A Grid Forming Converter Future Without Frequency Droop Control

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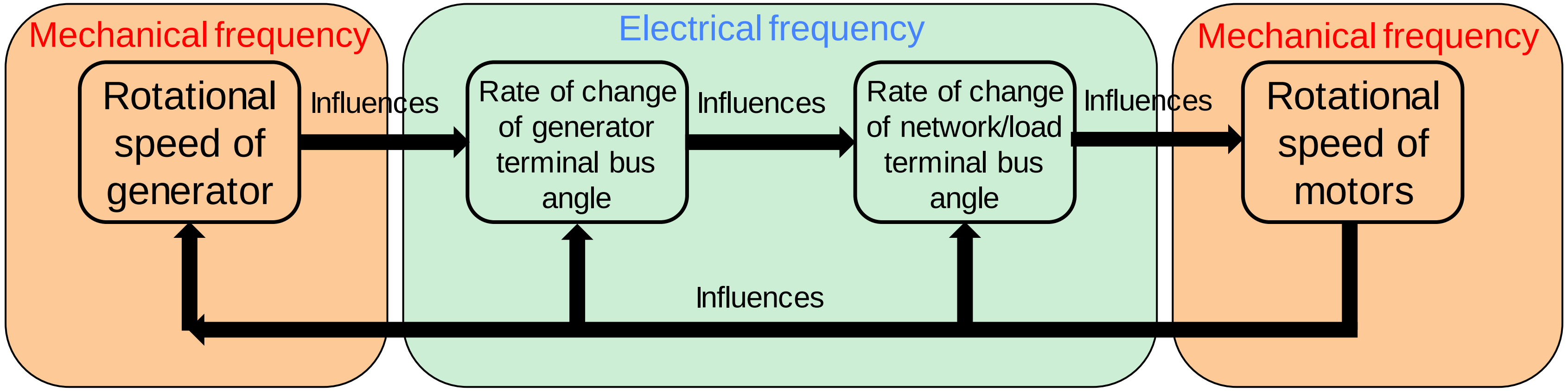
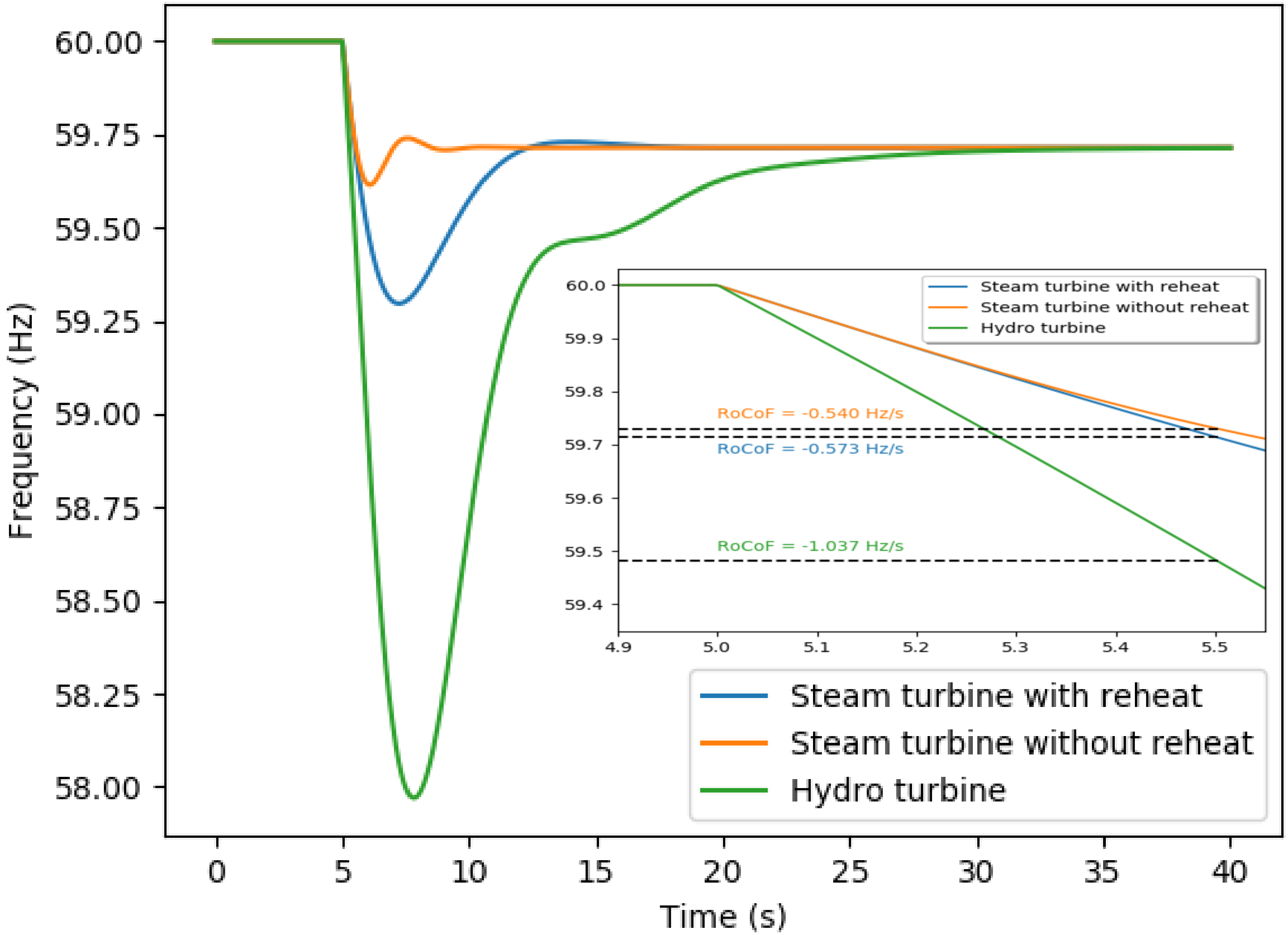
Frequency in a conventional system…

