Engineering IT-Enabled Electricity Services: The Case of Low-Cost-Green Azores Islands

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Acknowledgments

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Contributors

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- ***Prof. Wolfgang Gatterbauer***, CMU, Tepper Business
- ***Dr. Audun Botterud,*** Argonne National Lab

Azores Island—Flores

Figure 1: Satellite image of Flores Island.

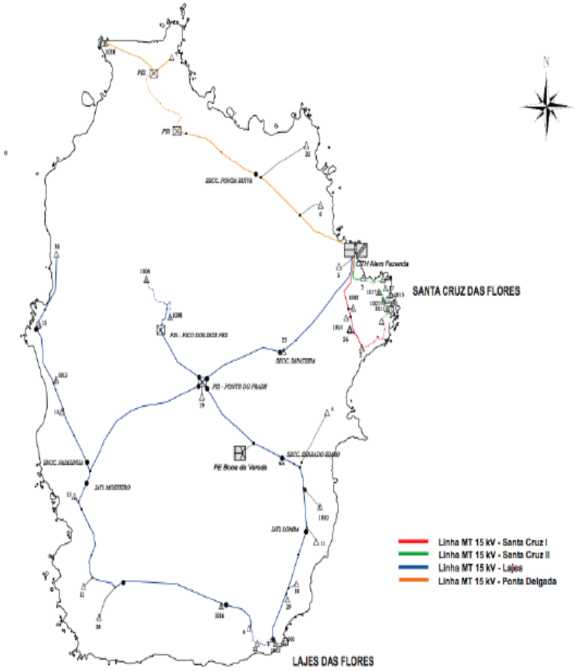


Figure 2: Electrical Network of Flores Island.

Outline

- *Part I*: Intro to IT-enabled sustainable electricity services.
- ***Part II:*** Electrical characteristics of the Azores Islands studied. (Flores and Sao Miguel); characteristics of resources and demand.
- *Part III*: Decision-making tools for balancing forecast demand and generation; wind power and demand power prediction methods.
- ***Part IV:*** Methods for managing network congestion; delivery loss minimization.
- ***Part V:*** Automated Control for Balancing Supply and Demand in Response to Hard-to-Predict Deviations from Forecast
- ***Part VI:*** New methods for ensuring reliable service during equipment failures (on-line scheduling, transient stabilization methods using power electronics).
- ***Part VII:*** Methods for long-term decision making (investment in the ``right" technology).

Part I: Introduction to IT-Enabled Electricity Services

- The challenge of designing and operating low-cost green electric energy systems.
- Modeling and problem posing– based on the basic ECE disciplines!
- Dynamical systems view of today’s and future electric energy systems.
- The key role of off-line and on-line computing. Too complex to manage relevant interactions using models and software currently used for planning and operations.
- One size IT solution does NOT fit all; but the same interactions variables-based framework can be used—Dynamic Monitoring and Decision Systems (DYMONDS)[5]

The challenge of designing and operating low-cost green electric energy systems

- Today’s sources of energy rely on expensive and polluting fuels
- Making the future (electric) energy system ``green”:  Use more ``sustainable” resources.
- This trend could lead to high electricity bills and/or hard to provide Quality of Service (QoS)
- Need to take a step back and re-think how today’s electric energy systems are operated, sensed and controlled. Production, consumption and delivery must be improved.
- What are obvious enhancements given technological progress (hardware and software)?

Modeling and problem posing– based on the basic ECE disciplines!

