

# Integrating reliability constraints on power systems in long term planning tools

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## 1 Introduction

- Electricity trends
- Technical background

## 2 Method

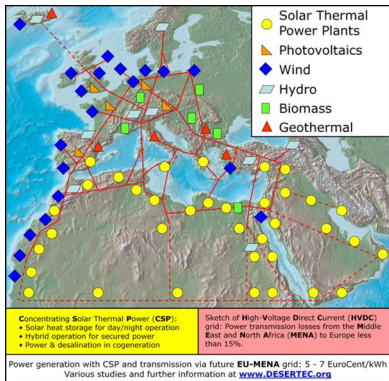
- Thermodynamic framework for power systems
- The “one-loop grid”

## 3 Results: load fluctuations management

- Frequency variations

## 4 Discussion

# As a spur: new paradigms of development



# Electricity trends: *main issues*

- 1 Increasing of electricity consumption
- 2 Lowering fossil fuel in the generation shares
  - Integration of **renewables**
  - Emergence of **distributed energy resources**
  - Development of **demand side management** (demand response)
- 3 Item 2 favours the development of smaller grids to reduce power transmission losses.

# It is too good to be true ...

Indeed, electricity must comply with real-time adequacy between supply and demand. Future generation shares must fulfill constraints on:

- 1 **Energy flows:** adequacy in terms of quantity of energy supplied
- 2 **Power capacities:** load adjustments (base, mid area, peak)
- 3 **Ancillary services:** reliability of power systems to handle load fluctuations

## Definition

- Ancillary services prevent from **power outages**, by ensuring the quality of the power delivered.
- **Reliability** is defined as the capability of a power system to recover a stable state after a load fluctuation.

# ... because generation technologies are different.

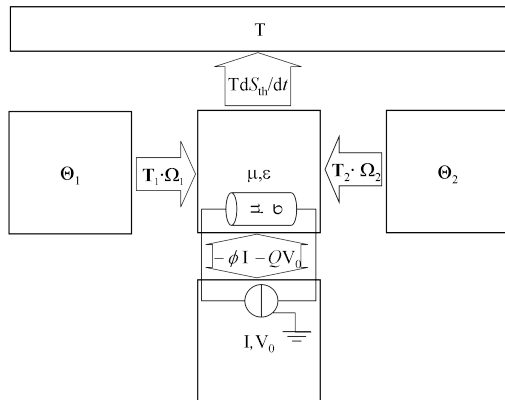
- ① Integrating renewable sources to a large extent leads to:
  - Oversizing of generation capacities and investments: *back-up reserve*
- ② Power plants vs. constraints on power systems:

	Conventional sources	Renewables
1. Energy flows	yes	yes
2. Power capacities	yes	yes
3. Ancillary services	yes	?

- ③ If your proposed generation share does not produce enough ancillary services, then you have to ensure them anyway. Consequently you need an extra-production of energy dedicated to reliability requirements. That is what we want to quantify next.

# Thermodynamic framework

- 1 Necessary step.
- 2 A global description of power transactions.
- 3 Finding the more reversible evolution.

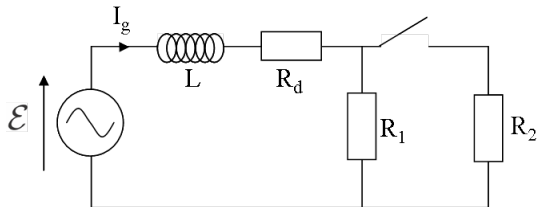


# Thermodynamic framework: *back-up slide*

- Subsystems exchange heat with the thermostat at the temperature  $T$ .
- Generators and motors exchange mechanical work.
- We introduce the coupling energy between the electromagnetic field and the generators.
- The operator can adjust the excitation  $I$ .
- Electrical charges are exchanged with the mass at the potential  $V_0$ .

# Aggregated representation of power systems

The reversibility condition enables a basic representation of power systems.



- The **electromotive force**  $\epsilon$  represents the generators.
- The **impedances** gather the inductive and resistive properties of the system.
- Connecting  $R_2$  models a load fluctuation.

