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DIT 615 & DAT300
THE ELECTRICAL POWER SYSTEM

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LTH 96-99, 00-01, M.Sc. Electrical Engineering

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Use of renewable energy sources
Rural areas in Africa, Avialablitity and control

University West, Senior lecturer, 07-09, 11-12
Distribution level

Chalmers University of Technology, Researcher, 12-13

Pöyry Swedpower AB, (fd Vattenfall Power Consultant AB), 09-13
Grid connection of wind power

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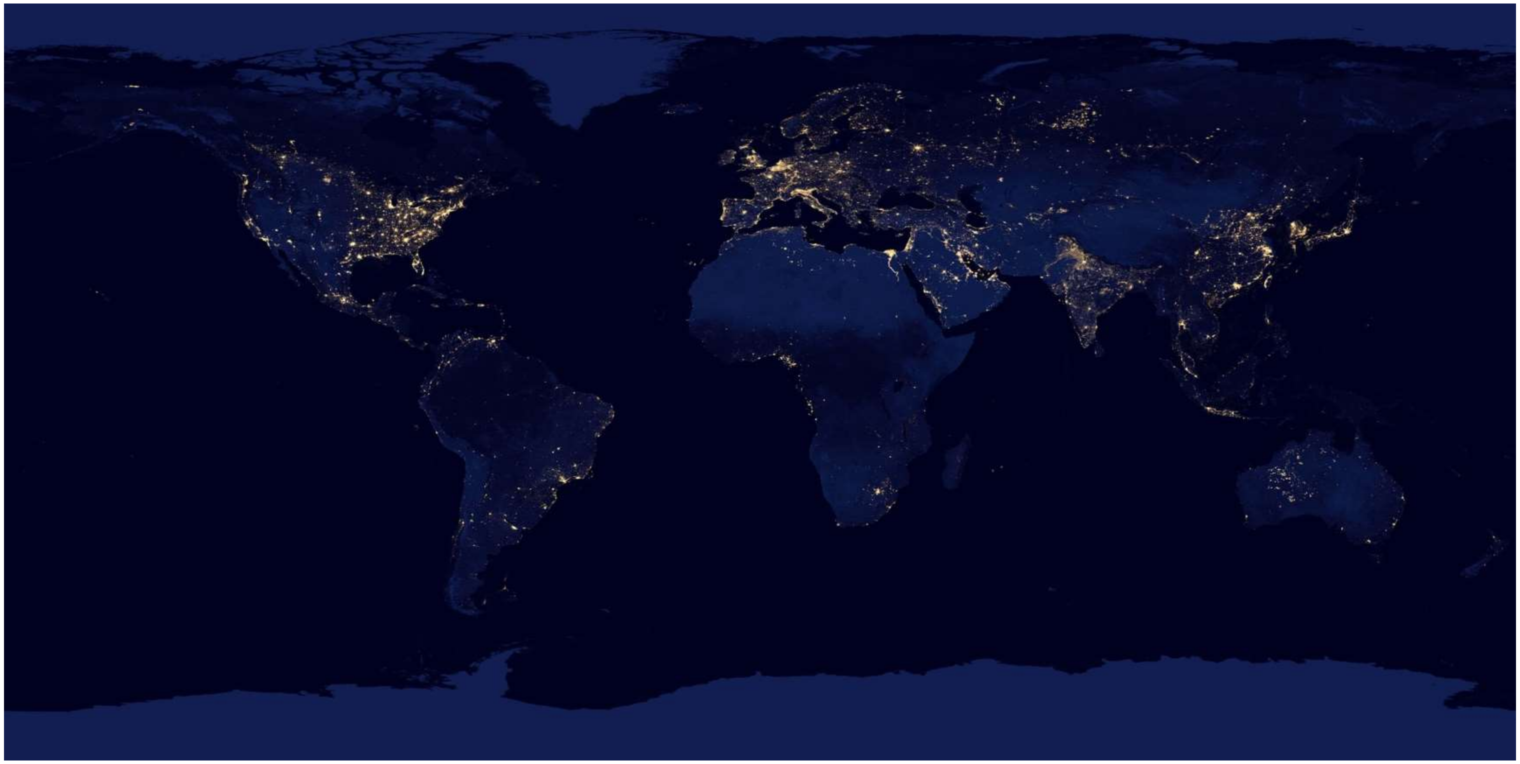
Content

- Introduction
- Basic concepts
- Grid structure
- HVDC and super grids
- Communication in power systems
- Reliability
- Smart grid
- Operation
- Want to know more

Where is the Electric Power System

Where is the Electric Power System



Is electricity expensive?

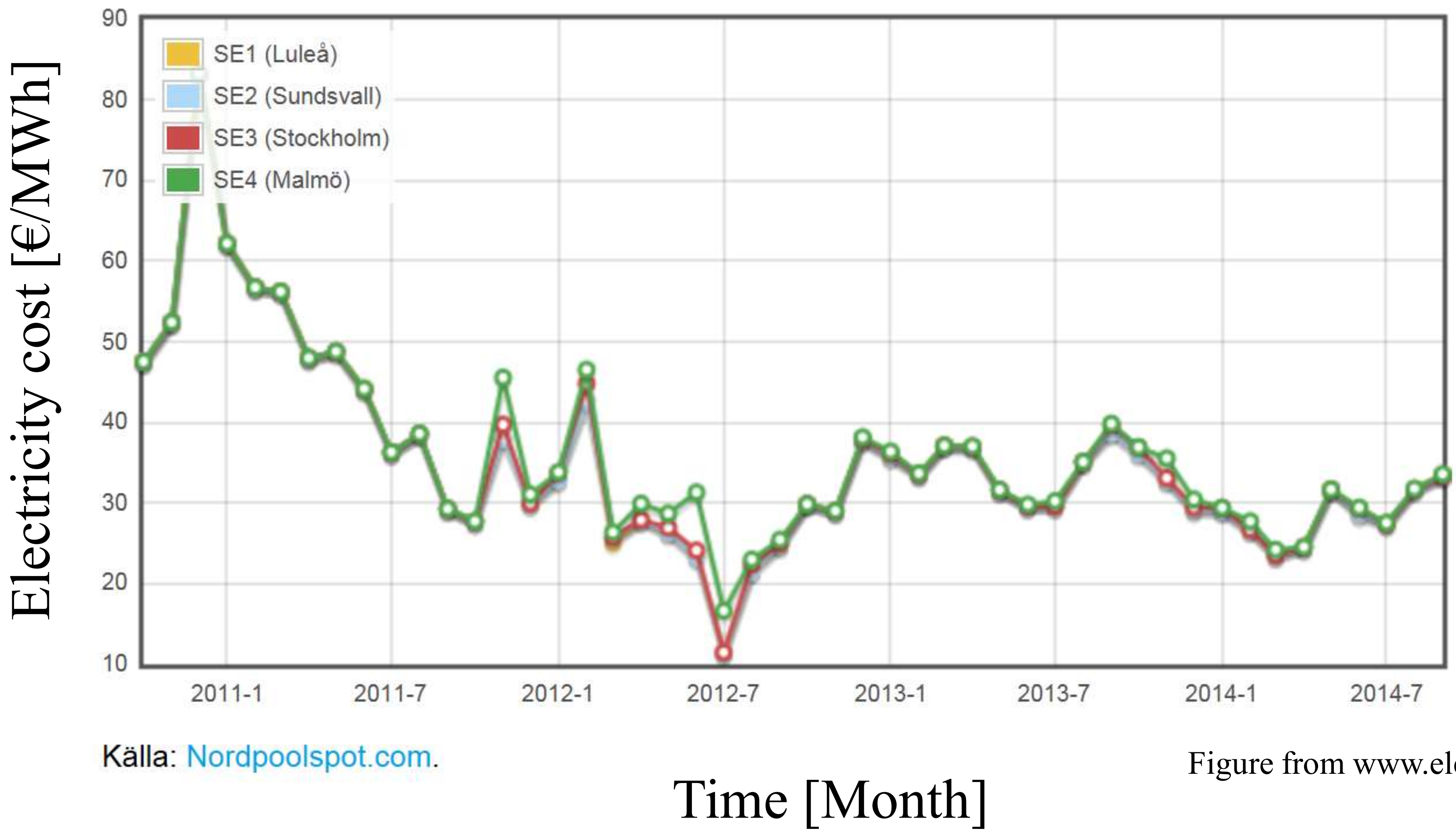
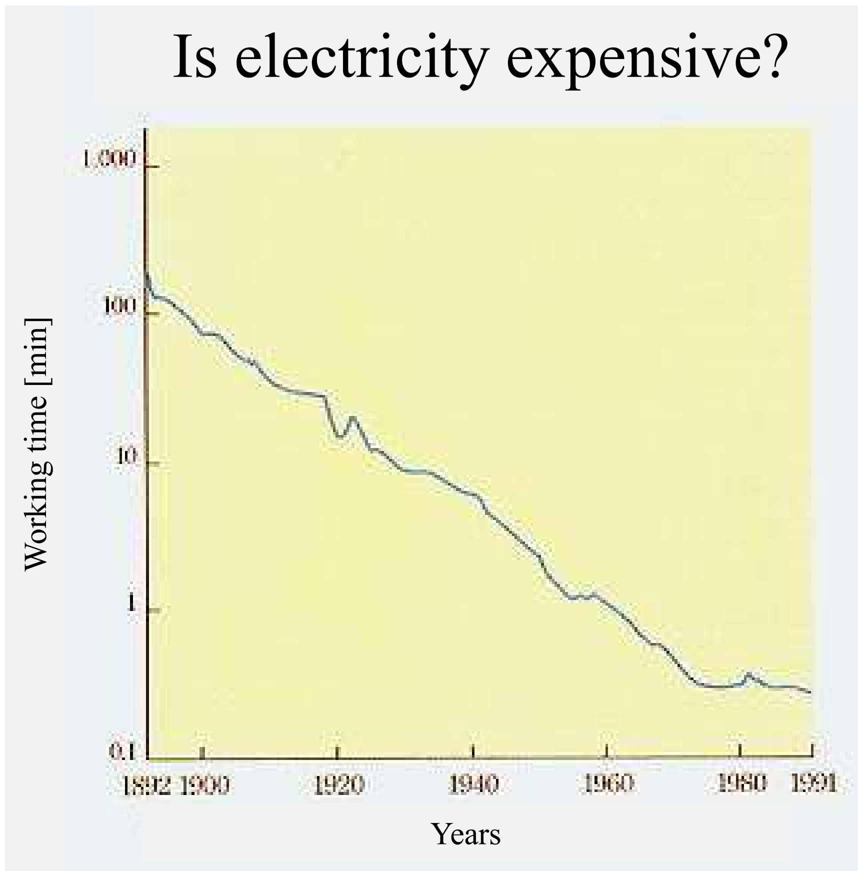


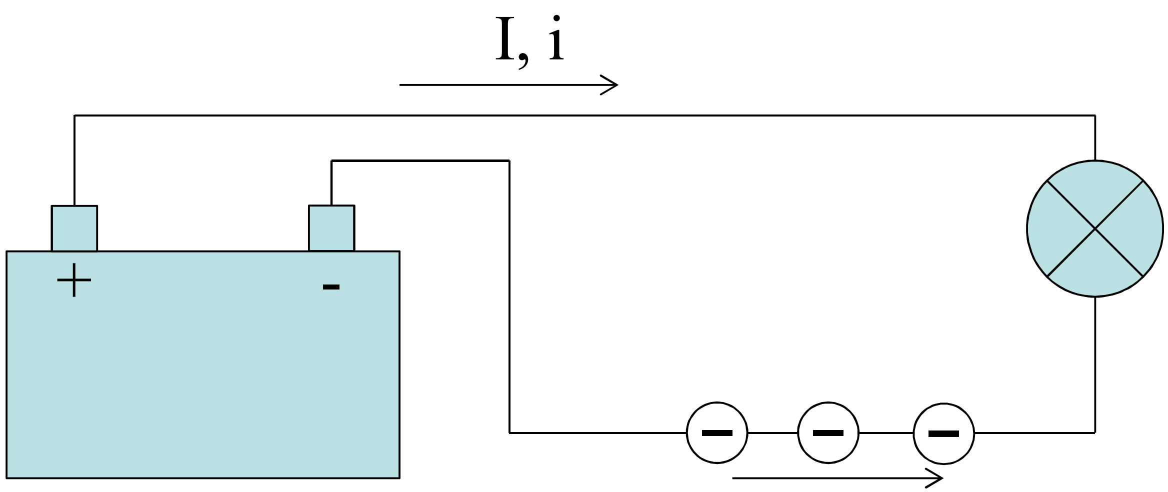
Figure from www.elen.nu

Is electricity expensive?



