



New Energy Space Modeling for Next Generation SCADA and Protocols for Electricity Service at Value

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Outline

- ❖ Challenges, opportunities; worries
- ❖ Problems with integrating OT/IT; overwhelming complexity (temporal, spatial, contextual); need for new SCADA; evolution of balancing authorities (BAs) to intelligent Balancing Authorities (iBAs)
- ❖ Proposal for overcoming complexity -- modeling using common specifications (triplet--energy, power, rate of power change)
- ❖ Natural extension of ACE over time and stakeholders
- ❖ Next generation SCADA; standards/protocols for iBAs.
- ❖ Optimization in energy space—service at value
- ❖ Clear market signals for the right time/system components

Why worry?

- ❖ Overwhelming complexity –cant guarantee performance
- ❖ Disconnects between innovation and industry needs; lack of frameworks for assessing potential value of innovation in terms of understandable/quantifiable concepts
 - smart grid standards do not address communication contents for specifying functionalities and ensuring performance
 - stalled innovation at value; huge development cost (microgrids)
- ❖ Challenge of teaching changing electric energy systems to students based on fundamental disciplines; both engineering students and others; pose multi-disciplinary problems and propose solutions using common concepts

Contextual complexity in the evolving industry

- ❖ Vertical “seams” within a BA
- ❖ Horizontal “seams” between BAs

Observations:

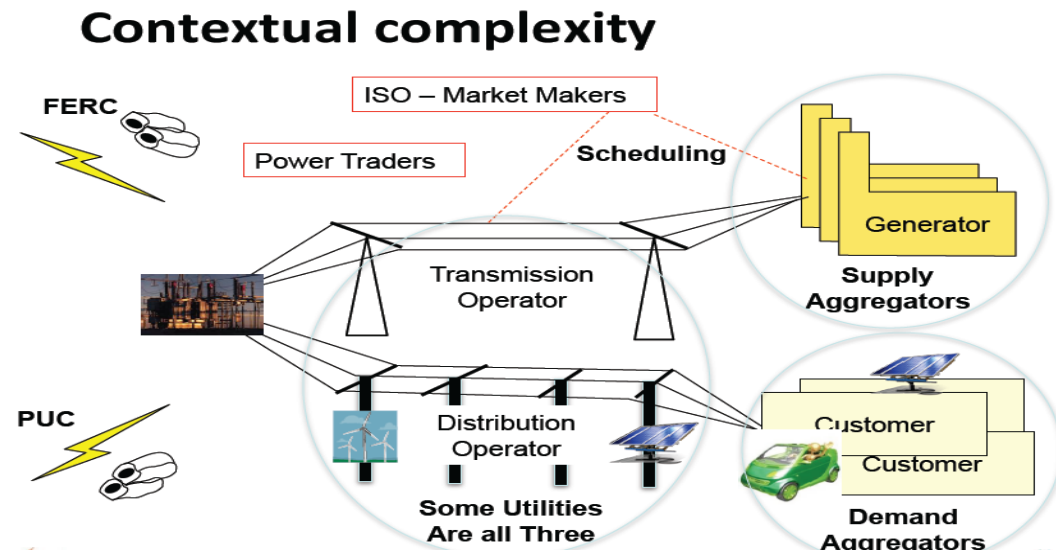
O1: Worst-case-based standards—do not work

O2: Highly inefficient (preventive)

O3: Do not apply local grid small users

O4: No incentives for flexible OT/IT deployment*
(yet functioning IT/OT critical!)

Industry reacting to mandates! Exhausted, cant rethink new problems.



**Toward more secure network environment
in critical sector, IPRI, MIT Report, 2017, contact<joel@joelbrenner.com>*

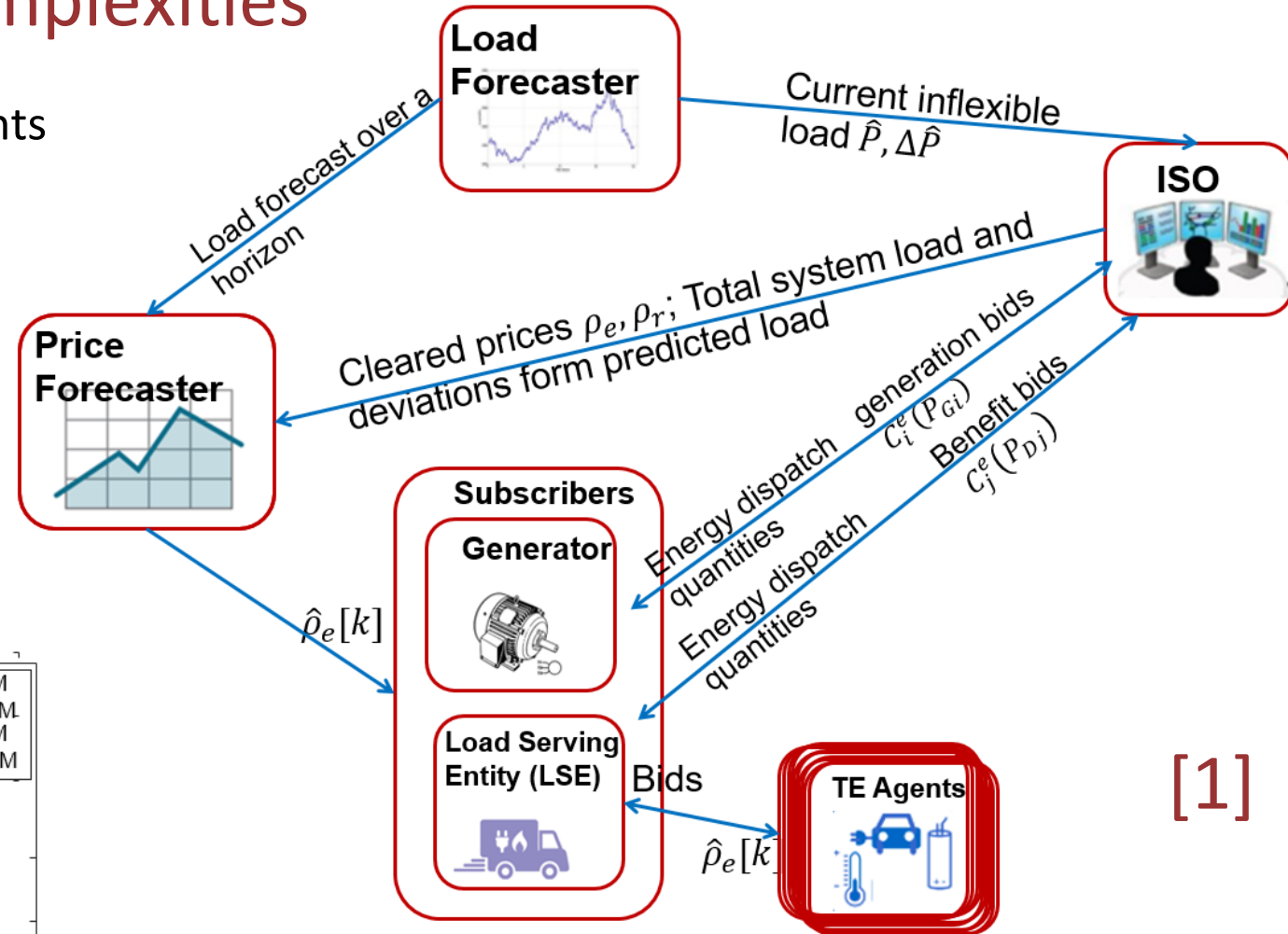
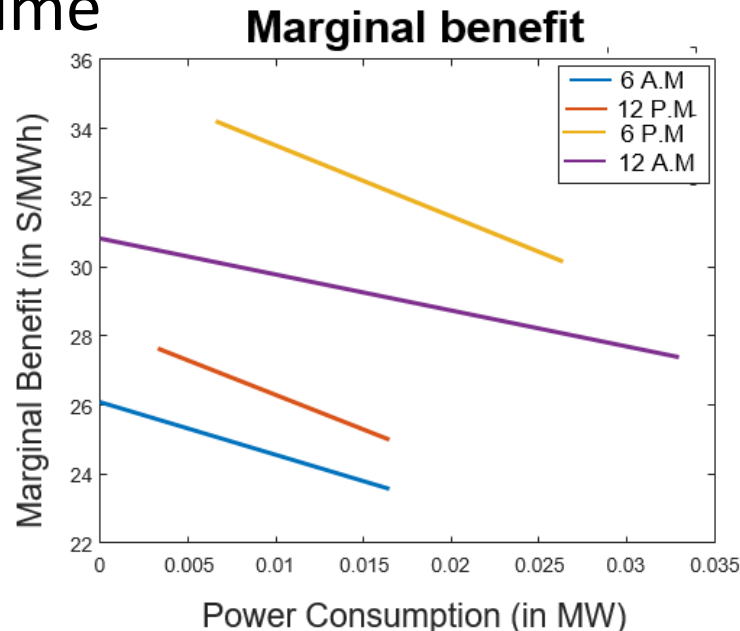
NO SYSTEMATIC WAY FOR MANAGING INTERACTIONS AT VALUE!

Bidding and market clearing—example of interdependencies/complexities

❖ Economic--technical dependence

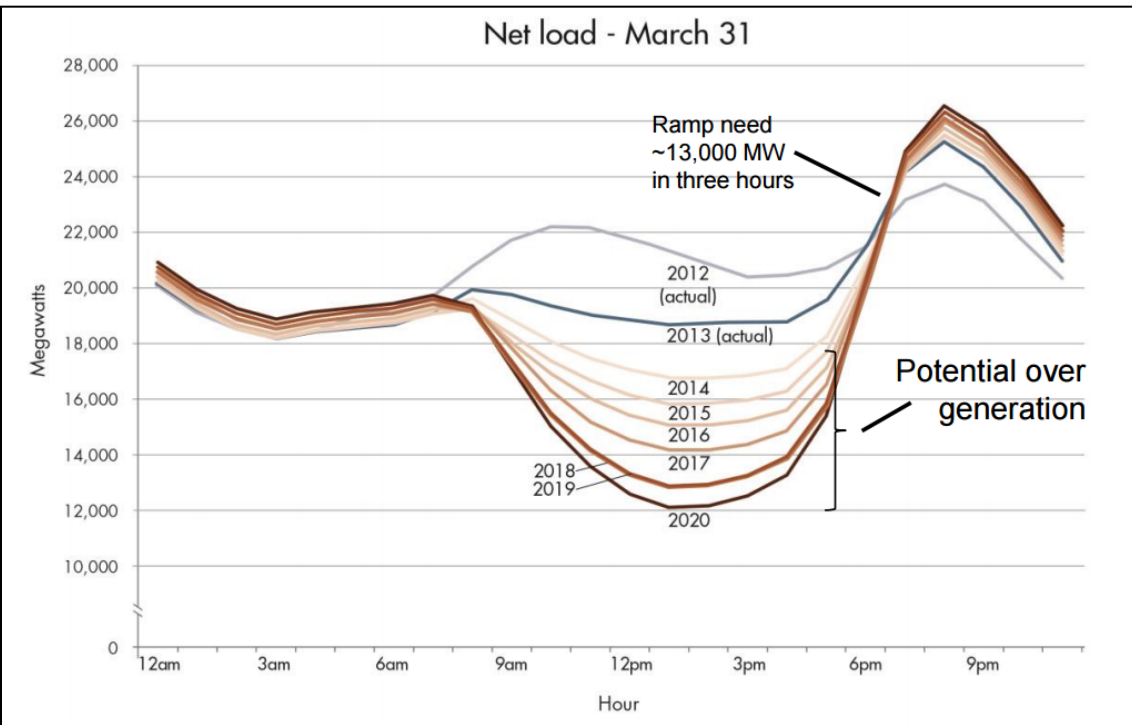
- Creates bid functions for TE market participants using their energy-based droops
- Connects to third-party software for market clearing (grid analysis/optimization)
- Market clearing is done using optimal power flow (OPF); model predictive control (MPC) to manage risks

