A TRAJECTORY TRACKING WIDE-AREA CONTROLLER FOR STABILIZING TRANSIENT DISTURBANCES

01

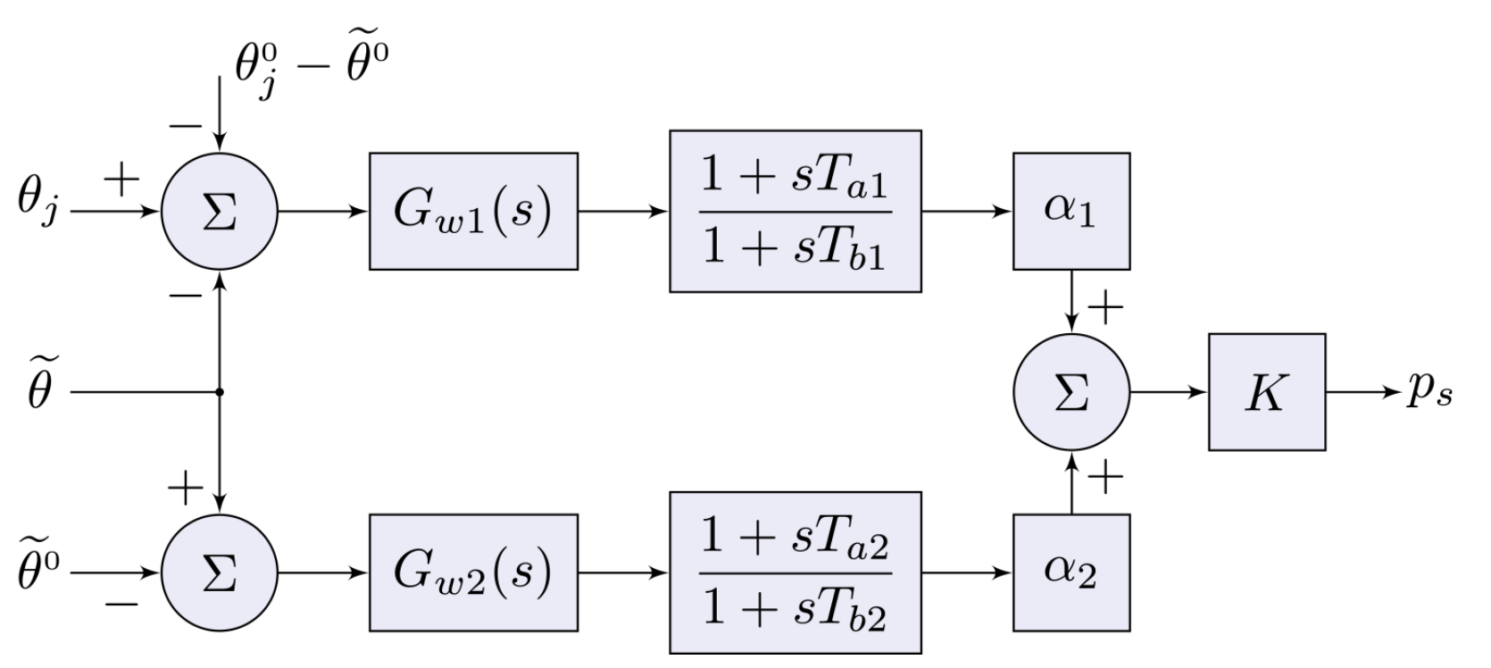
STUDENTS: RYAN ELLIOTT

Background

- When power systems that lack sufficient synchronizing torque are subjected to a severe disturbance they may fail to maintain rotor angle stability.
- To mitigate this risk, stability limits are imposed on certain transmission corridors that inhibit the full utilization of existing thermal capacity.
    - In turn, this increases the investment and operation costs of the transmission system.
- The combination of wide-area measurement systems (WAMS) and fast-acting inverter-based resources (IBRs) enables new approaches to address these problems.

