TRANSFORMING THE ELECTRIC GRID: A ROLE FOR HMW INVERTERS

April 2008

Alex M. Stanković

Northeastern University, Boston

astankov@ece.neu.edu

Presentation Map

- Energy Systems - Past & Present
- Energy Systems - Future,

Why Energy Systems?

Systems aim to achieve level reliability that far exceeds the reliability of individual components, through corrections of control actions based on evaluating or sensing its current state.

Why Energy Systems?

Systems aim to achieve level reliability that far exceeds the reliability of individual components, through corrections of control actions based on evaluating or sensing its current state.

Examples of energy system reliability targets:

Reliability %	N "nines"	Down time
99.9	3	9 hr/yr
99.999	5	5 min/yr
99.99999	7	3 sec/yr
99.9999999	9	2 cycles/yr

Why Energy Systems?

Systems aim to achieve level reliability that far exceeds the reliability of individual components, through corrections of control actions based on evaluating or sensing its current state.

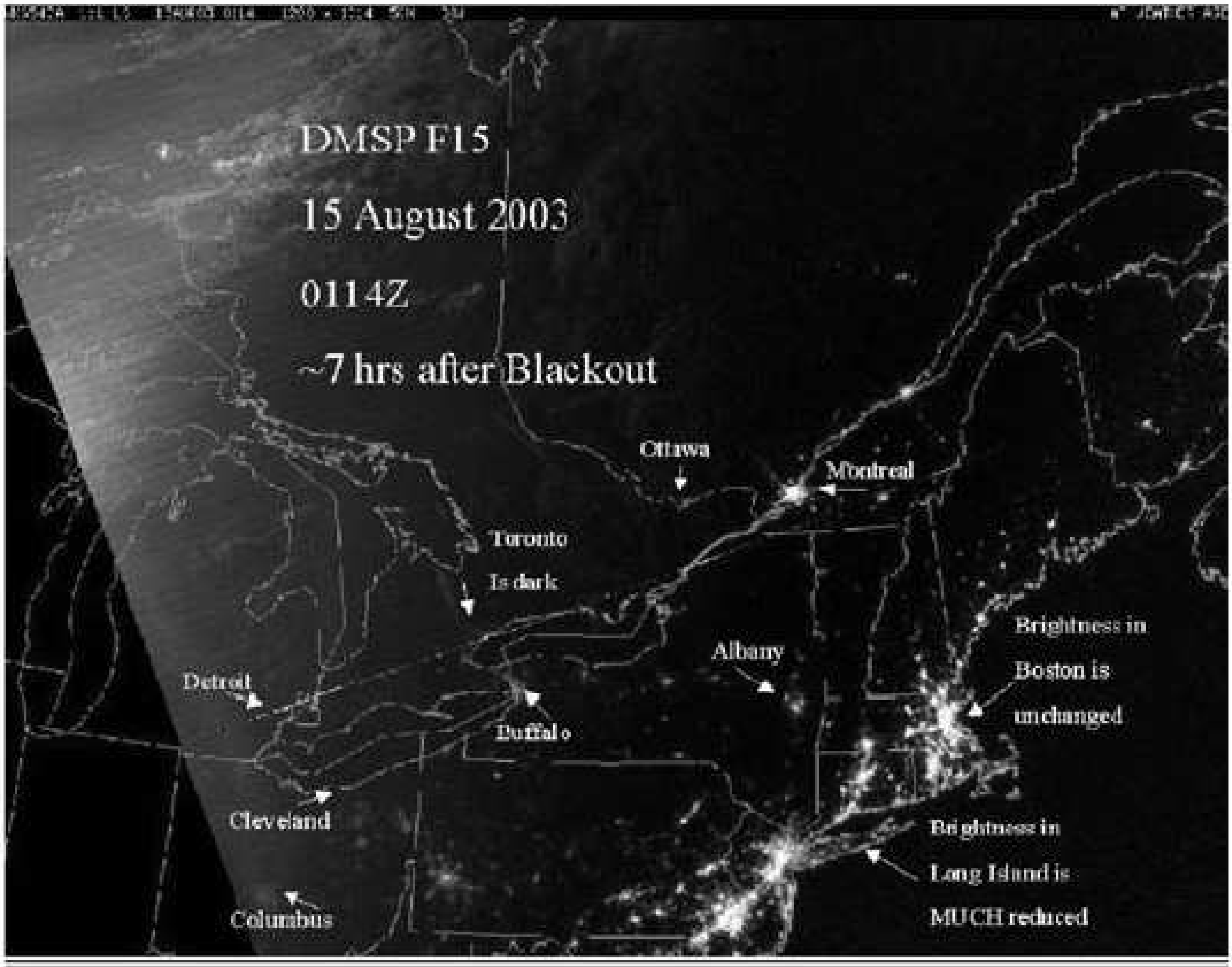
Examples of energy system reliability targets:

Reliability %	N "nines"	Down time
99.9	3	9 hr/yr
99.999	5	5 min/yr
99.99999	7	3 sec/yr
99.9999999	9	2 cycles/yr

Events from real life (G.T. Heydt):

Losing in roulette	N=1.6
Losing the PowerBall lottery	N=6
FAA design for aircraft	N=9-12

Cascading Faults



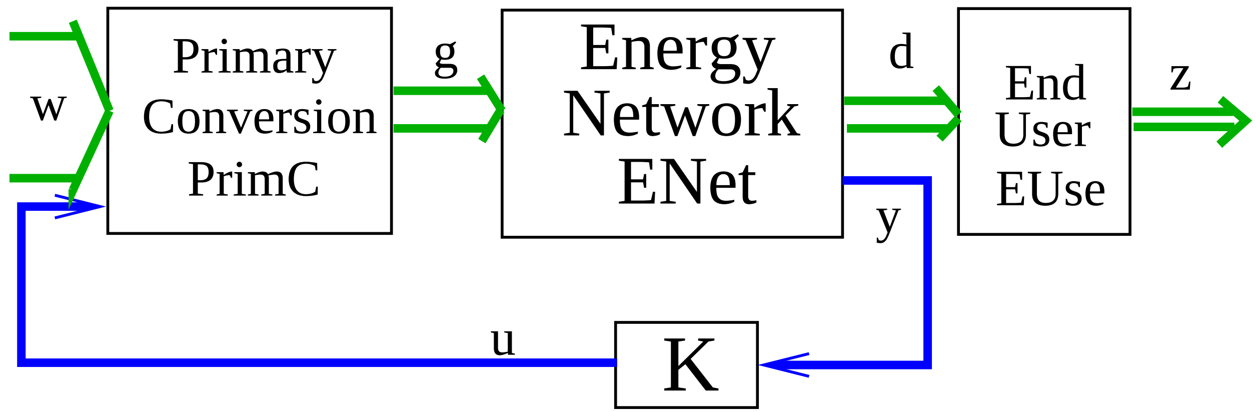
Characteristics of Energy Networks

- Built for efficiency.
- Multi-scale in time (>10 orders of magnitude), space (>7 orders of magnitude) and by power flow (>10 orders of magnitude).
- Hybrid - continuous and discrete acting components.
- Normal and faulted operation (nature and human adversaries).