- Conventional system:
  - Electromagnetic properties of the network and machines lock their behavior to be in sync
  - A change in load is automatically/naturally reflected in speed of rotation of the machine
  - System frequency is governed by speed of rotating machines



Traditional frequency response trajectory…

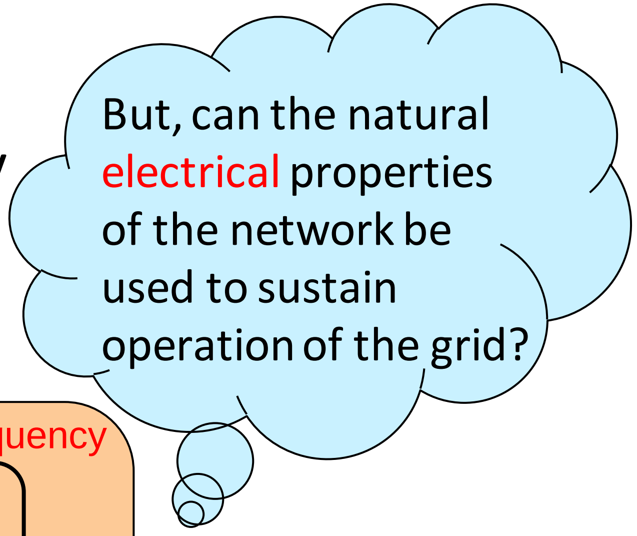


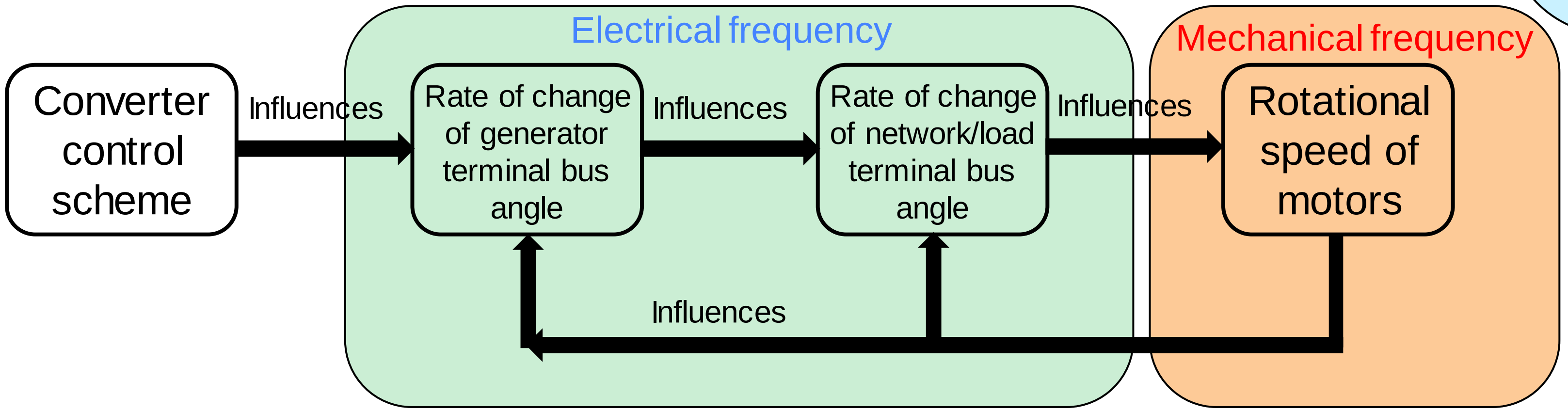
Adapted from frequency response plots in Chapter 11, Power System Stability and Control, Prabha Kundur

- Single isolated machine with 10% load increase
- Typical values used for all parameters
  - Default 'large' RoCoF
- Faster control can be obtained in isochronous mode:
  - Increased torsional stress
  - Ramp rate considerations
  - Possible fighting in interconnected mode due to speed being controlled

Frequency in all inverter system…

- All converter system:
  - Break in the electromagnetic link between source and network
    - Lock has to be obtained through a controller
  - No physical link between generation/load balance and frequency
  - Converters can operate at any frequency





Can ideal L shaped frequency response, or better, be achieved?

Frequency control in a high IBR system…

Would we still need it…?

