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A Grid as Smart as the Internet

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Outline

- Why would we like the electric grid to be as smart as the Internet?
- What makes the Internet smart?
- Why previous attempts to make electric grids Internet-like unsuccessful?
- How to make the grid as smart as the Internet?

Electric Grids are Changing

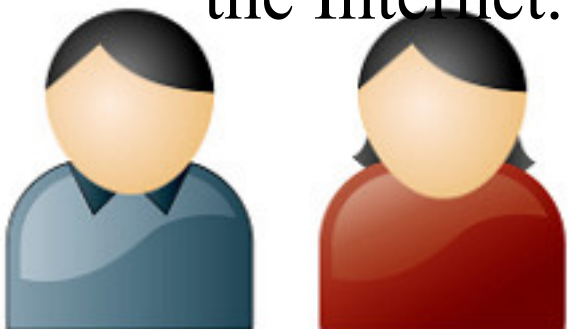
- Renewable generation
- Demand response
- Energy storage
- Electric vehicles

EV/PHEV

Changing Grids

- Sources of electricity are changing from *large* fossil fuel generators to *dispersed* renewable energy resources, much like the (information) sources of the Internet.

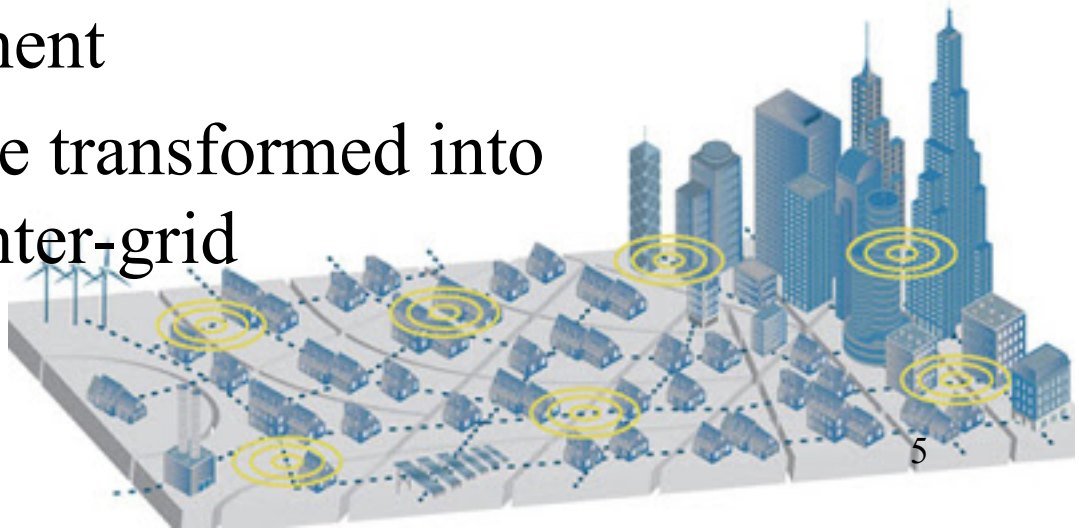
- Users of electric energy change from purely *consumers* to *producers-consumers-managers* of electricity, much like the (information) users of the Internet.