Current

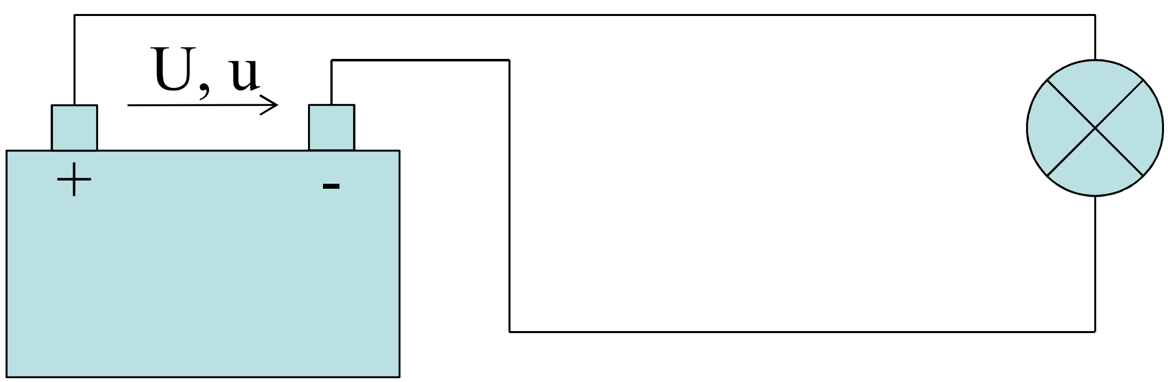
Current is a flow of electrons (charge) from negative to positive but the current goes from positive to negative.



Unit Ampere [A]

Voltage

Voltage is the tension between positive and negative (and the current want to release that tension)

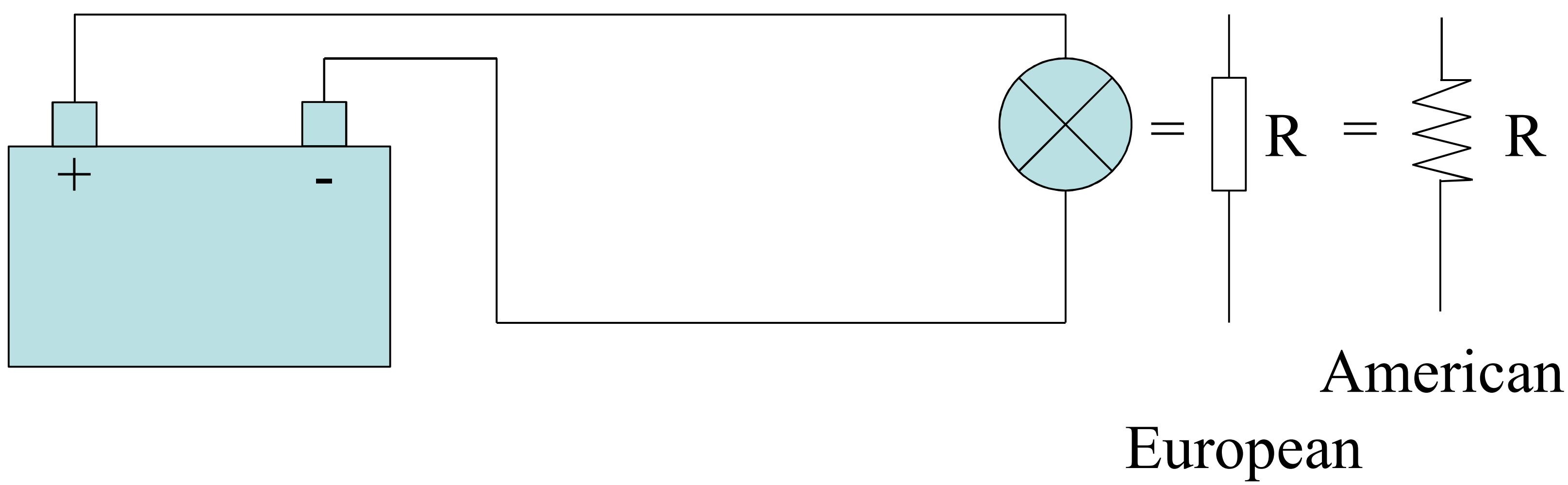


Unit Volt [V]

Resistance

Resistance is the thing that prevent the current to release the tension.

When the current passes through the resistance it does some work.



Unit Ohm or [Ω]

Resistance (2)

Resistivity (ρ) are the intrinsic material property.

For this course relevant example

$$R=\frac{\rho l}{A}$$

where l is the length and A is the conduction area.
Typical materials: Aluminum, Copper.
Low resistive materials: Silver, Gold

Conductitvity (σ) is the inverse of (ρ)

Unit Resistivity [Ohms m]

Unit Conductivity [Smho/m] or Siemens/m

Resistance (3)

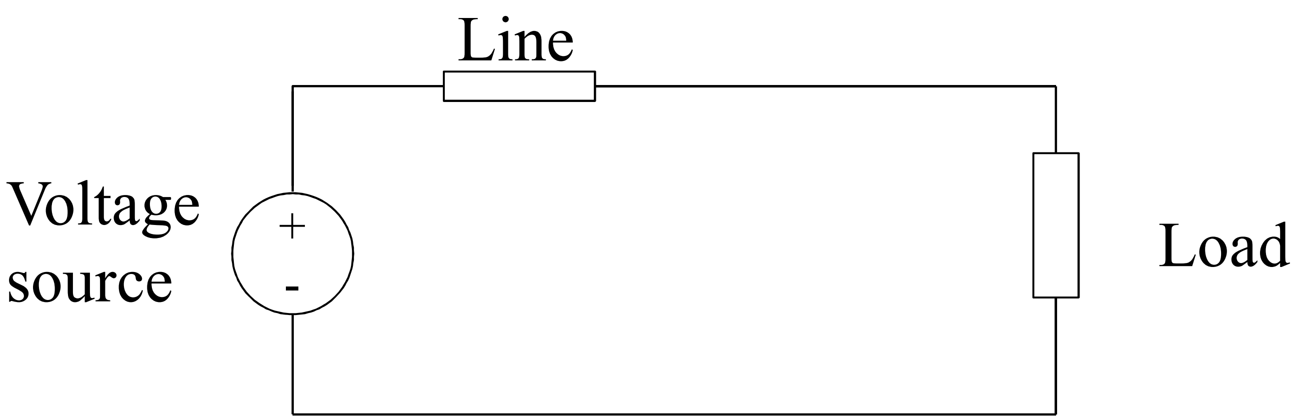
If you do not want ”any” current to flow you use a **insulation** material, a **dielectric** material.
Typical materials: Plastics, Ceramics

Semiconducting material is material that under some circumstances conduct current and sometimes not. (Normally under electrical stress)
Typical material: Silicon, Germanium

Resistance (4)

Resistances can be found everywhere, everything that gets warm and use electricity is working like a resistance.
Typical application: Electric stove, water boiler etc.

Also losses in the grid are caused by resistances.



Ground

Ground (Earth B.E.) is the electric neutral place.

Actual the reference place, to which the voltage level is compared.

To make sure that you actual have a good reference point you always creates your ground in electric power system.

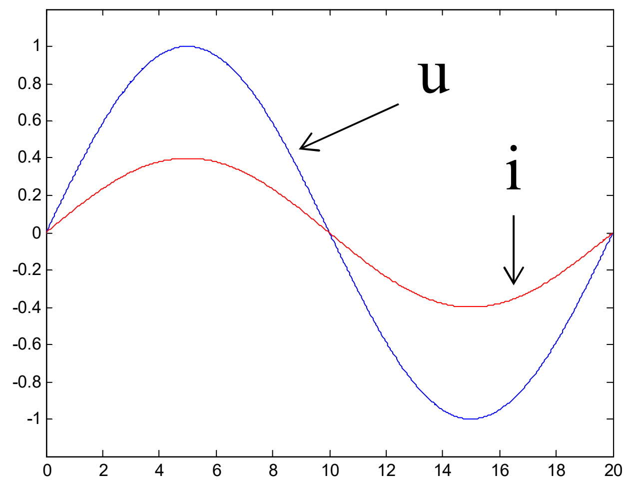
AC ?

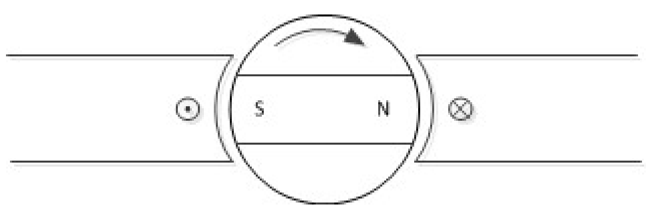
AC (Alternating current) is the most common use “type” of current in electric power systems.

It is a current that changes 50 (60) times per second and varies sinusoidal. Use the voltage as reference.

Why AC?
Easy to create electrical machines and easy to transform the voltage

Voltage and current in AC system with resistive load





RMS value

Root mean square (RMS) is the DC equivalent value of the current or the voltage.

$$X_{RMS} = \sqrt{\frac{1}{T}\int_0^T X^2 dt}$$

X can be both current and voltage

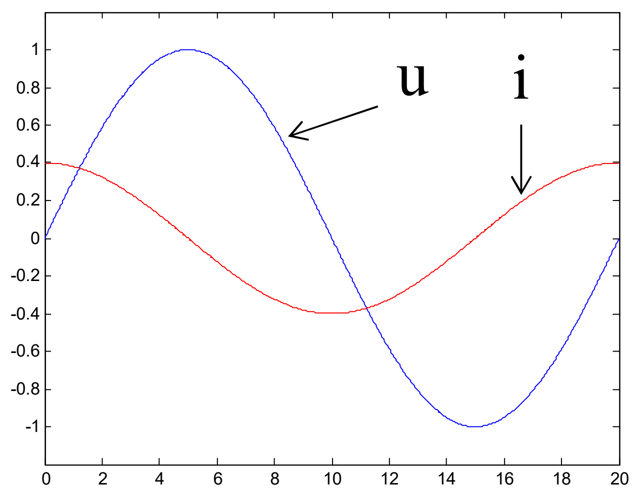
For pure sinusoidal system

$$X_{RMS} = \frac{\hat{X}}{\sqrt{2}}$$

Capacitance

A capacitance is a property that is working against changes in the voltage. Therefore the current will be a quarter of a period before the voltage.

Voltage and current in AC system with capacitive load



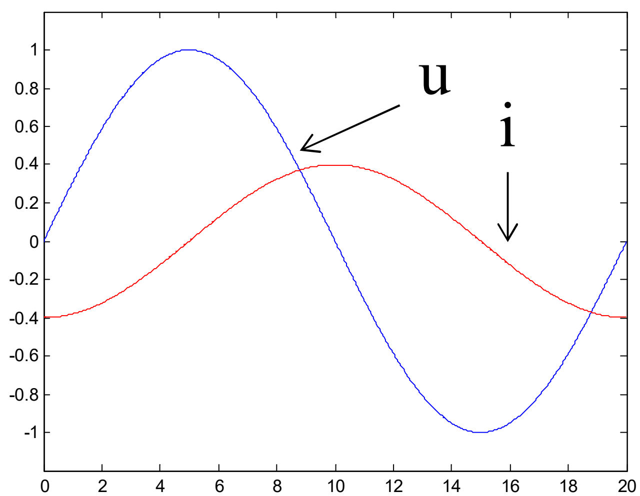
Why capacitance?
Its there but we can use to control, (device capacitors.)
In EPS it is cables and certain loads.

