines. The advantage is that it can interconnect systems on different frequencies as well as asynchronous systems
  - With very high voltages DC is more efficient at transporting electricity than alternating current
  - However the changing of the voltage is complicated and expensive, and therefore a high-voltage DC power supply is used only during transportation over long distances (more than 600 km for overland lines).
  - In practice the HVDC is used when connecting remote sources (typically dams and other renewable sources), or when connecting electrical systems with different frequency alternating current.
  - "Natural" sources of DC are basically any non-rotating power plants (battery, solar cells, dynamo - exemption)

Production of Electricity







Production of Electricity

- **Alternating current** (AC)
  - Electrons flowing back and forth, volatile, periodically alternating
  - In normal network frequency of 50 Hz the current changes direction every 10 milliseconds
  - Electricity is produced in the form of a sine curve
  - Electrons almost do not wander through the conductor, they tap into the neighboring electron and passes its charge, so it gets from the source to the appliance
  - They move with much shorter routes, leading to significantly lower losses in the network

What is the use?

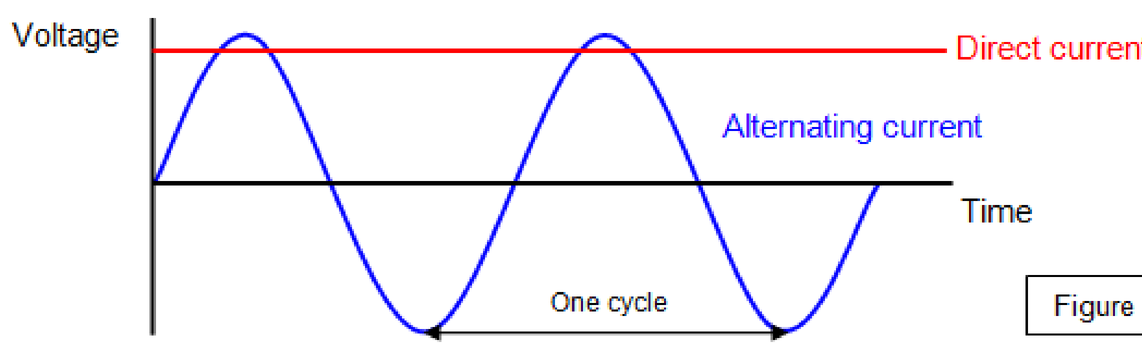
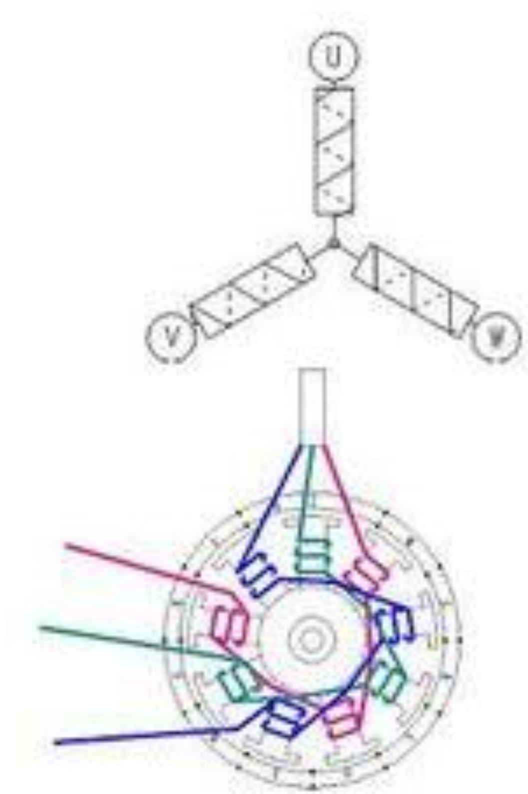


Figure 1

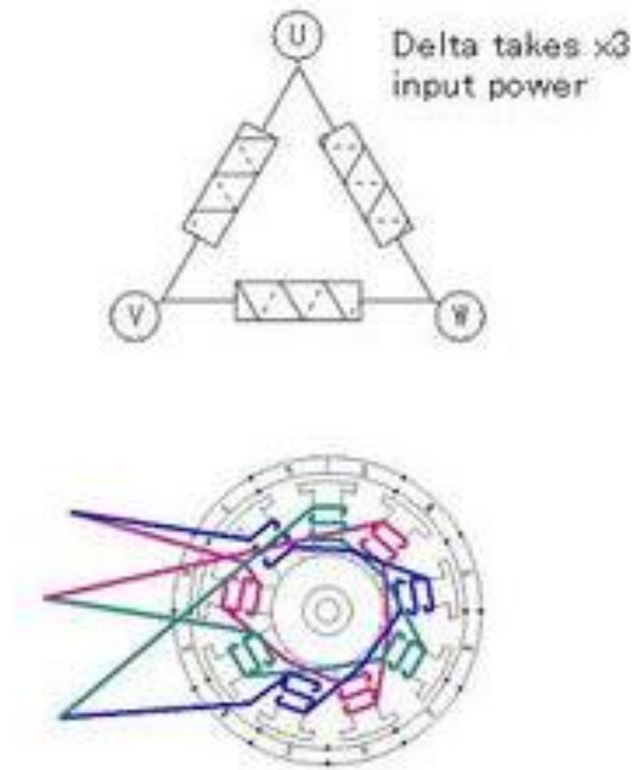
Production of Electricity

- **Alternating current** (AC)
  - The main advantage of AC versus DC is easy increase and decrease of voltage and much cheaper industrial production and distribution
  - It is used in mass production of electricity and for the transmission of power at a greater distance, withsignificantly lower losses that are achieved using higher voltages
  - High voltage transport lines are used for remote supplies using easily transformable alternating current.
  - Very simple transformers are used for change in voltage, which consists of two coils wound around a common magnetic core. The proportion of the incoming and outgoing voltage is proportional to the proportion of the number of coil windings.
  - The sources are all rotating motors, dynamos and nowadays mainly structurally simpler alternators
  - The disadvantage of AC is the need to maintain a stable frequency network (ie **synchronize all connected generators**).

Production of Electricity

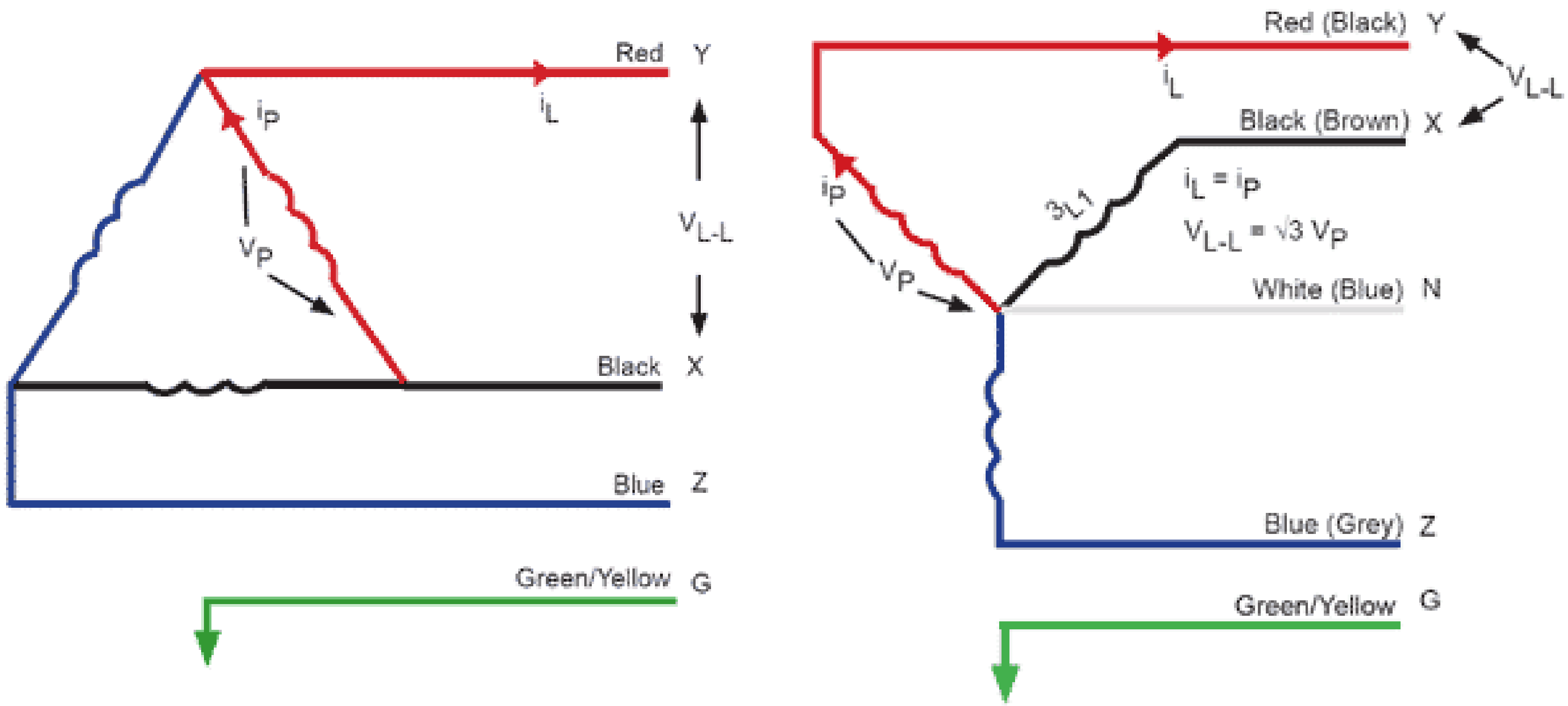


Star wiring, phase conductors



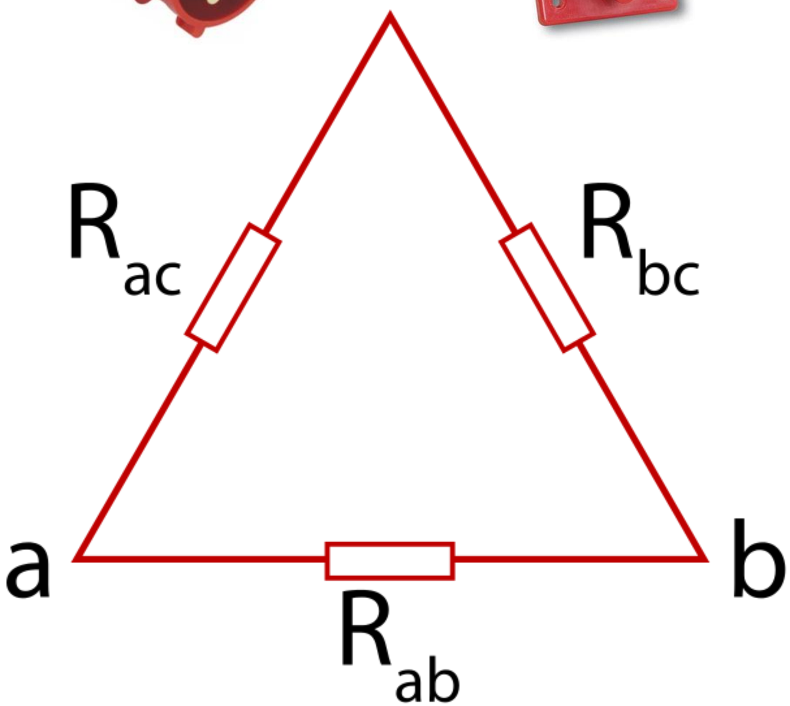
Delta wiring, stranded (composite) conductors