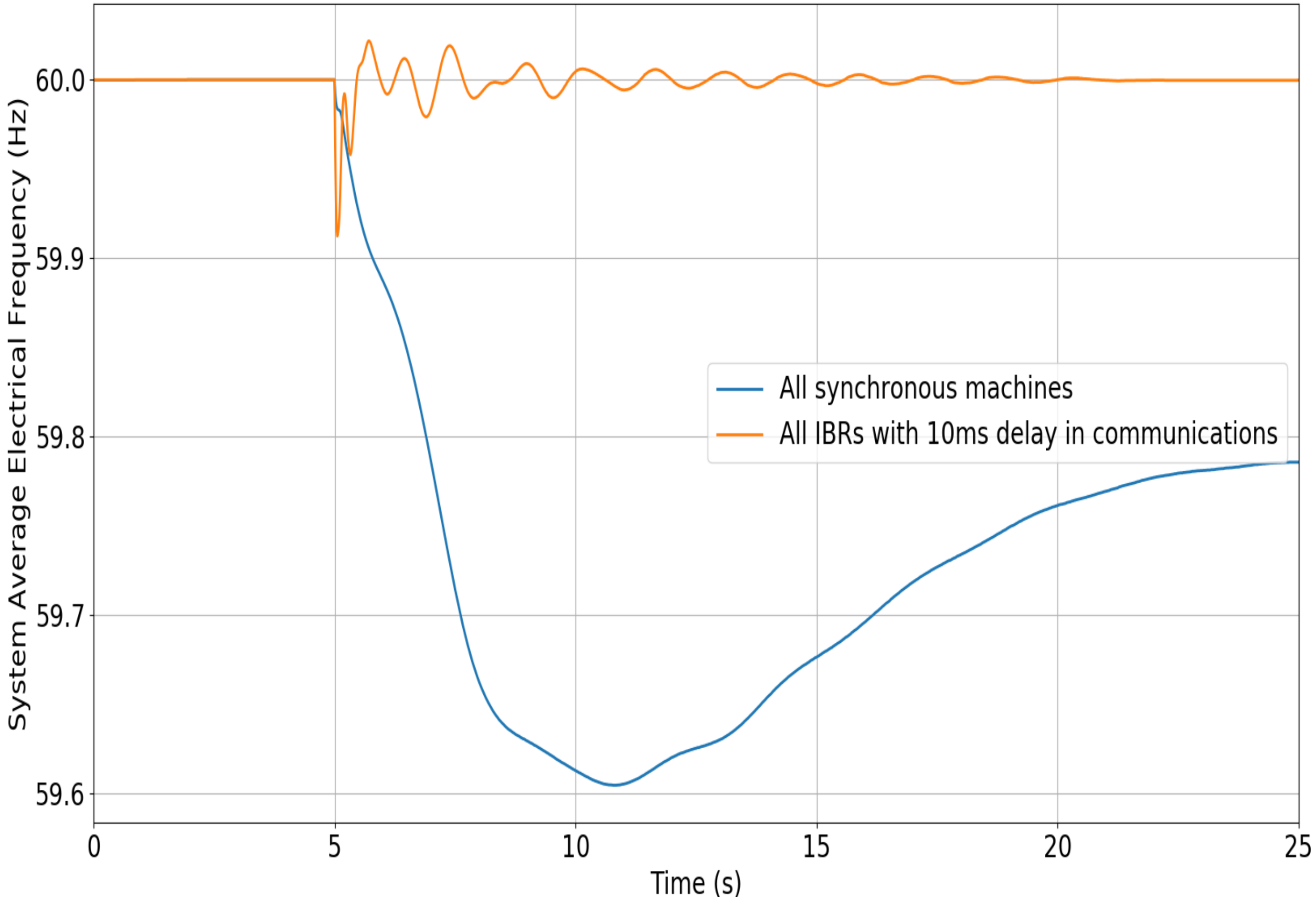
- Traditional needs for frequency control
  - Motor drives
  - Clocks
  - Transformer magnetics
  - Machine torsional stress
  - And many more…

Can we do it in a better manner…?

- Changes in the system
  - Lower source time constants due to static generators
  - Faster control capability
  - Loads interfaced through power electronics
  - Smart transformers
  - Power flow control devices
  - Increased observability

Just because it can be done, should it be done?

With high percentage of IBRs, do we need to hold onto to frequency droop control...?

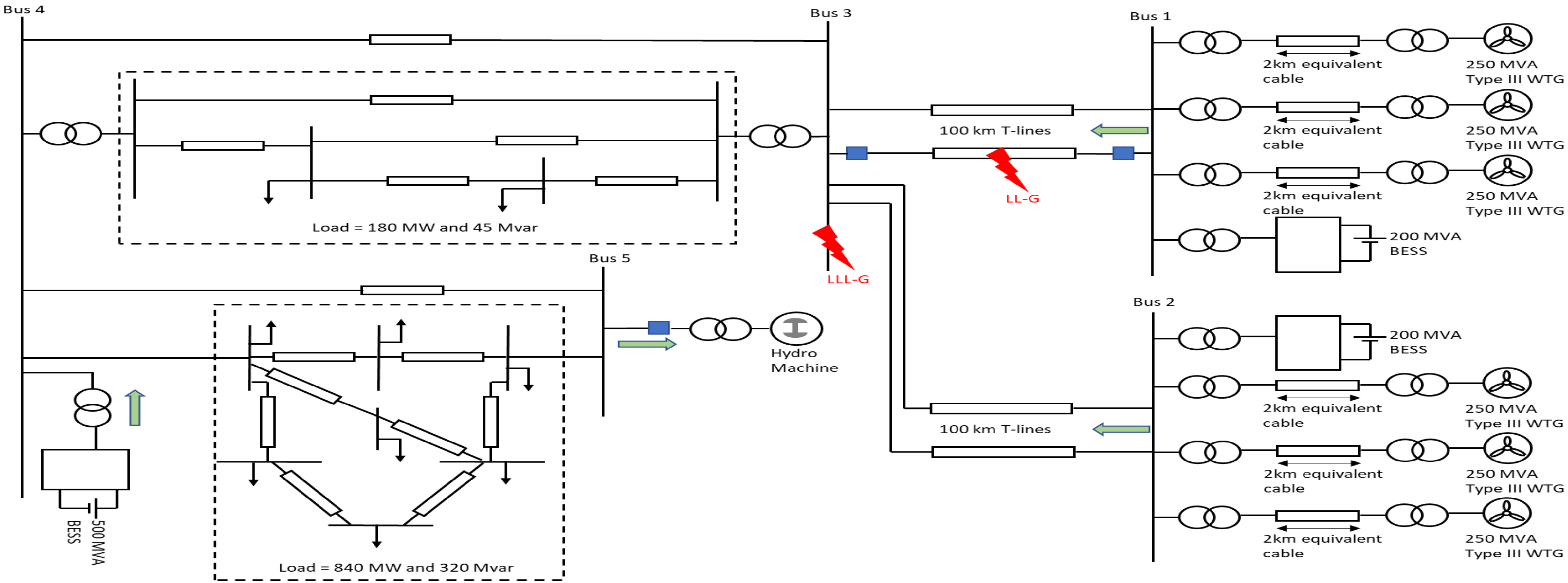


- Lower (to zero) inertia sources allow for faster movement
- Since mechanical speed is not the controlled variable, reduced chance of fighting in interconnected mode.
- Distributed slack bus concept used for sharing of power
- Better than ideal L shaped response

