Multi-Layered Simulation using the SGRS Simulator; Interaction of TE and Flywheel Controlled Dynamic System

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Outline

- Link multi-time scale simulations
  - Adaptive load management (ALM): slow time-scale
  - Fast dynamics with flywheel control: fast time-scale

- Market needs to specify reactive power set point
  - Reactive power set point is critical to whether there is an equilibrium
  - Depending on the reactive power set points, sometimes dynamics cannot be stabilized

- Demonstrate stable and unstable responses on Smart Grid in a Room Simulator
Interactive Communication

- Communication for multi time-scale simulation with ALM and fast dynamics for generators

Importance of Reactive Power

- Typically the market only specifies the active power set point
- However the reactive power is critically important to the equilibria and stability of the system

Power Factor $PF = 0.99$ (Without Shunt Capacitor)

Flores Island – Market Control

- Based on prices, market computes active power set points $P^*$ from each component
Flores Island – Dynamics Control

- Since currently the market does not specify reactive power set points $Q^*$, data for $Q^*$ is randomly created
- Place a voltage source inverter and the variable speed drive on the hydro and diesel generator buses
- Control the sum of the power out of the hydro and diesel generators to match the active and reactive power set points
Flores Island – Variable Speed Drive Control

- Determine the variable speed drive set points based on the set points from the market

- Controllable inputs for the variable speed drive are

\[ u_k = g_k \left( x_k, y_{ck1}, y_k^{\text{ref}} \right) \]

\[ u_k = \begin{bmatrix} u_{1d} & u_{1q} & u_{2d} & u_{2q} \end{bmatrix}^T \]

\[ x_k = \begin{bmatrix} i_{1d} & i_{1q} & q_{C1} & i_{S2d} & i_{S2q} & i_{R2} & \omega & \theta \end{bmatrix}^T \]

\[ y_{ck1} = \begin{bmatrix} v_d & v_q \end{bmatrix}^T \]

\[ y_k^{\text{ref}} = \begin{bmatrix} \omega_2^{\text{ref}} & i_{1d}^{\text{ref}} & i_{1q}^{\text{ref}} \end{bmatrix}^T \]

- Set points for the variable speed drive are

\[ y_k^{\text{ref}} = h_k \left( y_{ck1}, r_k^{\text{ref}} \right) \]

\[ y_{ck2} = \begin{bmatrix} i_{Gd} & i_{Gq} \end{bmatrix}^T \]

\[ r^{\text{ref}} = \begin{bmatrix} P_G^* & Q_G^* \end{bmatrix}^T \]

\[ P_G^* = V_d \left( i_{1d}^{\text{ref}} + i_{Gd} \right) + V_q \left( i_{1q}^{\text{ref}} + i_{Gq} \right) \]

\[ Q_G^* = V_q \left( i_{1d}^{\text{ref}} + i_{Gd} \right) - V_d \left( i_{1q}^{\text{ref}} + i_{Gq} \right) \]

Solve for \( i_{1d}^{\text{ref}} \) and \( i_{1q}^{\text{ref}} \)
Simulation Results – Hydro/Diesel Generator Bus

Total Power out of Diesel Generator Bus

Total Power out of Hydro Generator Bus
Simulation Results – Wind Generator Bus

**Stable Case:**

- Wind Generator Bus Voltages
  - $v_{B2d}$
  - $v_{B2q}$

**Unstable Case:**

- Reactive Power Load Consumption

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- Carnegie Mellon
Conclusions

- Demonstrated multi time-scale simulation with feedforward market controller and feedback flywheel controller
- Showed that with a high reactive power load, the system may not reach a stable equilibrium

Future Work

- Market level controller specify the reactive power set point
- Design fast dynamic control, so that we don’t need voltage source inverter at each bus
- Combine with other time-scale simulations (AGC)