# Numerical application

- Generator properties: 1650 MVA, 240 tons, 1 m radius.
- Transmission properties: 400 kV,  $R_d$  null.
- Demand side properties:  $R_1 = 110 \Omega$ ,  $R_{\text{load}} = 55 \Omega$

# Equations ruling the “one-loop grid”

- Mechanical energy conservation for frequency relaxation

$$\frac{1}{2} \frac{d(J\Omega^2)}{dt} = P_{\text{mech}} - \sum_{\varphi} e_{\varphi}(t) i_{\varphi}(t)$$

- Electrical equation for load voltage relaxation

$$(R_d + R_{\text{load}}) I_g + L \frac{dI_g}{dt} = \mathcal{E}(t)$$

- Relaxation time constants:

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$$\tau_{\text{mech}} = \frac{J\Omega_0^2}{P_{\text{mech}}} \quad \mathbf{16 \text{ s}}$$

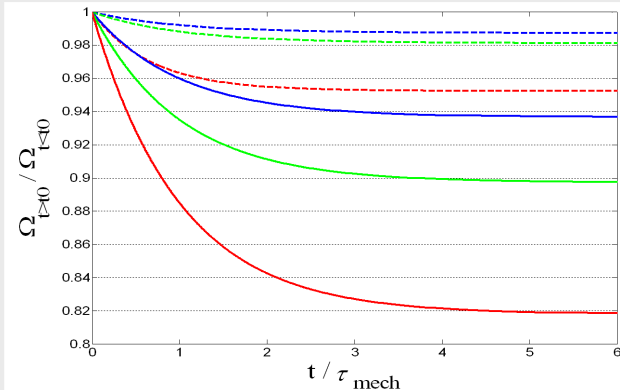
$$\tau_{\text{elec}} = \frac{L}{R_{\text{load}}} \quad \mathbf{14 \text{ ms}}$$


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# Frequency variations

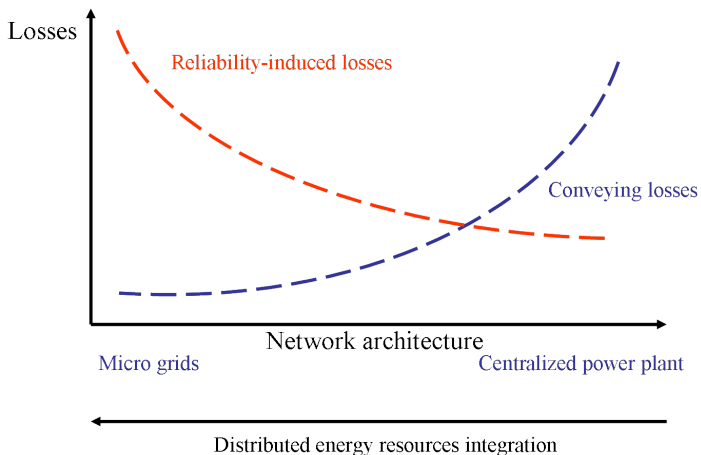
- Generator:  
1650MVA, rotor:  
240tons, 1m radius.
- Transmission:  
400kV,  $R_d$  null.
- $R_l = 110 \Omega$ ; after  
fluctuation:  $R_{load} = 55$   
or  $100 \Omega$ .
- Frequency is 50Hz.

- $R_{load} = 100 \Omega$ ,  $L = 0.8H$
- $R_{load} = 100 \Omega$ ,  $L = 0.6H$
- $R_{load} = 100 \Omega$ ,  $L = 0.4H$
- $R_{load} = 55 \Omega$ ,  $L = 0.8H$
- $R_{load} = 55 \Omega$ ,  $L = 0.6H$
- $R_{load} = 55 \Omega$ ,  $L = 0.4H$



- 1 L is crucial to increase the reaction delay.
- 2 Maintaining reactive power (i.e. the value of L) and kinetic reserve requires dedicated amount of energy.

# Losses on power systems



Thank you!