Energy Storage System Response

Presentation for IPS Connect
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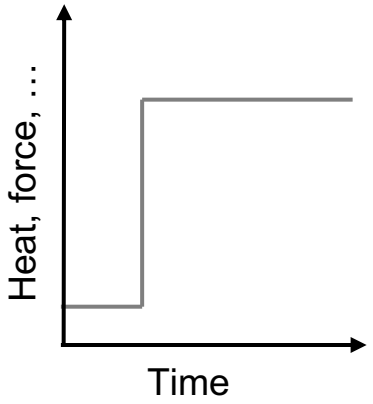
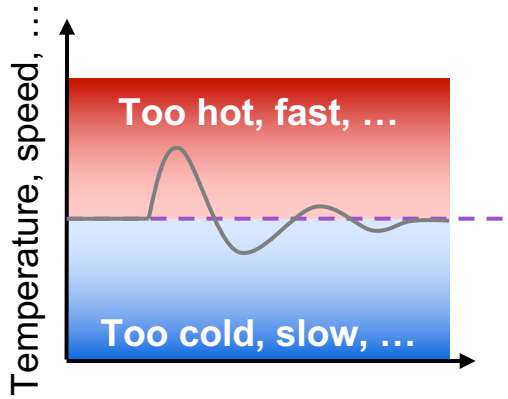
Outline / Goals of Presentation

- Lay some fundamentals regarding grids and system response
- Explain the problem and why we care
- Discuss related challenges and opportunities of batteries and other energy storage systems

What is System Response? Why does it matter?

Input, “force”, or “disturbance” → **System** → Output or “state” over time





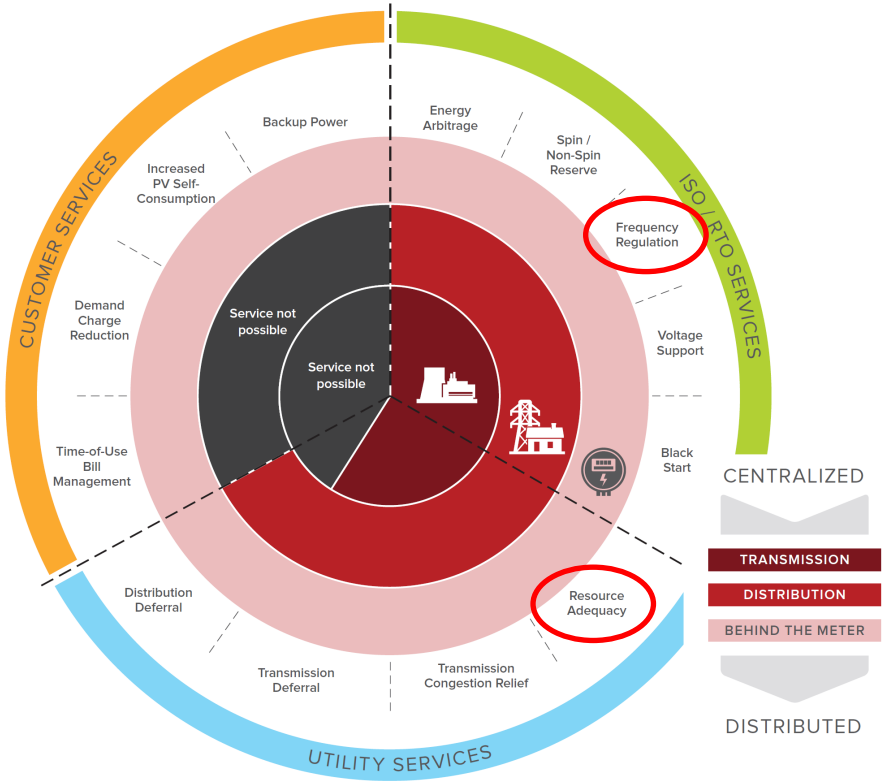
We want to return to the target or “sweet spot” as quickly, reliably, etc. as possible to prevent damage, maintain comfort, etc.

Ok, what about grids and renewable energy?