Energy Internet

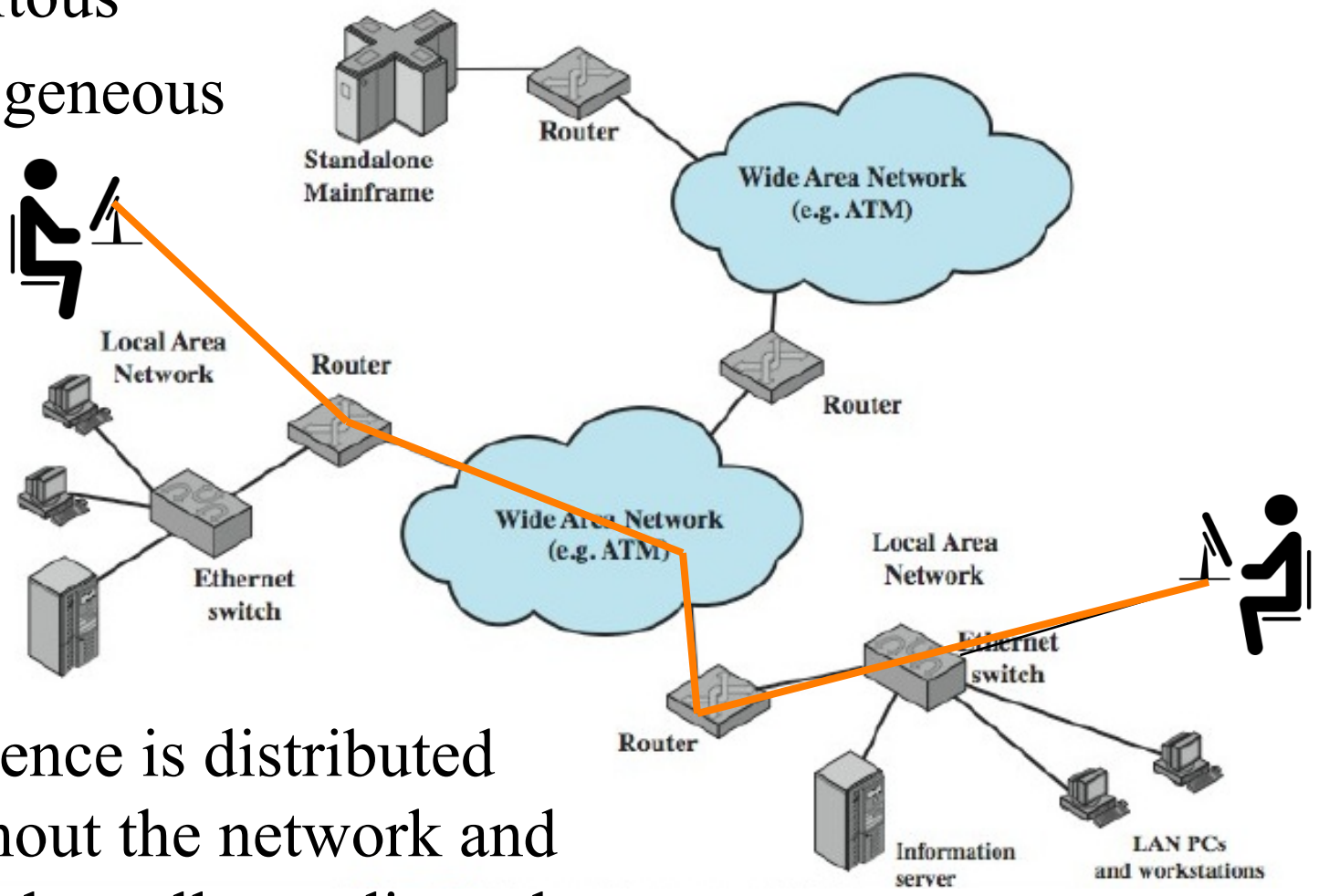
J. Rifkin. *The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World*. New York: Palgrave Macmillan, 2011

- Energy, mostly renewables, will be produced in thousands and millions homes, offices, and factories and *share* with each other
  - » through an "Energy Internet"
- Energy will also be stored in homes, buildings, EV, etc.
- Dispersed management
- Electric grid must be transformed into an energy sharing inter-grid



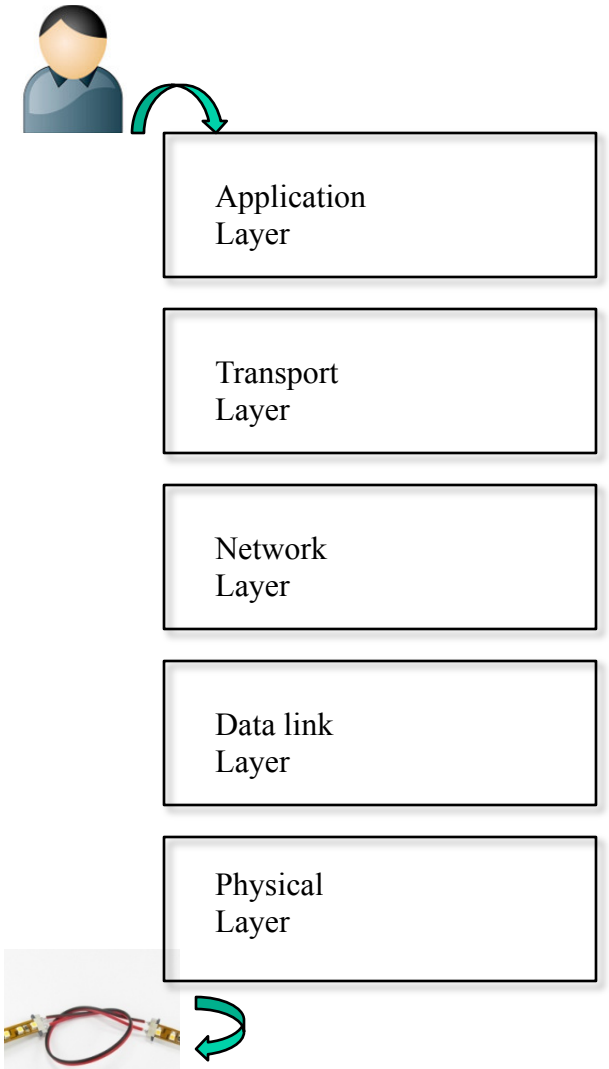
The Success of the Internet

- Ubiquitous
- Heterogeneous



- Intelligence is distributed throughout the network and extremely well coordinated.

