Autonomous Energy Grids: Bringing Everything Together

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NREL Workshop
September 13-14, 2017

Vision for autonomous energy grids (AEGs)

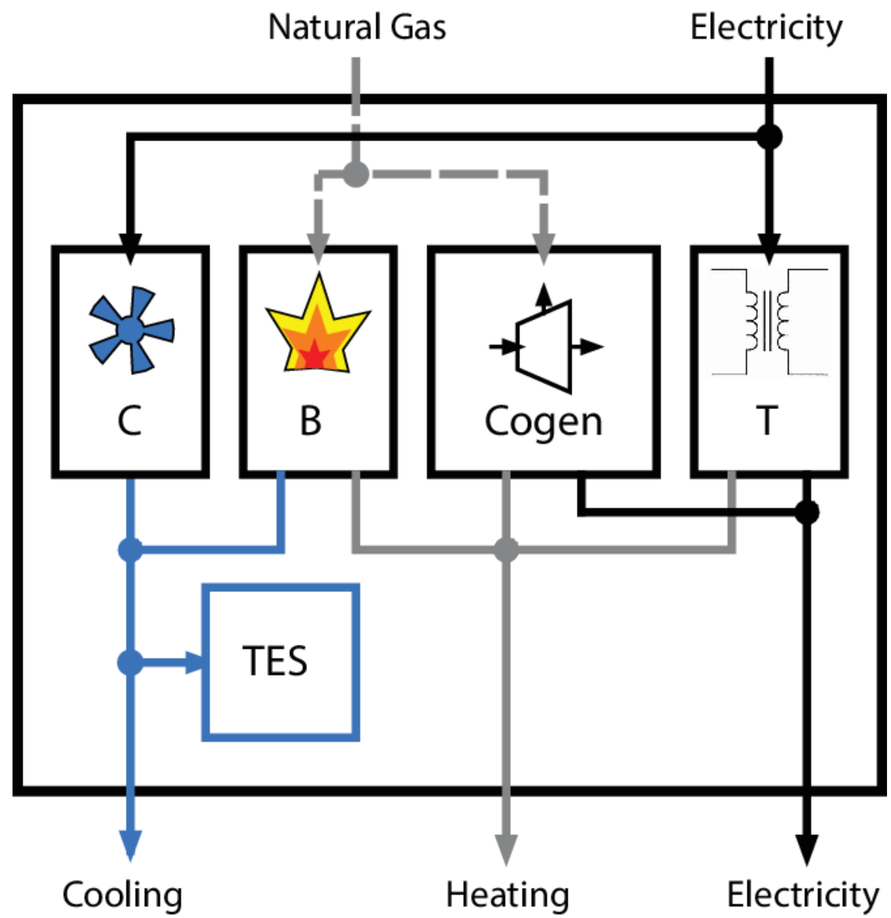
- Autonomous grids – able to seamlessly connect and disconnect from other grids.
- Incorporate variable generation, energy storage, controllable loads, multiple energy carriers, energy conversion.
- Supported by a scalable, reconfigurable, self-organizing information and control infrastructure.
- Capable of a high level of security and resilience.
- Self-optimizing in real time for economic and reliable performance.

Transition

- What might motivate/justify a move to AEGs?
  - Economic benefits for consumers? For utilities? Others?
  - Reliability improvements.
- What technical issues might arise in transitioning to a network of AEGs?
  - Can older devices be incorporated? Example: autonomous vehicles have trouble coping with illogical drivers.
  - Standards and interoperability.
- Socio-economic issues arising from stranded assets due to reduced reliance on the grid.
  - Who pays? Poorer consumers who can't afford to join an AEG?
  - Policy.
- Who is responsible for the design of AEGs (cable size, protection, communications, …)? What about safety?

Energy hubs as AEGs

- Energy hubs are building blocks of multi-energy systems.
- Questions relating to dynamics, optimization.
  - Example: fuel cells are non-minimum phase.
- Chilled water plant, C.
- Steam boiler plant, B.
- Gas turbine cogeneration plant, Cogen.
- Electrical transformer, T.
- Thermal energy storage, TES.