Unit Farad [F]

Inductance

A inductance is a property that is working against changes in the current. Therefore the current will be a quarter of a period after the voltage.

Voltage and current in AC system with reactive load



Why inductance?
Its there but we can use to control, (device reactor).
In EPS it is lines, transformers and in most loads

Unit Henry [H]

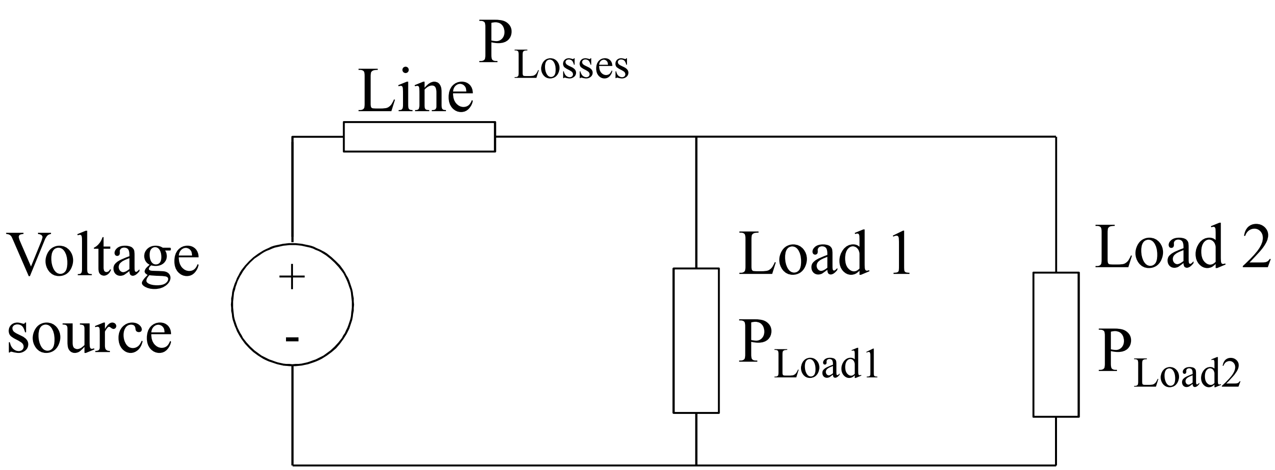
Reactance

- The capacitance and inductance in a component can be modeled as reactance (X_c or X_L) is like a resistance equivalent and can be handled like a resistance but with shift in time.
- The shift can be seen as 90º
- $X_C = \frac{1}{2\pi \cdot f \cdot}$ where C is the capacitance
- $X_L = 2\pi \cdot f \cdot L$ where L is the inductance
- Use complex number (but with a j) to handle them together with resistance we call impedance (Z).
  - $Z = R + jX$

Unit Ohms[Ω]

Active Power

Active power is the power that we normally get something useful from. But also losses.
(All electricity that is converted in a resistance to something else)



All things that comes out must come in

Unit Watt [W]

Reactive Power

- Mathematical way to handle the current that is not in phase with the voltage.
- Introduced as a new type of power.
- Caused by capacitance and inductance but with different sign
  - Capacitance (+)
  - Indutance (-)
- Will cancel each other
- Effects in the EPS due to reactive power
  - Will cause voltage changes (voltage drop)
  - Will cause losses

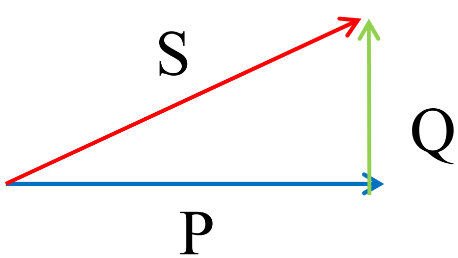
Unit Volt-Ampere reactive [VAr]

Apparent Power

- Contain both the active and reactive power.
- It is the actual power in the system
- Effects in the EPS
  - Will cause voltage changes (voltage drop)
  - Will cause losses

$$S = \mathrm{u} \cdot i^*$$ For AC

$$S = \sqrt{3} \cdot u \cdot i^*$$ For 3 phase AC



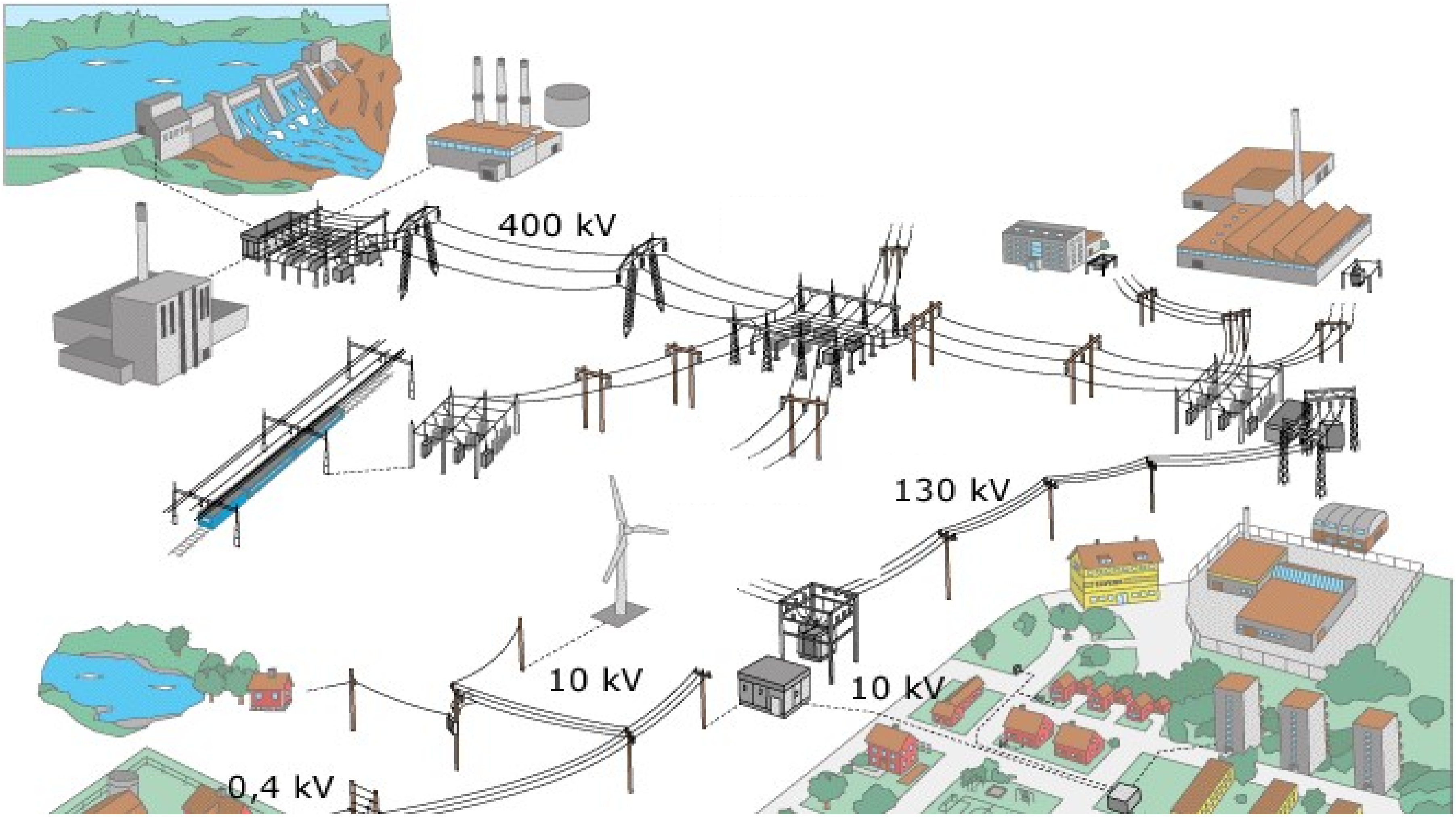
$$S = P + jQ$$

Unit Volt-Ampere [VA]

Power factor or cos(φ)

- The cosines of the angle between the voltage and the current is called the power factor (PF)
- No way to know if it capacitive or inductive (always positive)
- Have to add description
  - Capacitive = leading
  - Inductive = lagging
- Normally in EPS is the PF 1-0,9 lagging, or at least used to be.

Structure of the Electric Power System

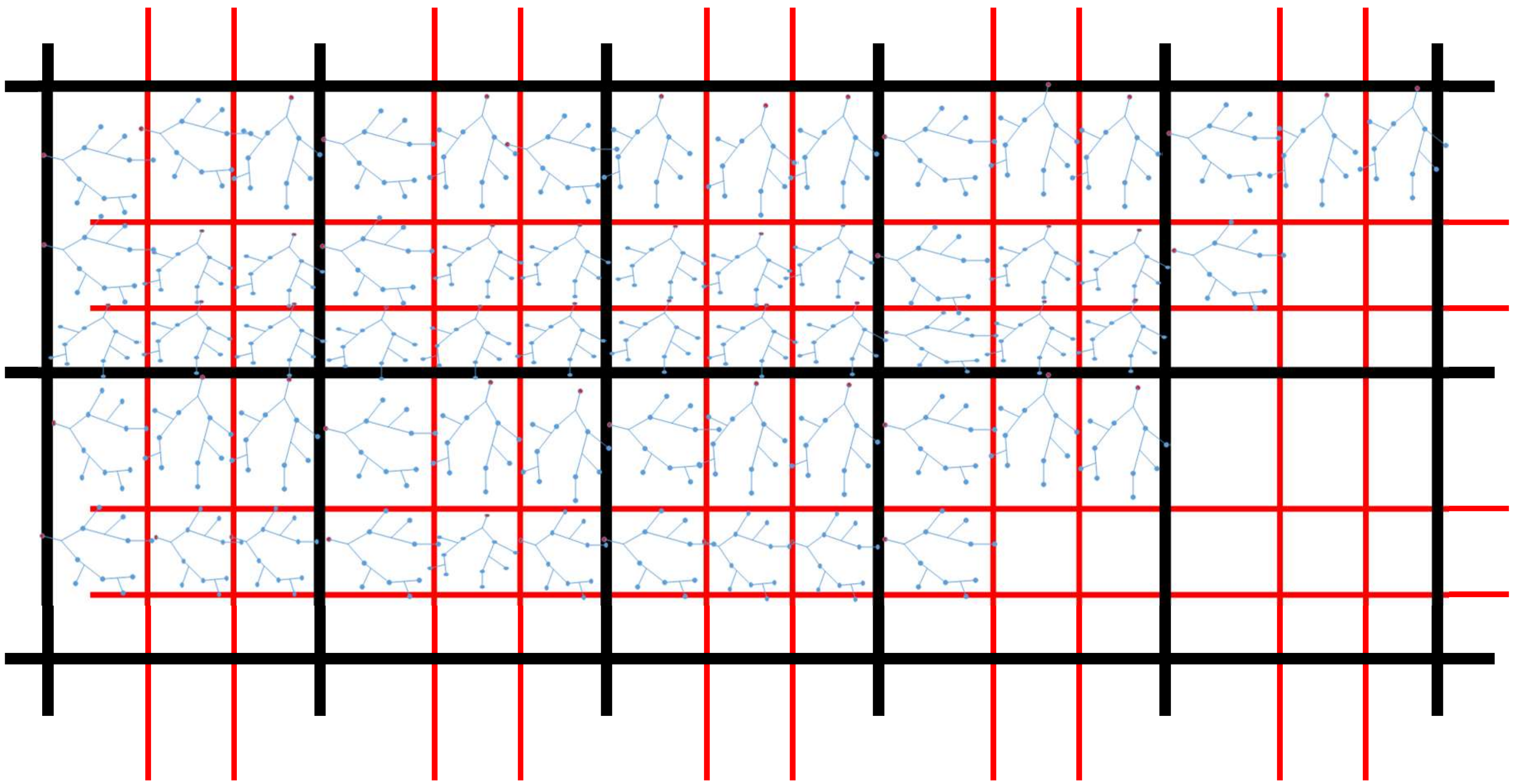


Good things to know about

Name	Voltag level (~)	Layout	Typical owner
Transmission grid **HV, UHV, EHV**	220-1000 kV	Meshed	Transmission system operator
Regional grid or Subtransmission **HV**	50-130 kV	Meshed	Large utilites
Distribution grid **MV**	10-36 kV	Built in radial or rings but operated on radial	Local utilities Distribution system operator
Local grid and in houses **LV**	400 V	Radial	Local utilities or consumer

