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Grid Physics and Markets: A Non-Engineer's Perspective

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ESIG Down Under:

Understanding the Physics - Markets interface

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Who am I?

- Senior Fellow at Energy Innovation working on policies for power sector transformation and decarbonization. Lots of focus on market design at the hourly/sub-hourly to investment scale.
- Not an electrical engineer, but was a physicist (working on high-energy theory and quantum gravity, completely relevant to bulk power system design, right?)
- Goal is to offer an outsider's perspective. I've learned a lot over the last 13 years of working on renewables policy, but everyday I realize more and more how much I don't know.

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Markets and Physics: Three Approaches

- **Direct Markets**: These use security constrained economic dispatch to integrate physical constraints for transmission and matching supply and demand locally in hourly or sub-hourly intervals. Physics connects to markets best with transparent presentation of constraints through "shadow price", aka locational marginal pricing with deviations from system price for congestion and electric losses
- **Standards**: Standards for generator performance and other bulk power system assets helps create standardized products which can be bought, sold or traded for more economic efficiency. Standards also create opportunities for new technologies, markets in the broader sense, to help meet standards behind the bus-bar. Standards can hinder or accelerate
- **Tenders and Requests for Proposal**: Transmission and distribution utilities, network operators in aus-speak invest to fulfill their obligations and serve customers. These tenders meet physical requirements, but how they are written affects the implementation of new technologies and protection schemes (as with standards). Tenders narrow or wider in scope affect how "physics" problems get resolved.

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Questions from ESIG 2019
"Toward 100% Renewable Energy Pathways: Key Research Needs"

- Simulation Tools: New tools and understanding the limitations of old one
- Protection schemes that work well as synchronous generators are replaced by power electronics
- New designs for bulk power system restoration and black start with high power electronics
- Impact of system harmonics and resonance on power electronic converters; design of mitigation measures

- Control and stability with high contribution of power electronic converters
- How to unlock advanced capabilities of power electronics? Standards or markets?
- What is the role of synchronous generation during transition to high VER penetration grid?
- DC components within AC grid. What is the balance between the two, how are they planned and operated together.

Increasing Role of Market

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Communication vs Power Provision

- We think of machines in the bulk power system as giant taps for electricity.
- But they also maintain the overall machine that is the grid.
- To do so they have to effectively communicate and react to contingencies, this done explicitly and via state variables like frequency, voltage, harmonic distortion etc.
- My outsider observations coalesce into three themes:
  - The Machine is the Filter
  - Passive vs Directed Response
  - The Fractal Grid

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The Machine is the Filter

- Bulk powers system resources monitor local conditions via sensors and/or pure electromechanics.
- Each machine effectively "filters" the "signal" that is voltage, phase, harmonics etc. at the point of interconnection and reacts in a predictable way.
- Moving to inverters, sensors, batteries, capacitors and processors brings this into the digital age, but we still want common models for how new generating machines will monitors the signal and reacts to it, and for how new loads do likewise (e.g. ride-through, conditions for tripping etc.).
- Challenge for markets is how to define appropriate functionalities in interconnection. Do we create different classes of resources that participate in markets differently, or move to a universal model and make resources adapt (i.e. hybridized)? For example, start-times on fossil units. What responsibilities do loads have? Should they change their protection schemes to adapt?

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Passive vs Directed Response

- Each resource connected to the grid has agency, and that agency can be reactive to local conditions (passive response) and it can also be directed via a central dispatch signal (directed response).
- In the passive case, the resource has a predictable electro-mechanical or algorithmic response which must be modelled ahead of time to understand collective effects, stability, disturbance response etc. But resources also receive dispatch order from the system operator.
- Traditionally, different resources communicate with each other via state variables like frequency over short durations, and central dispatch orders of system operator. Emergent aggregate behavior is analog.
- What happens if we can add fast low-latency communication to coordinate resources milli-seconds? How do we pay for this? Are these new products for markets?

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The Fractal Grid

- Lorenzo Kristov (then at CAISO) proposed that we could see the evolution of a fractal grid, where the system is organized in a series of layers that take on some operational responsibilities and pass through others akin to object-oriented programming.

- Some of this already happens at points of intersection but could become more generalized with aggregators or active control schemes.

- How does system security operate in this context and align with markets?

- How do networked microgrids interact to support security? Via set protocols and agreed-upon burden sharing or economic trading instead?

Structural issues with markets and new physics

- Micro-Economic focus, not good at infrastructure/platform build out.

- Markets need a fungible commodity to trade and take advantage of collective intelligence.

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Looking forward to panel discussion and learning more from real experts!

(follow up at eric@gimon.org)