Toward standards for dynamics in future electric energy systems—

The basis for plug-and-play industry paradigm

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Outline

- Overview of current NERC standards and evolving standards for wind and solar plants
- Issues with current standards
- Our proposal :
  - Plug-and-play (TCP/IP) like protocols/standards
  - Introduction of intelligent Balancing Authority (iBAs)
- Examples of iBAs
- Theoretical foundations for new standards (TCP/IP like)
- Proof-of-concept examples of controller designs which meet such protocols

NERC standards Transmission Planning Standards

- System simulations and associated assessments are needed periodically to ensure that reliable systems are developed that meet specified performance (http://www.nerc.com)

Category	Contingencies	System Stable and both Thermal and Voltage Limits within Applicable Rating	Loss of Demand
A	No contingency	Yes	No
B	Event resulting in the loss of a single element.	Yes	No
C	Event(s) resulting in the loss of two or more (multiple) elements.	Yes	Planned/ Controlled
D	Extreme event resulting in two or more (multiple) elements removed or Cascading out of service.	Evaluate for risks and Consequences. - May involve substantial loss of customer Demand and generation in a widespread area or areas. - Portions or all of the interconnected systems may or may not achieve a new, stable operating point. -Evaluation of these events may require joint studies with neighboring systems.	

Evolving standards for Wind and Solar Generation Technologies

- voltage/var control/regulation
- voltage ride-through
- power curtailment and ramping
- primary frequency regulation
- inertial response

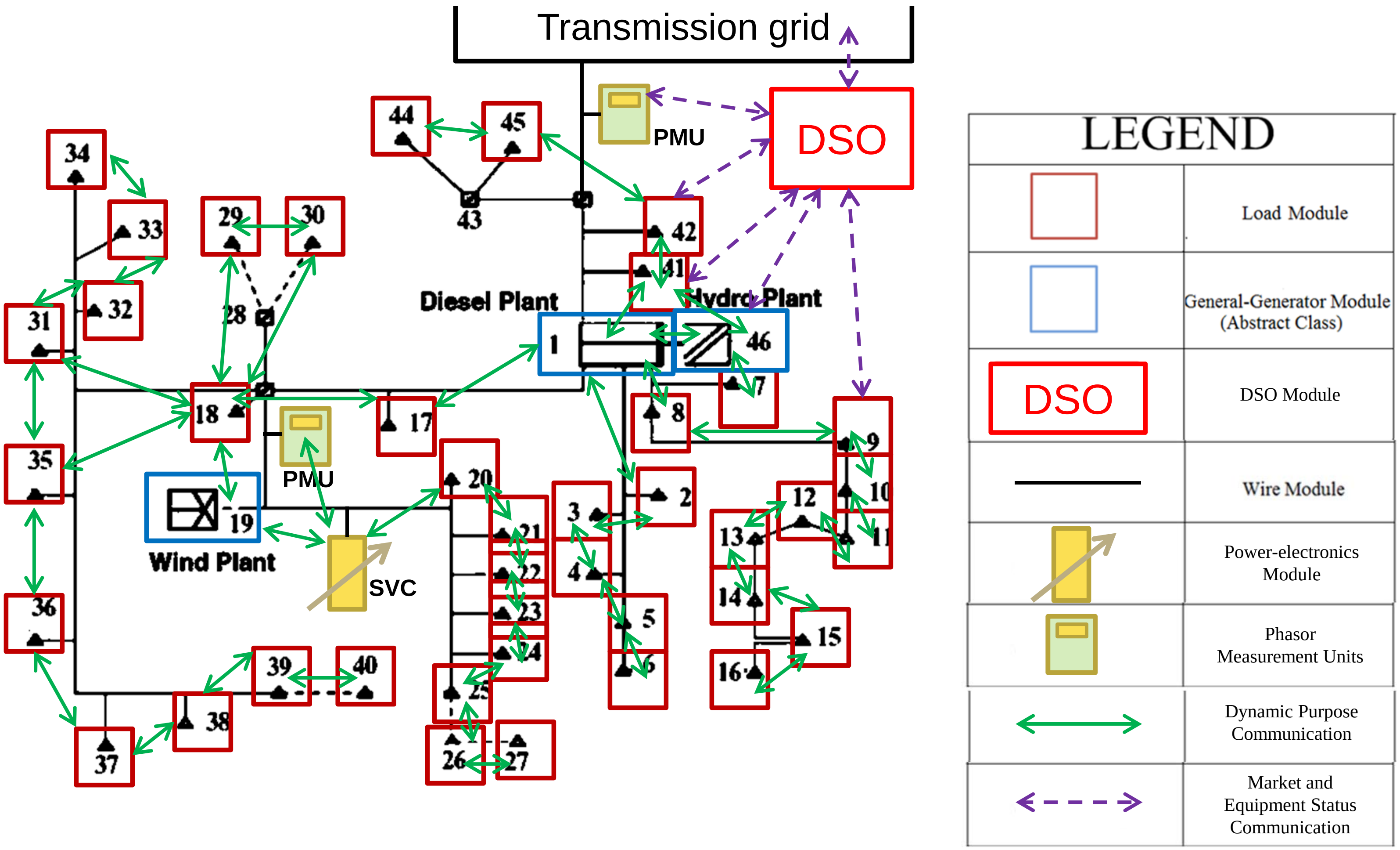
http://www.nerc.com/files/2012_IVGTF_Task_1-3.pdf

