POWER GRIDS, SMART GRIDS AND COMPLEX NETWORKS

Antonio Scala

CNR-ISC @ Univ. di Roma “La Sapienza”
LIMS London Institute for Mathematical Science
IMT Alti Studi Lucca

Sakshi Pahwa and Caterina Scoglio @ KSU
Guido Caldarelli and Alessandro Chessa @ IMT Lucca
Alfonso Damiano e Mario Mureddu @ DIE Cagliari
Walter Quattrociocchi @ LIMS

May 21, 2013

Prelude

NATO OTAN

This workshop is supported by: The NATO Science for Peace and Security Programme

Advertisement: the Netonets community

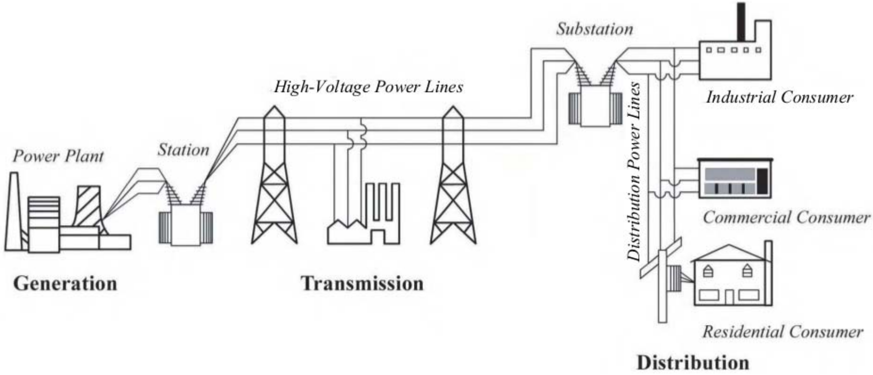
www.netonets.org

Critical Infrastructures & Complex Networks

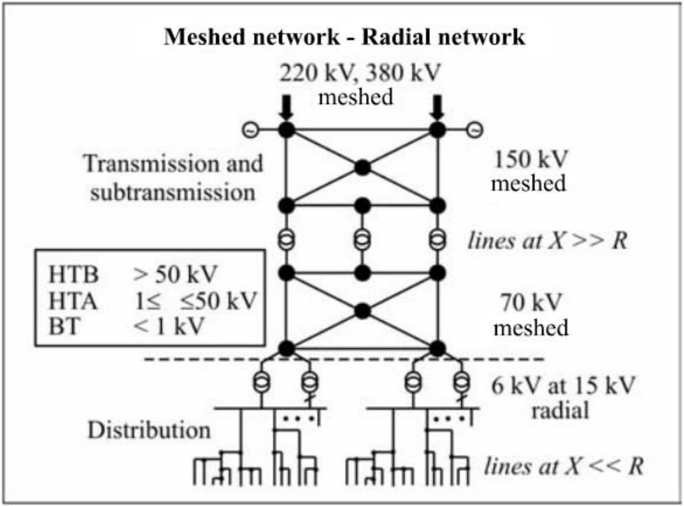
Summary

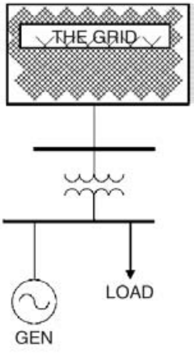
- Electric System and Distributed Generation
- Voltage Controllability
- Blackouts
- Routing Protocols & Self Healing