❖ Example of Time Varying Bid function:

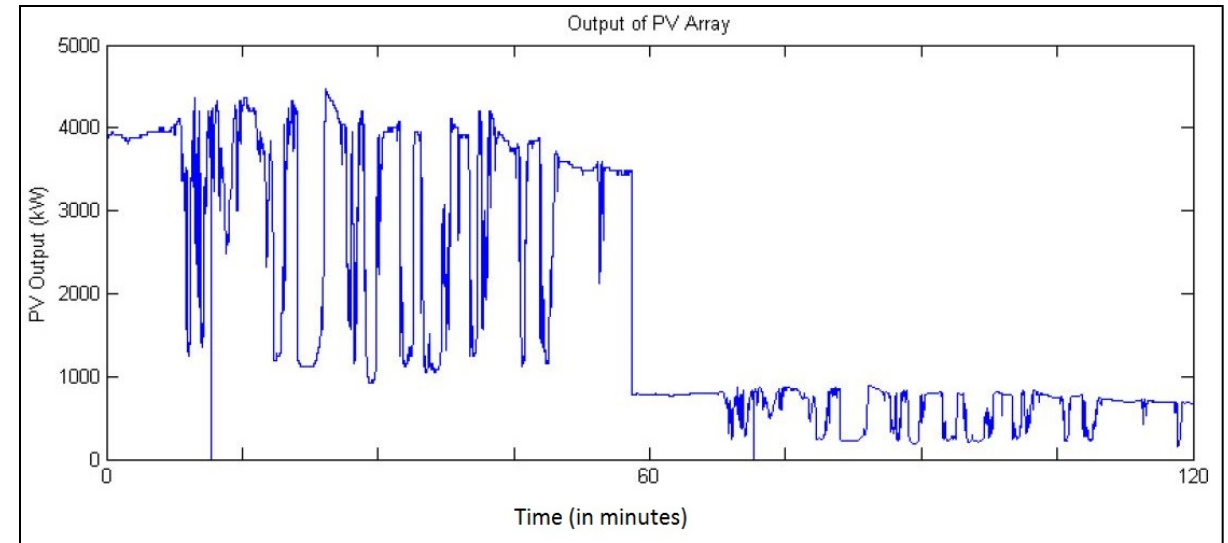


[1] R. Jaddivada and M. Ilić, "A distribution management system for implementing synthetic regulation reserve," *2017 North American Power Symposium (NAPS)*, Morgantown, WV, USA, 2017, pp. 1-6.

Temporal complexity in new electric power grids



Ramp requirement due to increased wind integration [5]



Disturbances due to solar PV integration [6]

[5] California ISO (2016) What the duck curve tells us about managing a green grid Calif. ISO, Shap. a Renewed Futur, pp.1-4

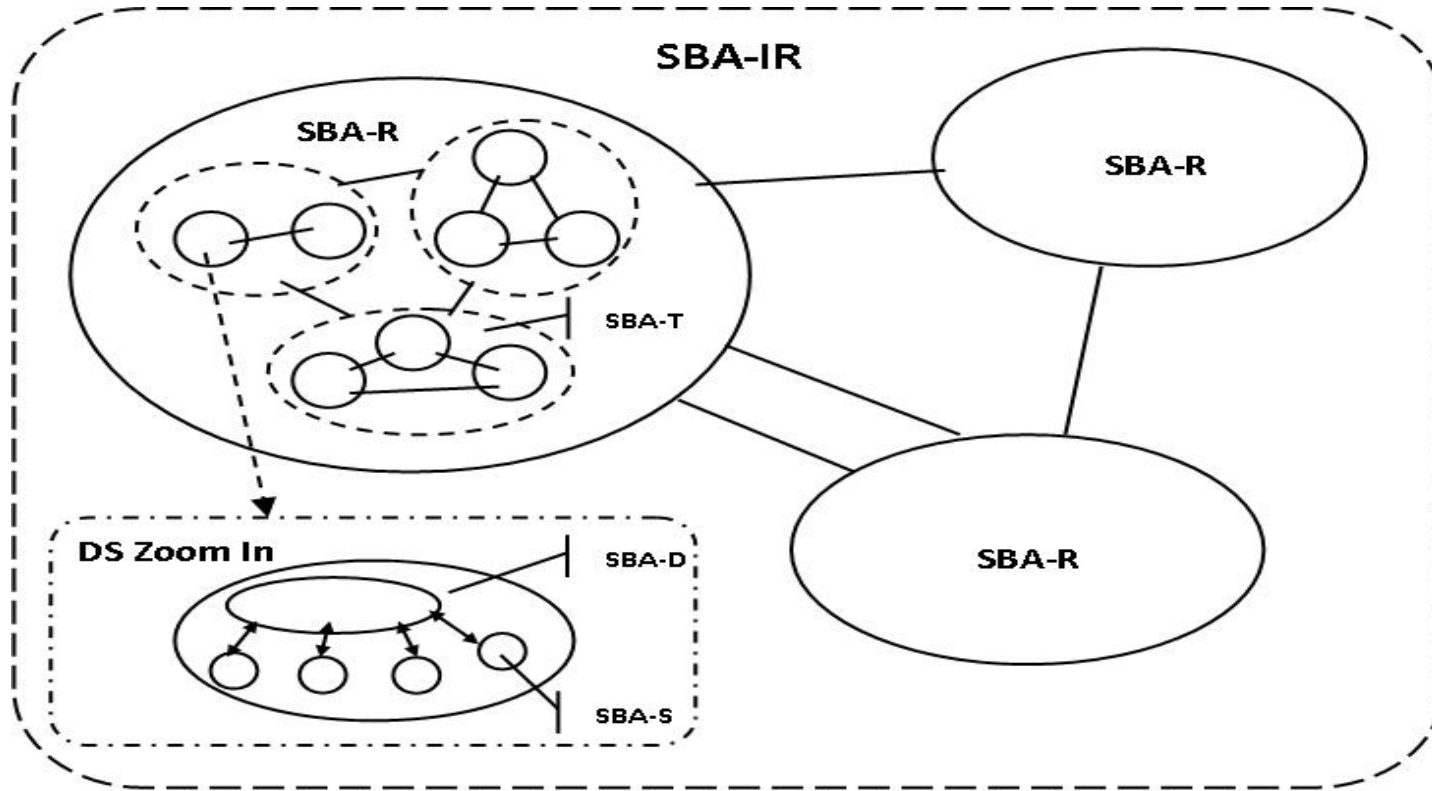
[6] Salcedo, R.O., Nowocin, J.K., Smith, C.L., Rekha, R.P., Corbett, E.G., Limpaecher, E.R. and LaPenta, J.M.

(2016) Development of a real-time Hardware-in-the-Loop power systems simulation platform to evaluate commercial microgrid controllers (No. TR-1203). Massachusetts Inst of Tech Lexington Lincoln lab.

Is there a more general simple paradigm?

FROM BAs to (SBAs) iBAs

-general idea---rethink physical dynamics in terms of interaction variables



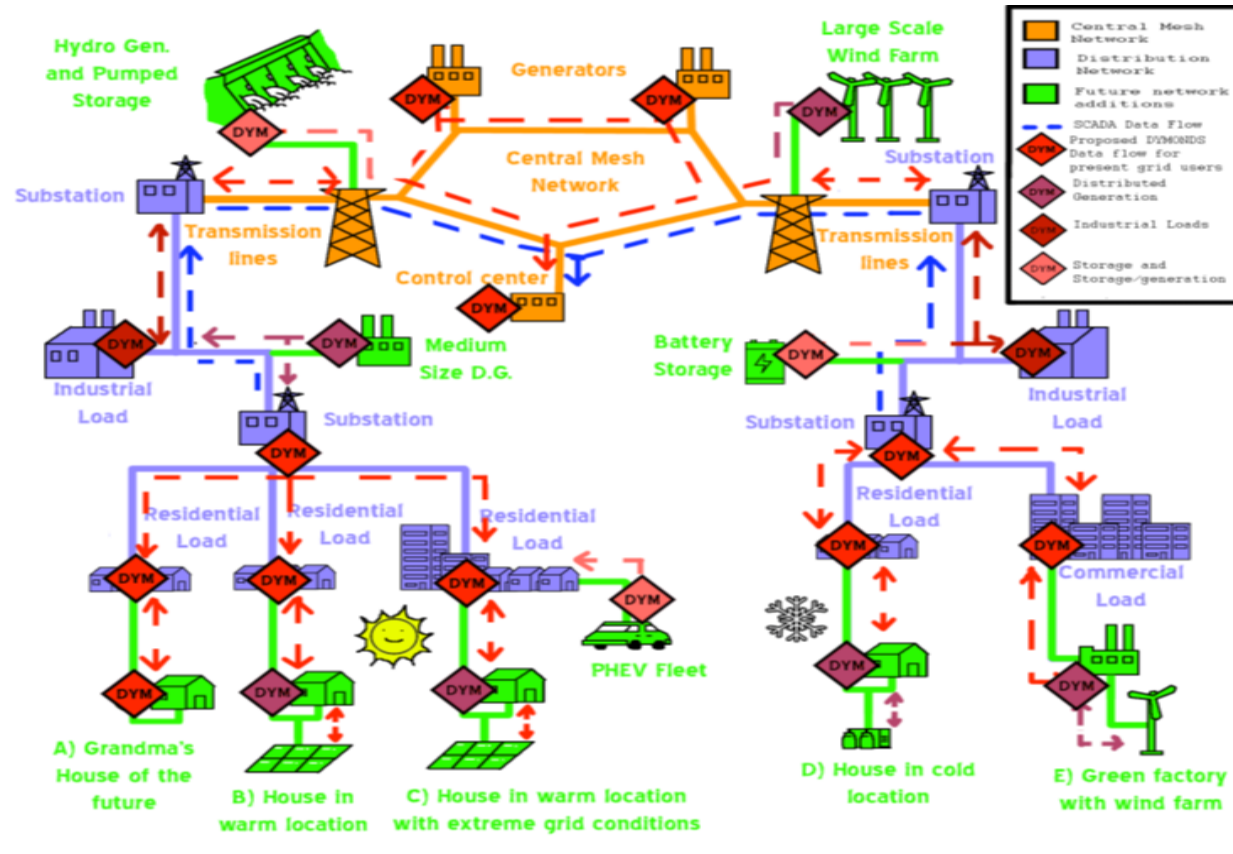
- SBA: Smart Balancing Authorities (Generalization of Control Area)
- IR: Inter-Region
- R: Region
- T: Tertiary
- D: Distribution
- S: Smart (intelligent) Component

- Note: SBAs renamed to iBAs (suggestion by a PSERC member)

Recommendations for enhancing OT/IT

- ❖ **Rec. 1** Move beyond worst case mandatory standards
- ❖ **Rec. 2** Systematic methods for benchmarking
- ❖ **Rec. 3** Enhance today's SCADA
- ❖ **Rec. 4** Create a dynamic interactive IT/OT environment
- ❖ **Rec. 5** Evolve today's Balancing Authorities (BAs) into intelligent Balancing Authorities (iBAs)
- ❖ R&D under way for such solutions; industry should work closely with academia toward next generation IT/OT

Next generation SCADA-Dynamic Monitoring and Decision Systems(DyMonDS)*



Basics for a working IT/OT:

O1: Multi-directional info flow

O2: Basis for on-line resource management

O3: End-to-end participation in supply/demand/delivery

O4: Possible to set simple specifications for ranges of power and energy characterizing different components

O5: Multi-layered –

--Detailed information local to components, iBAs

--Granular (aggregate) information exchange between iBAs

[Ilic, M.D. (2011) Dynamic monitoring and decision systems for enabling sustainable energy services

Proceedings of the IEEE, 99(1), pp.58-79.

