MAKING ELECTRIC POWER SYSTEMS BOTH SECURE AND EFFICIENT:
PROTOCOLS FOR DYNAMIC ENERGY CONTROL (PDEC)

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Major control engineering problem:

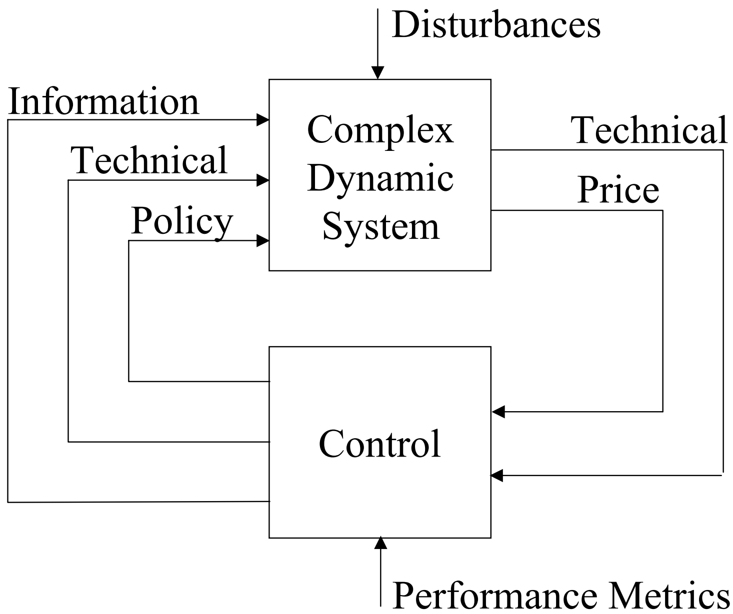
- Meeting robustness (ability to minimize the effects of low-probability, high impact disturbances)

  -Needs to be done in the least conservative, i.e. flexible, way possible (no modeling nor decision tools for this)

  -Additional major challenge: Models that relate technical, economic and policy states

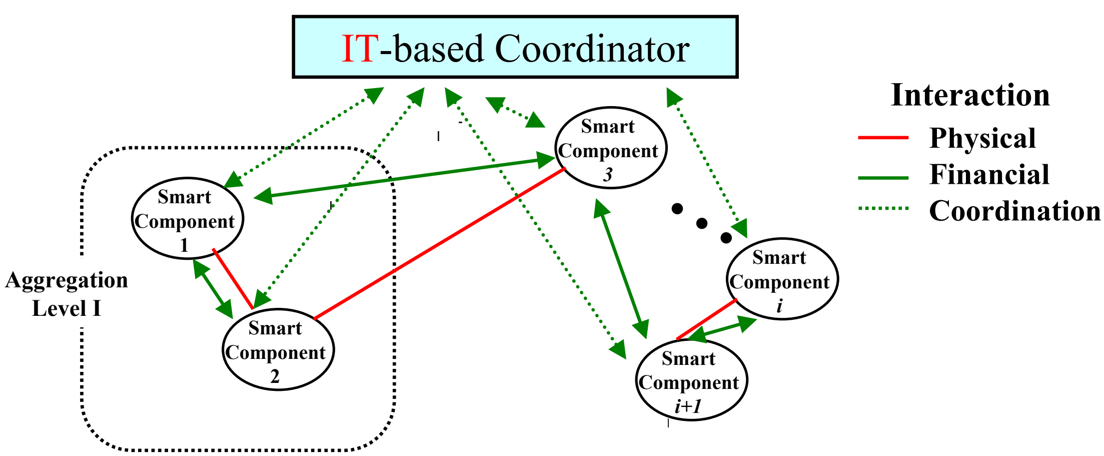
  -Solutions organizational structure-dependent (different architectures for which models are needed)

Basic Organizational Structure



- Temporal and spatial complexity
- Evolving structures
- Reliability and flexibility metrics

Basic Problem of Interest



- Two Question
  - Optimizing Performance at Component Level subject to System Imposed Constraints
  - Satisfying System-wide Performance Criteria

Proposed solution:

- Develop first complex dynamic models which capture major interdependencies within and among various layers of the system
- Pursue temporal and spatial aggregation of these models (a mind-twisting adaptive model reduction of a very heterogeneous hybrid model)
- Design controllers which are effectively IT-based decision making tools for providing flexible dynamic robustness of a given organizational structure
- Implementation leading to flexible information-flow based protocols within and among various industry layers.

The $M Question: Is it possible to be secure and efficient at the same time??