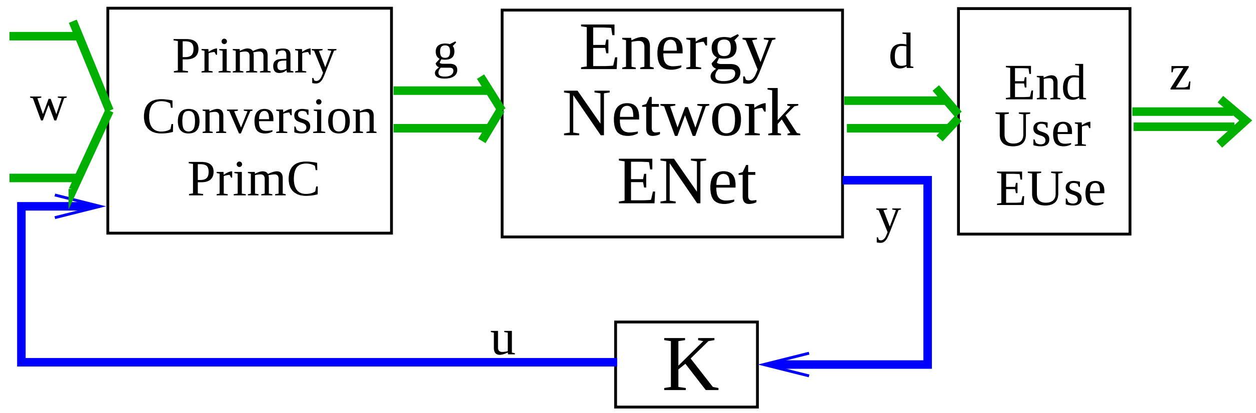
Characteristics of Energy Networks

- Built for efficiency.
- Multi-scale in time (>10 orders of magnitude), space (>7 orders of magnitude) and by power flow (>10 orders of magnitude).
- Hybrid - continuous and discrete acting components.
- Normal and faulted operation (nature and human adversaries).
- Two main layers - energy and information flow.
- Limited actuation.
- Uncertainty (epistemic and aleatory).
- Input/Output characteristics are regularized by physics (conservation laws, coherences and invariants).

Existing Energy Systems



Existing Energy Systems



- **w** too large, little from renewables,
- Unable to integrate novel components,
- Non-functional markets,
- Over-designed components - variations in **z**,
- Over-designed components - fault accommodation,
- Cascading faults.

Existing Energy Systems - Technical

- Not enough adaptation due to the insufficient information layer - control is too local, sometimes myopic,
- Significant variations in the part of $\mathbf{w}$ from renewables - large bandwidth and stochastic nature,
- No storage - a slow system is tracking variable $\mathbf{z}$,
- Large variations in $\mathbf{z}$ (and $\mathbf{w}$) - cyclic and stochastic,
- Individual blocks have substantial loses,