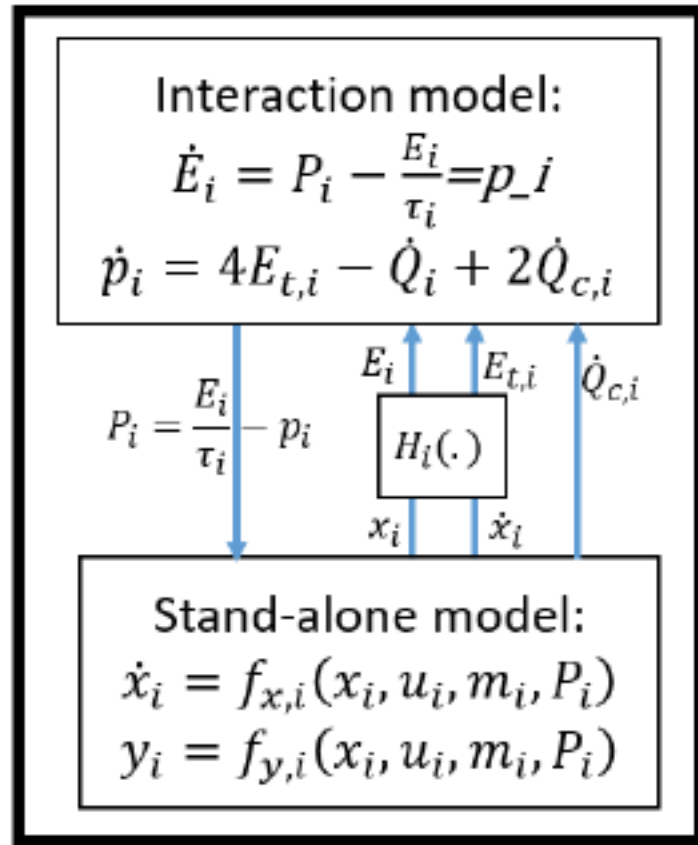
Back to basics--Overcoming complexity by systematic modeling

- ❖ Functions of distributed decision makers as well as the objectives of higher level aggregating entities can be established using a **unifying modeling energy-based framework**.
- ❖ An outgrowth of specifications/standards used today for AGC
- ❖ Possible to operate the system by specifying performance in terms of ACE-like variables, now for all iBAs and over a stratum of temporal horizons.
- ❖ **The challenge: Extension of ACE (temporally, spatially, contextually)**

Unifying energy-based modeling of dynamics

- ❖ Component level (module, system (S) within the system of systems (SoS))
- ❖ Interactive model of interconnected systems
- ❖ Model-based system engineering (MBSE)—
 - multi-layered complexity
 - component (modules) – designed by experts for common specifications (energy; power; rate of change of power)
 - interactions subject to conservation of instantaneous power and reactive power dynamics; optimization at system level in terms of these variables
 - physically intuitive models

Component-level model in energy space*



Definitions:

Instantaneous Power: $P_i = \langle e_i | f_i \rangle \forall (e_i, f_i) \in \mathcal{E}_i \times \mathcal{F}_i$

Rate of change of Reactive Power: $\dot{Q}_i = \langle e_i | \dot{f}_i \rangle - \langle f_i | \dot{e}_i \rangle$

Stored energy: $E_i = H_i(x_i)$

Stored energy in tangent space: $E_{t,i} = H_i(\dot{x}_i)$

Dissipated energy: $D_i = B_i(x_i)$

Time constant: $\tau_i = \frac{E_i(x_i)}{D_i(x_i)}$

Capacitive Reactive Power production: $\dot{Q}_{c,i} = \langle e_{j,i} | \dot{f}_{j,i} \rangle - \langle f_{j,i} | \dot{e}_{j,i} \rangle$

$\forall e_{j,i}, f_{j,i} \subseteq \mathcal{X}_i; j \in \mathcal{C}_i$ – capacitive elements in sub-system i

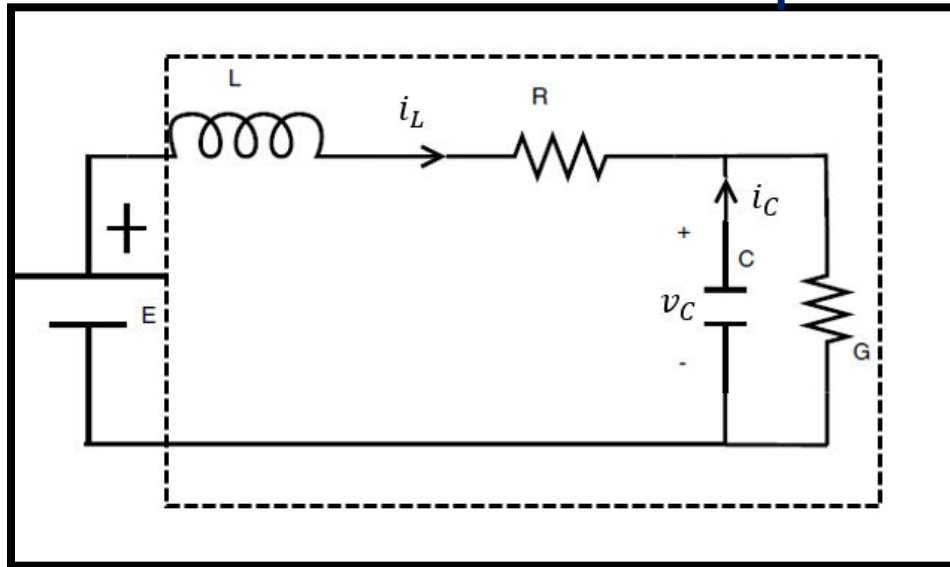
$E_{t,i}$ = Rate of change of component exergy