Further reading: Deepak Ramasubramanian and Evangelos Farantatos, "Constant Frequency Operation of a Bulk Power System with Very High Levels of Inverter Based Resources," *CIGRE Science & Engineering*, vol. 17, pp. 109-126, February 2020. [Online]

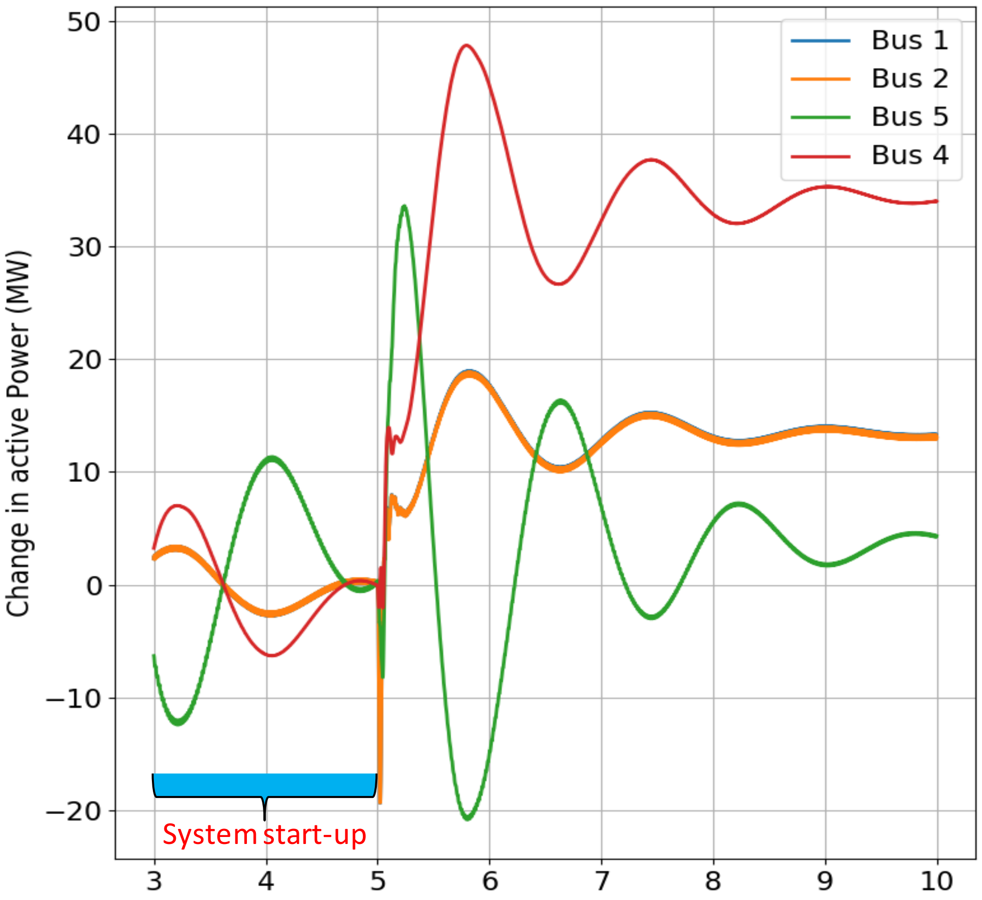
Small system test setup…

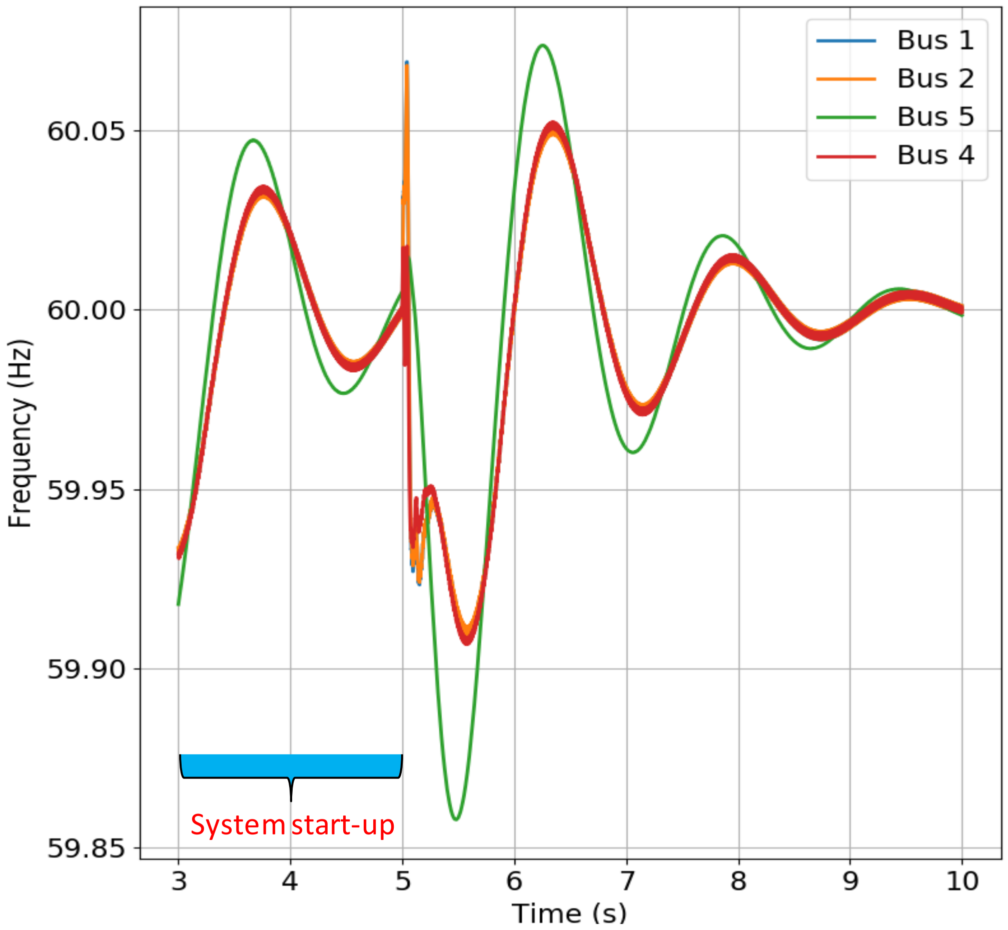
- 85% of load met by IBRs, 15% met by a single rotating machine



All IBR power control (distributed slack bus method) is carried out by the BESS

Response for an increase in load...

