

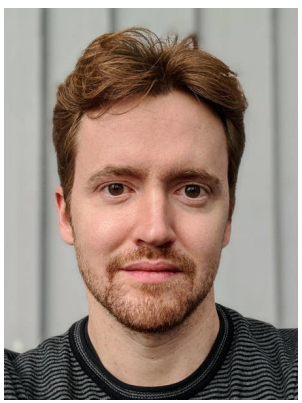
Data-Driven Operation of Autonomous Power Systems

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EECI School M07, May 6-10, 2024, Barcelona



Florian
Dörfler



Saverio
Bolognani



ETH zürich

AUTOMATIC CONTROL LABORATORY

https://control.ee.ethz.ch

https://bsaver.io/EECI

Outline

- Motivation
- Overview
- Organizational info
- A bit about you

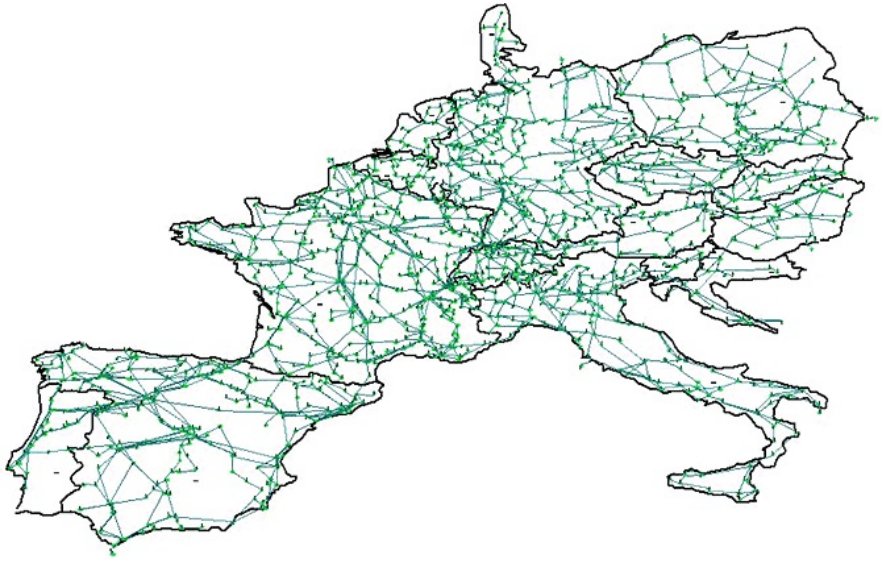
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The largest and most complex machine ever built by mankind



NASA Goddard Space Flight Center



- **electric energy** is critical for our technological civilization
- energy supply via **power grid**
- **challenges**: nonlinear, vast, multi-scale (temporal & spatial), uncertainty, ...

power system has always been **complex** beast even before distributed renewables

Almost 150 years of history

A few **core fundamental principles**

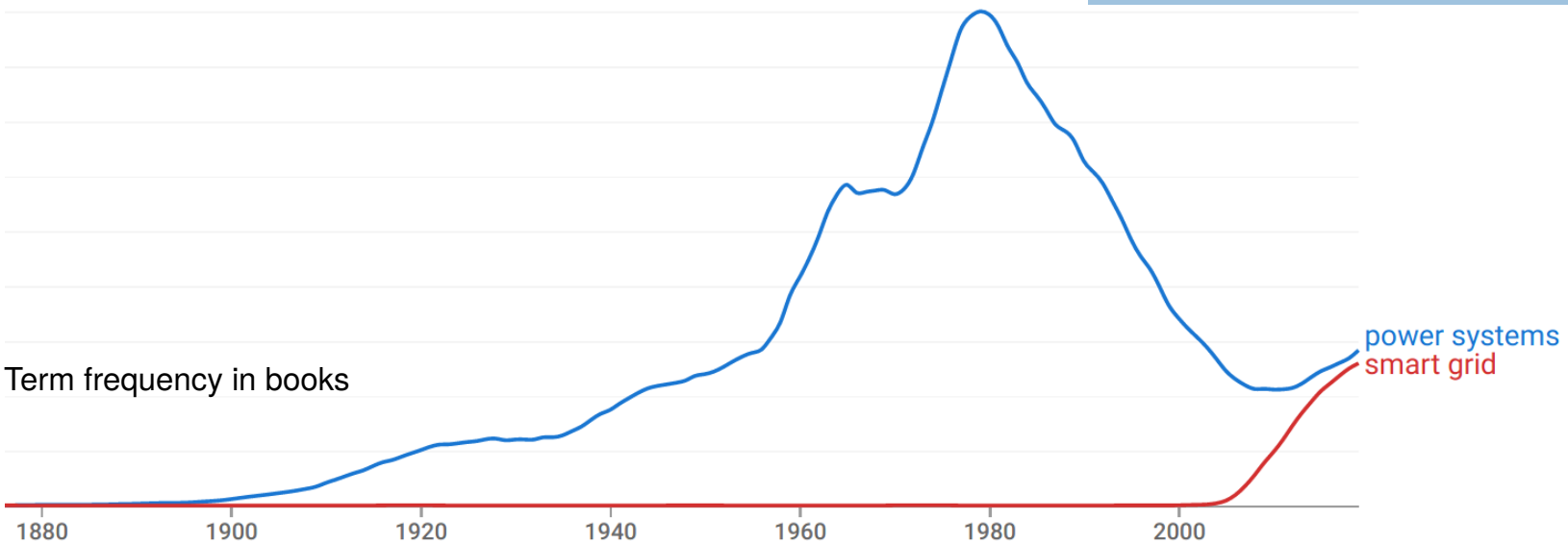
- (linear) electrical circuits
- electromechanical energy conversion