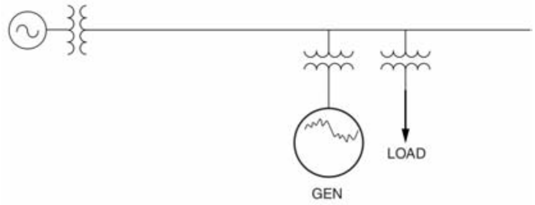
Electric System Overview



Meshes & Trees







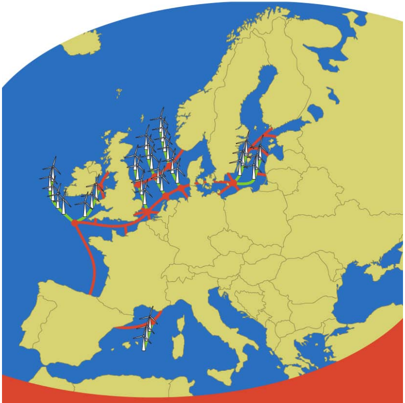
end user VS distribution operator

Desertec

Airtricity

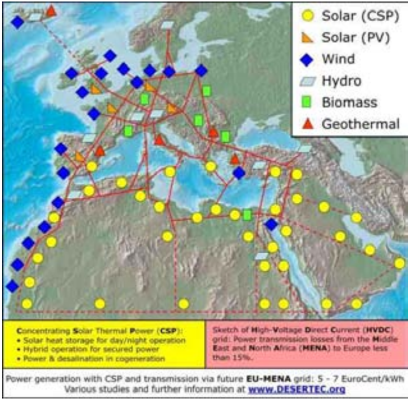
European Offshore Supergrid® Proposal

Vision and Executive Summary



Creating a More Powerful Europe

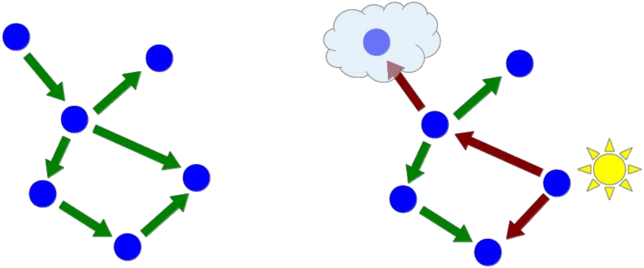
EU-MENA



Solar (CSP)
Solar (PV)
Wind
Hydro
Biomass
Geothermal
Concentrating Solar Thermal Power (CSP):
• Solar heat storage for day/night operation
• Hybrid operation for secured power
• Power & desalination in cogeneration
Sketch of High-Voltage Direct Current (HVDC) grid: Power transmission losses from the Middle East and North Africa (MENA) to Europe less than 15%.
Power generation with CSP and transmission via future EU-MENA grid: 5 - 7 EuroCent/kWh
Various studies and further information at www.DESERTEC.org

Pan-Asia Energy Infrastructure

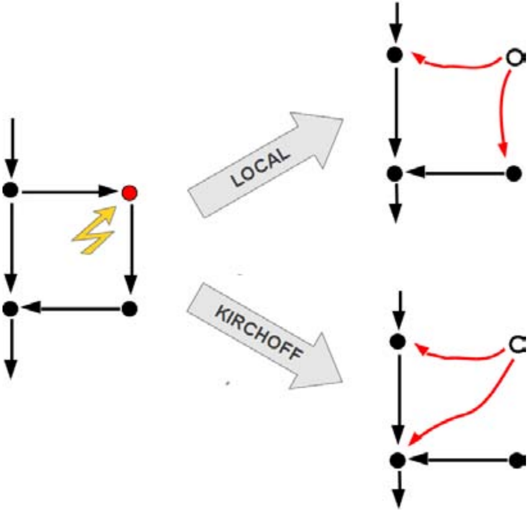
Renewable Sources



- distributed generation can be highly uncorrelated
- flows can reverse

SYSTEMIC BLACK OUTS

Failure propagation: Kirchoff VS Local



DC power flow

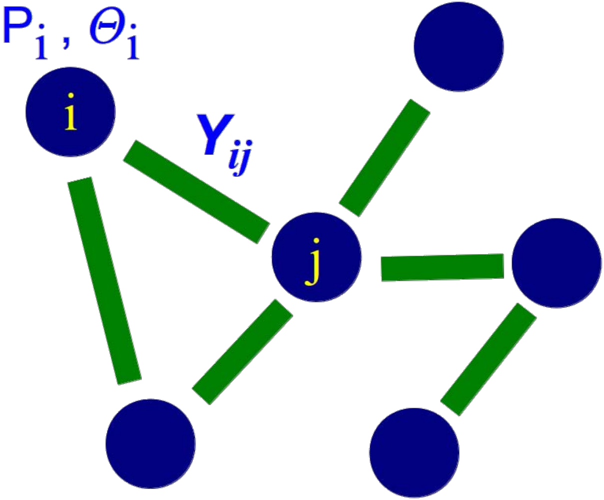
Linearization of the AC power flow equations for small phase-angle differences along branches leads to the DC power flow system

$$\mathcal{L}\vec{\theta} = \vec{P}$$

- P_i total power ($generation - load$) on the i^{th} bus
- θ_i phase angle on the i^{th} bus
- $\mathcal{L}$ Laplacian associated with the admittance matrix Y

we also consider the maximum capacities C *of the branches*

Grids & Networks



Metrics

Standard blackout indices to measure blackout size

- load shed
- energy unserved
- duration
- number of blackouts
- number of customers affected

