ETH zürich

Forskningsutmaningar i framtidens elkraftsystem

Elkraft 2017, Chalmers, maj 2017

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PSL Power Systems Laboratory

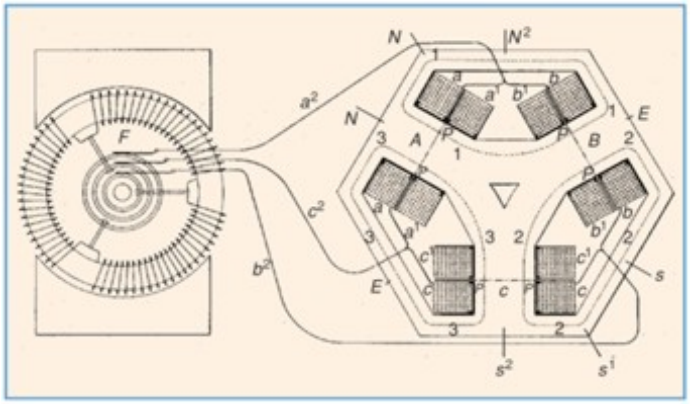
Innehåll

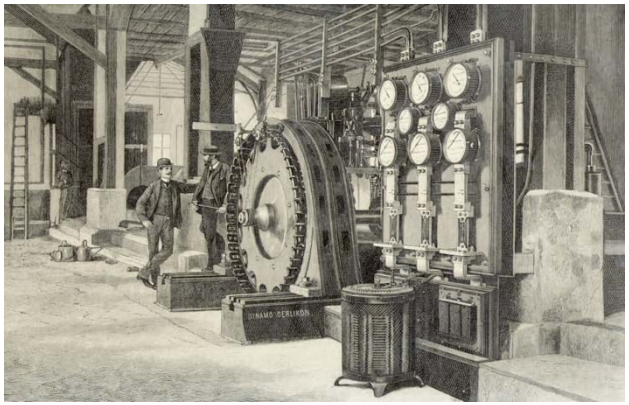
- Kortversion av elkraftsystemets utveckling
- Betydelsen av forskning och vetenskap för elkraftsystemets utveckling
- Viktiga framtida forskningsutmaningar, GAs personliga åsikter
- Samspelet mellan forskning och kraftindustri
- Slutkommentarer

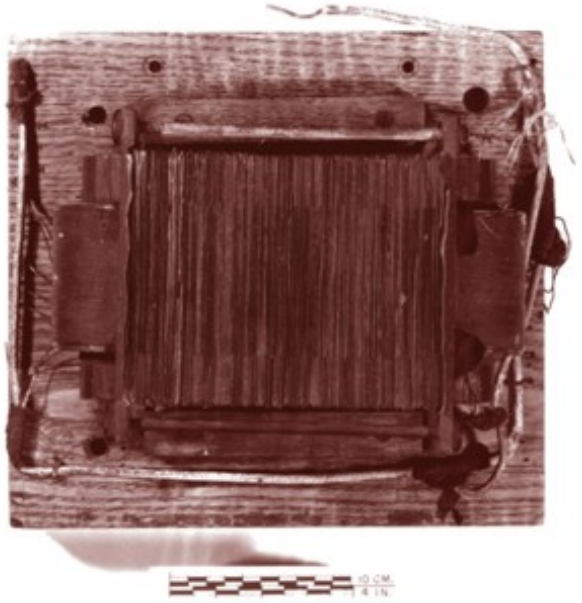
History of challenges in electric power engineering

From Goran Strbac, Imperial College

Challenge 1: To make it work (≈ 1880 – 1920)