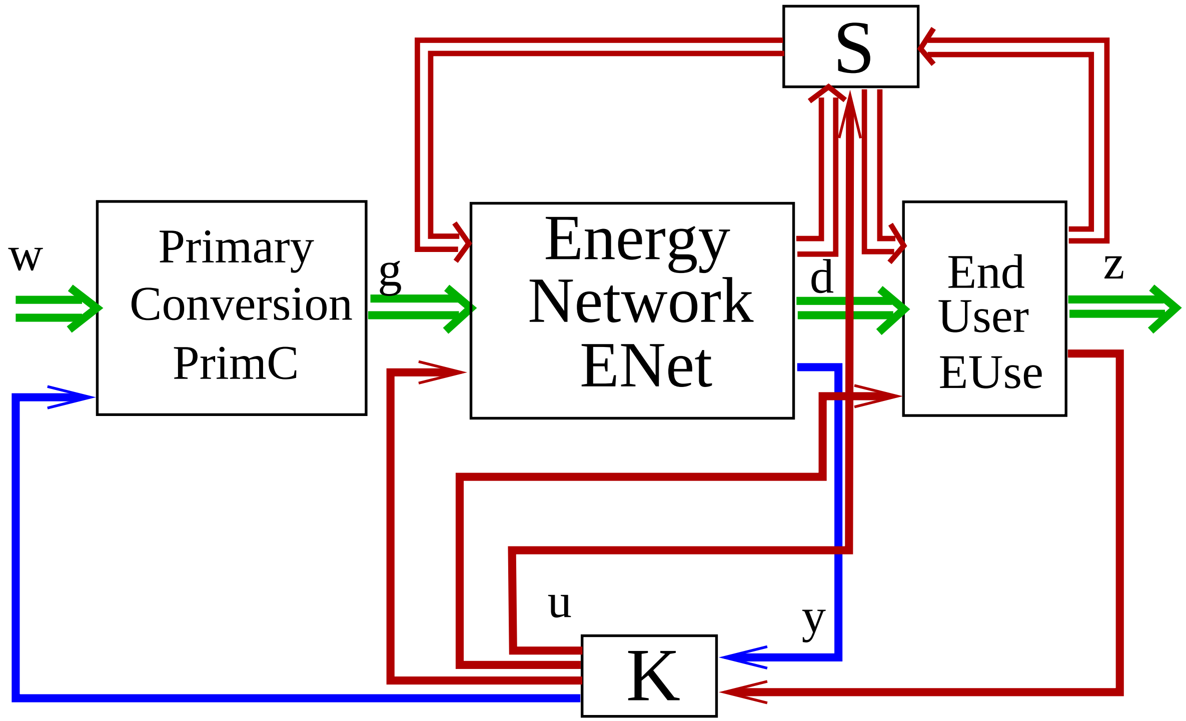
Existing Energy Systems - Technical

- Not enough adaptation due to the insufficient information layer - control is too local, sometimes myopic,
- Significant variations in the part of $\mathbf{w}$ from renewables - large bandwidth and stochastic nature,
- No storage - a slow system is tracking variable $\mathbf{z}$,
- Large variations in $\mathbf{z}$ (and $\mathbf{w}$) - cyclic and stochastic,
- Individual blocks have substantial loses,
- The inflexible overall architecture sometimes results in complex behavior - the system is very large, and the control authority is limited,
- Legacy components stifle innovation.
- Fault accommodation in slow hardware.

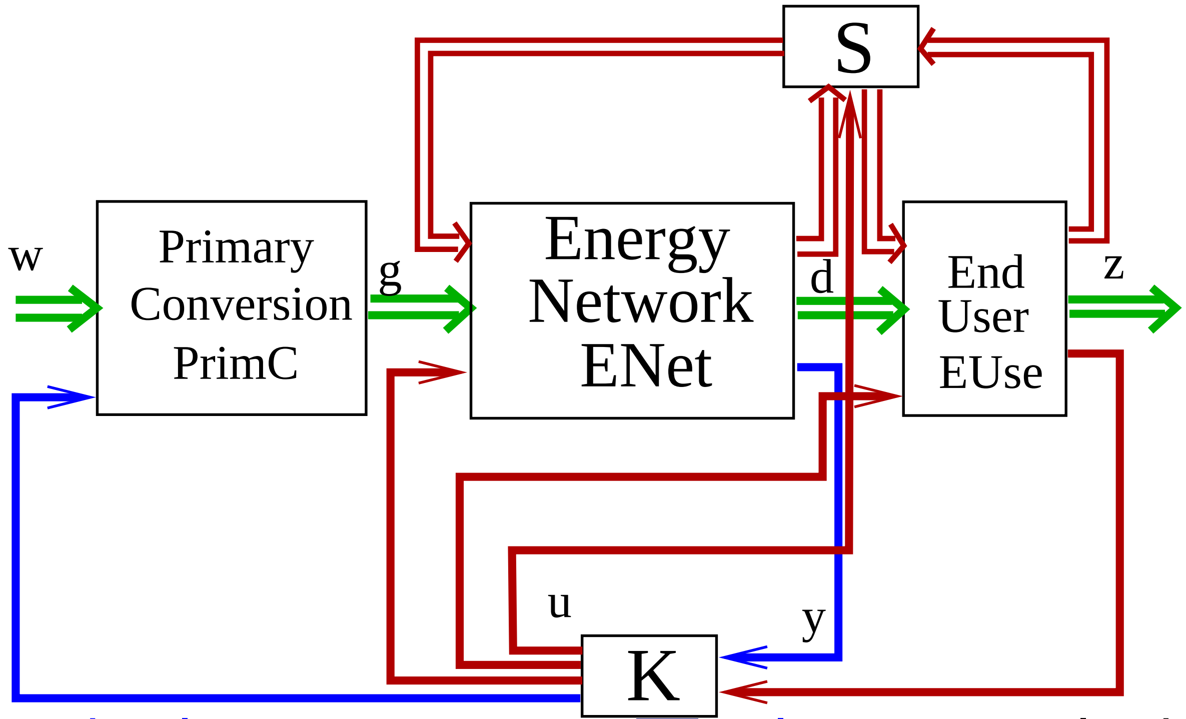
Presentation Map

- Energy Systems - Past & Present
- Energy Systems - Future,

Future Energy Systems VLSIE



Future Energy Systems VLSIE



- Information layer (sensors, coordinated K = local + global context, loads inside)
- Better blocks,
- More **w** from renewables,
- Flatter control - decoupling from above and below, faster, more authority via storage and routing,
- Better design while steering component development.

