# Power Systems Control from Circuits to Economics

Florian Dörfler    Andrej Jokić

disc dutch institute of systems and control

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

University of Zagreb

## Who are we?

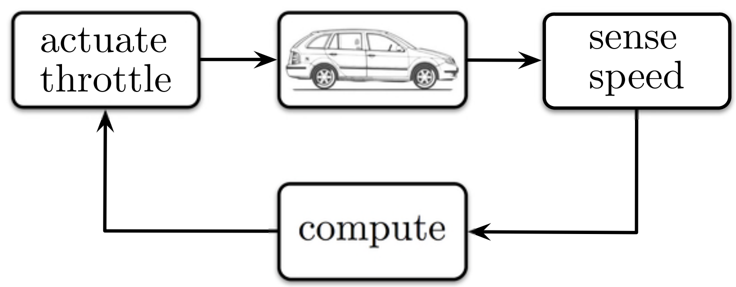
Florian

Andrej

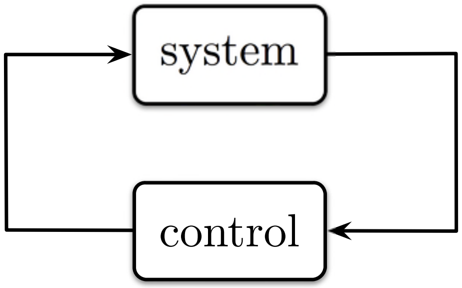


**why should control engineers or even pure control theorists care about power systems ?**

## The “simple” control loop



## The “simple” control loop



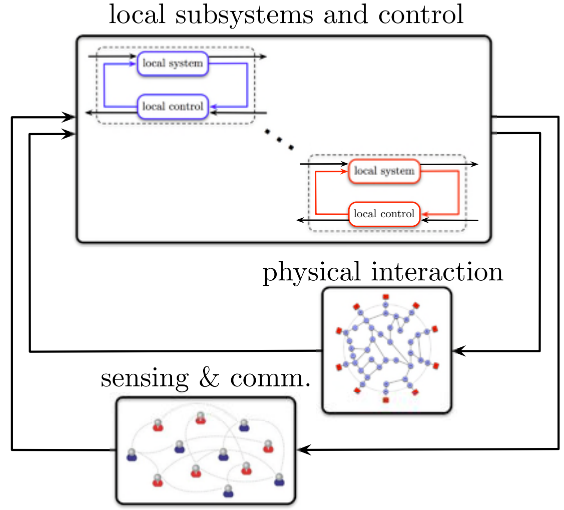

“Simple” control systems are well understood.

“Complexity” can enter this control loop in many ways:

models, disturbances, constraints, uncertainty, optimality,
. . . all of which are embodied in power systems.



## More recent focus: “complex” distributed decision making




Such distributed systems include **large-scale** physical systems, engineered **multi-agent** systems, & their interconnection in **cyber-physical** systems.

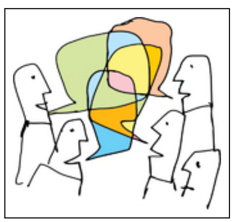


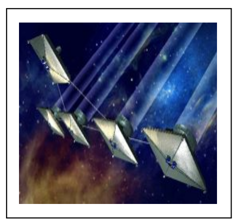
## Timely applications of distributed systems control

often the centralized perspective is simply not appropriate


robotic networks


decision making


social networks


sensor networks


self-organization


pervasive computing


traffic networks


smart power grids



# what makes power systems (IMHO) so interesting?

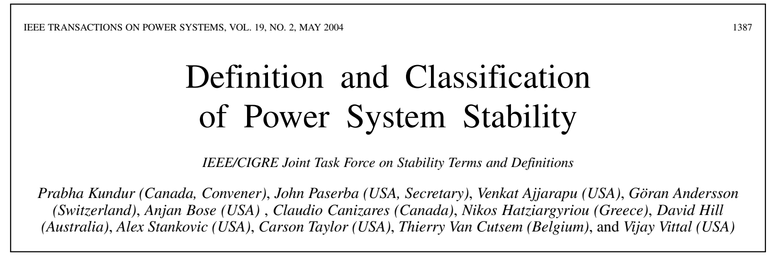
## My main application of interest – the power grid