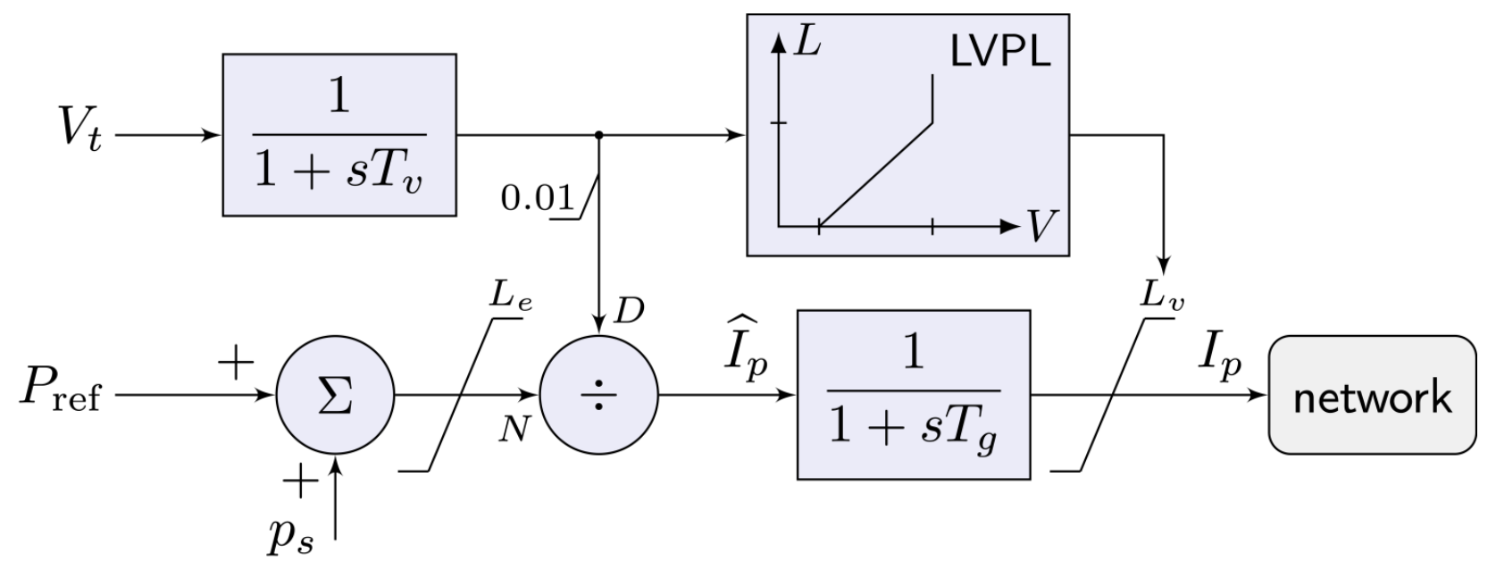
Trajectory Tracking Control

- Drives the local bus voltage angle toward a trajectory that tracks the angle of the center of inertia.
- Arises from a time-varying linearization of the equations of motion for a synch. machine.
- Utilizes real-time data collected from wide-area measurement systems to improve observability.