$\dot{Q}_i - 2\dot{Q}_{c,i}$ = Rate of change of component anergy



Simple examples of interactive model in energy space

Electrical circuit example



Using definition of electrical real and reactive power entering ports

$$P = Ei \quad \dot{Q} = E \frac{di_L}{dt}$$

$$E^m = \frac{1}{2} L i_L^2$$

Magnetic
Stored Energy

$$E^e = \frac{1}{2} C v_C^2$$

Electric
Stored Energy

$$E_t^m = \frac{1}{2} L \left(\frac{di_L}{dt} \right)^2$$

Magnetic Energy
in Tangent Space

$$E_t^e = \frac{1}{2} C \left(\frac{dv_C}{dt} \right)^2$$

Electric Energy
in Tangent
Space

For $E = E^m + E^e$, substituting constitutive relation imply

$$\frac{dp}{dt} = \frac{d^2 E}{dt^2} = 4E_t - \dot{Q}$$

Mech. Mass spring example

Using definition of mechanical real and reactive power entering ports

$$P = \tau_m v_1 \quad \dot{Q} = \tau_m \frac{dv_1}{dt}$$

$$E^m = \frac{1}{2} m v_1^2$$

Stored Energy
in Rotor

$$E^e = \frac{1}{2k} \tau_m^2$$

Stored Energy
in spring

$$E_t^m = \frac{1}{2} m \left(\frac{dv_1}{dt} \right)^2$$

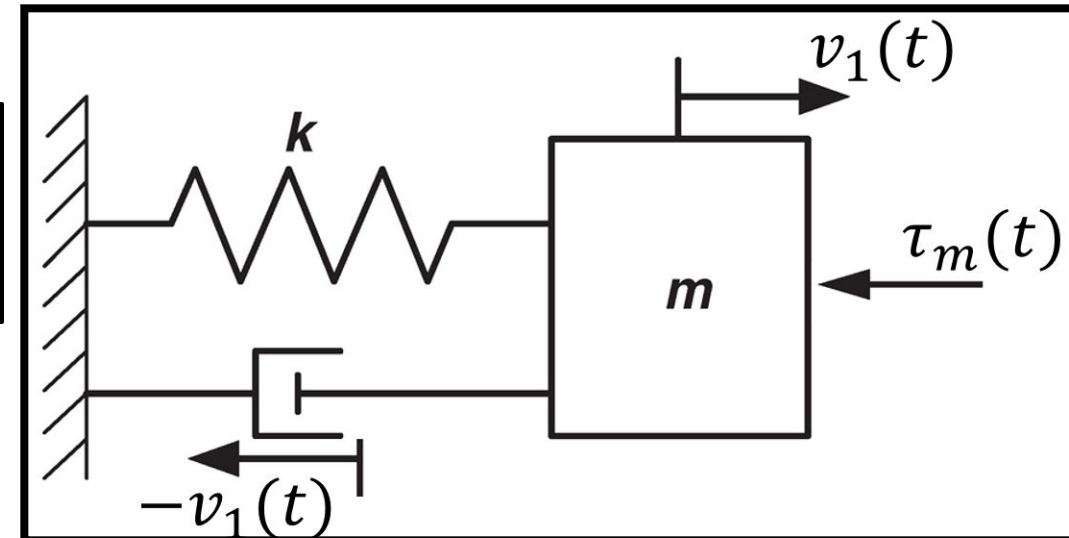
Energy in Tang.
Space in Rotor

$$E_t^e = \frac{1}{2k} \left(\frac{d\tau_m}{dt} \right)^2$$

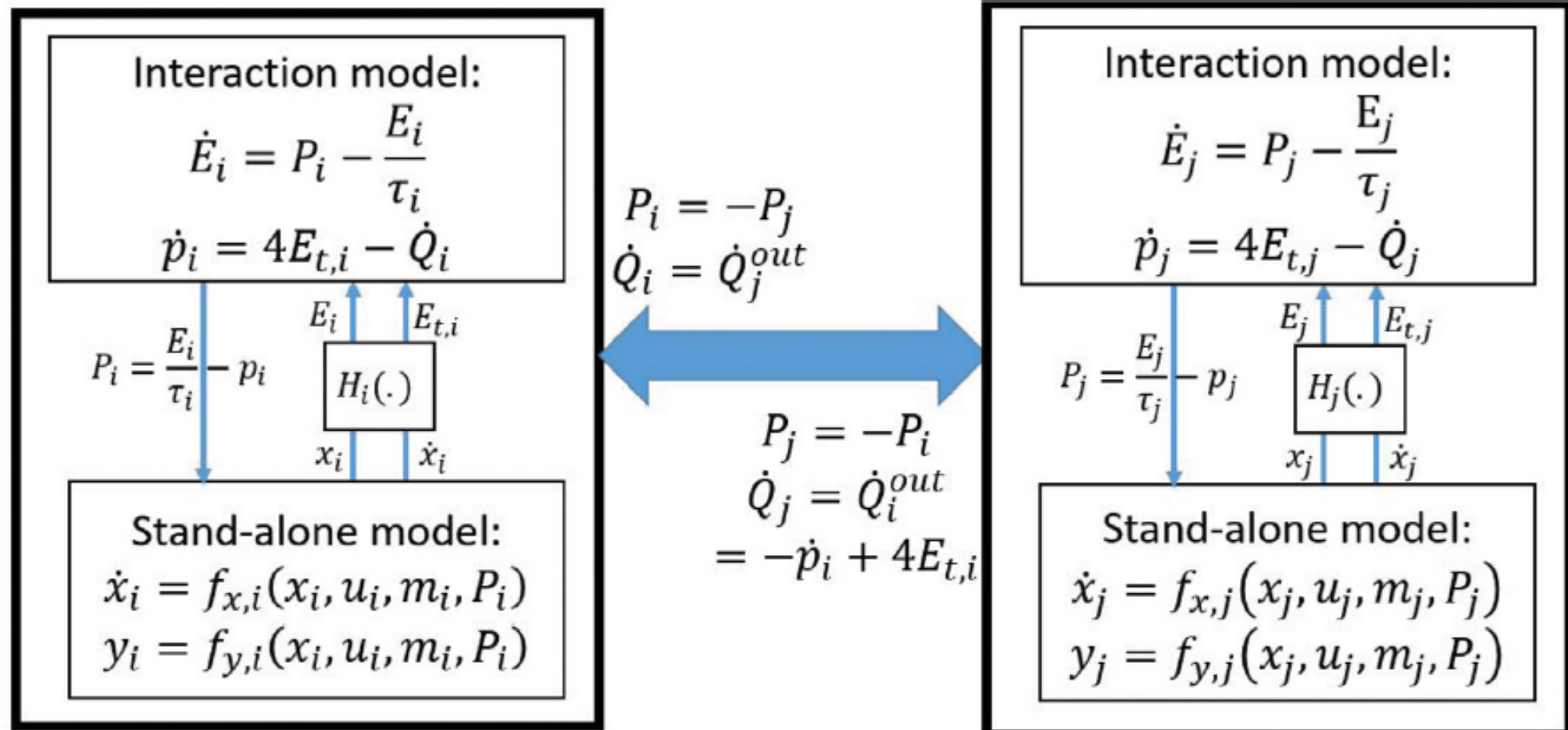
Energy in Tang.
Space in Spring

For $E = E^m + E^e$, substituting constitutive relations imply

$$\frac{dp}{dt} = \frac{d^2 E}{dt^2} = 4E_t - \dot{Q}$$



MBSE in energy space --Multi-layered interactive model

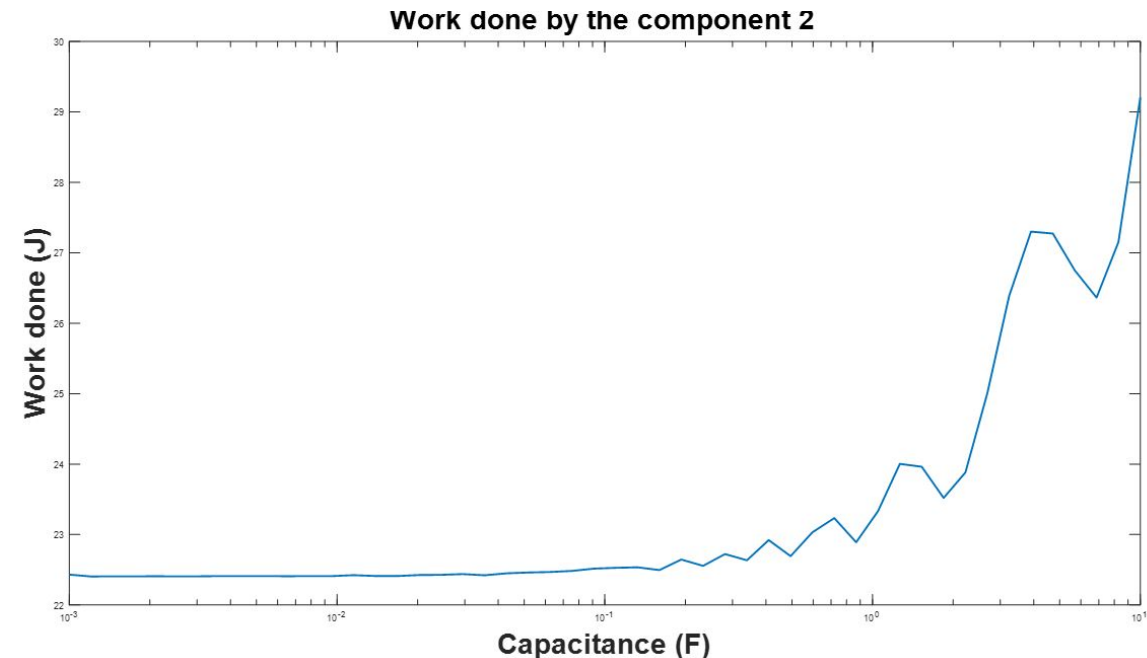
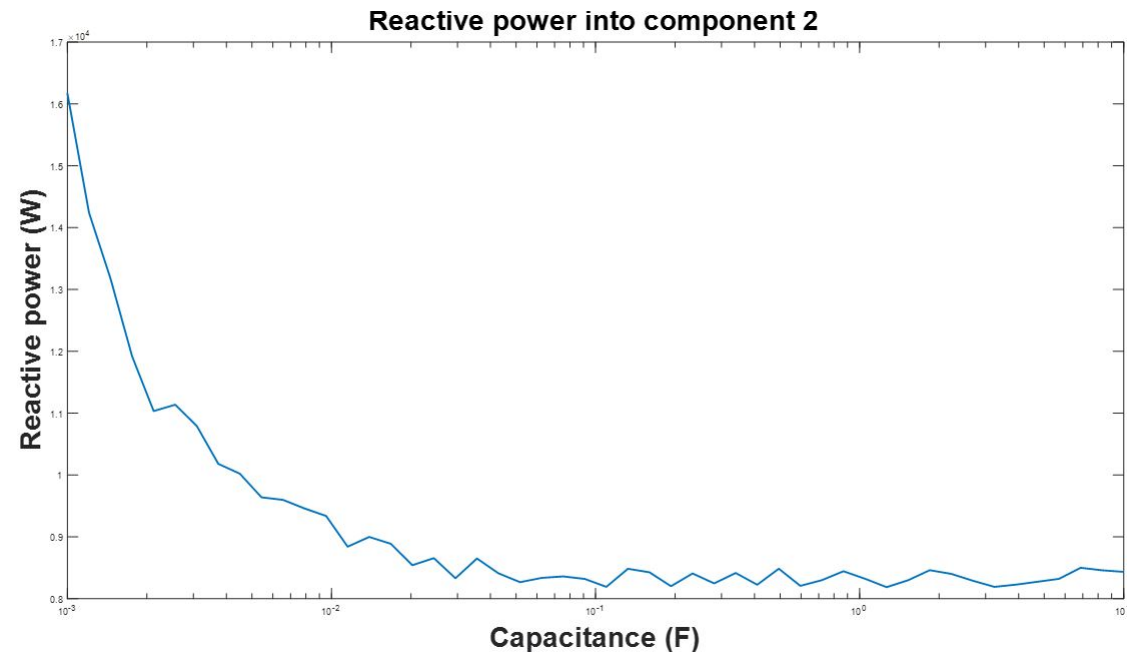
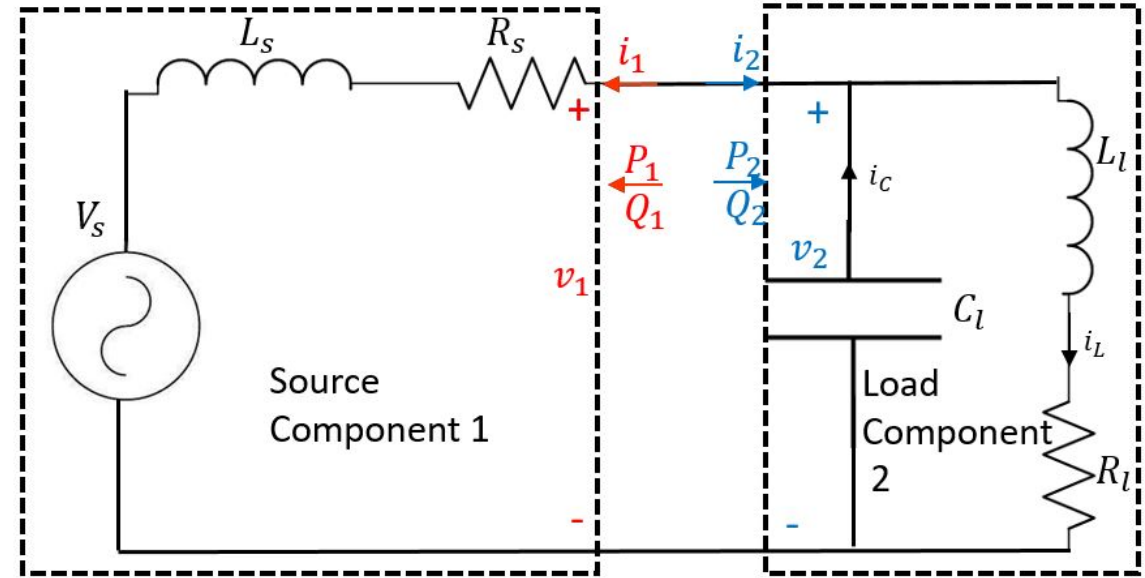


Optimization in energy space

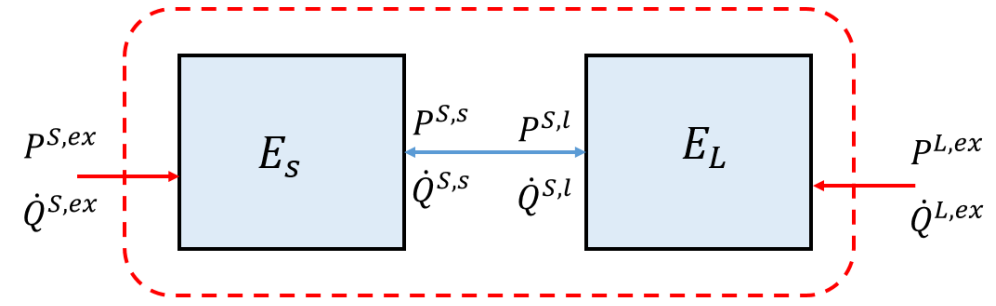
- ❖ Optimization problems for coordinating iBAs become **linear low-order convex optimization problems in the energy space**
- ❖ Optimizers (aggregators, ISOs, markets) to find the best values from the range specified by the iBAs.
- ❖ The protocol is a win-win protocol, since all entities operate within the ranges they specify. If it is not possible to find feasible solution, coordinating entities can plan accordingly
- ❖ Primal-dual optimization-based protocols in energy space can be mapped into corresponding pricing.