- An important ECE challenge: How to pose the problem, and how to design sensing, communications, automated control and decision-making computer algorithms using well-understood concepts from basic ECE disciplines?
- The boundaries between electric energy processing and other types of energy processing (mechanical to electrical in generators; chemical/wind/hydro, diesel into mechanical and/or electrical) becoming more gray than in the past as new energy resources are used
- One possible unifying path– *model the electric energy systems as dynamical systems and use systematic control design to pose the design objectives, and data-driven feedback and decision making for adaptation (18-618, Spring 2012)*

An illustrative future system

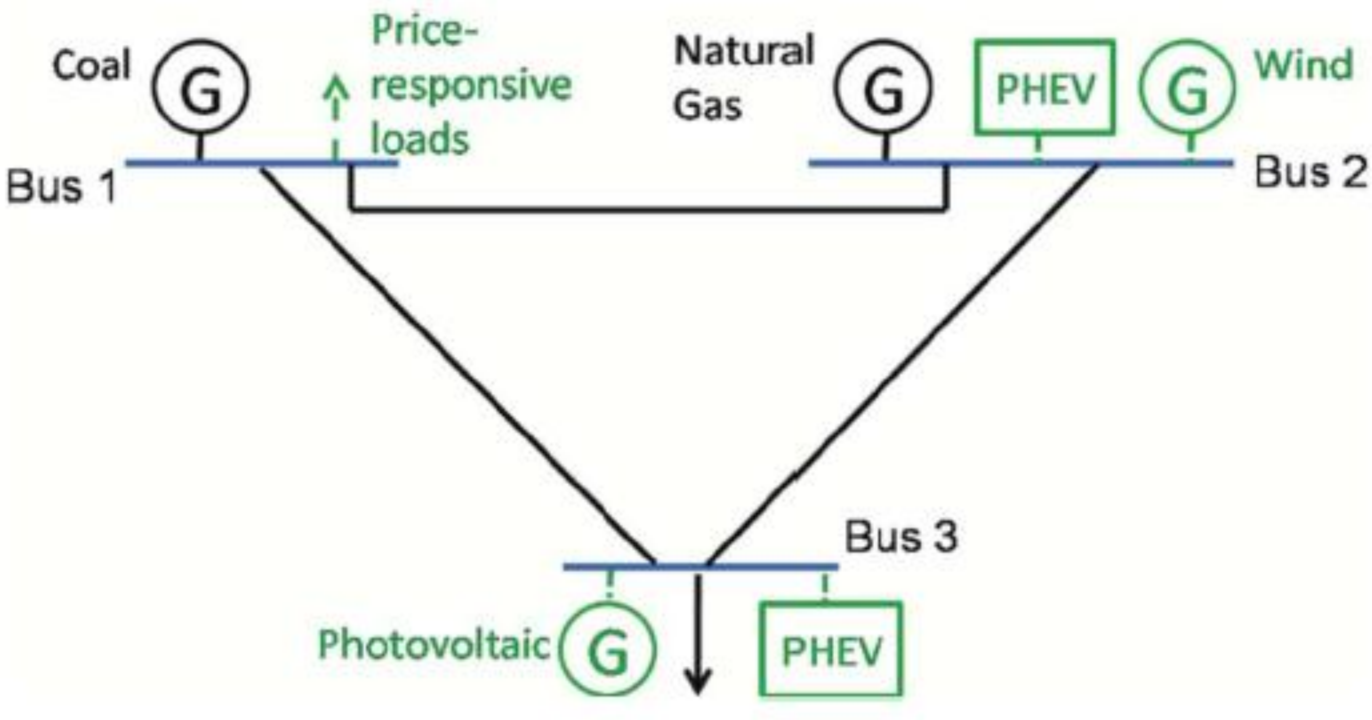
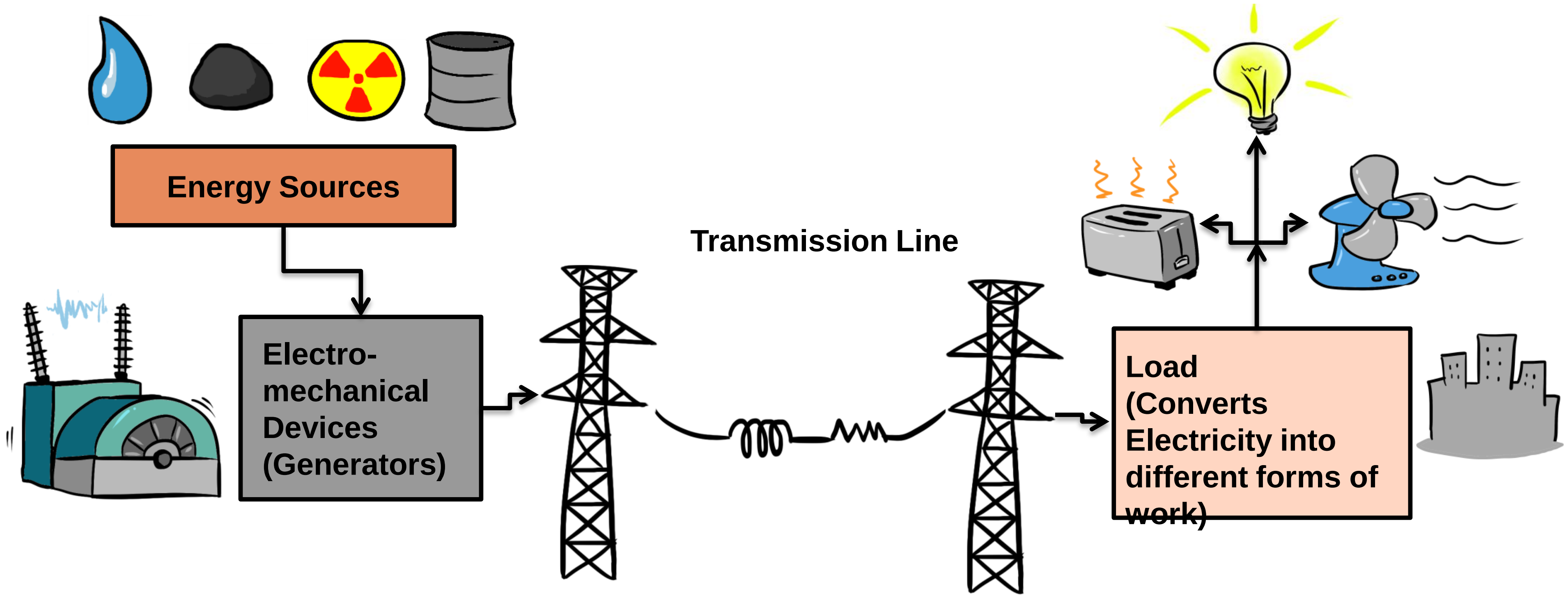


