Seminar SRBE-KBVE

"Un Black out électrique: pourquoi, comment, et après ?" - "Een elektrische blackout: waarom, hoe, en nadien ?"

10th of May 2012

Le système électrique et le blackout Considérations générales

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ULB
ECOLE POLYTECHNIQUE DE BRUXELLES

Outline

- **Introduction**
- **Kirchhoff's laws and consequences**
- **Model of the power system**
- **Balancing considerations**
- **Stability of the power systems**
- **Time scale effects**
- **New challenges**

Introduction

- Electricity is a commodity, but:
  - A Volt of electricity?
  - An Ampere of electricity?
  - A MW of electricity?
  - A MWh of electricity?
- Consumer requirements
  - Security of supply P, Q, V
  - Power quality : V : variations, dip, unsymmetry,
    frequency, harmonics, flicker

Introduction

Single consumer

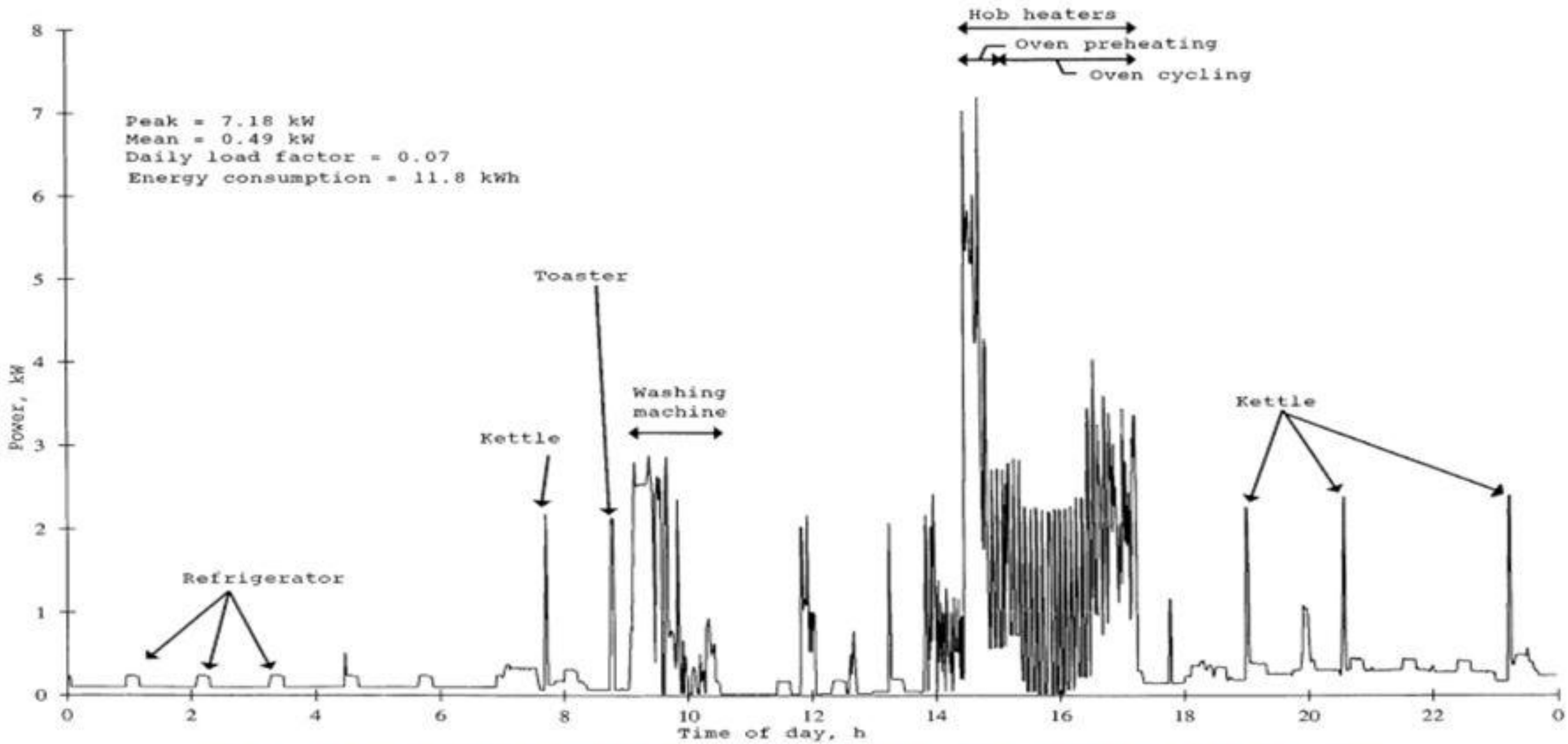

Fig. 1. Example of an electricity demand profile from an individual household recorded on a 1-min time base [7].

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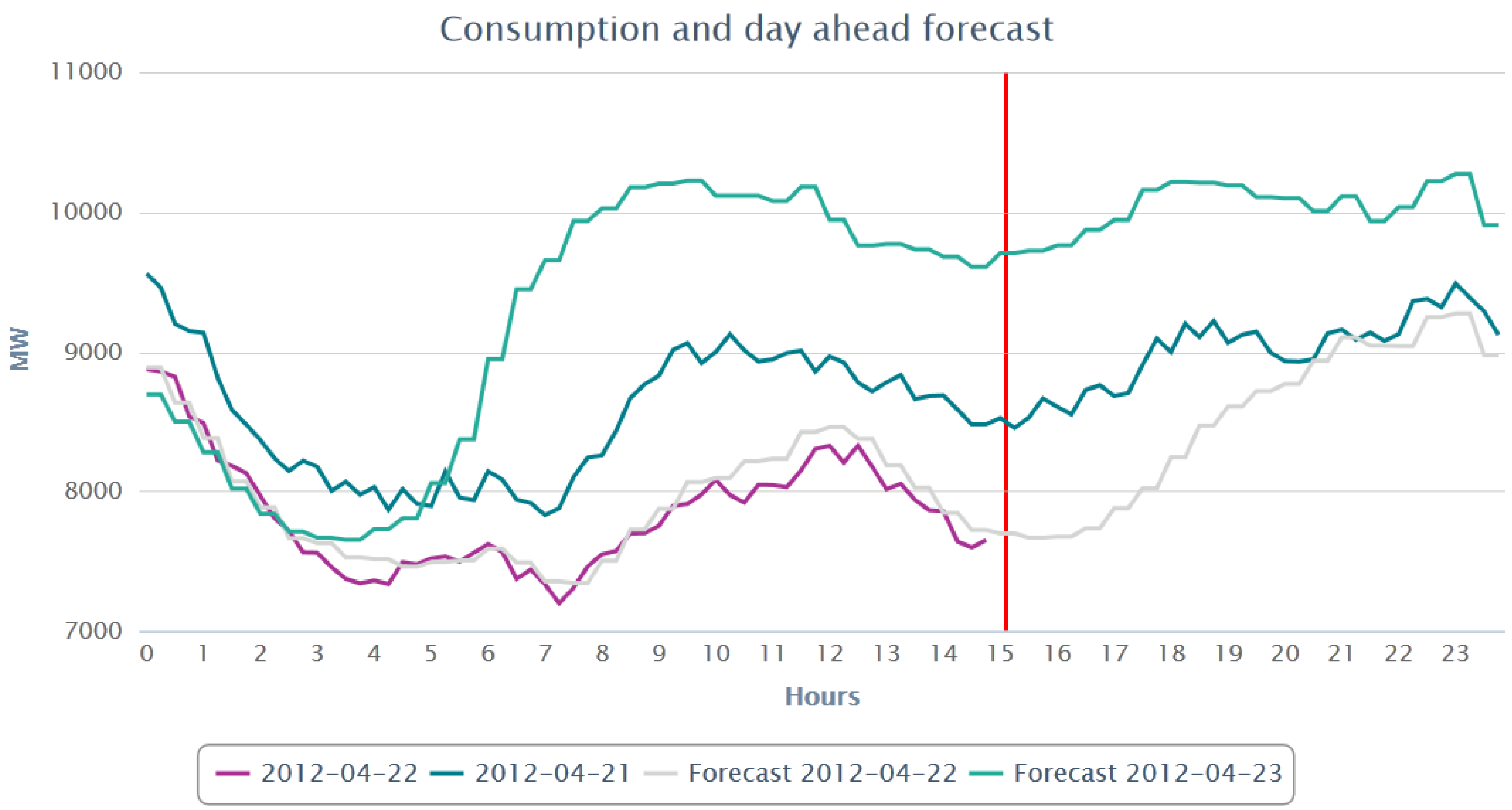
Introduction