Production of Electricity

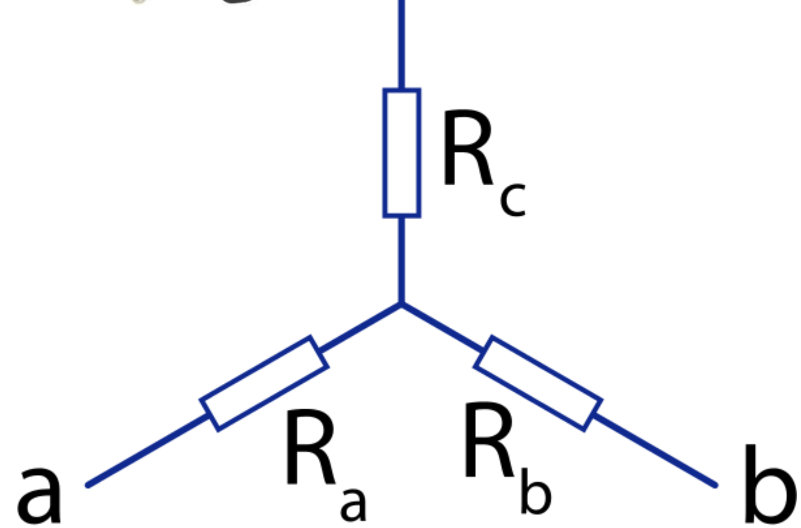


http://power.apitech.com/engineering-tools.aspx

Production of Electricity



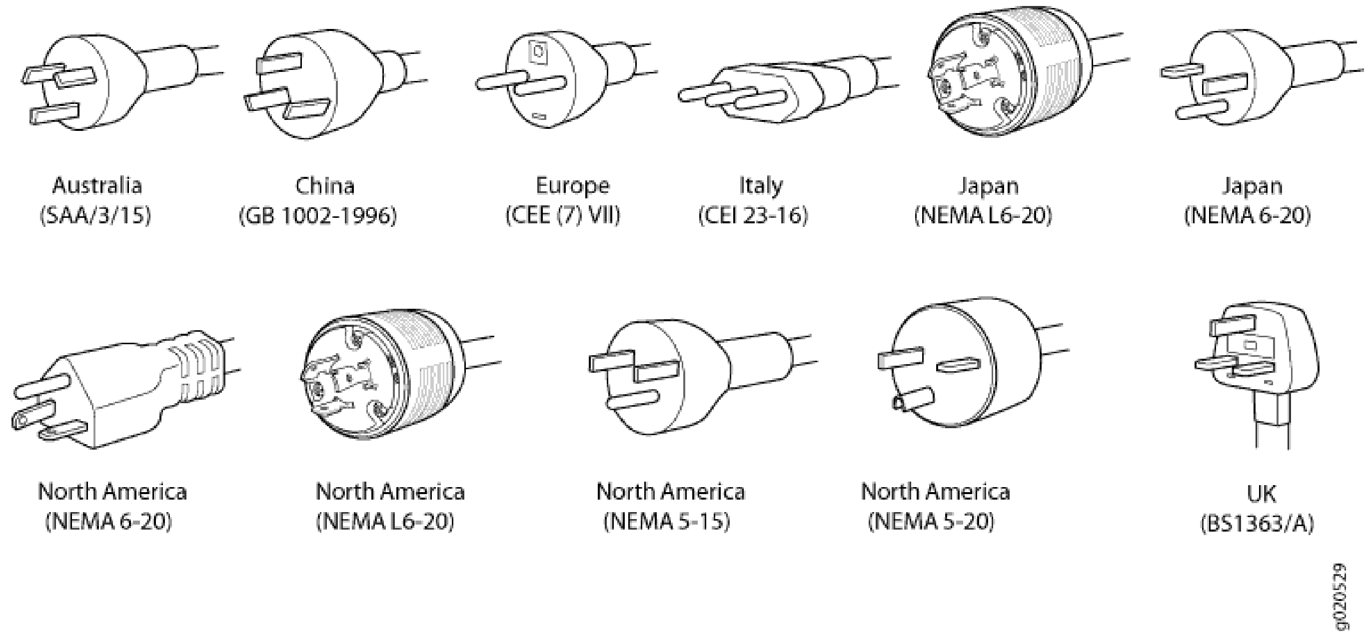
"Delta"

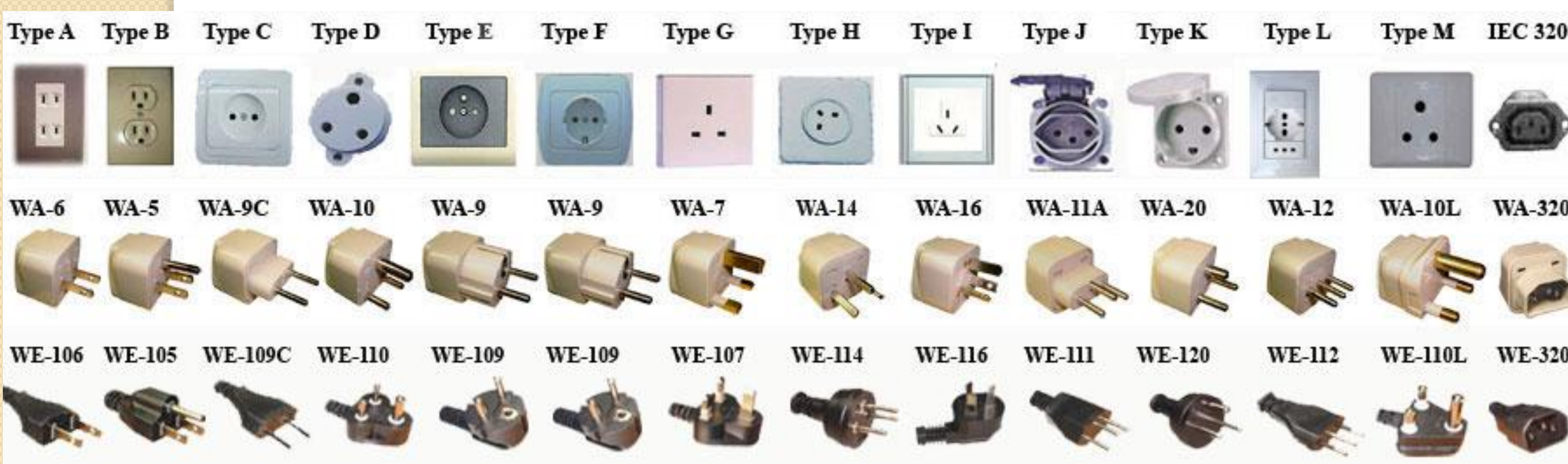


"Star"