OPTIMIZATION IN ENERGY SPACE--Importance of reactive power Q for efficiency

- ❖ Capturing rate at which energy can be injected into neighbors
- ❖ Candidate supply function to establish dissipativity at component level or sub-system level w.r.t stored energy in tangent space as a storage function
- ❖ Characterize inefficiency



Centralized optimization problem formulation in energy space



$$\min_{p^{S,s}(t), p^{S,l}(t), \dot{Q}^{S,s}(t), \dot{Q}^{S,l}(t), E_t^{S,s}(t), E_t^{S,l}(t)} \int_0^t \dot{Q}^{S,s}(\tau)^2 + \dot{Q}^{S,l}(\tau)^2 d\tau$$

Constraint Set 2:

Source Interaction dynamics:

$$\begin{aligned} \dot{E}_s(t) &= p_s(t) = \\ &= P^{S,s}(t) + P^{S,ex}(t) - \frac{E_s(t)}{\tau_s} \\ \dot{p}_s(t) &= 4E_{t,s}(t) - \dot{Q}^{S,g}(t) - \dot{Q}^{S,ex}(t) \end{aligned}$$

$$\begin{aligned} P^{S,s}(t) &= P_s(t); Q^{S,s}(t) = Q_s(t) \\ E_{t,s} &= E_s(\dot{x}_s) \end{aligned}$$

Constraint Set 3:

Load Interaction dynamics:

$$\begin{aligned} \dot{E}_l(t) &= p_l(t) = \\ &= P^{S,l}(t) + P^{L,ex}(t) - \frac{E_l(t)}{\tau_l} \\ \dot{p}_l(t) &= 4E_t^l(t) - \dot{Q}^{S,l}(t) - \dot{Q}^{L,ex}(t) \end{aligned}$$

$$\begin{aligned} P^{S,l}(t) &= P_l(t); Q^{S,l}(t) = Q_l(t) \\ E_{t,l} &= E_l(\dot{x}_l) \end{aligned}$$

Constraint set 1:

Interconnection constraints:

$$\begin{aligned} P^{S,g} + P^{L,g} &= 0 \\ \dot{Q}^{S,g} + \dot{Q}^{L,g} &= 0 \end{aligned}$$

Dissipativity constraint

$$\dot{p}^{S,ex} + \dot{p}^{L,ex} \leq \frac{\dot{E}_s}{\tau_s} + \frac{\dot{E}_L}{\tau_L}$$

Real and Reactive Power Limits

$$\begin{aligned} p_{g,min} &\leq P^{S,g} \leq p_{g,max} \\ p_{l,min} &\leq P^{S,l} \leq p_{l,max} \\ \dot{Q}_{g,min} &\leq \dot{Q}^{S,g} \leq \dot{Q}_{g,max} \\ \dot{Q}_{l,min} &\leq \dot{Q}^{S,l} \leq \dot{Q}_{l,max} \end{aligned}$$

$$\forall t \in [0, \infty)$$

Constraint set 4:

Source Stand-alone Component dynamics:

$$\begin{aligned} \dot{x}_s(t) &= f_{x,s}(x_s(t), u_s(t), P_s(t)) \\ y_s(t) &= f_{y,s}(x_s(t), u_s(t), P_s(t), \dot{Q}_s(t)) \\ u_s^{min} &\leq u_s(t) \leq u_s^{max} \\ y_s^{min} &\leq y_s(t) \leq y_s^{max} \end{aligned}$$

Constraint set 5:

Load Stand-alone Component dynamics:

$$\begin{aligned} \dot{x}_l &= f_{x,l}(x_l, u_l, P_l) \\ y_l &= f_{y,l}(x_l, u_l, P_l, \dot{Q}_l) \\ u_l^{min} &\leq u_l \leq u_l^{max} \\ y_l^{min} &\leq y_l \leq y_l^{max} \end{aligned}$$



Interaction model of closed loop solar PV (droop)

EnergySpace Model:

$$\dot{E}(t) = P_{rad}(t) + P_{bat}(t) + P_e(t) - \frac{E(t)}{\tau} = p(t)$$

$$\dot{p}(t) = 4E_t(t) - \dot{Q}_{rad}(t) - \dot{Q}_{bat}(t) - \dot{Q}_e(t)$$

$$\text{Here, } E(t) = \frac{1}{2} Li(t)^2 + \frac{1}{2} Cv(t)^2$$

- The power electronics switch control of battery can be so designed that would ensure

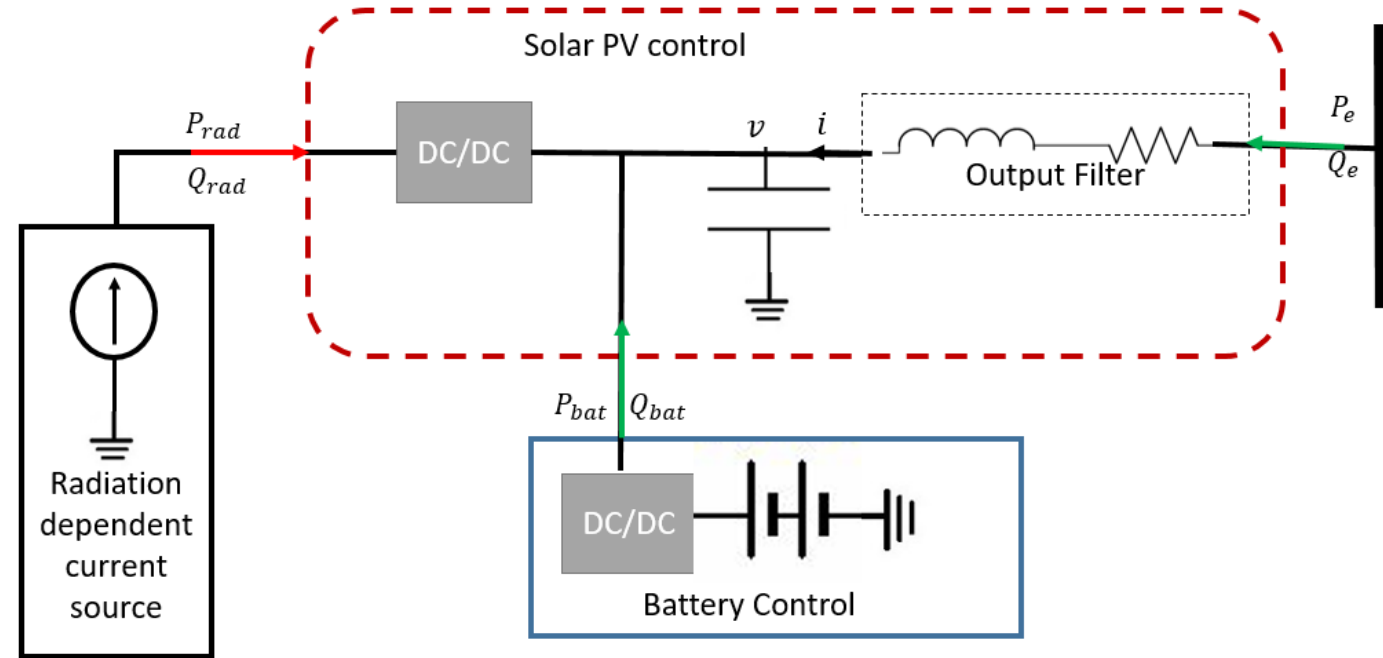
$$P_{bat}(t) = -P_e[n] + P[n] - K_i^P (i_F(t) - i_F^{ref}[n]) - K_V^P (V(t) - V^{ref}[n])$$

$$Q_{bat}(t) = -Q_e[n] + Q[n] - K_i^P (i_F(t) - i_F^{ref}[n]) - K_V^P (V(t) - V^{ref}[n])$$

- By substituting these control equations in the interaction model, writing the quasi-static relations for every sample n , one can obtain the quasi-static relation:

$$\text{Coupled Droop: } \alpha \Delta P[n] + \beta \Delta Q[n] = \Delta V[n]$$

P, Q are the desired feedforward electrical power injections into the grid communicated over time samples k and n for short-term and long-term respectively



Over much longer time scale identified by sample number k , it is possible to obtain the following relation (assuming converter efficiencies are all 100%)

PV Energy-conversion Droop Relation:

$$\Delta P[k] + \Delta P^{Bat}[k] = \Delta P^{rad}[k]$$

DER Energy Conversion Droop Relation: $\Delta P[k] = \sigma \Delta W[k]$

Interaction model of closed-loop DER (droop)

General DER-level Problem embedded in Market interface:

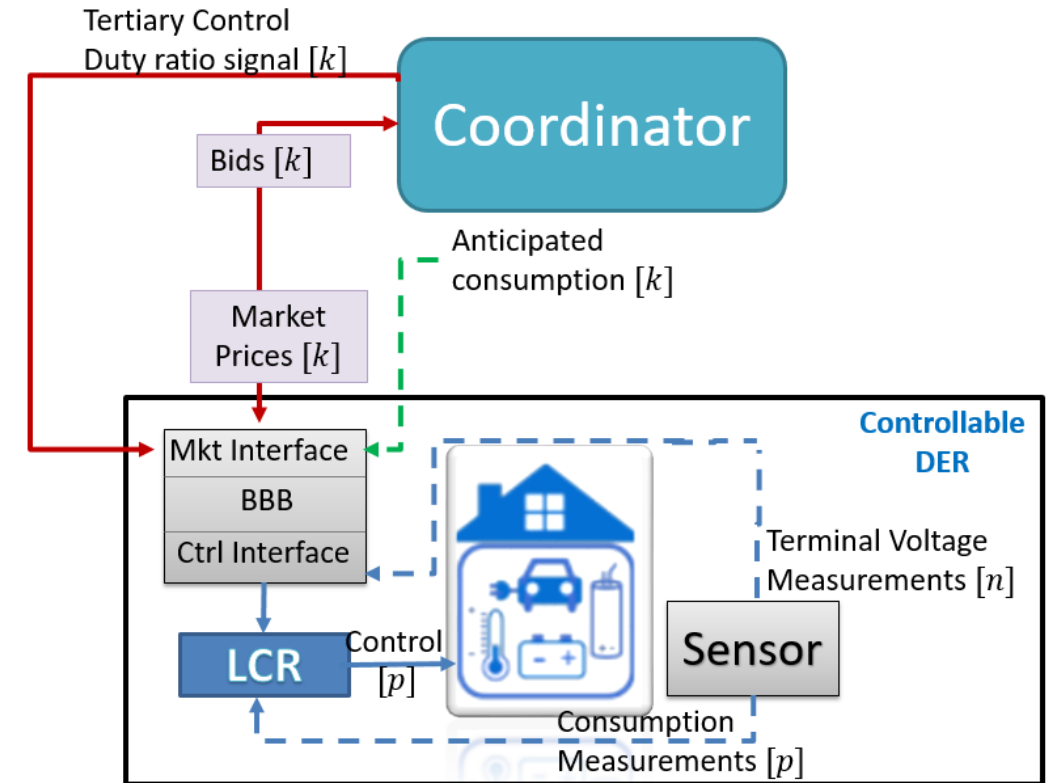
$$\min_{P_{s,l}[k], Q_{s,l}[k]} \lambda^{S,P}[k] P_{s,l}[k] + \lambda^{S,Q}[k] Q_{s,l}[k]$$

$$\begin{aligned} \Delta P_l[k] + \Delta P_l^{Bat}[k] &= \sigma \Delta W_l[k] && \text{Comfort Specification} \\ \alpha \Delta P_l[n] + \beta \Delta Q_l[n] &= \Delta V[n] && \text{Coupled Droop relation} \\ \Sigma P_l[n] &= P_l[k] && \text{Slow-fast timescale} \\ \Sigma Q_l[n] &= Q_l[k] && \text{coupling of control signals} \\ V^{min} &\leq V_l[n] \leq V^{max} && \text{Voltage limits} \\ e_l[k+1] &= e_l[k] + P^{Bat}[k] && \text{Battery limits (optional,} \\ p^{Bat,min} &\leq P_l^{Bat} \leq p^{Bat,max} && \text{only if one exists)} \\ 0 &\leq e_l[k] \leq e^{max} && \end{aligned}$$

Constraint set with slower
time samples at k

$$\Psi_l(P_l[k], Q_l)$$

Stabilizing advanced nonlinear controller with capability of disturbance rejection can be embedded in the controller interface which is also superposed by the dispatch commands sent.



Note also that instantaneous reactive power $\dot{Q}_1$ and magnitude of oscillation of reactive power in periodic signals Q_2 are related as

$$\dot{Q}_1 = \omega Q_2$$

In p.u. analysis, thus $\dot{Q}$ as per definition of Q_1 can be replaced by Q as per the definition of Q_2



Important observations-lessons learned

- ❖ With carefully designed fast local primary control it becomes possible to derive a GENERALIZED DROOP for using as a module (subsystem) specification when performing higher level optimization in energy space (secondary, tertiary level control)---VALUE OF POWER ELECTRONICS/CONTROL
- ❖ ENERGY DROOP --- characterizes provable ramp rate at the time scale of interest
- ❖ N.B. GENERALIZED DROOP DEFINES STABLE CLOSED-LOOP DYNAMICS OF MODULE. THE DROOP COEFFICIENT IS NOT A RESULT OF HIGHER LEVEL OPTIMIZATION (THIS IS CONTRARY TO SOME SOA METHODS PROPOSED)

Energy space interpretation of market signals

- ❖ Notably, pricing is needed for energy, power and power rates, only. This makes pricing alignment with technical protocols straightforward and it becomes possible to design novel regulatory schemes in support of this alignment.
- ❖ Examples of interactive stabilization using energy space for a small system, and of transactive energy market (TEM) implementation are briefly summarized.

Aligning markets and operation at value

SYSTEM

Note:

Two-component example shown for having less notation

Network under consideration with location prices has been considered in [Illic2018]

Real Power Bids : $C_S^P(P^{S,s}), P^{s,min}[h], P^{s,max}[h]$

Reactive Power Bids : $C_S^Q(Q^{S,s}), Q^{s,min}[h], Q^{s,max}[h]$

Real Power Bids : $C_L^P(P^{S,l}), P^{l,min}[h], P^{l,max}[h]$

Reactive Power Bids : $C_L^Q(Q^{S,l}), Q^{l,min}[h], Q^{l,max}[h]$

Dispatch : $P^{S,s}[h], Q^{S,s}[h]$

ClearedPrices : $\lambda^{S,P}[h], \lambda^{S,Q}[h]$

SOURCE
COMPONENT

Dispatch : $P^{S,l}[h], Q^{S,l}[h]$

ClearedPrices : $\lambda^{S,P}[h], \lambda^{S,Q}[h]$

LOAD
COMPONENT

Market signals—provable valuation!

Assuming internal dynamics have settled at the coordinator level,

Source Interaction dynamics:

$$\begin{aligned}\dot{E}_S(t) &= p_S(t) \\ &= P^{S,s}(t) + P^{S,ex}(t) - \frac{E_S(t)}{\tau_S} \\ \dot{p}_S(t) &= 4E_{t,S}(t) - \dot{Q}^{S,ex}(t) - \dot{Q}^{S,s}(t)\end{aligned}$$

$$P_s(t) = P^{S,s}(t); Q_s(t) = Q^{S,s}(t)$$

Generator-level Problem:

$$\begin{aligned}\min_{u_s(t)} \int_0^t & \lambda^{S,P}(\tau) P_s(\tau) + \lambda^{S,Q}(\tau) \dot{Q}_s(\tau) d\tau \\ \dot{x}_s &= f_{x,s}(x_s, u_s, P_s) \\ y_s &= f_{y,s}(x_s, u_s, P_s, \dot{Q}_s) \\ u_s^{min} &\leq u_s \leq u_s^{max} \\ y_s^{min} &\leq y_s \leq y_s^{max}\end{aligned}$$

Coordinator-level problem:

Inefficiencies

$$\min_{\substack{P^{S,s}(t), \dot{Q}^{S,s}(t) \\ P^{S,l}(t), \dot{Q}^{S,l}(t)}} \int_0^t \left[\dot{Q}^{S,s}(\tau)^2 + \dot{Q}^{S,l}(\tau)^2 + C_S^P(P^{S,s}) + C_L^P(P^{S,l}) + C_s^Q(\dot{Q}^{S,s}) + C_l^Q(\dot{Q}^{S,l}) \right] d\tau$$

bids

Interconnection constraints:

$$\begin{aligned}P^{S,s}(t) + P^{S,l}(t) &= 0 & (\lambda^{S,P}(t)) \\ \dot{Q}^{S,s}(t) + \dot{Q}^{S,l}(t) &= 0 & (\lambda^{S,Q}(t))\end{aligned}$$

Real and Reactive Power Limits

$$\begin{aligned}p^{s,min}(t) &\leq P^{S,s}(t) \leq p^{s,max}(t) \\ p^{l,min}(t) &\leq P^{S,l}(t) \leq p^{l,max}(t) \\ \dot{q}^{s,min}(t) &\leq \dot{Q}^{S,s}(t) \leq \dot{q}^{s,max}(t) \\ \dot{q}^{l,min}(t) &\leq \dot{Q}^{S,l}(t) \leq \dot{q}^{l,max}(t)\end{aligned}$$

Convex optimization problem!

Load Interaction dynamics:

$$\begin{aligned}\dot{E}_L(t) &= p_L(t) \\ &= P^{S,l}(t) + P^{L,ex}(t) - \frac{E_L(t)}{\tau_L} \\ \dot{p}_L(t) &= 4E_{t,L}(t) - \dot{Q}^{L,ex}(t) - \dot{Q}^{S,l}(t)\end{aligned}$$

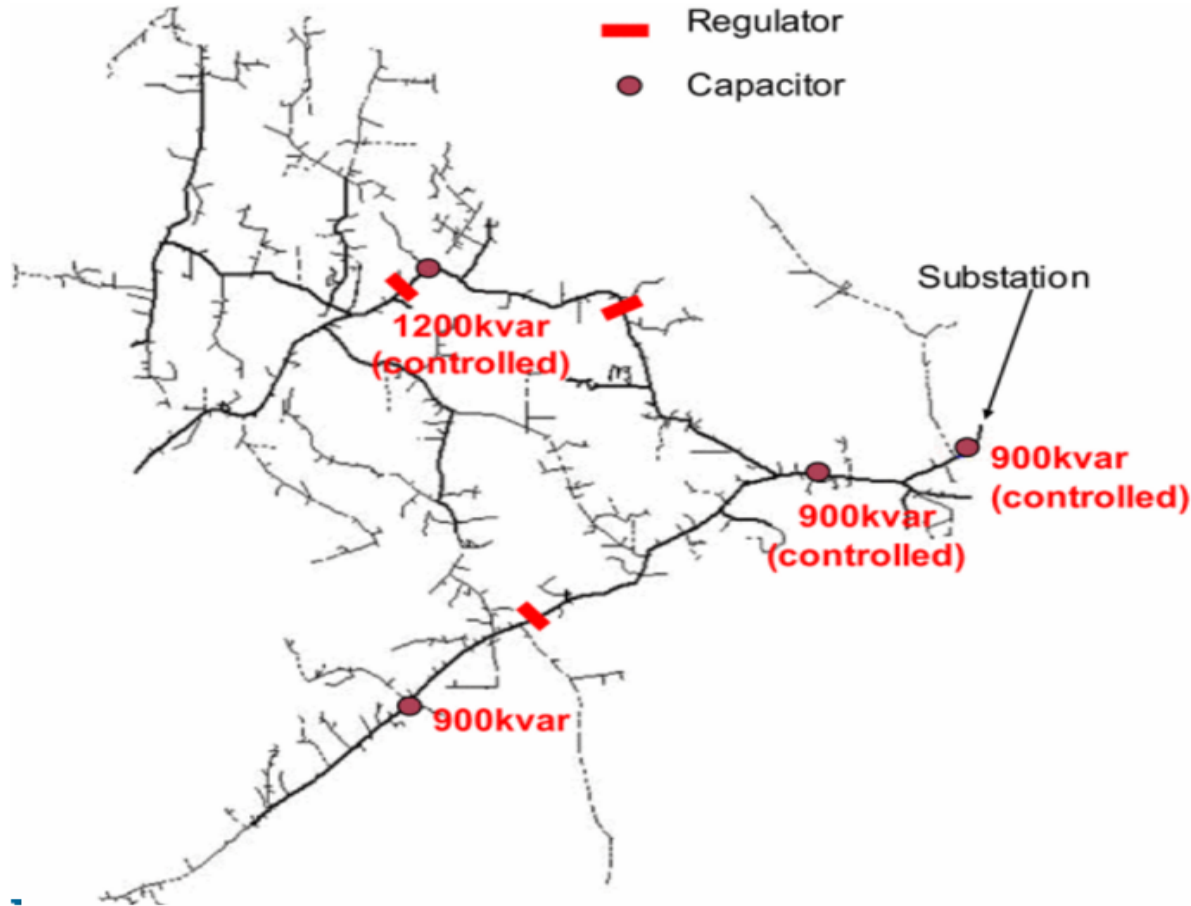
$$P_l(t) = P^{S,l}(t); Q_l(t) = Q^{S,l}(t)$$