NERC 2012 Special Assessment: Interconnection Requirements for Variable Generation September 2012

Need for a new paradigm

- Today's industry approach– the worst case approach, inefficient and does not rely on on-line automation and regulation other than energy feed-forward economic dispatch
- Emphasis on large-scale time-domain system simulations for transient stability, voltage, collapse, power flow feasibility, etc
- Primary control is constant gain tuned assuming no dynamic interactions with the rest of the system
- Existing and emerging system-level unacceptable interactions; no incentives for ``smarts" of modules

Information exchange in the case of Flores---new (lots of dynamic control and sensing)



Possible dynamical problems seen by particular dynamic components

	Dynamical problems							
Types of Component		Small signal instab.	Transient instab.	SS R	SSCI	Freq. instab.	Volt. Instab.	Power flow imbalance
	Synchronous generators	?	?	?	?	?	?	?
	Wind generators	?	?	?	?	?	?	?
	Solar plants	?	?	?	?	?	?	?
	FACTS	?	?	?	?	?	?	?
	Storage	?	?	?	?	?	?	?

Table 1.

Our proposal: TCP/IP like standards

- Given **specified disturbances and range of operating conditions within a known system**:

  - specified with e.g voltage, power
  - similar to LVRT curves for wind turbines
  - with specified duration

- **All components** (synchronous gens, wind gens) **should guarantee** that they would not create any of the problems in Table 1. (Clear objectives goals for components, assigned responsibility for system reliability)

- Two key **questions**: Q1-- Why does it matter?

  Q2)--- Can this be technically done?