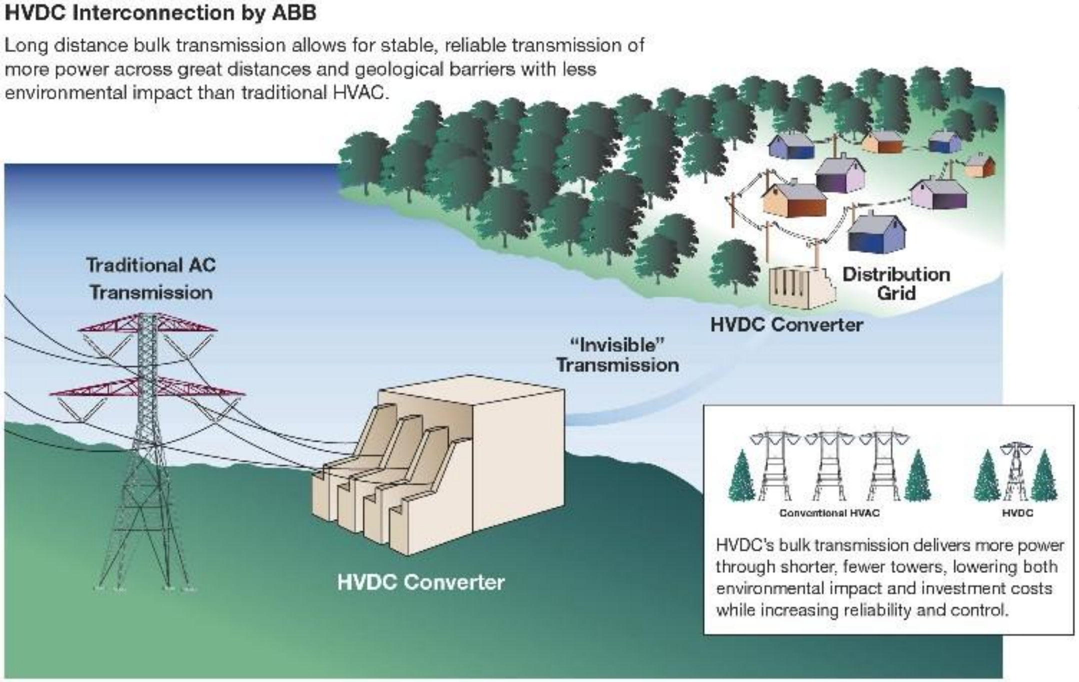
Types of plugs/sockets in the world

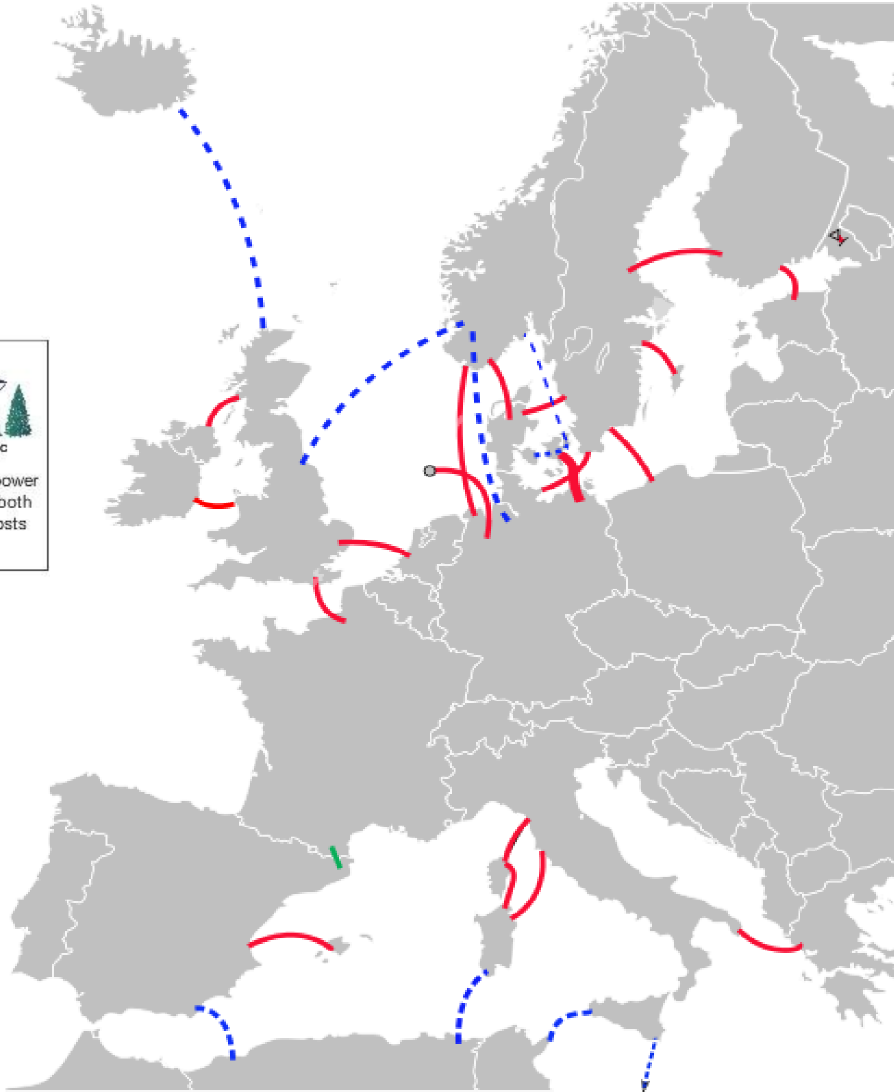
Types of plugs/sockets in the world



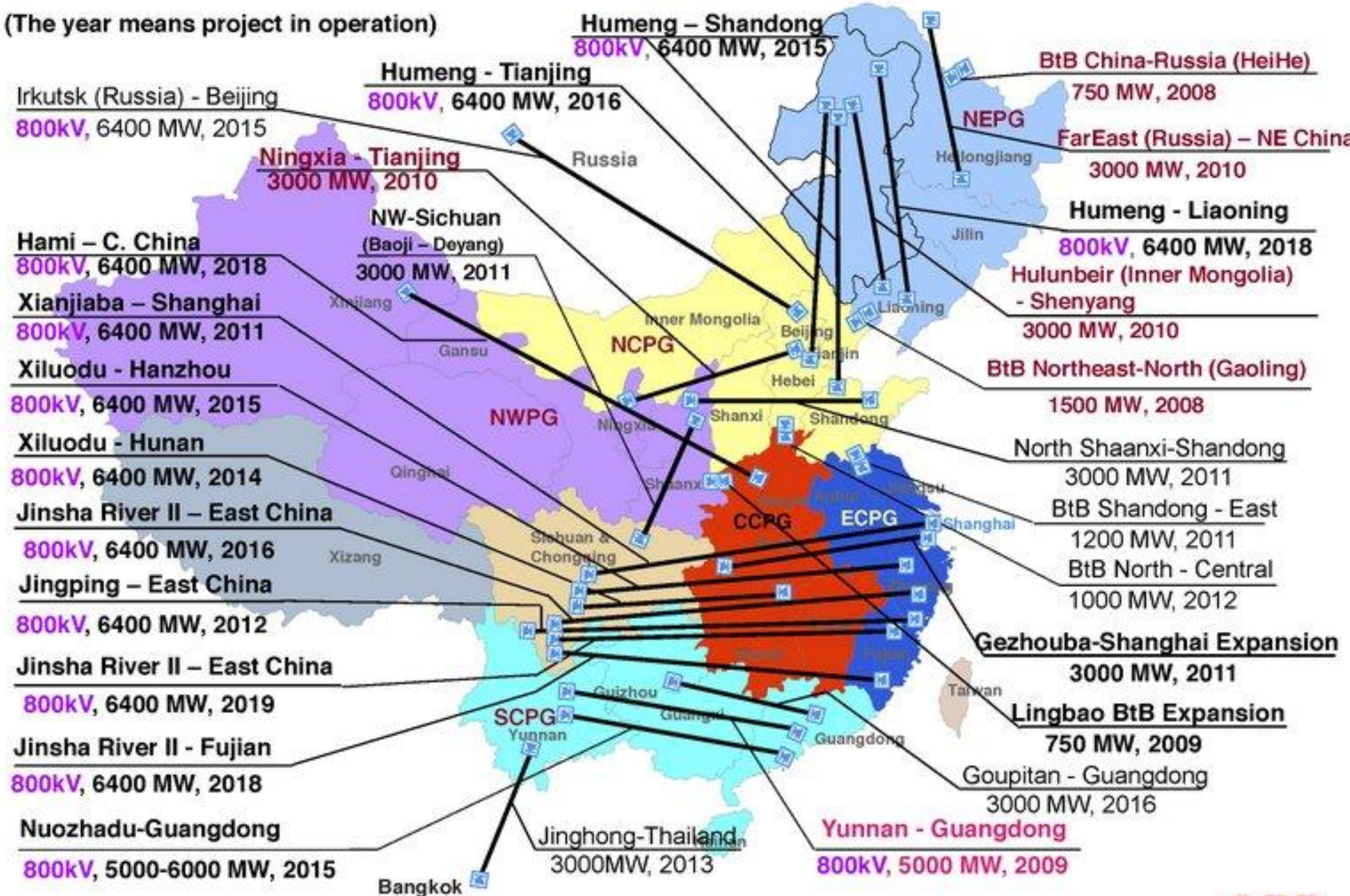


Production of Electricity





Planned Future HVDC Projects by 2020 in China



(Indicative map)

ABB

Transfer and Distribution of Electricity

- *The power system involves a process of electricity generation from different types of primary sources (fossil fuels, hydropower, wind, geothermal, nuclear, solar), qualitative transformation of the electric energy, transmission and distribution, and end use. All these processes are carried out through the electricity grid (transmission, distribution).* ***They are dynamic - at any time must equal the energy consumed energy produced.*** *Electrical energy is only a transitional form, it soon turns into light, heat or mechanical.*

- *The transmission system (transmission, distribution) is a set of interconnected devices that allow the transmission of electrical energy from the source to the consumer*

Transfer and Distribution of Electricity

- **The power system** is an interconnected set of equipment for the generation, transmission, transformation and distribution of electricity, including electrical connections and direct lines, systems and metering, protection, control, security, information technology and telecommunications.

- The power system has several parts, namely:

- **production**
- **power stations**
- **network**
- **power lines**

Transfer and Distribution of Electricity

- *Electric power plants are installations that convert any energy into electricity.*

- *Electric stations is a complex of buildings and equipment, which enables the transformation, compensation, conversion or transmission and distribution of electricity, including the resources necessary to ensure their operation.*
- *Electric stations are **transformer stations** (used to change the voltage of electricity at the same frequency and its distribution), **switching station** (serving the same distribution of electrical energy without voltage transformation and without conversion), **converter stations** (used to convert the type of voltage or frequency) and **compensating stations** (used to compensate reactive components of alternating current, or line parameters).*

- *Power grid/lines is an important part of every device and allows transmission of electrical power and signals over distance. Electrical wiring is formed by conductors which serve to conduct electrical current and insulation separating the living part from the environment (except for bare lines). We distinguish four kinds of electric lines: lines of bare conductors (mainly outside), lead in pipes and rails, bridge line of wire and cable management.*

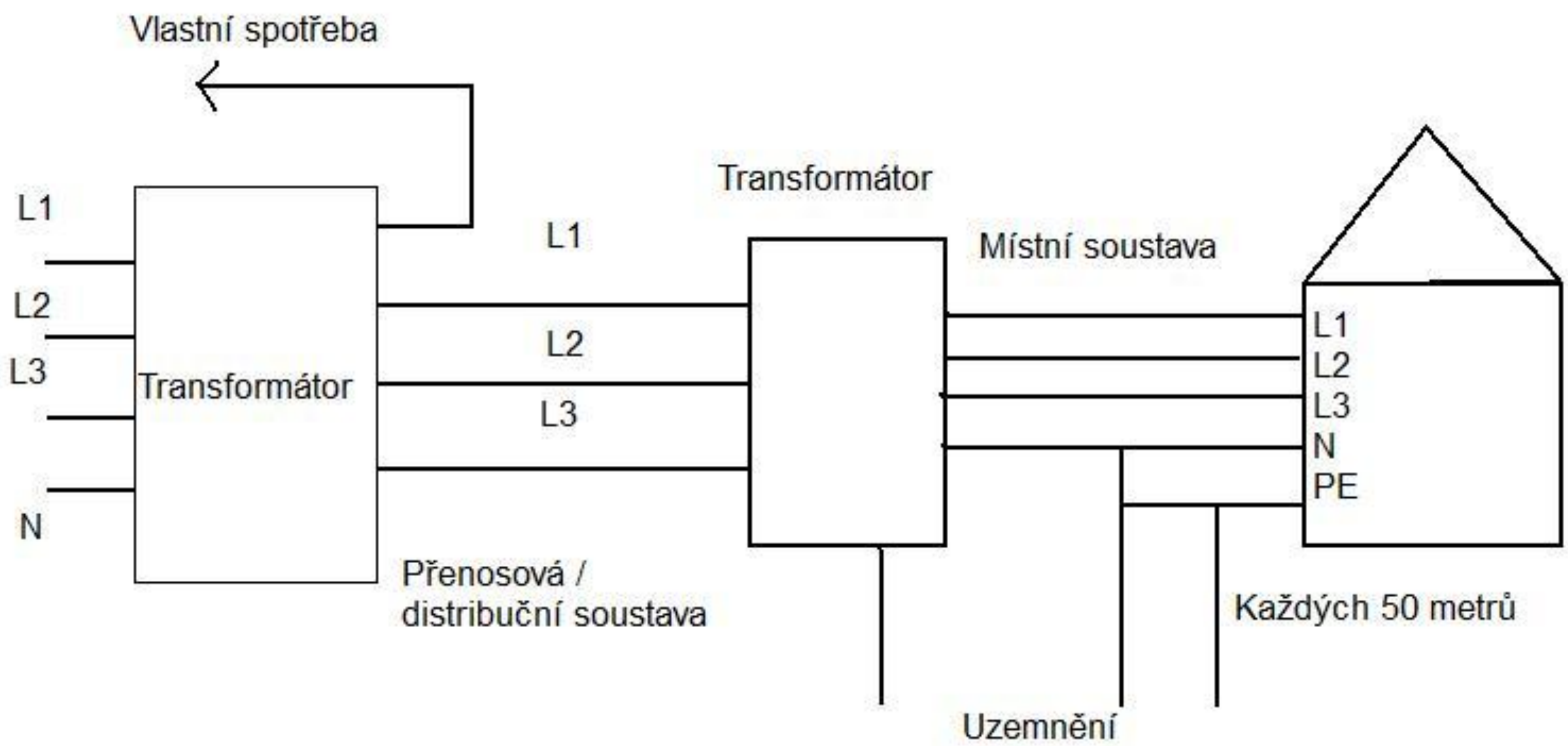
Transfer and Distribution of Electricity

Transfer and Distribution of Electricity

Switching station
Transformer station
Transformer

Transfer and Distribution of Electricity

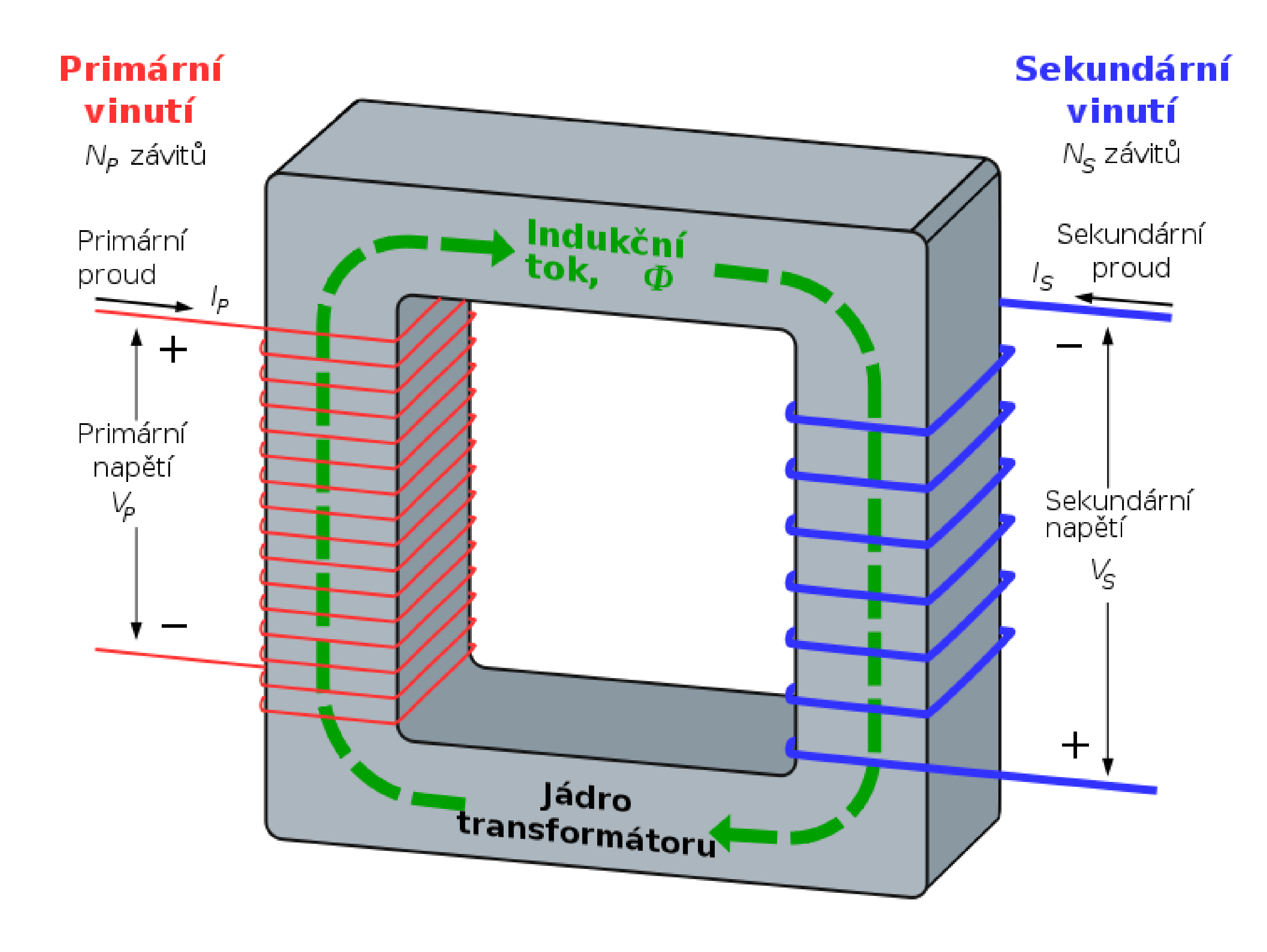
Transfer and Distribution of Electricity



Transfer and Distribution of Electricity

- The produced electricity must be transported to the place of consumption, according to Kirchhoff's laws electricity has the advantage that it does not need any energy to this movement, because electricity flows naturally from higher voltage to lower voltage points.
- To change the voltage in electric power systems the transformers are used.
- Electricity thus enters the high-voltage transmission (parent system), then it is transformed to a lower voltage distribution systems (grid) and then to low voltage (local system).
- Electricity is eventually distributed either by phase conductors or stranded conductors.
- **Materials for outdoor or cable wires are copper cables and wires (best electrical and mechanical properties, high resistance to external influences, but the high price and exceptional use), or Al, Fe or Al alloys, bronze and steel**