Current grid

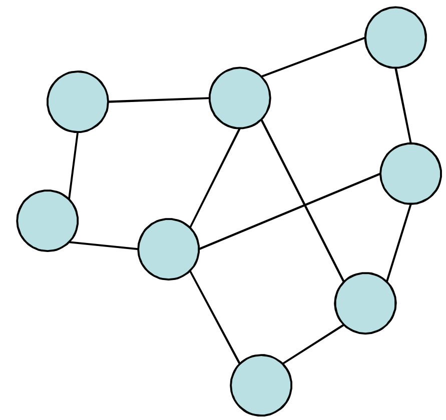
Transmission Subtransmission Distribution



Structure of power systems

- There are three main ways to build electric power system
  - Meshed
  - Radial
  - Ring
- Compared and built differently due to
  - How many customers (or sensitive customers) are connected
  - Risk of faults
  - Impact of faults in the grid
  - Costs

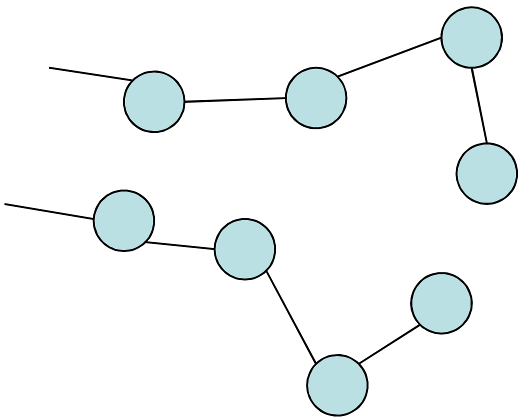
Meshed



Use at transmission and subtransmission grid.

+ Power will reroute if needed
- Many costumers will be affected in case of interruption
  - Low risk (treesafe, ground wires etc.)
- Expensive few important lines can we afford
  - High cost (both economical and environmental (social))
  - Complicated protection system

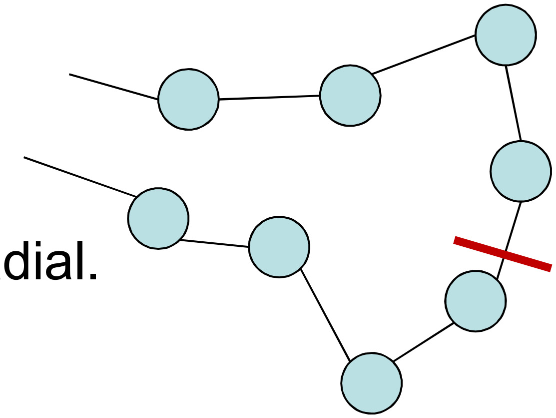
Radial



For LV grid and some lines for production.

+ Low cost
+ Few costumers will be affected in case of interruption
+ Few experience voltage dips
+ Simple protection systems
- No back-up

Ring

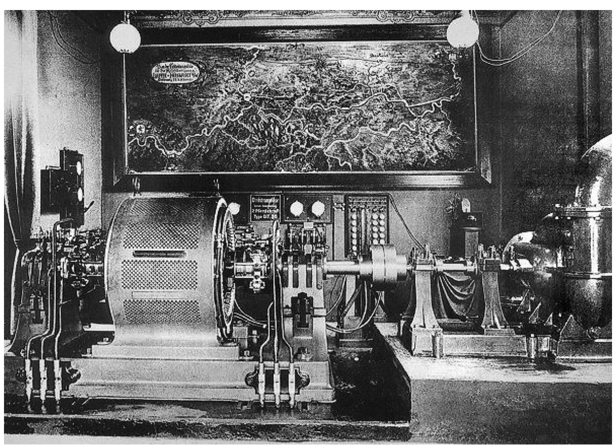


Built in MV distribution grid but operated in radial.

- \+ Low cost but not as low as radial
- \+ Few costumers will be affected in case of interruption
- \+ Few experience voltage dips
- \+ Simple protection systems
- \- Back-up but it will require some action.

History of the power systems

AC transmission was first demonstrated at an exhibition in Frankfurt am Main 1891



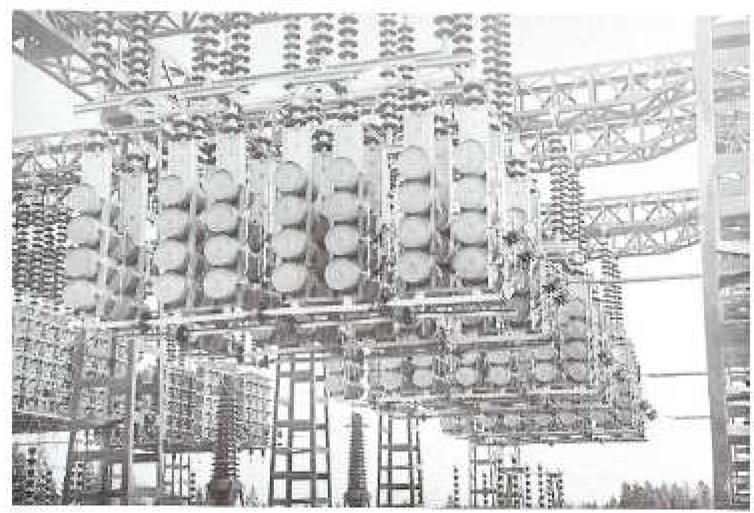
170 kW transferred 175 km from Lauffen hydropower station to the exhibition area at 13000-14700 V

History of the power systems in Sweden

First 3-phase transmission system installed in Sweden between Hellsjön and Grängesberg 1893
voltage 9650 V, 70 Hz, 70 kW

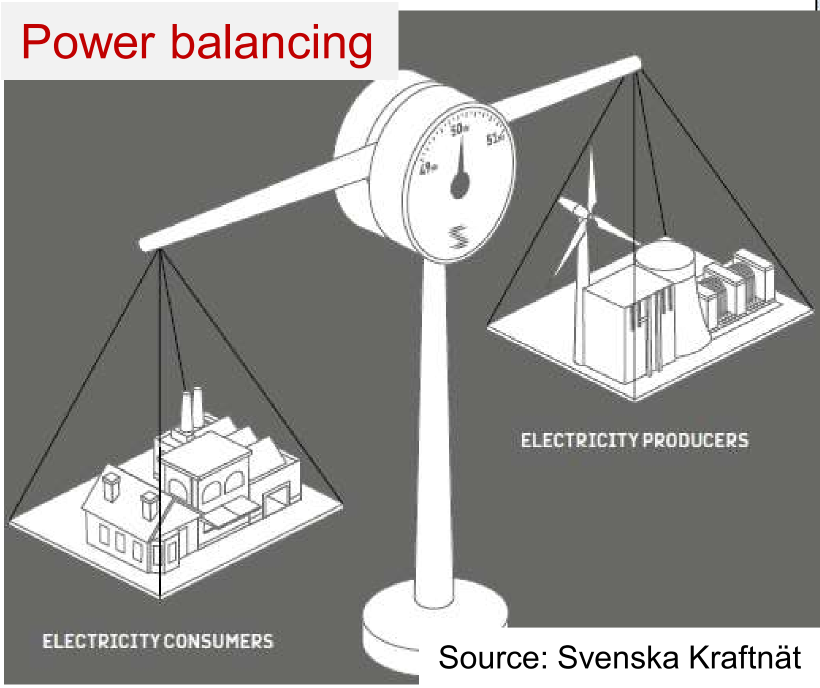
First 400 kV system Harsprånget Hallsberg 1952

Series compensation introduced 1954

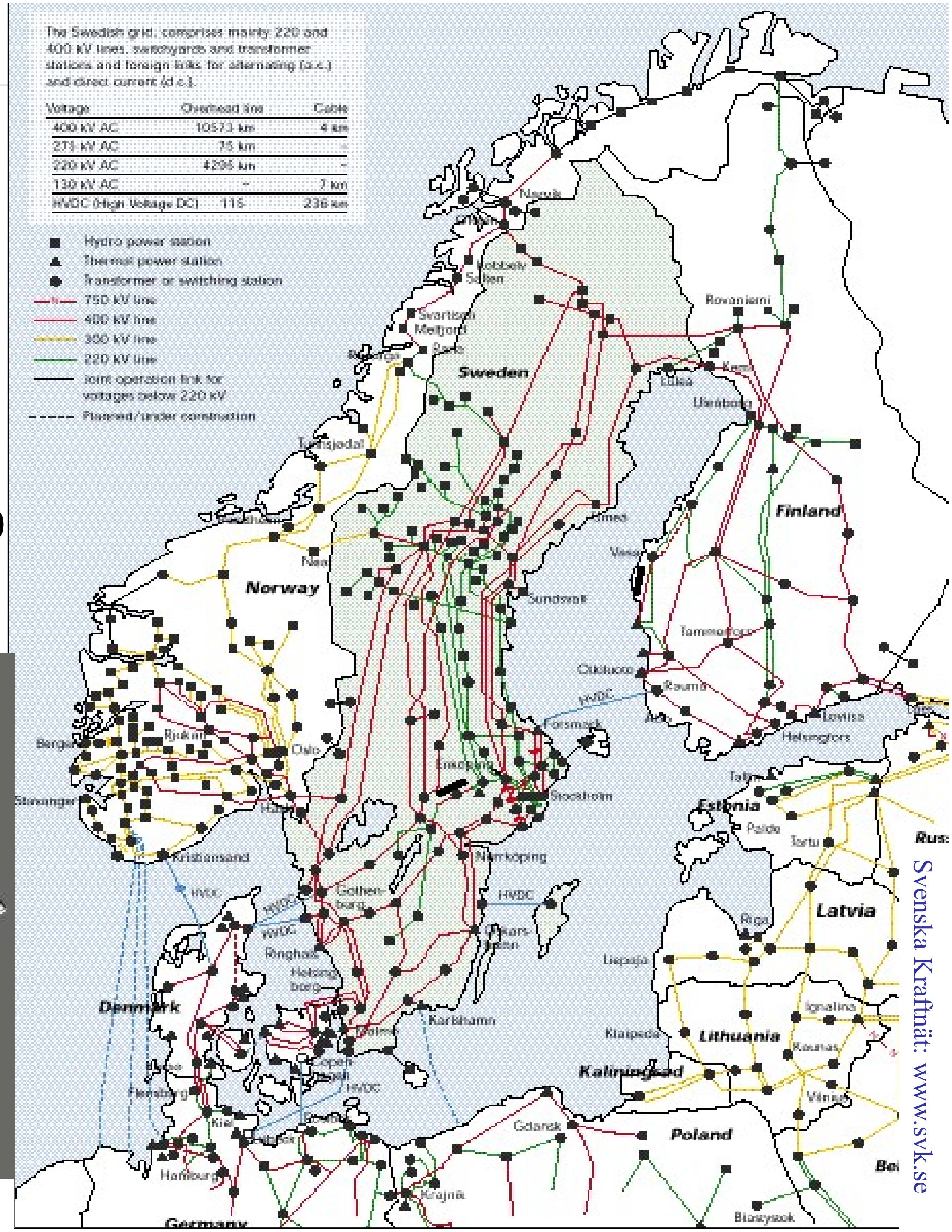


- Transmission 400, 220 kV
- Regional 130 kV
- Distribution *70*, 40, 30, 20,10 kV
- Local 400 V (Industry 10-130 kV)

