Transmission and Distribution Systems

Dr. Goran Majstrović
Energy Institute Hrvoje Pozar (EIHP)
Croatia

ERRA Tailor-made Educational Workshop: Power System Basics for Non-Engineers
January 26-28, 2020 | Muscat, Oman

Contents

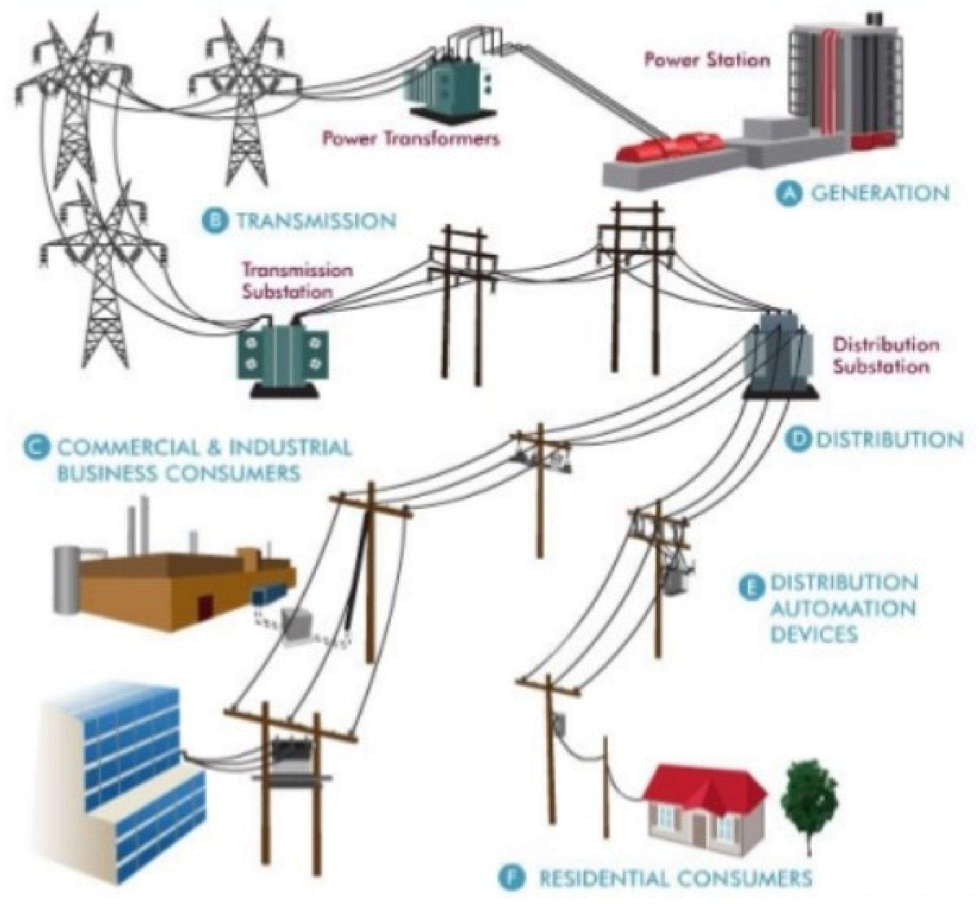
1. **Electricity transmission**

   - Description of transmission: comparison with distribution
   - Main transmission system equipment
   - Reliability and quality issues
   - Transmission system planning

2. **Electricity distribution**

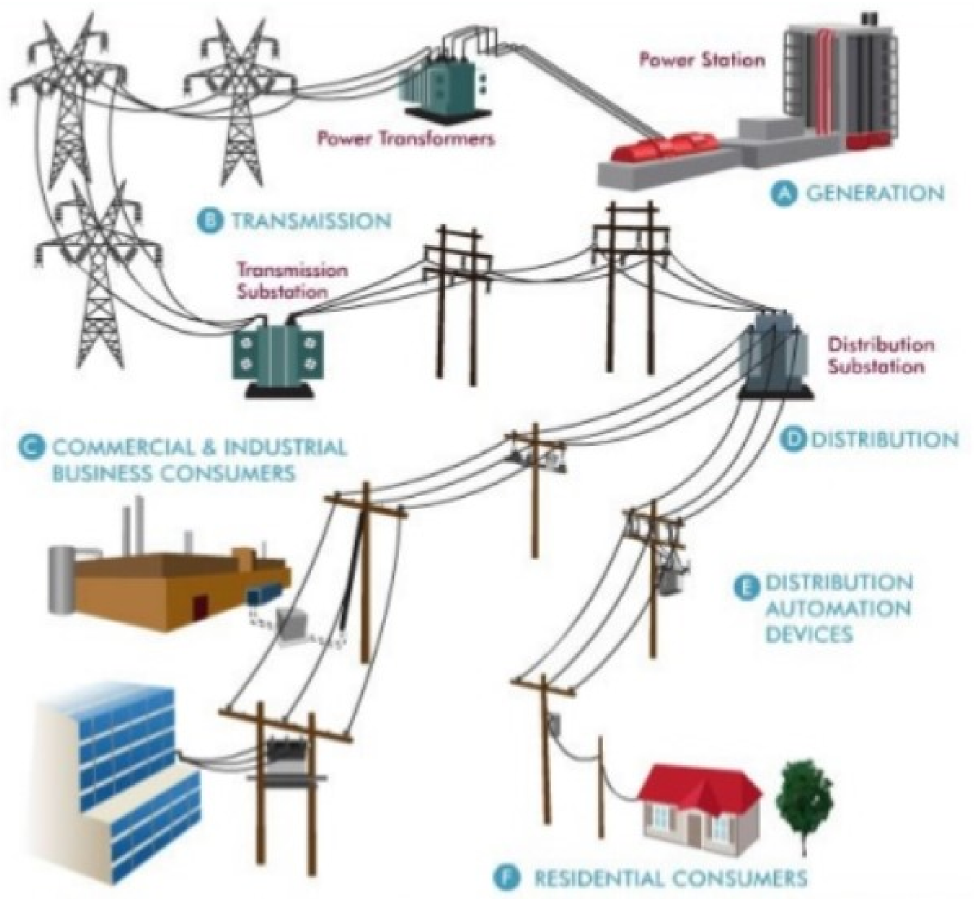
   - Main distribution system equipment
   - Reliability and quality issues
   - Distribution system planning
   - Distributed generation issues
   - Smart grids and smart meters

Power system is the most complex “device” in mankind history



1) billions of independent and connected devices
2) millions of independent and connected users
3) different needs and possibilities
4) simultaneous production/consumption with no (significant) storage
5) physical specifics (frequency, voltage, dynamics..)
6) financially intensive with long component lifetime and payback period competing in the spot market

Power system is the most complex "device" in mankind history



Power system (grid) is the greatest engineering achievement

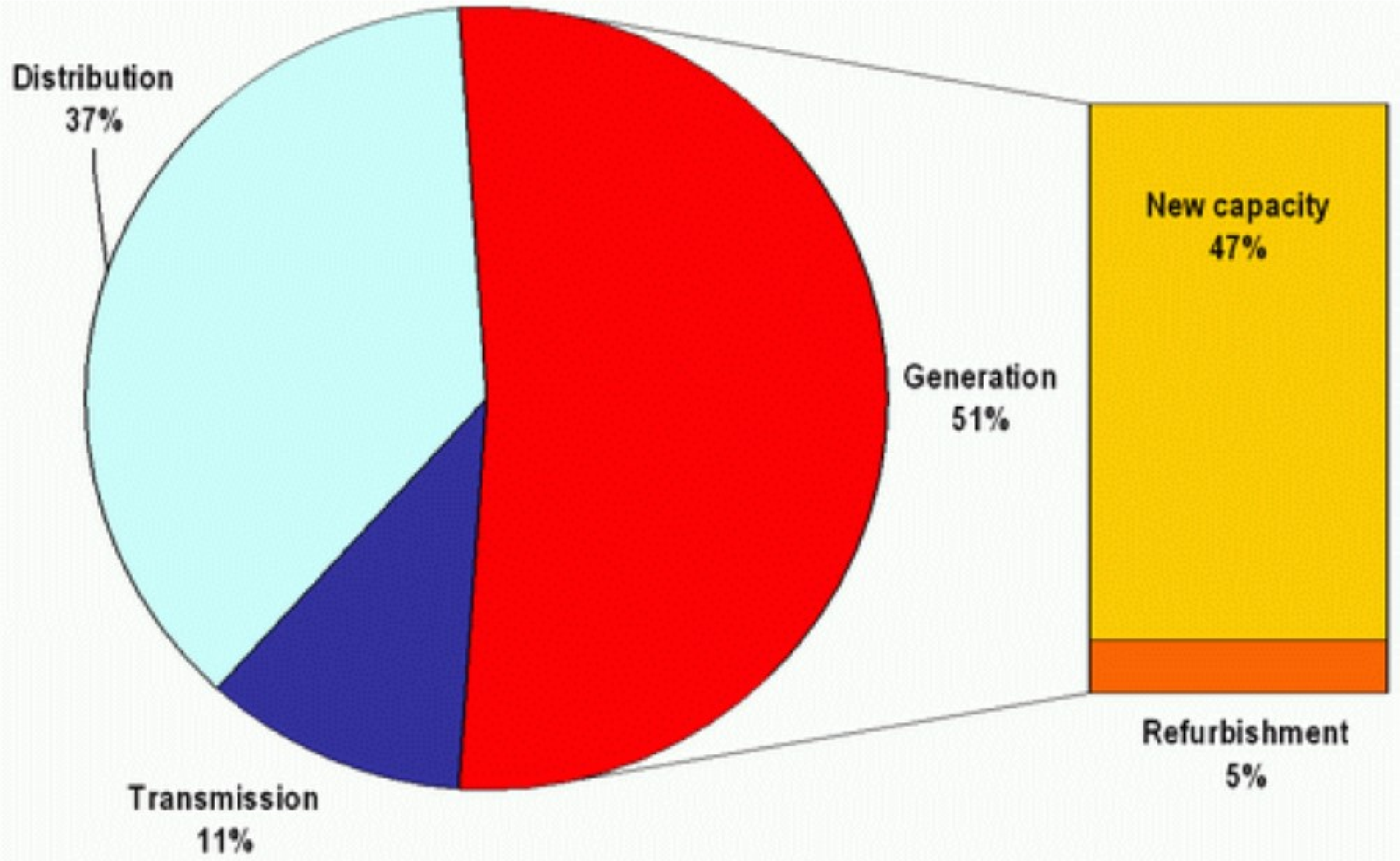
AND

its design and operation are much more complex than any aircraft

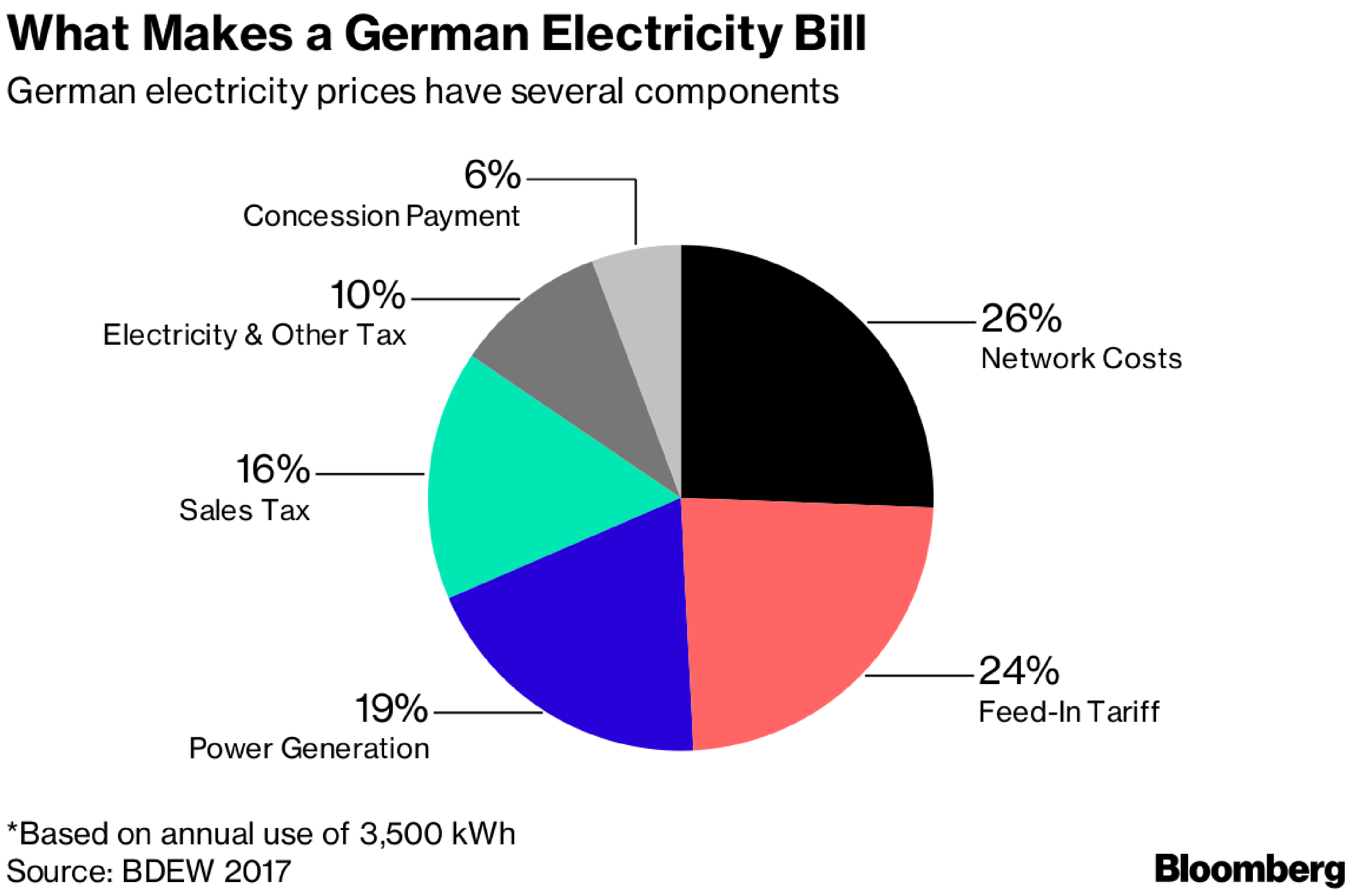
BUT

we seem to think we can randomly connect new devices to it with no overall game plan in mind.

Power system components' share



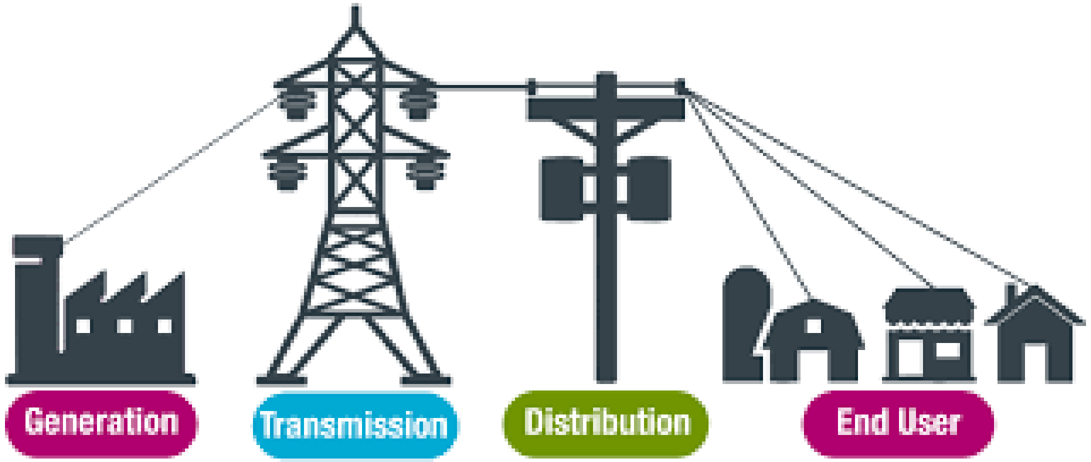
Electricity bill shares



#1 ELECTRICITY TRANSMISSION

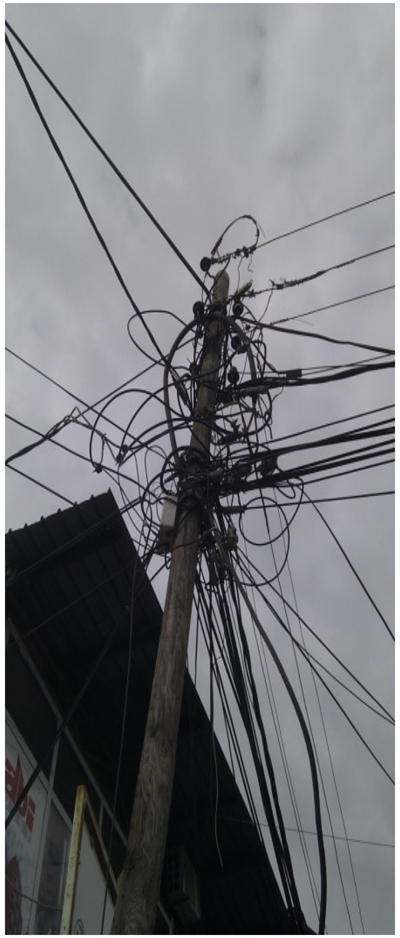
Transmission system definition

Transmission system definition



Electric power transmission is the **bulk movement of electrical energy** from an electricity generating site to distribution network.

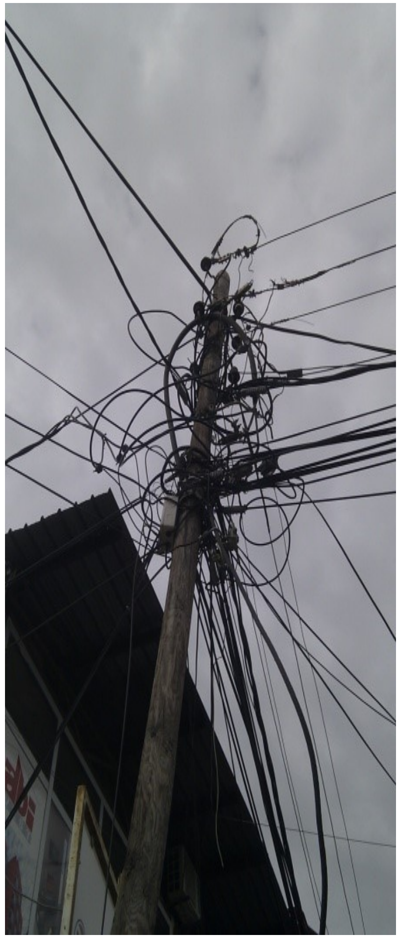
Transmission VS Distribution



Traditional definitions of T&D vary a lot among countries, power systems and companies. Generally, there are 3 main distinctions:

1. **By voltage level:** Transmission is usually above 35 or 66 kV
2. **By function:** Transmission includes EHV lines and transformers, distribution mainly comprises of feeders, service transformers and more equipment
3. **By configuration:** Transmission mostly includes loops, distribution radial networks

Transmission VS Distribution



Modern definitions of T&D are evolving in market sense:

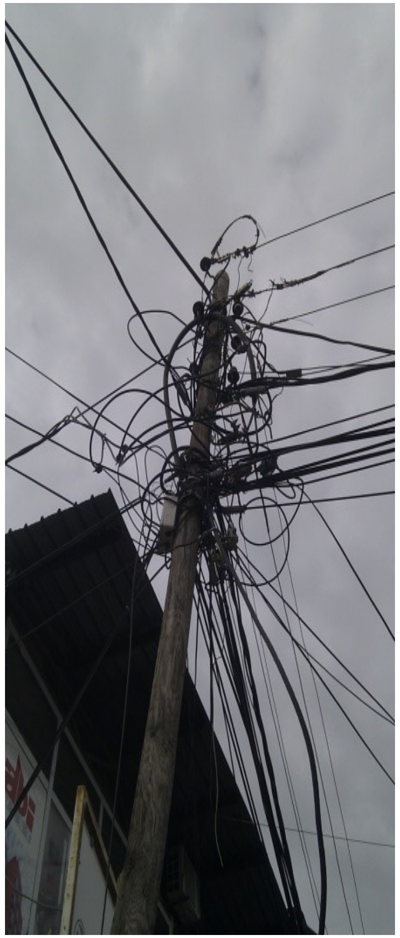
1. **Transmission** assumes wholesale level grid

2. **Distribution** assumes retail level grid

Due to unbundling easier distinction of:

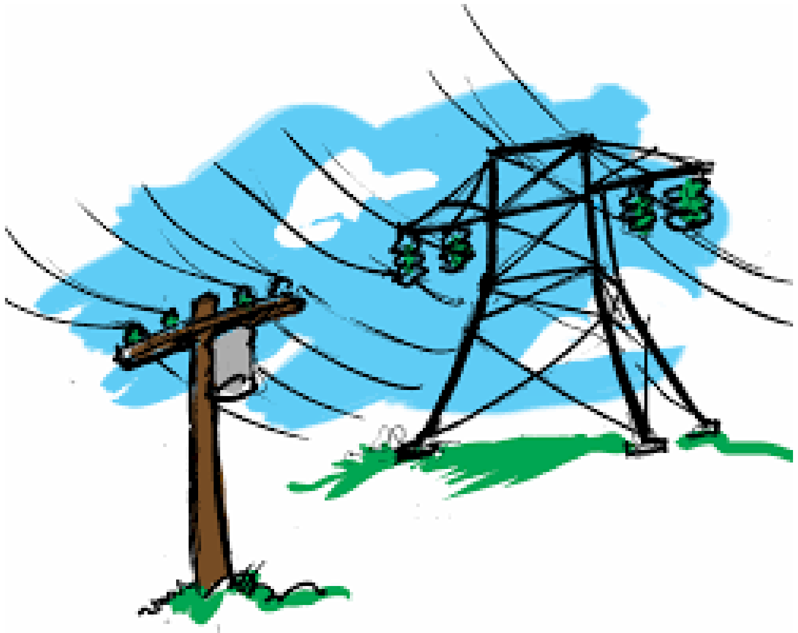
- ownership
- operation
- maintenance

Differences between transmission and distribution



	Transmission	Distribution
Topology	Meshed	Radial/meshed
Electricity market	Wholesale	Retail
Quality of supply		More critical
Congestions	More critical	
Investments	Individual - more critical	Total - more critical
System control	More critical	

Electricity network basics



T&D distinction vary a lot among countries

Transmission: 66 – 1100 kV

High voltage (HV): 66 - 220 kV (50 – 300 MVA)

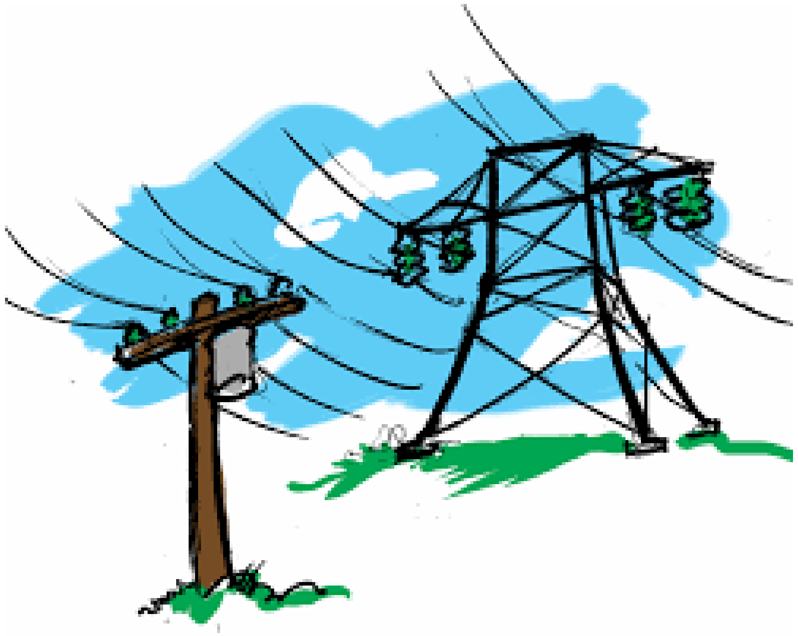
Extra high voltage (EHV): 330 - 1100 kV (500-2000 MVA)

Distribution: 0.4 kV - 66 kV

Mid voltage (MV): 1 - 66 kV (1-50 MVA)

Low voltage (LV): 0.4 – 1 kV (0.01-1 MVA)

Electricity network basics



Typical mid-size system with few hundred thousand customers might have up to:

~hundred transmission lines
~hundred substations
~few hundred feeders
~few tens of thousands of service transformers
~**2000 MW** of the peak load
~4000 MVA of transformer capacity
~6000 MVA of feeder capacity
~**9000 MVA** of energy transformer capacity

Non-coincident demand

Transmission network basics

1. **More economically efficient** to transfer electric power at **high voltage**: higher voltage → lower equipment unit costs per MW → lower losses

2. Very expensive to change voltage levels

3. **More economically efficient** to produce electricity in large amounts

4. Distributed generation sometimes provide the lowest overall costs due to T&D constraints and respective costs

Network losses

$$Power\ (P) = Voltage\ (V) * Current\ (I)$$

$$Loss = I^2 R = \left(\frac{S}{V}\right)^2 R = \frac{P^2 + Q^2}{V^2} R \approx \frac{R}{V^2} P^2 = K \cdot P^2$$

For the same P, a higher V reduces I → reduced losses

(raising V by a factor of 10 reduces I by a corresponding factor of 10 and therefore the losses by a factor of 100)

Transmission network basics

REDUNDANCY:

Transmission system is **redundant** - power can be routed from any power plant to any load center through a variety of routes, based on the Kirchoff laws

REGULATORY PROBLEM:

Single outage must not jeopardize power transfer.