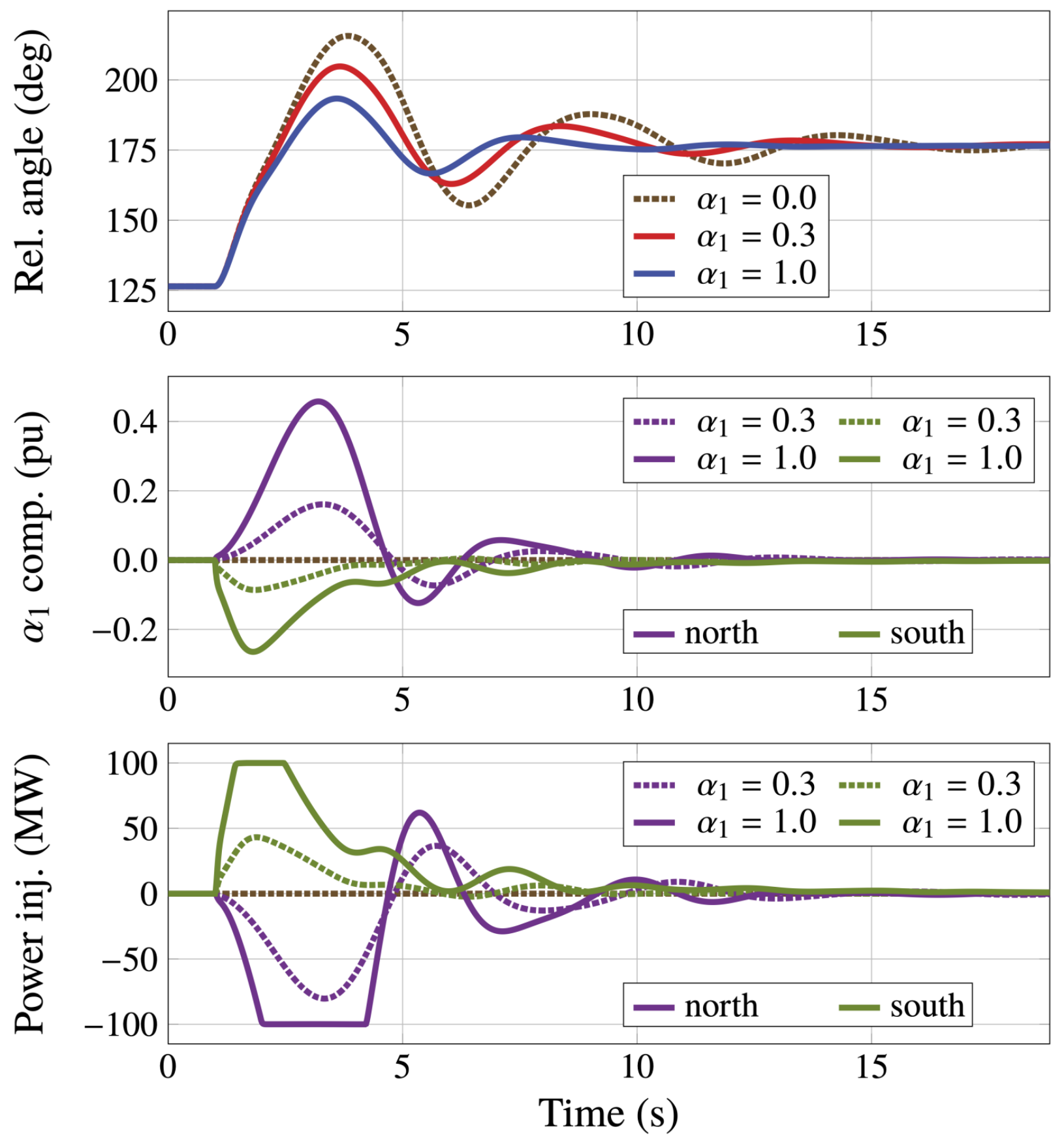
Converter Interface Model

- The controller sends an aux. input to the interface of an inverter-based resource.
- This modulates the real power output of the device, such as a battery energy storage system.
- The inverter-based resource is modeled as a unity power factor controllable current source.
- The *low-voltage power logic* (LVPL) block imposes a voltage-dependent limit on the injected current.