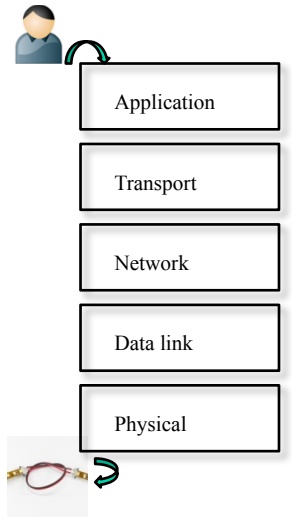
How is it Done at a Node?



- Layering
  - » User interfaces with the application layer
  - » Physical layer interfaces with communication medium
  - » Other layers in between
- Encapsulation
  - » Upper layer uses services of the lower layer

What Makes the Internet Smart?

- Sharing of responsibility
  - » Each node performs the min, and the *basic* function of sending data from one node to the next.
  - » A group of nodes, working together, share the responsibility of completing the task.
- Division of intelligence
  - » Layering
  - » Encapsulation
- Standard protocols.



Making the Grid Internet-like

- Previous attempts focus on construction of energy routers.
- Back to basics.

Information

- Data is added onto the flows of electrons/photons
- The basic function of each node represents a router which is designed to send data from here to there.

Electric energy

- Power is carried directly by electrons
  - More power means moving more electrons
  - Flows of electrons follow physical laws (Kirchhoff)
- Nodes of a grid are physical connections of lines, switches, etc.