Consumers must not pay for system overbuilding.

→transmission operation, maintenance and planning **more complex in market environment**

Transmission network basics

RELIABLE CAPACITY:

Maximum reliable capacity of the line is usually less than its physical or thermal limit due to system security criteria

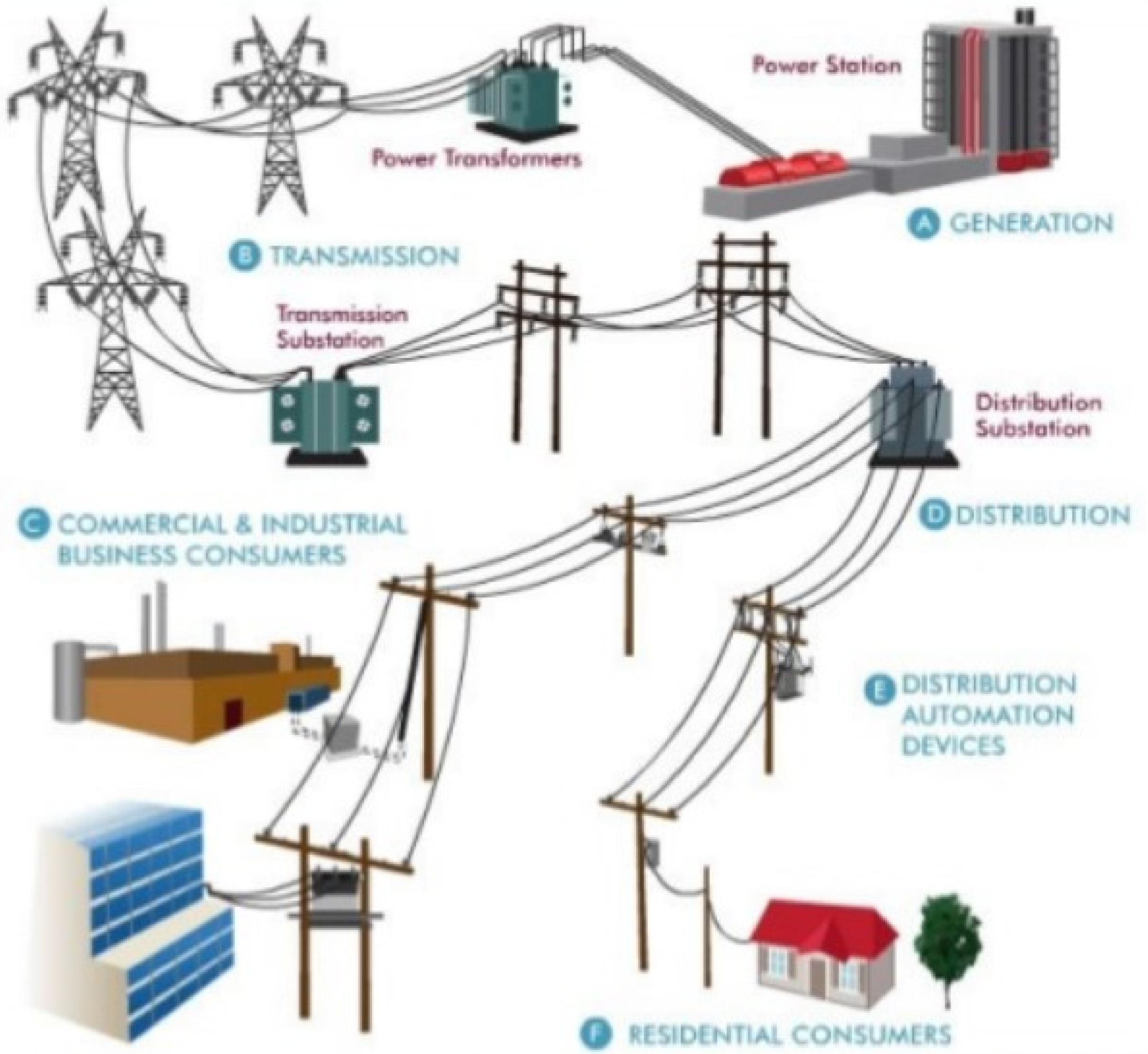
REGULATORY PROBLEM:

→ to find real value of reliable capacity

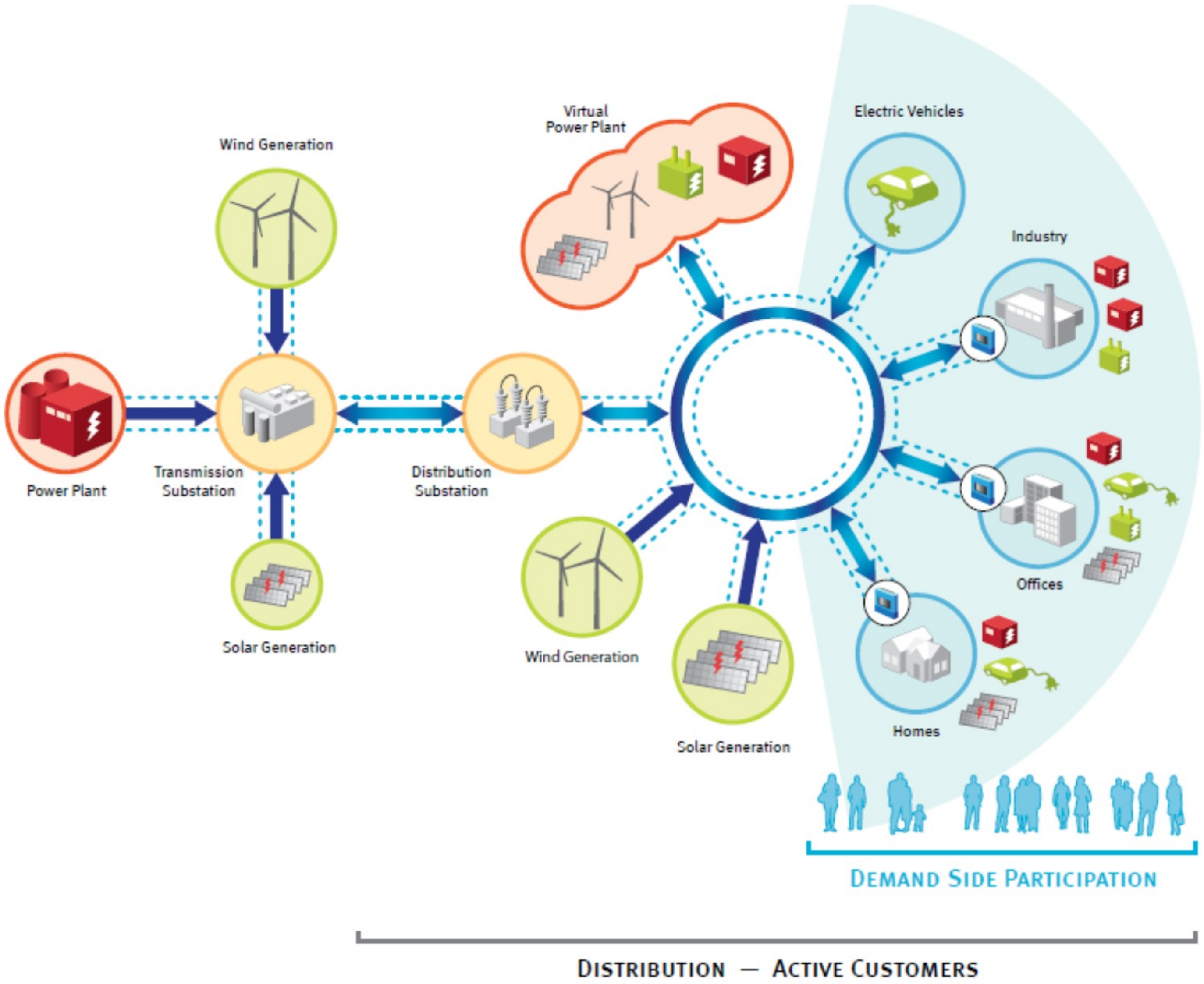
→ not to corrupt possible power exchanges without solid technical reason

Transmission system equipment

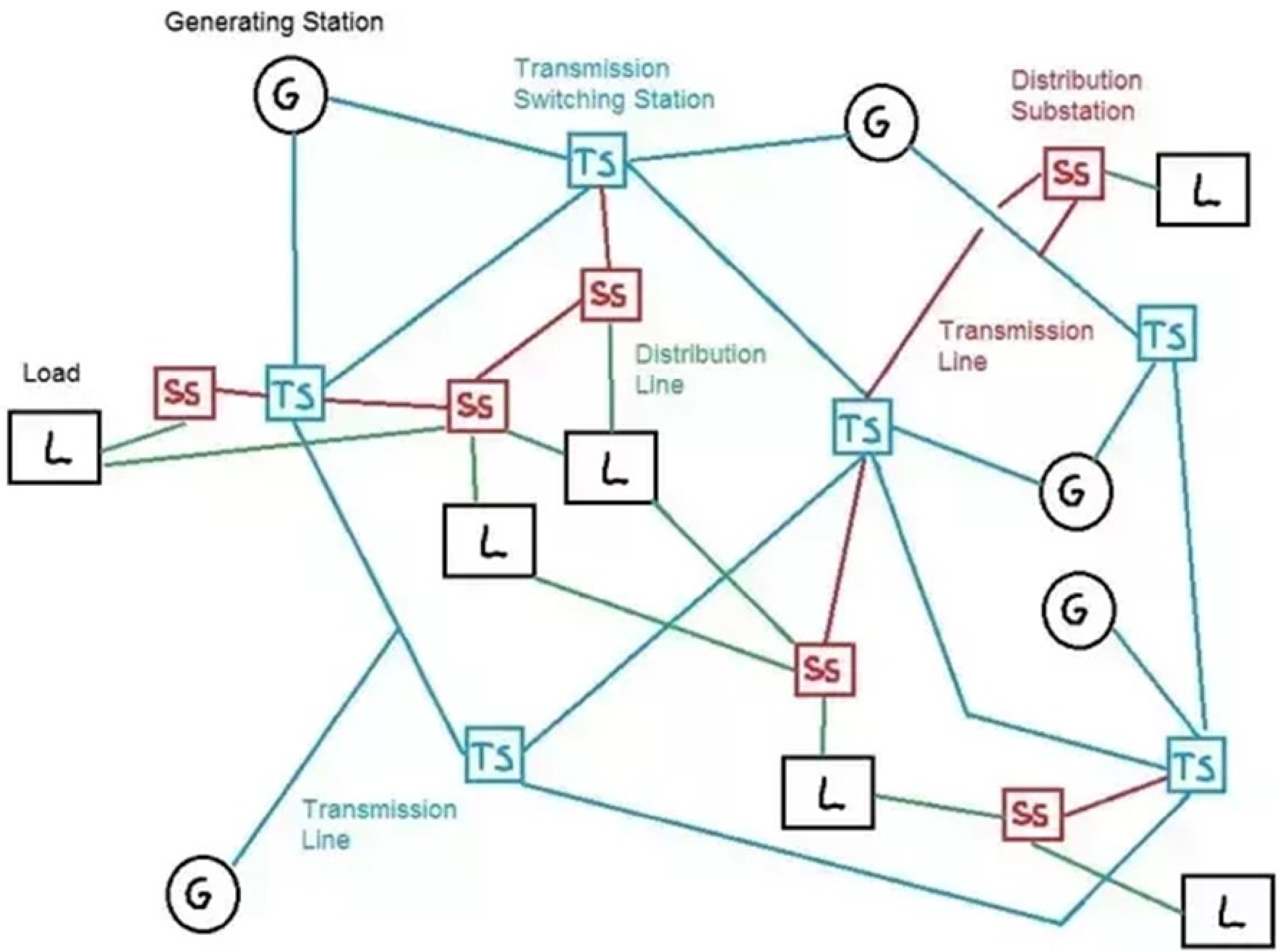
Classic power system



New age power system



Classic power system



Transmission records

- **Highest AC transmission voltage:**
  1150 kV Ekibastuz-Kokshetau (Kazakhstan)

- **Highest DC transmission voltage:**
  +/-600 kV on HVDC Itaipu (Brazil)

- **Highest pylons:**
  345 m at Yangtze River Crossing (China)

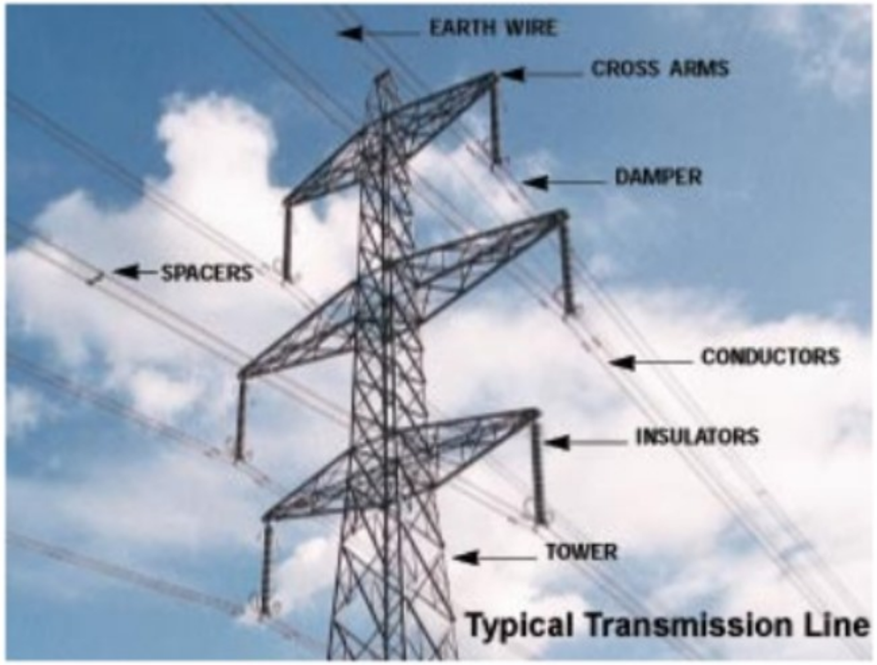
- **Longest powerline:**
  1700 km at Inga-Shaba (Congo)

- **Longest span of powerline:**
  5376 m at Ameralik Span (Grenland)

- **Longest cable:**
  290 km at Basslink, Bass Strait (Australia)

- **Deepest cable:**
  1000 m HVDC link Galatina (ITA)-Arachtos (GR)

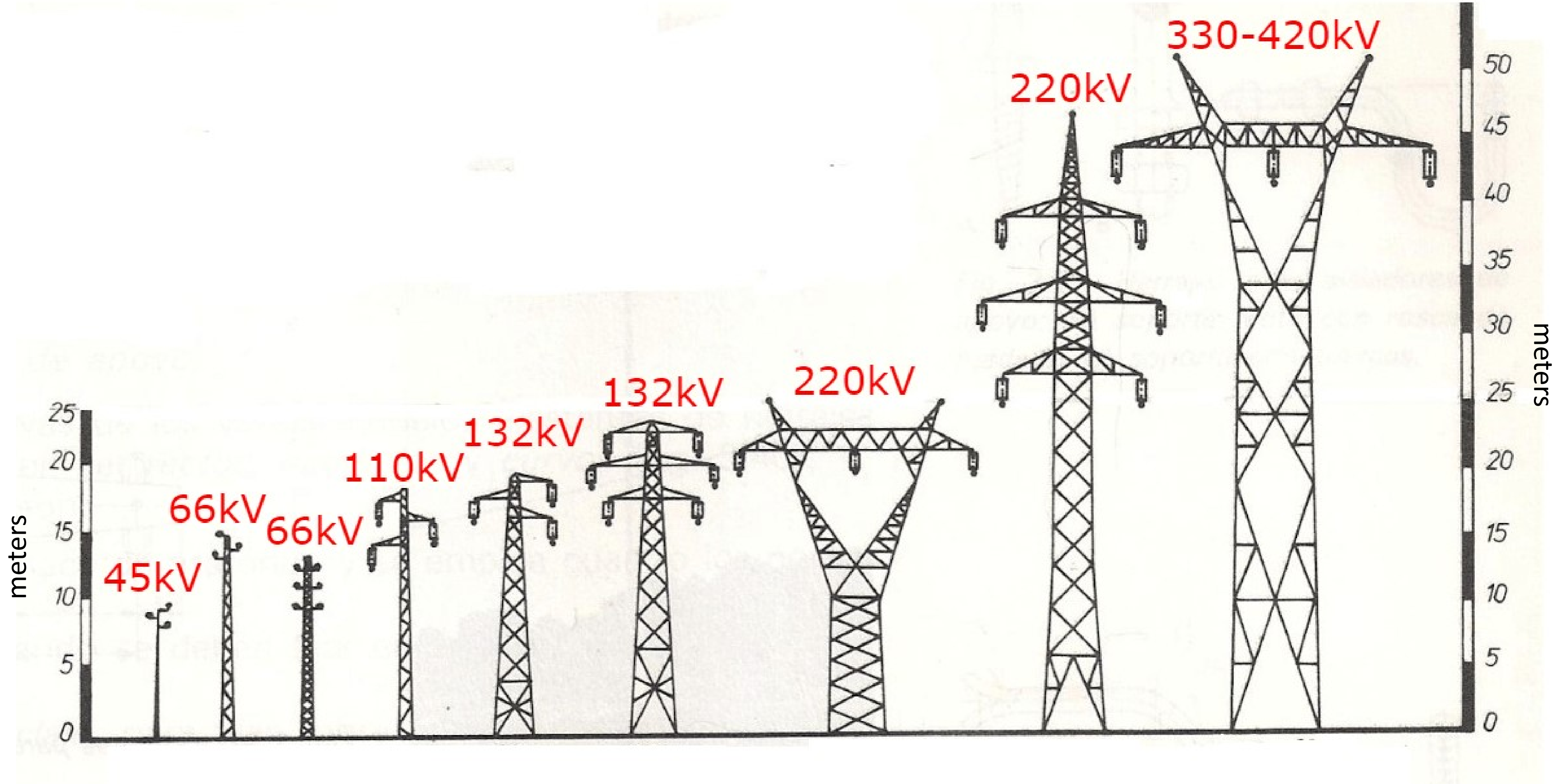
Main transmission equipment



Lines

Substations

Power line towers



Power line towers

A single-circuit 330 kV line

A double-circuit line

Parallel single-circuit lines

Four circuits on one tower line

six circuits of three different types

Various powerlines (110/220 kV) in Germany with double and quadruple circuits

Power line towers

S.No.	Voltage level	G. clearance(m)
1.	≤33 KV	5.20
2.	66 KV	5.49
3.	132KV	6.10
4.	220 KV	7.01
5.	500 KV	8.84

Height of Tower

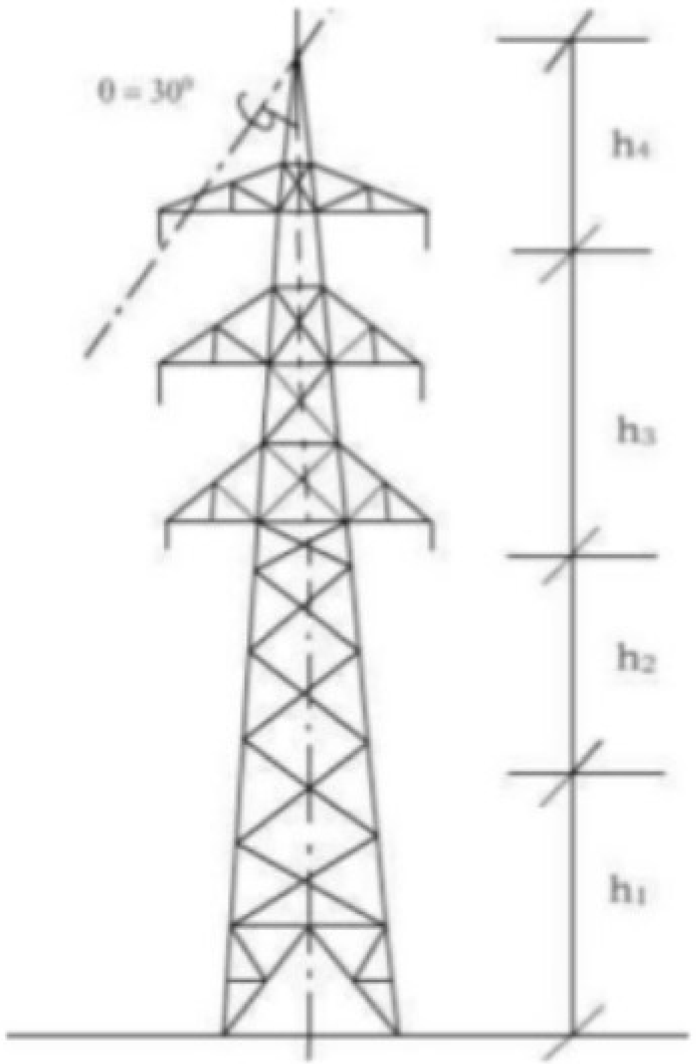
$$H = h_1 + h_2 + h_3 + h_4$$

h_1 = Minimum permissible ground clearance

h_2 = Maximum sag

h_3 = Vertical spacing between conductors

h_4 = Vertical clearance between earth wire and top conductor



Spacing between conductors (phases)

Mecomb's formula

$$Spacing(cm) = 0.3048 \cdot V + 4.010 \frac{D}{W} \sqrt{S}$$

Where-

V= Voltage of system in KV

D= Diameter of Conductor in cm

S= Sag in cm

W= weight of conductor in Kg/m

VDE formula

$$Spacing(cm) = 7.5\sqrt{S} + \frac{V^2}{2000}$$

Where-

V= Voltage of system in KV

S= Sag in cm

Lines and cables

Electricity lines and cables **conductors** are usually made of:

- Aluminium
- Copper

The **reason** ?