Large versus small systems

- Physics-based energy storage inherent in the rotating mass of large generators results in 'slow' changes in frequency.
  - Controls govern the time constants in inertia-less AEGs.
  - Is it even necessary for tight frequency control in AEGs?
- Diversity across large numbers of loads gives smoothing and predictability.
  - Probably not the case for many AEGs.

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Some technical issues

- Protection.
  - "If it can't be protected then it can't be built."
  - What level of sophistication is required?
  - Who designs and pays?
  - Adaptation is probably necessary as AEGs reconfigure.
- Is it necessary for tight frequency control in AEGs?
- Synchronizing AEGs and the grid requires frequency control (and special circuit breakers).

Data analytics

- The highly adaptive nature of AEGs implies the need for real-time assessment of network structure and parameters.
  - Real-time state and parameter estimation.
  - Needed for optimization, control, protection, …
- Techniques for wide-area monitoring (using PMUs) may not be applicable for AEGs.
- Learn the patterns of generation and load.
  - Diurnal behaviour of consumers, solar production.
  - Determine occupancy. Though privacy issues.
  - Exploit weather forecasts.

Optimization

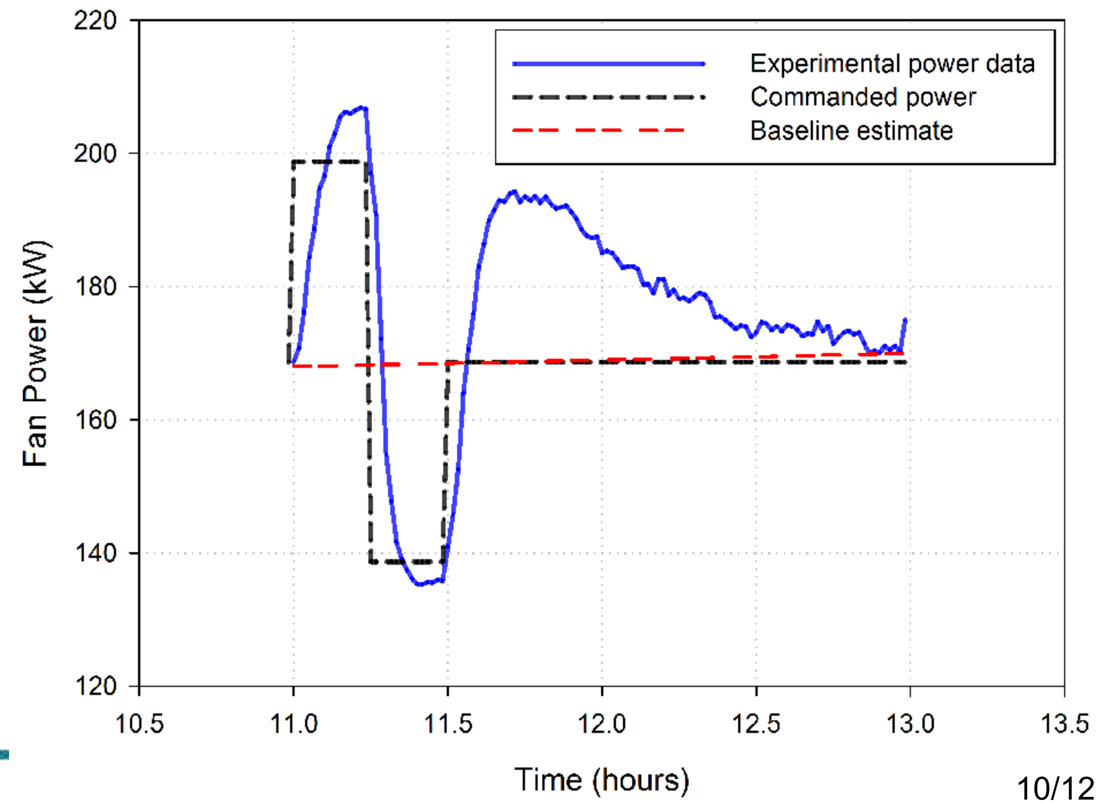
- Purchase agreements with neighbours, utility.
  - How much should I pay?
  - Consumers are unlikely to want to get involved so the process should be automated.
- Optimization of storage with limited future information invariably results in suboptimal scheduling.
  - Exploit learned behaviour as best possible.
- Games will (most likely) arise through competing objectives.
  - Benign interactions don’t happen by chance. Everyone wants to exploit the cheapest energy.
- Need to consider stochasticity.
  - Determine both the optimal operating condition and optimal policies that address deviations from the forecast.
  - Can this be handled in a distributed manner?