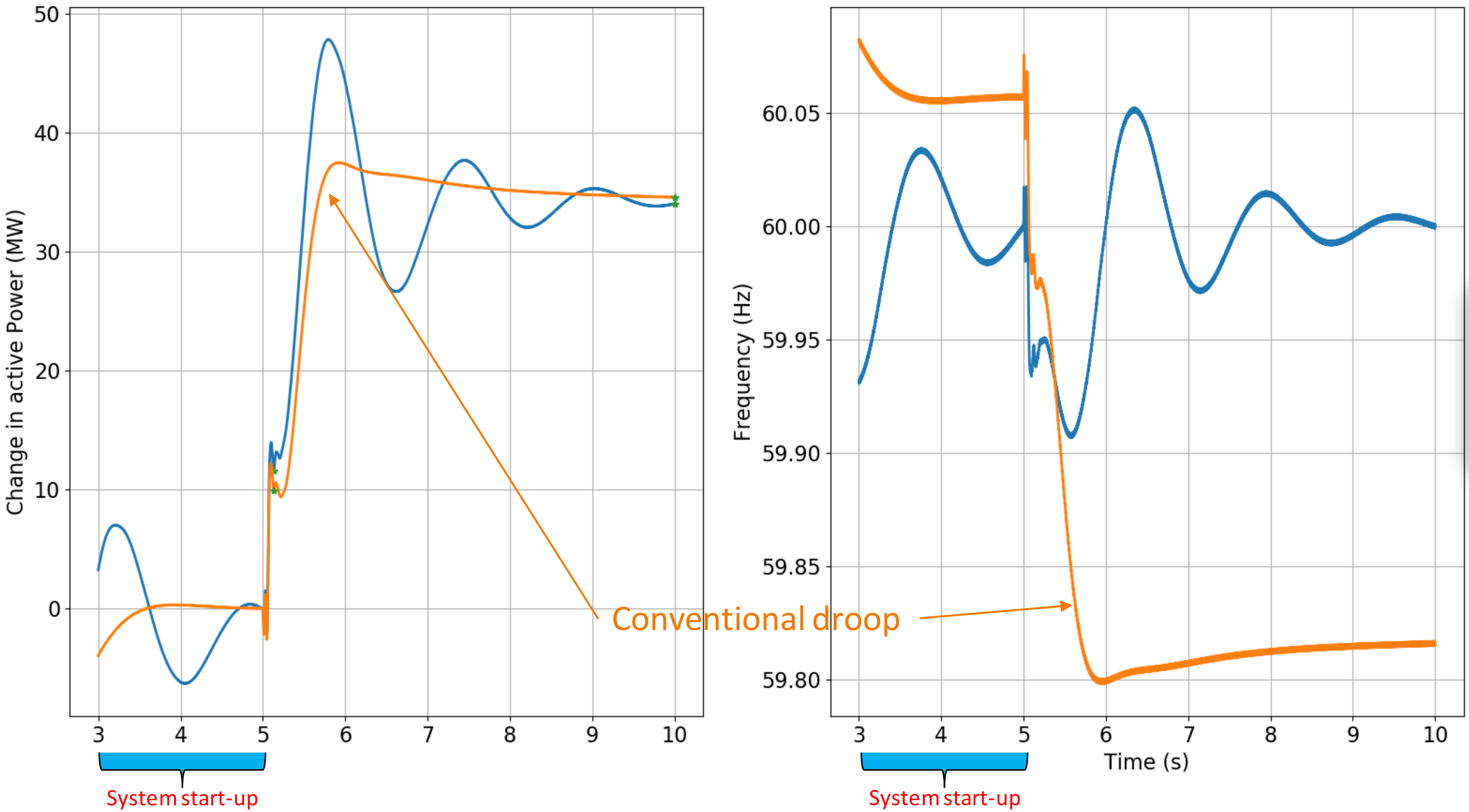




- Bus 4 is electrically closest to the load change

Does this response however have a greater transient impact than conventional droop control?