- Electric conductivity
- Weight, strength and durability
- Cost
- Installation flexibility

Lines and cables

Aluminum conductor **advantages**:

1. Better weight (lighter) than copper
2. Cheaper than copper
3. Aluminum conductors reinforced with steel (ACSR) are primarily used for mid- and high-voltage

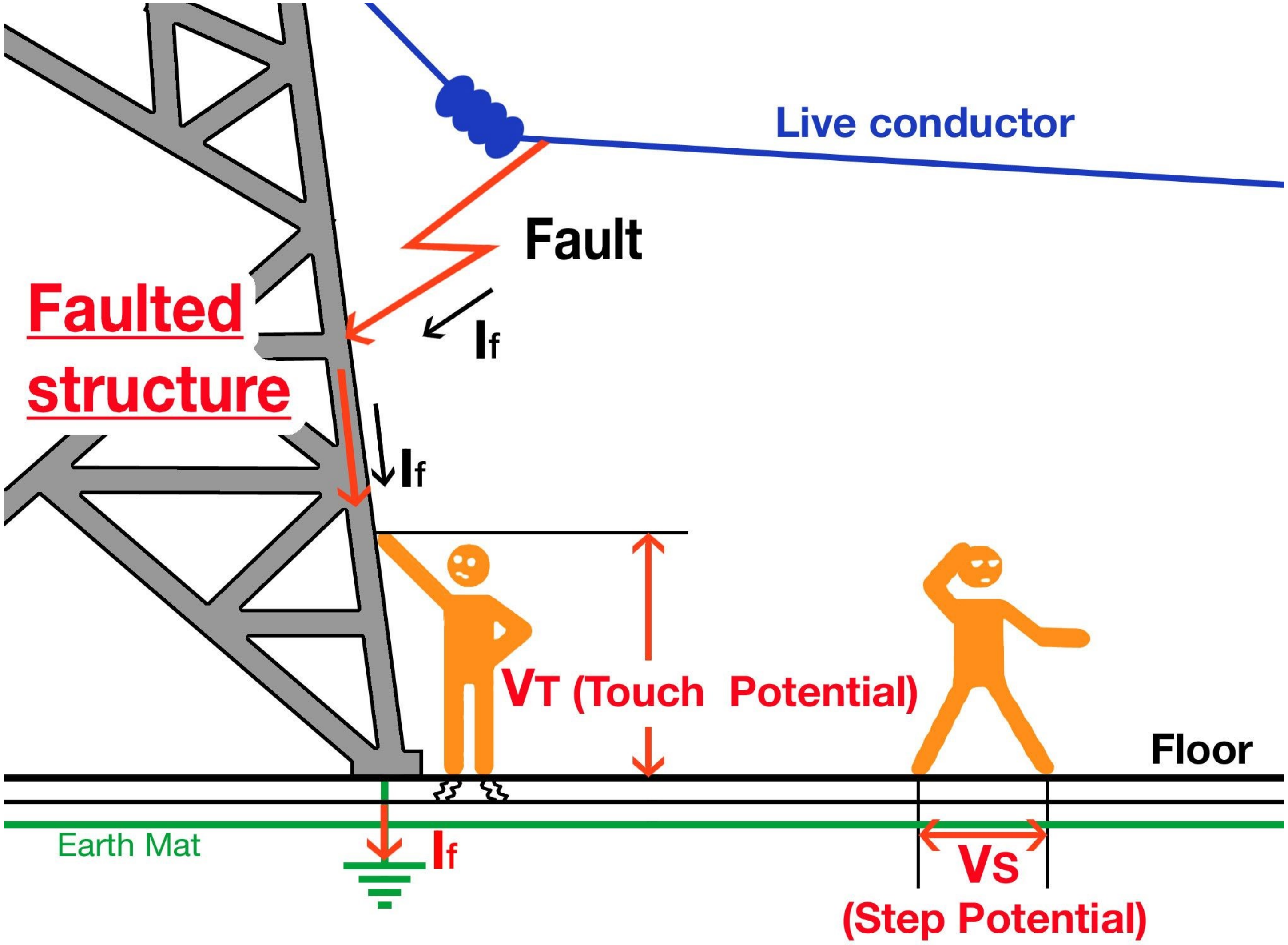
Copper conductor **advantages**:

1. Better conductivity
2. Less insulation and armoring
3. Higher resistance to heat
4. Primarily used at low-voltage

Insulation

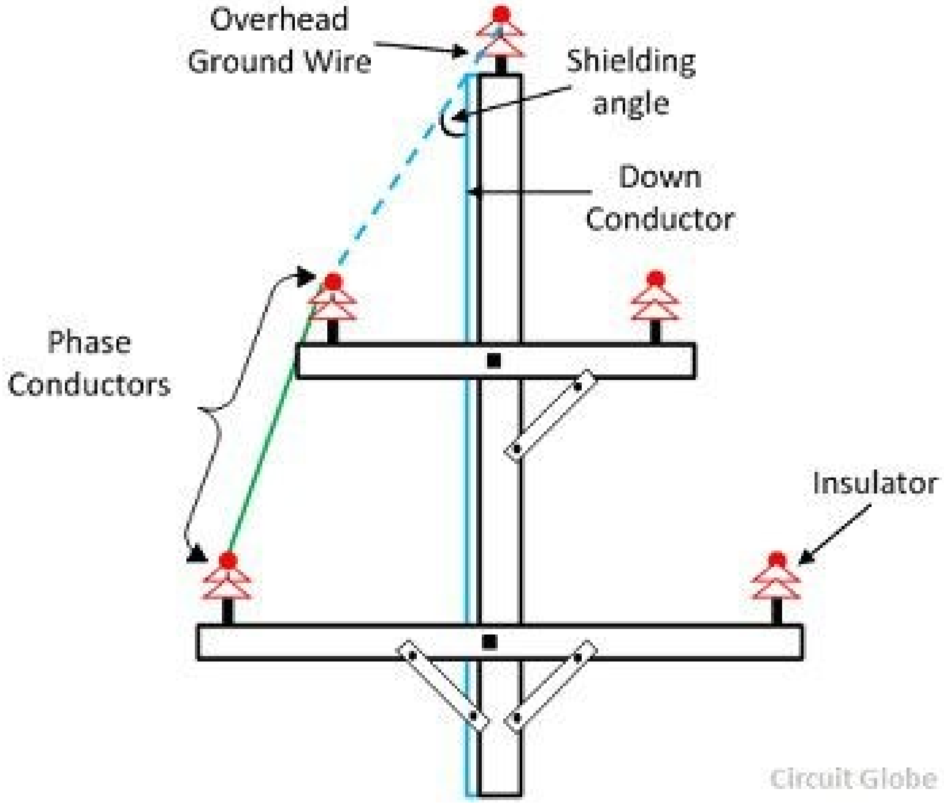
- Transmission lines are **not insulated (isolated by “air”)**
- Transmission line is carrying extreme high voltage and it would require a lot of **thick insulation**.
- **Low chance** of touching it - height from the ground.
- It is **too costly** to insulate these lines.
- In case of **underground cables**, insulation is required to avoid the live cables touch earth and get shorted.
- **Distribution** lines are closer to ground and people and therefor **insulated**.

Lines and cables

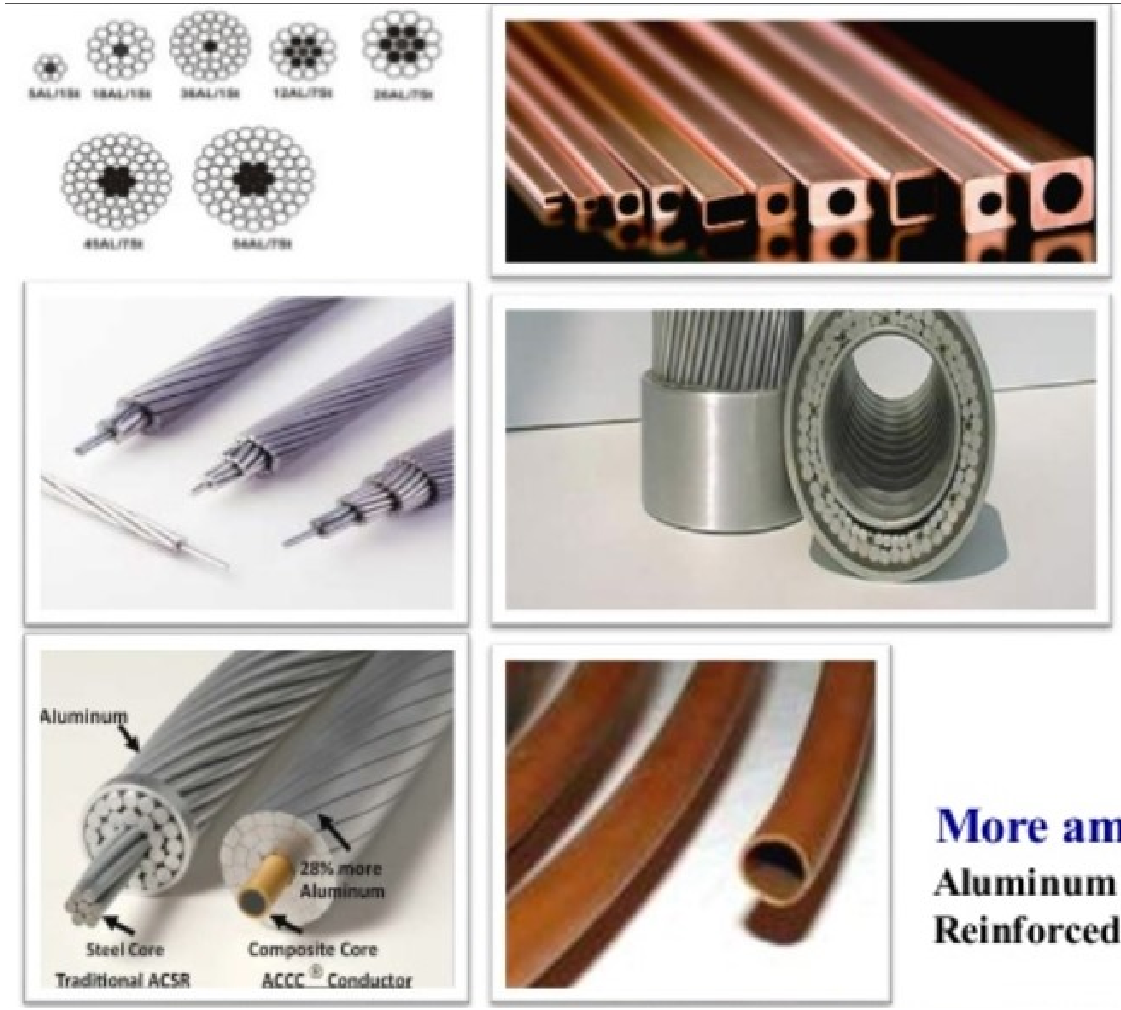


Lines and cables

Conductors	
1. Suspended wires for electric power transmission are bare, except when connecting to houses, and are insulated by the surrounding air. Cooper has been replaced by Aluminum with steel wire core to provide the material strength.	
1. Underground cable – insulated	
1. Sea cable – insulated	



Lines and cables



More amps on the same size

Aluminum Conductor Composite Reinforced (ACCR)

Lines and cables

Types

1. Hard Drawn Copper
2. Cadmium Copper Conductor
3. Steel Cored Copper Conductor
4. Copper Weld Conductor
5. Alluminium
6. Hard Drawn Alluminium
7. All Alluminium Conductor
8. All Alluminium Alloy Conductor
9. Alluminium Conductor Steel Reinforced (ACSR), (ACCC)

Criteria

1. Cost
2. Life
3. Brittle
4. Weight
5. Resistance
6. Power loss
7. Tensile Strength
8. Low specific-gravity
9. Temerature Co-efficient
10. Shorter Sag

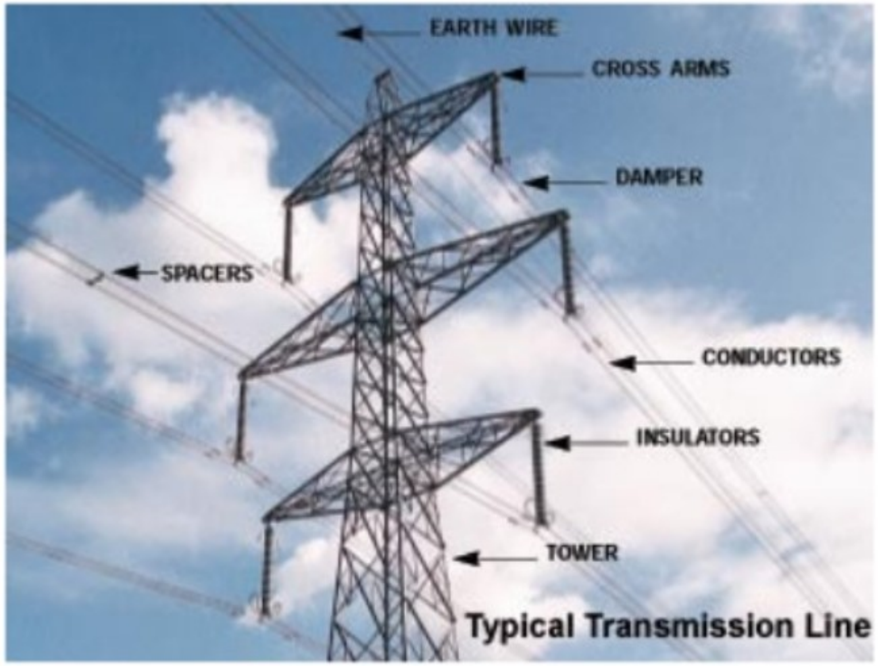
Profiles

Lines and cables

Example: HVDC submarine cable

Voltage level:	±450 kV
Rated power:	**700 MW**
Diameter:	13 cm

Main transmission equipment



What is earth (ground) wire ?

1. OHL are equipped with ground conductor (shield wire or earth wire)

2. It is grounded conductor at the **tower top** to minimize the likelihood of direct lightning strikes to the phase conductors

3. **Sometimes** there are **two ground conductors**

4. Ground conductor **may include optical fibers** (OPGW) used for communication and control

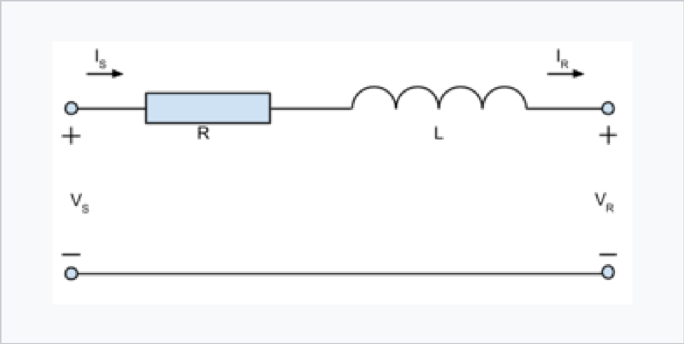
Lines and cables

Short line (<80 km) can be characterized with:

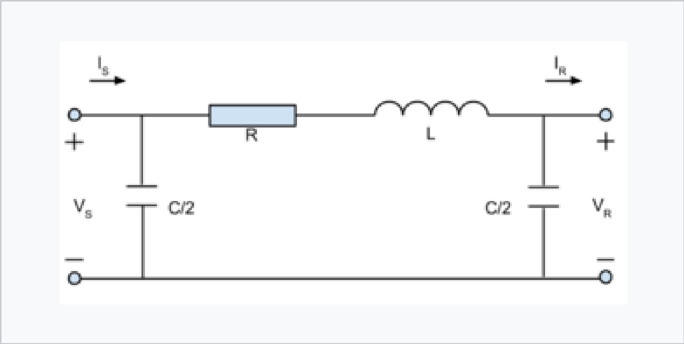
$$Z = zl = (R + j\omega L)l$$

Where:

Z - total series line impedance
z - series impedance per unit length
l - the line length
ω – sinusoidal angular frequency



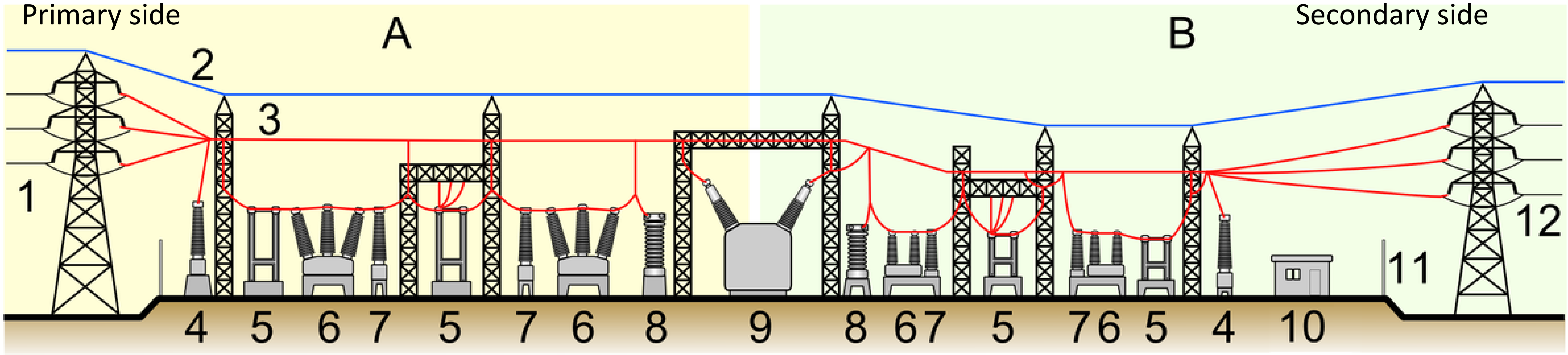
Short length of power line



Medium length of power line

Substations

Substations



1. Primary power lines
2. Ground wire
3. Overhead lines
4. Voltage transformer
5. Disconnect switch
6. Circuit breaker
7. Current transformer
8. Lightning arrester
9. Energy transformer
10. Control building
11. Security fence
12. Secondary power lines

Substations

GIS (up to 420kV)
(image courtesy of Siemens)

Gas-insulated system (**GIS**)

Lower space, more reliable, more expensive

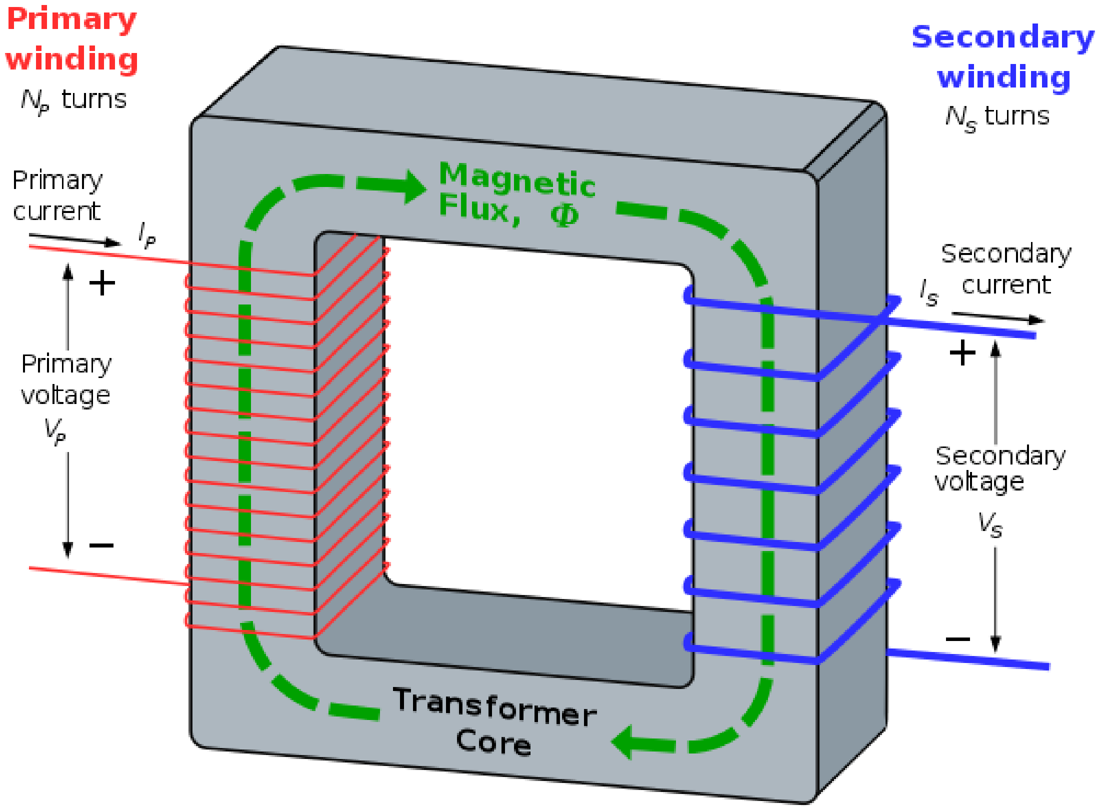
Typical 132kV AIS bay

Air-insulated system (**AIS**)

Larger space, less reliable, less expensive

Transformers

Electrical device designed to **convert alternating current from one voltage to another** using magnetic induction principle. It can be designed to "step up" or "step down" voltages.



$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S} = \sqrt{\frac{L_P}{L_S}} = a$$

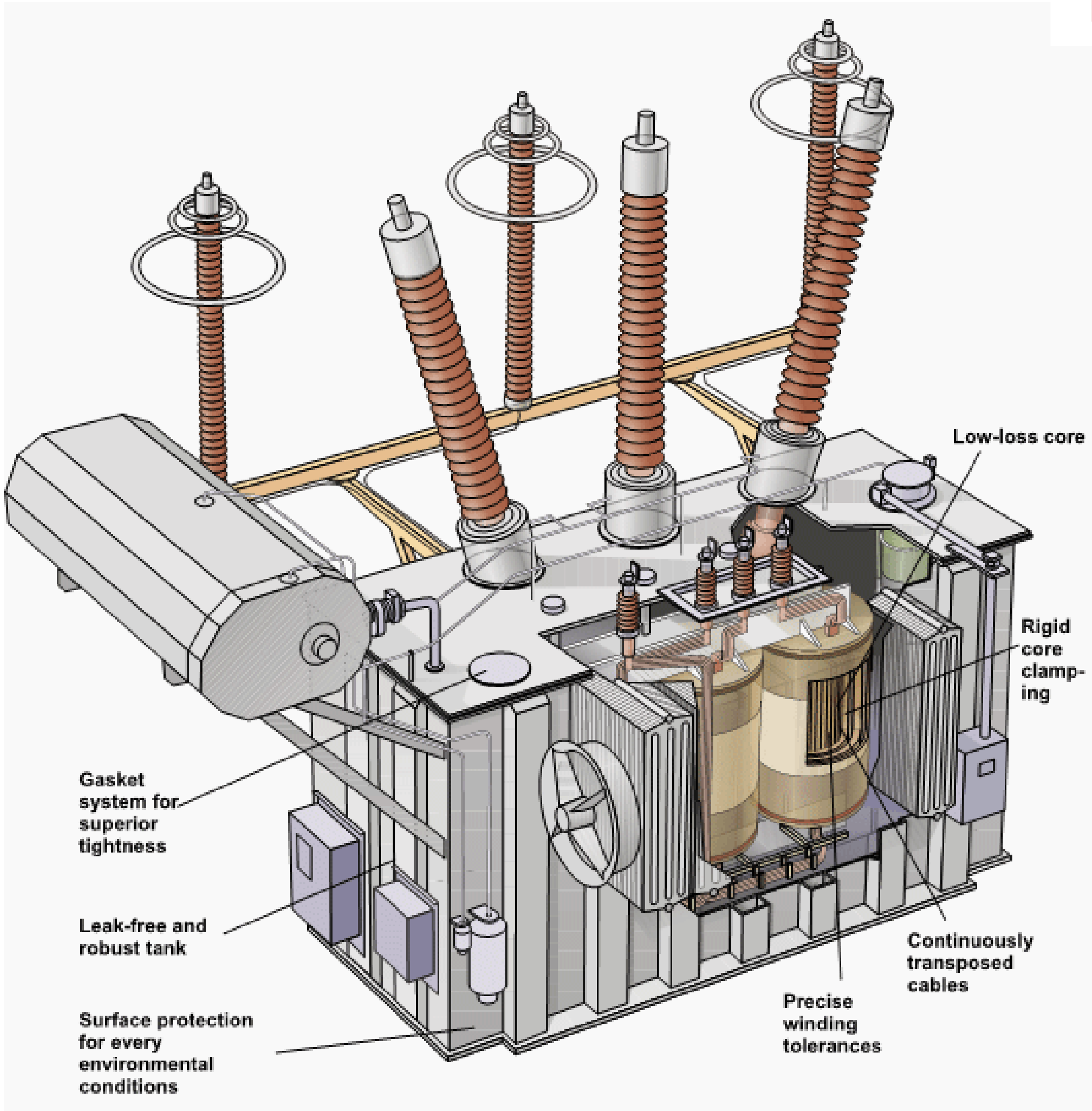
Why transformer ?