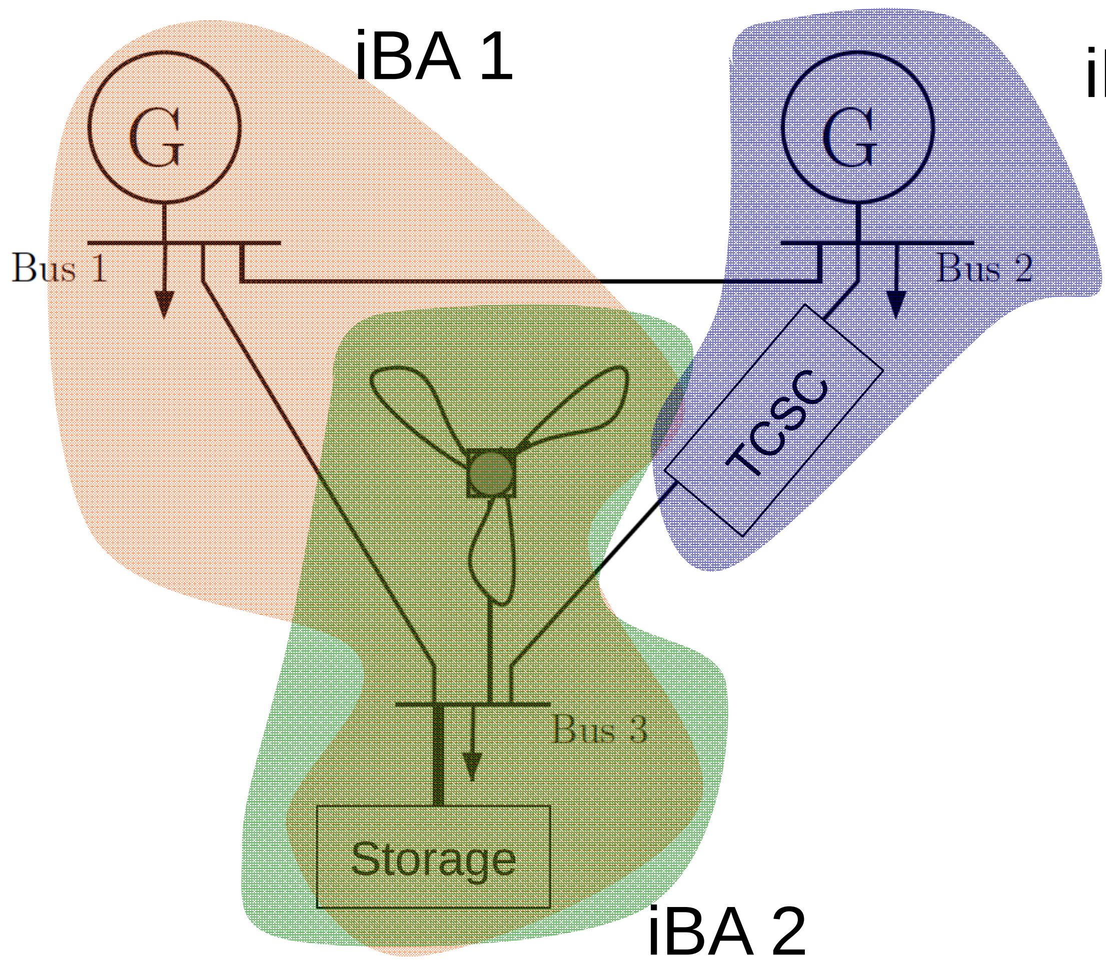
  Not one way to achieve these!

Not one way to meet the standards -iBAs

- **iBAs (intelligent Balancing Authorities)**
  - **Single component** or **group of components** which meet the desired objectives: Given **specified disturbances** their components do not cause any of the dynamical problems in Table 1.
  - **Dynamic notion** of Control Areas—intelligent Balancing Authorities (iBAs)
- iBAs **would utilize advanced control design** methods to meet the protocol; could be either decentralized or wide area control (cooperative control to save on number of controllers and energy used within the iBA)
  - Huge potential for **exploiting efficiently new technologies** like **storage** and **FACTS** and at the same time have guaranteed system performance

S.Baros, M.Ilic intelligent Balancing Authorities (iBAs) for Transient Stabilization of Large Power Systems IEEE PES General Meeting 2014

A1: Examples of iBAs—it matters for ensuring both reliable and efficient operations



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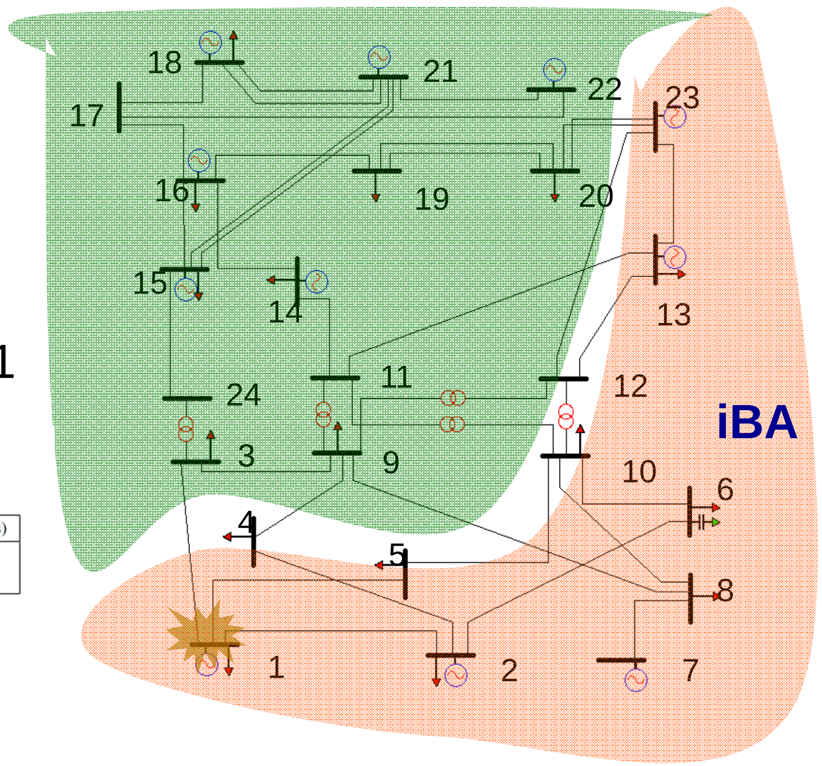
Possible to create iBAs for meeting transient stability distributed standard