Power balancing



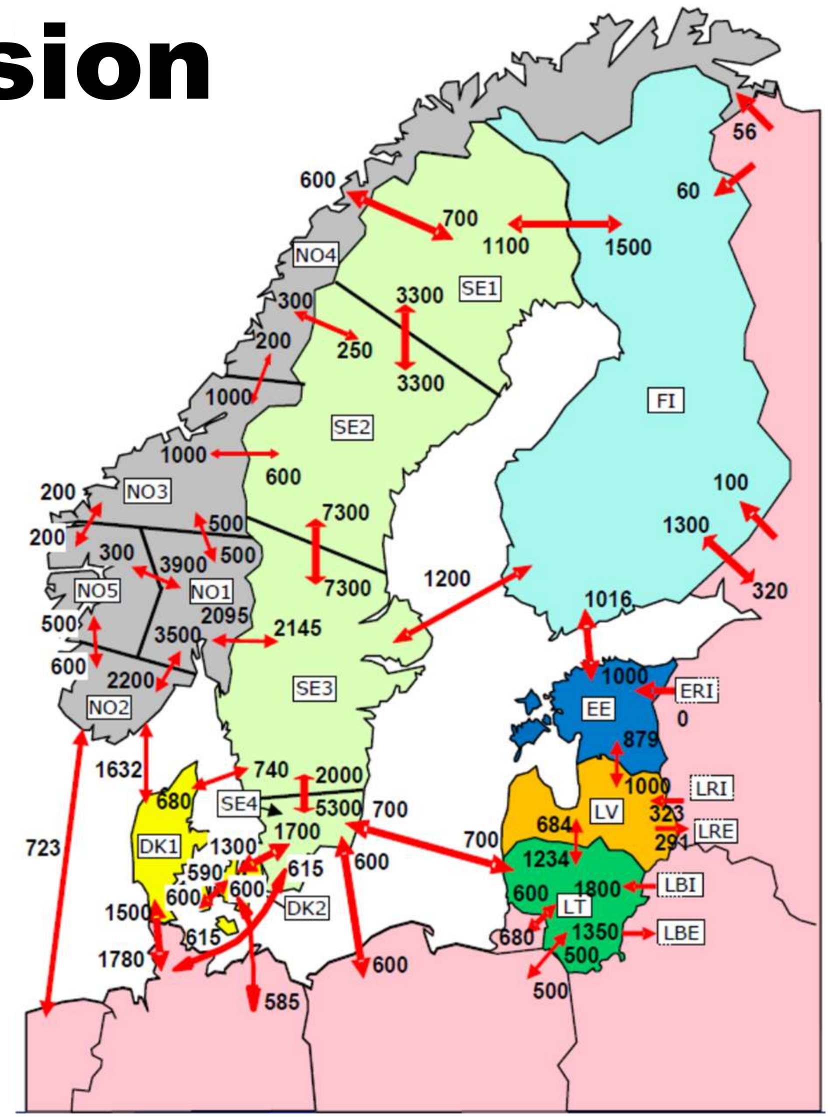
Source: Svenska Kraftnät



Svenska Kraftnät: www.svk.se

Corridors and limits in the transmission grid

- Updates every hour
- Dynamic limits
- Thermal limits
- Voltage limits



The Swedish grid

Level [kV]	No of Customers	Customer [%]	Energy [GWh]	Energy [%]	Mean energy per customer [MWh/c]
<=1	5 487 510	99,83	69 061	56,48	13
3-6	56	<0,01	449	0,37	8 019
10-15	6310	0,11	20860	17,06	3 306
20-25	1971	0,04	6795	5,56	3 448
30-36	339	0,01	1149	0,94	3 389
40-45	103	<0,01	2819	2,31	27 372
50-77	132	<0,01	3806	3,11	28 832
110-245	239	<0,01	17 329	14,17	72 508
Tot:	5 496 660	100	122 268	100	Av: 22

Transmission grid 15 000 km
Lines that would cover 13 turn

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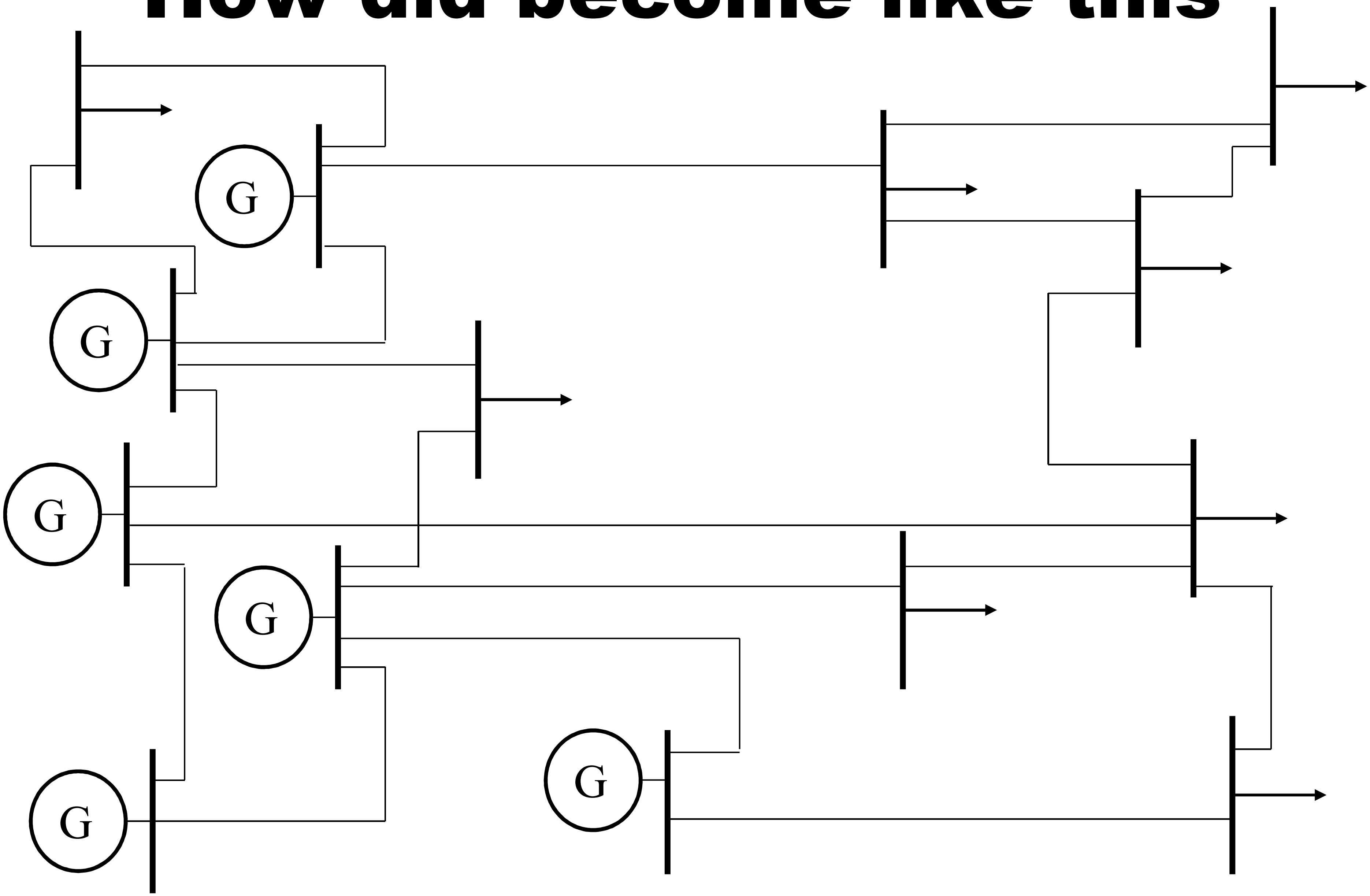
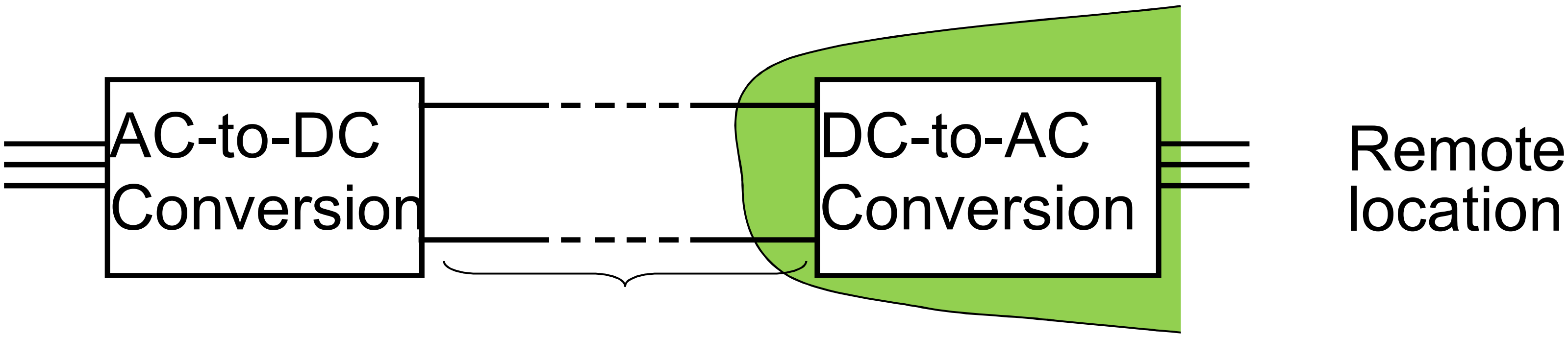
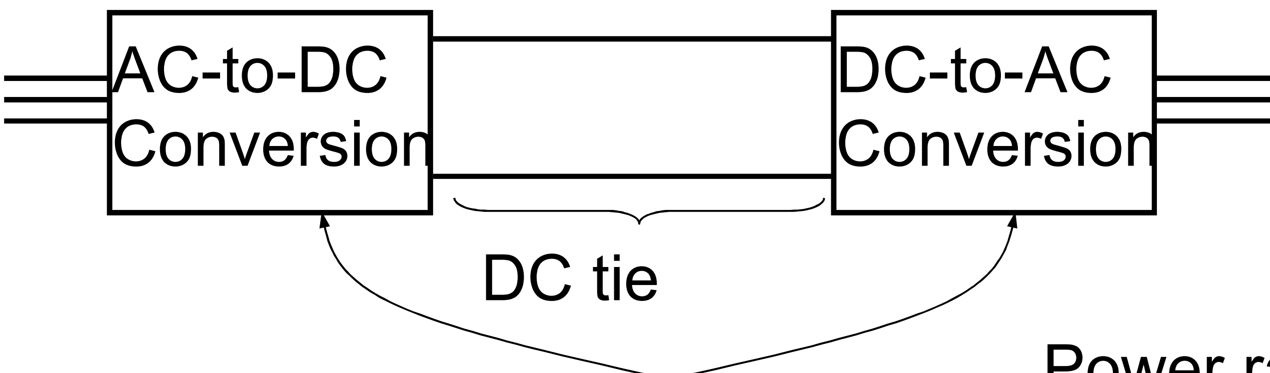
How did become like this



What is an HVDC



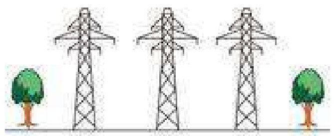
Long distance DC transmission lines:
> 50km submarine, > 1000km overhead



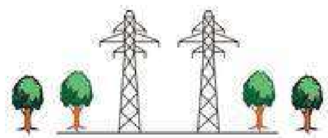
Different frequency or
incompatible frequency control

Power range:
*00 MW ~ *000 MW

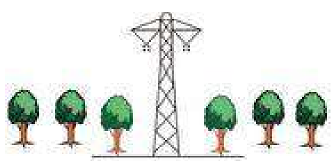
Why HVDC?