Fig. 5. Small example of the future electric energy system.

Conventional Power System



Energy Sources

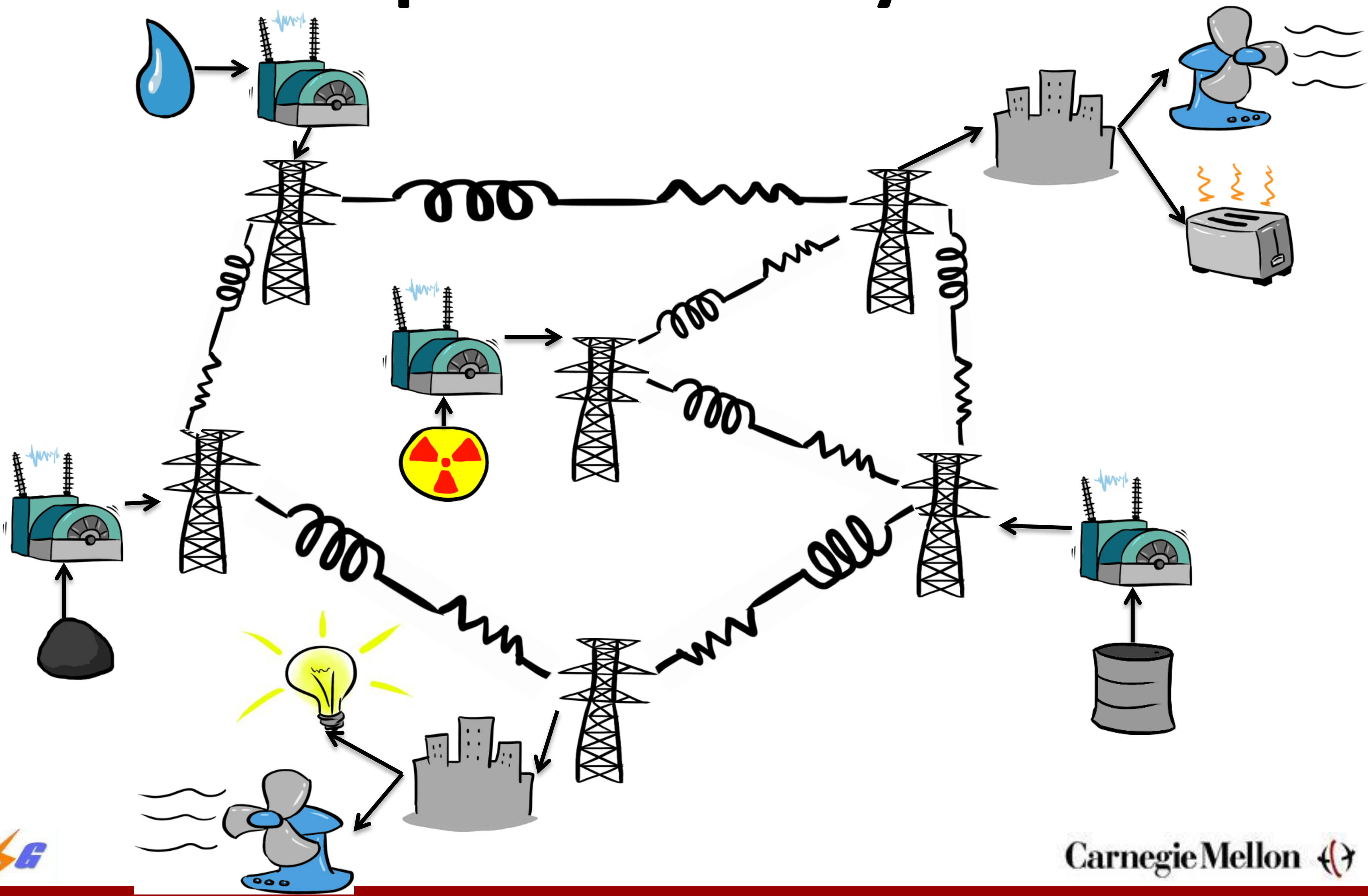
Electro-mechanical Devices (Generators)

Transmission Line

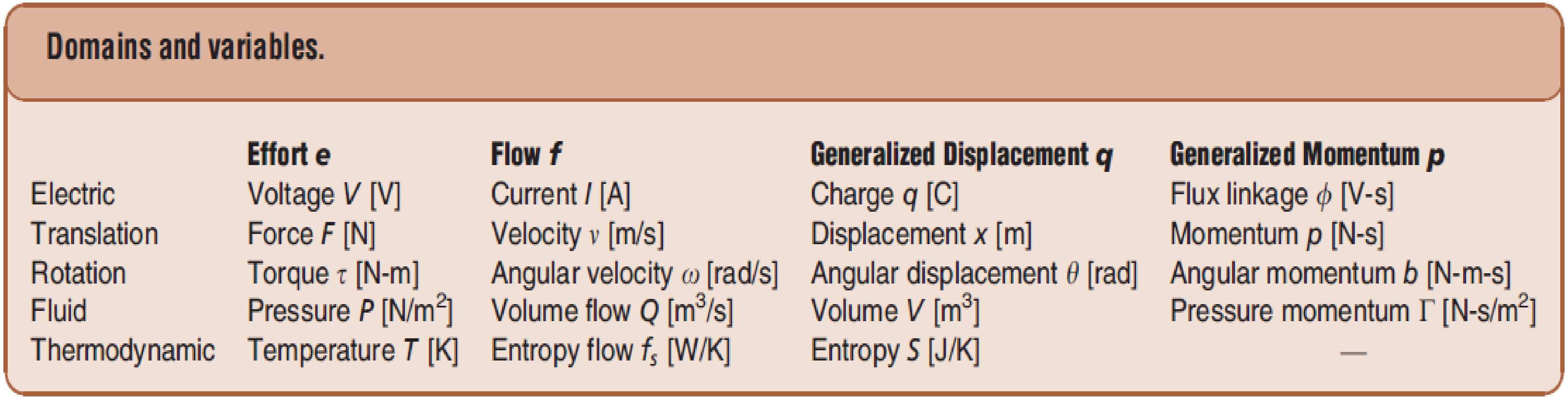
Load (Converts Electricity into different forms of work)