For the same P=V*I

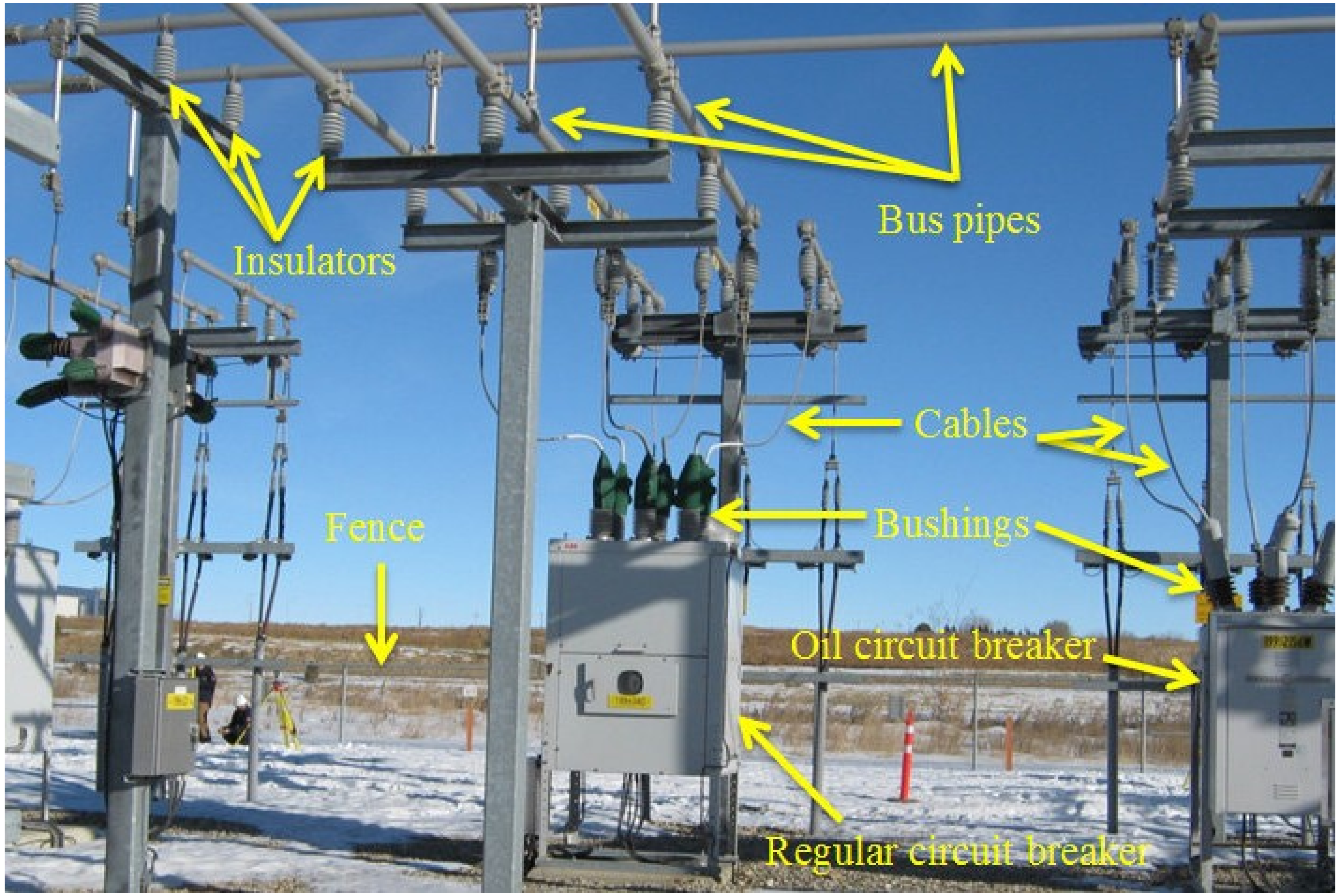
→ higher V reduces I

→ reduced losses

Transformers



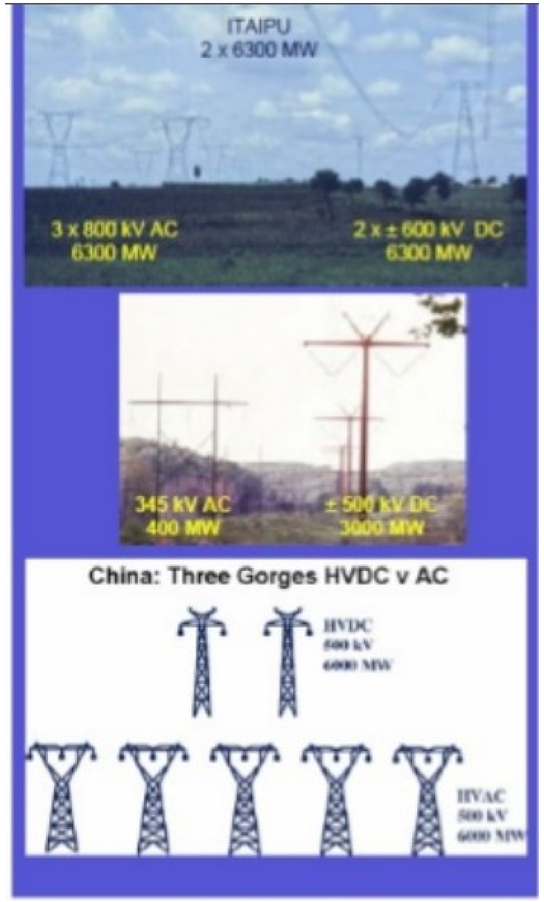
Switchyards



A **switchyard** is a **substation** without step-up or step-down transformers.

Switchyard main function is to transmit and distribute the electricity from generating unit at incoming voltage and switch the power supply through switchgears including circuit breaker, busbar, isolator, relays etc.

Alternating or direct current ?

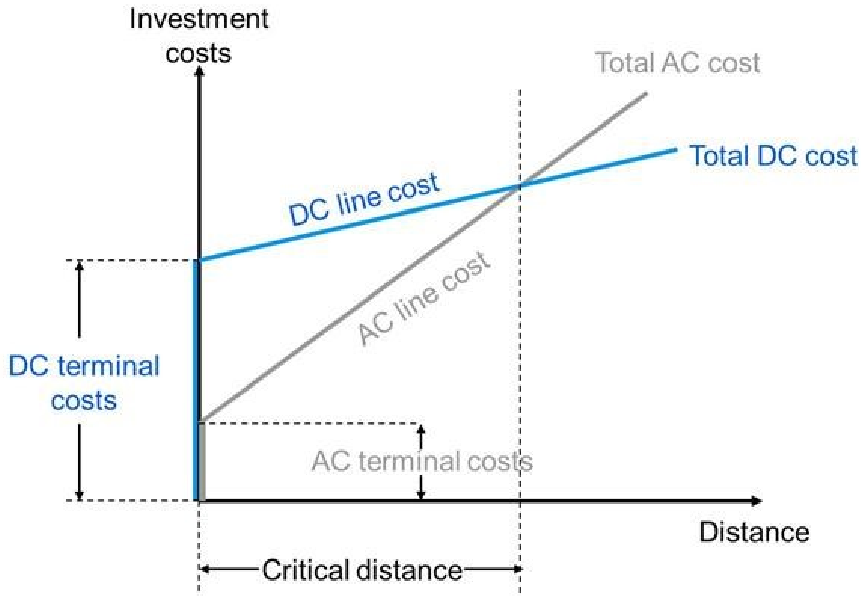


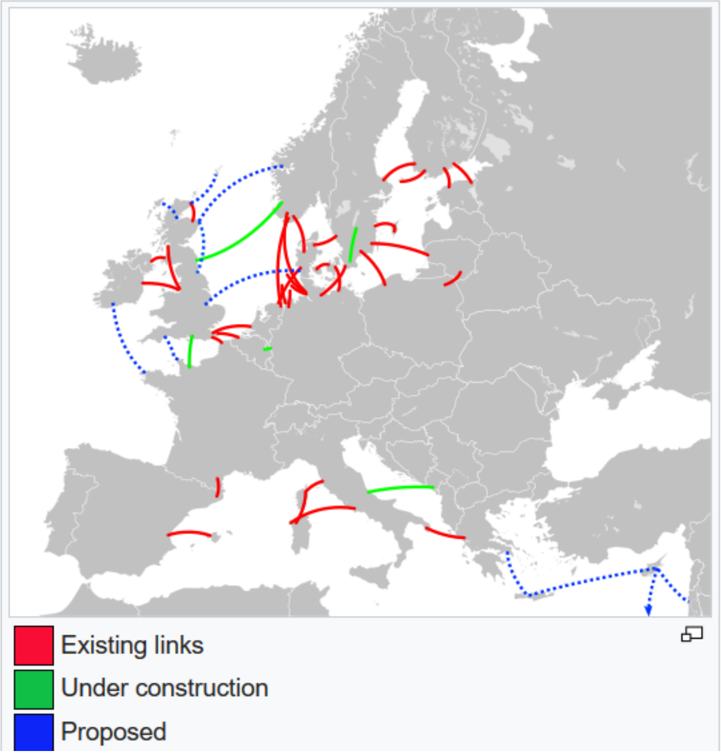
DC applications:
- Long-distance, bulk-power transmission
- Sea and land cables
- Asynchronous connections
- Power flow control
- Congestions relief

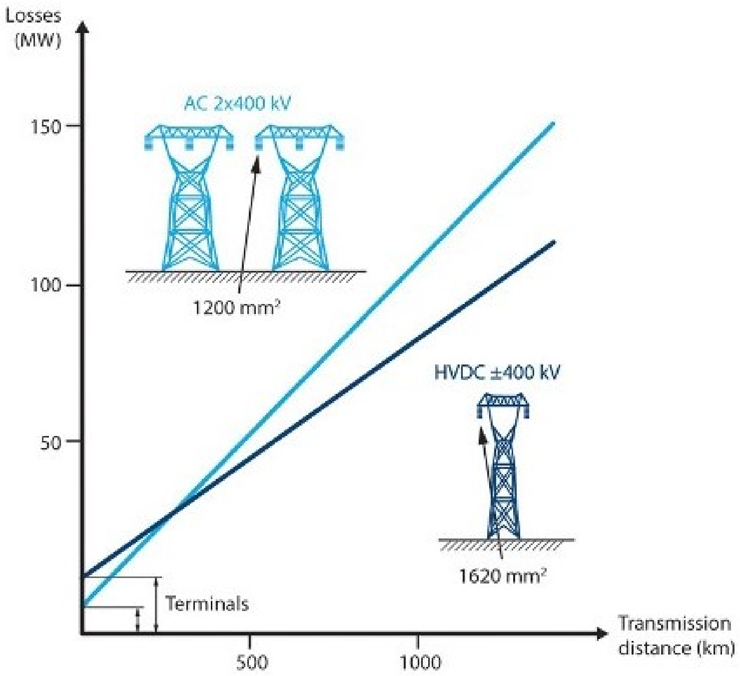
DC ratings:
- Power up to:
  - 4000 MW at 500 kV
  - 4800 MW at 600 kV
  - 6400 MW at 800 kV

- Voltage up to 800 kV

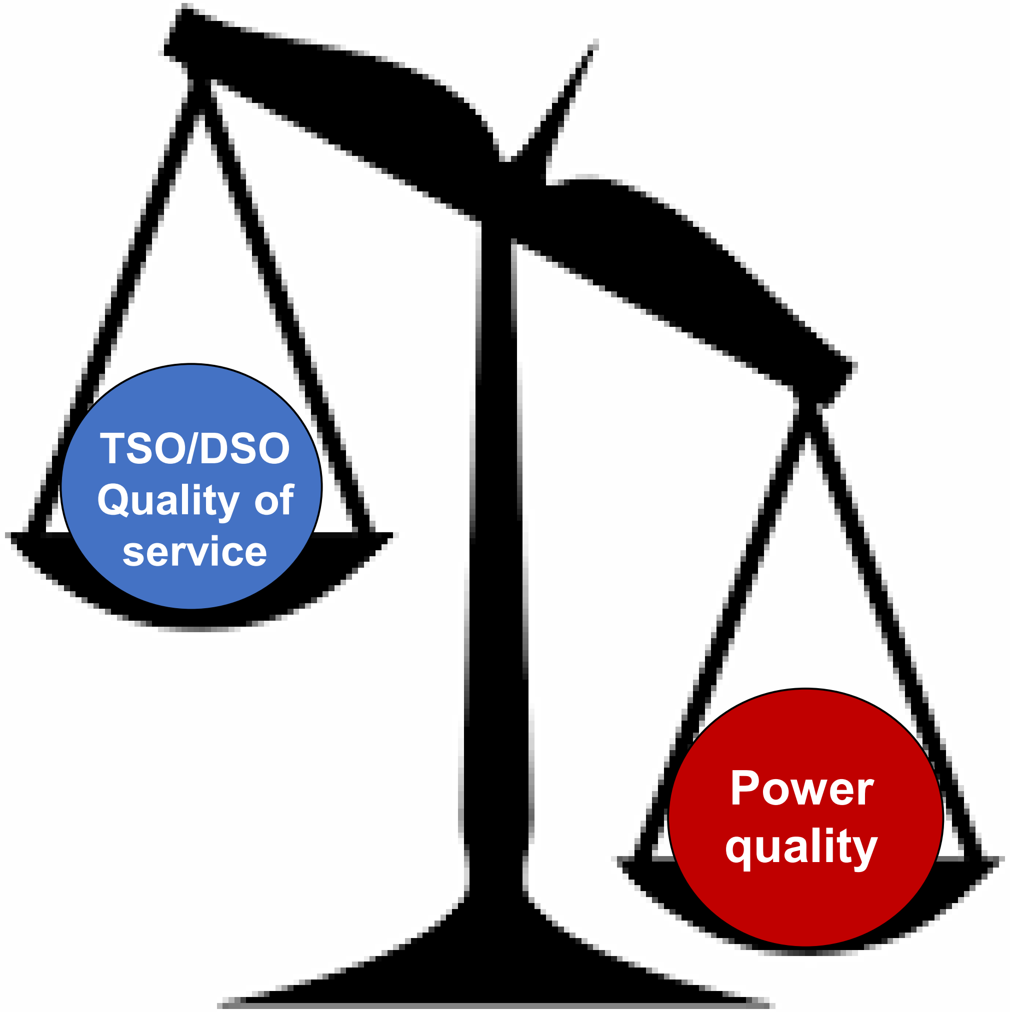
Alternating or direct current ?



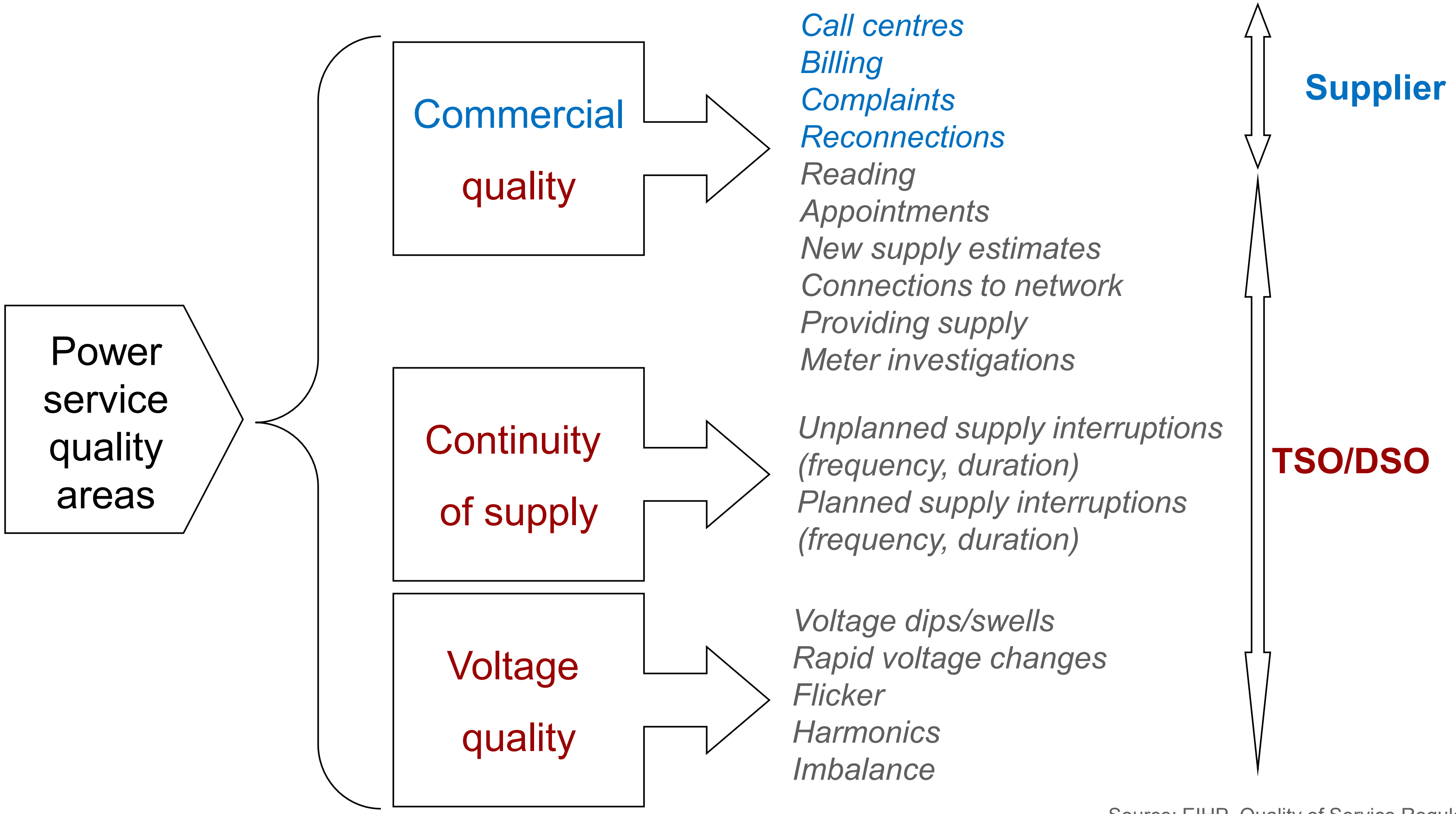




Reliability and quality issues


TSO/DSO
Quality of
service
Power
quality

Reliability and quality issues



Source: EIHP, Quality of Service Regulation, EnCS

Reliability and quality issues

Source: EPRI - The Cost of Power Disturbances to Industrial and Digital Economy Companies

Half of all computer problems and one-third of all data loss can be traced back to the power line… Contingency Planning Research, 1996

A manufacturing company lost more than $3 million one day last summer in Silicon Valley when „light went out"…. New York Times, 2010

Berkeley Lab Study Estimates $80 billion Annual Cost of Power Interruptions…. Berkeley Lab, 2015

30-40 % of all business downtime is related to power quality problems… Electric Power and Light Magazine, 2008

$50 Billion per year in the USA is lost as result of power quality breakdowns… Bank of America Report 2012

ENERGY REGULATORS
REGIONAL ASSOCIATION

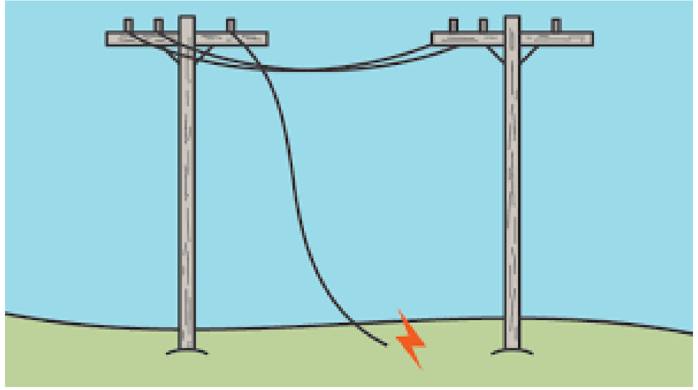
Transmission system planning

Bangkok, Thailand

USA

„Plans are nothing, planning is everything”
Dwight D. Eisenhower

Transmission system planning



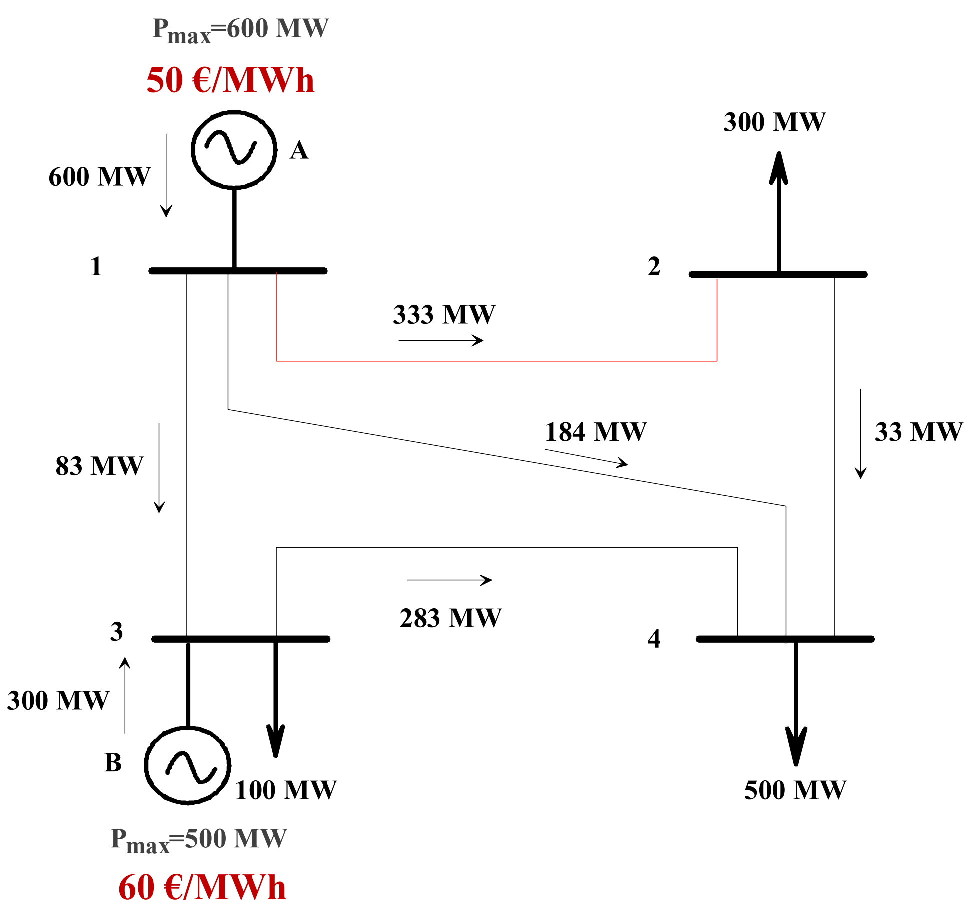
N-1 security criterion - the system has to maintain in a secure condition under the following single outage:

1. loss of a single transmission circuit
2. loss of a single energy transformer
3. loss of a single generator
4. loss of a HVDC pole
5. loss of a single shunt connected reactive component (capacitor bank, SVC…)

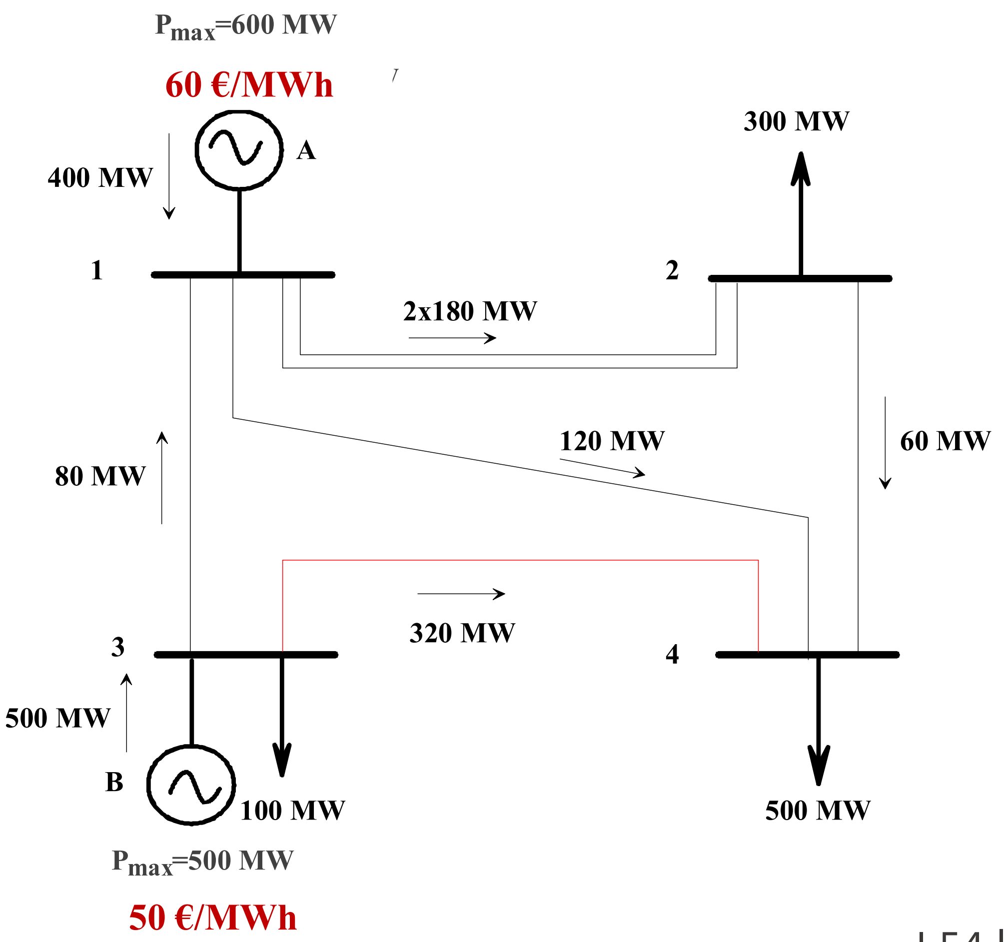
Transmission system planning - example

BASE CASE – overloading of the line 1-2

(transmission capacity of all lines 300 MW)