- Secure performance requires the worst case design, much reserve (inefficiency, aggregate level thinking).
- Efficient performance requires dynamic response/adaptation to changing conditions so that the overall resources are used most efficiently (distributed decision making, much flexibility at ALL level of the grid).
- THE ONLY WAY TO MAKE THE SAME SYSTEM ROBUST (LOCALIZED RESPONSE TO A DISTURBANCE), AND EFFICIENT UNDER NORMAL CONDITIONS IS TO HAVE HIGHLY RESPONSIVE (``SMART'') GRID AND RESPONSIVE END USERS. THIS IS QUALITATIVELY DIFFERENT MODE FROM THE CURRENT OPERATING PRACTICES. DISTRIBUTION OF SMALL SCALE ACTORS REPLACING VERY LARGE FEW ACTORS HELPS.

Evolving Organizational Structures (Paradigms) [1,2,3]

- 1. Existing paradigm: Centralized, large scale
- 2. Transitional paradigm: Aggregation across non-traditional boundaries
- Likely end state paradigm: Very decentralized, large number of small scale actors

The Electric Power Industry Case

- THE MOST EXCITING IS THE FOLLOWING:

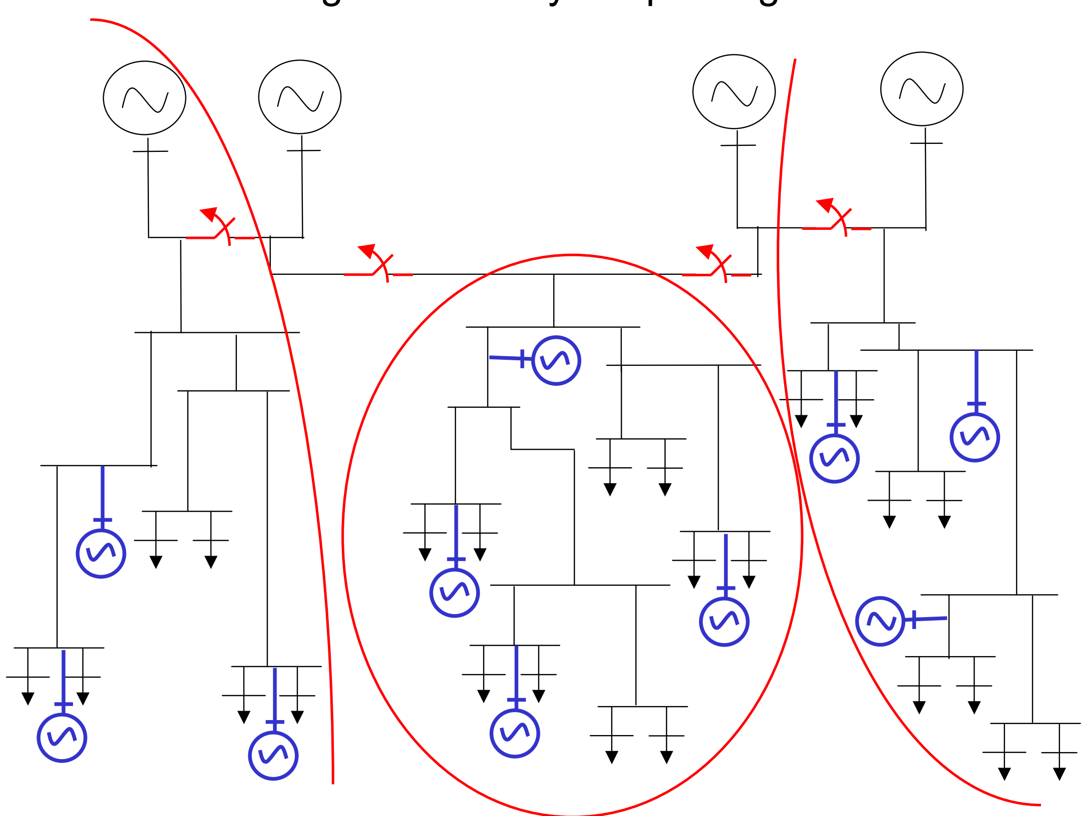
IT IS POSSIBLE TO DEVELOP TOOLS FOR FLEXIBLE AND ROBUST PERFORMANCE OF A COMPLEX SYSTEM, SUCH AS THE ELECTRIC POWER INDUSTRY; THE CONCEPTUAL CHALLENGES TO CONTROL ENGINEERING VARY VASTLY DEPENDING ON WHICH STRUCTURE IS IN PLACE