Global consumption (Elia)



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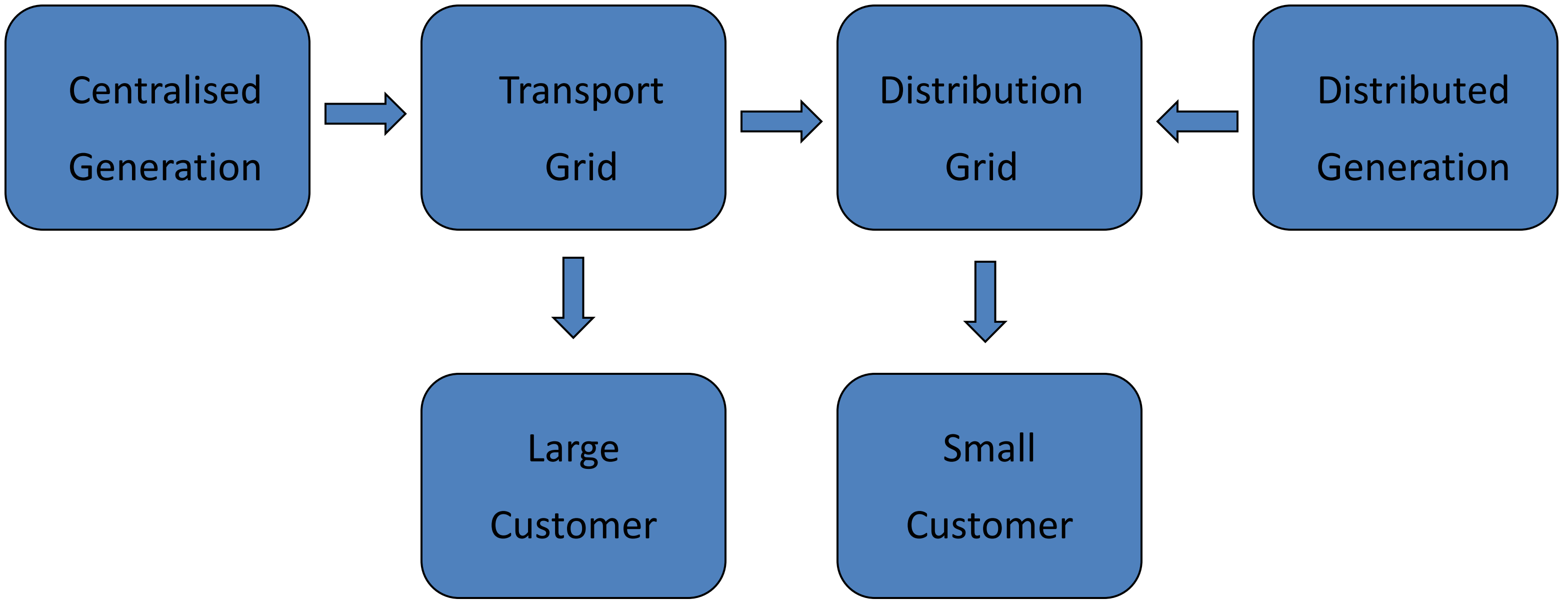
Introduction

Generation

- Thermal plant : response time, CO_2, fuel cost
- Nuclear plant : better constant power, waste
- Hydro plants : distance, empty reservoir
- Gaz turbine plant : fast, CO_2, gaz cost
- Photovoltaïc unit : when sun is present
- Eolic unit : when wind is blowing
- Cogen unit : if heath is required