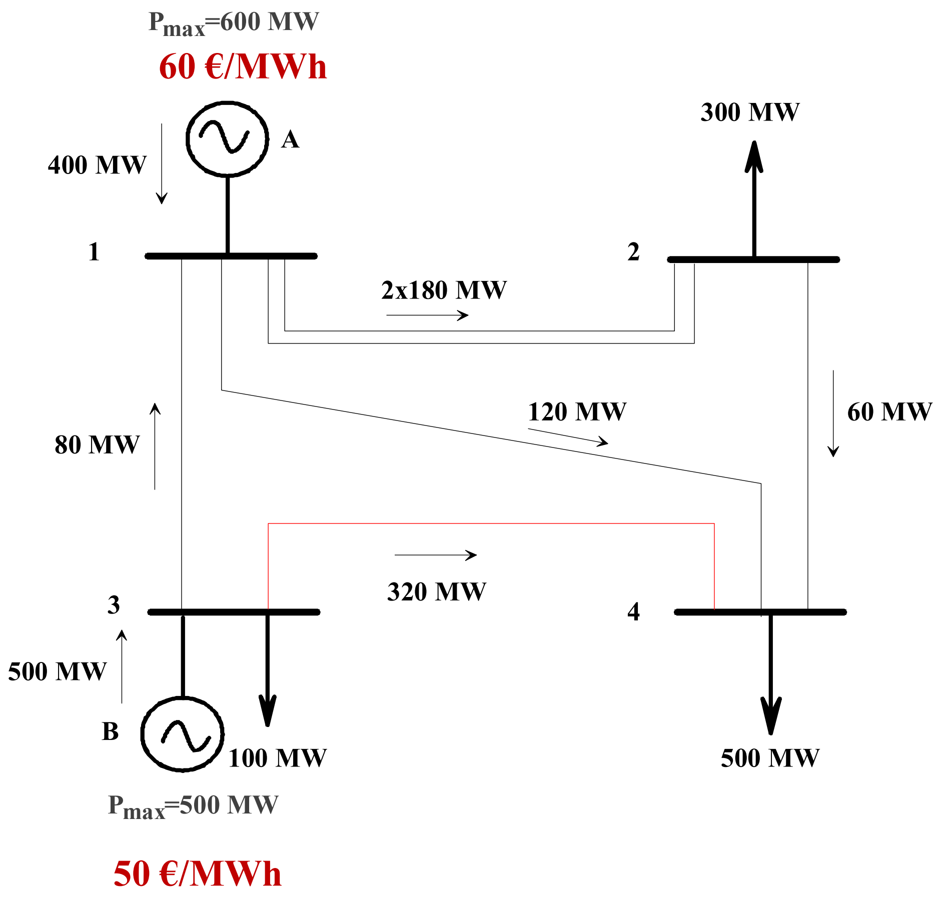
CASE 1 – different generators bidding behavior



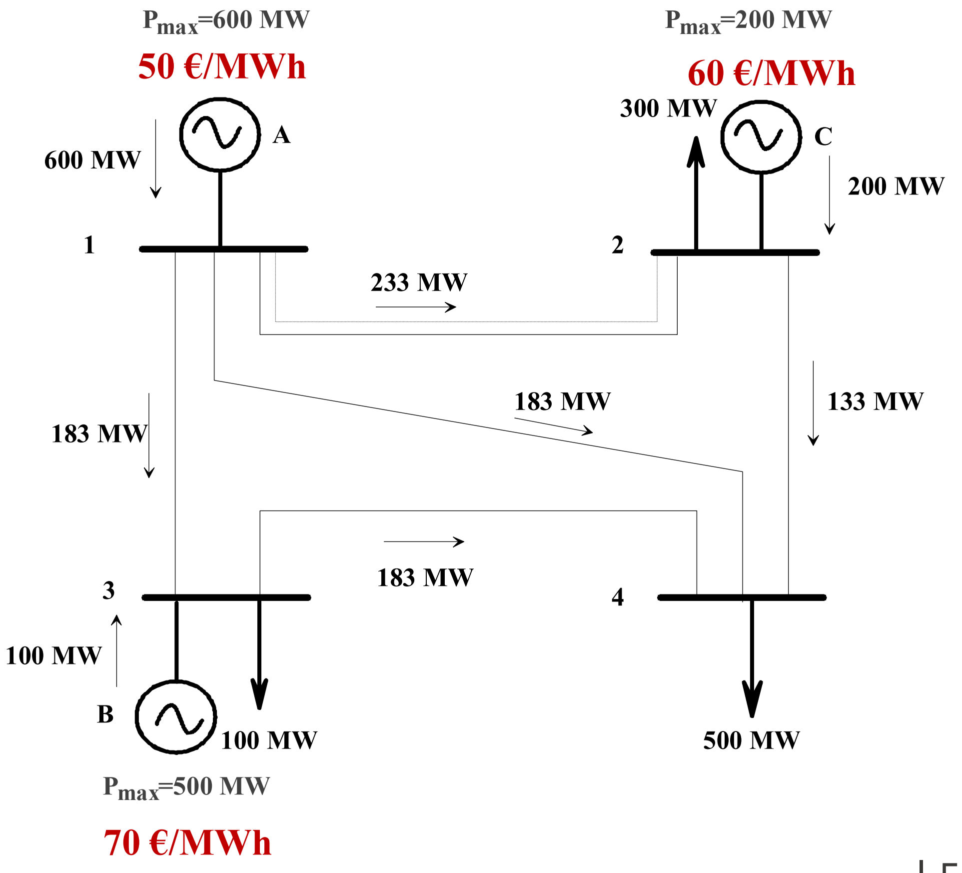
CASE 1 RESULT: TWO network investments needed

Transmission system planning

CASE 1 – different generators bidding behavior



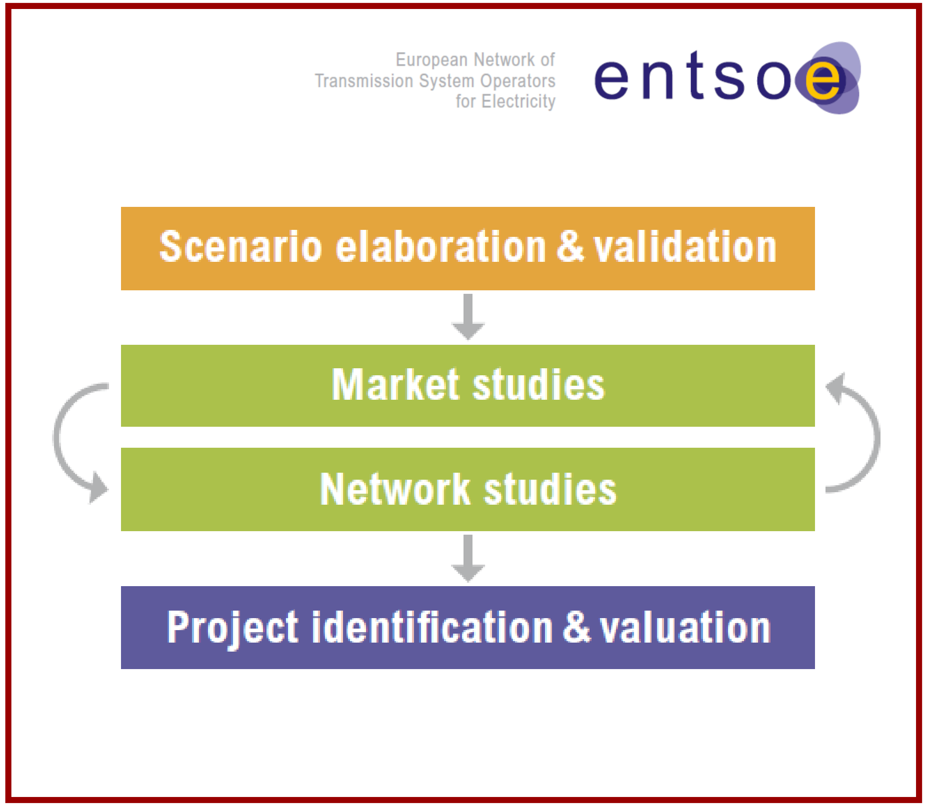
CASE 2 – new generator in the node 2



Transmission system planning uncertainties

1. New power plants size and locations
2. Load growth
3. RES integration
4. Future market transactions
5. Unknown generators dispatch
6. Electricity market price

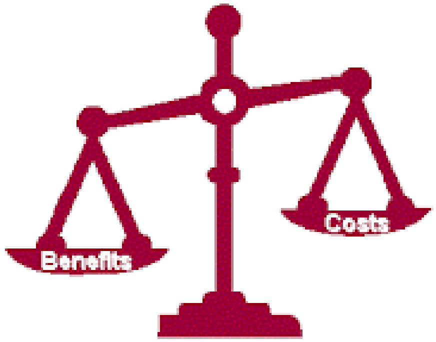
Transmission system planning methodology



Scenario analyses:

1. list of candidate projects
2. technical (worst case) analysis
3. reviewed list of candidate projects
4. economic analysis (cost-benefit)
5. prioritization
   - technical
   - economic

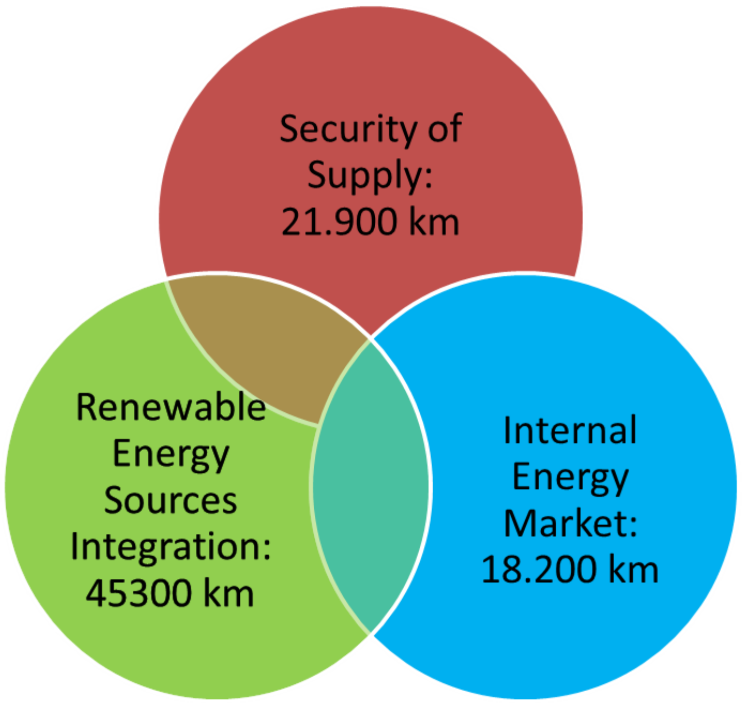
Transmission system planning criteria



- **TYPES OF BENEFIT:**
  - benefit due to reduction of expected annual undelivered electricity costs
  - benefit due to annual losses reduction
  - benefit due to reduction of annual re-dispatching costs
  - benefit due to annual congestion costs reduction
- **TYPES OF COSTS:**
  - investment costs
  - operation and maintenance costs

Transmission system planning

ENTSO-e: 150 billion EUR & 52 300 km lines in next 10 years
(87% (45 300 km) related to RES)

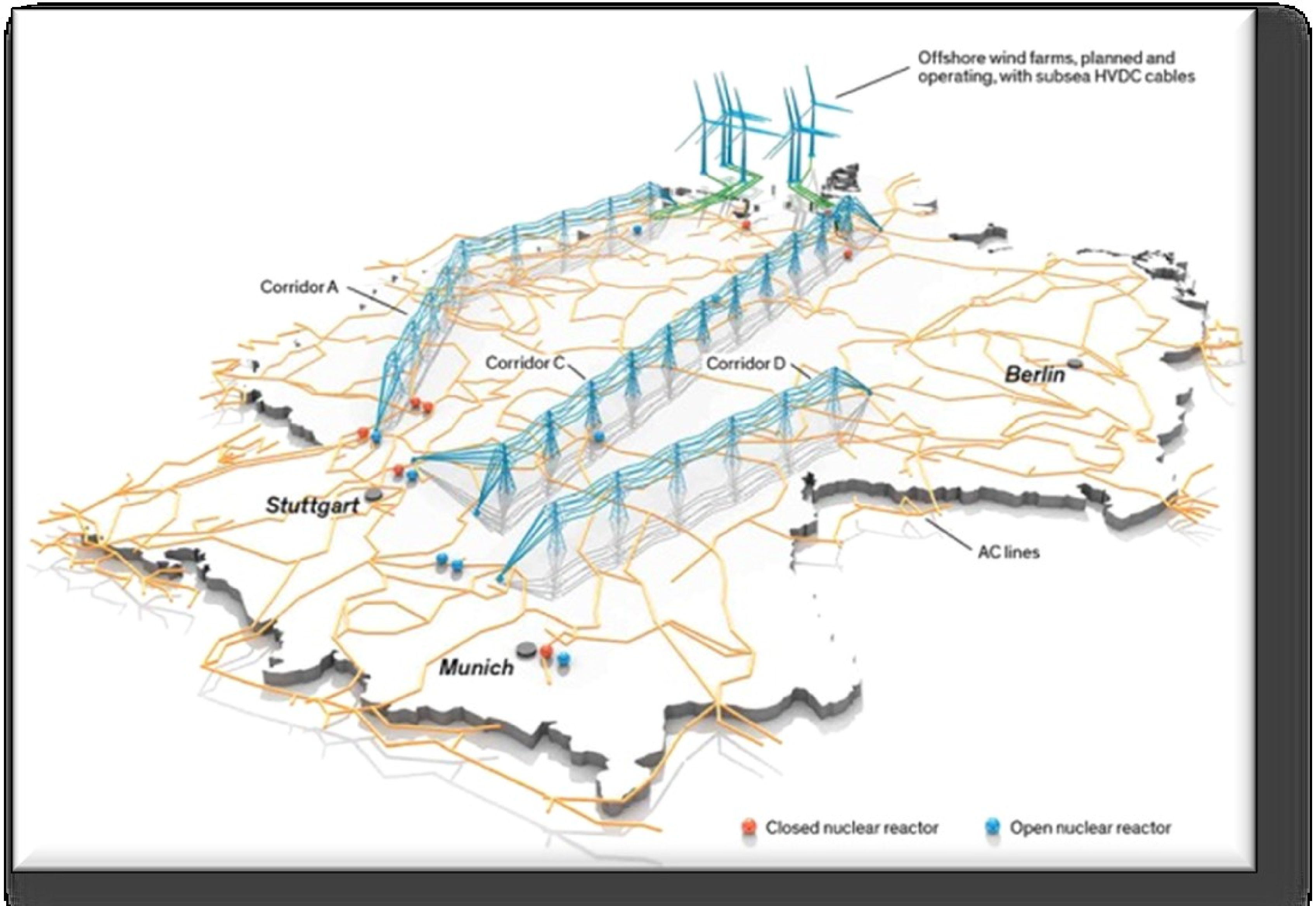


Source: ENTSO-e

Investment cost breakdown (bil.€)

AT	1.9	**IE**	2.0
BA	0.1	**IS**	0.0[30]
BE	2.0-4.0	**IT**	5.9
BG	0.3	**LT**	0.7
CH	1.6	**LU**	0.2
CY	0.0	**LV**	0.4
CZ	1.5	**ME**	0.1
DE	34.8-54.2	**MK**	0.1
DK	3.7	**NI**	0.5
EE	0.2	**NL**	3.3
ES	4.3	**NO**	7.9
FI	0.8	**PL**	1.9
FR	8.4	**PT**	0.7
GB	15.9-16.2	**RO**	0.5
GR	2.6	**RS**	0.4
HR	0.2	**SE**	3.6
HU	0.1	**SI**	0.6
		SK	0.3
Total	**110-150**		

Transmission system planning

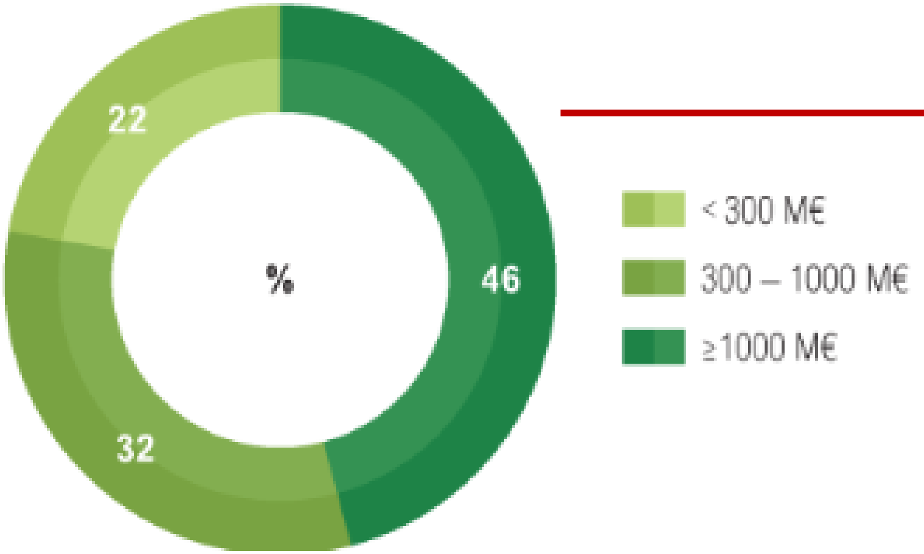


Why is 30% of all ENTSO-e transmission investments located in Germany ?

Huge generation portfolio change (from NPP to RES, from South to North) resulted with the need for huge new transmission corridors

Transmission system planning

ENTSO-E 10-YEAR DEVELOPMENT PLAN



Source: ENTSO-E

46 % of the projects display costs greater than 1 bil.€

NO MISTAKES ALLOWED !

€150bn
investments, of which 70-80 by 2030

1 to 2 €/MWh
impact on bills due to transmission investment

45 to 60%
RES across 4 Visions for 2030

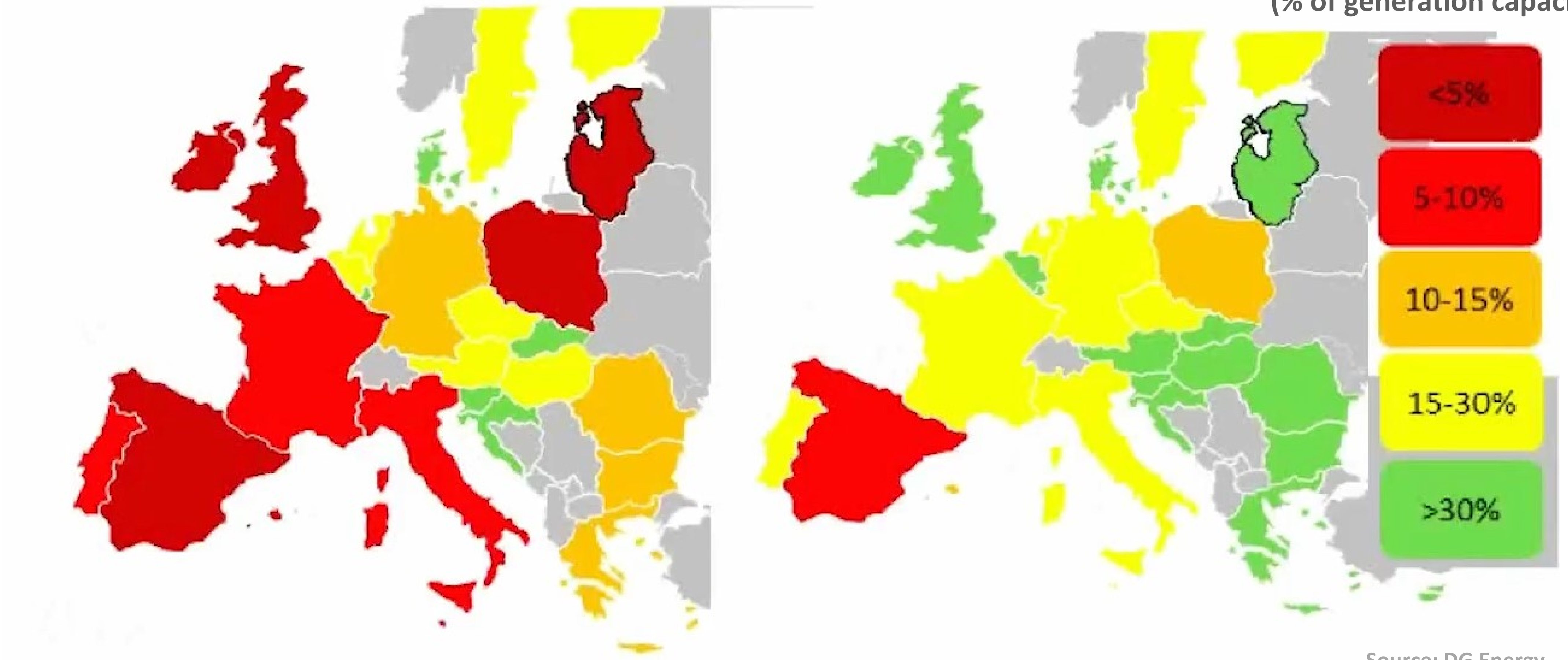
50% to 80%
emissions cut depending on the vision

1.5 to 5 €/MWh
potential reduction in wholesale prices

40%
reduction in congestion hours

Coordinated transmission planning

Importing abililty
(% of generation capacity)



Source: DG Energy

TARGET: Remove red colors !

Note: regional example - GCC Interconnection

WHAT ABOUT FUTURE ?