Critical changes

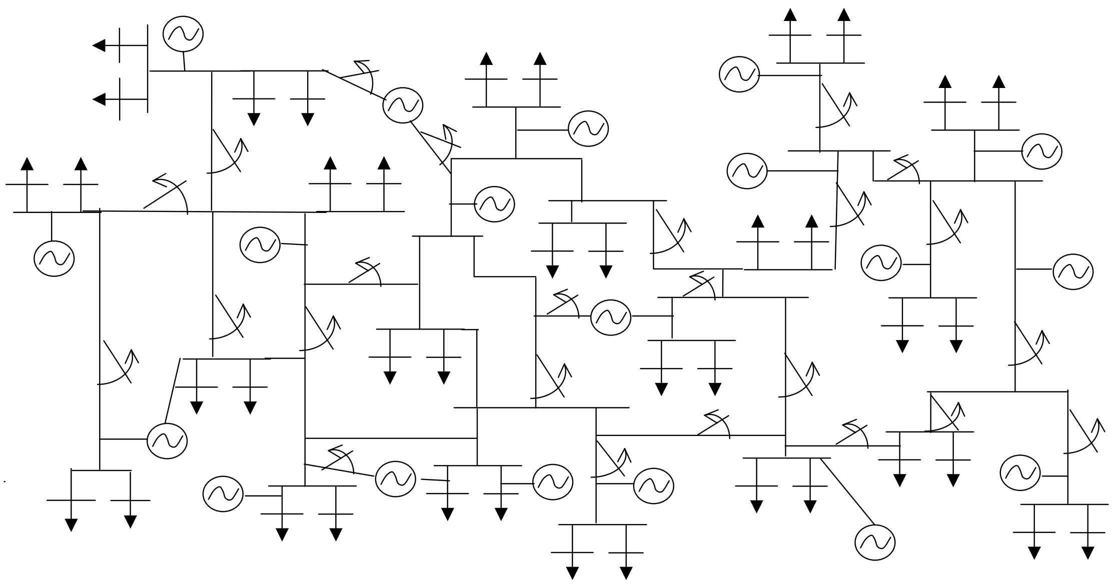
- Cost-effective DG technologies
- Cost-effective customer choice technologies
- Cost-effective low voltage wire control
- Distributed IT infrastructure

- Industry restructuring

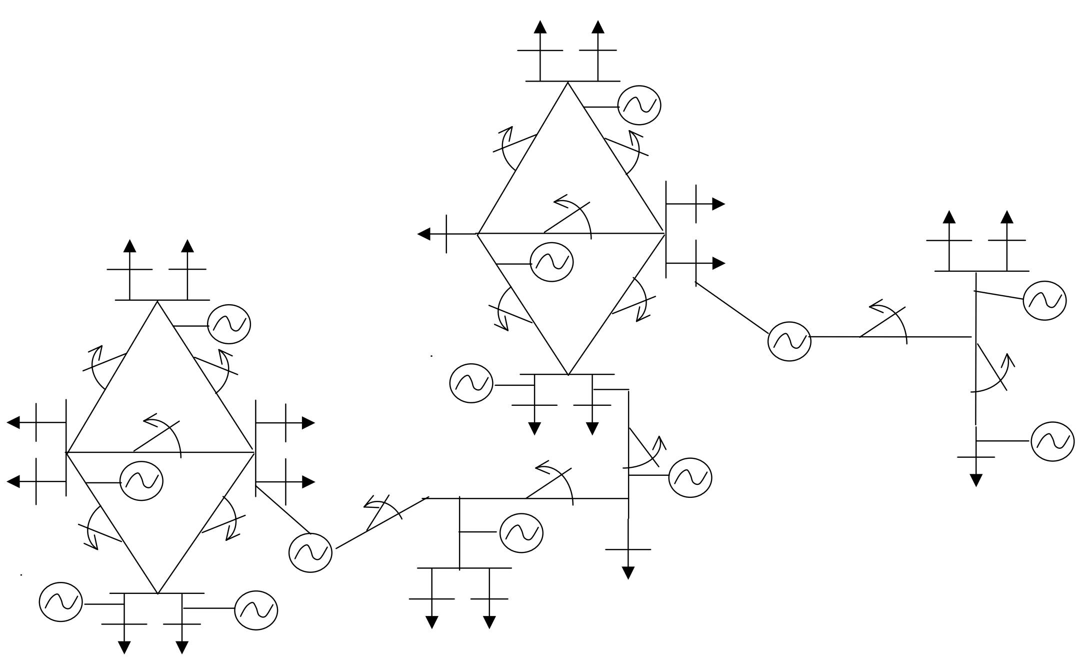
Integrated and hybrid paradigm



Decentralized Paradigm



Re-aggregation



Change from 1. --3.