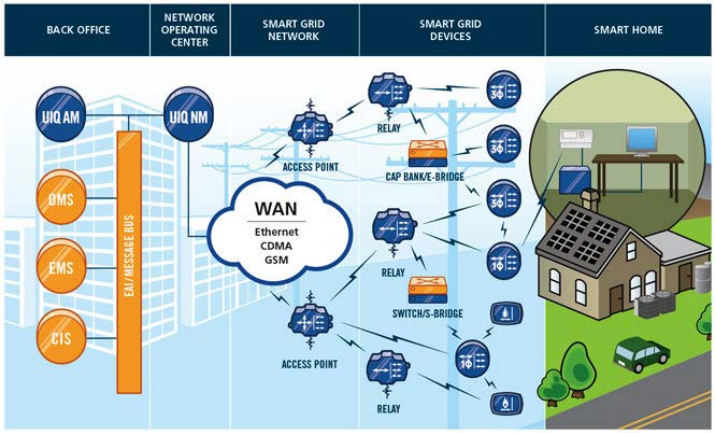


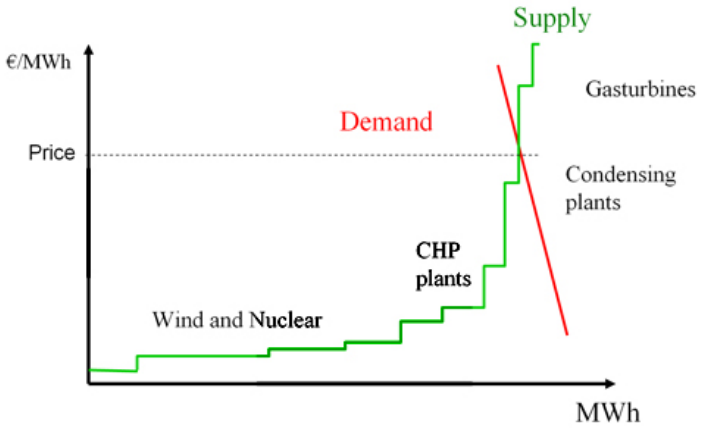




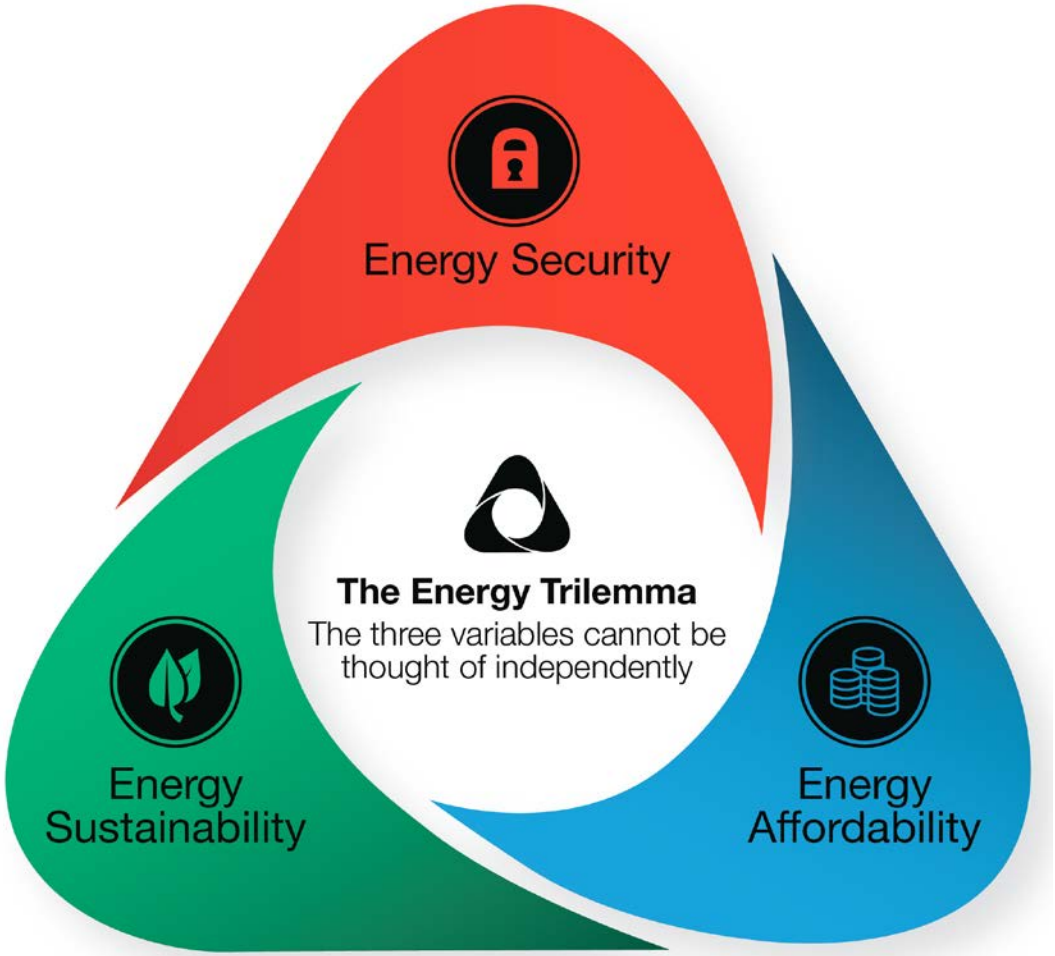
Challenge 2: To make it big and affordable (≈ 1920 – 1990)

Challenge 3: To make it sustainable, market based and still affordable (≈ 1990 -)





The Energy Trilemma



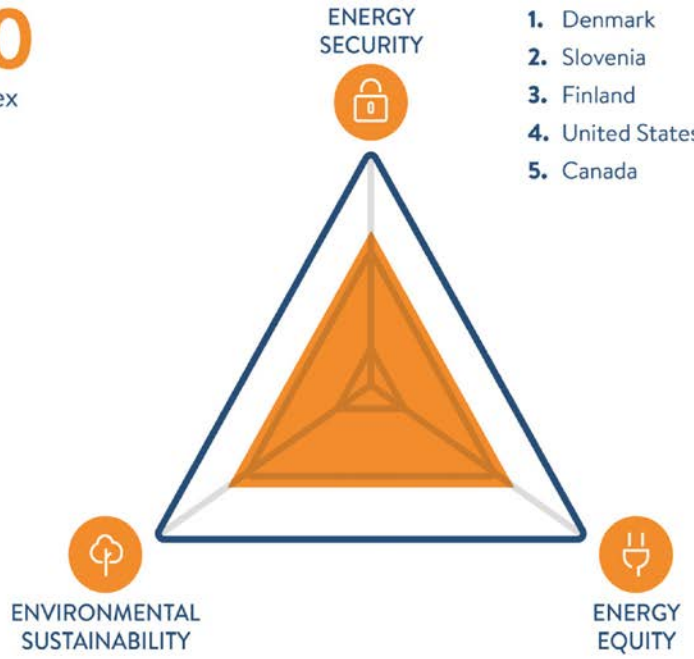
Source:
Arup's "Five minute guide to Energy Trilemma"