Consumer-level Problem:

$$\begin{aligned}\min_{u_l(t)} \int_0^t & \lambda^{S,P}(\tau) P_{s,l}(\tau) + \lambda^{S,Q}(\tau) \dot{Q}_{s,l}(\tau) d\tau \\ \dot{x}_l &= f_{x,l}(x_l, u_l, P_l) \\ y_l &= f_{y,l}(x_l, u_l, P_l, \dot{Q}_l) \\ u_l^{min} &\leq u_l \leq u_l^{max} \\ y_l^{min} &\leq y_l \leq y_l^{max}\end{aligned}$$

Non-linearity handled at distributed components

Test System: IEEE-8500 system*



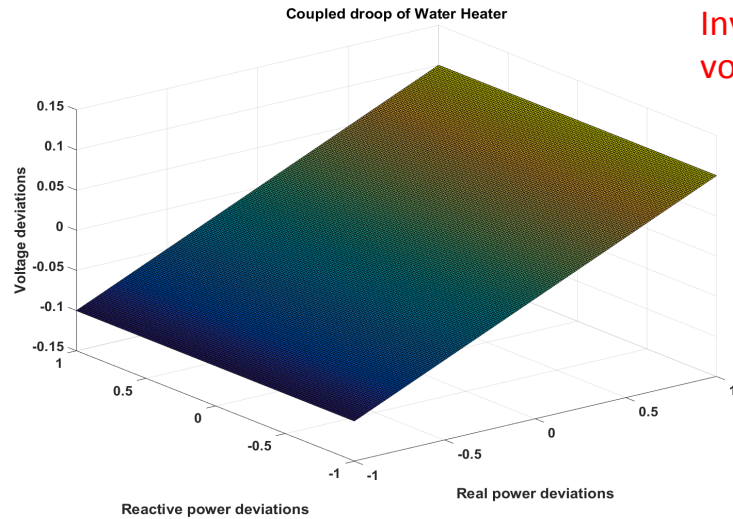
Detailed End-device information [PNNLRepo]

- Nominal peak load = $10773.2 + j2700.0$ kVA
- Houses: 1977 from 500.0 to 3500.0 sf, total area 3941782 sf
- Electric water heaters: 1013 totaling 4574.7 kW
- Air conditioners: 1977 totaling 26150.6 kW
- Solar: 1777 totaling 6755.2 kW
- Storage: 857 totaling 4285.0 kW
- Water heater load is resistive
- HVAC load ZIP=0.2,0.0,0.8 with variable power factor as input
- (the fan load ZIP=0.2534,0.7332,0.0135 and pf=0.96)
- Non-responsive ZIP load is input all constant current, pf=0.95

Upcoming NIST Report on TEM, Phase 2, October 2018.

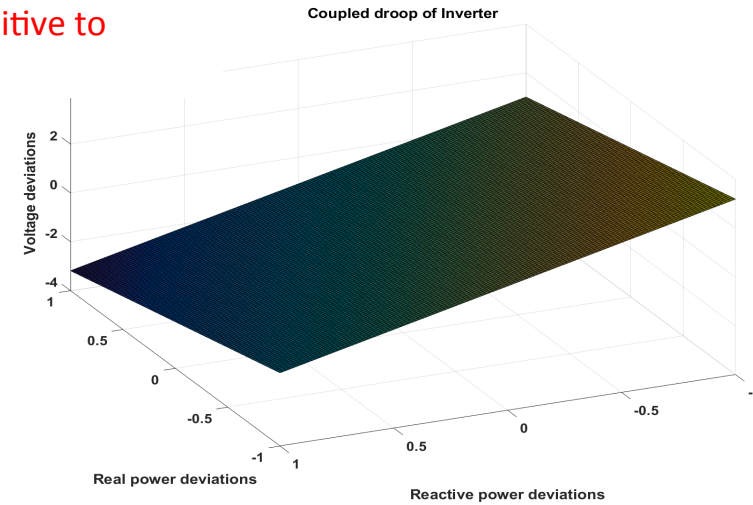
Implementable market bids based on generalized physics-based coupled droops

WATER HEATER/ HVAC

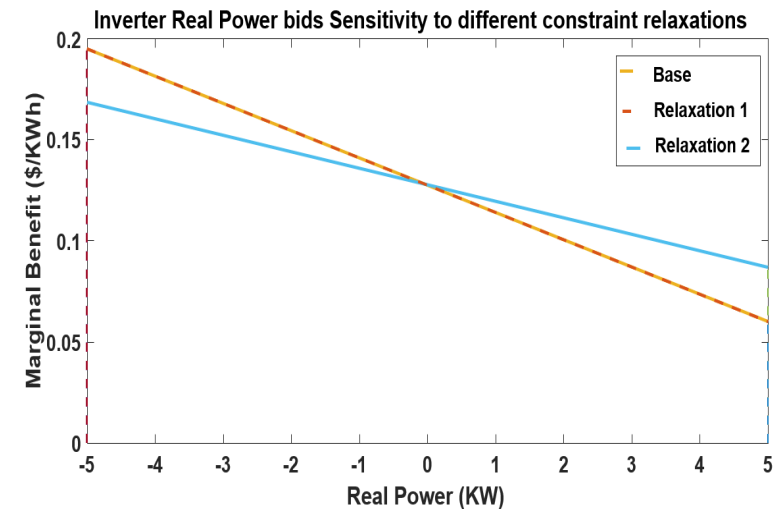
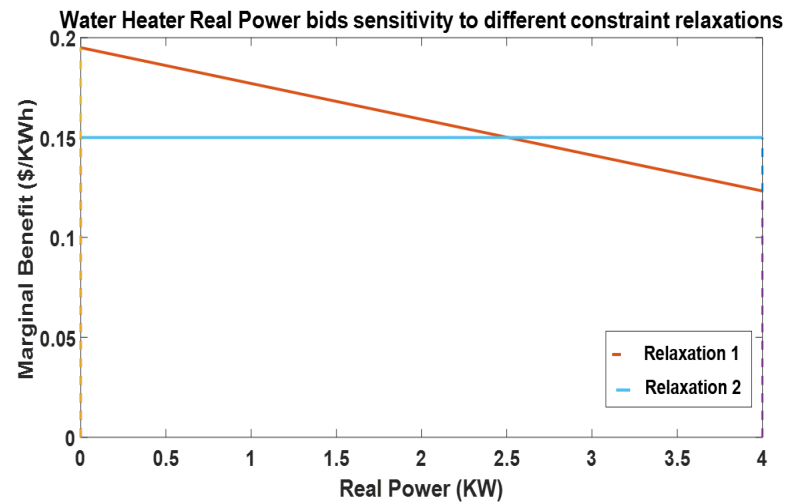


Inverter more sensitive to voltage violations

SOLAR PV/ BATTERY

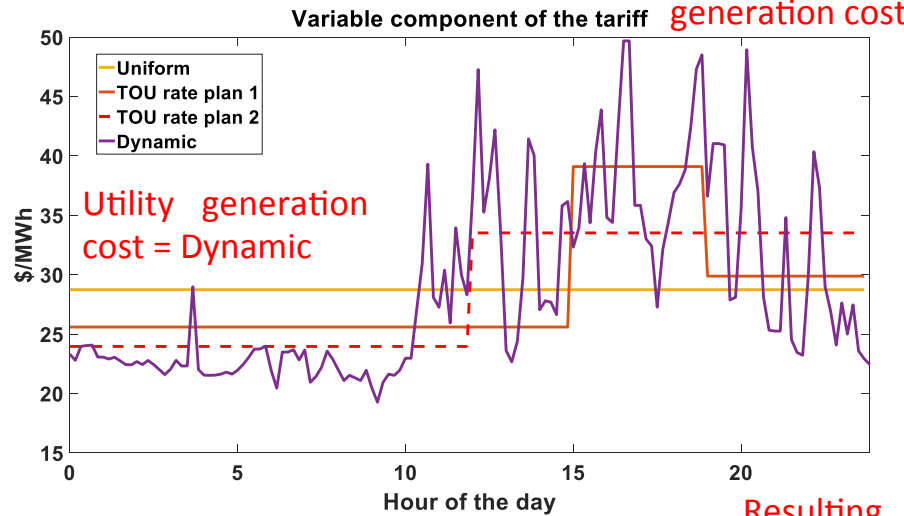


Effect of comfort constraint relaxation on the price elasticity



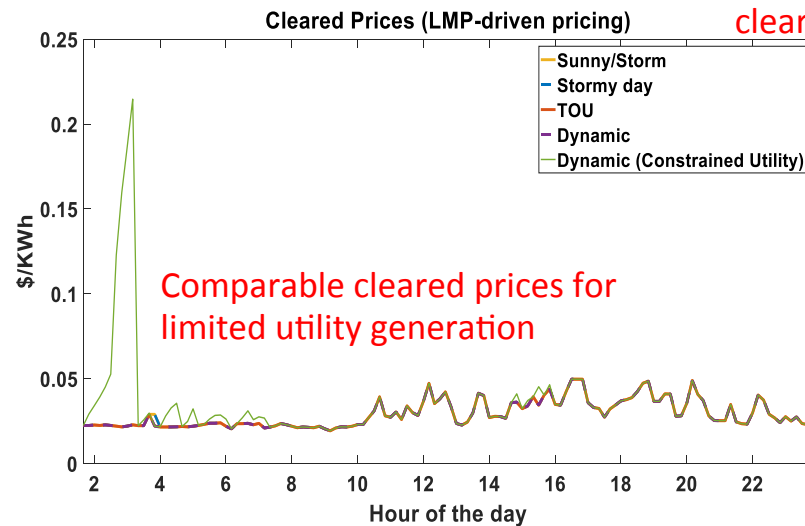
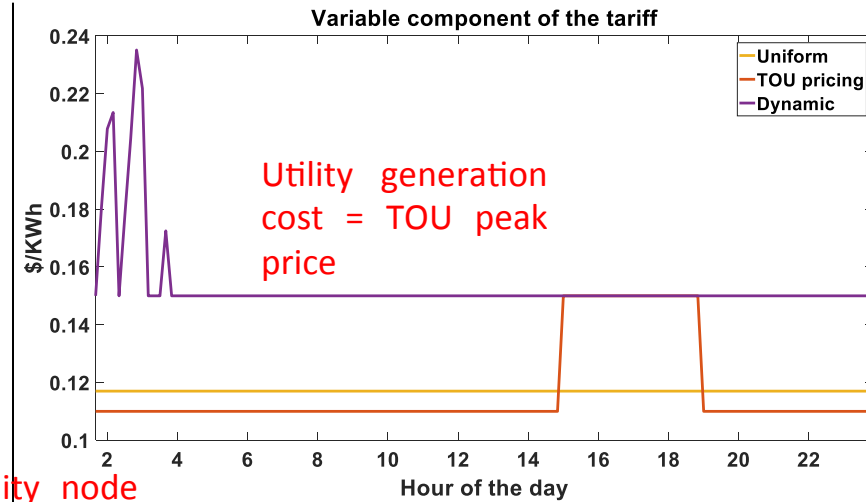
Multi-layered interactive decision-enabled dynamic pricing (TEM) Vs conventional pricing mechanisms