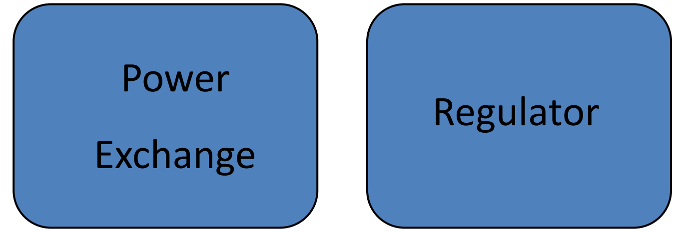
Introduction

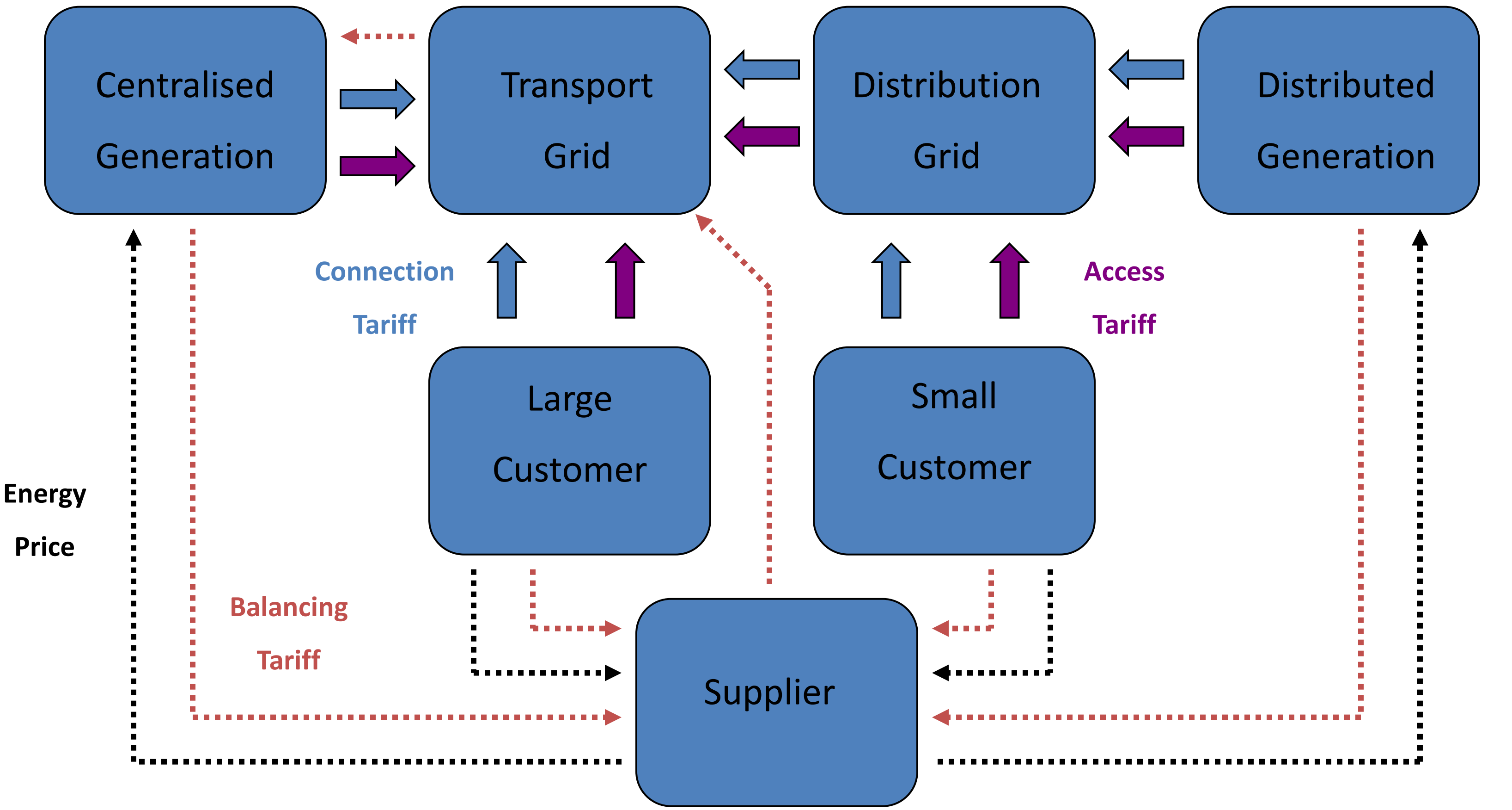
Power system : physical



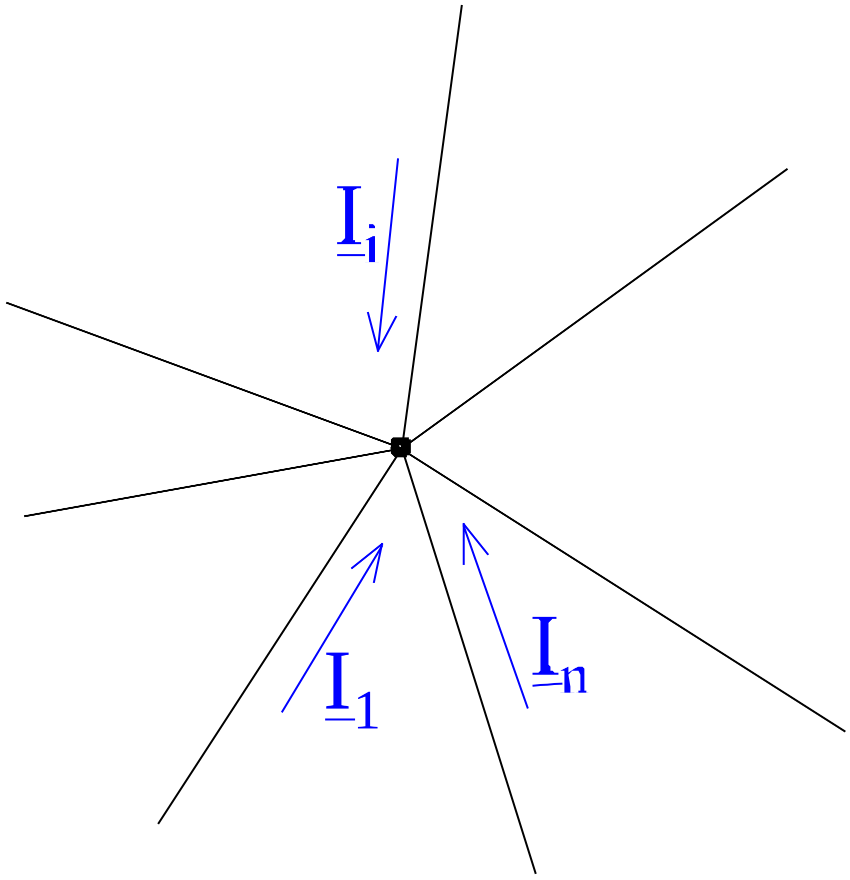
Introduction

Power system : financial



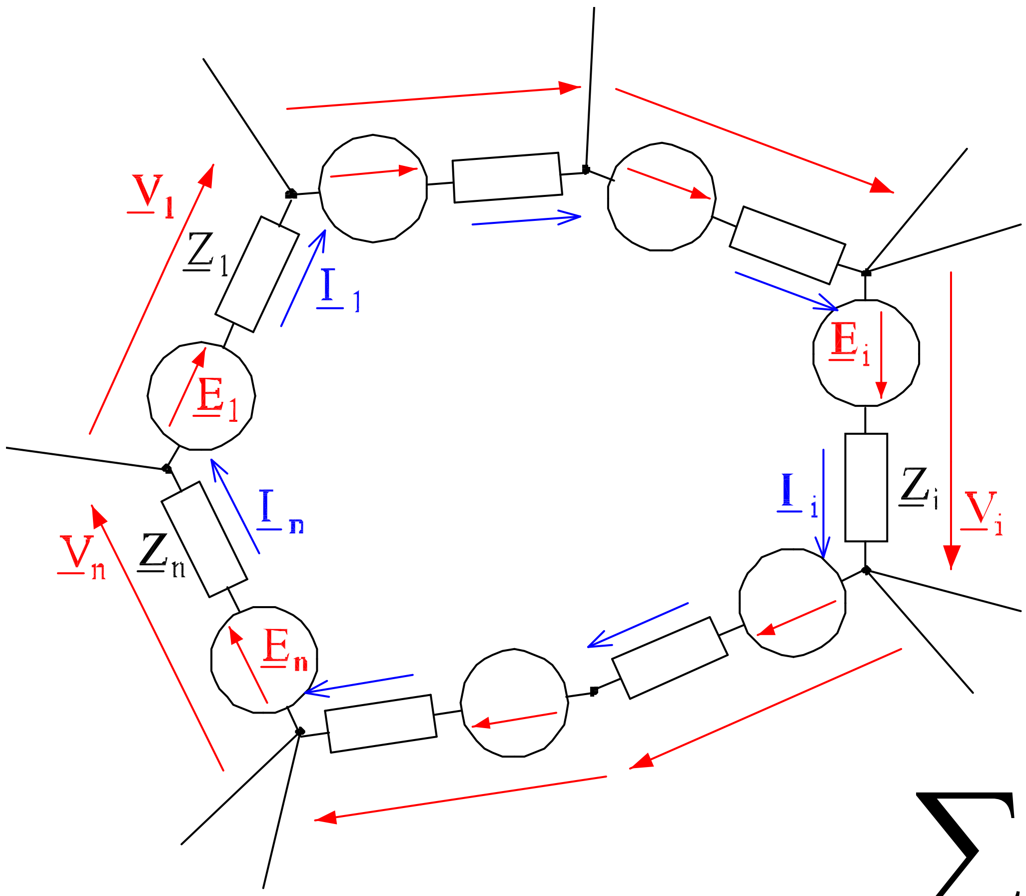


Kirchhoff’s laws and consequences



$$\sum_{i=1}^{i=n} \underline{I}_i = 0$$

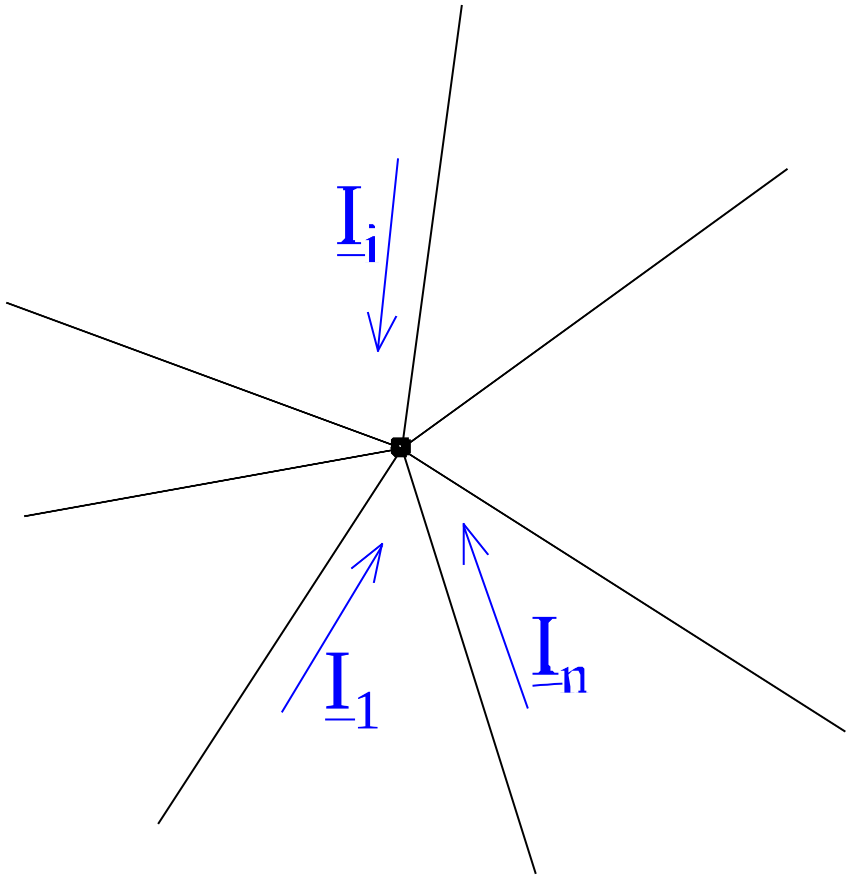
Kirchhoff's laws and consequences



$$\sum_{i=1}^{i=n} \underline{V}_i = 0$$

$$\sum_{i=1}^{i=n} (\underline{E}_i - \underline{Z}_i \underline{I}_i) = 0$$

Kirchhoff’s laws and consequences



$$\sum_{i=1}^{i=n} \underline{I}_i = 0$$