Transfer and Distribution of Electricity



Transfer and Distribution of Electricity

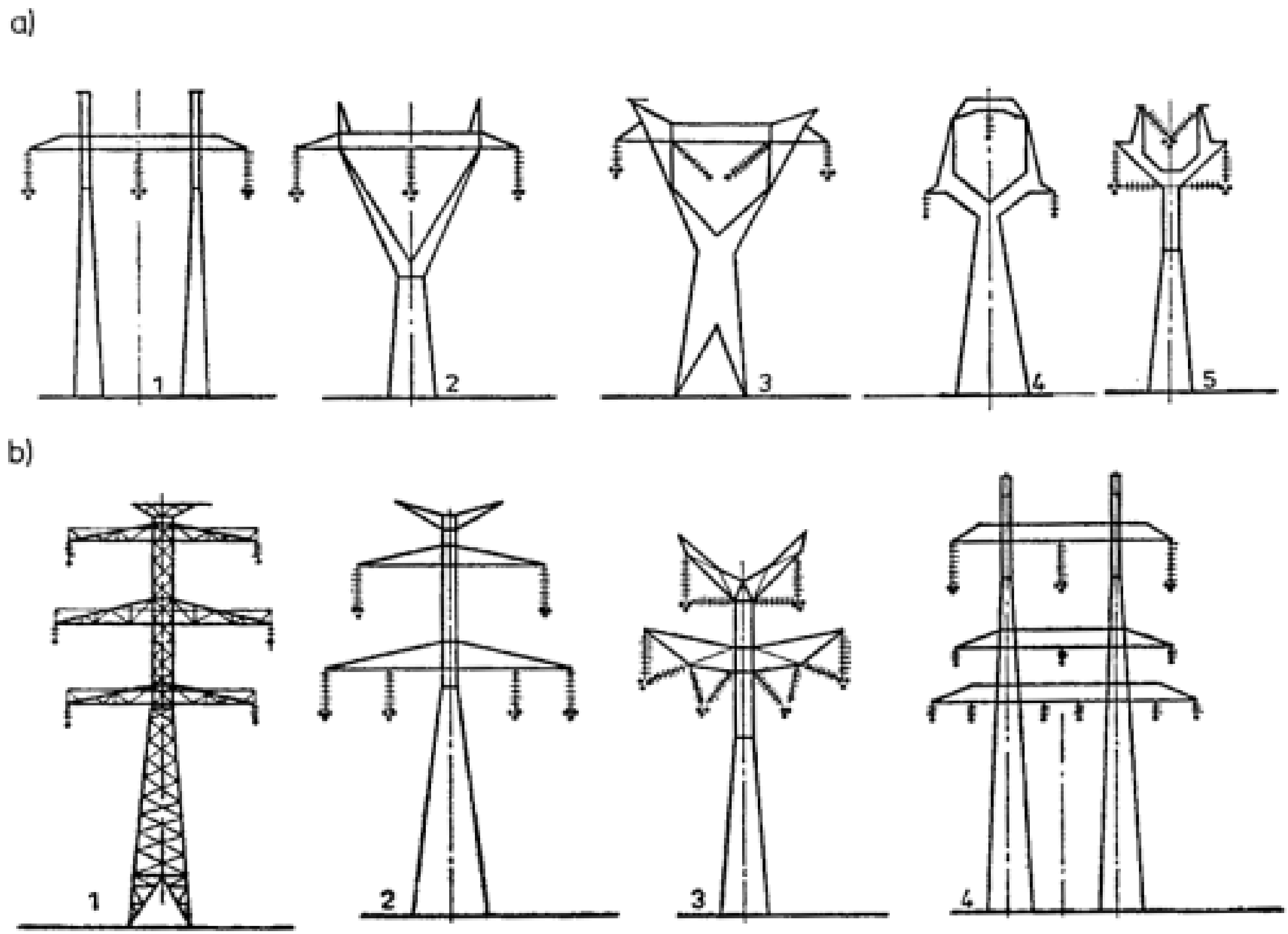
- *Electric lines* are part of the grid. It is a set of interconnected power stations and lines for the transmission and distribution of electric energy.

- AC lines
  - UHV (800+ kV) Transmission
  - EHV (230 – 800 kV) Transmission
  - HV (69 kV to 230 kV) Transmission/Distribution
  - MV (0,6 – 69 kV) Industrial/Distribution
  - LV (50 V – 600 V) Local
  - ELV (less then 50 V) -

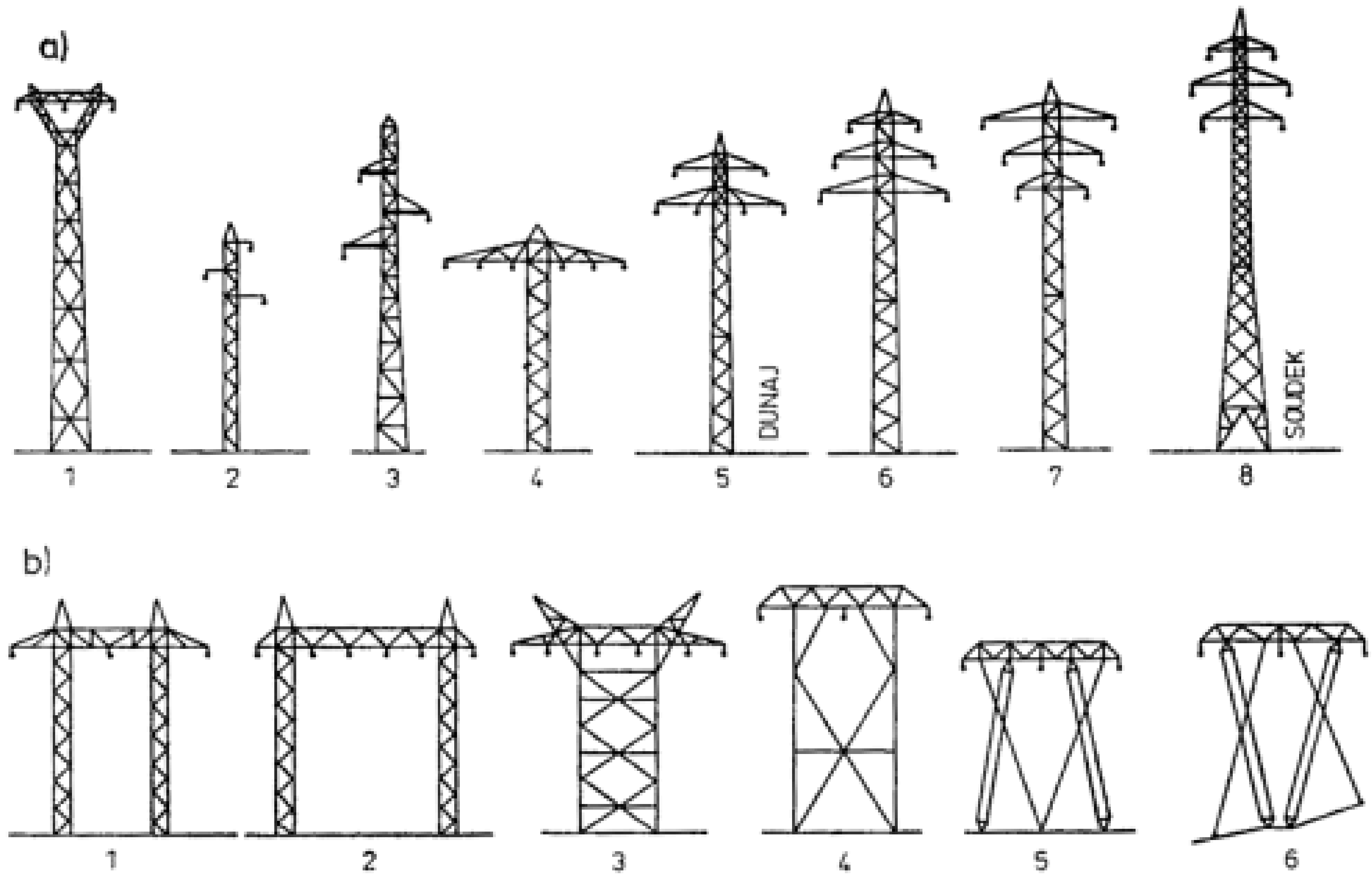
Transfer and Distribution of Electricity

Transported Capacity in Electric Grids	
Voltage	**Transported capacity**
230/400 V	3,55 kWe
22 kV	10,76 MWe
110 kV	268,9 MWe
220 kV	1 075 MWe
400 kV	3 555 MWe
Source: „*Elektroenergetika I,*“ n.d., s. 5.	

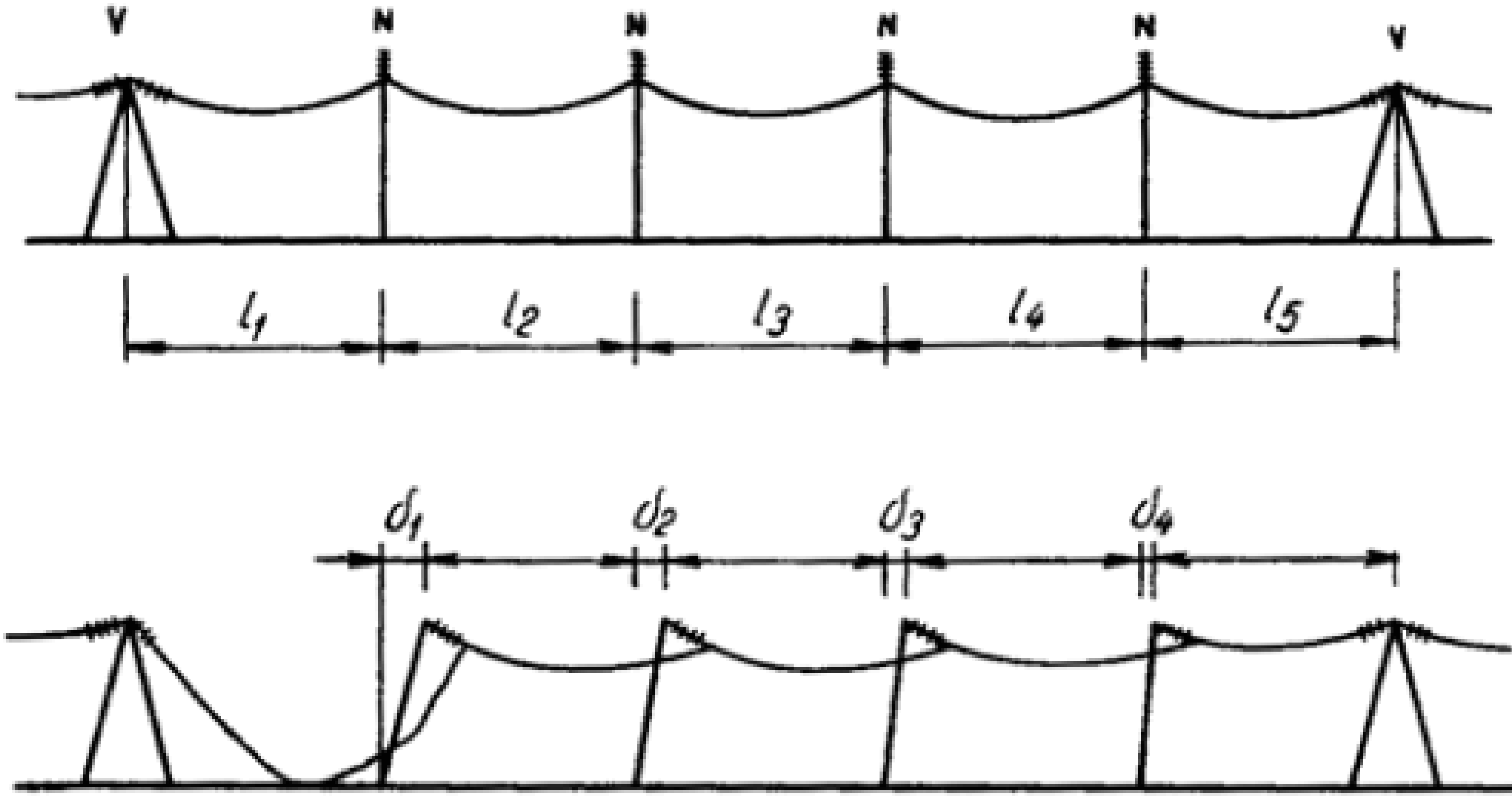
Transfer and Distribution of Electricity