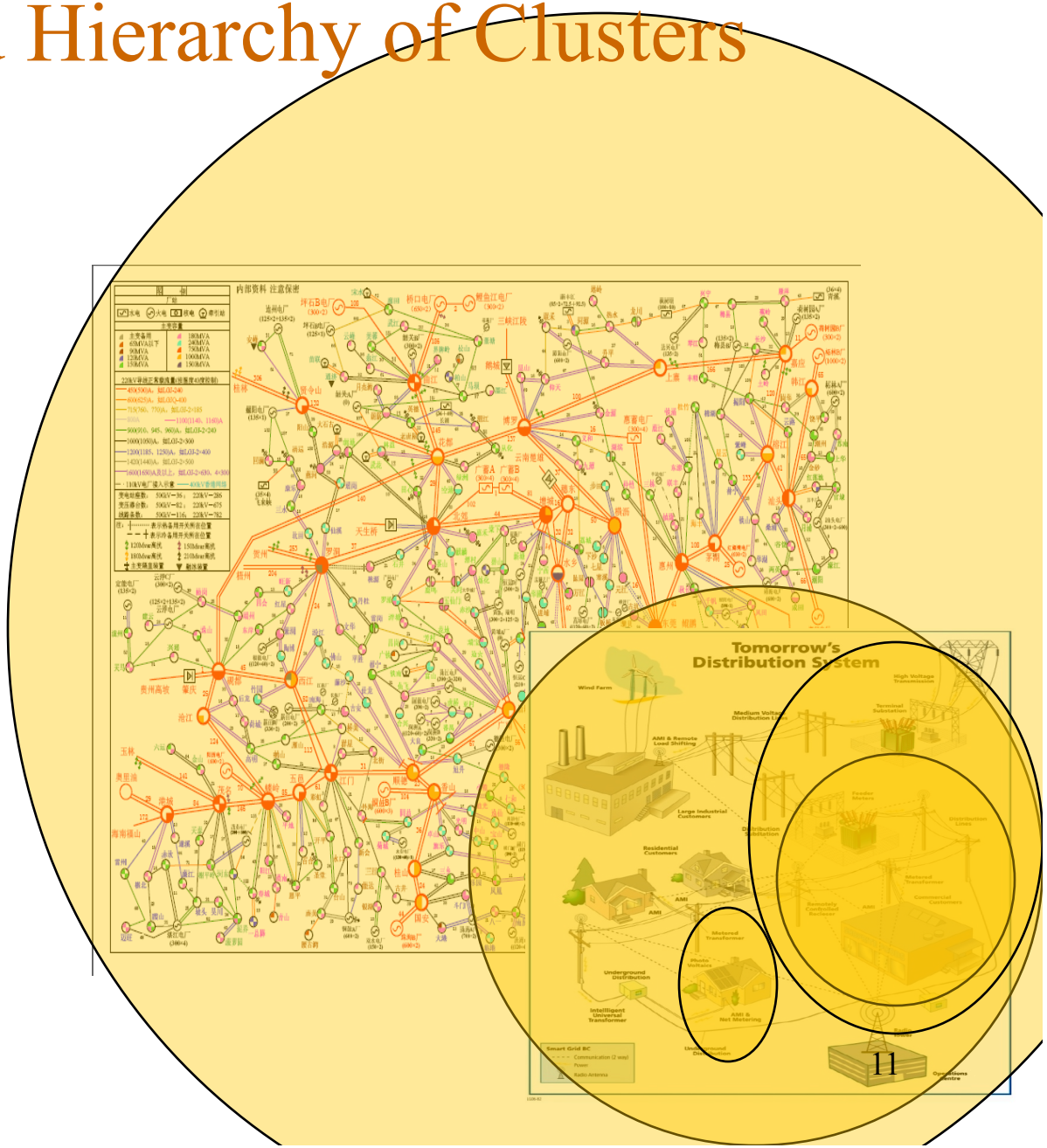
How to Make

A Grid as Smart as the Internet

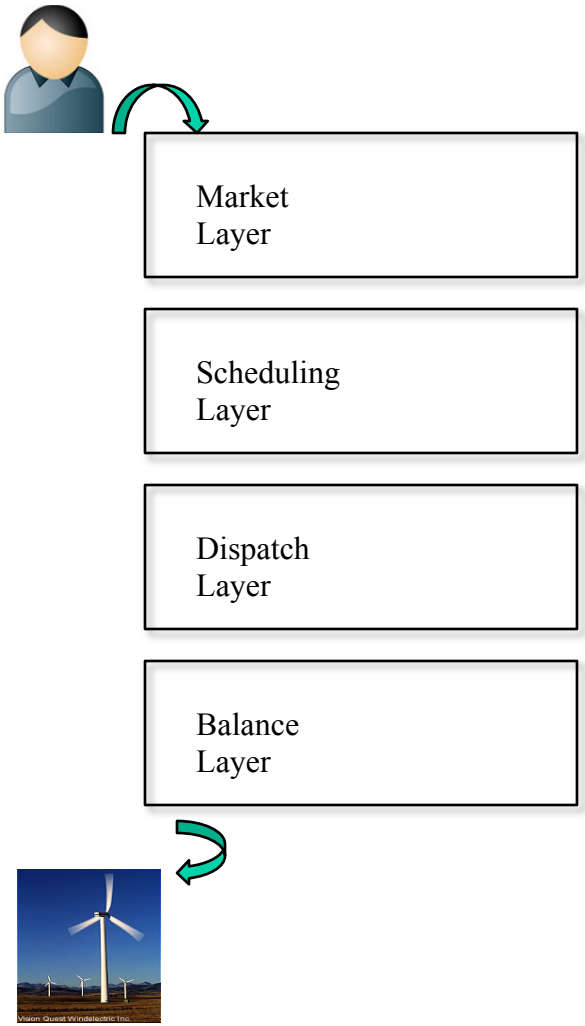
- Recognizing the fact that the key to grid operation is that the net power (including import/export) must be balanced within any area.
- We must expand the idea of an energy router from a node to an area.
- We call an area that has the intelligence to manage power balance a cluster and its intelligence an E-router.
- Transmission system with an EMS is a cluster.
- A smart home that can manage its power balance is also a cluster, so is a smart building with BEMS, a micro-grid, ….
- By empowering the periphery of the grid with the intelligence and responsibility to maintain its net power balance, we call it a smart Grid with Intelligent Periphery (GRIP).

Nested Hierarchy of Clusters

- Transmission
- Distribution Substation
- Distribution Feeder
- Microgird, Aggregator
- Smart homes, buildings, etc