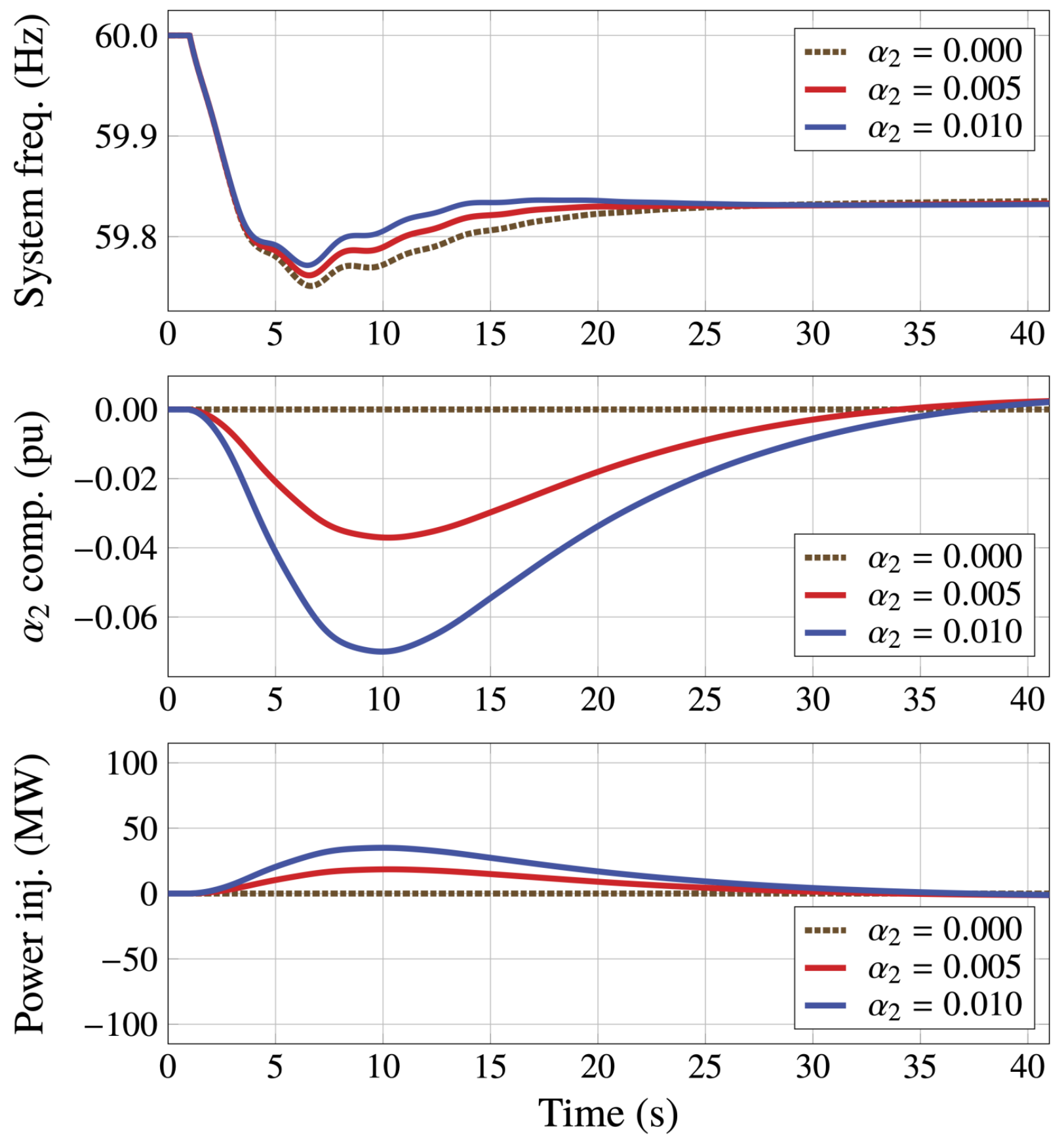
Large-Scale Sensitivity Studies

- Time-domain simulations of a large nuclear plant in Arizona being tripped offline for various values of α_1 where $\alpha_2 = 0$.
- The top subplot shows the difference between the rotor angle of the representative generator in Alberta and the generator in San Diego.
- The bottom two subplots show the behavior of the ESSs located near the load centers in Calgary and San Diego.
- Following the disturbance, the gen. speed in Alberta is faster than the C.O.I. speed, and the gen. speed in San Diego slightly slower.
- To mitigate the system separation in the first swing, the ESS in Alberta charges and the one in San Diego discharges.