For Bus 4, comparing with conventional droop control…



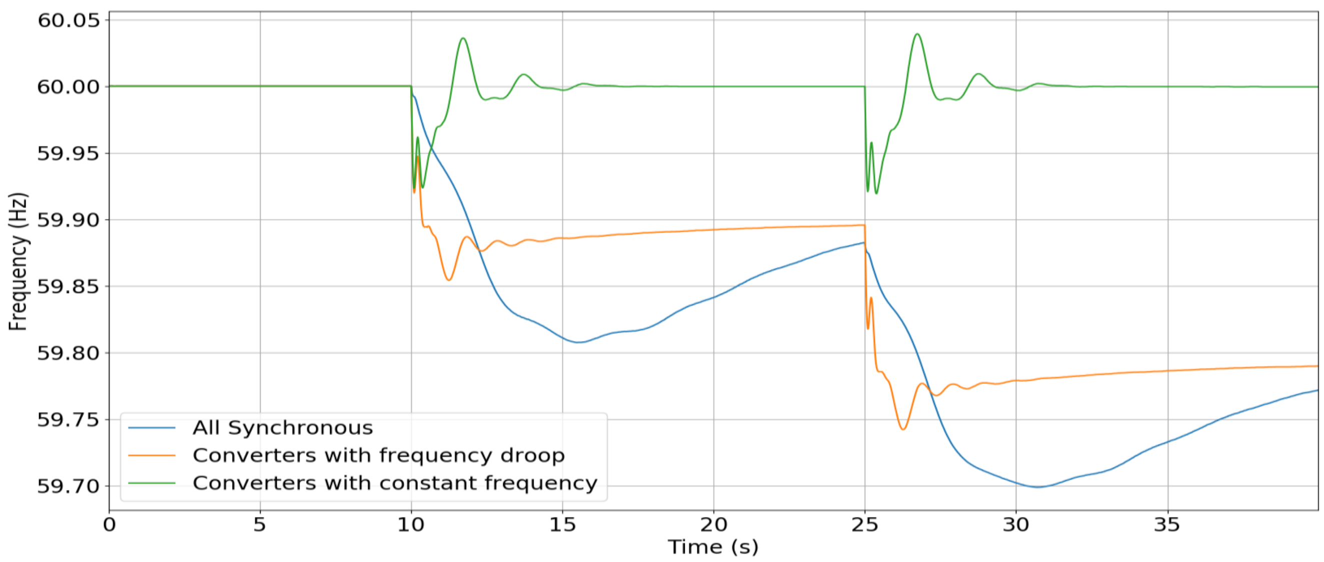
Approximately 10 kWh additional energy required

Reliability Implications of Constant Frequency Operation

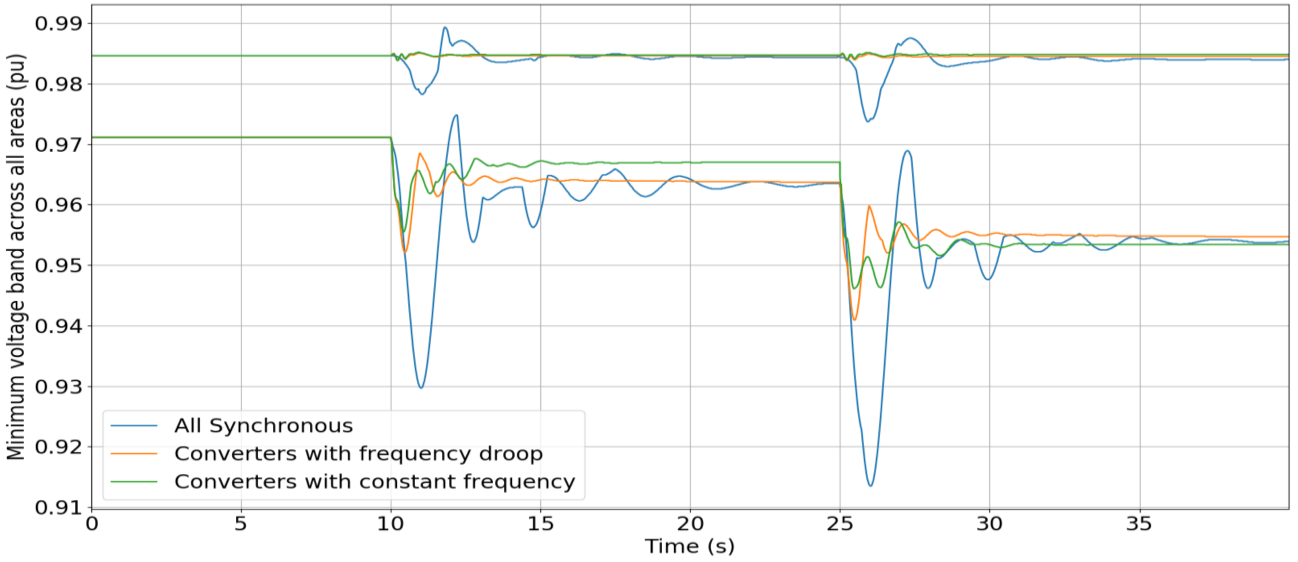
- **System Stability:**
  - What will be stability definition, mechanism, and metrics?
  - In a 100% converter system instability relates to current injection deficit due to limited power reserves (low wind/solar)
  - Can (and should) UFLS operate?

- **Power sharing upon a disturbance:**
  - Just frequency droop is not applicable
  - Newer control schemes required
    - Angle droop as self-automated control
    - Next generation monitoring and control for area wide control