Layered Architecture of GRIP

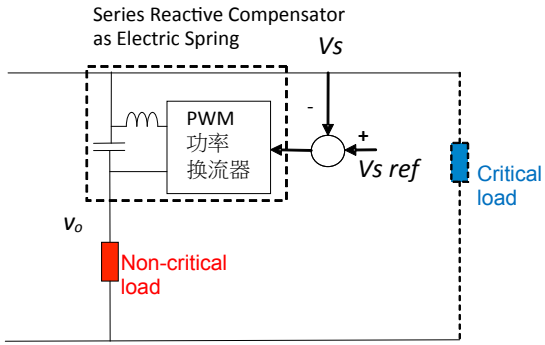


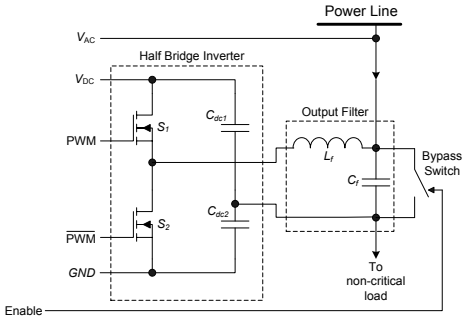
- Users of the grid (clusters) participate in the market for buying and selling electricity.
- Instantaneous net power (including import and export) must be balanced in all clusters of the physical grid.
- More steps must be taken to ensure that the grid has the *ability* to maintain power balance. In the EMS, that is done by Scheduling and Dispatch.
- Available resources are *dispatched* to maintain net power balance. When additional resources (e.g., unit commitment) are necessary, they must be *scheduled*.

Balance: Electric Spring

S.Y.R. Hui, C.K. Lee and F.F. Wu, "Power control circuit and method for stabilizing a Power Supply", PCT patent application 61/389,489, filed on 4 October 2010

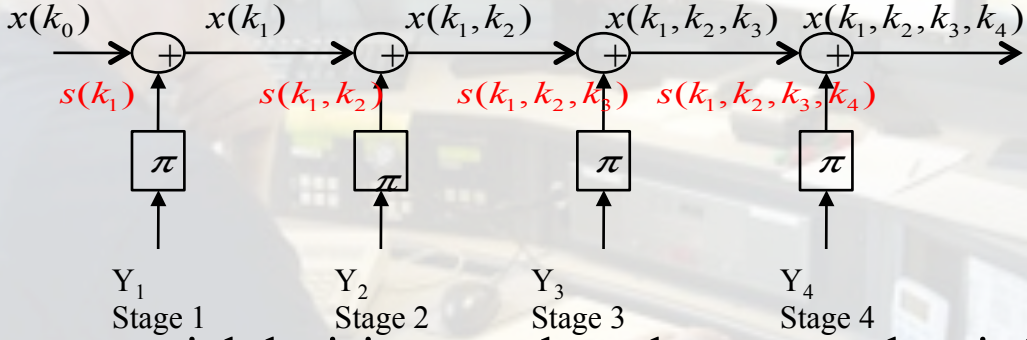
- Maintaining instantaneous power balance in the transmission grid is accomplished by the use of speed-governor control (for real power) and excitation control (for reactive power) located in the generators.
- For periphery clusters, we invented a device called Electric Spring to smooth out power imbalances.
- Electric spring is a power electronic device that adjusts power consumptions in non-critical loads to guarantee constant power to the critical loads





Dispatch: Risk-limiting Dispatch

- Dispatch available resources (generation/load) to maintain net power balance of the cluster seconds/minutes/hours ahead.
- We developed a comprehensive formulation of power dispatch problem, called Risk-limiting Dispatch, which is based on the framework of multi-stage stochastic optimization



$$S(t) = x(k_0) + s(k_1) + s(k_1,k_2) + s(k_1,k_2,k_3) + s(k_1,k_2,k_3,k_4)$$

- The sequential decisions are based on up-to-date info provided by the smart grid sensor networks.
- RLD guarantees "net supply-demand balance" at the time of operation within the risk level specified by the user.
- Solution methodology has been developed.
- Risk-limiting scheduling can similarly developed.

Conclusion

- We propose a grid with intelligent periphery (GRIP), that is as smart as the Internet,
  - The key is to require all users (clusters) bear *responsibility* of maintaining net power balance (scheduling, dispatch, balance).
  - Layering and encapsulation.
- A seamless transition from existing grids to smart GRIP is possible because:
  - E-routers for the core cluster (i.e., EMS of the transmission system) are in existence. E-routers for the periphery clusters (distribution systems, users) are to be developed.

Conclusion (cont.)

- Users of the grid have the options of either to form a cluster or remain passive (not participating in the market, not managing its power balance). Passive users in a cluster are treated as loads – no change as today.
- Clusters are independent. The sophistication of E-routers for different level of clusters is obviously different, but even for the same level it may be different due to individual preference for degree of optimization.

- GRIP facilitates maximum energy sharing and utilization (renewables, storage, demand response, EV, …) with management closer to sources/consumptions where most up-to-date info is available.
- The architecture of electricity dictates that of others in the multi-energy "energy internet".

Thank You!

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