- Slow
- Inconsistent (dependent on regulatory uncertainties, pricing mechanisms and technology transfer process)
- Temporary tax fixes to ``facilitate'' the process

Major questions:

- Concerning DG
- Concerning distributed power systems (grids) of the future
- Concerning customer choice
- Their interplay and interdependencies

The likely end state paradigm:

- Conceived by late Prof. Schweppe (1978--homeostatic control) ;
- Becoming commercially feasible (cost-effective supporting technologies; distributed IT infrastructure in place; low additional cost for implementing customer choice) --Economist, August 2000 article

Major R& D challenges:

- Understand the value of various technologies under specific paradigms
- Develop operating, maintenance and planning decision tools (control engineering) for all three paradigms and their transitions
- Value IT for all three paradigms

Our vision

- 1. REGULATED PARADIGM
- ---Technological R&D challenges (methods for flexible IT-based coordination under competitive supply; 20-30 years of research could be used for more active technology transfer; concepts difficult, because of large-scale nature; examples)
- ---Necessary PBR instead of RoR

Our vision

- 2. TRANSITIONAL PARADIGM
- --Technological (much decentralized decision making, yet need for new types of aggregation--syndicates, and minimal level of their coordination; very difficult, entirely new concepts, not studied in the past)
- -Regulatory (3R for syndicate forming, pricing, PBR for networks ; very difficult)

Challenges under paradigm 2.

- HYBRID SYSTEMS (half regulated, half competitive; half large scale generation, half DG; some customers price responsive, some not; physical system evolving continuously, signals discrete; mix of technological and regulatory forces)
- Conceptual breakthrough: SMART SWITCHES to respond to technical, pricing and regulatory signals (information) at various levels of aggregation (syndicates)

Challenges under paradigm 3.

- Ultimately the easiest
- Many very small distributed decision makers (users, DG, wire switches); very little coordination, but learning through distributed IT infrastructure; literally no coordination (homeostatic control, CS swarm intelligence; SIMPLE SWITCHES)
- Regulatory (simple value-based competitive incentives; no regulation)

Our ongoing research

- Re-examination of switches (technical, regulatory) for paradigms 1.-3.
- Preliminary results: Under paradigm 1. The existing switching logic not sufficient to guarantee performance; very complex to improve; under paradigm 2., even harder; paradigm 3.--proof of new concepts stage, quite promising, simple

Going from paradigm 1 to 2./3

- Customers beginning to respond to the market forces (considering alternatives--user syndicates, customer choice, DG, etc)
- DGs forming portfolios (syndicates)
- Distribution companies (wire owners) designing for synergies, MINIGRIDS
- Manufactures providing equipment /design

Optimality in paradigms 1.--3.

- Paradigm1 : Despite the popular belief, not optimal long-term under uncertainties (much more remains to be done if dynamic social welfare is to be optimized in a coordination way)
- Paradigm 2: Performance very sensitive to the smartness of switches and aggregation
- Paradigm 3: Feasible, near optimal under uncertainties; switching to implement differential reliability

Transition from current to more reliable and flexible organizational structures as affected by various system feedback:

- Technological advances (from complex coordinating switching to many decentralized switches)
- Regulatory progress (from RoR through PBR to no regulation type signals)
- Economic (pricing) processes (signals for dynamic investments)
- Political forces (obstacle/catalyst-switches)
- Their interplay: Hybrid system

The critical concept

- Flexible reliability-related risk management
- Closely related to the questions of back-up power at times of price spikes/interruptions
- From extensive interconnections for reliability to distributed reliability provision; and, flexible (smart) delivery system.

Hard engineering issues

- Current engineering practices are not well suited for flexible (efficient) use of capacity

  -worst case design, hard to relate to efficiency

  -reliability challenge concerns very low probability, high impact events; hard to manage; fat tail distributions

  -general spatial and temporal complexity

Hard financial questions

- This industry does not lend itself to well established financial approaches

  -no arbitrage assumption problematic

  -insufficient to apply macro-economics for wholesale markets without carefully aggregating effects of micro-actions (retail)

  -no tools for managing fat tail distribution events

The resulting situation:

- No good engineering nor financial tools to manage complexity presented to us
- An incremental approach without any understanding of the outcomes
- THE MAIN CHALLENGE: NO INCENTIVES TO SUPPORT RELIABILITY/SECURITY NOR FLEXIBILITY; NO INVESTMENTS IN NEW CAPACITY OF RIGHT TECHNOLOGY FOR SECURITY AND EFFICIENCY.