The next four slides drawn by Andrew Hsu.

More Complex Power System



Modeling Dynamics of Electric Energy Systems



Domains and variables.

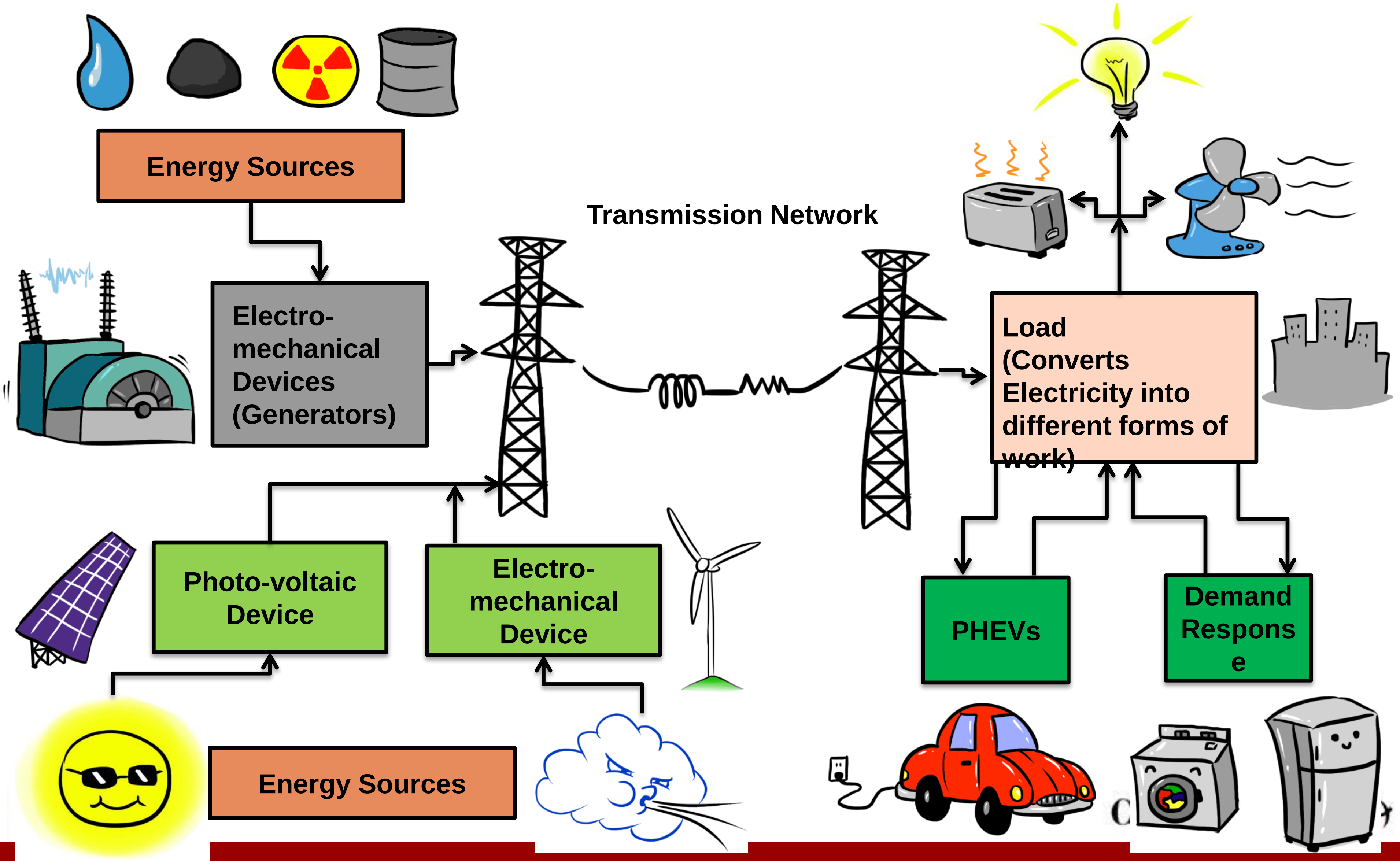
	Effort *e*	**Flow *f***	**Generalized Displacement *q***	**Generalized Momentum *p***
Electric	Voltage V [V]	Current I [A]	Charge q [C]	Flux linkage ϕ [V-s]
Translation	Force F [N]	Velocity v [m/s]	Displacement x [m]	Momentum p [N-s]
Rotation	Torque τ [N-m]	Angular velocity ω [rad/s]	Angular displacement θ [rad]	Angular momentum b [N-m-s]
Fluid	Pressure P [N/m^2]	Volume flow Q [m^3/s]	Volume V [m^3]	Pressure momentum Γ [N-s/m^2]
Thermodynamic	Temperature T [K]	Entropy flow f_s [W/K]	Entropy S [J/K]	—