FIGURE 3: TOP 10 ENERGY TRILEMMA INDEX PERFORMERS OVERALL AND PER DIMENSION

TOP 10

2016 Trilemma Index

1. Denmark
2. Switzerland
3. Sweden
4. Netherlands
5. Germany
6. France
7. Norway
8. Finland
9. New Zealand
10. Austria



ENERGY SECURITY

1. Denmark
2. Slovenia
3. Finland
4. United States
5. Canada
6. Russian Federation
7. Germany
8. Nigeria
9. Netherlands
10. Sweden

ENVIRONMENTAL SUSTAINABILITY

1. Philippines
2. Iceland
3. Switzerland
4. Norway
5. Costa Rica
6. Denmark
7. Ireland
8. Sweden
9. Singapore
10. Colombia

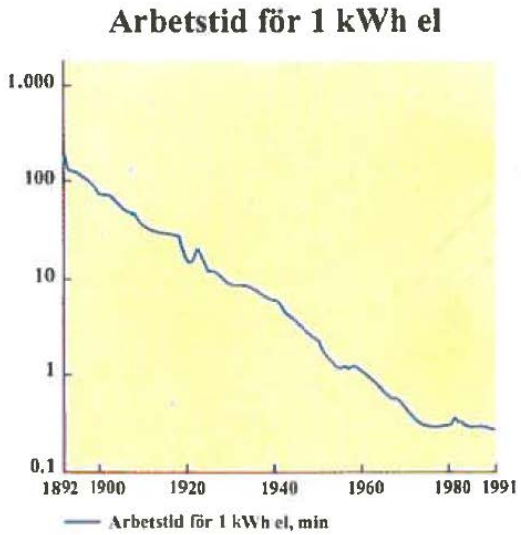
ENERGY EQUITY

1. Luxembourg
2. Switzerland
3. Netherlands
4. Qatar
5. Czech Republic
6. Austria
7. Bahrain
8. United Kingdom
9. France
10. Denmark

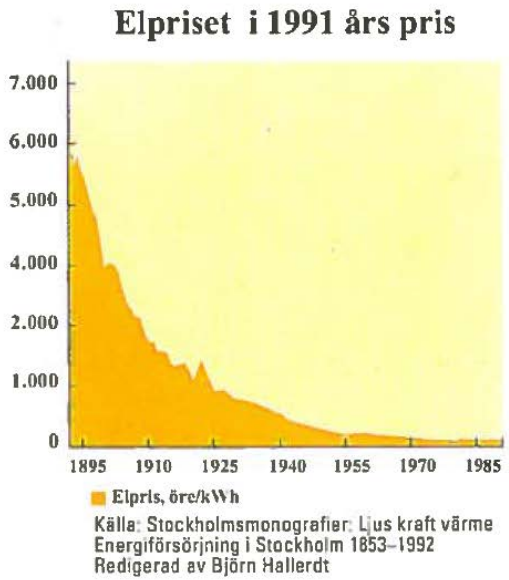
Source: World Energy Council/Oliver Wyman, 2016

Price of Electric Power

Minutes work needed to buy 1 kWh electric power. (Blue collar worker)



Inflation adjusted electricity price.



Some Facts

The electric power system is based on original results from fundamental (non-applied) scientific research

A. Volta, H.C. Ørstedt, M. Faraday, …

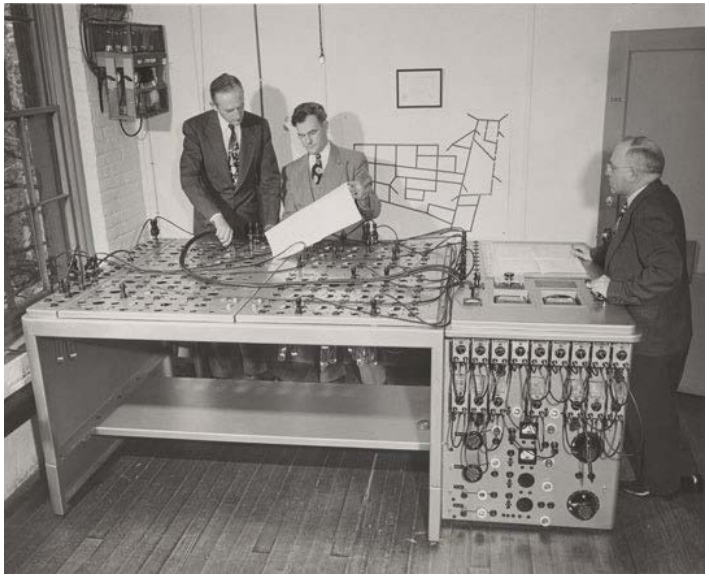
Based on the results from fundamental research, engineers and researchers designed and built the first power systems

G. Ferraris,T.A. Edison, N. Tesla, …

The electric power system has been further developed by using results from both applied and fundamental research

Modelling and Simulation

Power engineers were pioneers in using (mathematical) modelling and simulation as design and analysis methods.



First PhD Thesis in Engineering at KTH, Stockholm, 1928

THE DYNAMIC STABILITY OF LONG TRANSMISSION LINES

BY

IVAR HERLITZ

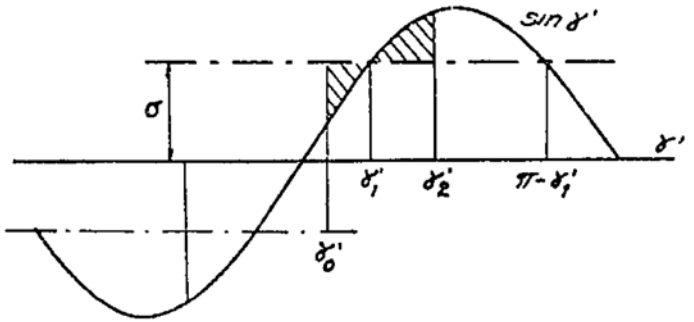


Fig. 2.