Transfer and Distribution of Electricity

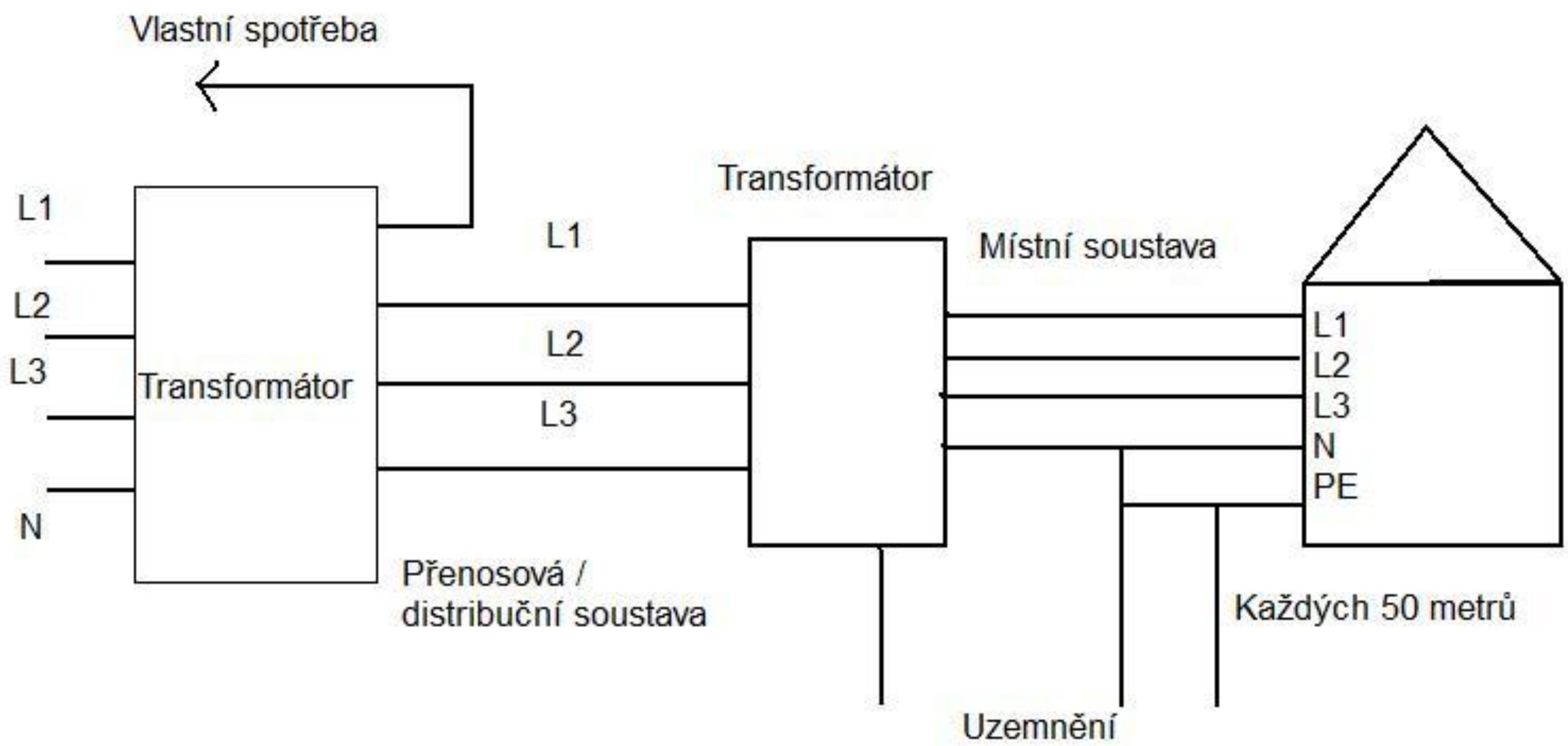


Transfer and Distribution of Electricity



Transfer and Distribution of Electricity

Transfer and Distribution of Electricity



Pricing and Market

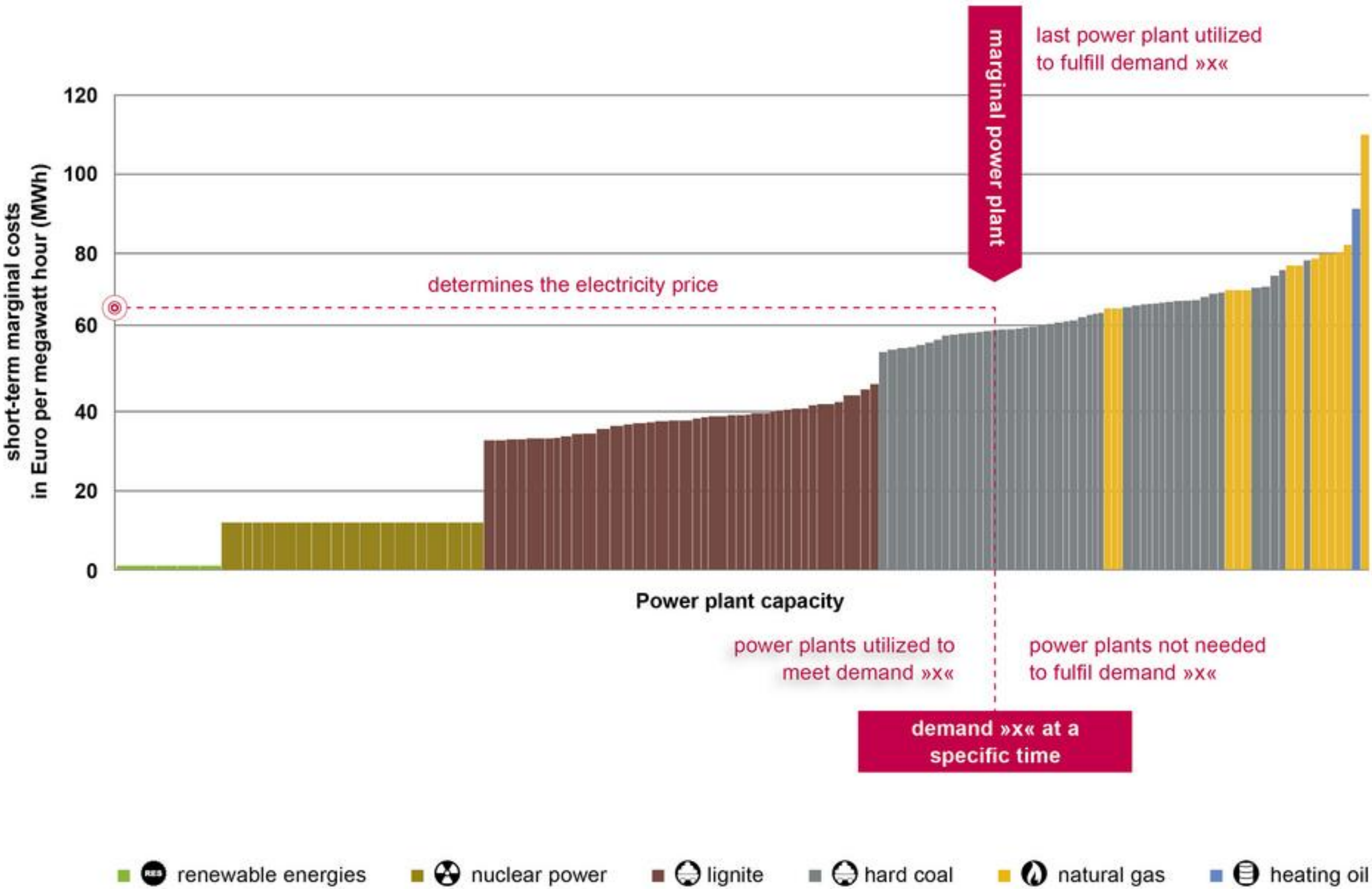
<table>
<tr><th colspan="2">Factors influencing the price of electricity production</th></tr>
<tr><th>Supply Side</th><th>Demand Side</th></tr>
<tr><td>• Production capacity
• Capital expenditures (CAPEX) through depreciation
• Operational expenditures (OPEX)
    • Fuel
    • Emission Allowances
• Weather
    • Hydrology
    • Wind
    • Temperature
• Global price of energy (oil)</td><td>• Macroeconomic factors
• Weather</td></tr>
<tr><td colspan="2">Source: Next Finance (2007): Trh s elektrickou energií v Evropě, Praha, dostupné on-line (http://www.pxe.cz/pxe_downloads/Info/pxe_analyza.pdf), s. 5; adjusted by T. Vlček</td></tr>
</table>

Merit Order Effect (MOE)

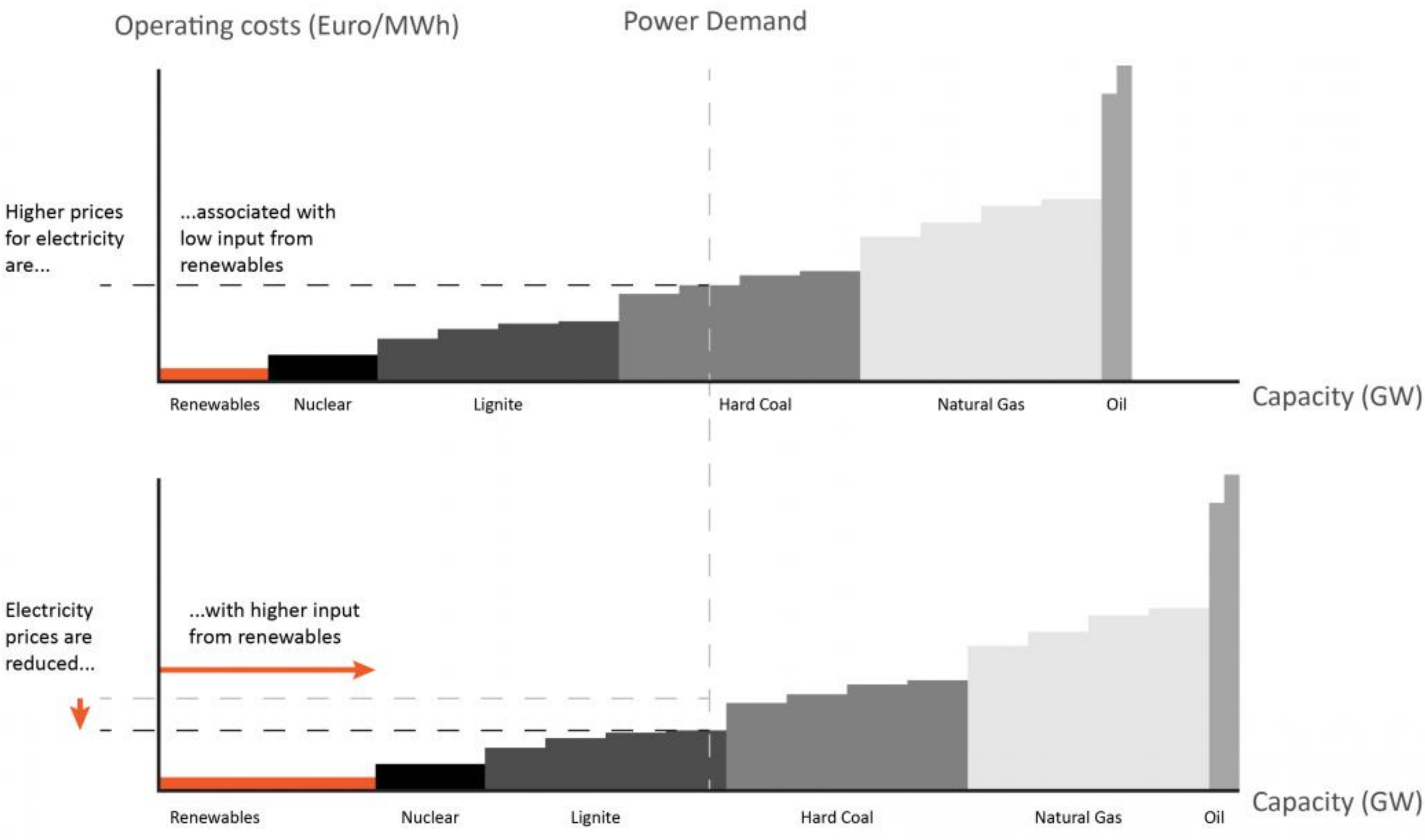
- way of ranking available sources of energy, especially electrical generation, based on ascending order of price together with amount of energy that will be generated
- marginal costs of production reflect the order
- those plants with the lowest marginal costs are the first ones to be brought online to meet demand, and the plants with the highest marginal costs are the last to be brought on line

How supply and demand determine electricity prices

The merit order principle



Illustrating electricity price fluctuations due to the Merit Order Effect



Merit Order Effect (MOE)

- Are RES good or bad?