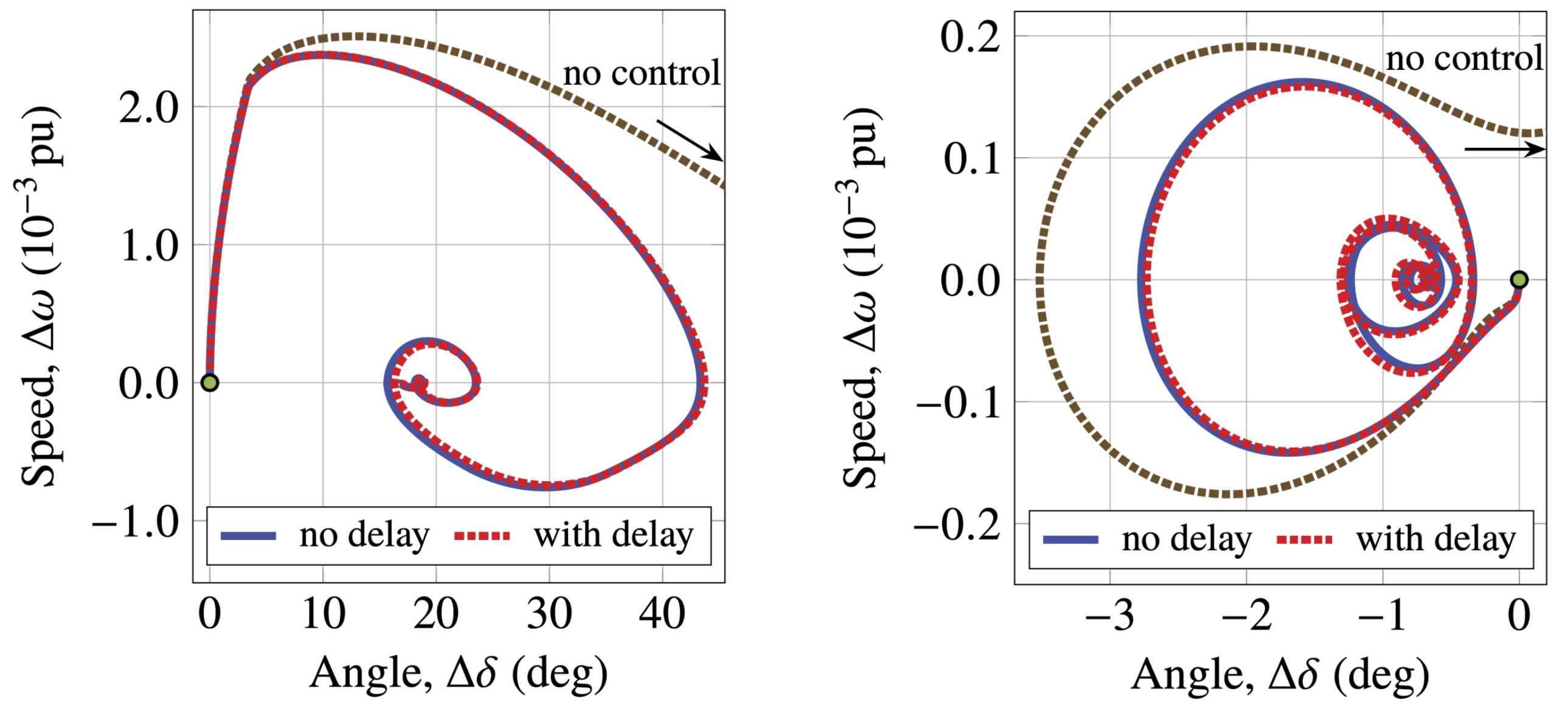


Control Parameter Sweeps

- Time-domain simulations of the same disturbance for various values of α_2 where $\alpha_1 = 0$.
- As α_2 increases the depth of the nadir is reduced, and the frequency rebounds more quickly.
- The bottom two subplots show the behavior of a representative controller, which is the same for each ESS in this case.
- When the speed of the center of inertia deflects downward, $\widetilde{\theta}(t)$ declines from its initial value value $\widetilde{\theta}(t_0)$.
- This results in a negative α_2 component that causes every ESS in the system to inject power that is in phase with the error.