A Role for HMW Inverters

HMW inverters are a key enabling technology:

- A network with controlled flows (cf. free-flow today),
- Accommodate faults faster (before thermal, mechanical and chemical aspects start to dominate the design),
- Enable energy storage (especially large and fast),
- Enable better control - decompose the network to smaller, manageable pieces.

Getting there...

- Progress of technology in energy systems - “like visiting a graveyard in the company of Nietzsche” - Willems,

Getting there...

- Progress of technology in energy systems - “like visiting a graveyard in the company of Nietzsche” - Willems,
- Society expects 1) carbon-free electricity, 2) networks resilient to outages, and 3) functional markets and public policy.

Getting there...

- Progress of technology in energy systems - “like visiting a graveyard in the company of Nietzsche” - Willems,
- Society expects 1) carbon-free electricity, 2) networks resilient to outages, and 3) functional markets and public policy.

  Transition:
- The efficiency is determined by the energy flow layer,
- Key enablers for improvement are in the information flow layer,
- The trajectory to future energy systems will be economy and policy driven (e.g., energy levels for sensors vs. storage).

Getting there...

- Progress of technology in energy systems - “like visiting a graveyard in the company of Nietzsche” - Willems,
- Society expects 1) carbon-free electricity, 2) networks resilient to outages, and 3) functional markets and public policy.

Transition:

- The efficiency is determined by the energy flow layer,
- Key enablers for improvement are in the information flow layer,
- The trajectory to future energy systems will be economy and policy driven (e.g., energy levels for sensors vs. storage).
- “The energy crisis appears to me to be more a crisis of momentum than of energy – a crisis of enterprise, solidarity, common spirit, determination and cooperation for the common good.” - Ulam