- The grid requires a dynamic balance between generation and load in order to maintain steady frequency near 60 Hz.
- The balance is buffered by inertia or rotating mass of synchronous machines.
- However, wind and solar introduce several challenges here:
    1. They do not provide inertia, which means there is less time for frequency control to respond to prevent brownouts or blackouts.
    2. They are variable, which means frequency controls must be more active to balance supply and demand.
    3. They are not dispatchable and their output does not generally match the load.
    4. Behind-the-meter (BTM) generation (rooftop solar) may also
        - disconnect during an under-frequency event, potentially causing cascading failures and blackout
        - complicate underfrequency load shedding schemes, which will also shed generation

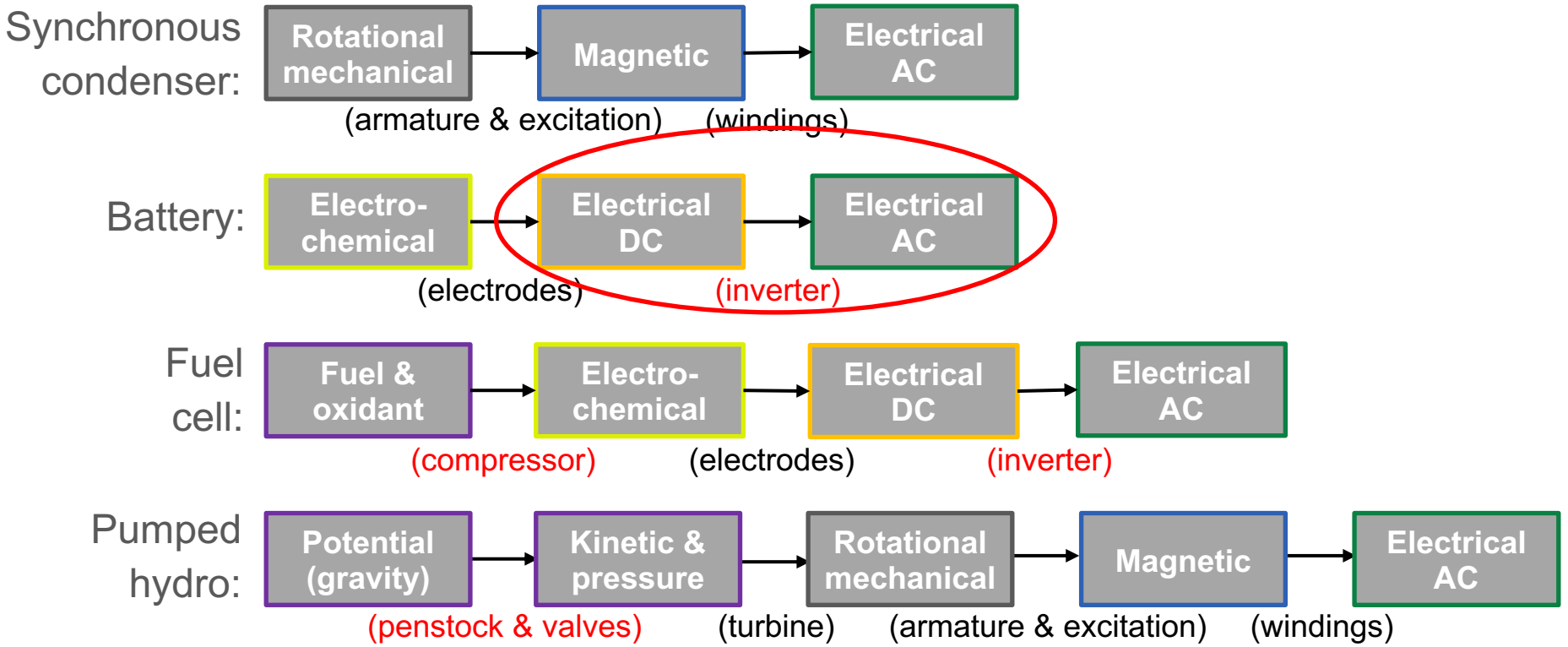
The Case for Batteries

- In theory, batteries can address these challenges (and more) by providing:
  1. “synthetic inertia”
  2. frequency regulation
  3. renewable energy “firming” – making wind and solar dispatchable
- All of these require energy storage, but over widely different timescales from milliseconds to hours.
- So, what are the limits on the response of batteries and other energy storage?



