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)

<table>
<thead>
<tr>
<th>Category</th>
<th>Contingencies</th>
<th>System Stable and both Thermal and Voltage Limits within Applicable Rating</th>
<th>Loss of Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>No contingency</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>B</td>
<td>Event resulting in the loss of a single element.</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>C</td>
<td>Event(s) resulting in the loss of two or more (multiple) elements.</td>
<td>Yes</td>
<td>Planned/Controlled</td>
</tr>
<tr>
<td>D</td>
<td>Extreme event resulting in two or more (multiple) elements removed or Cascading out of service.</td>
<td>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.</td>
<td></td>
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</tbody>
</table>
Evolving standards for Wind and Solar Generation Technologies

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

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

<table>
<thead>
<tr>
<th>Types of Component</th>
<th>Dynamical problems</th>
</tr>
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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
Possible to create iBAs for meeting transient stability distributed standard

**Given disturbance**

Tripping of generator 1

**TABLE 1**
CONTINGENCY CONSIDERED ON THE IEEE RTS 24 BUS SYSTEM

<table>
<thead>
<tr>
<th>CONTINGENCY (CATEGORY B)</th>
<th>DURATION (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripping of generator 1 after 3-phase fault on its terminal bus</td>
<td>0.17</td>
</tr>
</tbody>
</table>

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