4. **The limit of stability.**

Important contributions also by Vannevar Bush, MIT

What about the future?

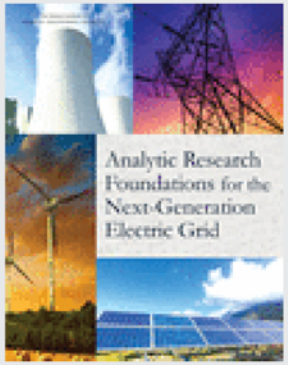
“Plans are useless, but planning is indispensable.”

Dwight D. Eisenhower

Planning used to be predictive

New paradigm: Planning is exploratory

THE NATIONAL ACADEMIES PRESS



Analytic Research Foundations for the Next-Generation Electric Grid

DETAILS

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AUTHORS

Committee on Analytical Research Foundations for the Next-Generation Electric Grid; Board on Mathematical Sciences and Their Applications; Division on Engineering and Physical Sciences; National Academies of Sciences, Engineering, and Medicine

Selected Salient Future Research Challenges (GA's view, May 2017)

1. Energy System Integration

2. Modelling, analysis, and simulation of Cyber-Physical Systems

3. Modelling and understanding the interaction between different stakeholders, i.e. customers, power producers, prosumers, grid companies, regulators, …

4. Integration of methods and results from other disciplines more effectively

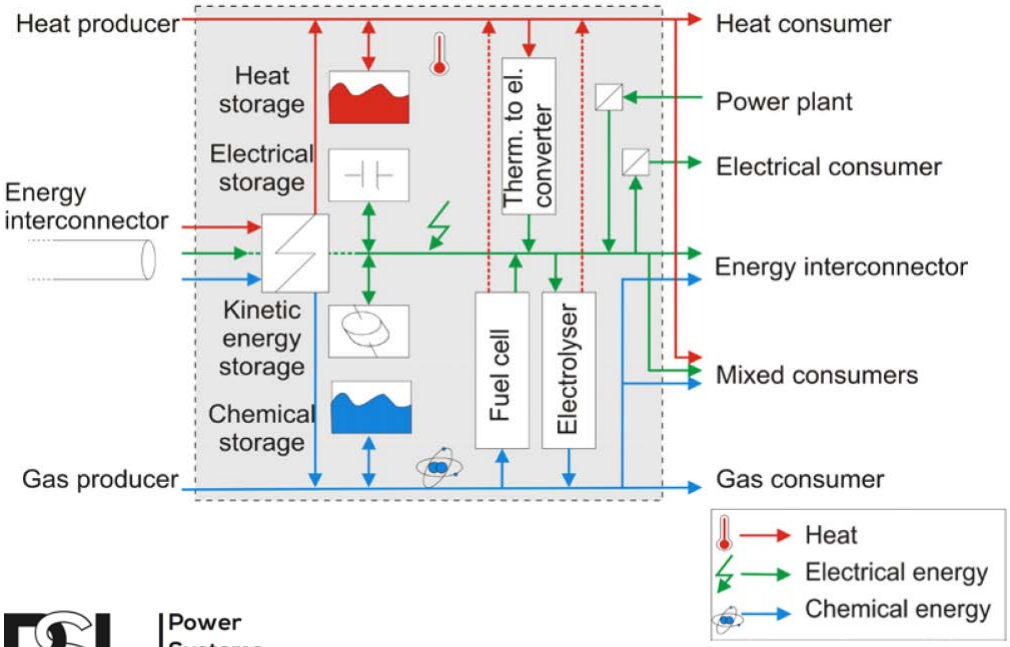
1. Energy System Integration

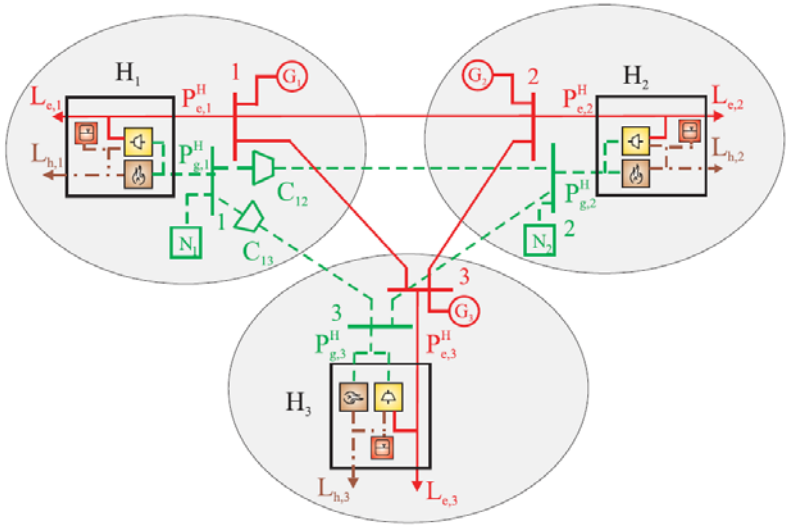
- The electric power system will be the back-bone of the future energy system
- Optimization considering **ALL** energy carriers needed to achieve the sustainability goals
- Human activities, e.g. use of transportation and demand response, must be included in the optimization and control approaches
- Consideration of interaction between different voltage levels (active distribution grids with storage)