ACKNOWLEDGMENTS

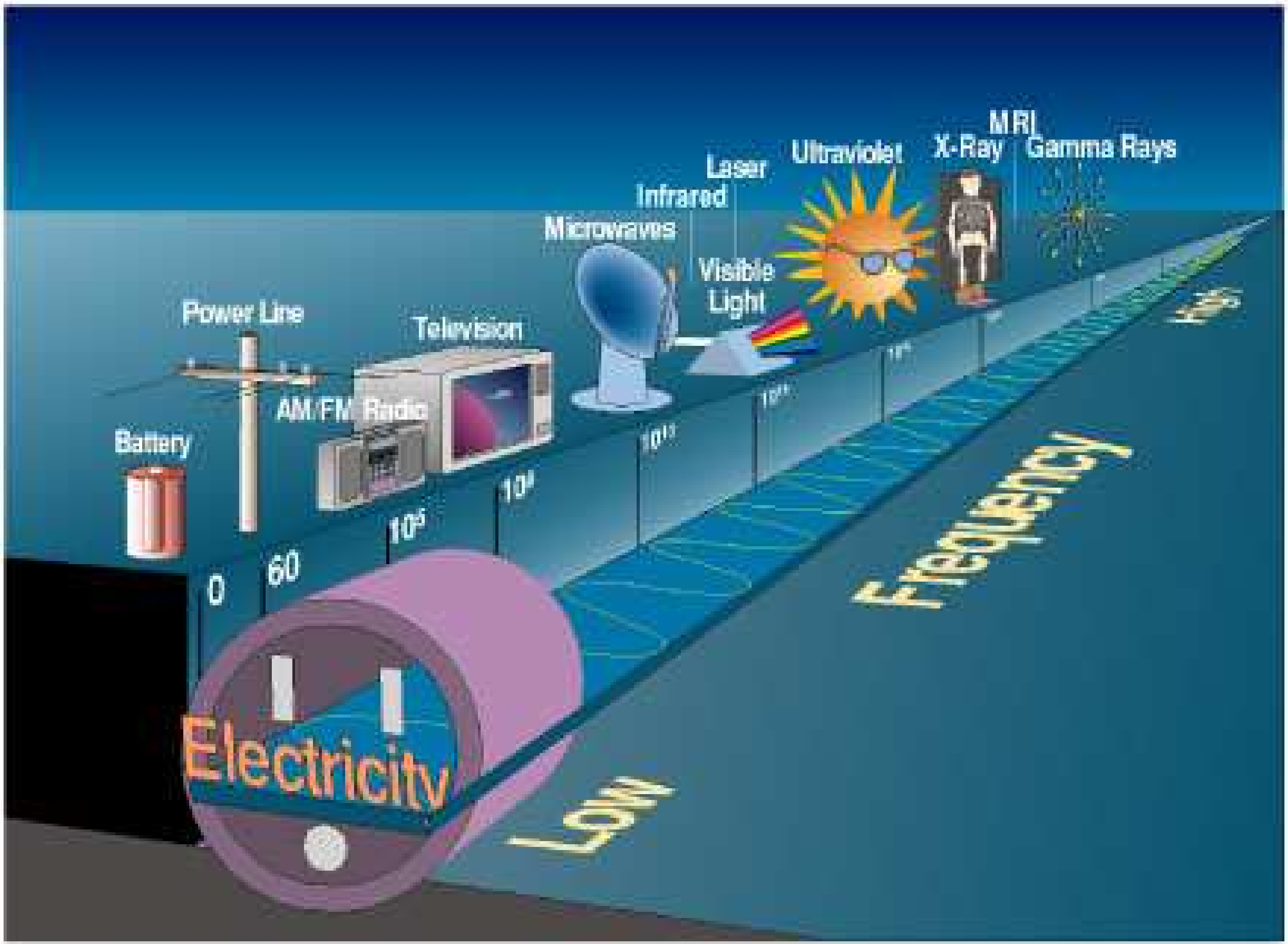
My heartfelt thanks to many colleagues and former students consulted about energy systems: M. Amin, G. Andersson, T. Aydin, M. Begovic, D. Boroyevich, C. DeMarco, I. Dobson, G. Escobar, J. Hauer, D. Hill, M. Ilic, C. Jacobson, I. Kamwa, J. Kolar, P. Kokotovic, B. Krogh, J. Lang, H. Lev-Ari, P.-A. Lof, N. Martins, P. Mattavelli, M. Morari, M.A. Pai, M. Perisic, R. Ortega, N. Rau, J. Sanchez-Gasca, A. Saric, P. Sauer, S. Sanders, A. Sangiovanni-Vincentelli, D. Siljak, C. Taylor, G. Verghese, F. Wu.

Contact info:

astankov@ece.neu.edu
www.ece.neu.edu/faculty/stankovic

Future...

A new positioning of energy processing within EE (C. Gellings):



NAE Grand Challenges

14 grand challenges for engineering in the 21-st century (Feb. 2008):

- 1. Environmentally friendly power.
- 2. Nuclear fusion.
- 3. Carbon dioxide sequestration.
- 6. Sustaining the aging infrastructure.

NAE Grand Challenges

14 grand challenges for engineering in the 21-st century (Feb. 2008):

- 1. Environmentally friendly power.
- 2. Nuclear fusion.
- 3. Carbon dioxide sequestration.
- 6. Sustaining the aging infrastructure.

A recurring theme: “The vast networks of electrification are the greatest engineering achievement of the 20-th century.”

Grand Challenges in Energy Engineering

IEEE Power Engineering Society, 2002:

- 1. Total control of power flow in networked systems.
- 2. Self-healing networks to achieve zero outages.
- 3. Zero-error state estimation.
- 10. Real time dynamic simulation of a 50 000 node, 2 000 generator, 500 000 MW system.