NASA Goddard Space Flight Center

- **Electric energy** is critical for our technological civilization
- Energy supply via **power grid**
- **Complexities**: nonlinear, multi-scale, & non-local



## One system with many dynamics & control problems

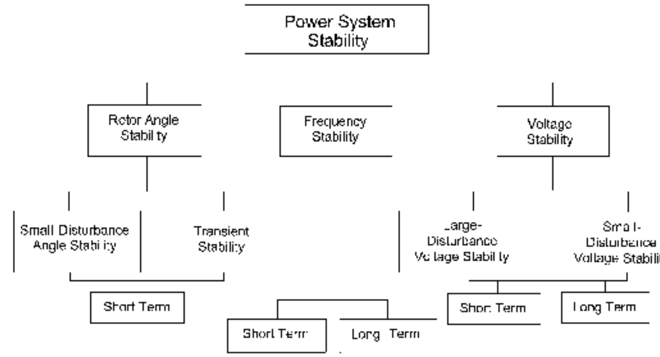


IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 19, NO. 2, MAY 2004 1387

# Definition and Classification of Power System Stability

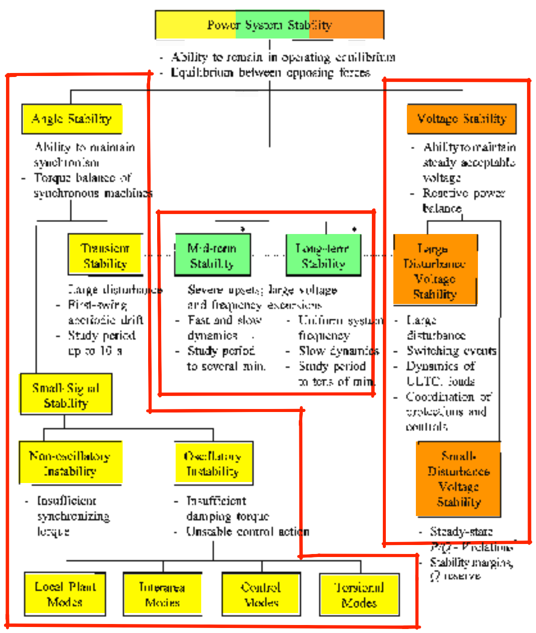
*IEEE/CIGRE Joint Task Force on Stability Terms and Definitions*

*Prabha Kundur (Canada, Convener), John Paserba (USA, Secretary), Venkat Ajjarapu (USA), Göran Andersson (Switzerland), Anjan Bose (USA), Claudio Canizares (Canada), Nikos Hatziargyriou (Greece), David Hill (Australia), Alex Stankovic (USA), Carson Taylor (USA), Thierry Van Cutsem (Belgium),* and *Vijay Vittal (USA)*