We use at the fraction f of failed links

Some assumptions

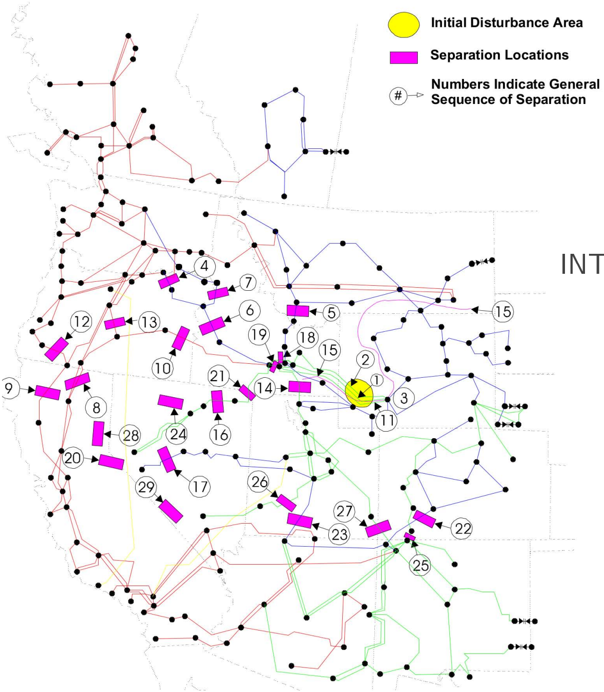
- If after an initial failure some other lines exceed their thermal limits, these overheated lines are not tripped instantaneously, but almost will be trip within few minutes
- all external characteristics (load configurations and renewable generation) remain unchanged in this relatively short time span
- no operator action is taken in this relatively short time span
- reaction time (typical between 15 minutes to an hour) not available for fast adjustments

DC cascades

- Not considering transients
- Not considering phase sync
- Not considering voltage instabilities
- Just a sequence of load sheddings

Model

- Fix initial conditions
- Solve power flow & cut branches with flows above capacity until all branches are OK
- Report final configuration



WESTERN INTERCONNECTION (WSCC)

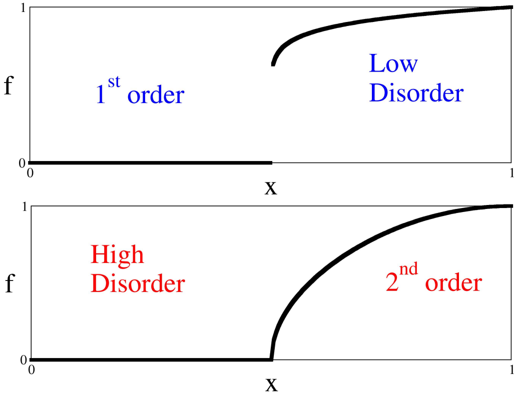
July 2, 1996

Sequence of

system separations

Mean Field

Kirchoff Laws $\Longrightarrow$ Long range $\Longrightarrow$ model can be solved “mean field”



approximation: **ELS** (**E**qual **L**oad **S**haring)