⇓

$$\sum_{i=1}^{i=n} P_i = 0$$

$$\sum_{i=1}^{i=n} Q_i = 0$$

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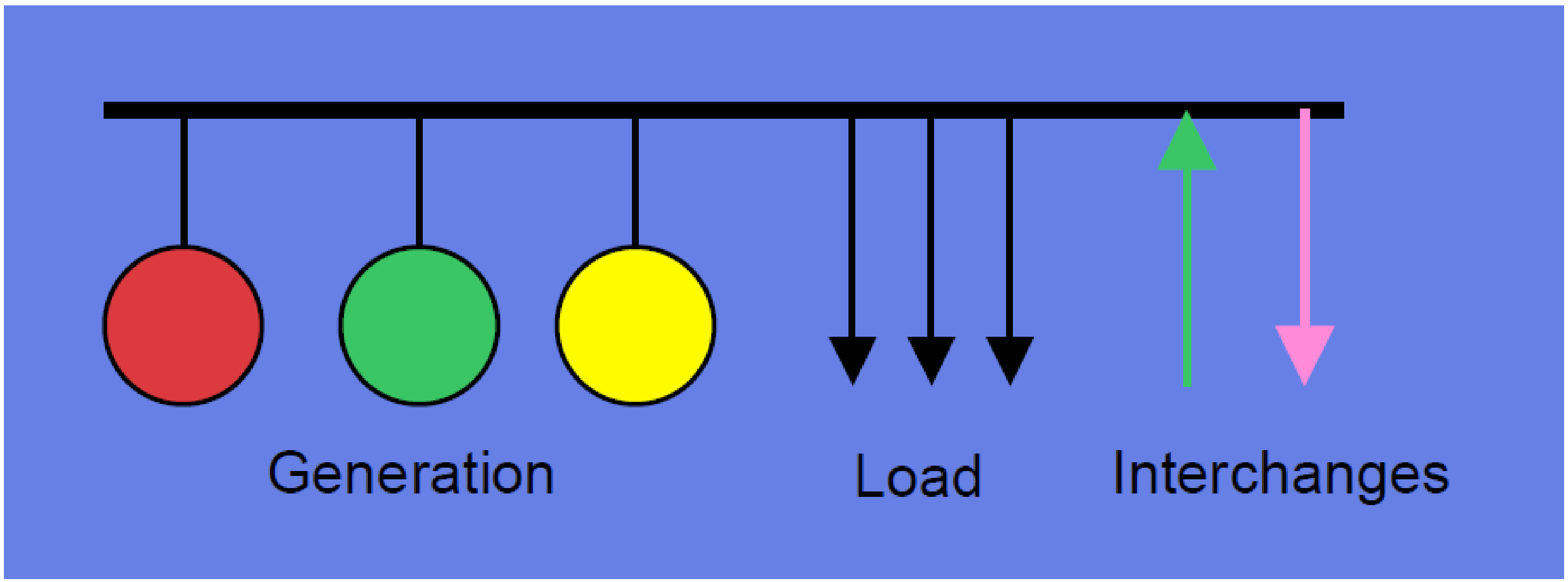
Kirchhoff's laws and consequences

$$\sum P_g - \sum P_l - \sum P_{loss} + P_{import} - P_{export} = 0$$



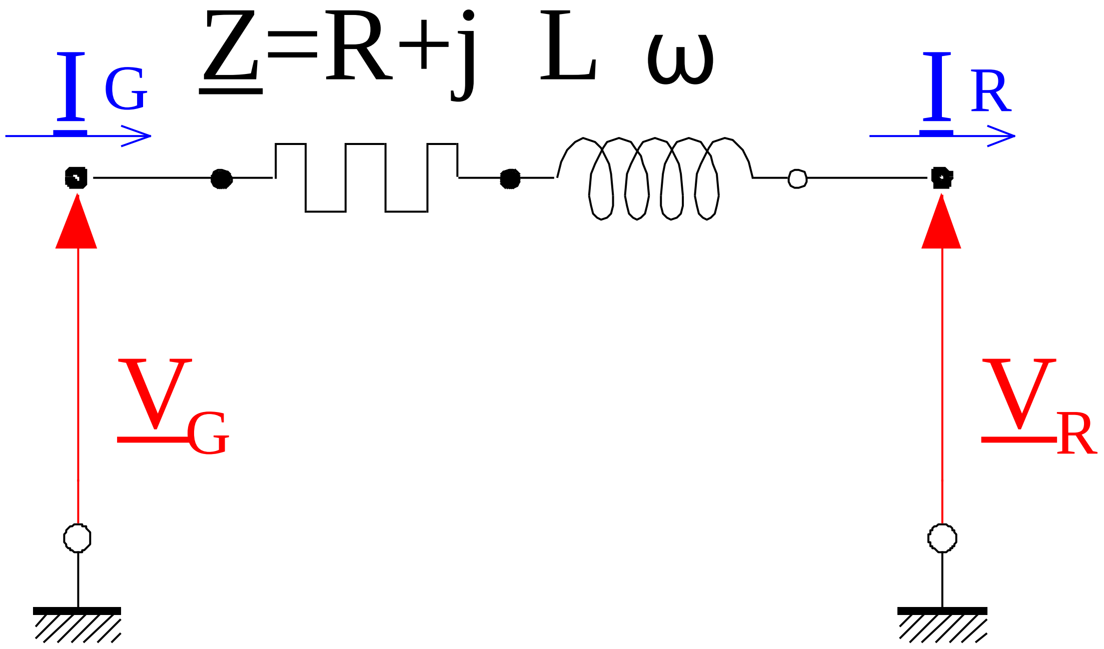
Model of the power system

Some symplifying assumptions

- **All electrical quantities are in steady-state at the nominal frequency → phasors**
- **Three-phase symmetrical (positive sequence model)**
- **No mutual inductances**
- **All elements in the network are linear**