European interconnection system history

1951 UCPTE
1960 OES
1961 UFIPTE
1963 NORDEL
1974 SUDEL (exYU)
1977 SUDEL (GR)
1985 ALBANIA
UKTSOA
ATSOI

1991 War in ex YU
1992 CENTREL

1993 disconnection USSR and RO, BG
⇨2. sin.zone UCPTE

1995 CENTREL and DDR ⇨ UCPTE

1997 MO, DZ and TN MAGREB ⇨ UCPTE

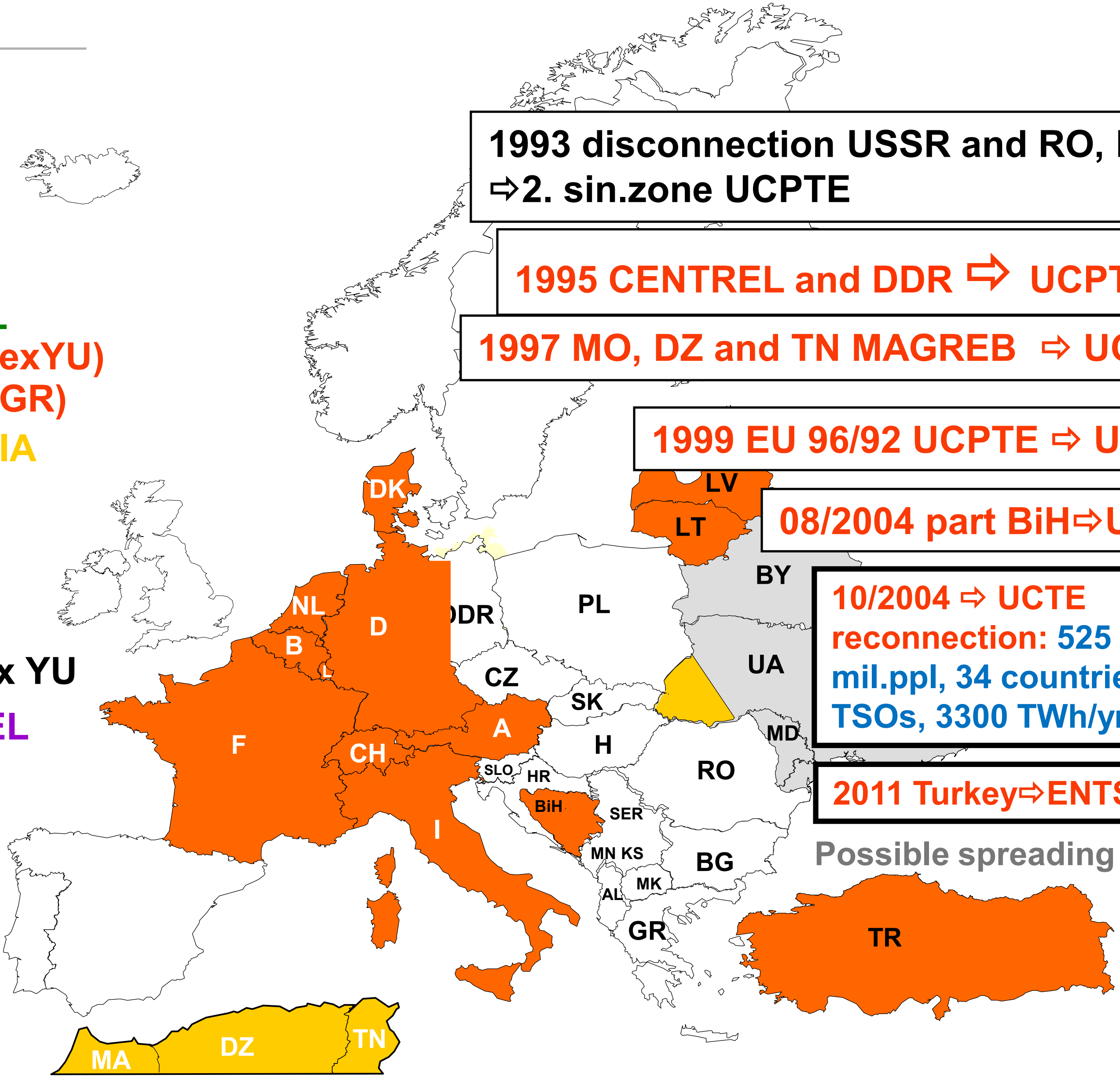
1999 EU 96/92 UCPTE ⇨ UCTE

08/2004 part BiH⇨UCTE

10/2004 ⇨ UCTE reconnection: 525 mil.ppl, 34 countries, 42 TSOs, 3300 TWh/yr

2011 Turkey⇨ENTSO-E

Possible spreading to east



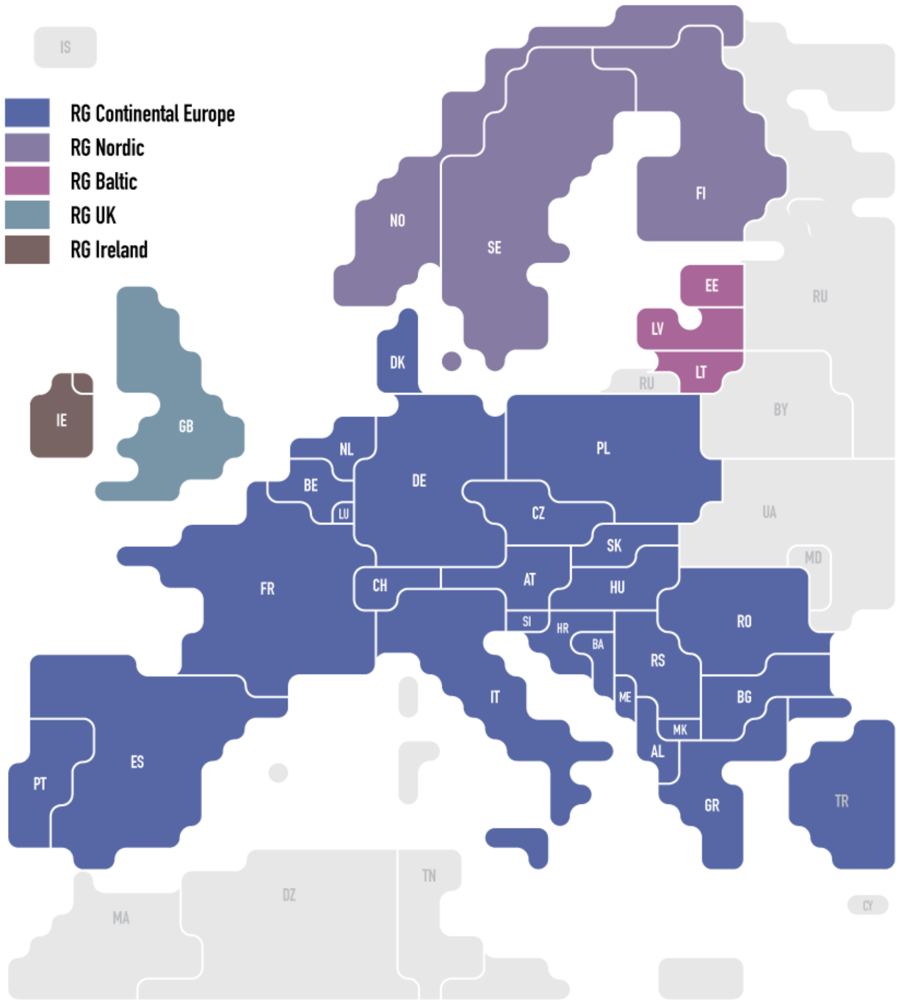
European interconnection system history

41 TSOs from 34 countries

532 million citizens served

828 GW generation

305 Thousand Km of transmission lines



the largest synchronous electrical grid in the world by connected power

European interconnection system future

What's after 2020 ?
The Clean Energy Pakage

27% renewables by 2030 =
+/- 45% for the power system

Sector Coupling:
- Power
- Gas
- Transport

New electricity network challenges !

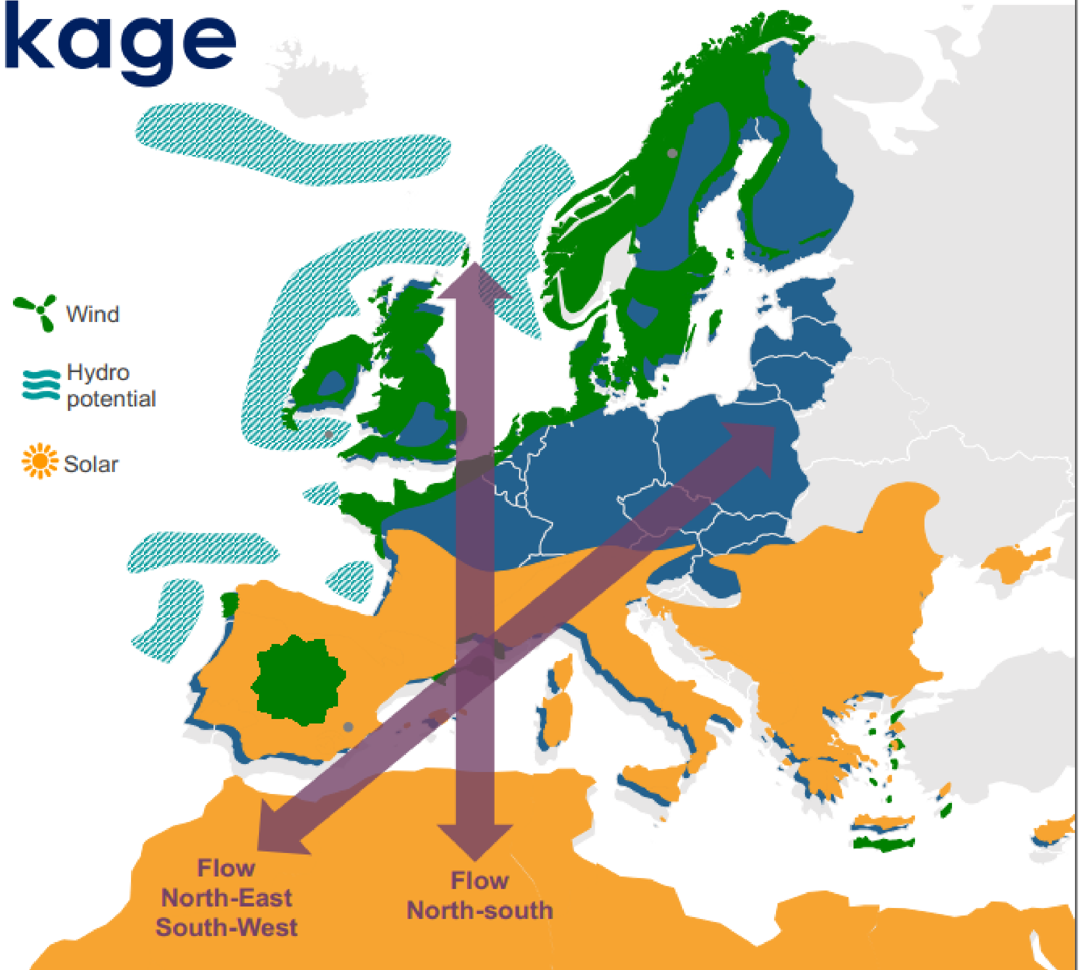


Illustration of main RES potential across Europe towards 2030

#2 ELECTRICITY DISTRIBUTION

Contents

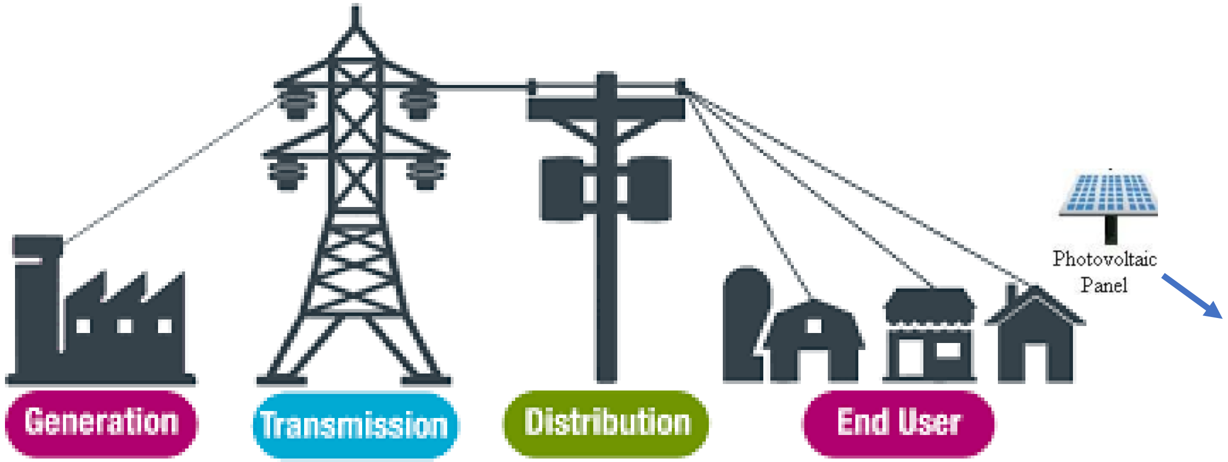
Yokohama, Japan

2. Electricity distribution

- Main distribution system equipment
- Reliability and quality issues
- Distribution system planning
- Distributed generation issues
- Smart grids and smart meters

Distribution system definition

Distribution system definition



Electric power distribution is **the final stage in the delivery of electric power,** carrying electricity from the transmission system to individual consumers.

Recently, electricity distribution got **additional task**: to evacuate electricity generated from distributed sources to the system.

Coincidence factor

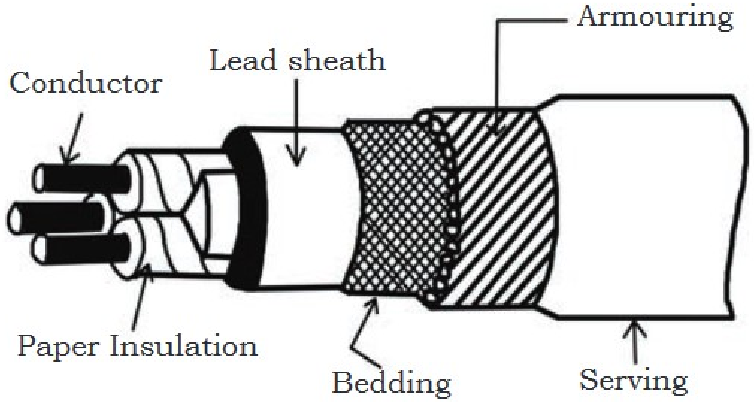
Coincidence factor, C(N) - measure of simultaneity of peak demands of N customers.
Peak load = N x individual peak demand x C(N).

Typical values of **C(N) for N > 100 are in the range 0.2 to 0.5**. On large voltage level can go up to 0.8.

The coincident load curve can be viewed as the expectation of a customer's **noncoincident curve**.

Distribution system equipment

Distribution lines

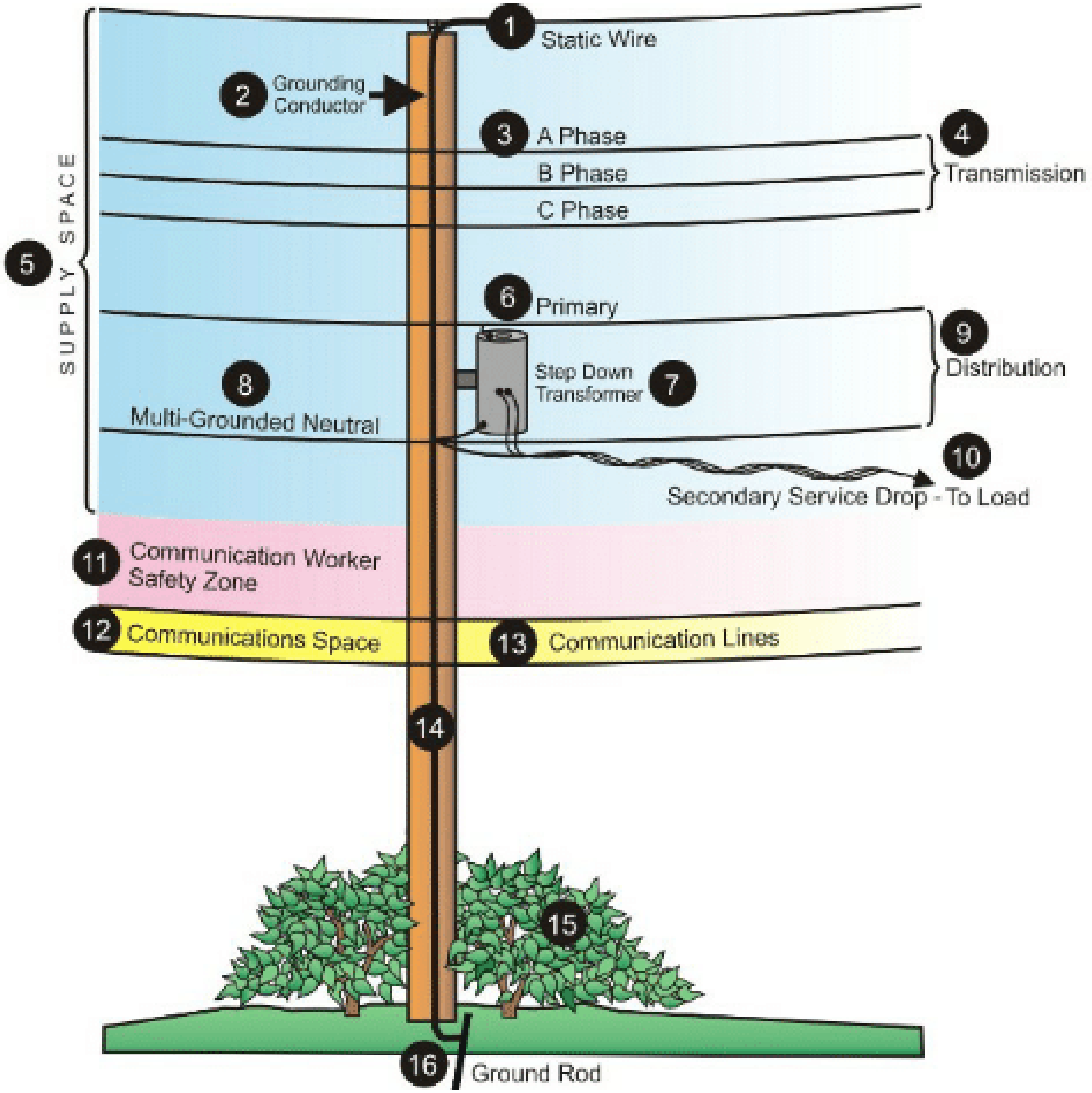


Distribution cables are divided according to the:

1. **voltage** (low, mid voltage)
2. **formation** (single core, two cores, three cores…)
3. **material** used:

   a) PVC (Polyvinyl Carbide Cable)
   b) PILCA (Paper Insulated Lead Covered Armored Cable)
   c) XLPE (Cross-linked Poly-Ethylene Cable)

Distribution lines



Reliability and quality issues

Reliability indicators

System Average Interruption Frequency Index – **SAIFI:**

$$SAIFI = \frac{Total\ number\ of\ customer\ interruptions}{Total\ number\ of\ customers}$$

Customer Average Interruption Frequency Index – **CAIFI:**

$$CAIFI = \frac{Total\ number\ of\ customer\ interruptions}{Total\ number\ of\ customers\ who\ had\ at\ least\ one\ interruption}$$

Reliability indicators

System Average Interruption Duration Index – **SAIDI:**

$$\mathrm{SAIDI} = \frac{\text{Total duration of all interruptions}}{\text{Total number of customers}}$$

Customer Average Interruption Duration Index – **CAIDI:**

$$CAIDI = \frac{\textit{Total duration of all interruptions}}{\textit{Total number of customer interruptions}}$$

Reliability indicators

Momentary Average Interruption Frequency Index – **MAIFI:**

(instanteneous, if utility separate this interruption from those within SAIFI and CAIFI statistics)

$$MAIFI = \frac{Total\ number\ of\ customer\ momentary\ interruptions}{Total\ number\ of\ customers}$$

Customer Total Average Interruption Duration Index – **CTAIDI:**

$$CTAIDI = \frac{Total\ duration\ of\ all\ interruptions}{Total\ number\ of\ customers\ who\ had\ at\ least\ one\ interruption}$$

Reliability indicators

SAIFI ≤ CAIFI

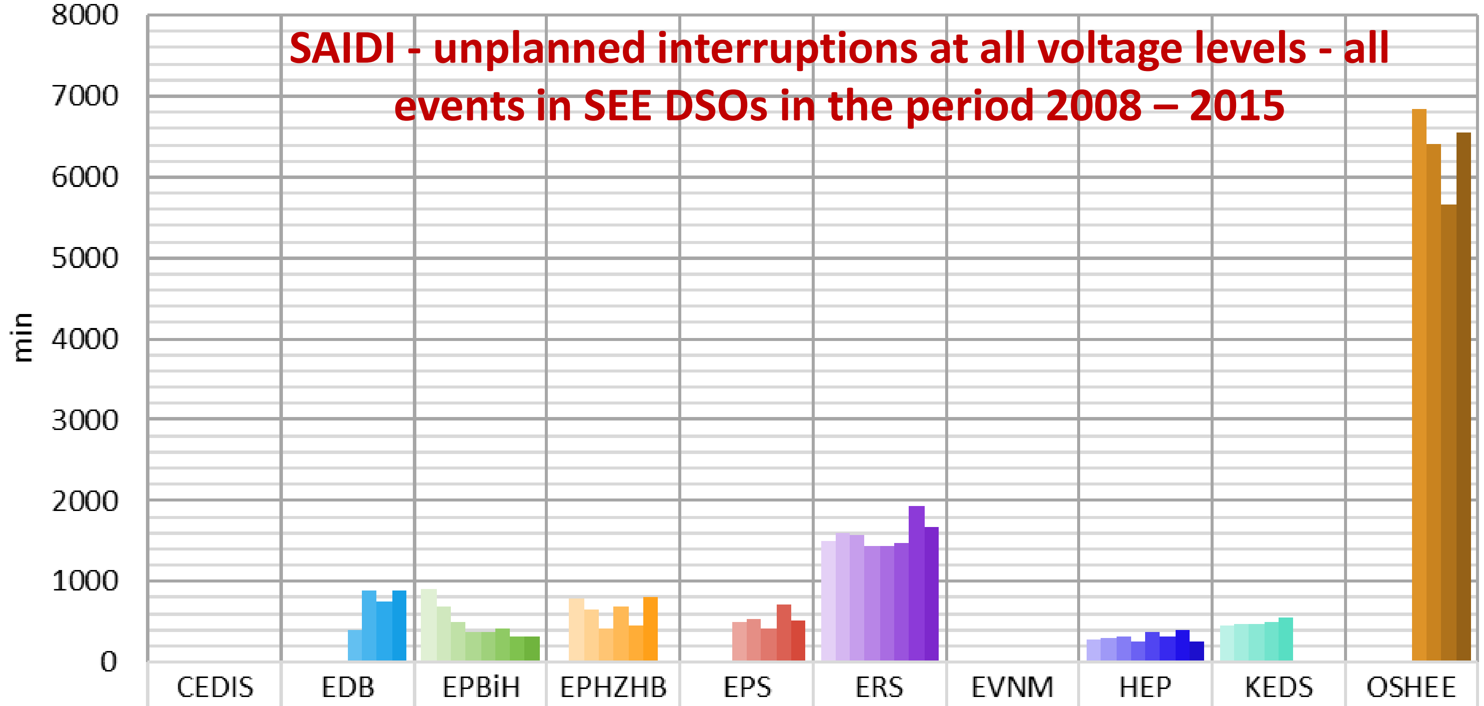
SAIDI ≤ CTAIDI

CAIFI ≥ 1

$$\frac{\text{SAIDI}}{\text{CTAIDI}} = \frac{\text{SAIFI}}{\text{CAIFI}}$$

= fraction of customers who experienced at least one interruption

Reliability indicators



	CEDIS	EDB	EPBiH	EPHZHB	EPS	ERS	EVNM	HEP	KEDS	OSHEE
2008	0	0	903	0	0	1501	0	270	445	0
2009	0	0	689	784	0	1589	0	296	471	0
2010	0	0	495	654	0	1582	0	307	476	0
2011	0	0	380	412	501	1434	0	251	494	0
2012	0	402	383	699	541	1444	0	372	548	6849
2013	0	890	415	448	409	1476	0	320	0	6407
2014	0	740	317	802	710	1925	0	402	0	5662
2015	0	878	312	0	522	1679	0	265	0	6547

Source: USEA SEE DSO Bechmarking Report, EIHP 2015

Reliability indicators

الشركة العُمانية لنقل الكهرباء ش.م.ع.م
OMAN ELECTRICITY TRANSMISSION COMPANY S.A.O.C
إحدى شركات مجموعة نماء
Member of Nama Group

Network Reliability

Increased network reliability from 99.896% in 2005 to 99.9984% in 2018

Interruption Time

Reduced average interruption time from 98 min. in 2005 to 7.2Min in 2018

Network Availability

Increased stability of network availability from 97.7% in 2005 to 99.8% (summer) and 98.5% (annual in 2018

Number of Grid Stations

Increase in number of grid stations from 29 in 2005 to 89 in 2018 (Includes 8 in Dhofar Region)

Installed Capacity

Increase installed capacity from 7,060 MVA in 2005 to 47,470 MVA by end 2018

ISO 27001 :	Information Security Management Systems
ISO 14001 :	Environmental Management Systems
OHSAS 18001 :	Health and Safety Management Systems
ISO 55001 :	Asset Management