$$\underline{x} = \Big[\underbrace{I_L, V_C,}_{\text{Electrical States}} \quad \underbrace{v_{mass}, F_{spring},}_{\text{Mechanical States}} \quad \underbrace{f_S, T}_{\text{Thermodynamic States}}\Big]$$

$$\frac{d\underline{x}}{dt} = \underline{f}\left(\underline{x}, \underline{u}, \underline{p}\right), \qquad \underline{x}(0) = \underline{x}_0$$

Table from: D. Jeltsema and J.M.A. Scherpen. Multidomain modeling of nonlinear networks and systems. Control Systems Magazine, Aug. 2009

Future Power Systems



Energy Sources

Electro-mechanical Devices (Generators)

Transmission Network

Load (Converts Electricity into different forms of work)

Photo-voltaic Device

Electro-mechanical Device

PHEVs

Demand Response

Energy Sources

Potential Use of Real-Time Measurements for Data-Driven Control and Decision-Making (new)

- GPS synchronized measurements (synchrophasors ; power measurements at the customer side.
- The key role of off-line and on-line computing. Too complex to manage relevant interactions using models and software currently used for planning and operations.
- Our proposed design: Dynamic Monitoring and Decision Systems (DYMONDS)

“Smart Grid” ←→ electric power grid and IT for sustainable energy SES [5,6]

Energy SES

- Resource system (RS)
- Generation (RUs)
- Electric Energy Users (Us)

Man-made Grid

- Physical network connecting energy generation and consumers
- Needed to implement interactions

Man-made ICT

- Sensors
- Communications
- Operations
- Decisions and control
- Protection

Proof-of-Concept for Low-Cost Green Flores and Sao Miguel

- Collected data and used to derive dynamic models (linear and non-linear; with wind power dynamics, flywheels and power-electronics-control included)

  -equilibrium solutions (power flow); predictive models for wind power and demand power

  -demonstrate the use of DYMONDS decision-making algorithms (distributed, MPC-based) for enabling efficient integration of wind power; efficient integration of Adaptive Load Management (ALM); efficient integration of electric vehicles (EVs)

  - demonstrate new methods for automated load following, E-AGC and E-AVC for balancing hard-to-predict small wind power fluctuations

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