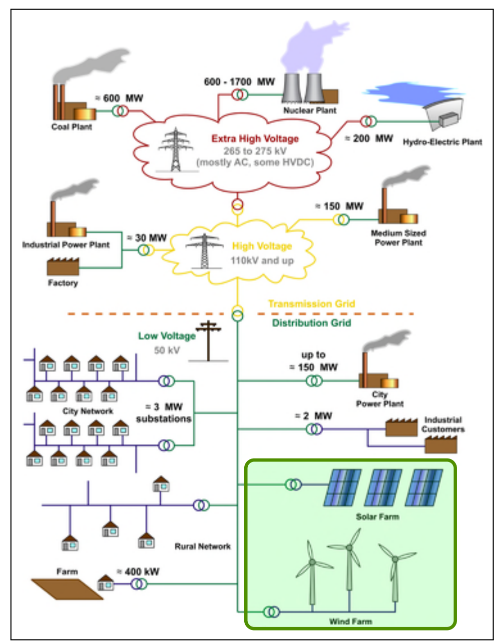



## Many aspects: spatial/temporal scales, cause & effect, . . .






## (Conventional) operation of electric power networks




**Top-to-bottom** operation:

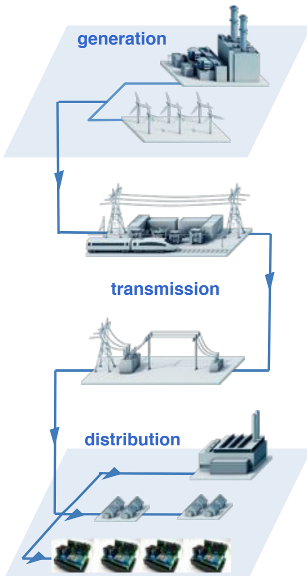
- **purpose** of electric power grid: generate/transmit/distribute
- **operation**: hierarchical & based on bulk generation
- things are changing . . .

## A few (of many) game changers

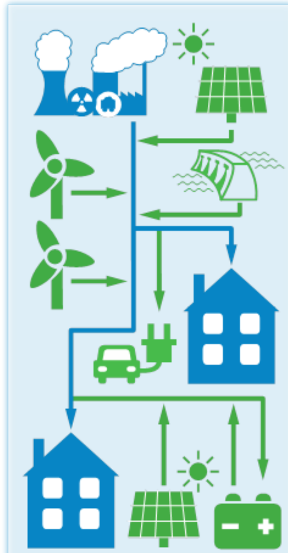
synchronous generator
⇒ power electronics

scaling

distributed generation

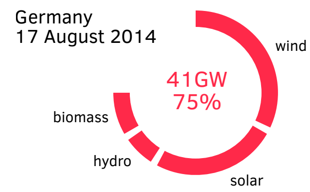


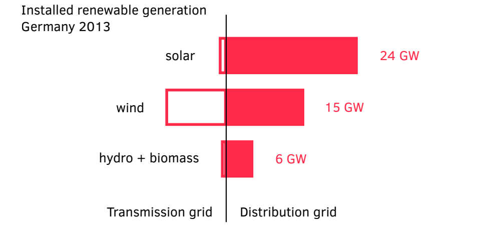

other paradigm shifts

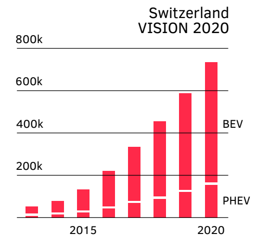


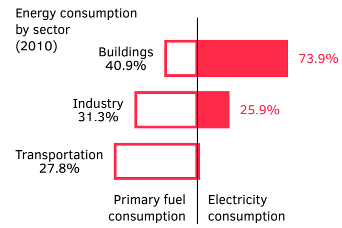


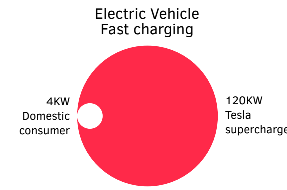
## A little bit of drama: examples close to home



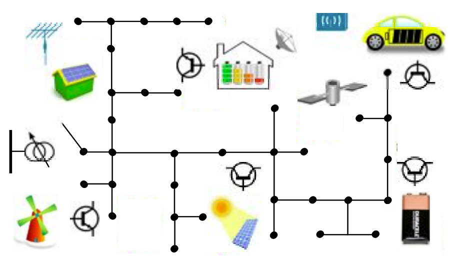






## Paradigm shifts & new scenarios . . . in a nutshell



1. controllable fossil fuel sources ⇒ stochastic renewable sources
2. centralized bulk generation ⇒ distributed low-voltage generation
3. synchronous generators ⇒ low/no inertia power electronics
4. generation follows load ⇒ controllable load follows generation
5. monopolistic energy markets ⇒ deregulated energy markets
6. centralized top-to-bottom control ⇒ distributed non-hierarchical control
7. human in the loop & heuristics ⇒ "smart" real-time decision making