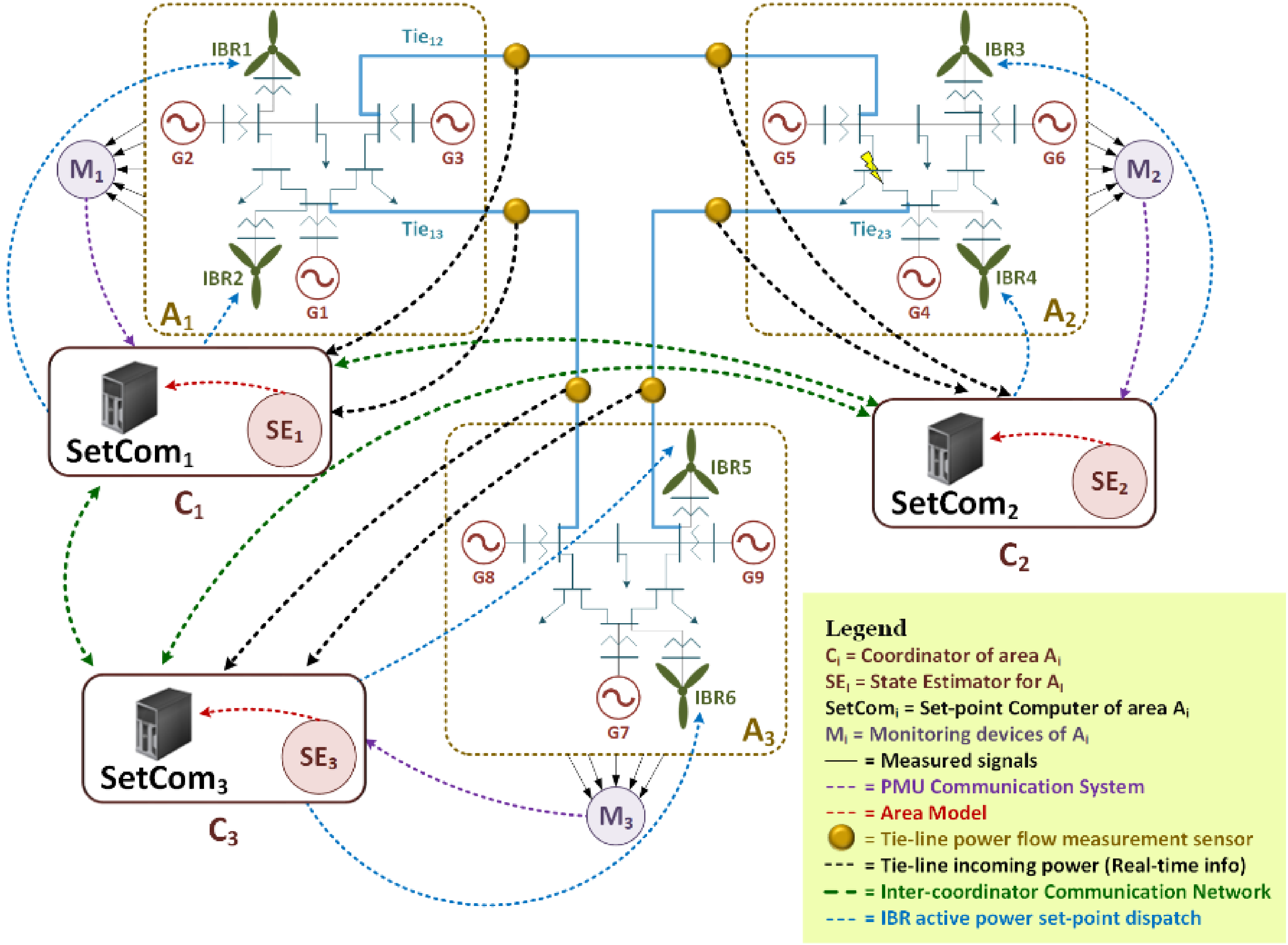
Generation Trip – Frequency Response



Generation Trip – Voltage Response



Hierarchical Decentralized Frequency Control

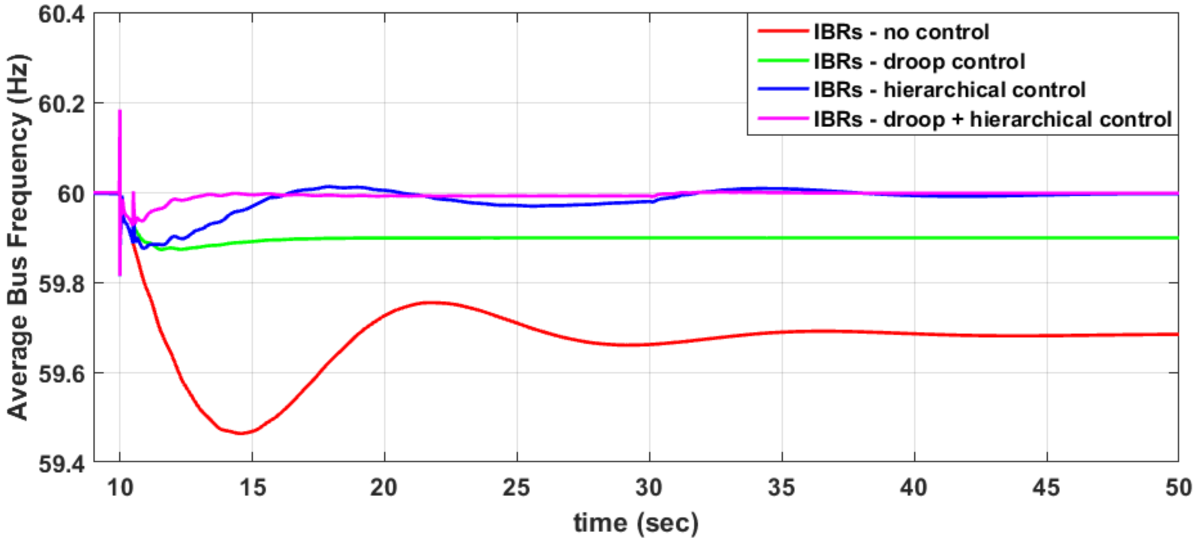


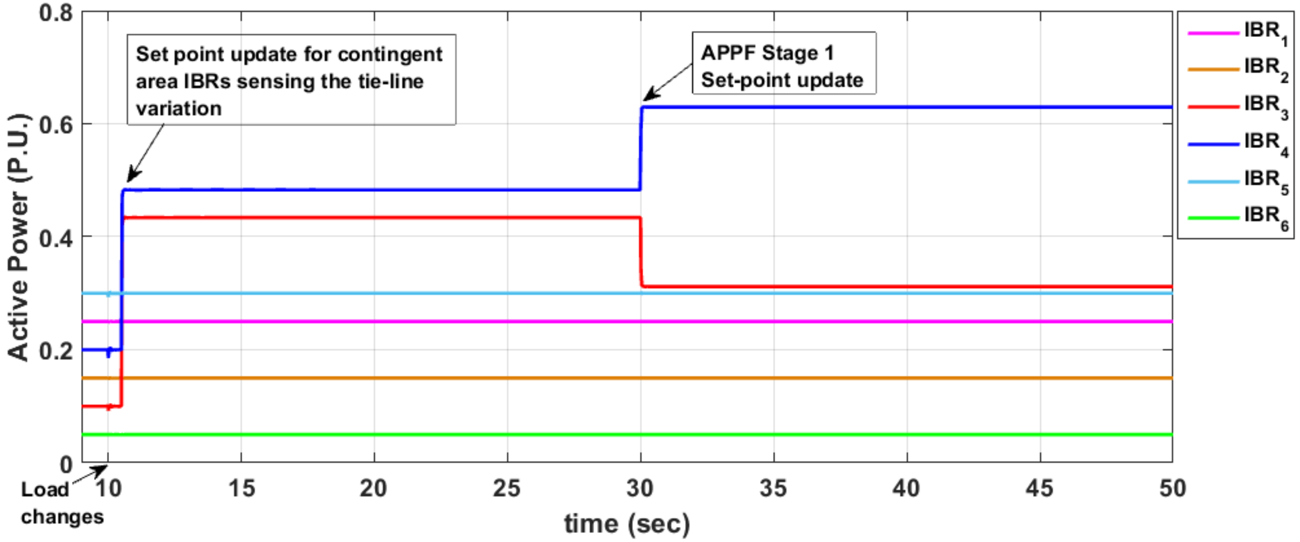
Contingent Area Detection and Imbalance Estimation