Possible way forward [3,5]

- Revisit current engineering practices for reliable operation and planning
- Move toward industry structures which support complete products provision and valuation (beyond energy; reliability; transmission) –REAL OPPORTUNITY
- The demand for these must come from the customers; PROTOCOLS FOR CHOICE

Toward the Protocols for Dynamic Energy Control (PDEC)

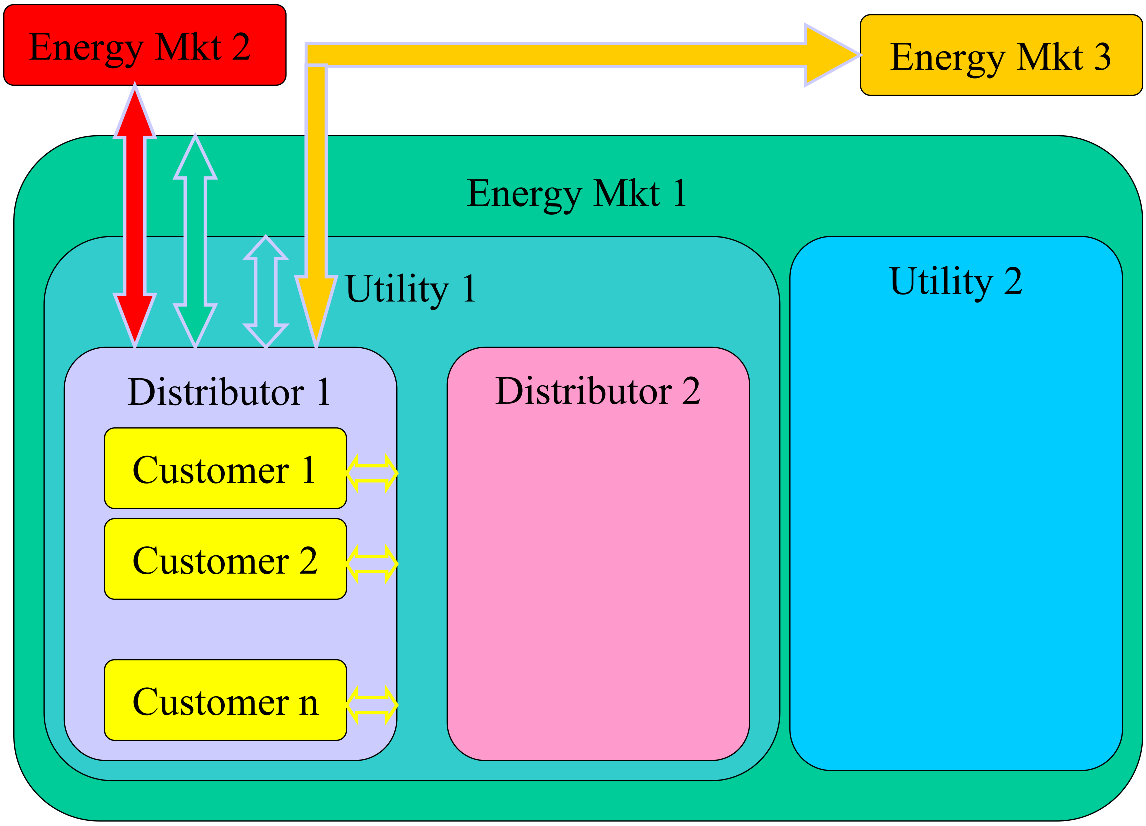
- Over the past several years much developed at the conceptual level [4];
- Further research planned for fundamentals of PDEC for the changing industry [3]
- Need to develop PDEC concepts and work with industry/software developers.
- Possible LLNL/CMU collaboration.
- Can be extended to other infrastructures.

Toward Complete Products

- Energy Bids/Specs under normal conditions (by suppliers and consumers)
- Quality of Service Bids/Specs (frequency and voltage) under normal conditions
- Bids for Reliability/Security (willingness to be interrupted and willingness to provide reserve)—this is the way to distribute reliability related risks among many industry participants, and overcome the problem of low probability high impact events