Given disturbance
Tripping of generator 1

TABLE I
CONTINGENCY CONSIDERED ON
THE IEEE RTS 24 BUS SYSTEM

CONTINGENCY (CATEGORY B)	DURATION (secs)
Tripping of generator 1 after 3-phase fault on its terminal bus	0.17



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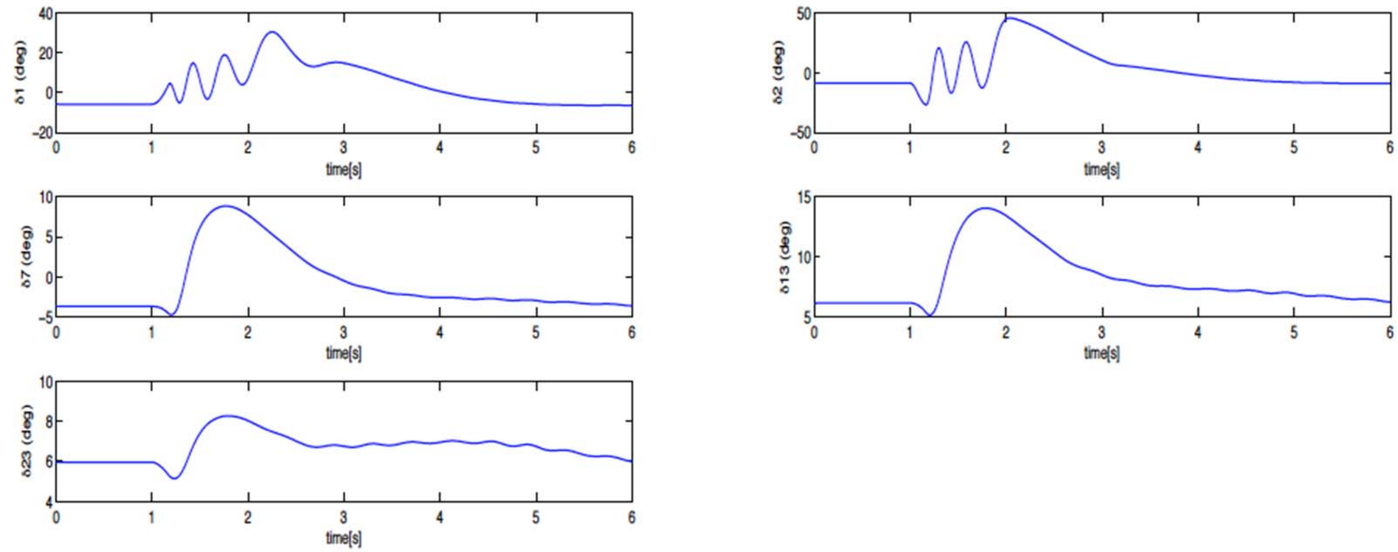
Rotor angle response of iBA generators



(b) Transient stabilization of critical generators i=1,2,7,13,23 with iBA-based control in low-load scenario

Q2: Can we have a unifying theoretically sound approach to TCP/IP like standards for smart grids?