Model of the power system

Model of a line



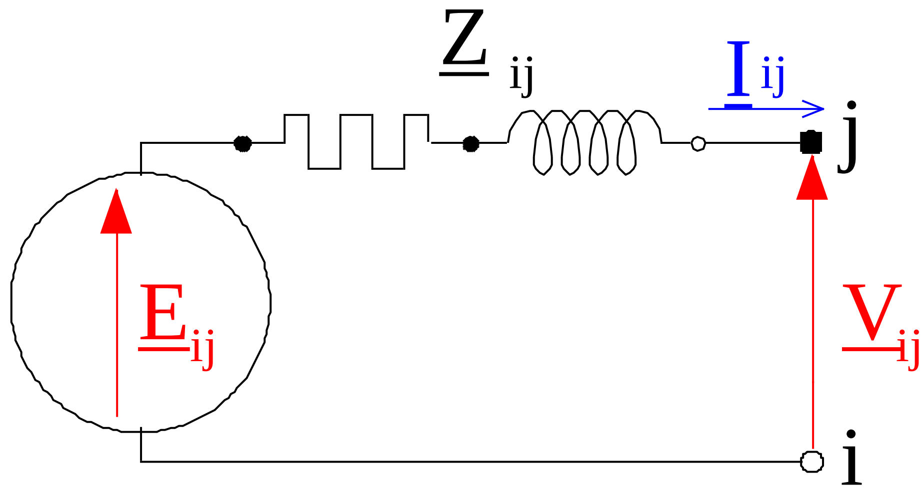
Short line

X= ωL > R for HV overhead lines

Model of the power system

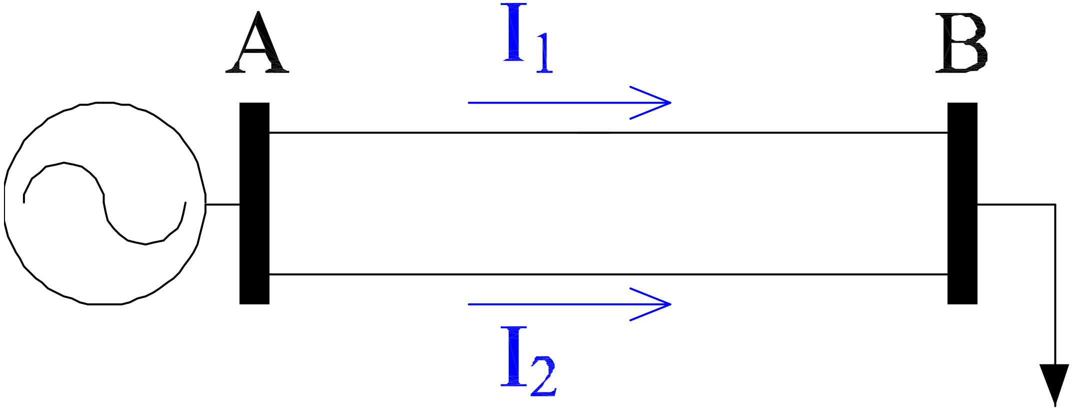
Model of a network seen from one node :

=



Kirchohff's laws and consequences

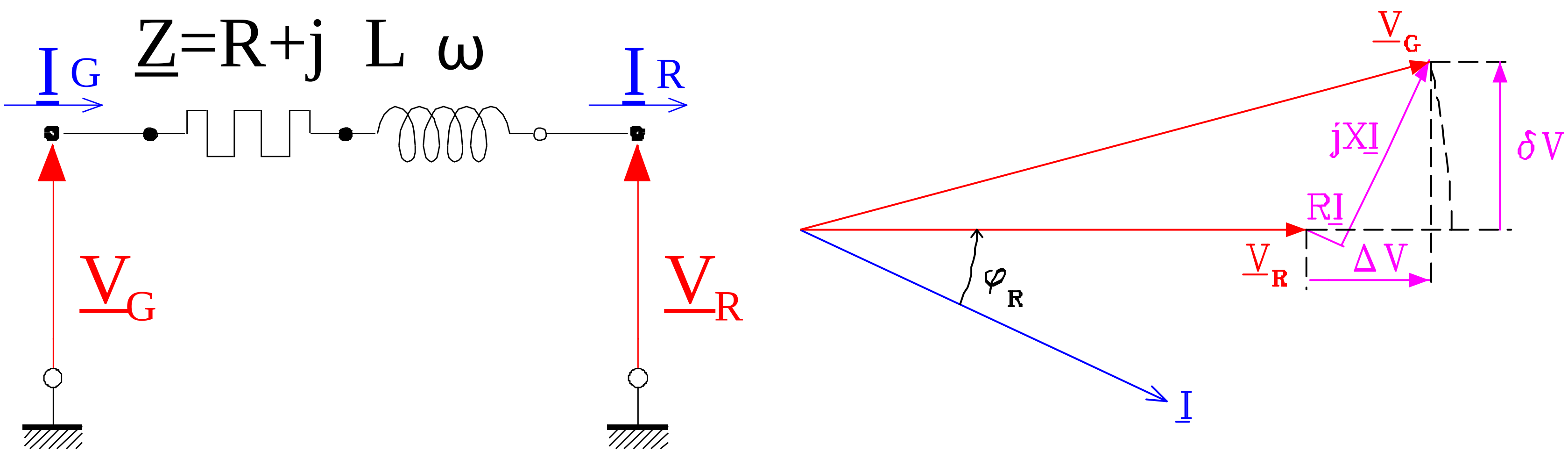
- Example of trivial consequence of the second law



- If we have in parallel a line and a cable, the cable could be overloaded

Kirchohff's laws and consequences

- Other example of consequence of the second law



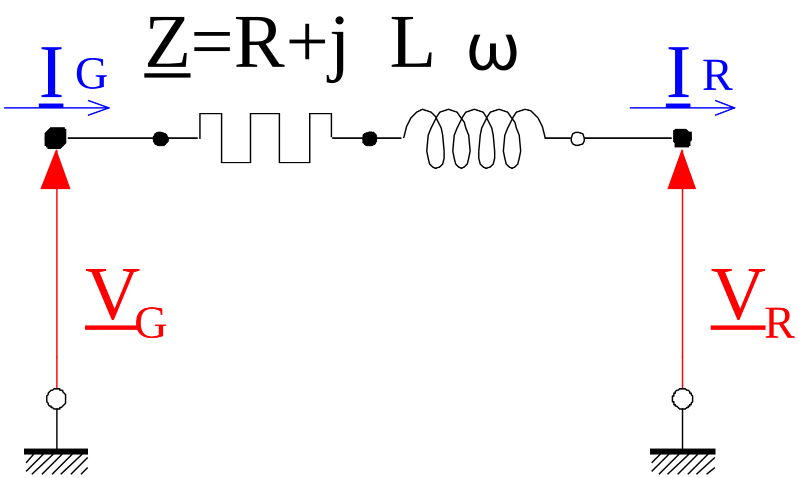
$$\Delta V = (R\,P_R + X\,Q_R) / (3\,V_R)$$
$$\delta V = (X\,P_R - R\,Q_R) / (3\,V_R)$$

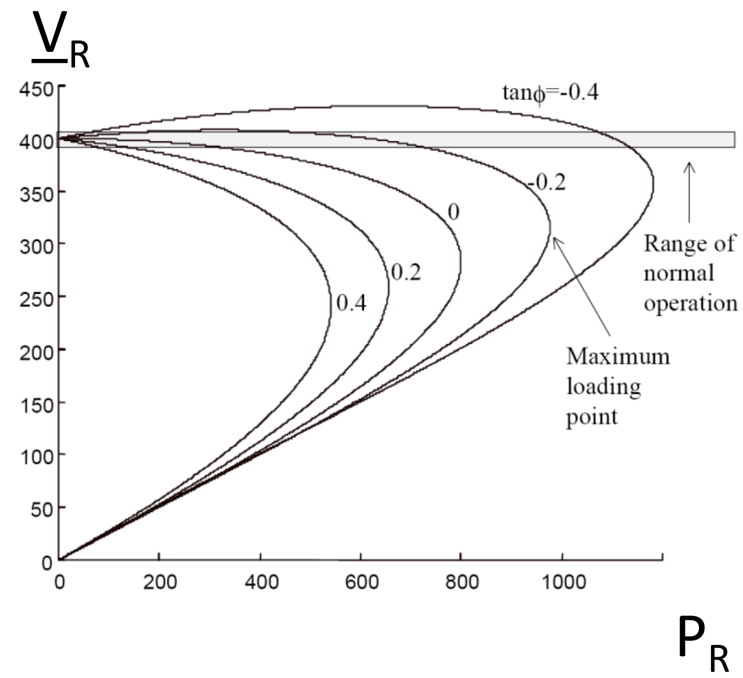
Reactive power flow affects the voltage amplitude

Real power flow leads to phase difference on the voltage phasors.