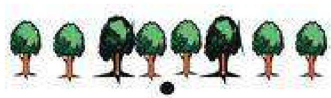
Conventional HVAC



Conventional HVAC
with RPC/FACTS



HVDC



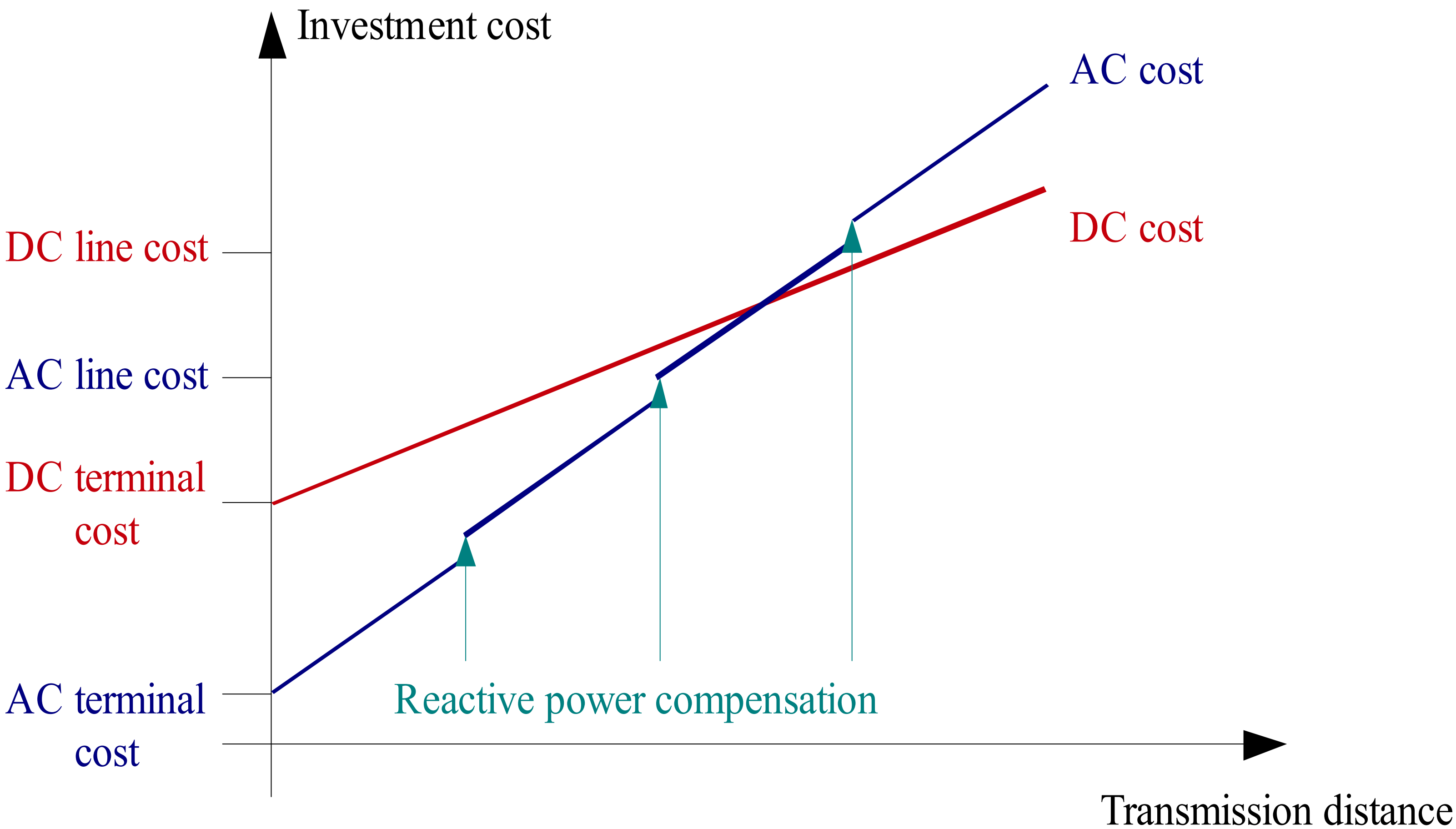
DC & AC

(Same power being transmitted)

HVDC Transmission features

- Transmission of large amount of power over long overhead lines
- For crossing long submarine distances
- HVDC enables transmission of more power with less Right of Way (ROW)
- Control over the power exchanged between two areas
- Flexibility of HVDC enables improvement of performance of the overall AC/DC system
- Investment cost

AC vs. DC – Cost


Investment cost
AC cost
DC cost
DC line cost
AC line cost
DC terminal cost
AC terminal cost
Reactive power compensation
Transmission distance

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Super Grids?

European Visions

- Hydro power & pump storage -Scandinavia
- >50 GW wind power in North Sea and Baltic Sea
- Hydro power & pump storage plants - Alps
- Solar power in S.Europe, N.Africa & Middle East

Germany (draft grid master plan)

- Alternatives to nuclear-distributed generation
- Role of offshore wind / other renewables
- Political commitment
- Investment demand and conditions
- Need to strengthen existing grid

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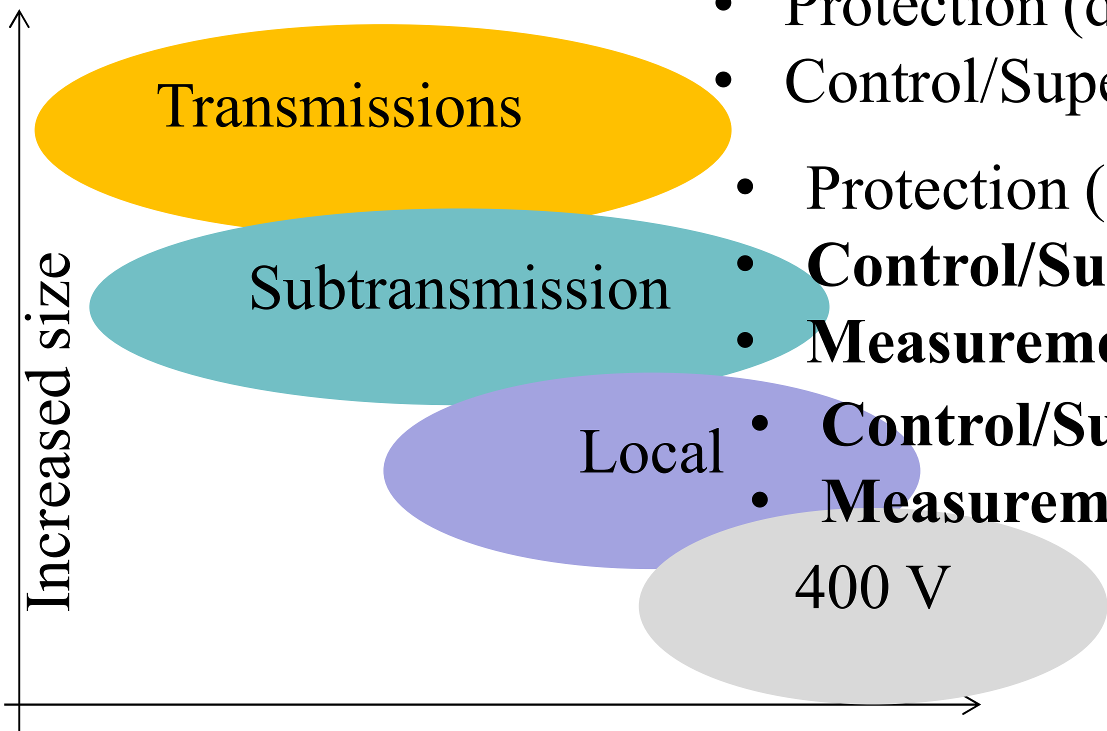
Increased focus of ICT in the EPS tomorrow by Jimmy



- Protection (designated fibers)
- Control/Supervision (separate network)

- Protection (designated fibers)
- **Control/Supervision (separate network)**
- **Measurements (shared network)**

- **Control/Supervision (separate network)**
- **Measurements (shared network)**

- **Measurements (shared network)**
- **Communication with/between customer (Internet)**

Increased amount of data
Lower security demands
Lower demand on speed
Higher demand on integrity

Reliability in Sweden

2015	No of interruptions	
Voltage level	Announced	Unannounced
24 kV	1986	4166
12 kV	6176	10219
<10 kV	120	79
0,4 kV	6421	29964
Sum	**14703**	**44428**

Based on 87 % of the 5,4 million customers in Sweden

Source: DARWin 2015 statistics

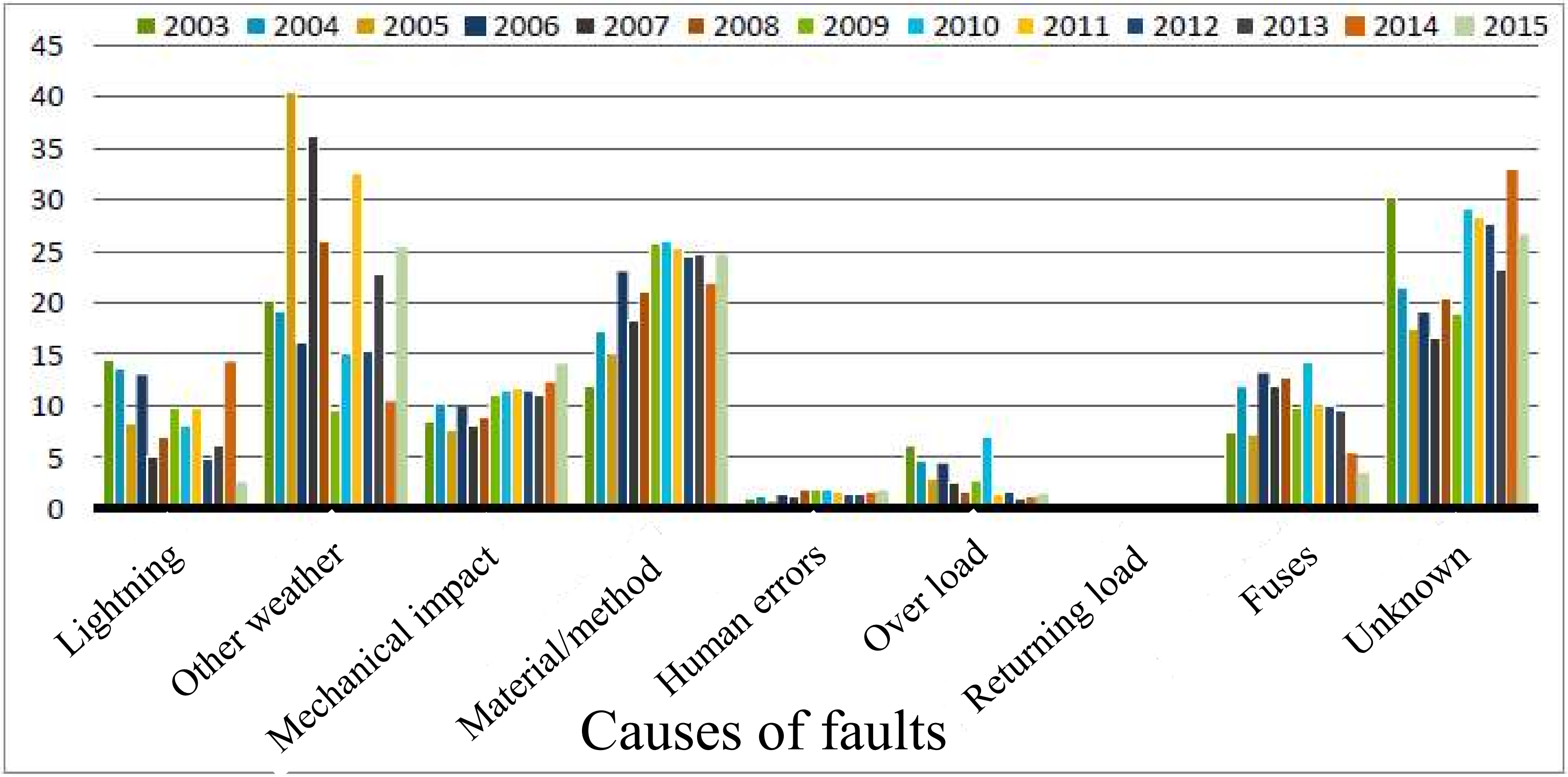
Reliability in Sweden

2015	SAIFI	SAIDI	CAIDI	ASAI		
Voltage level	[No./y]	[Min/y]	[Min/y]	[%]	No. of events	No. customer events
24 kV	0,30	30,52	101,40	99,994	4166	1420306
12 kV	0,64	77,62	121,91	99,985	10219	3005101
<10 kV	0,00	0,49	149,51	99,999	79	15477
0,4 kV	0,03	10,34	314,33	99,998	29964	155309
Sum	0,97	118,98	112,18	99,977	44428	4596193
All grids	**1,28**	**130,25**	**101,38**	**99,975**	**46006**	**6063691**