N-1 Contingency Analysis



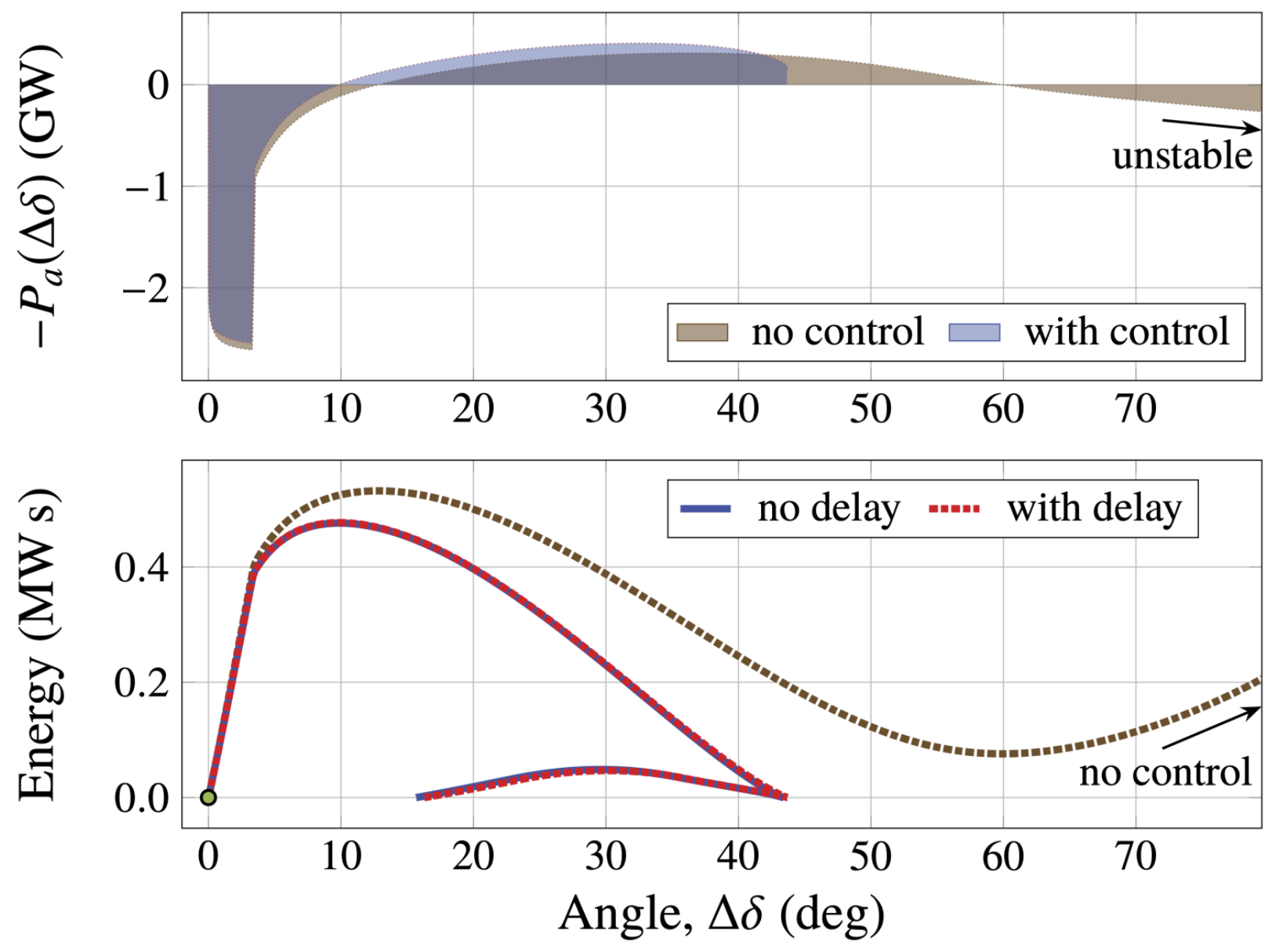
- These phase portraits plot the LTV speed deviations $\Delta\omega_i$ versus $\Delta\delta_i$ for two machines.
- Without control, the curves do not arrive at the post-disturbance equilibrium; however, with control, they do.
- The control action expands the region of attraction to encompass the point in the plane where each generator resides immediately after the fault.

A Modern Twist on the Equal Area Criterion

- The accelerating power in the C.O.I. reference frame is given by

$$P_a^i(t) = P_m^i(t) - P_e^i(t) - \frac{H_i}{H_T}\left[\sum_{k\in K} P_m^k(t) - P_e^k(t)\right]$$

- The top subplot of Fig. 9 shows the accel. power of G34 in Alberta as a function of $\Delta\delta_i$.
- The bottom shows the integral of P_a^i over $\Delta\delta_i$, which is a bound on the kinetic energy.
- Without control, the decelerating area is insufficient to cancel the accelerating area.
- The machine loses synchronism and pulls away from the stable equilibrium.



Future Work, References, and Acknowledgments

- Techniques and considerations for setpoint management.
- Optimal estimation of the C.O.I. speed/angle from purely local information.
- Improved hybrid methods for determining transient stability margins.
- Broaden applications to other types of inverter control.

Graduate Students: Ryan Elliott
Faculty: Daniel Kirschen, Payman Arabshahi

[1] R. T. Elliott, P. Arabshahi, and D. S. Kirschen, "A generalized PSS architecture for balancing transient and small-signal response," IEEE Trans. Power Syst., pp. 1–1, 2019.

[2] A. Michel, A. Fouad, and V. Vittal, "Power system transient stability using individual machine energy functions," IEEE Trans. Circuits Syst., vol. 30, no. 5, pp. 266–276, May 1983.

ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY *of* WASHINGTON

ADVISORS: DANIEL KIRSCHEN, PAYMAN ARABSHAHI

SPONSORS: ELECTRICAL & COMPUTER ENGINEERING, UNIVERSITY OF WASHINGTON