...followed by 150 years of **intertwined development** of

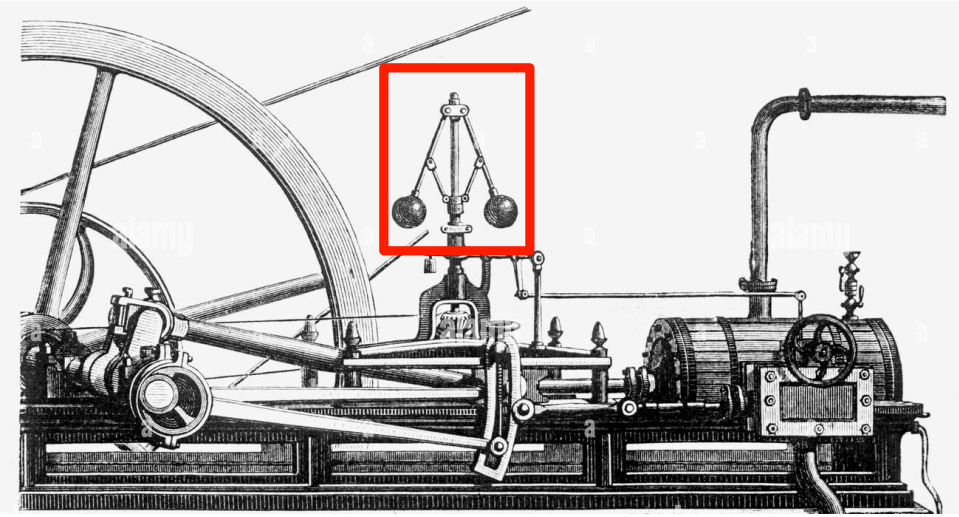
- mathematical models
- specialized technologies and industry
- expensive infrastructure
- regulations and standardization

A **very** mature field!

Difficult to innovate
Scientifically “well explored”



Brief history of power systems automation



flywheel governors regulating power & speed of “engines”

early contributors to (control) design & analysis: James Watt, James C. Maxwell, Willard Gibbs, Edward J. Routh, Adolf Hurwitz, . . .

→ nowadays called **droop control** & still basis of power system control

make it work	**make it big**	**make it sustainable**
physical design & redundancy	organically grown control	towards pervasive automation

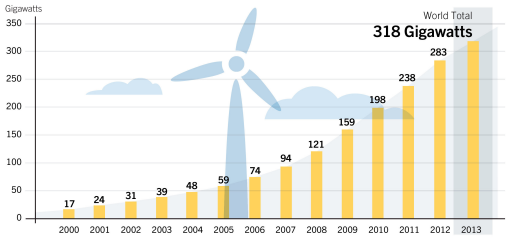
Tesla / Edison ⟶ time

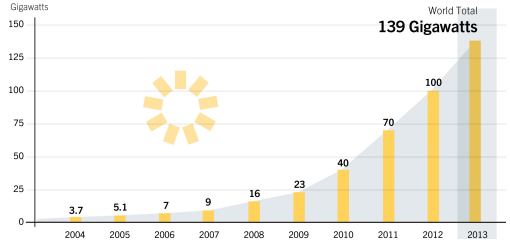
increasing automation (= control & optimization) as answer to challenges