Modeling of Energy Networks – Energy Hubs

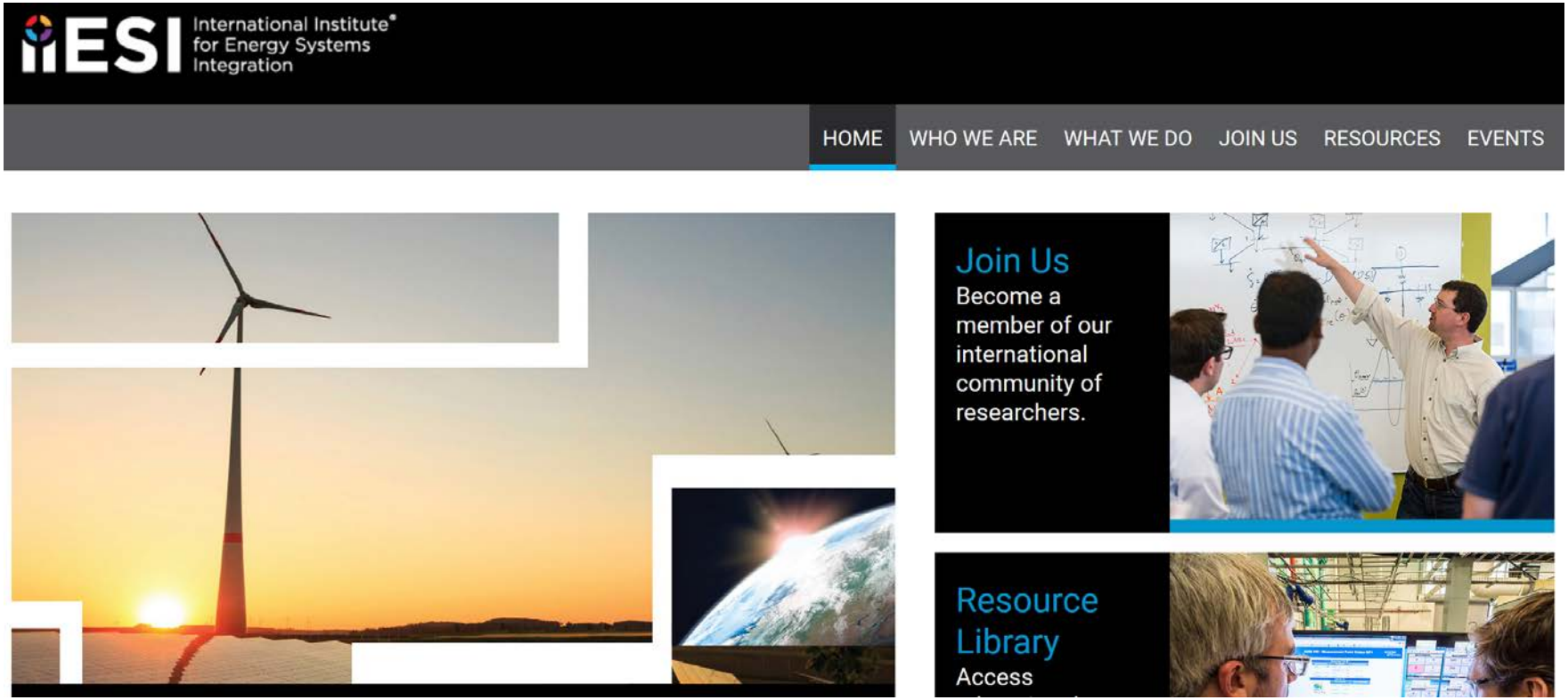
- Energy Hub concept allows unified modelling of energy networks and resulting synergies of electricity networks ($\mathbf{P_{el}}$, $\mathbf{E_{el}}$), natural gas networks ($\mathbf{P_{gas}}$, $\mathbf{E_{gas}}$) and district heat networks ($\mathbf{P_{heat}}$, $\mathbf{E_{heat}}$)

- Energy Hub concept allows analysis and optimization of investment optimality, operation efficiency and operation reliability.





Geidl, Andersson et al., 2007 and 2008



http://iiesi.org/

2. Cyber-Physical Power Systems

- Future power systems increasingly dependent on ICT: Urgent need for models encompassing both ”Cyber” and ”Physical” systems
- Dynamic power system models need to be revised: synchronous machines will not (always) be pre-dominant in the future
- Problem: Different investment horizons in Cyber and Physical systems
- Risk of ”lock-in effects”