Source: omangrid.com

Distribution system reliability

Equipment outage can cause power supply interruptions

Distribution is more problematic due to its radial nature
Reliability drops as faults are closer to customer

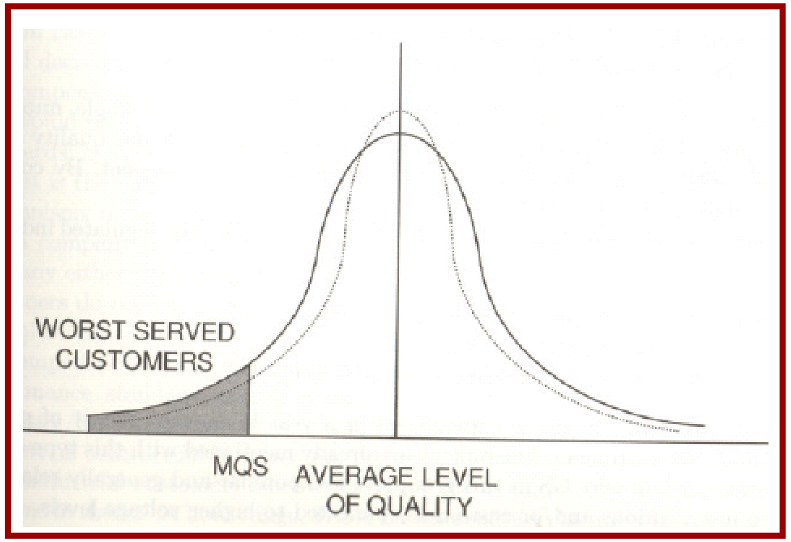
Reliability definition is based on:

Frequency – number of interruptions
Duration – of interruptions

Outages are usually divided as:

Planned outage – maintenance activities
Forced outage - faults

Reliability and quality issues



Minimum quality standard

System-level:

- ***Advantage:*** *represents the system quality level in a compact way*
- ***Disadvantage:*** *can hide low quality areas*

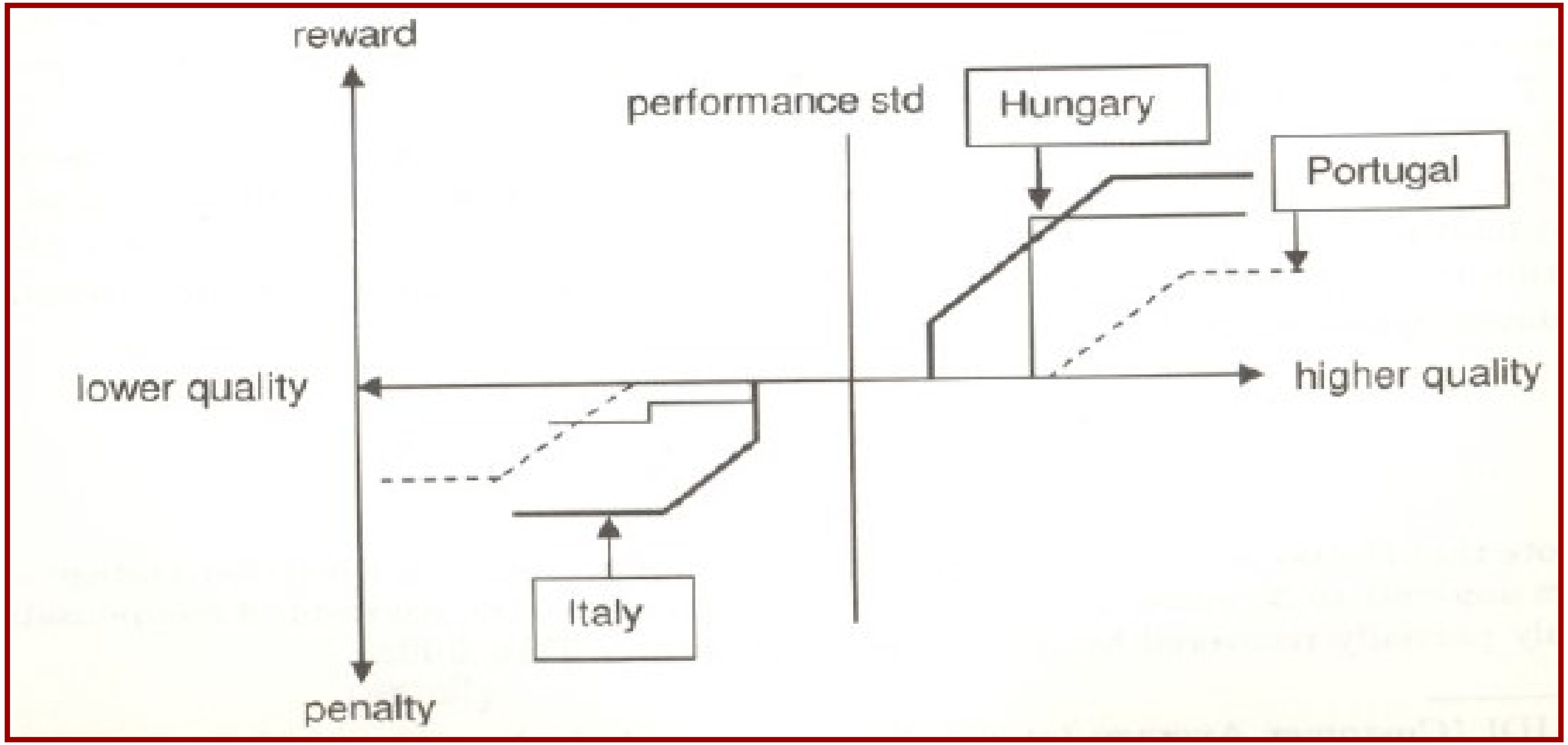
Individual:

- ***Advantage****: measures the quality level offered to each customer*
- ***Disadvantage:*** *necessary equipment to measure them; high costs*

QoS introduced in: Italy – 2000, Norway, Ireland – 2001, UK – 2002, Hungary, Portugal – 2003, Sweden – 2004

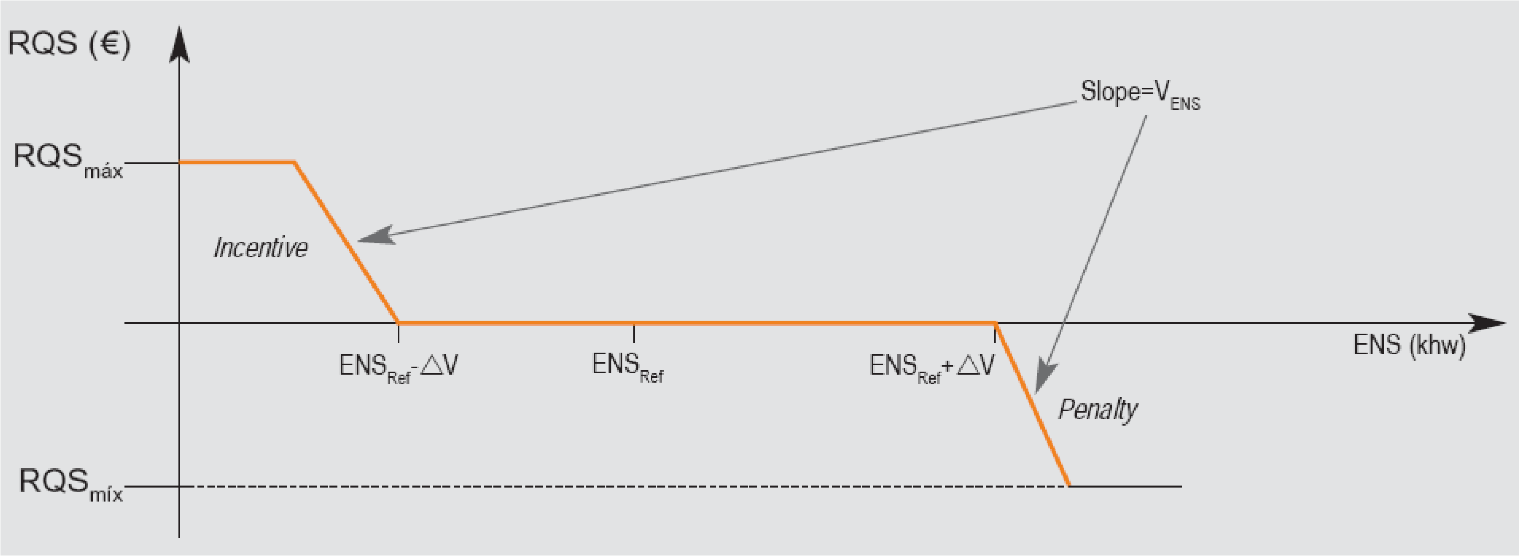
Reliability and quality issues

ELECTRICITY NOT SUPPLIED
-TSO/DSO incentive scheme-



Reliability and quality issues

TSO/DSO ENS INCENTIVE SCHEME – Portugese case -



- The reward and the penalty have the same maximum value: $|RQS_{min}| = |RQS_{max}|$ = 5 000 000 €
- Target: ENS_{Ref} = 0,0004 x ES (ES=energy supplied in the year)
- Dead band: ± △V = 0,12 x ENS_{Ref}
- Value of ENS: V_{ENS} = 1,5 €/kWh

Distribution system planning

Distribution network planning targets

1. **Reliable** and **economically acceptable** power supply with regards to network user future needs

2. **Adequate dimensioning** to sustain reliable operation and desirable power quality level

3. **Harmonized operation with transmission** network and different customer devices

4. **Economically optimal harmonization** between needs of two types of network users: distributed generators and consumers

Distribution network planning criteria

(N-1) operation reliability criteria ONLY if this is cost-effective

High occurrence probability outages MUST NOT result with:

1. Permanent disturbance of operation limits (voltage, current), jeopardizing safe operation, causing network damage or lifetime shortening

2. Number and duration of supply interruption above permitted values despite transmission backup,

3. Disturbance cascades: further disconnection caused by network protection activation which are not directly affected

Distribution network planning criteria

Important criteria is – **age** !

Expected lifetime:

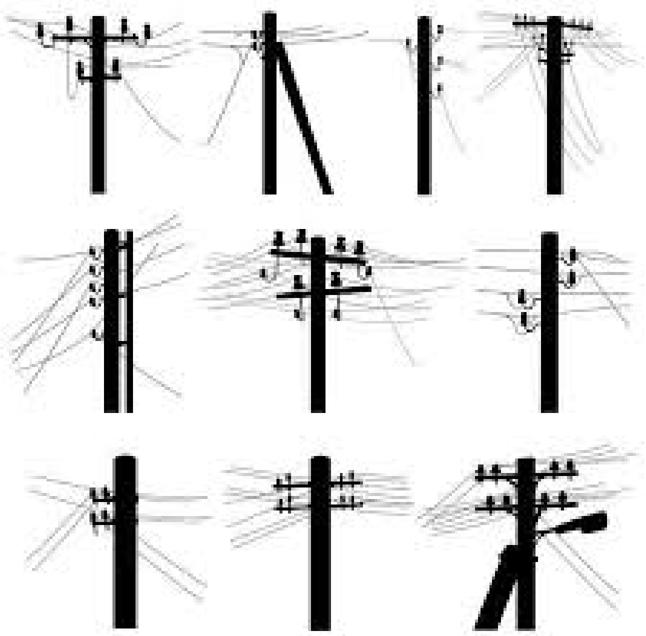
- for the electric component of MV OHL: **35 yrs**
- for supported MV overhead lines:
  (excluding wooden poles) **60 yrs**
- for wooden poles of MC overhead lines: **40 yrs**
- for cable MV lines: **40 yrs**
- for energy transformers: **50 yrs**
- for MV switching devices: **30 yrs**

Distribution network revitalization criteria

Technical criteria for the replacement and reconstruction:

1. technical defect
2. technical fault recovery is cost-effectively unjustified
3. unsatisfactory characteristics of network elements given the expected operative conditions in the planning period (load, short circuit),
4. non-compliance with current and future technical regulations
5. lack of trained personnel for the maintenance of specific components
6. lack of spare parts

Middle voltage planning criteria



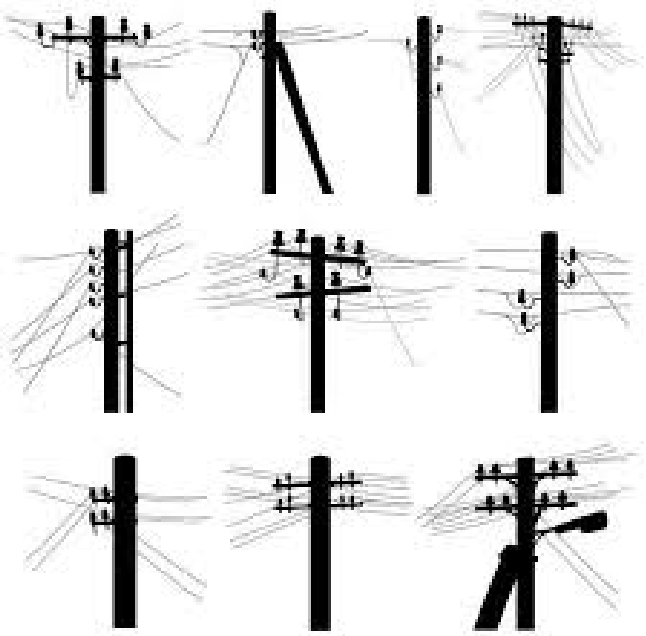
General MV development principle:

1. **To decrease number of votage levels** in the cases of:
   a) two distribution system transformation levels 110/35 kV and 35/10 kV)
   b) two MV levels (35 kV and 10 kV)

2. **To have one MV level system (20 kV)**

3. **To have one direct transformation (110/20 kV)**

Low voltage planning criteria



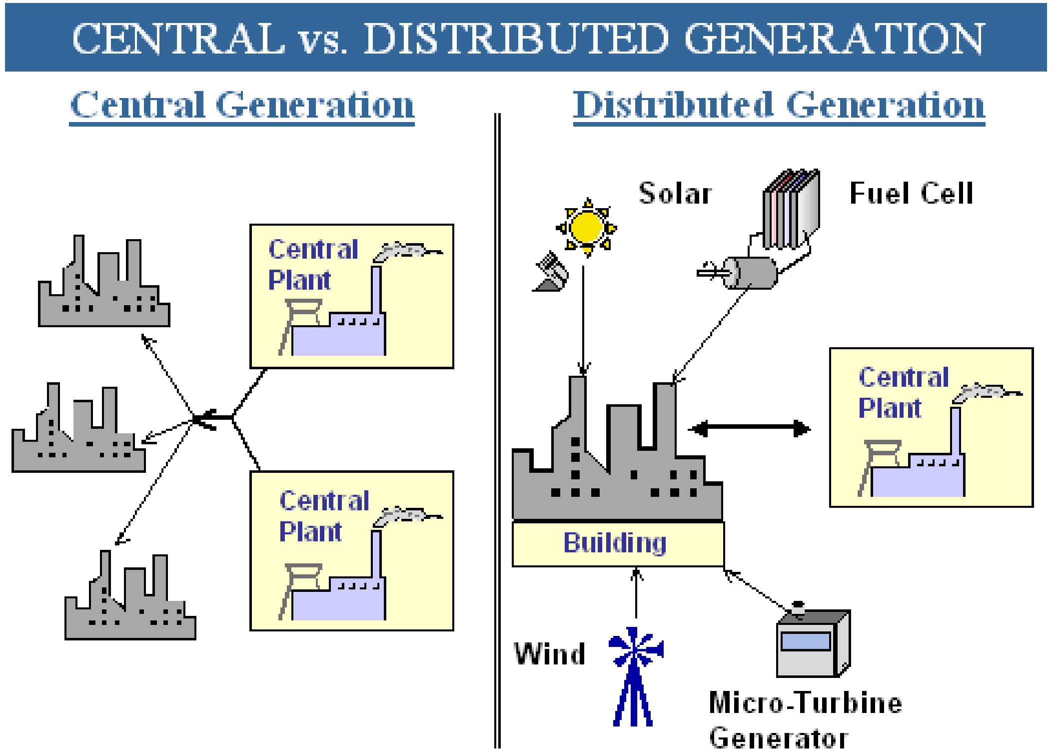
General LV development principle:

1) short LV feeders and simplification of TS 10(20)/0.4 kV
2) transformers with relatively low capacity

This concept assumes limited investment in upgrading of each LV feeder while additional supply would be reached by increasing number of LV feeders along with new TS 10(20)/0.4 kV in the existing network

Distributed generation issues

Distributed generation definition



Distributed generation (DG) OR
Distributed energy resources (DER) OR
On-site generation (OSG) is:

electrical generation and storage performed by a variety of small, grid-connected or distribution system connected devices

Distributed generation issues

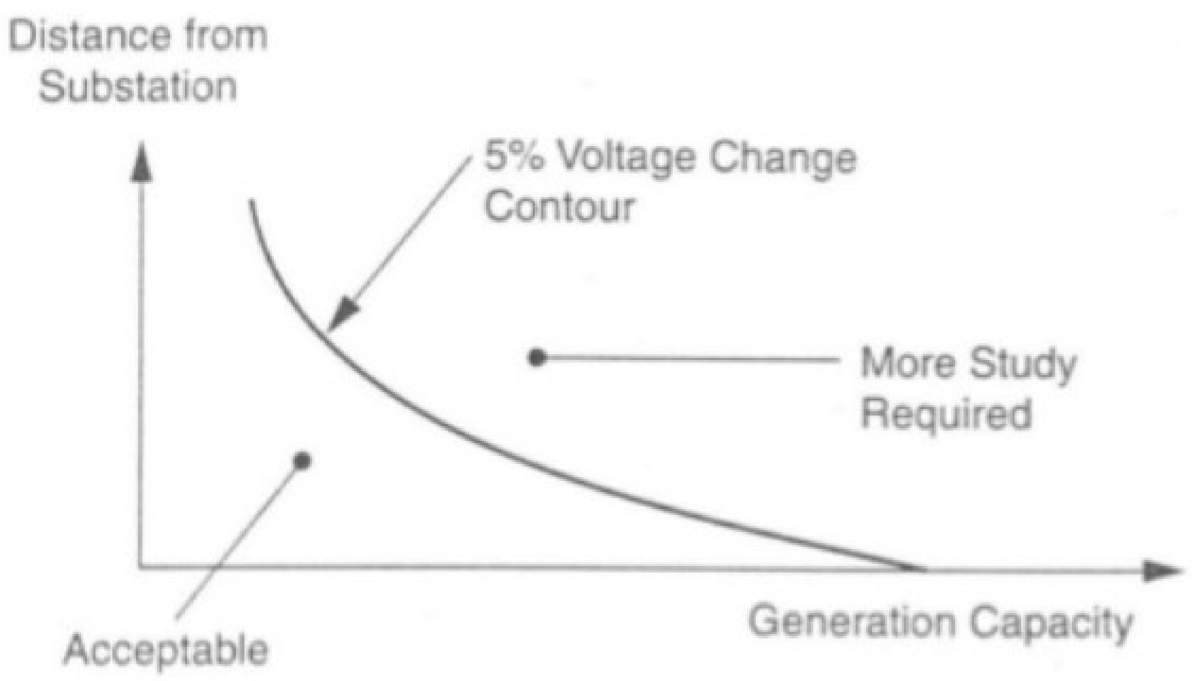
ADVANTAGES	DISADVANTAGES
Reduces energy bill	Reduces power quality
Hedge against price spikes	Increases cost of operation and maintenance
Reduces transmission losses	Reliability issues
Reduces network needs	Decreases DSO income needed for grid operation and maintenance*

* In Europe there are no distribution network charges for the generators

PROBLEM: **What if RES capture 100% of the market ?**

Distributed generation issues

Voltage drops along the feeder
if the DG is interrupted to determine **max. capacity of DG**



Net metering

Net Metering - electricity billing mechanism that allows consumers who generate some or all of their own electricity to use that electricity **anytime**, instead of when it is generated.

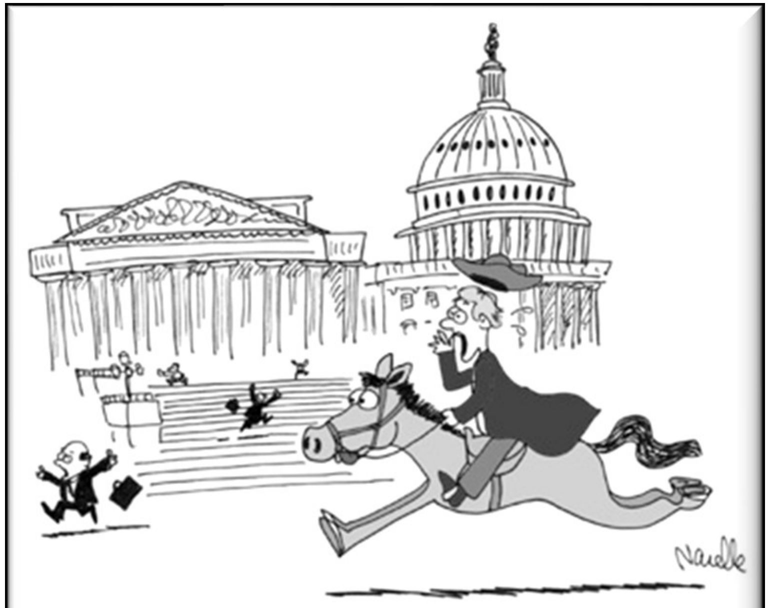
"HOWEVER BEAUTIFUL THE STRATEGY, YOU SHOULD OCCASIONALLY LOOK AT THE RESULTS"

Winston Churchill

1. Grid is essential for RES integration
2. Grid for RES is very expensive
3. Someone has to pay for it
4. **RELIABILITY** is the most important and **NOT FOR FREE**

PROBLEM: Why would a net metering customer ever want to install batteries, when they are getting reliability for free?

Distributed generation issues



The facts are coming! The facts are coming!

The path to RES and DG integration is

not just replacing plants

but of

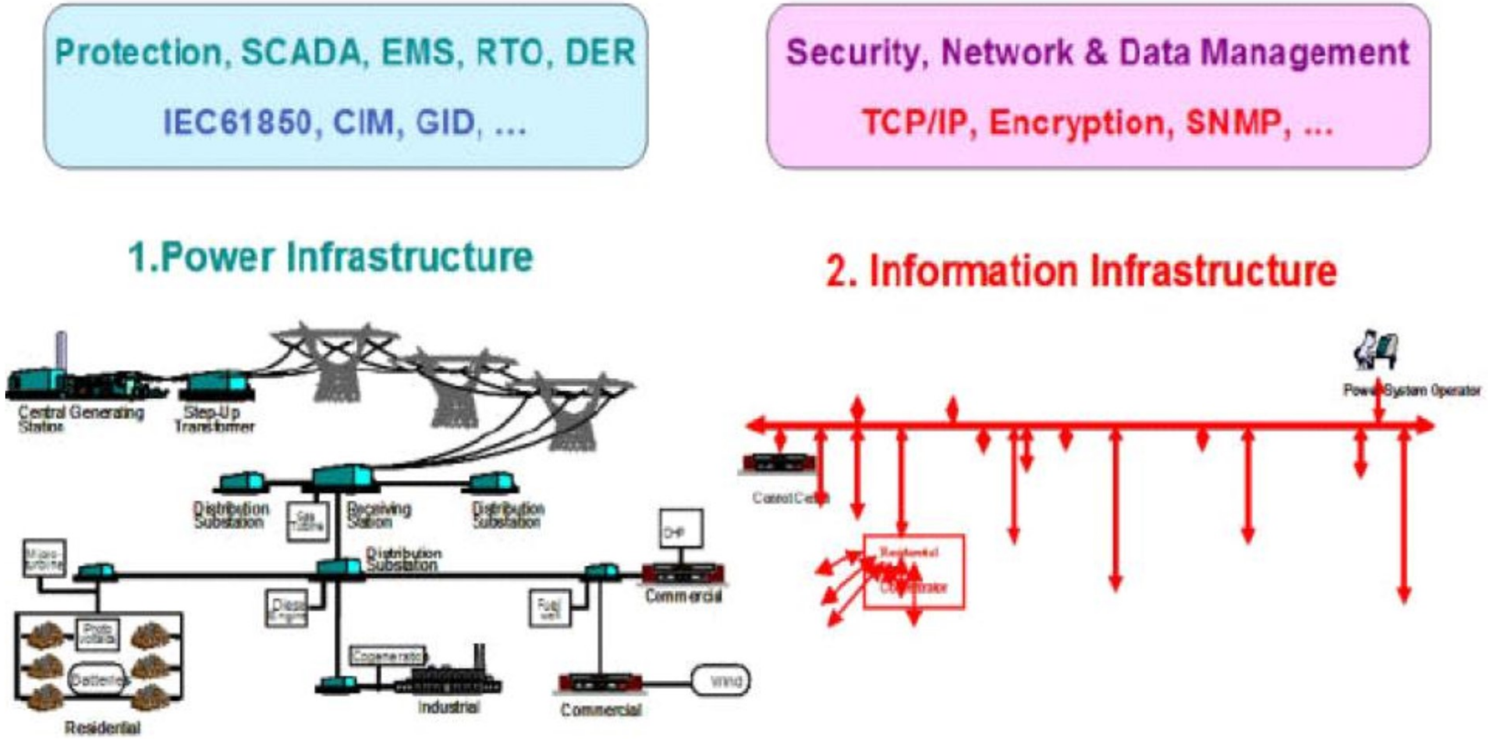
redesigning the entire system to

accommodate them.