Based on 87 % of the 5,4 million customers in Sweden

Source: DARWin 2015 statistics

Reliability in Sweden



Based on 87 % of the 5,4 million customers in Sweden

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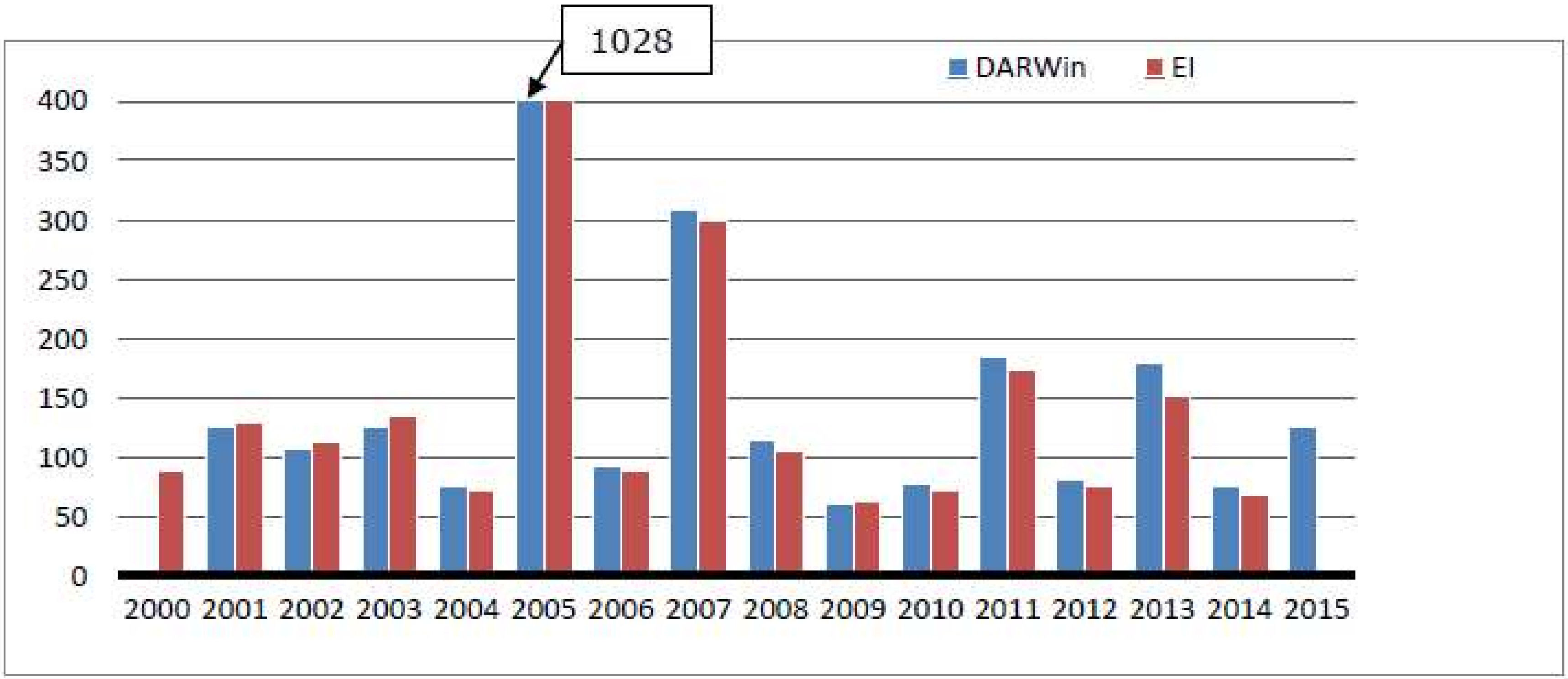
Reliability in Sweden



Average SAIDI in distribution grid

Based on 87 % of the 5,4 million customers in Sweden

Source: DARWin 2015 statistics

Why “smart grid”?

- Environmental
  - Less losses
  - Less land need
  - Less raw materials
  - Less visual impact
  - Decreased EMF etc.
- Economy
  - Less losses
  - Utilize low “electricity prices”
  - Reduce the need for regulating power.
  - Less new power lines

Examples of smart grid

1. **New components**
   - Smart meters
   - BLL and BLX
2. **New technologies for use in EPS**
   - ICT in EPS
   - Electrical storage
   - Solid state transformer
3. **New strategies**
   - DSM
     - Peak shaving
     - Electric vehicles in distribution systems
   - DG
   - Dynamic line rating
     - OH-line
     - Cable
   - Network reconfiguration

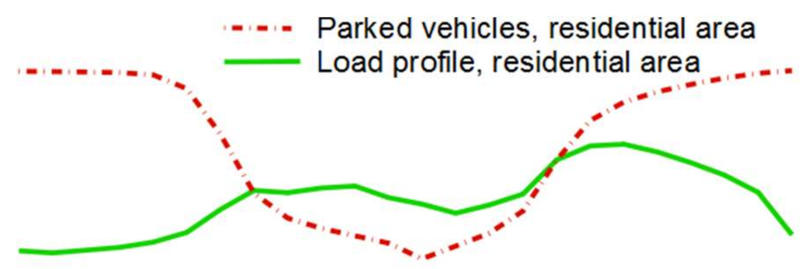
Demand side management Load control vs. Storage

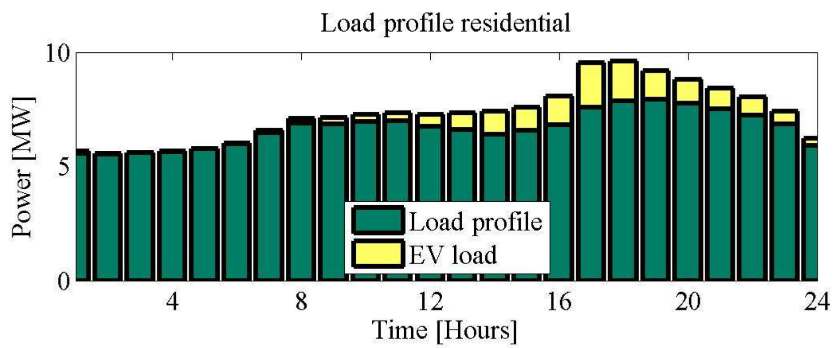
+ Loads are distributed in different areas.
+ Close to the other loads
+ Cheaper
- Hard to control
- Uncertian about available capacity
- Peak shaving, limtited by the flexibility of the customers

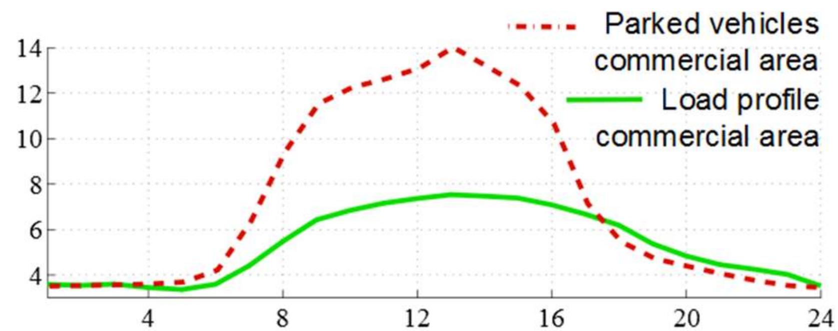
+ Placement and design adaptable after need
+ Esier to control
+ Ancillary services
- Expensive
- Peak shaving, limtited by size of the storage

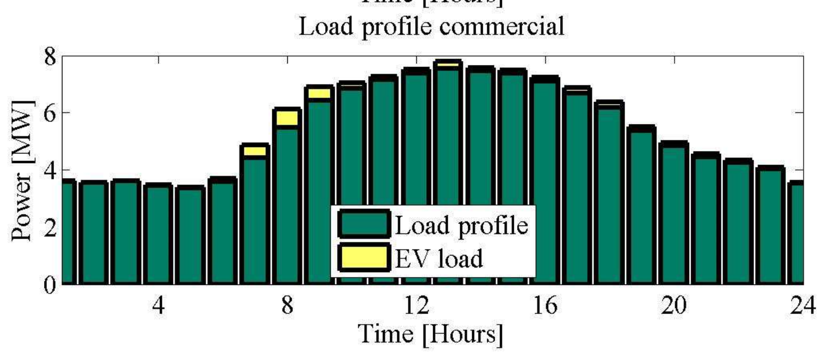
Load control of electric vehicle

- Power ”slow charging”
  - 2-4 kW
- Energy per day
  - 8 kWh
- Gives 2-4 h/day of charging









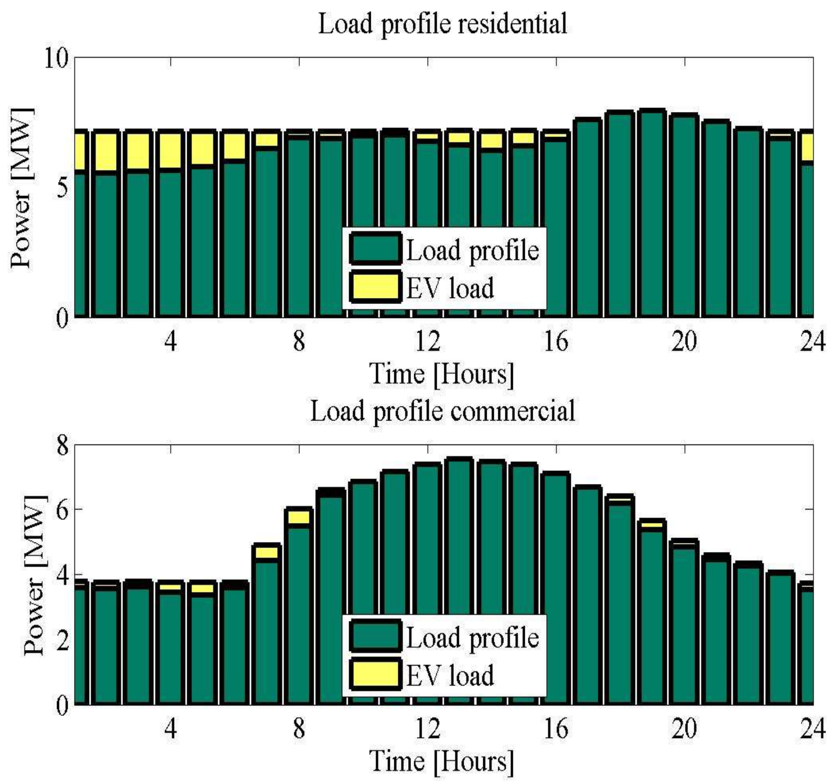
Residental = Charging by night

Commercial = Charging by day

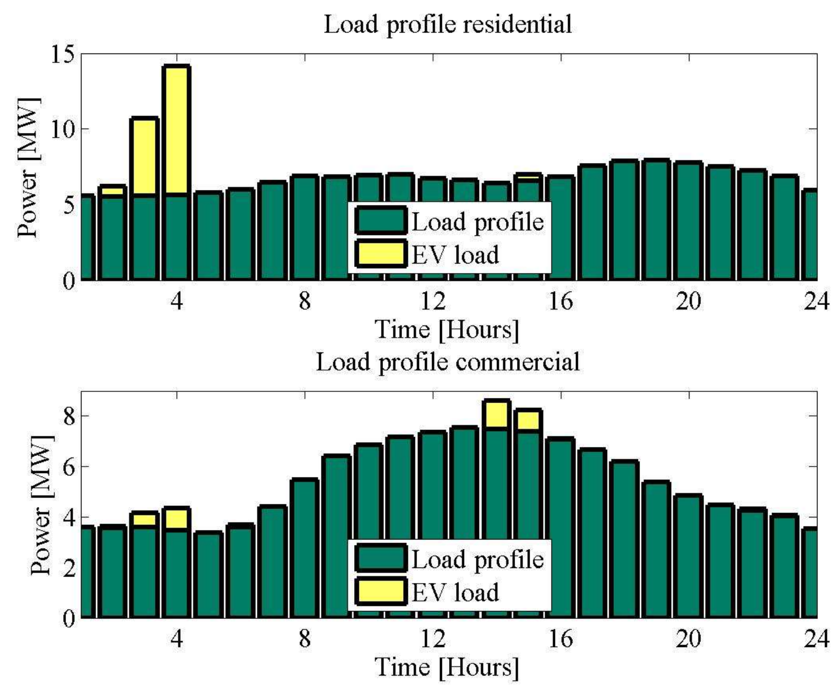
Figures by David Steen

Load control of electric vehicle

Control to minimize grid losses.