Stage 1: Autonomous Primary Local Area Control

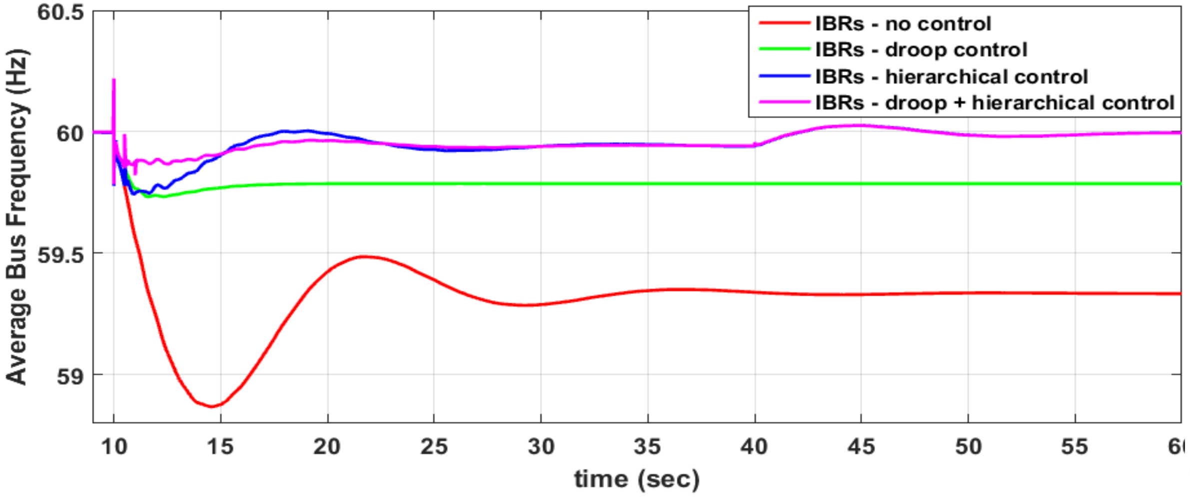
Stage 2: Coordinated Secondary Area Control

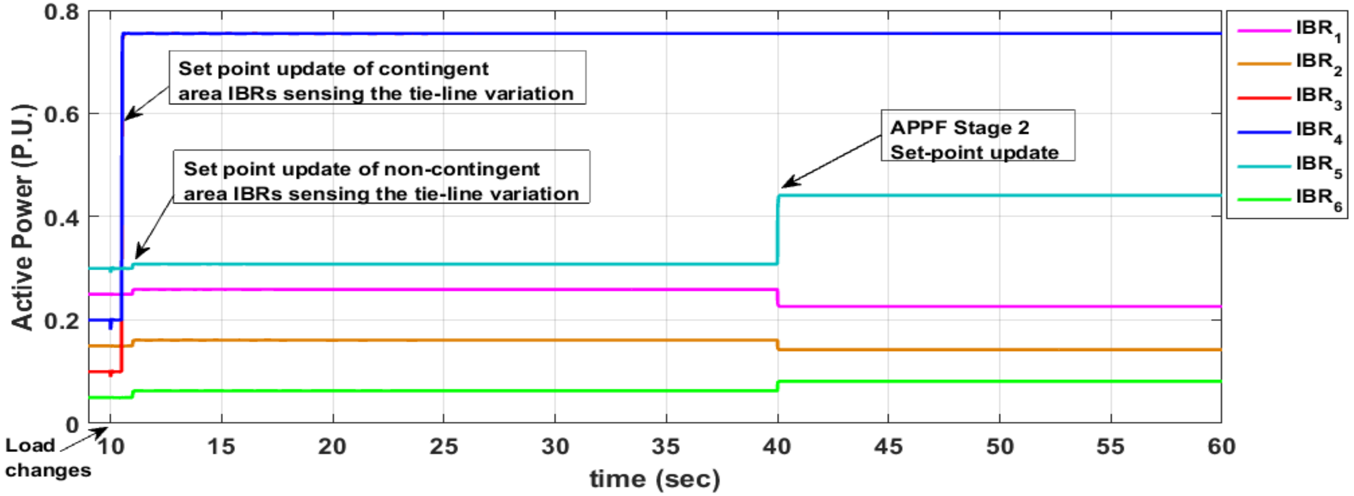
Demonstrating Results - Self Sufficient Contingent Area





Demonstrating Results - Self Deficient Contingent Area





Summary…

- As the power system transitions with increased IBR percentage, it could be possible to take advantage of quick and highly flexible IBR response characteristics

- Frequency droop control was a necessity with mechanical speed being the controlled variable
  - It may not be a necessity with electrical frequency and angle

- Power sharing across balancing areas can still be achieved

- Additional energy/power burden to bring about this operation paradigm is minimal

Together…Shaping the Future of Electricity