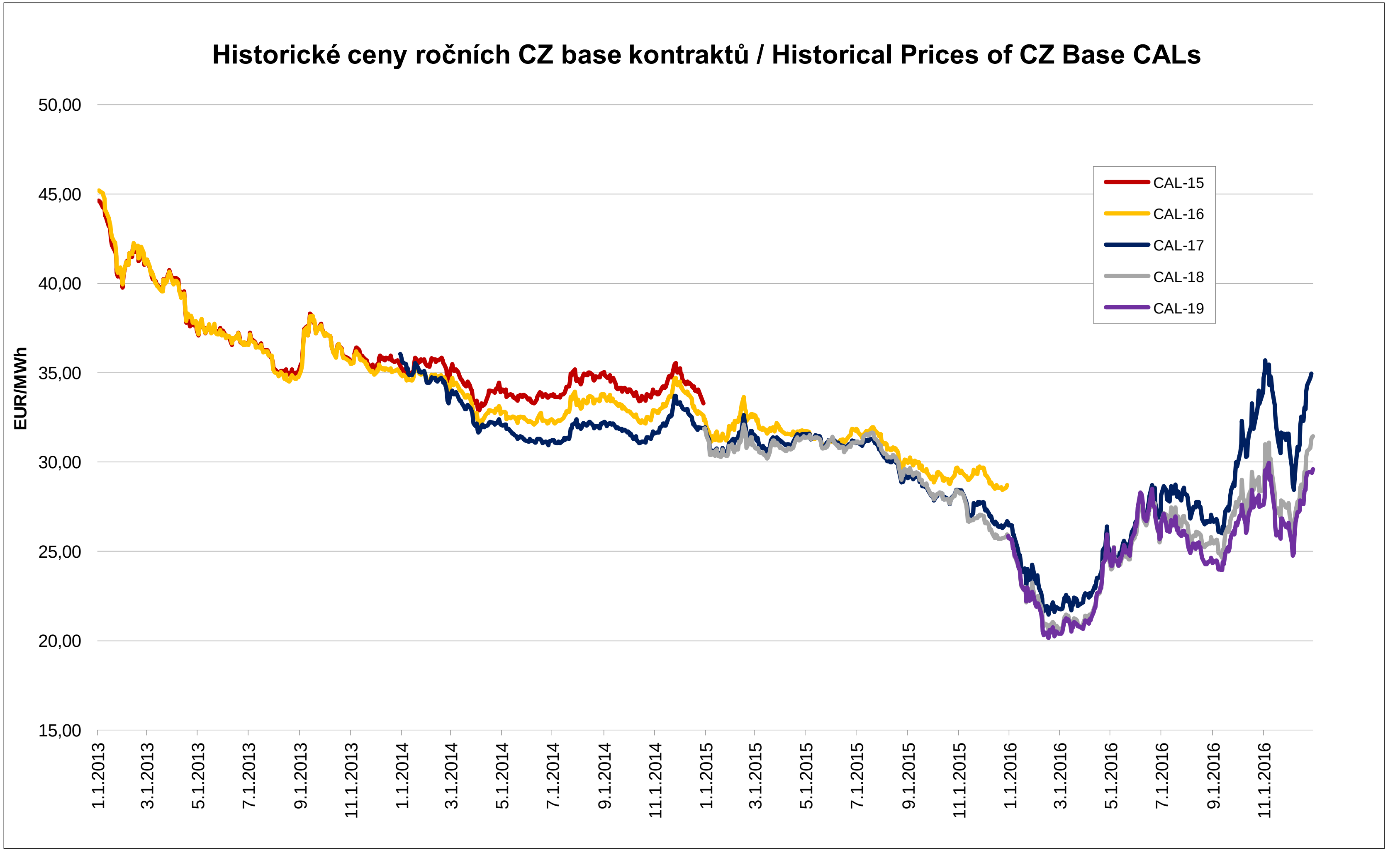
Customer‘s point of view

- Electricity price dropped considerably
- Higher competitiveness for industry vs. support of RES paid by both

Producer‘s point of view

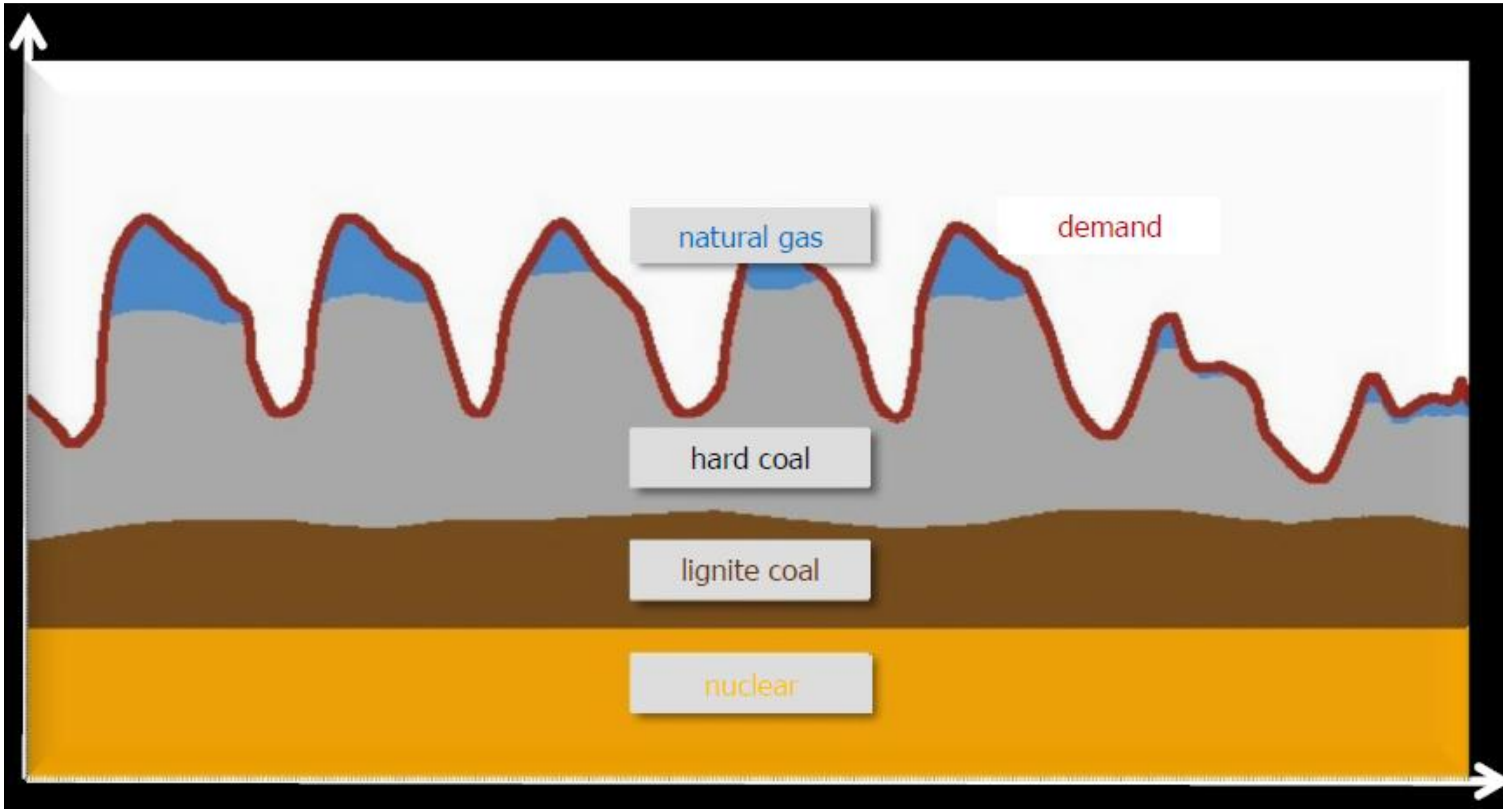
- Lower revenues
- Deformed investment environment
- New market opportunities vs. loss of market

Merit Order Effect (MOE)



Source: PXE

Merit Order Effect (MOE)



Electricity price is determined by the most expensive plant. 1,000 MW coal or nuclear makes no difference for the market. **Nuclear does not equal cheap electricity for the consumer, only sufficient generating capacity equals cheap electricity!**

Pricing and Market - Consumers

- In a liberalized market the final price of electricity consists of the price of electricity (commodity) and a number of regulated components that reflect the naturally monopolistic character, such as transmission and distribution.
- Also the support for RES is among the price components.
- The regulated components are set by the Energy Regulatory Office.

Pricing and Market - Consumers

Share of price components for electricity supply to households in 2010 and 2014		
Electricity incl. margin	42,27 %	30 %
Market operator	0,12 %	0,2 %
System services of ČEPS	3,94 %	2 %
Renewables, cogeneration and decentralized sources	4,41 %	10 %
Electricity distribution and transport	31,86 %	40,2 %
Ecological tax	0,72 %	0,6 %
VAT	16,67 %	17 %
Source: Energetický regulační úřad		

Pricing and Market - Consumers

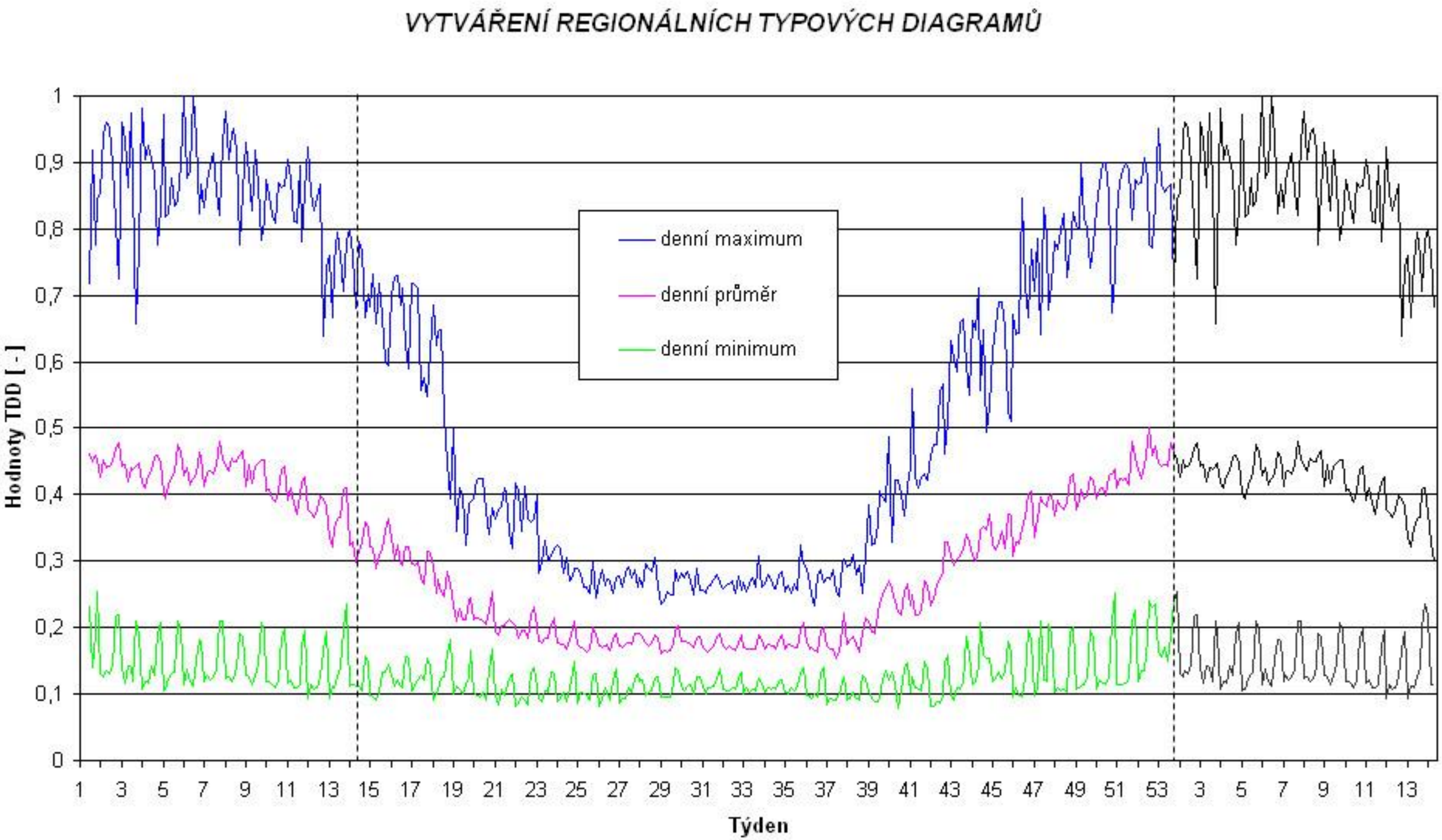
The development of contribution to the RES, CHEP and DS for end consumers								
Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Contribution in CZK per 1 MWh	52,18	166,34	370,00	419,22	583,00	495,00	495,00	495,00

Regulation of Electricity Flows

• The power system is dynamic, permanently active, and within seconds changing system.
•Currently, it is optimized for 50 Hz frequency.
•In this network frequency, the generated active power (which is equal to the sum of active power producing generators throughout the system) is just equal to consumption (sum of inputs of all appliances and network losses).
•The balanced supply of electricity and its consumption is the optimum state of the network.