Control to minimize the cost of the drivers. Based on spot price of electricity.



Figures by David Steen

N-1 criteria (Contingency)

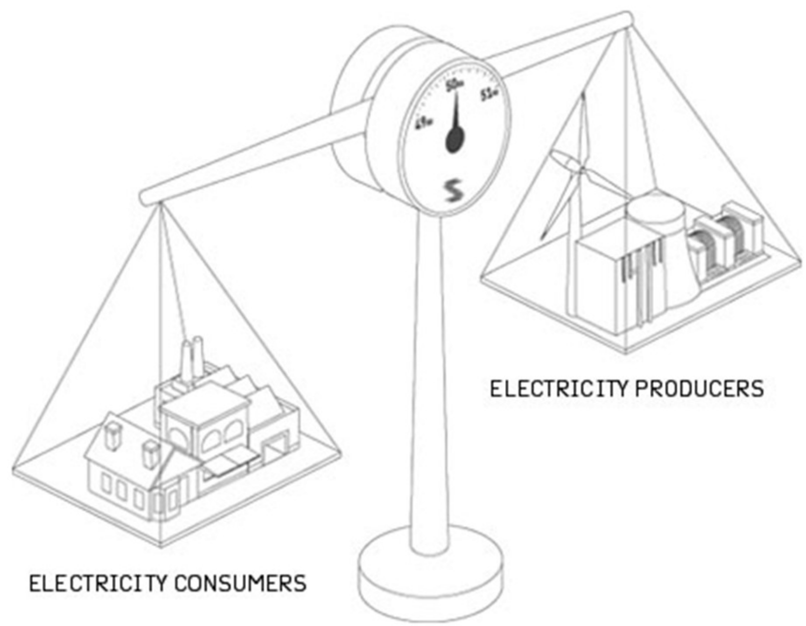
- "This rule guarantees that the loss of any set of elements of the network is compatible with the operational criteria of the system, taking into account available remedial actions." UCTE OH appendix 3 (Continental Europe)
- "N-1 criteria are a way of expressing a level of system security entailing that a power system can withstand the loss of an individual principal component (production unit, line, transformer, bus bar, consumption etc.). Correspondingly, n-2 entails two individual principal components being lost."
- Valid for:
  - Power station
  - Power lines
  - Transformers and substation.
  - Mainly in the transmission and subtransmission grid.

”Normal” operation

- Voltage
- Frequency 49,9-50,1 Hz
- Transmission of power within limits
- Reserve power available
- System ready for (n-1) faults

Frequency regulation

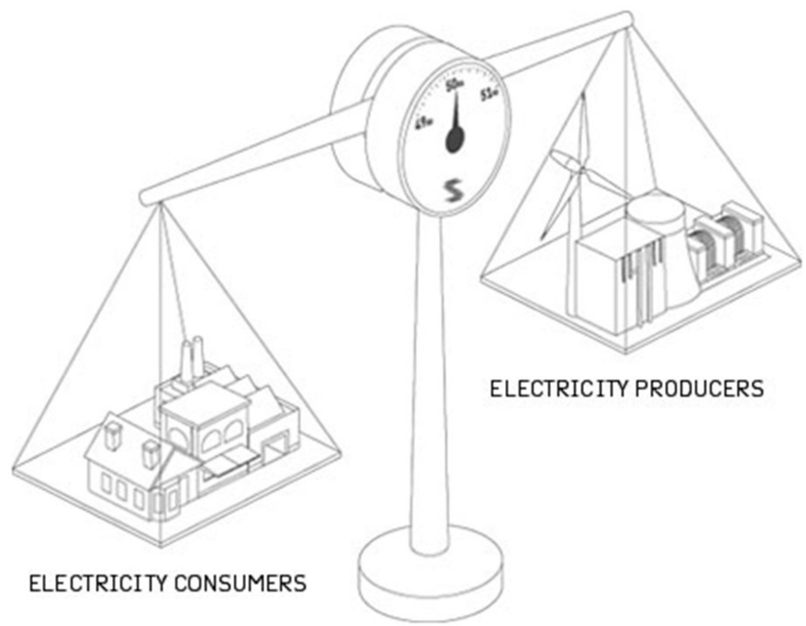
- Frequency decrease due to Loss of production
- Frequency increase due to Loss of load



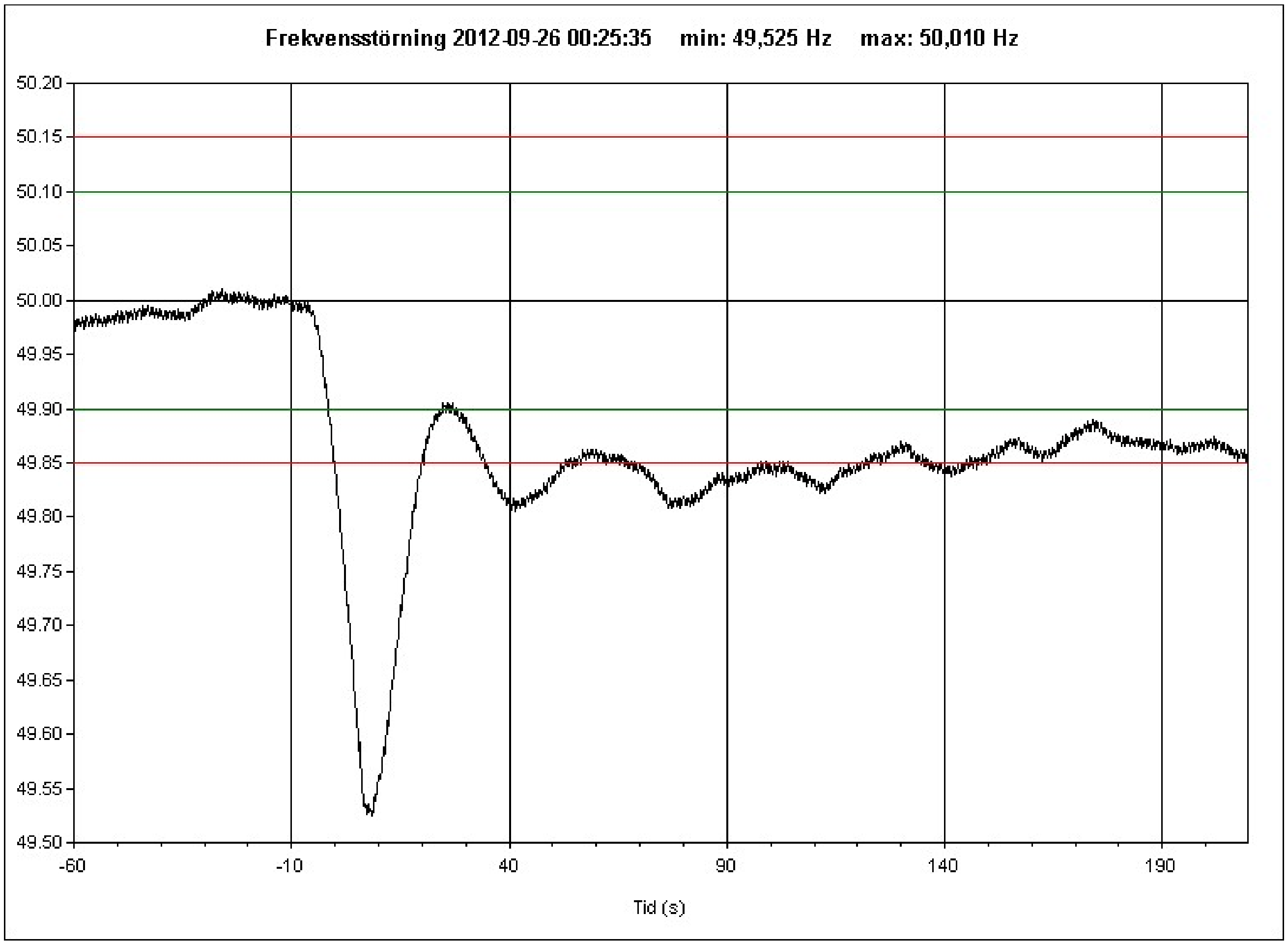
http://www.svk.se/Start/English/About-us/Our-Activities/System-Responsibility/

Frequency regulation in practice

- Operator (SvK) keeps an eye on the frequency
- Primary control
  - Stop the frequency drift
- Secondary control
  - Restore the frequency
- If it deviates, the operator will activate bids on the regulation market
- Activation automatic (aFRR) or by phone call (mFRR)



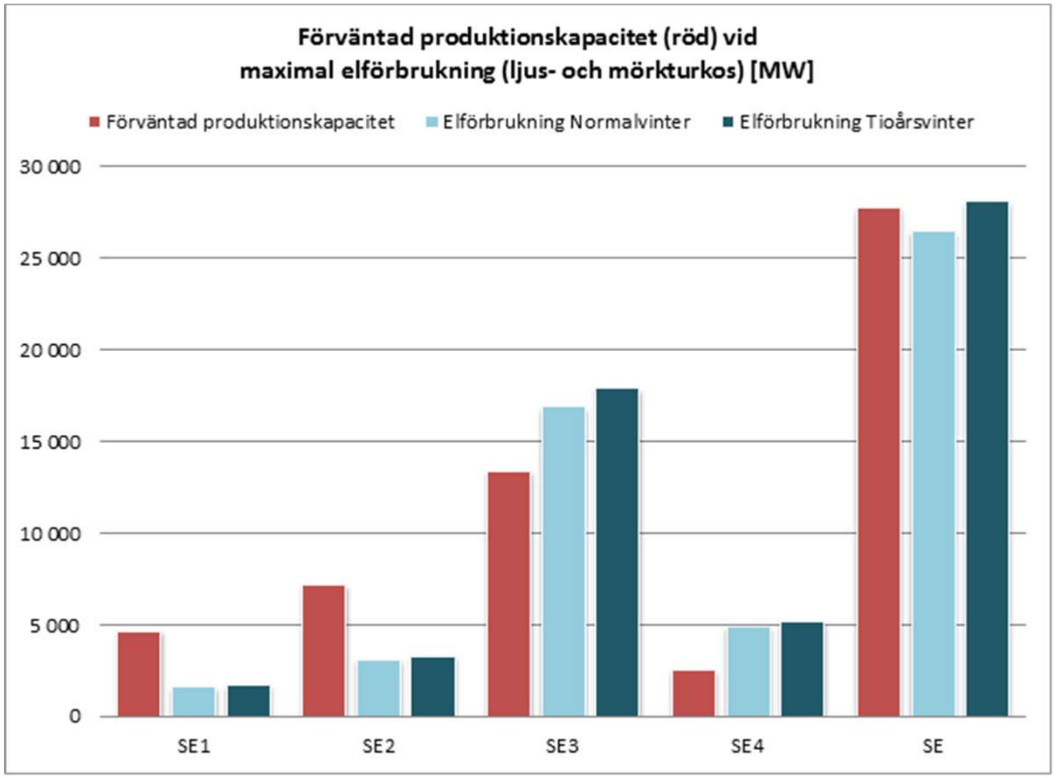
http://www.svk.se/Start/English/About-us/Our-Activities/System-Responsibility/


Frekvensstörning 2012-09-26 00:25:35 min: 49,525 Hz max: 50,010 Hz
50.20
50.15
50.10
50.05
50.00
49.95
49.90
49.85
49.80
49.75
49.70
49.65
49.60
49.55
49.50
-60
-10
40
90
140
190
Tid (s)

Power shortage

Will there be enough power during peak load?

The winter months is when the load is at its highest?



Want to know more

Power System analysis and design,
Duncan & Glover

ENM125 Sustainable Electric Power System
SP 2

The End

Do you have any questions?