Cyber-Physical Models of Power Systems

Daniel Kirschen & François Bouffard,
IEEE Energy & Power Magazine, 2009

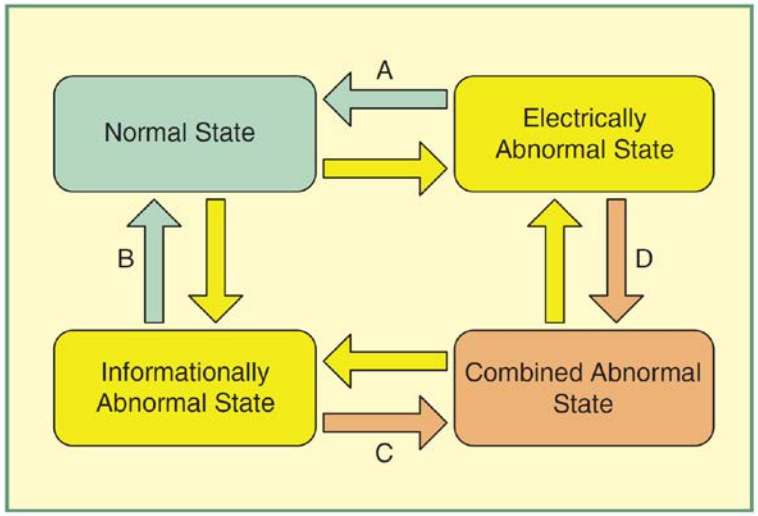
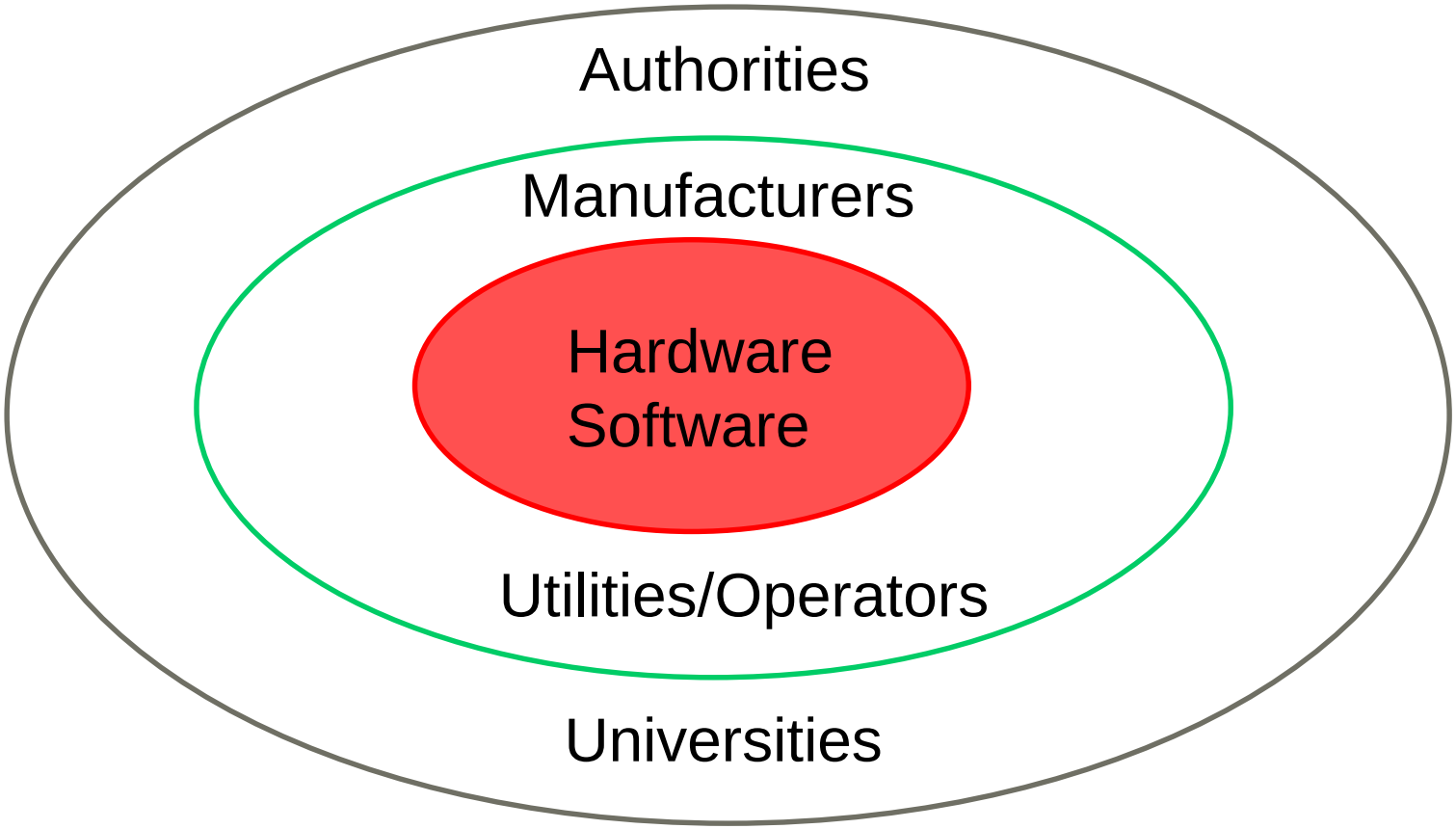


figure 2. Expanded power system security analysis framework.

3. Interaction Between Different Stakeholders

The Traditional Structure of an Infra-structure System (T.P. Hughes, ≈ 1980)



New and Important Considerations

- ”Homo Economicus” vs ”Citizen”
- ”Zero marginal cost” economies (Jeremy Rifkin) → tariffs
- Pricing of externalities, i.e. environment etc
- Internationalization of energy systems
- …

4. Interaction with Other Disciplines

- Energy systems have natural connections with almost all scientific disciplines
- Collaborations with economists, natural scientists and engineers from other fields have created the system we have today. These collaborations should be continued and further developed and deepened.
- More collaborations with social scientists and the humanities needed.

BUT,

one has to be careful ….

“Everything should be made as simple as possible, but not simpler.”

Albert Einstein (?)