## Challenges & opportunities in tomorrow's power grid

www.offthegridnews.com

**☹perational challenges**

- more uncertainty & less inertia
- more volatile & faster fluctuations
- deregulation & decentralization

**☺pportunities**

- re-instrumentation: comm & sensors and actuators throughout grid
- elasticity in storage & demand
- advances in understanding & control of cyber-physical & complex systems

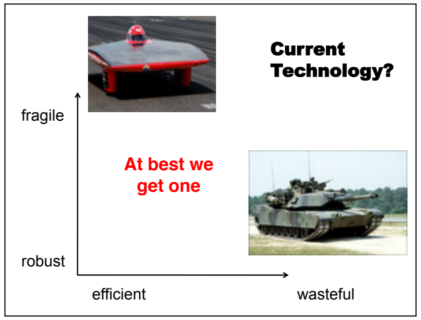
# Some profound insights by the giants in the field

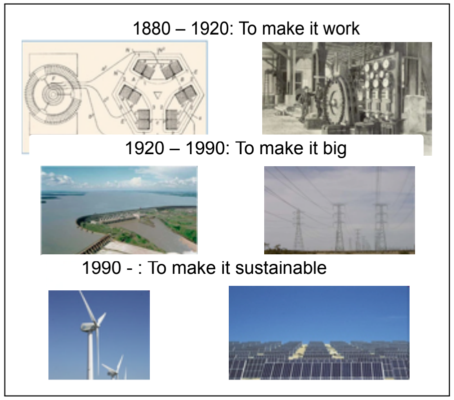
trade-offs & hard limits in control

[J. Doyle, UCSB '12]

a third challenge in power systems

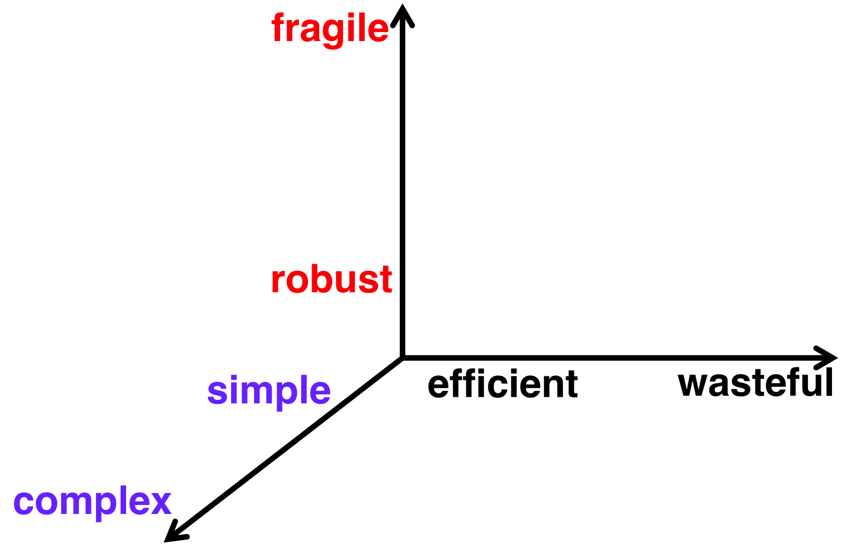
[G. Andersson, LANL '14]