•Negative symptoms: worsening power quality (frequency reduction), overvoltage, undervoltage networks, brownout, blackout, island operation
•The reasons for the emergence of those conditions are different from planned and unplanned shutdowns of generating units, through unexpected damage to transformers, substations and networks, the consequences of the current weather conditions (eg. heavy snowfall, the sharp drop in the outdoor temperature, etc..), or changes in electricity production from renewable resources (ie., wind and solar power).
•These conditions are prevented by regulatory backups

Baseload vs. Peakload



Regulation of Electricity Flows

Simplified Chart of Regulatory Backups of ČEPS, a.s.			
Systém Service	**Code**	**Timframe**	**Description**
Regulatory Backup – Seconds (Regulační záloha vteřinová)	RZV	30 seconds	Primary regulation
Regulatory Backup – 15 Minutes (Regulační záloha dosažitelná do 15 minut)	RZ15	15 minutes	Secondary regulation, sources with 10 and 15 minutes start-up time
Regulatory Backup – 30 Minutes (Regulační záloha kladná dosažitelná do 30 minut)	RZ30+	30 minutes	Tertiary positive regulation (dispatch regulation, load adjustment, import) within 30 minutes
Negative Regulatory Backup – 30 Minutes (Regulační záloha záporná dosažitelná do 30 minut)	RZ30-	30 minutes	Tertiary negative regulation (dispatch regulation, load adjustment, import) within 30 minutes
Regulatory Backup – 30+ Minutes (Regulační záloha (netočivá) dosažitelná v čase delším než 30 minut)	RZN>30	30+ minutes	Regulatory dispatch backup, import, within 30+ minutes
Source: ČEPS, a.s. (2010): *Roční příprava provozu na rok 2011*, Praha, ČEPS, a.s., on-line text (http://www.ceps.cz/doc/soubory/20101203/RPP_2011.pdf), s. 4.P3. Výběr a úprava T. Vlček.			

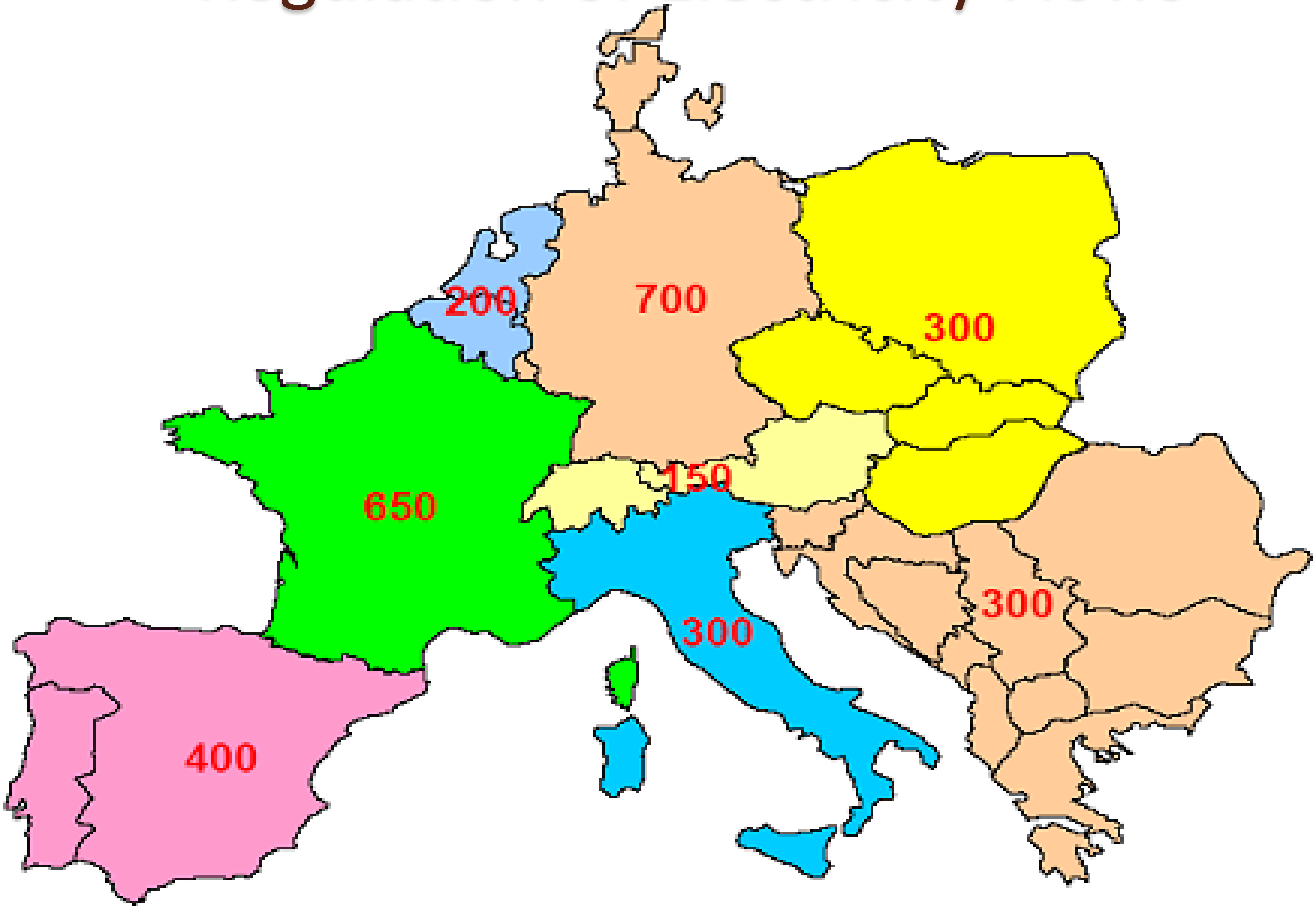
Regulation of Electricity Flows

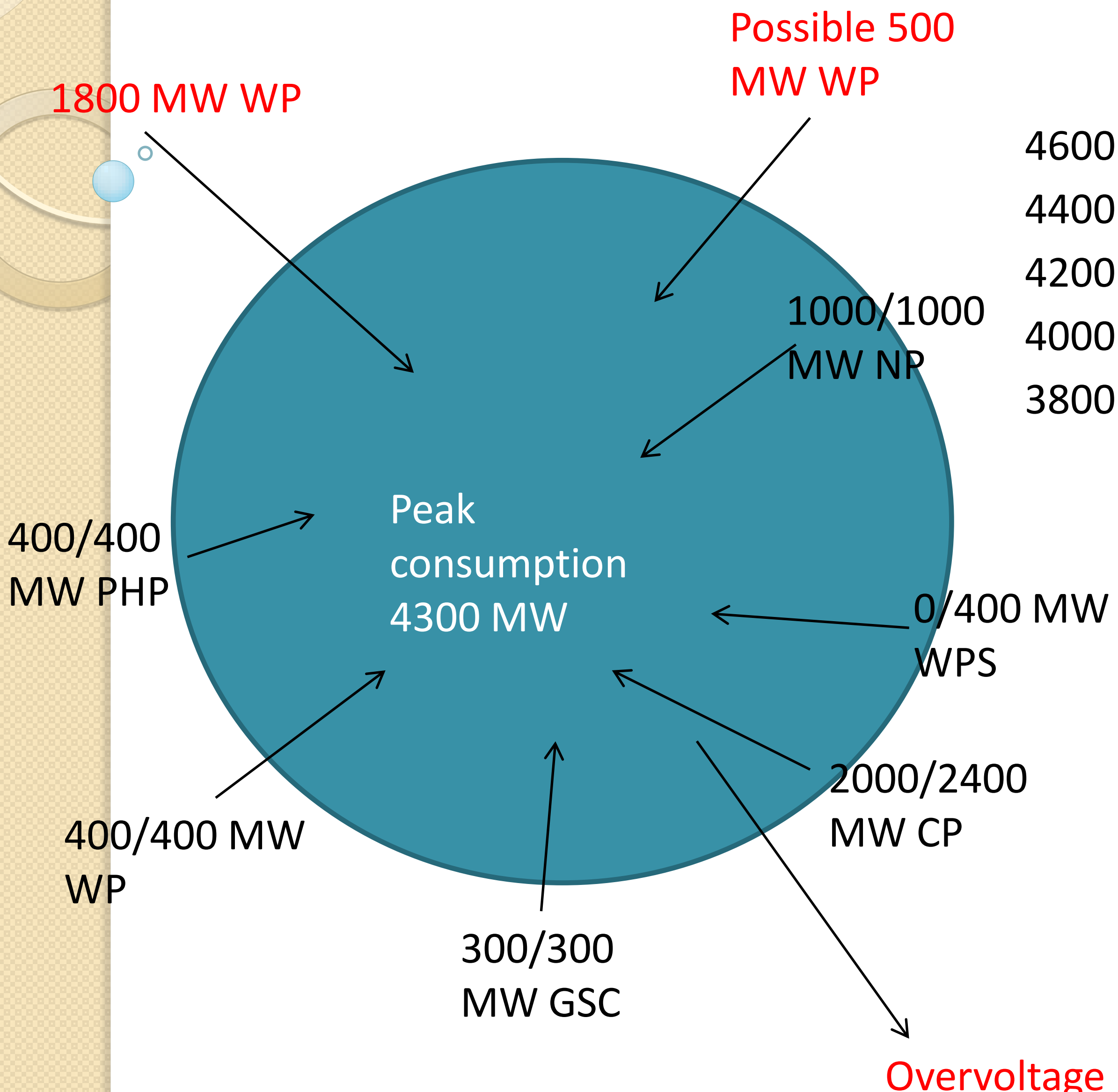
https://youtu.be/9Fi-eu4lQMo?t=5m5s

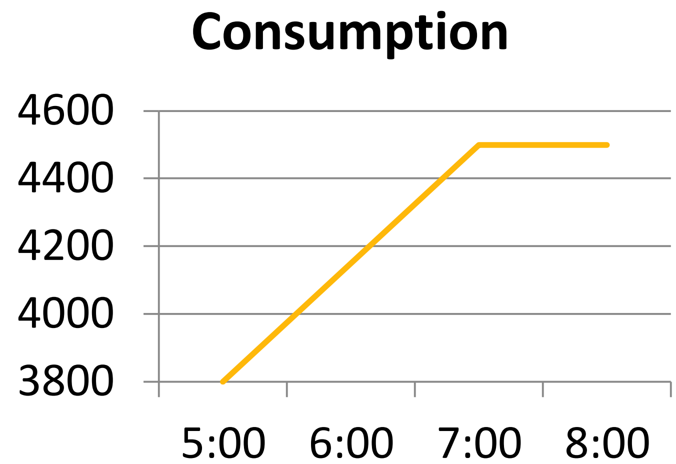
Regulation of Electricity Flows

Maximal regulatory backup for 2011 (Czech Republic, MW)										
	RZV		**RZ15**				**RZ30+**		**RZ30-**	
	RZPR		**RZSR**		**QS10**		**RZTR+, RZN30+**		**RZTR-, RZN30-**	
	Night	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**
Work days	88	88	290	340	500	600	220	360	220	310
Weekends	88	88	290	340	500	600	210	360	220	310
Source: ČEPS, a.s. (2010): *Roční příprava provozu na rok 2011*, Praha, ČEPS, a.s., on-line text (http://www.ceps.cz/doc/soubory/20101203/RPP_2011.pdf), s. 4.P3-4.P4. Úprava T. Vlček.										