Model Loads

Demand Increase

$$L_i(\alpha) = L_i^0 \times (1 + \alpha)$$

- α parametrises the *increase of the loads*

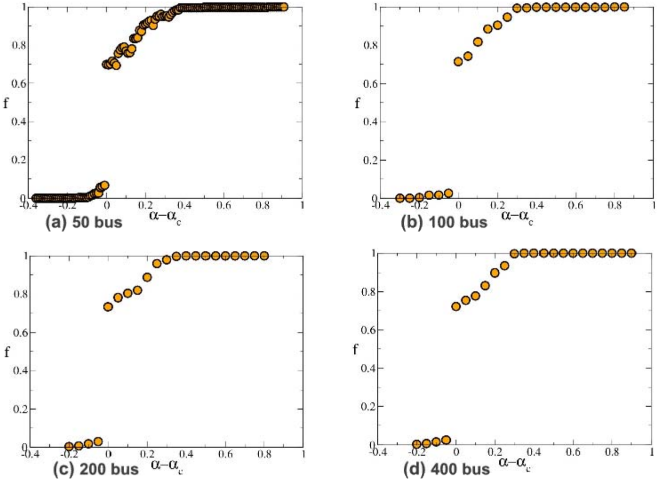
Renewables' Fluctuations

$$L_i = L_i^0 \times (1 + \sigma \xi_i)$$

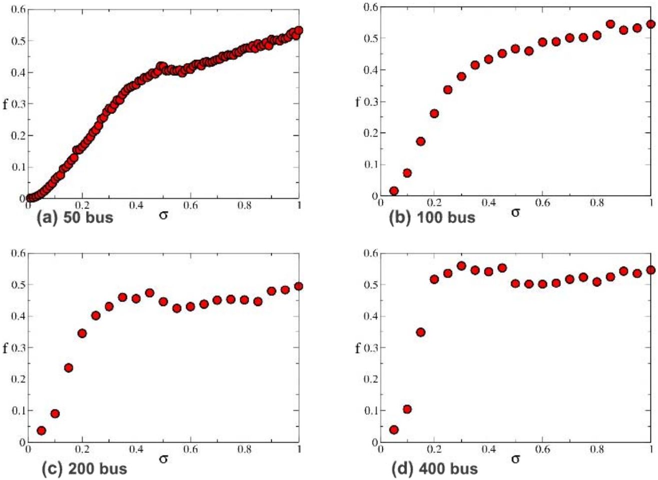
- σ parametrises the *strenght of the fluctuations*

We look at the fraction f of failed links

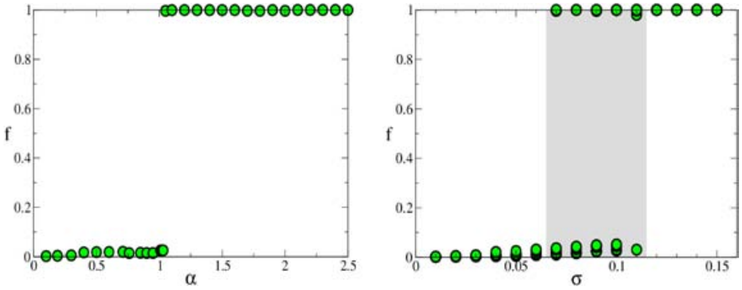
Demand Increase



Renewables' Fluctuations



Polish Grid



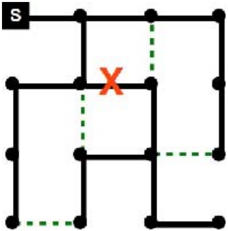
Summary 2

- Uniform load increase induces an abrupt breakdown of the system
- Distributed renewable sources induce a *stochastic* abrupt breakdown of the system
- Growing the size of the system enhances the abruptness of teh breakdown

integrating power grids $\Rightarrow$ *emergent systemic failures ?*

REDUNDANCY, NETWORK PROTOCOLS & SELF HEALING

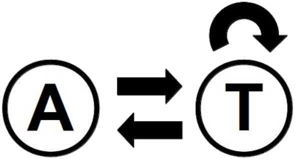
Redundant Trees



(a) Initial configuration (b) Link failure (c) Recovered Network

Routing Protocols

- Nodes are finite-state machines exchanging messages
- The topology of the message network is the same of the physical network



$A \Rightarrow T$ when all neighbours trip

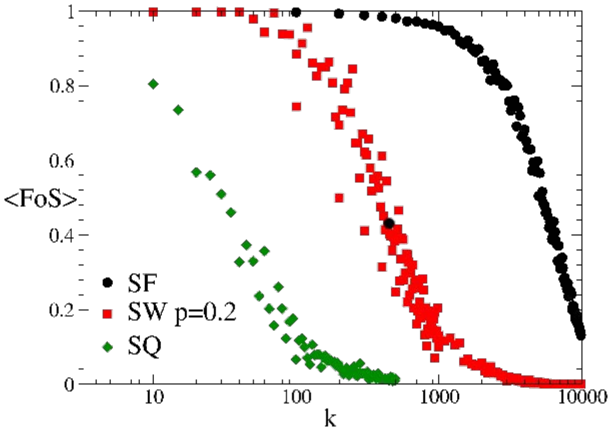
$T \Rightarrow A$ when a neighbour is active

$T \Rightarrow T$ while all neighbours are tripped

A active

T tripped

FoS Number of served nodes



redundancy $r = 30\%$

Summary 3

- low-voltage distribution networks have built in redundancy than could be optimised by statistical-physics approaches
- "smartness" can be introduced and accomplished customizing "on the market" routing protocols

smartness = stat-mech + distributed algorithms ?

THANKS TO:

- US grant HDTRA1-11-1-0048 “Self Healing Networks”
- CNR-PNR National Project Crisis-Lab
- FP7 IP MULTIPLEX - Foundational Research on MULTIlevel comPLEX networks and systems

antonio.scala@phys.uniroma1.it