Interaction at several industry layers and over various times

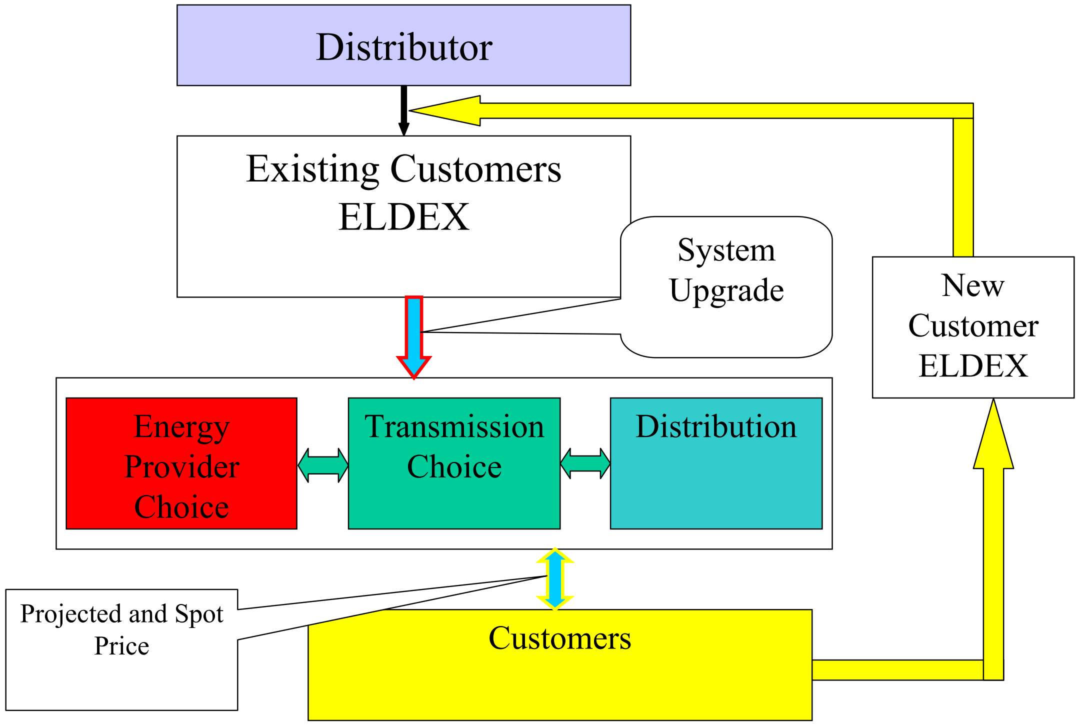
- The follow-up schematics represent
  - Basic interactions (protocols) across industry (replacement for vertically structured industry)
  - Basic Interactions Between a Distributor and the Others
  - Basic Interactions at the Energy Market Level
  - Basic Interactions Among Energy Markets



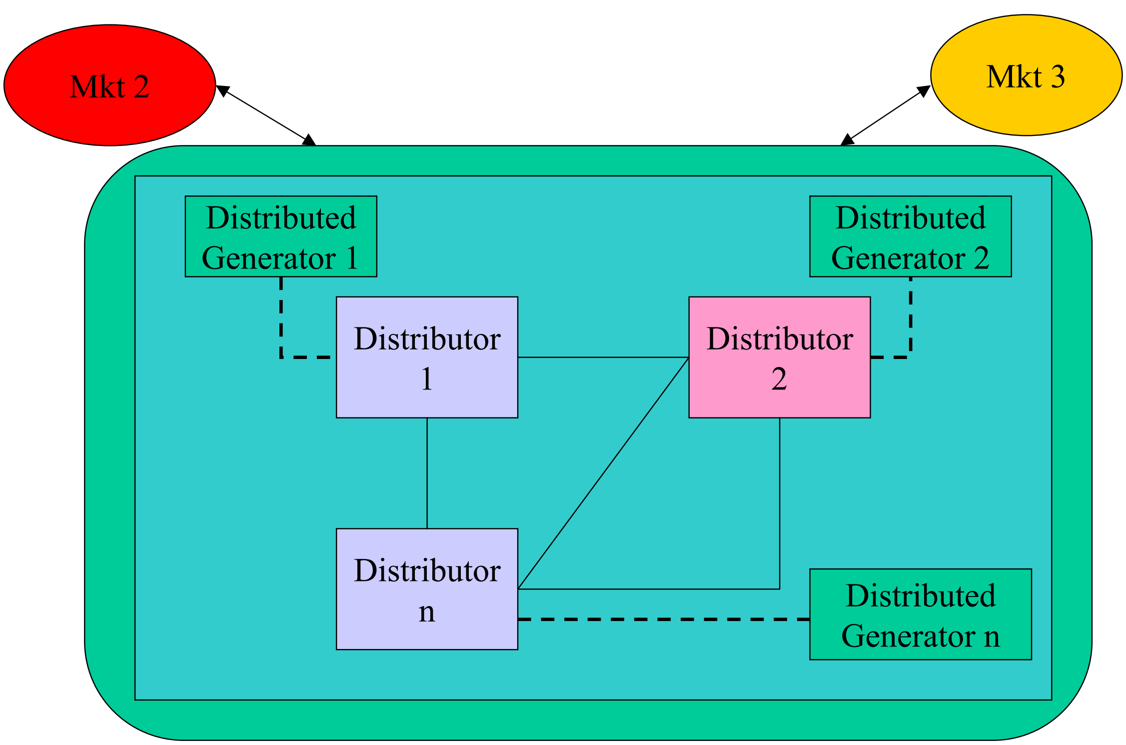
Role of industry protocols

- Communicate DYNAMICALLY demand and willingness to pay by the end users, to the distributors;
- Communicate services and conditions under which the distributor provides services to the group of customers;
- Provide ways for distributors to seek in the whole-sale the best services for its customers (delivery and generation)
- Provide a basis for sustainable value-based businesses for value-based reliability