Kirchohff's laws and consequences

- Other example of consequence of the second law





Balancing considerations

$$\sum P_g - \sum P_l - \sum P_{loss} + P_{import} - P_{export} = 0$$

- In case of outage, load variation,…,

  Pg mec ≠ Pg elec

- Speed and frequency will change according to the mechanical equations, depending on the inertia J of the plants
- It is driven by dynamic equations

Balancing considerations

$$\sum P_g - \sum P_l - \sum P_{loss} + P_{import} - P_{export} = 0$$

- If we assume that synchronization is maintained, f can be measured anywhere and used as a feed-back signal to change the mechanical power.
- A new stady-state point will be reached.
- If the control is proportional to the frequency, the new equilibrium point implies a Δf
- This allows a participation of all units which are controlled and have reserves (primary control)

Balancing considerations

- If we add an integral feedback based on an error signal which mixes $\Delta f + K\,\Delta P_{zone}$, we can go back to f_{nom} and to the planned balance on P import/export (secondary control)
- It is a short term process (seconds to minutes)
- It assumes that we reach a new equilibrium point.

Stability of the power system

- **Stability of a dynamic system:**
- Non linear

$$\dot{x} = F(x,u) \;\; and \;\; y = G(x,u)$$

- Linear

$$\dot{x} = Ax + Bu \;\; \text{and} \;\; y = Cx + Du$$

- Linearized

$$\dot{\Delta x} = A\Delta x + B\Delta u \;\; \text{and} \;\; \Delta y = C\Delta x + D\Delta u$$

Stability of the power system

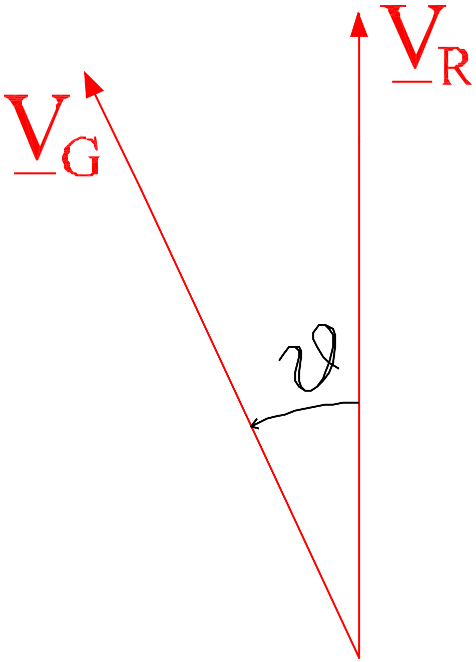
- **Power system stability :**
- Remains in a state of operating equilibrium under normal operating conditions
- Regain an acceptable state of equilibrium after a disturbance

Stability of the power system

- **What is acceptable:**
- No loss of synchronism
- No collapse of load voltage
- Not a too high frequency deviation
- No overload

- **Disturbance can be small or large**

Static Stability of the power system



$$P_R = \frac{3V_R V_G}{Z}\cos(\zeta - \theta) - \frac{3V_R^2}{Z}\cos\zeta$$

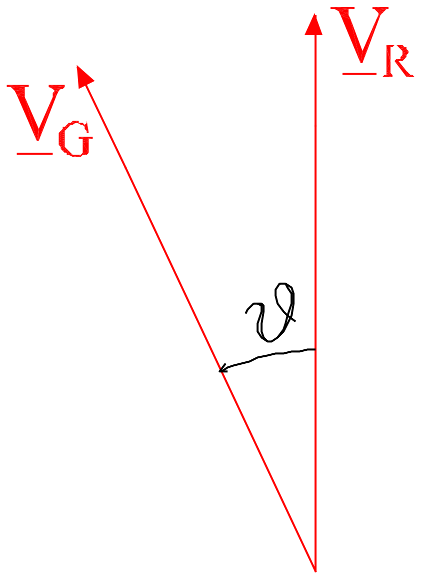
If the resistance of the line is neglected :