Smart grids and smart meters

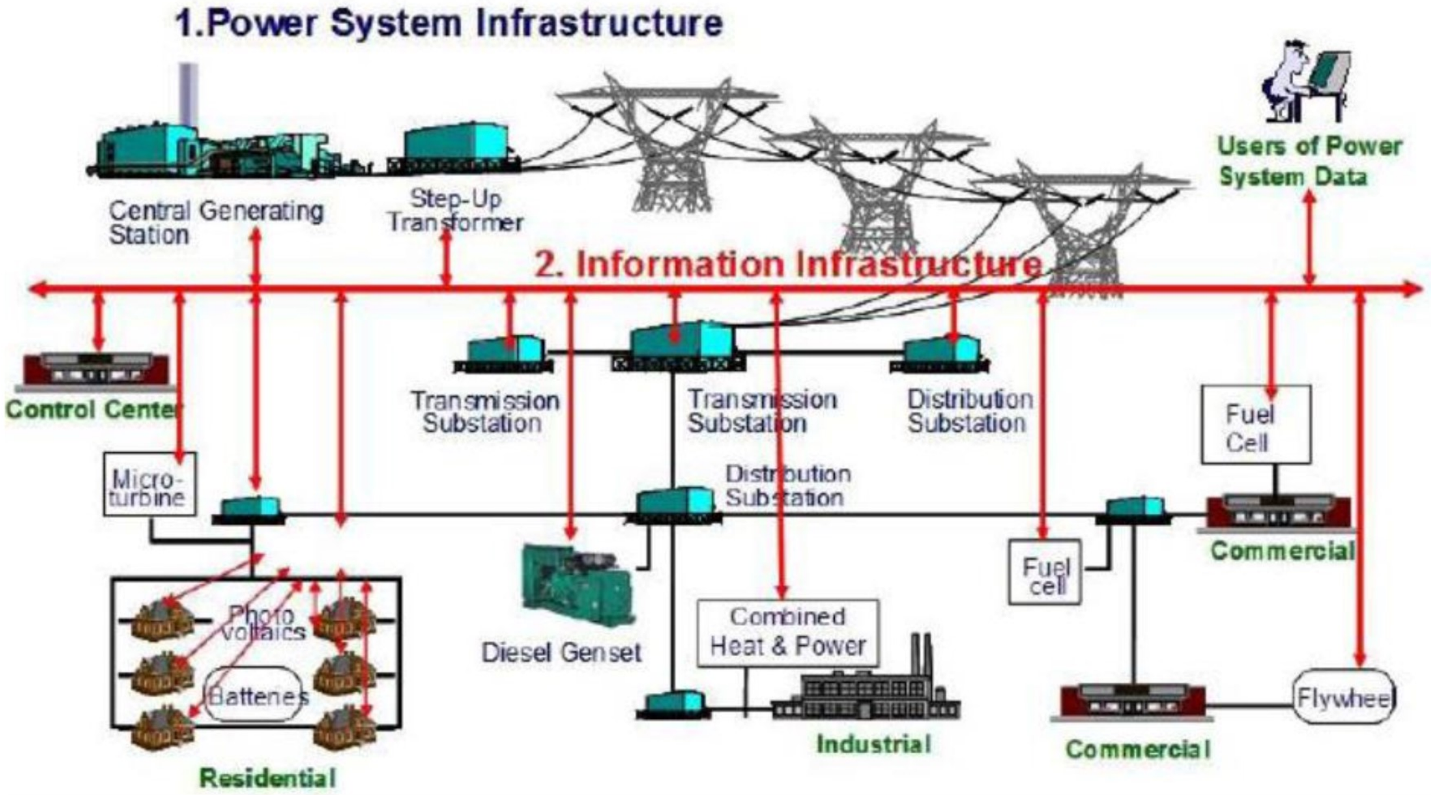
Smart grid

…once upon a time:



Smart grid terms

…today:



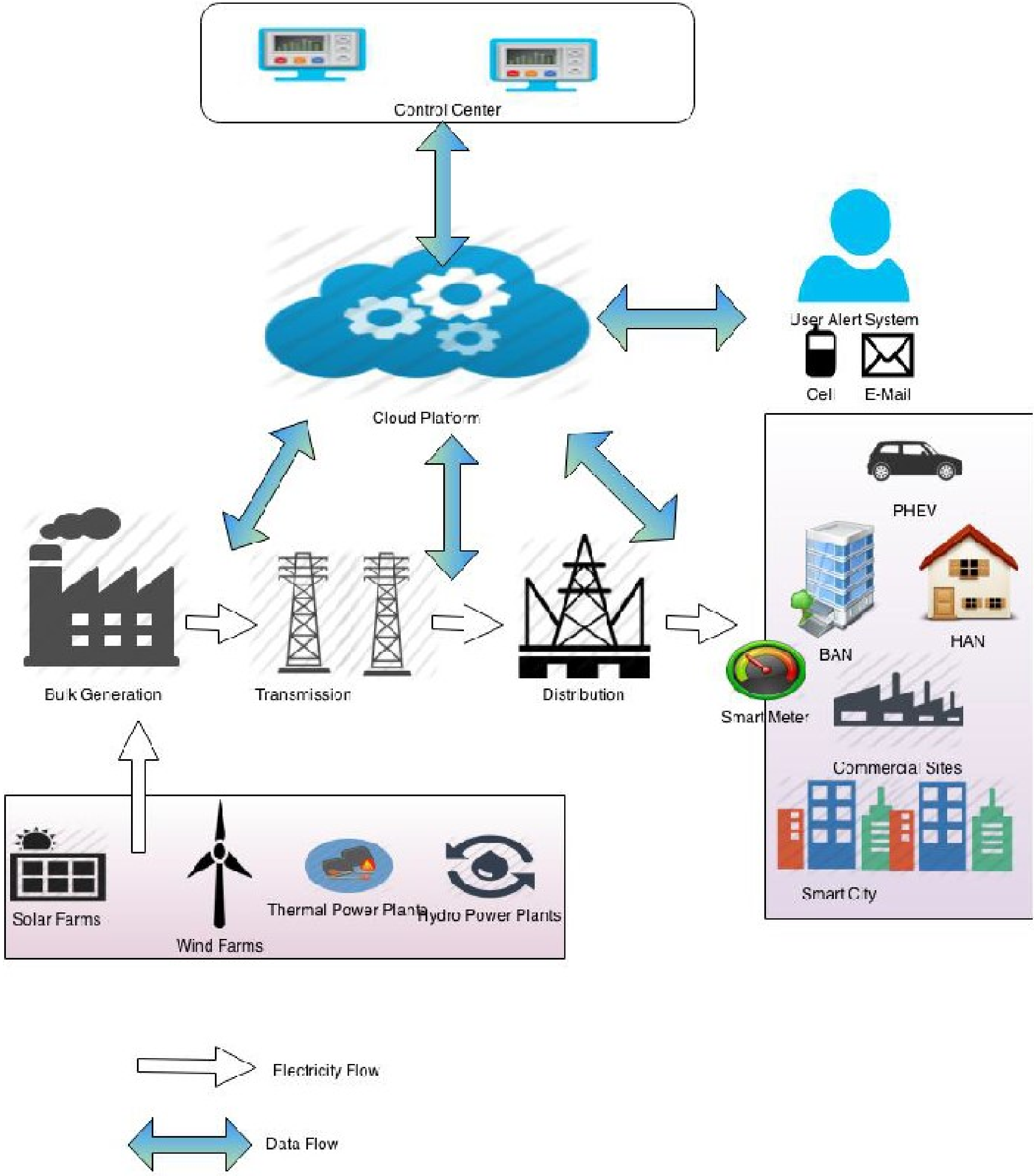
Smart grid definition

Introduced in 2007 in the US within Energy Independence and Security Act

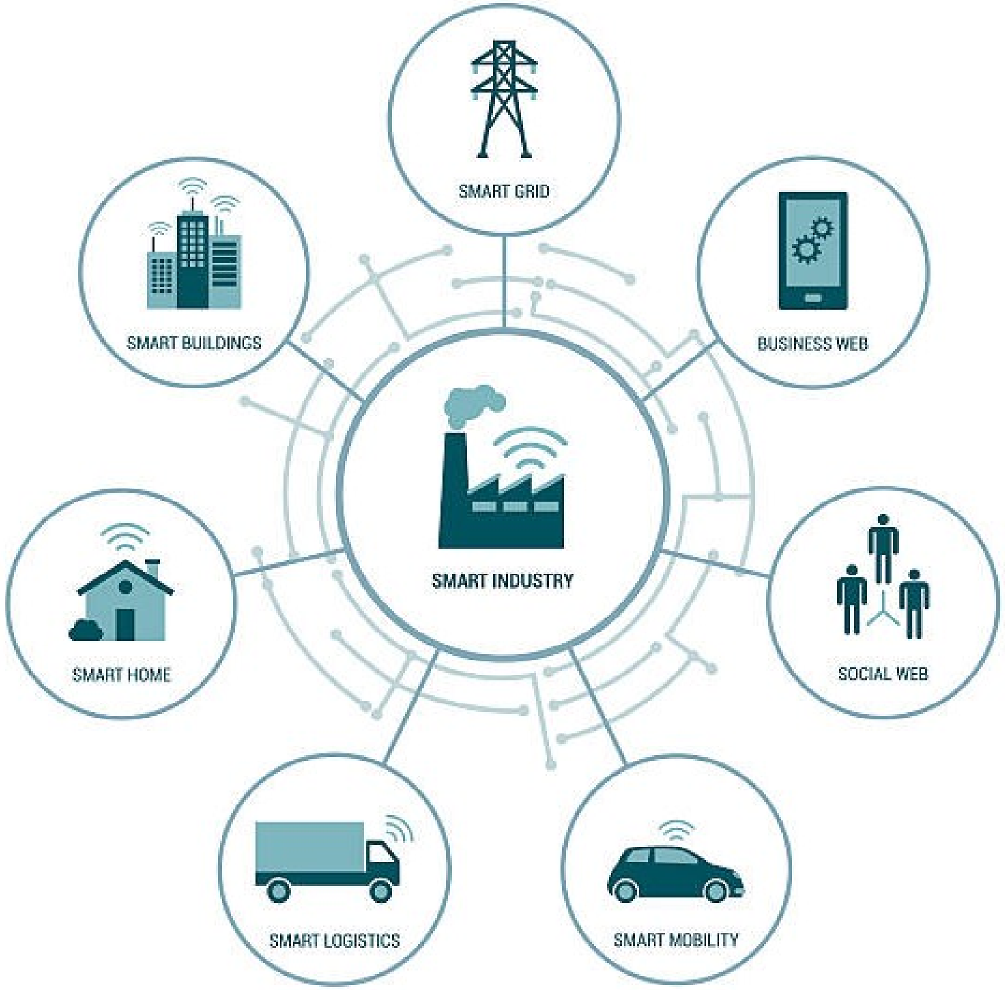
Electricity and ICT infrastructure used to provide electricity to consumers via **two-way digital communication**.

It was introduced **to overcome the weaknesses of conventional electrical grids** by using intelligent:

- monitoring
- control
- communication and
- self-healing technologies



Smart grid benefits



1. **More efficient** transmission and distribution
2. **Quicker** restoration after system disturbances
3. **Reduced** operations and management **costs**
4. **Reduced** peak **demand**
5. **Increased RES** integration
6. **Better integration of customer-owner** power generation systems, including RES
7. Improved **security and reliability**

Smart grid terms

FLEXIBLE

SELF-HEALING

INTELLIGENT

RESILIENT

INTEROPERABLE

EFFICIENT

CLEAN

RENEWABLE

SUSTAINABLE

AUTONOMOUS

SMART

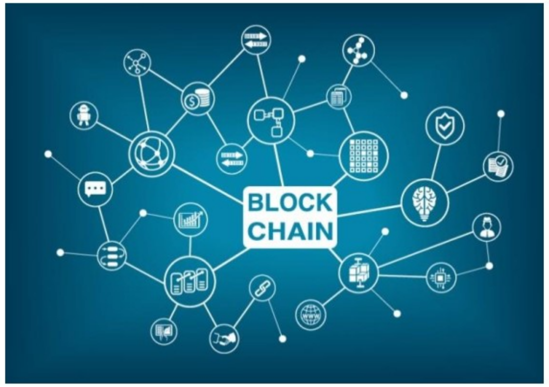
RELIABLE

Smart grid – current status

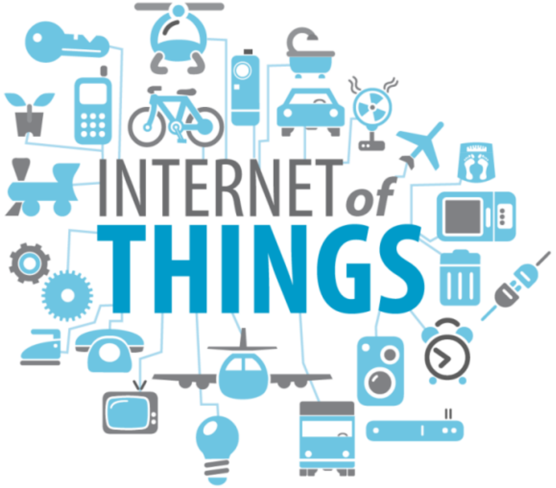
1. System Control
2. Protection System
3. Substation Automation
4. Demand Response
5. Smart Metering

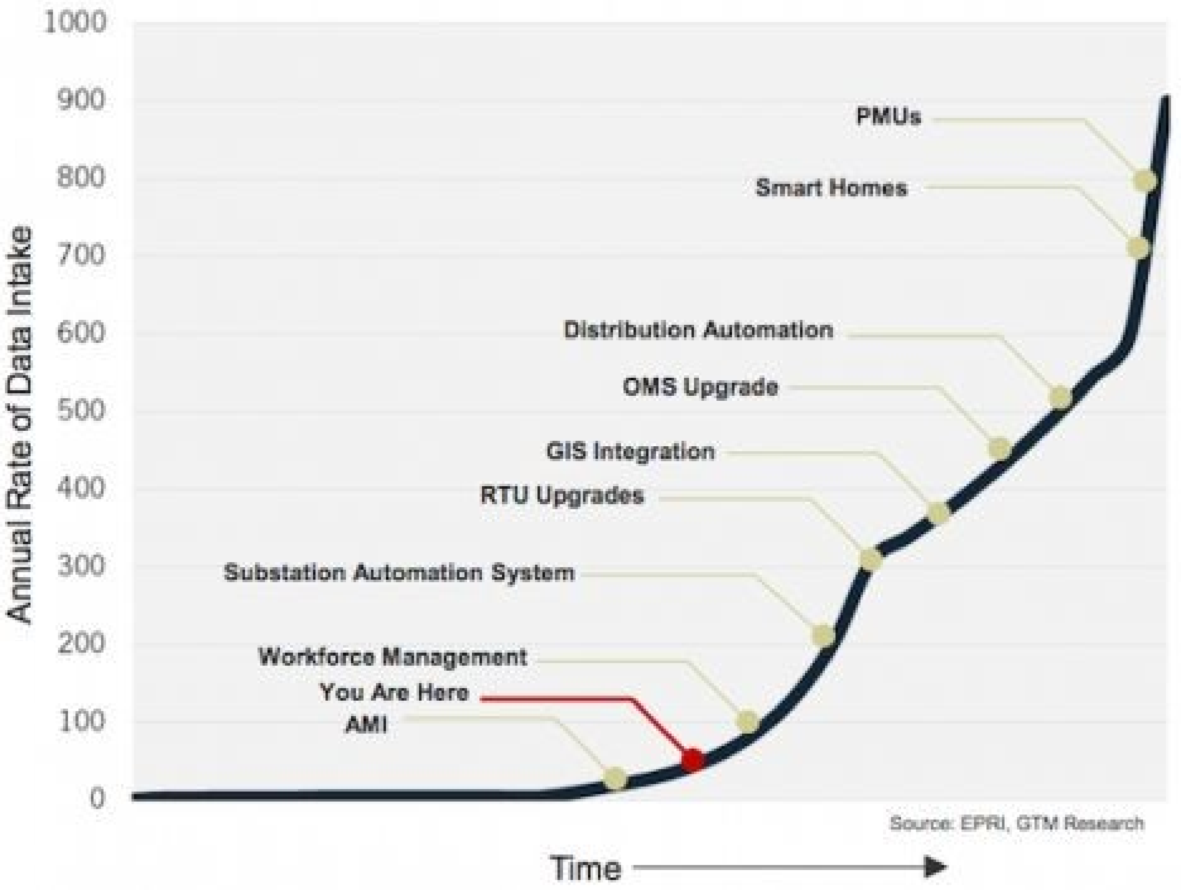
Smart grid - future needs

Blockchain technology: distributed energy market w/o suppliers, power exchanges, market operators…



Internet of things in 2020: 1 bil. comps, 6 bil. mobile phones, 28 bil. of things - connected





Smart meter communication technologies

GSM (Global System for Mobile Communications) – global cell phone data standard – wireless broadband

GPRS (General Packet Radio Service) – using GSM – wireless broadband

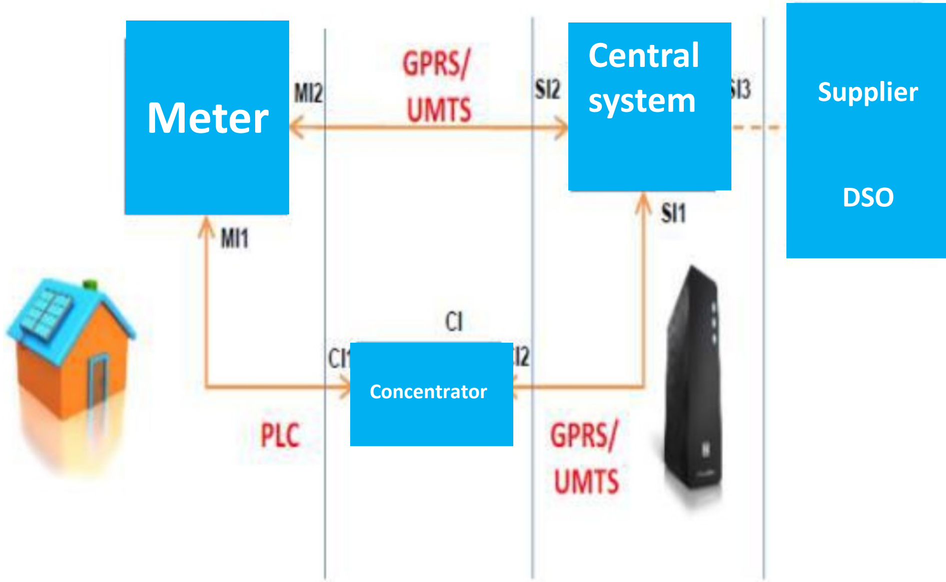
UMTS (Universal Mobile Telecommunications Service) – 3rd third-generation (3G) broadband, packet-based - wireless broadband

Ethernet - traditional technology for connecting wired local area networks (LANs) – optics broadband

IrDA (Infrared Data Association) - industry-driven - wireless infrared

PLC (Programmable Logic Controller) in LV network - industrial computer control system that continuously monitors the state of input devices and controls output devices

Phone line – wired phone protocols

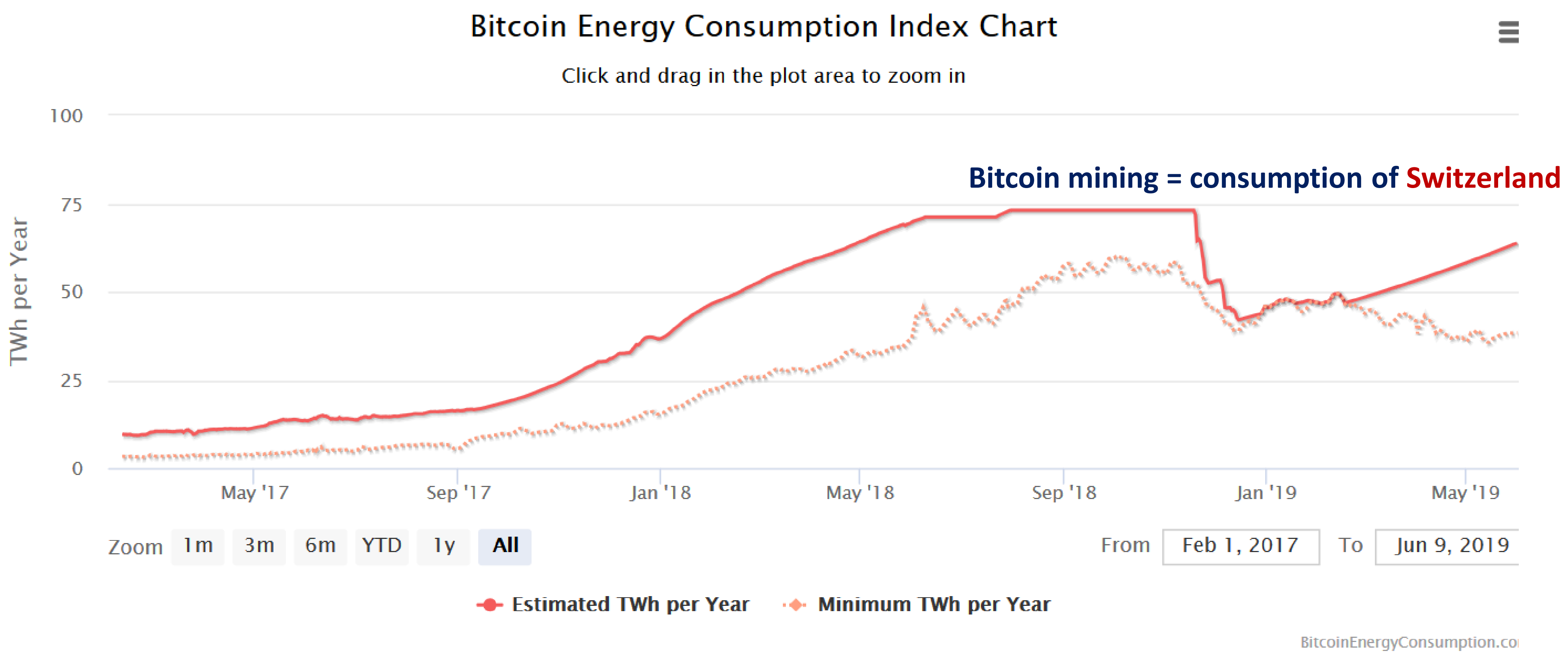


WHAT ABOUT FUTURE ?

New technology integration

Bitcoin Energy Consumption Index

NEW: Bitcoin Electronic Waste Monitor



30-60% of mining income = electricity costs

New technology integration

Crypto currency system electricity needs = 30 avg nuclear reactors output !


Google
One Google search uses enough electricity...
Google Search
I'm Feeling Lucky
Advanced Search
Preferences
Language Tools


...to power a 60W lightbulb for
HALF of a SECOND


The amount of Google searches done every
10 MINUTES...


...could power LAS VEGAS
for HALF AN HOUR
WELCOME
TO Fabulous
LAS VEGAS
NEVADA

EIHP

ERRA
ENERGY REGULATORS
REGIONAL ASSOCIATION

THANK YOU
FOR YOUR ATTENTION!

Goran Majstrovic
goran.majstrovic@eihp.hr