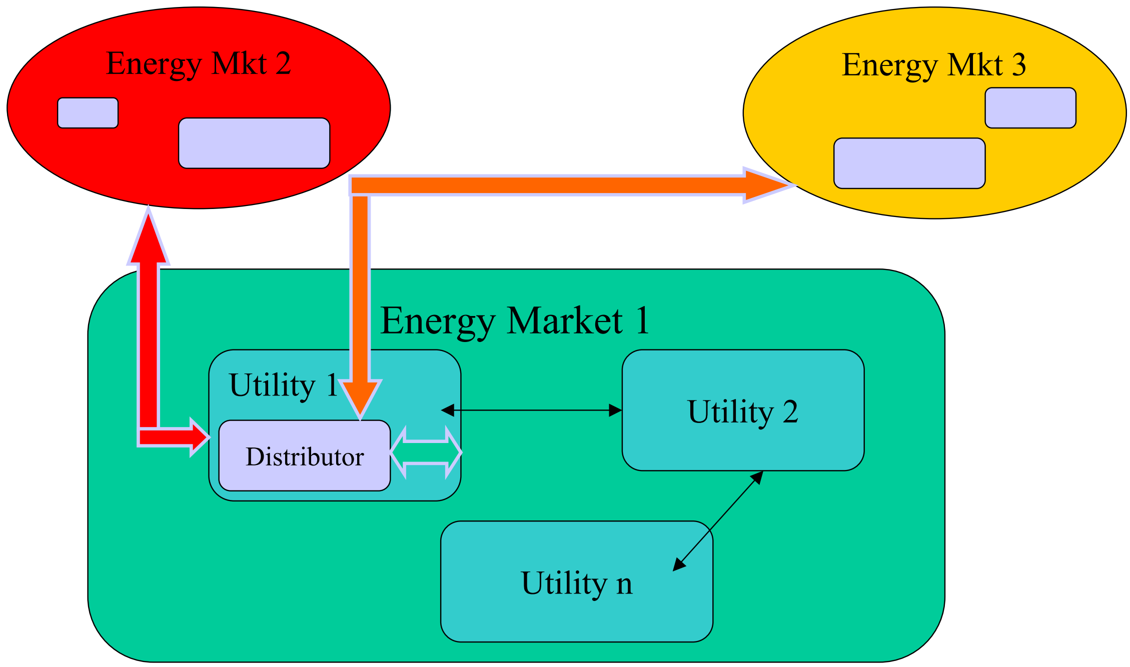
Dynamic Protocol --- Distributor Level



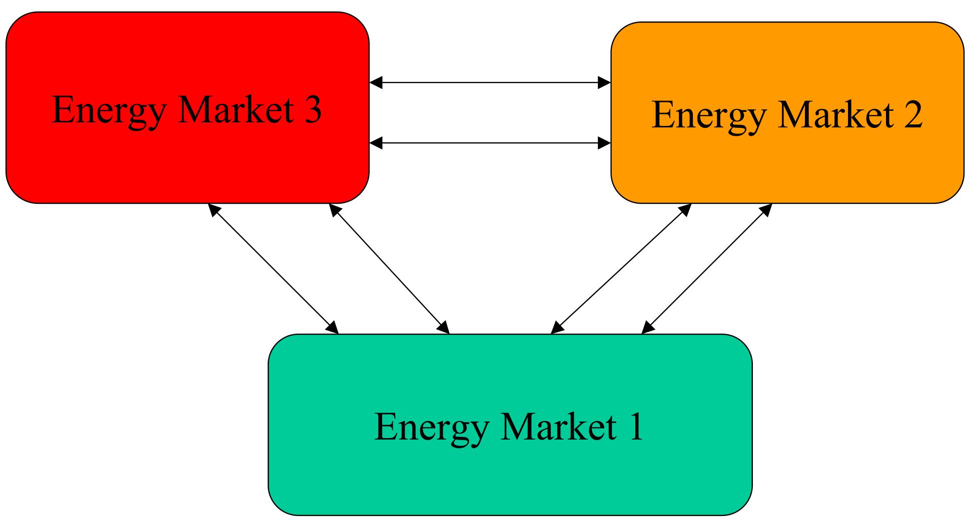
Dynamic Protocol --- Utility Level



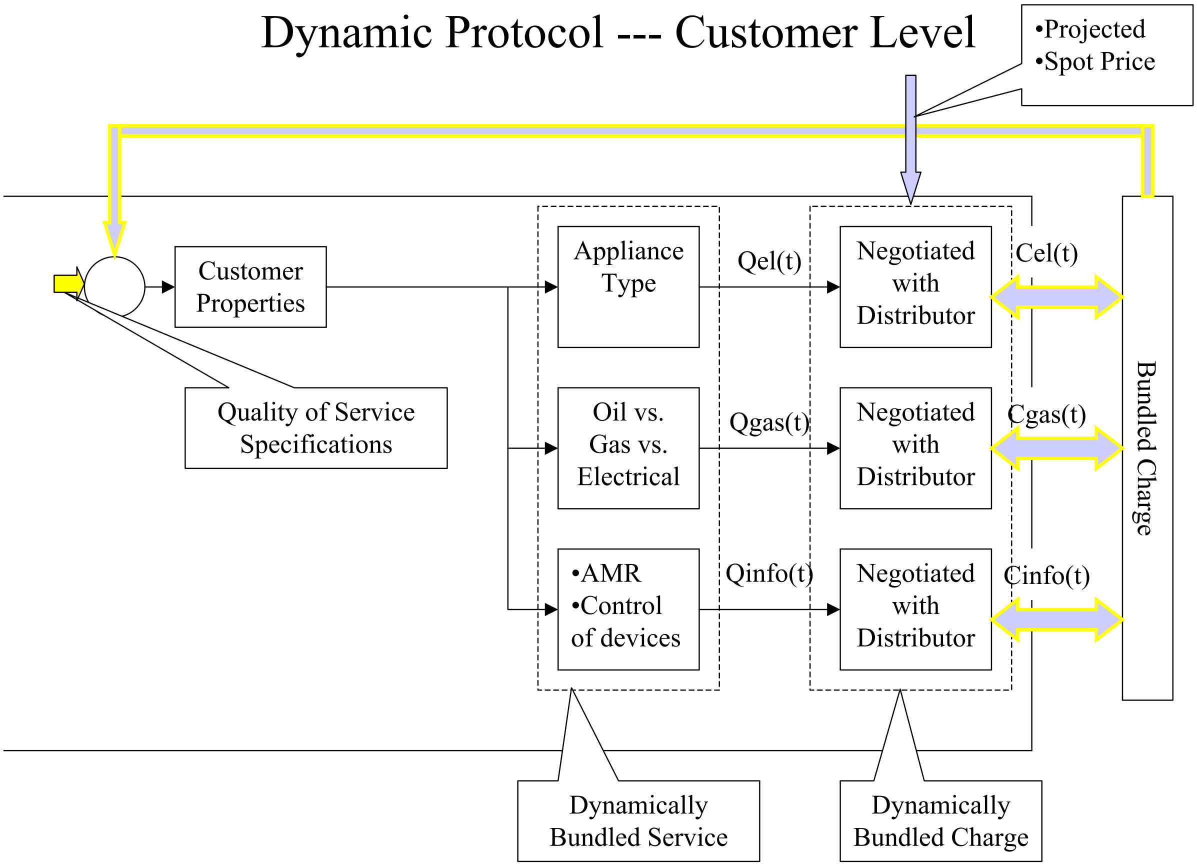
Dynamic Protocol --- Energy Market Level



Dynamic Protocol --- Multi Market Level



Dynamic Protocol --- Customer Level



Conclusions

- Systematic development of the envisioned protocols is an important interplay of economic, technical, policy and IT signals, all evolving at the well understood rates
- Only products/services specified in protocols are provided/sold; critical to have a complete set to provide service as desired by customers; regulated industry particular case
- Software supported, flexible implementations
- Without this, it may be impossible to perform both in an efficient and secure way.

Relevant references

- [1] Jelinek, M., Ilic, M., ``A Strategic Framework for Electric Energy: Technology and Institutional Factors and IT in a Deregulated Environment'', Proceedings of the NSF/DOE/EPRI sponsored Workshop on Research Needs in Complex Interactive Networks, Arlington, VA, December 2000, www NSF/ENG/ECS.
- [2] Ilic, M., ``Change of Paradigms in Complexity and Interdependencies of Infrastructures: The Case for Flexible New Protocols'', Proceedings of the OSTP/NSF White House Meeting, June 2001.
- [3] Ilic, M., ``Model-based Protocols for the Changing Electric Power Industry'', Proceedings of the Power Systems Computation Conference, June 24-28, 2002, Seville, Spain.
- [4] MIT E-Lab Newsletter, March 2001.
- [5] M.Ilic, A Control Engineering Approach to Making Complex Infrastructures More Efficient and Reliable, MIT ESD Internal Symposium Presentation, May 29, 2002 (available from the author at request)