Control

- Primary frequency control is fairly straightforward, particularly droop-based strategies.
  - Should avoid controls that need to know if the AEG is interconnected or not.
- Secondary control relies on optimization.
  - May require distributed/consensus algorithms.
- How useful are prediction-based algorithms when the future is so uncertain?
  - Example: model predictive control.
- Sophisticated systems may introduce vulnerabilities, whereas simpler, more secure systems are sub-optimal.
- Uncontrollable devices may overwhelm controllable assets.

Load control

- Loads frequently undergo discrete jumps.
  - Control strategies that exploit aggregation may not be applicable for small populations within AEGs.
  - Queueing/scheduling controls may be more useful.
- How can control response be validated when the baseline is unknown?
- Does controlling load incur an extra cost?



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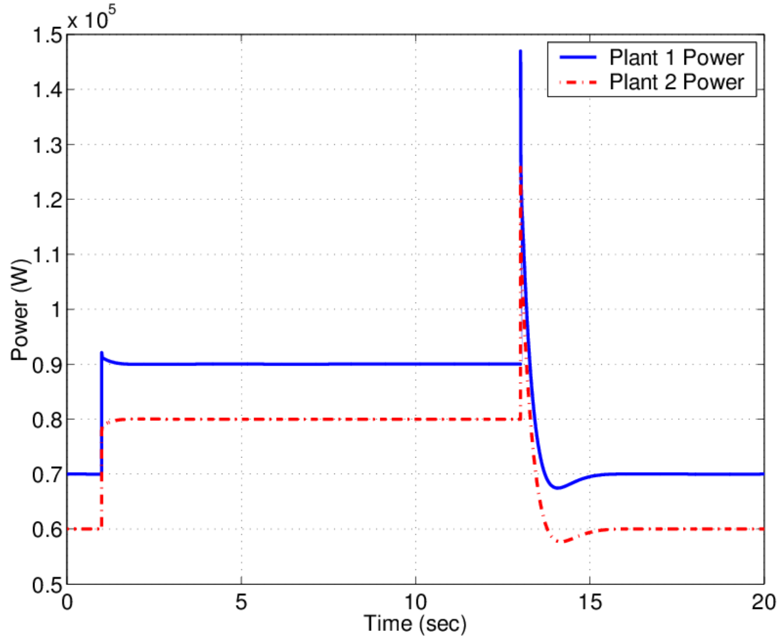
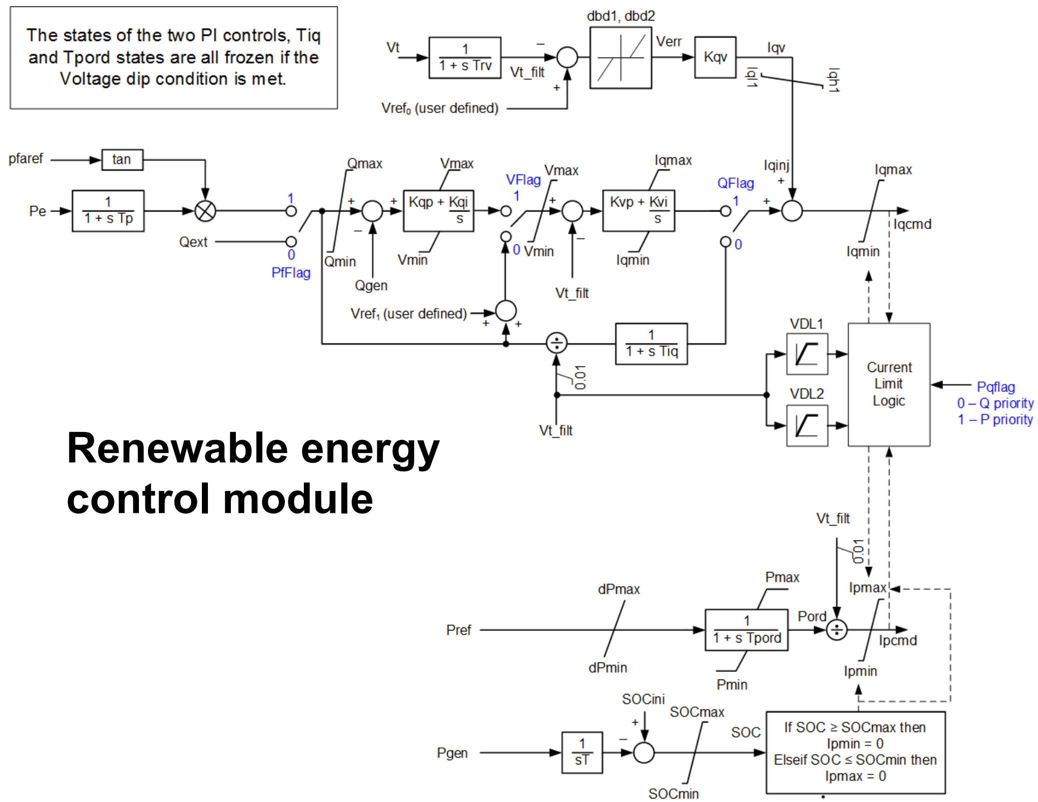
Analysis (1)