[Rocky Mountain Institute, *The Economics of Energy Storage*, 2015]

Fundamental Limits on Response Rates



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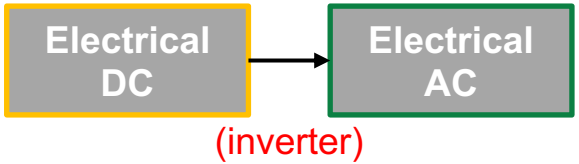
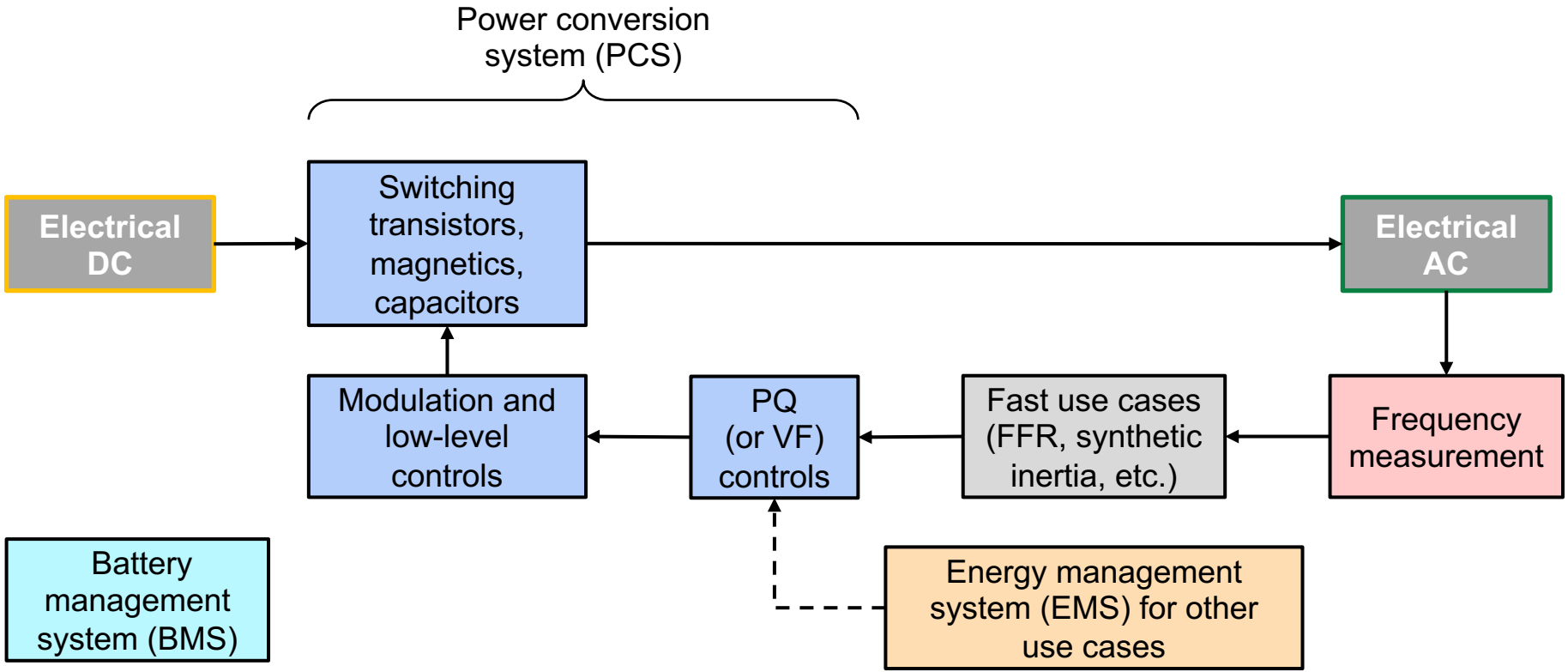


Fundamental Limits on Response Rates



Fundamental Limits on Response Rates

Large stack-up of control path delays:

Measurement delays

\+ polling and message-rate delays

\+ processing delays in controllers

\+ response time of inverter

= Limited performance for low-inertia applications

= Potential control instabilities

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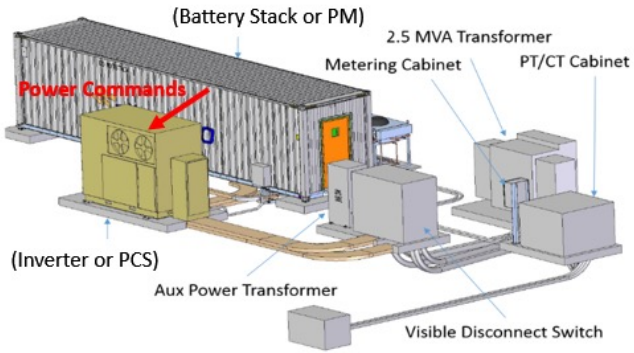
management
system (BMS)

Energy management
system (EMS) for other
use cases

HNEI's Experience with Molokai Battery for "Aggressive Response"[1]

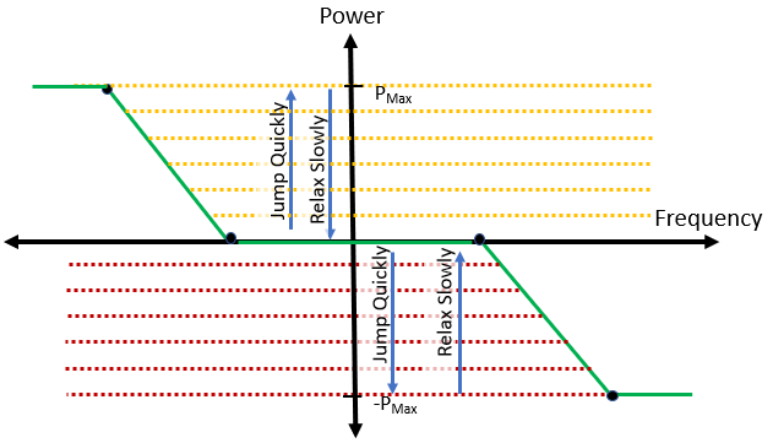
- According to detailed modeling study, the BIS (battery inverter system) was supposed to have a control path delay of < 50 ms due to the low-inertia nature of Molokai grid
- Larger delays (> 50 ms) are troubling
  - will limit battery's performance in avoiding over- and under-frequency events
  - could lead to control instability, particularly with the high gains that are needed
- At first the battery could only achieve 250 ms; this required rework of the frequency measurement and internal communications.



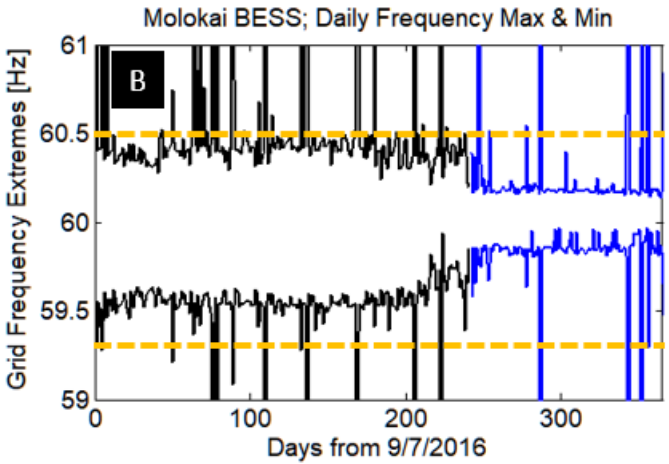
[1] [Moe Tun, "Testing and Operation of a Battery Energy Storage System with an Aggressive Response Supporting a Low-Inertia Grid", not yet published]

HNEI's Experience with Molokai Battery for "Aggressive Response"[1]

- A modified frequency-watt approach was used to apply fast frequency response to the low inertia grid.



- The system significantly reduces grid frequency excursions with 500 kW of authority (blue).



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Conclusions & Final Remarks

- In theory, batteries can respond very quickly (electrochemistry + transistors) but in practice it is challenging due to the stack-up of control path delays.
- This must be solved for apply the desired capabilities to low inertia grids.
- Here we have focused on active power; reactive power and voltage support can also be provided by these inverter-based energy systems, also with concerns in system response.

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