Time-varying LMP-driven

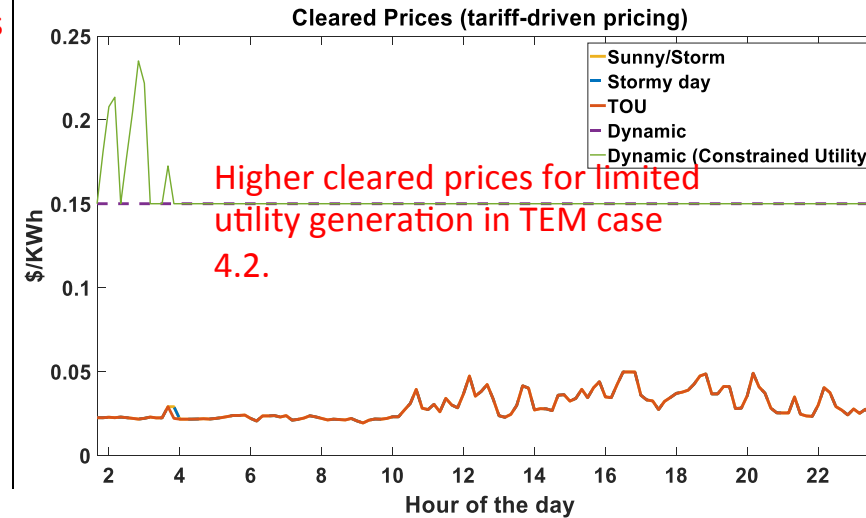


Possible tariff structure for each of the TEM cases, for assumed utility generation cost

TOU Tariff-driven

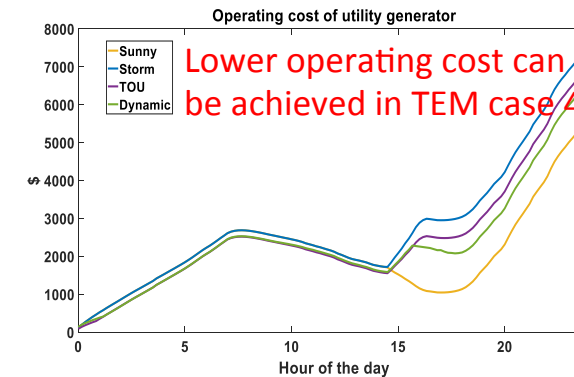
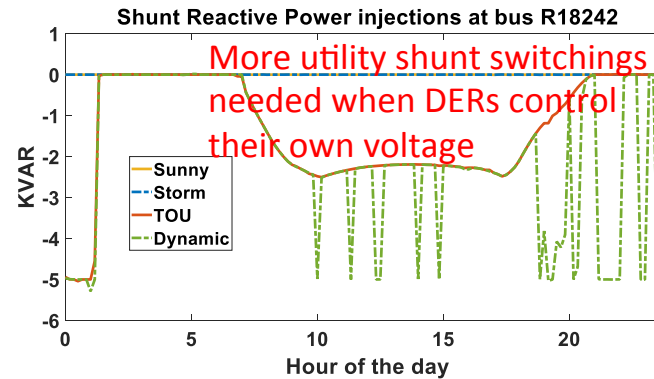
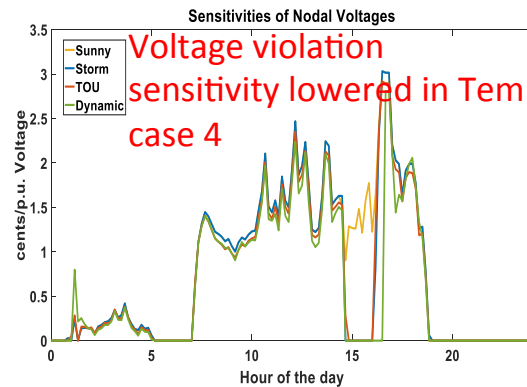
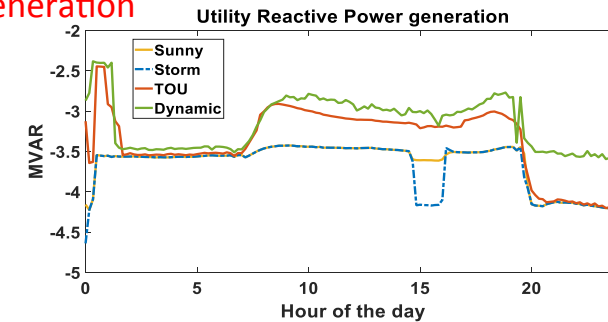
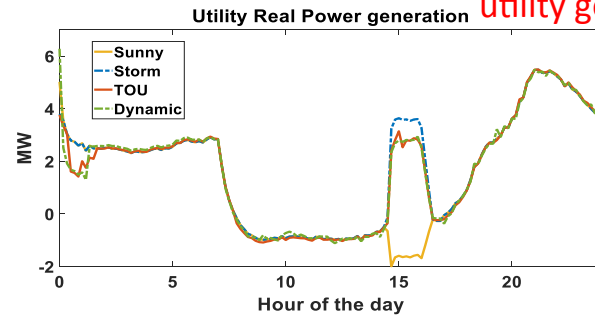
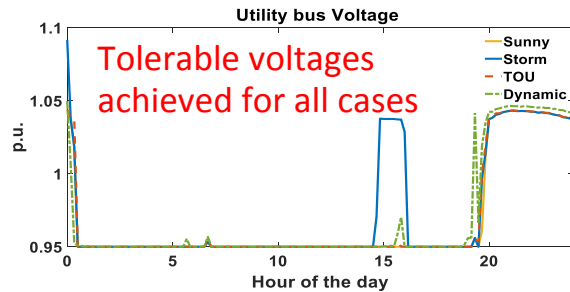


Resulting utility node cleared prices



Impact of transactive energy market (TEM) on utility— technical and economic metrics

Effect of MPC resulting in lesser
requirement of ramping reserves of
utility generation

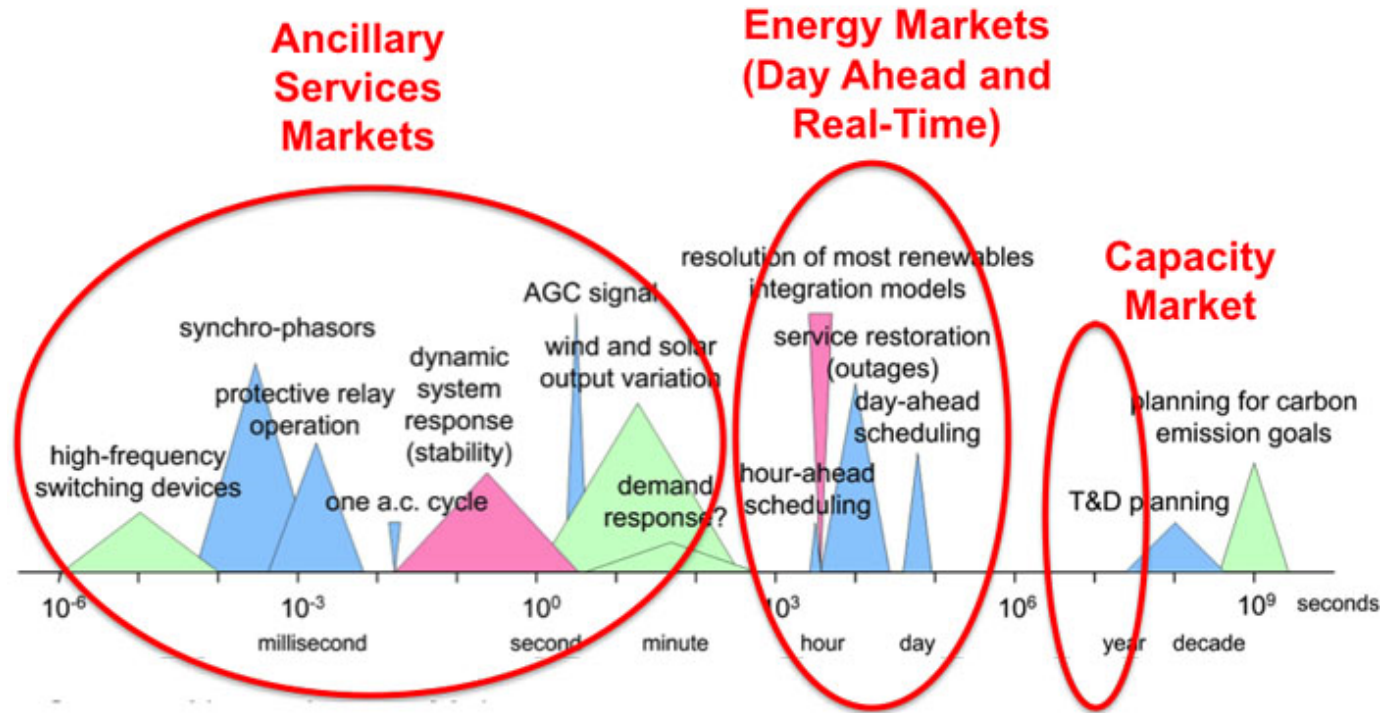


OBSERVATIONS—UTILITY COULD PLAY A MAJOR ENABLING ROLE; BASIS FOR PEAK LOAD PRICING AND PERFORMANCE BASED REGULATION

Cyber-security integral part of IT/OT system

- ❖ Aggregate variables representing iBAs for interacting with the rest of the system encrypted (by design!); could have IT/OT to dynamically aggregate and exchange information so that attacker never knows how is aggregation done
- ❖ Transparent multi-layered, not too complex. Could have lots of software for computing/and comparing with measurements to detect IT attacks.
- ❖ SEEDS project on iBA-based method for detection and protection against cyber attacks in energy systems

Typical Markets---dual-primal decomposition; provable; flexibility at value



Von Meier, A., (2006) Electric power systems: a conceptual introduction. John Wiley & Sons. PJM Interconnection LLC (2017) Demand Response Strategy Tech. rep.

Conclusions—

- ❖ Two (multi)-level transformed state space formulation of decision making in the changing electric energy industry lends itself to non-convex dual optimization problems
- ❖ Natural alignment of economic incentives, efficient scheduling and end user choice
- ❖ Can be used for establishing standards protocols and giving the right incentives (NEW PROTOCOLS FOR RELIABILITY/RESILIENCY; RISK MANAGEMENT)
- ❖ Next step— distributed management of uncertainty
- ❖ Lower layer specifications must be defined in terms of common technology-agnostic variables

Recommendations

- ❖ Recommendations for further discussion of the proposed energy-space based next generation SCADA for reliable and efficient data-enabled electricity services at value.
- ❖ The entire approach can be interpreted using concepts from basic disciplines, a possible path to multi-disciplinary education.
- ❖ This general proposal was made to FERC in an invited testimony on state of reliability.

THANK YOU