→ extrapolation: **autonomous power systems** featuring ubiquitous sensing & actuation, digitalization & communication technology, . . . & control

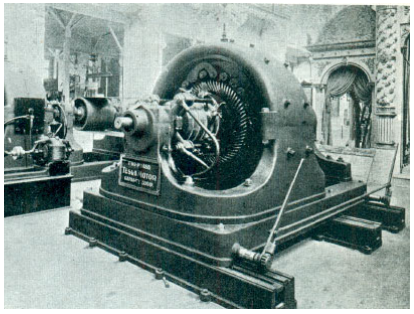
Recent power systems control challenges

→ integration of renewable sources





→ changing generation technology





opportunities:

- converter-interfaced sources

→ fast / modular / flexible actuation

- technological advances

→ sensing / actuation / communication

- scientific advances

→ control / optimization / learning

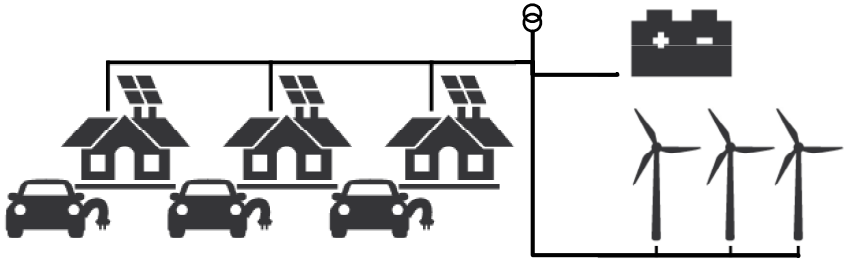
⇒ real-time automation of cyber-socio-technical power system

≡ **untapped opportunity for control**

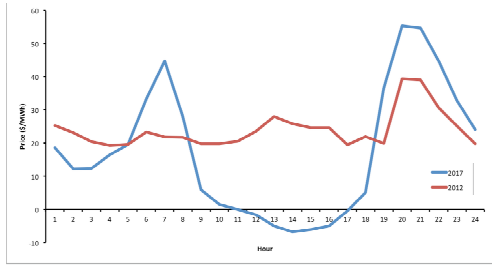
→ scaling



→ distributed generation & prosumption



→ liberalized markets




POWER IS NOTHING WITHOUT CONTROL

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A control-theoretic point of view on
Power system modeling (selected topics) +
Modern problems and solutions

- Monday 6/5 – **Circuit and power flow modeling**
  - Circuit equations and steady-state analysis
  - Power system topology and model reduction
  - "Direct" and "inverse" power flow problem
  - Existence of power flow solution and power flow feasibility
- Tuesday 7/5 – **Classical power system dynamics & control**
  - Modeling and analysis of synchronous machines
  - Reduced-order models for power network dynamics
  - Selected topics in power system stability & control
- Wednesday 8/5 – **Power Electronics Dominated Power Systems**
  - Low-inertia power systems: challenges & phenomenology
  - Power converter modeling & control specifications
  - Device-level: grid-forming converter control
  - System-level: operation of low-inertia systems
  - Data-enabled predictive control of converters
- Thursday 9/5 – **Real-time power system operation**
  - A geometric interpretation of power flow equations
  - Real-time optimal power flow
  - Dynamics on the space of power flow solutions
  - Feedback optimal power flow

We will not cover...

- Numerical optimization methods and algorithms for optimal power flow
- Stochastic optimization and risk management in grid planning/scheduling
- Specific technology-related topics (solar production, energy storage, ...)
- DC technologies (HVDC, microgrids, ...)
- Energy markets, dynamic pricing, demand/response
- Stochastic optimization, market bidding, aggregators
- Distributed control of power systems, hierarchical control, microgrids
- Wide-area frequency control
- ...