# We should keep John's and Göran's trade-offs in mind





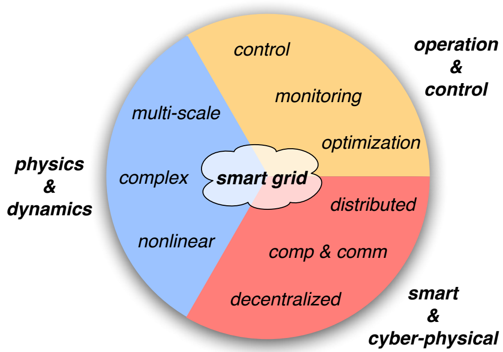

# The envisioned power grid

complex, cyber-physical, & "smart"

⇒ smart grid **keywords**

⇒ **interdisciplinary**:
power, control, comm, optim, econ, physics, . . . industry, & society

⇒ **research themes**:
*trade-offs in robustness, complexity, & efficiency*




*"[It remains] to put some serious science into the idea."* — [David Hill, PESGM '12]

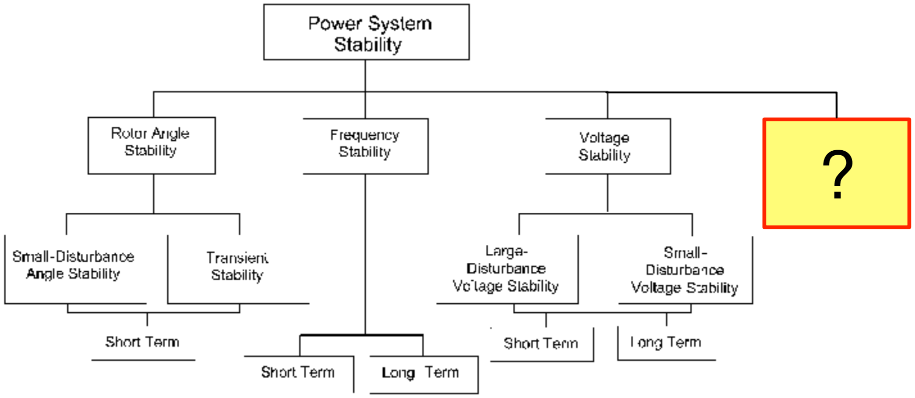


# Power Systems Control — from Circuits to Economics

| | | |
|---|---|---|
| **Wednesday, February 17, 2016** | | |
| 10.00 – 11.00 | Registration | |
| 11.00 – 11.30 | Florian Dörfler | General introduction |
| 11.30 – 12.30 | Florian Dörfler | Power System Modeling |
| 12.30 – 14.00 | Lunch | |
| 14.00 – 15.00 | Florian Dörfler | Power System Stability Control I |
| 15.00 – 15.15 | Break | |
| 15.15 – 16.00 | Florian Dörfler | Power System Stability Control I |
| 16.00 – 17.30 | Exercises | |
| **Thurday, February 18, 2016** | | |
| 09.00 – 10.15 | Florian Dörfler | Power System Stability Control II |
| 10.15 – 10.30 | Break | |
| 10.30 – 11.30 | Florian Dörfler | Power System Stability Control II |
| 11.30 – 12.30 | Exercises | |
| 12.30 – 14.00 | Lunch | |
| 14.00 – 15.00 | Andrej Jokic | Power System Economics I |
| 15.00 – 15.15 | Break | |
| 16.00 – 17.00 | Exercises | |
| 19.00 | Dinner | |
| **Friday, February 19, 2016** | | |
| 09.00 – 10.15 | Andrej Jokic | Power System Economics II |
| 10.15 – 10.30 | Break | |
| 10.30 – 11.30 | Andrej Jokic | Power System Economics II |
| 11.30 – 12.30 | Exercises | |
| 12.30 – 13.30 | Lunch | |
| 13.30 – 14.30 | Discussion of future research topics | |
| 14.30 | Drinks and closing | |

## A preview — to be resolved on the last day

The future will hold a new (and very dominant) stability issue






## let's start off with a quiz:

what is your background?

why are you interested in power?

what are your expectations?