- With much faster dynamics, how appropriate are phasor-based models?
- AEG systems are stochastic, hybrid (continuous/discrete) nonlinear dynamical systems, with uncertain delays.
  - A system may be stable in two different configurations but switching between them results in instability.
  - Can stability be guaranteed or is simulation required?
  - Are there computationally efficient approaches to handling uncertainty?



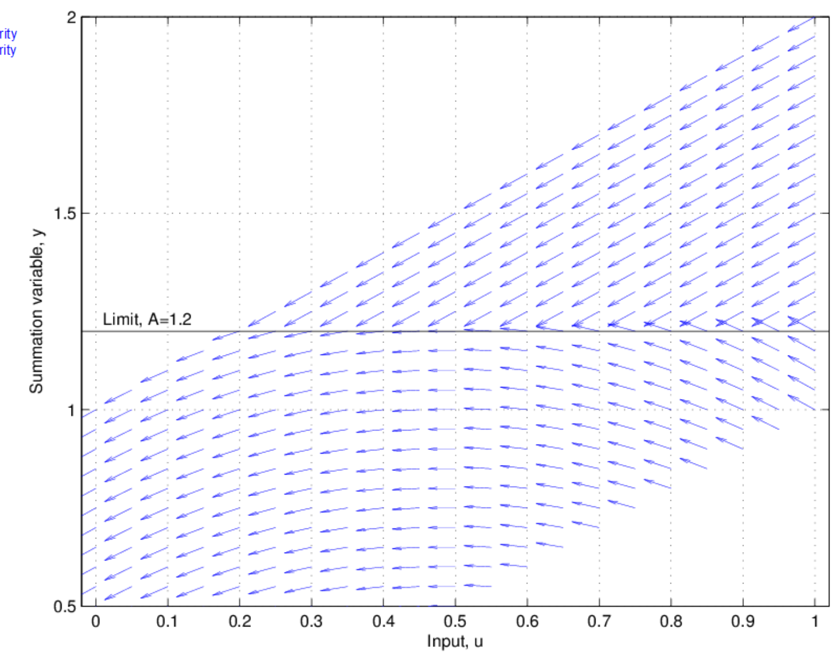
Analysis (2)

- Dynamic models may be complex.



Renewable energy control module

Deadlock due to poor implementation of non-windup PI control



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