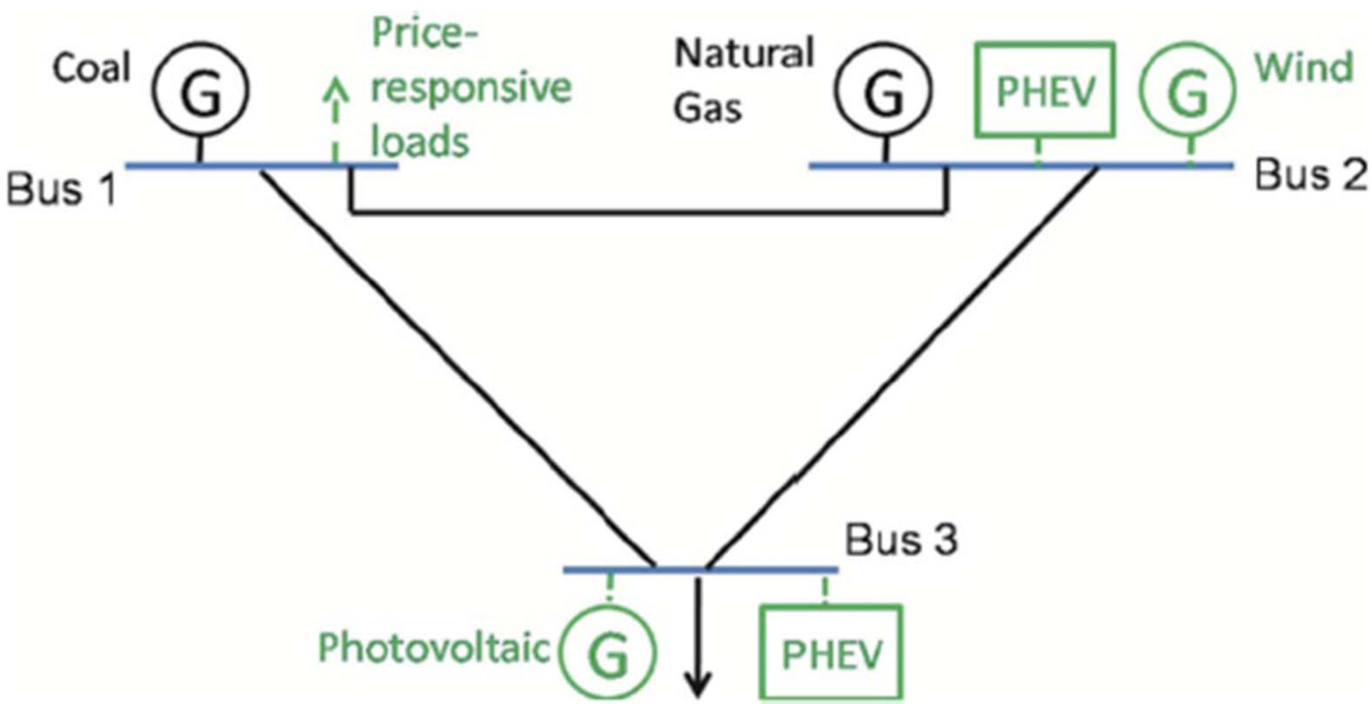


Fig. 5. Small example of the future electric energy system.

Basic functionalities

- Simple transparent TCP/IP like functionalities
- Transparency based on a unifying modular modeling of network system dynamics
- Provable performance-difficult
- Proposal—use interaction variables to specify family of standards sufficient to avoid operating problems
  - Measure of how well modules balance themselves in steady state
  - Measure of rate of exchange of stored energy between a module and the rest of the system over different time horizons

Unifying modeling and control approach—use of multi-scale interaction variables

- Standards/protocols --- specifications of module interactions for plug-and-play operations; architectures define how are sets of protocols organized
- Cyber design for managing multi-layered interactions
- New physics-based modeling and control as the basis for interaction variables-based protocols
- Illustrations of possible standards-based enhancements (transient stabilization using power electronics switching; storage control in micro-grids)

Must simplify as much as possible, but not more!

- Utilities are having hard time adding all these new components and their smarts for simulating system-wide dynamics
- Is there a ``smarter" way to model and define modular functionalities so that the interconnected system meets system-level performance (Table 1)?
- 80% of each solution is modeling (Petar Kokotovic, Chalenges in Control Theory, Santa Clara, circa 1982)

Conclusions

- Our proposal: Interaction variable-based
- Rigorous way to minimize information exchange among distributed entities
- Standards/protocols for interactive iBAs can set the basis for plug-and-play in smart grids—bounds on stored energy change and on rate of change of stored energy for T of interest
- Standards need to define transparent protocols for all dynamic components
  - Complexity of smart grids can be managed this way
  - At the same time system performance is guaranteed
- With current NERC standards system performance cannot be mapped into responsibilities of different components