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Schedule

- 9:00-10:30 Class
- 10:30-11:00 Coffee break
- 11:00-12:30 Class
- 12:30-14:00 Lunch break
- 14:00-15:30 Class
- 15:30-16:00 Coffee break
- 16:00-17:30 Class

Administration

European Embedded Control Institute (EECI)
INTERNATIONAL GRADUATE SCHOOL ON CONTROL (IGSC)

- administrative issues: admin-eeci@centralesupelec.fr
- 3 ECTS (1 for attendance)
- Homework for full credit

Slides on the course website or directly at

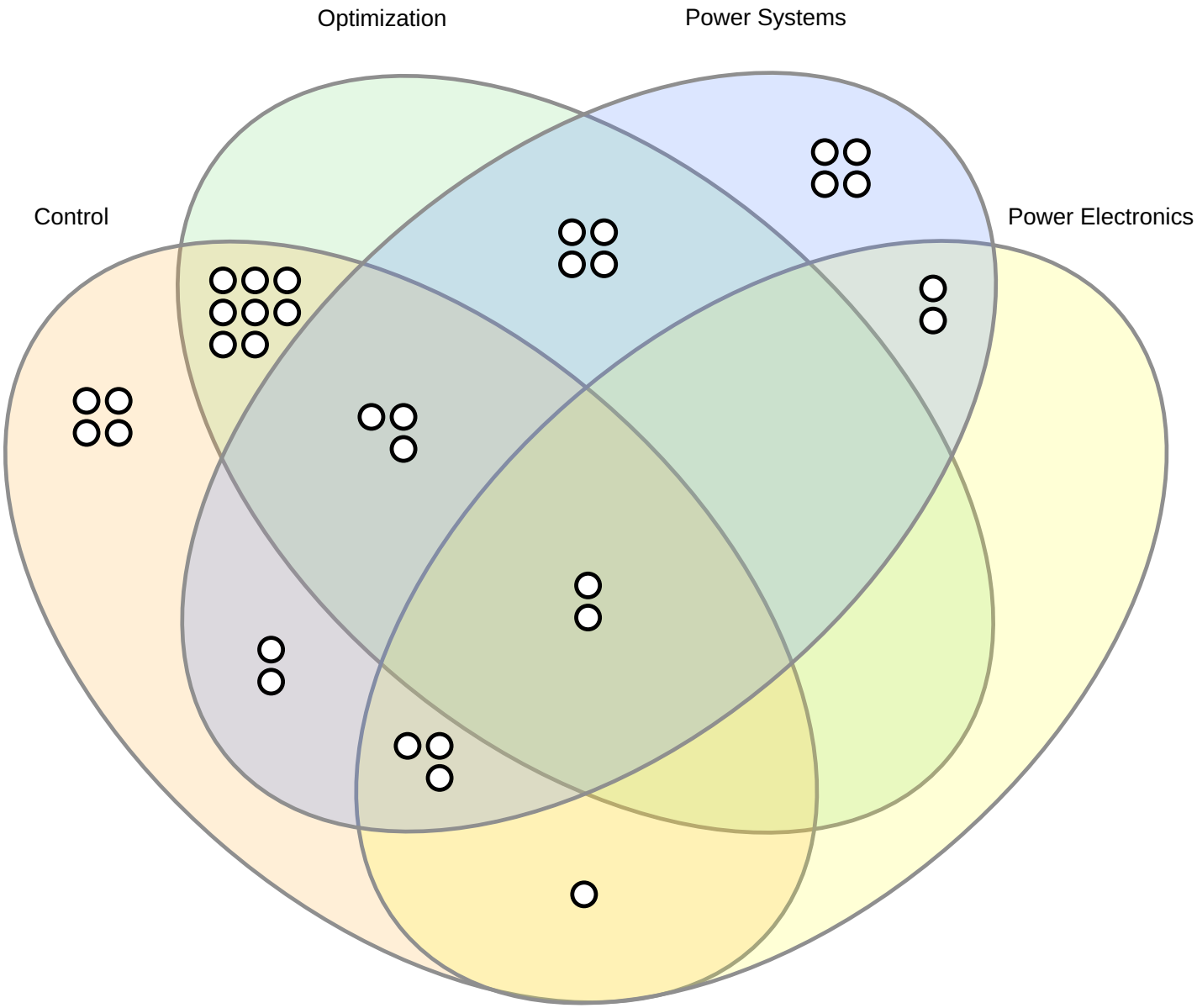
`https://bsaver.io/EECI-2024-slides`

They may be updated during the week.

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Statistics



Getting to know each other

One of the goals of PhD Schools is getting to know other to know other young scholars with the same interests.

During each break, **you will have the chance to introduce yourself and your research**

- what you are working on
- what you think is an exciting open problem in this domain
- what you would like to learn more about

We will do that spontaneously.