“Essentially, all models are wrong, but some are useful”

George Box

Solution of Non-Problems vs. Non-Solution of Problems

Lester H. Fink*

From "Electric Power Problems: The Mathematical Challenge"; Proceedings of a Conference, Seattle, Washington, March 18-20, 1980
Editors: A.M. Erisman, K.W. Neves and M.K. Dwarakanath; SIAM, Philadelphia/1980

”We suggest that, despite the very real distinction and differences between engineering and applied research, they are alike in requiring, for success, an understanding of the problem, and understanding of the (at least potentially) relevant tools, and creative application of the latter to the former.”

”Without understanding of real problems, pseudo-problems will be posed and possible ’solved’ while the real problems remain unaddressed; without understanding of potentially relevant tools, real problems will be grappled with only at disadvantage and will often remain intractable.”

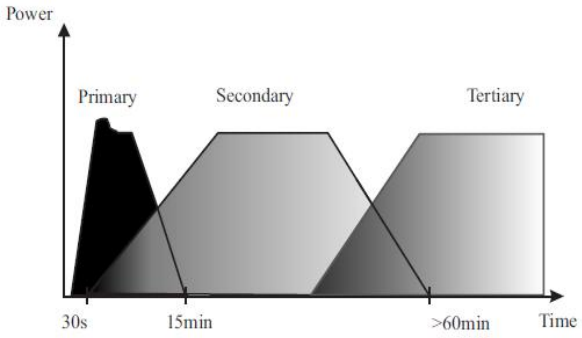
Complexity of Power Systems

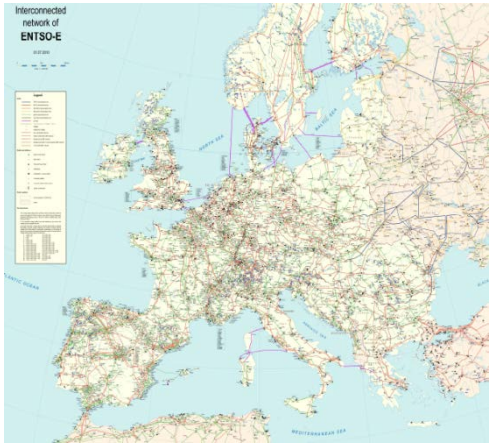
Complexity along several dimensions

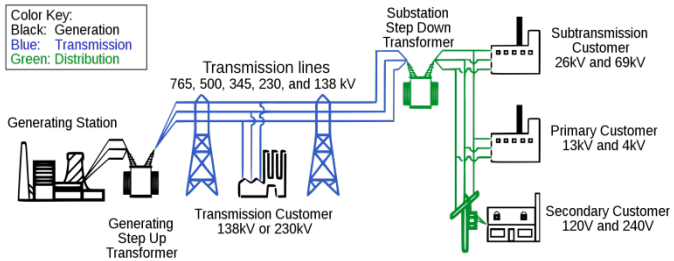
- **Time** **(milli)seconds** (e.g. frequency inertia, frequency&voltage control), **minutes** (e.g. secondary/tertiary frequency&voltage control), **hours/days** (e.g. spot market-based plant/storage scheduling), **months/years** (e.g. seasonal storage, infrastructure planning).

- **Space** **1‘000+ km**, e.g. interconnected continental European grid (Portugal – Poland: 3‘600 km, Denmark – Sicily: 3‘000 km).

- **Organizational** **from distribution grid** (e.g. 120/240 V, 10 kV) **to high-voltage transmission grid** (220/380/500/… kV, AC and DC). **different stakeholders**







Power Systems Laboratory

Cross-Disciplinary Challenges

- New technologies and methods for grid measurement and control (WAMS, big data, …)
- Improved models for grid operation (multi-time scales)
- Optimization under uncertainty
- Modelling and mitigation of high impact, low frequency events
- Data handling and analytics

Another problem to be solved:

Transfer of research results from academia and research institutes to industry

George Porter

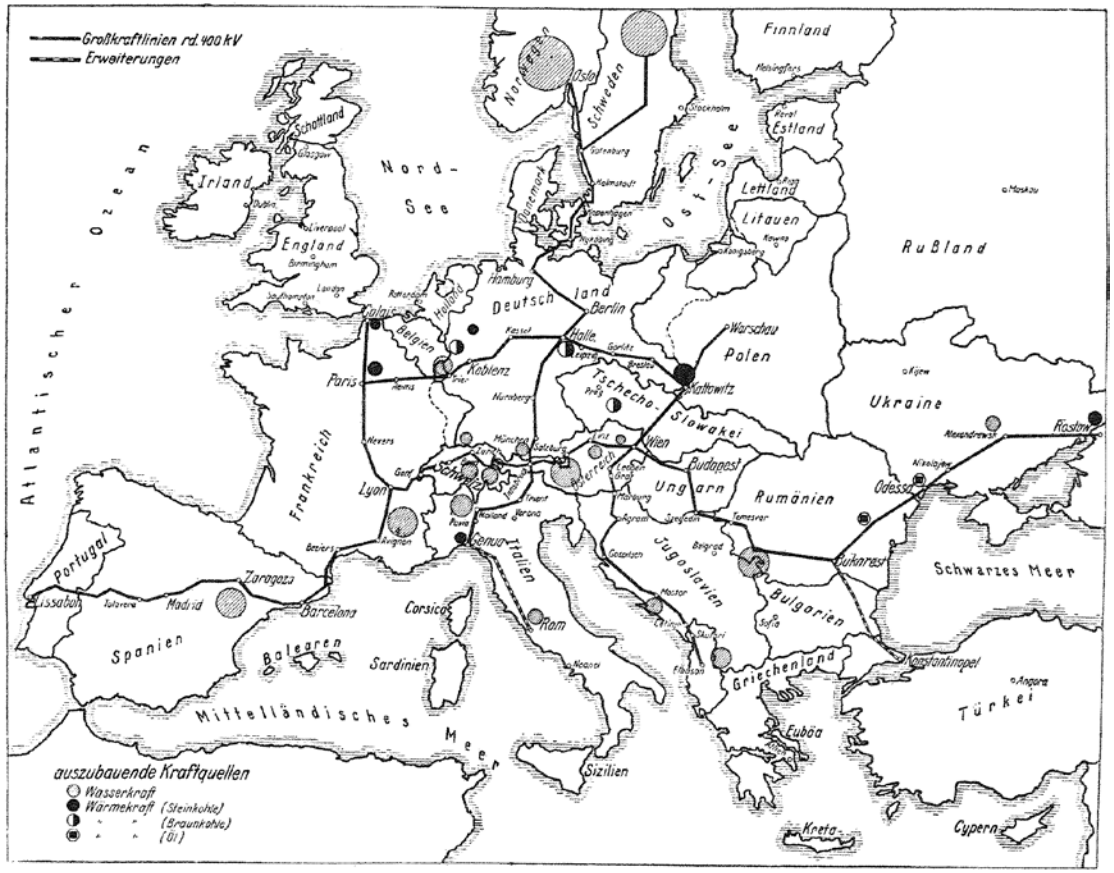
“There are two kinds of research:

applied research and not-yet-applied research.”

Piet Hein

“When you feel how depressingly slowly you climb,
it's well to remember that Things Take Time!

European Supergrid: A plan from the 1920s



Oskar Olivens Plan for a pan-European Supergrid
[Teknisk Tidskrift (1930), p. 438]

Cited in:
Mats Fridlund. “Den gemensamma utvecklingen; Staten, storföretaget och samarbetet kring den svenska elkrafttekniken.” *PhD Thesis.* Symposion, 1999

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The Global Grid

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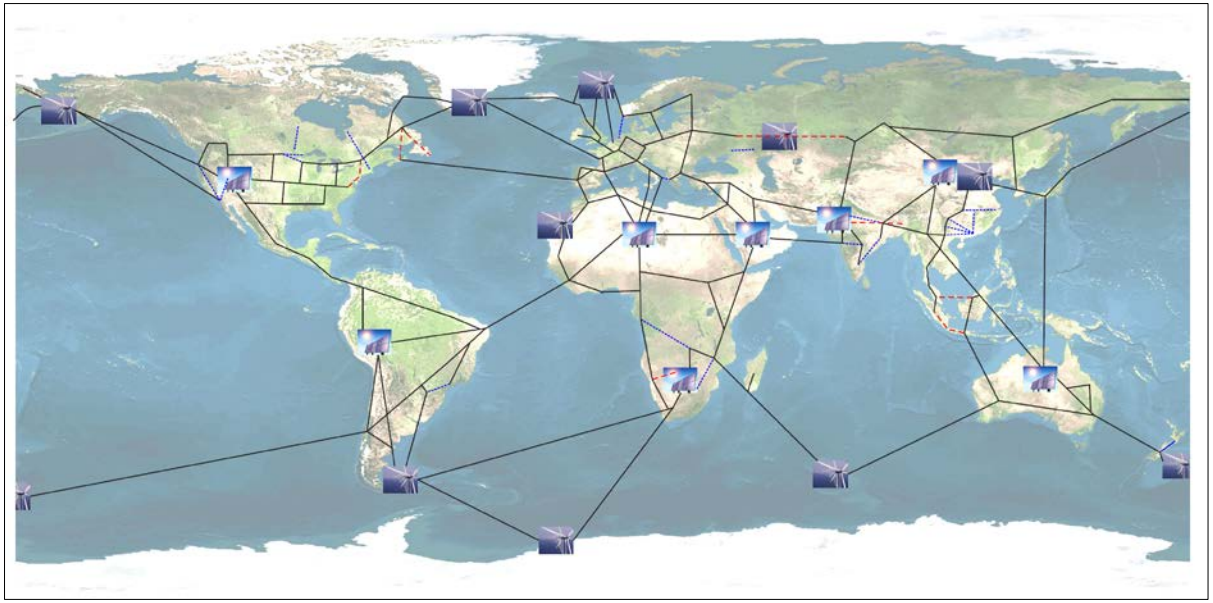


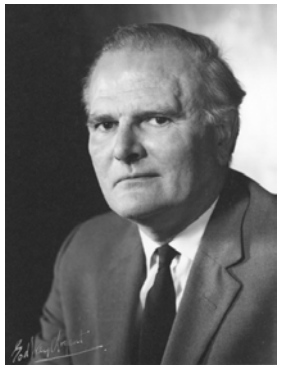
How to get more research results applied

- Researchers should work on ”real” problems
- Joint projects between research institutions and ”power industry”
- Exchange of personnel between research institutions and ”power industry”
- Increase share of engineers with research background in ”power industry”

Final Remarks

Peter V. Danckwerts

*"A scientist solves the problems he can,
the engineer solves the problems he has to."*



T.S. Eliot

*"We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time"*

Last Remark

Virginia Woolf

“It is far more difficult to murder a phantom than a reality.”

Thank you for your attention!