$$P_R = \frac{3V_R V_G}{X}\sin\theta$$

$\underline{V}_G = V_G \angle\theta$

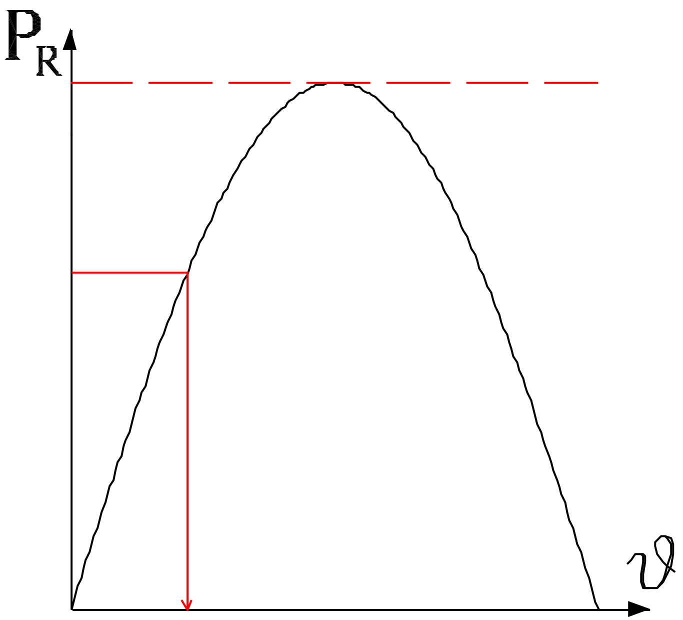
$\underline{V}_R = V_R \angle 0$

Static Stability of the power system



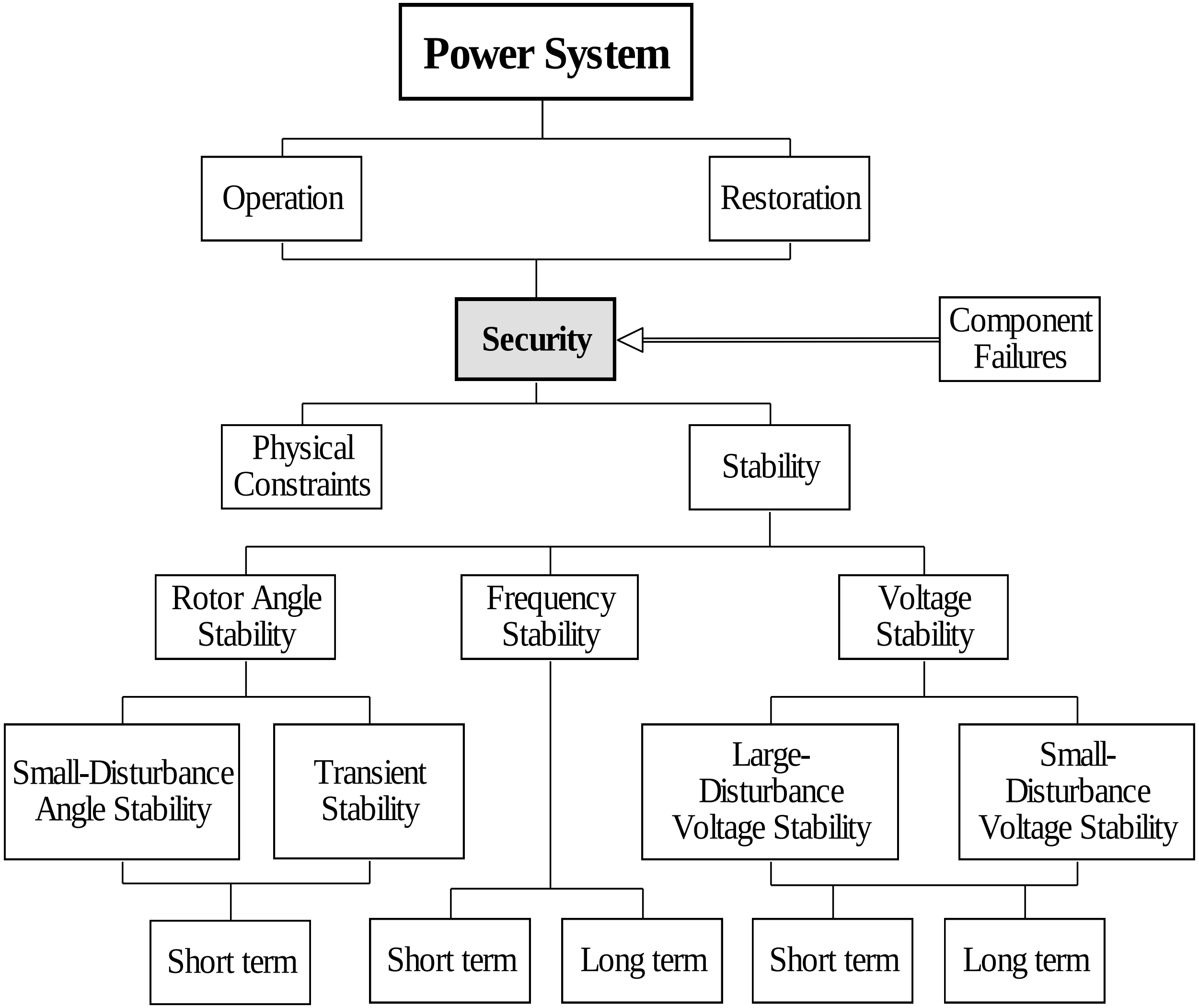
$$\underline{V}_G = V_G \angle \theta$$
$$\underline{V}_R = V_R \angle 0$$

$$P_R = \frac{3 V_R V_G}{X} \sin\theta$$

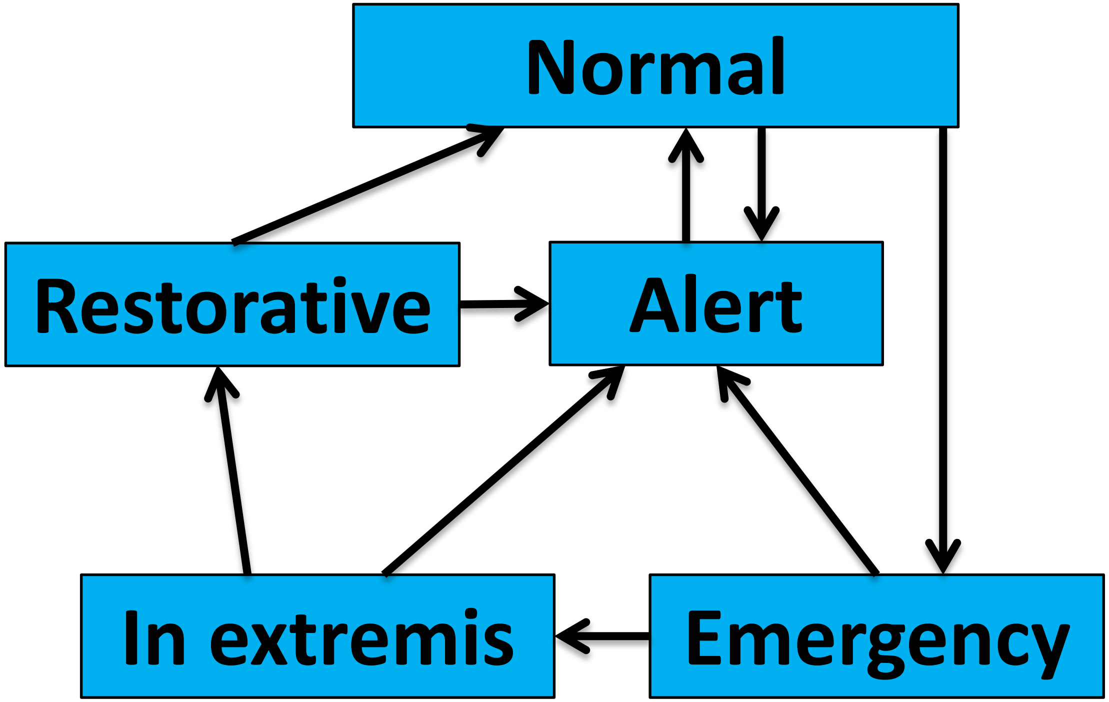


- To increase the powerflow, the generator rotor must shift (leading)but the power can not exceed ***3** V_R V_G **/ X***
- If the impedance increases (due to e.g. a line opening, the angle increaseand the maximal power decreases