Regulation of Electricity Flows

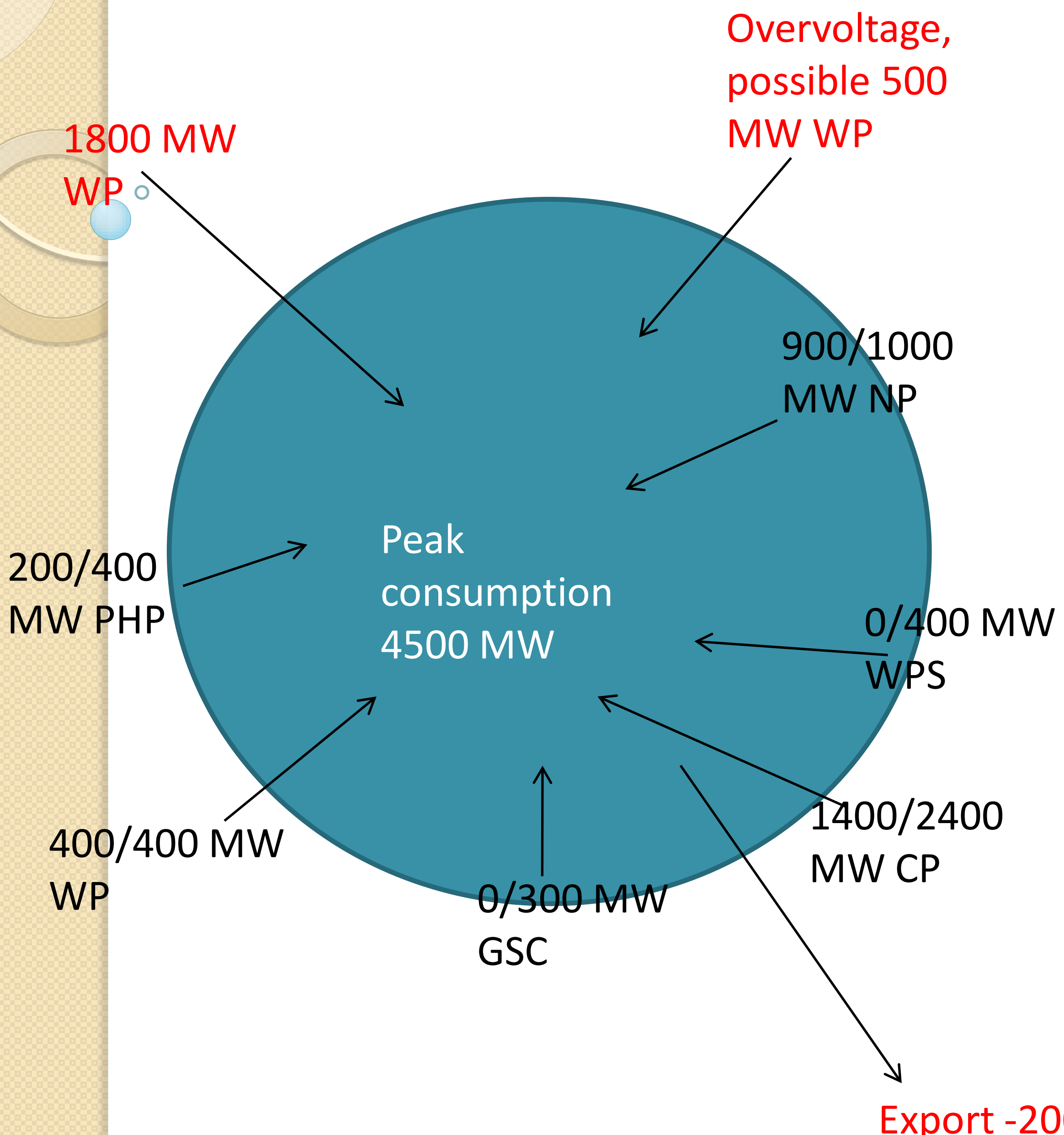






<u>Known consumption</u>
Base 3800 MW
Peak 4500 MW

6:30 Cons. 4300 MW
6:31 +1800 MW VTE from neighbour, rising frequency, overvoltage imminent



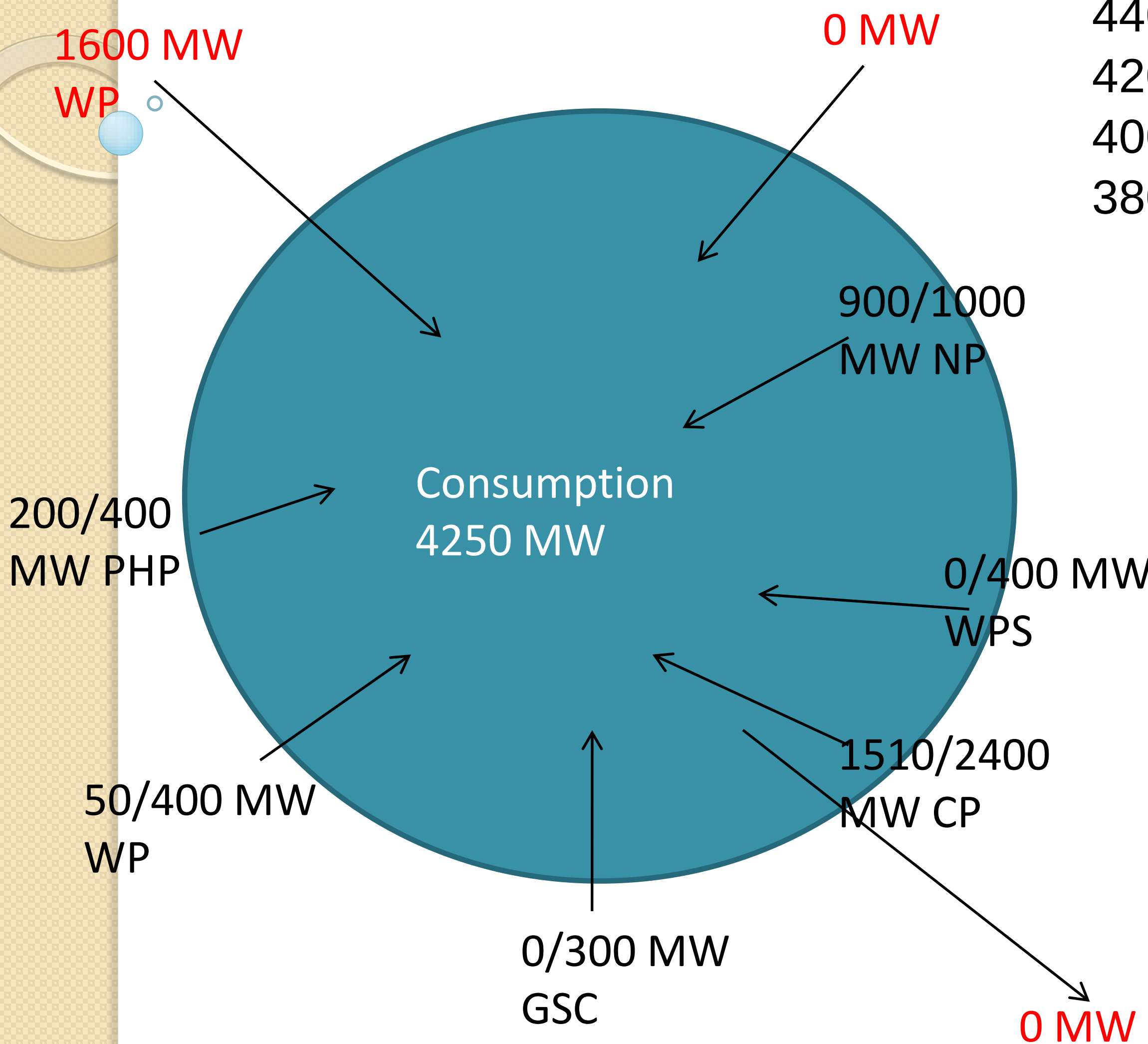
<u>Solution:</u>
PHP drop by 200 MW

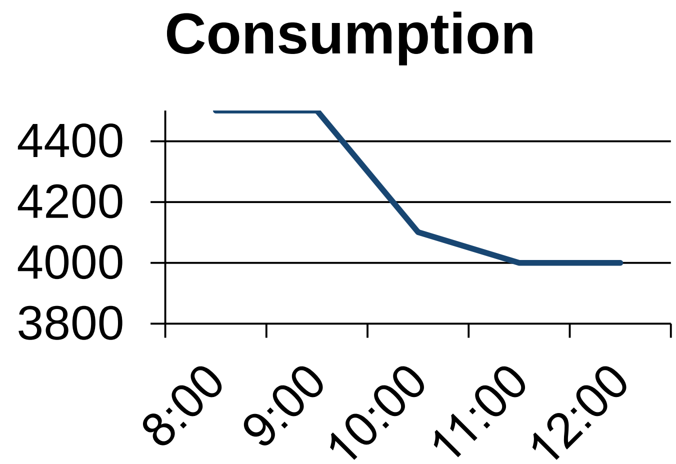
Seconds
-300 MW (GSC)
Export -200 MW

15 minutes
-800 MW (CP, -30 %, maximum without stopping the plant)

30 minutes
-100 MW (NP, 10 %)

With the electricity price of 30 euro the regulation cost 42 000 euro. (200 MW export, 200 MW PHP used, 1400 MW regulated)



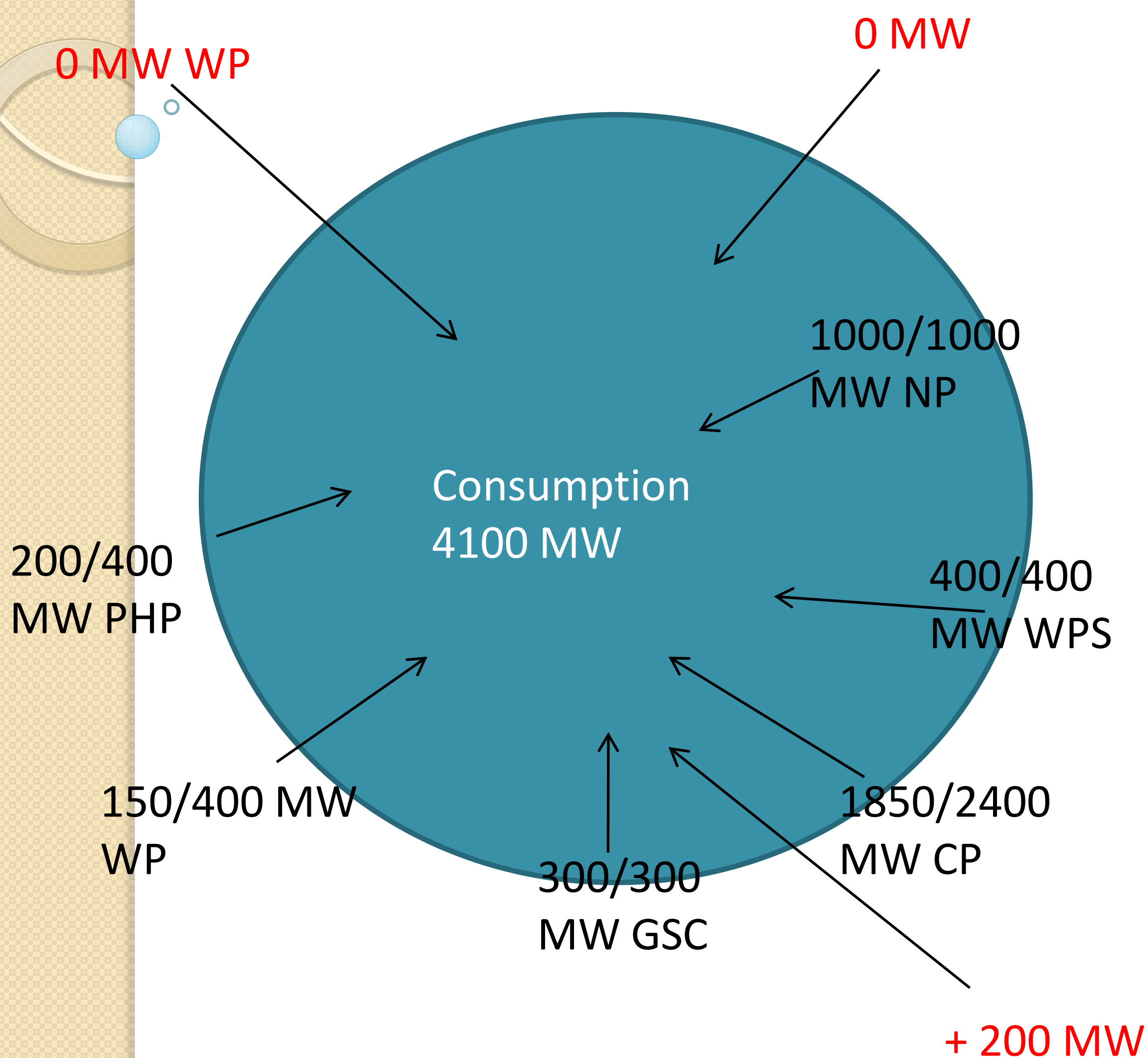


<u>Known consumption</u>

Base 3800 MW

Peak 4500 MW

9:15 Cons. 4250 MW
9:30 Cons. 4200 MW
9:31 Drop in the wind production reported. From 1600 to 0 MW in 30 minutes. Drop in frequency, electricity quality, undervoltage.
10:00 Anticipated cons. 4100 MW



At 10:00 the cons. 4100 MW and import 0 MW.

<u>Solution:</u>

Seconds
+ 300 MW RZV (GSC)
+ 100 MW RZV (WPS partly)

15 minutes
+ 200 MW import
+ 300 MW (rest of WPS)
+ 200 MW (some of the CP)
+ 100 MW (NP full operation)

30 minutes
+ 140 MW (rest of CP)

With the electricity price of 30 euro the regulation cost 34 200 euro. (200 MW import, 1140 MW regulated)