Stability of the power system

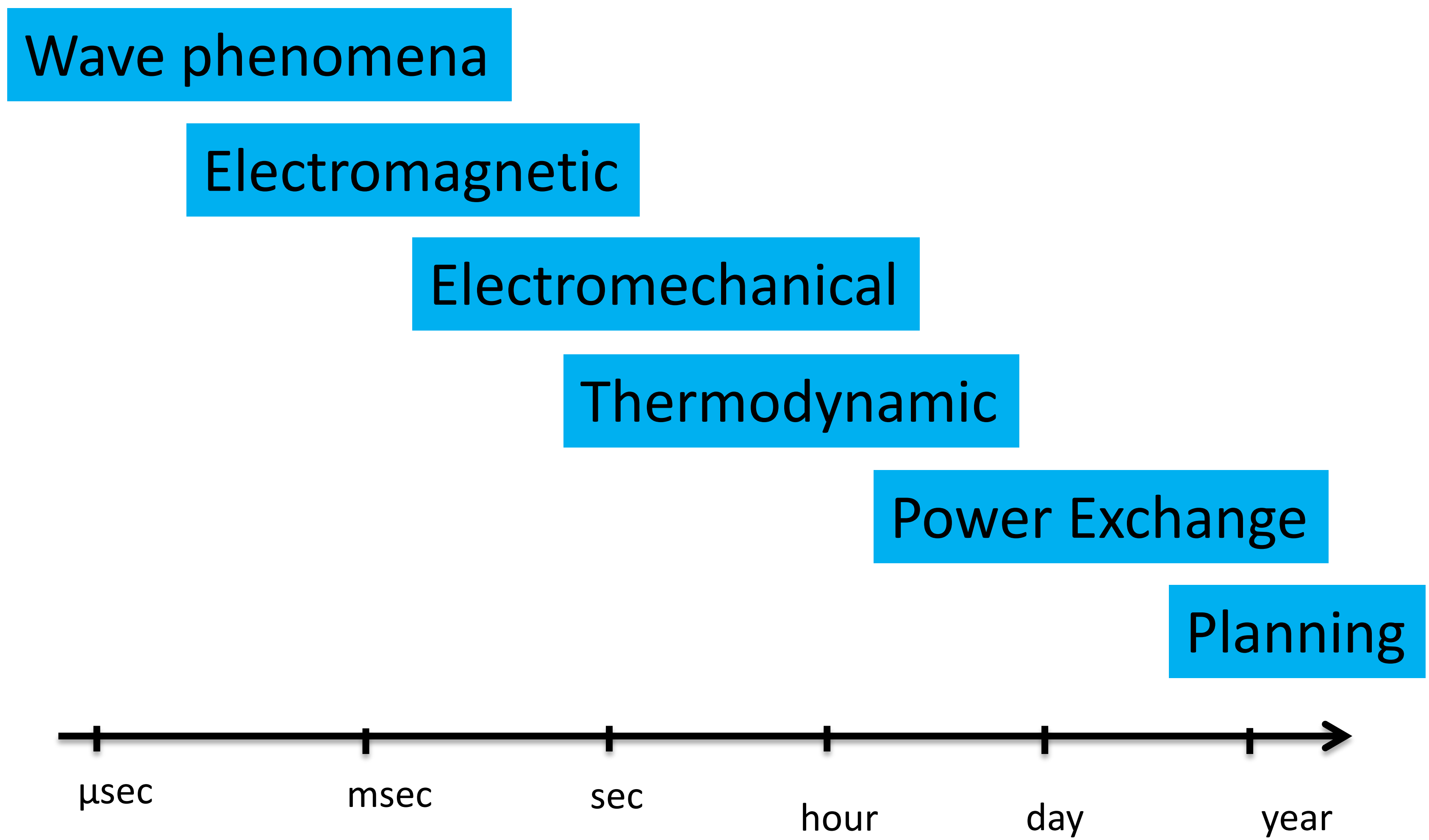


Security analysis of the power system



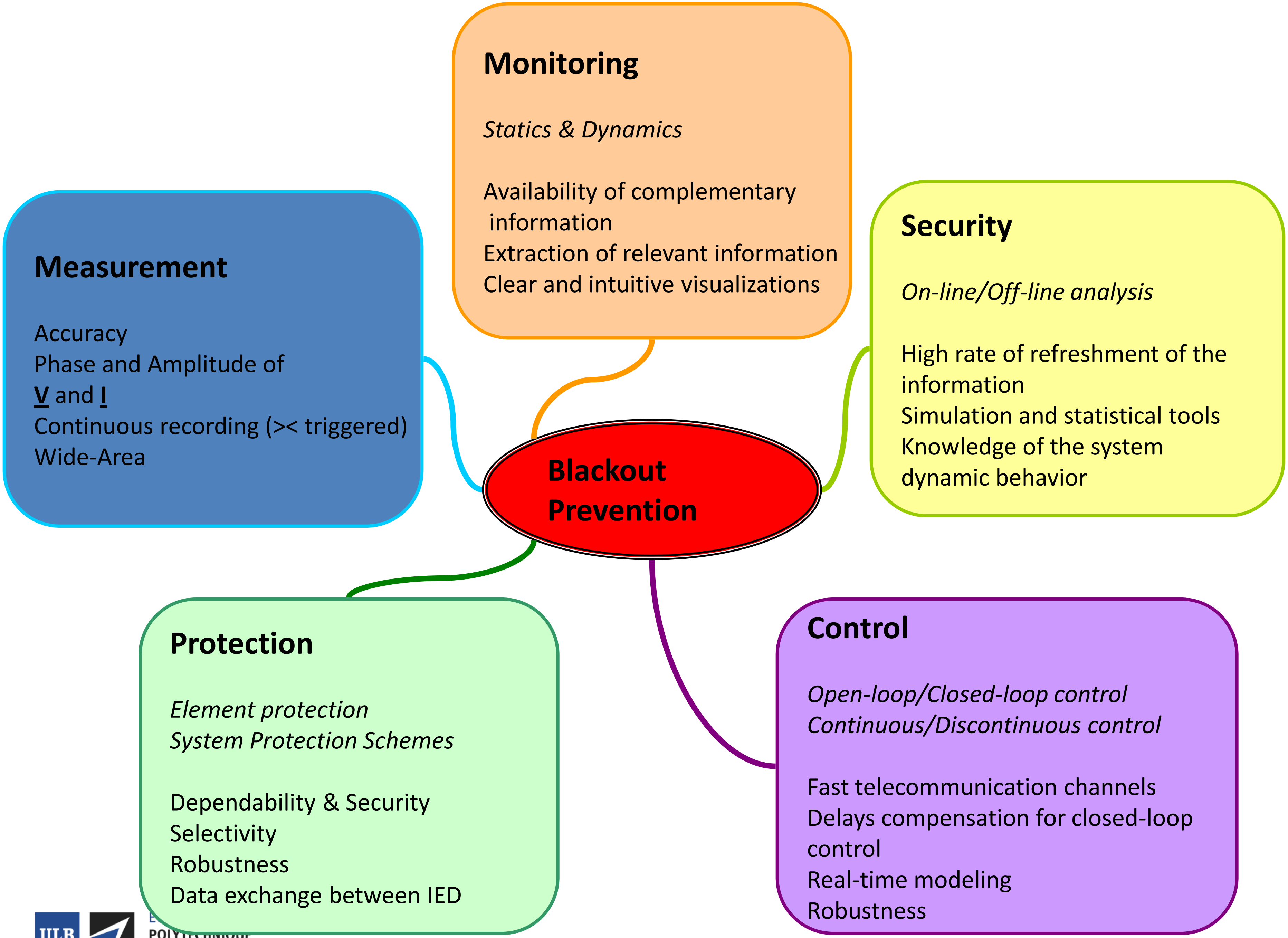
States of a Power system (Di Liacco – CIGRE)

Time scale effects



New challenges

- Distributed non dispatched generation
- Demand side response
- DC connections, FACTS and Phase Shifters
- Dynamic modeling
- Cascade studies an Risk analysis
- Security analysis : more or less than N-1?
- Intra-day market
- Ancillery services market
- Long term planning of generation resources



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Interarea Oscillations

Monitoring

Dynamic behavior understanding

Mode Shape of critical modes
Damping of oscillations
Oscillating areas/generators

Measurement

V and **I** at generator terminals
Accuracy of 10^{-3} (amplitude) and 0.1° (phase)
Rate of measurement 10 to 50Hz
Centralization

Security

Alert issue

Damping margin reduced
Major contingency threat
Possible countermeasures

Protection

System Protection Scheme

Sustained/growing oscillations
Interarea transfer reduction

Control

Local/Wide-Area Control

Power System Stabilizers
FACTS

Voltage Stability

Monitoring

Pinpointing of critical area

Index more relevant than voltage
Evolving of the instability
Geographical visualization

Measurement

__V__ at each bus of a weak area
Accuracy not critical
Status of each generator
Rate of measurement 1 to 5Hz
Centralization

Security

Prediction of evolving

Fast contingencies analysis in critical area
Dynamic recovery of load

Protection

System Protection Scheme

Based on intelligent index
Load shedding
Blocking of tap changers

Control

Local/Wide-Area Control

Modification of voltage set-point
Rescheduling of generation

References

- Kundur – Power System Stability
- Gomes-Exposito, Conejo, Canizares – Eletric Energy Systems – Analysis and Operation
- Machowski, Bialek, Bumby - Power System Dynamics – Stability and Control
- Kirschen – Fundamentals of Power System Economics
- Elia Website

Acknowledgments

- Prof. Poncelet, Warichet, Genêt, Klopfert