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Stabilizing Transient Disturbances with Utility-Scale Energy Storage Systems

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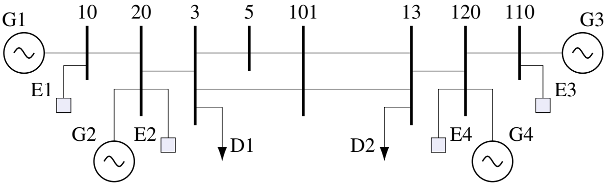
Overview

- Transient stability control is based on actions that are taken automatically to ensure the system remains in synchronism (e.g., RAS).
  - Classical examples include generator rejection and dynamic braking.
  - These methods rapidly absorb excess energy at key points in the system.
- Such approaches cannot inject real power to compensate for a deficit.
- Utility-scale IBRs (e.g., storage) enable bidirectional modulation of real power with the bandwidth necessary to provide synchronizing torque.
- R. Elliott, H. Choi, D. Trudnowski and T. Nguyen, "Real Power Modulation Strategies for Transient Stability Control," in IEEE *Access*, 2022.

Comparison of control strategies

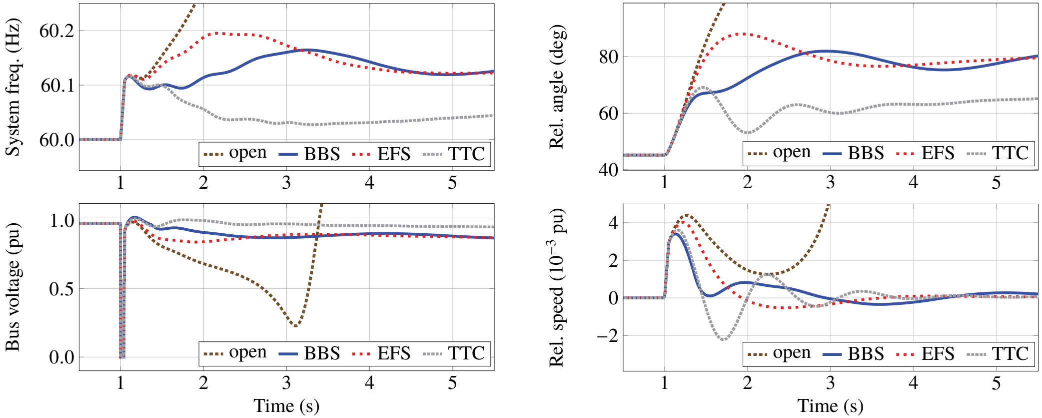
- Here we compare three control strategies:
  - Bang-Bang Speed (BBS) control, (Ojetola *et al.*, 2021)
  - Energy Function Sensitivity (EFS) control, (Kawabe and Yokoyama, 2011)
  - Trajectory Tracking control (TTC), (Elliott *et al.*, 2020)
- As an example system we consider a version of the KRK 2-area system augmented with energy storage.
  - The system is loaded so that Area 1 sends ~500 MW to Area 2.
  - The disturbance is a 3-phase bolted fault on the line between buses 3–5.



Index (No.)	Intercon. bus (No.)	Generator (MVA)	Energy storage (MW)	(MWh)
1	10	200	20	10
2	20	1800	180	90
3	110	200	20	10
4	120	1800	180	90

System response

- The bang-bang control approach yields the largest reduction in the first-swing rotor angle excursion (difference between G2 and G4 shown at right).



Critical clearing time comparison

- It's important that the controllers not inject power in steady-state in order to prevent adverse interaction with governing and AGC.
- The table at right shows how the CCT changes as the battery size increases.

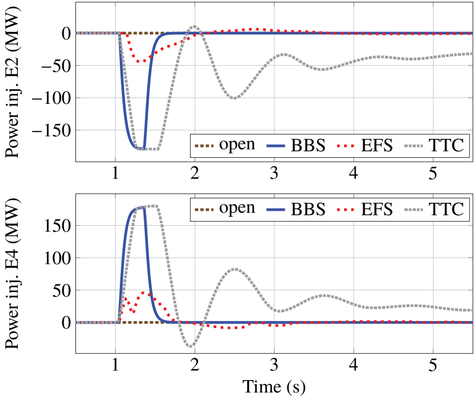
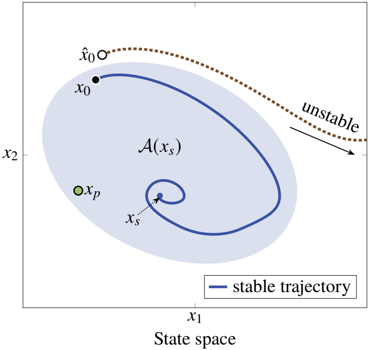


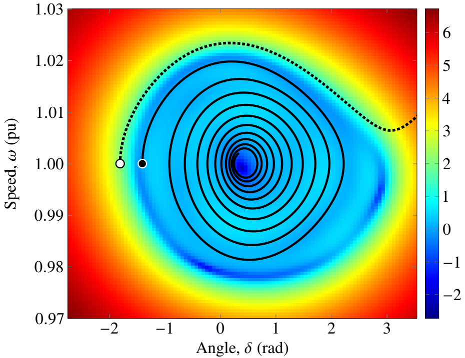
Table: Critical clearing time.

Rated power (% of gen.)	BBS (cyc)	BBS (Δ%)	EFS (cyc)	EFS (Δ%)	TTC (cyc)	TTC (Δ%)
0	2.0	–	2.0	–	2.0	–
5	6.0	200	4.5	125	7.0	250
10	6.5	225	5.0	150	10.0	400
15	8.0	300	5.5	175	12.5	525
20	9.0	350	5.5	175	14.5	625

Transient stability assessment

- Chief question: If a stable post-disturbance equilibrium exists, is the system able to navigate to it?
- Region of attraction: From initial conditions inside the ROA, the system converges to the stable equilibrium.





Comparison of stability assessment methods

- The figure at left shows a slice of the ROA for generator G2 following the 3-phase fault near bus 5, generated using brute-force simulation.
- At right, the Transient Energy Function (TEF) method. The TEF method is conservative because it doesn't account for generator or IBR controls.

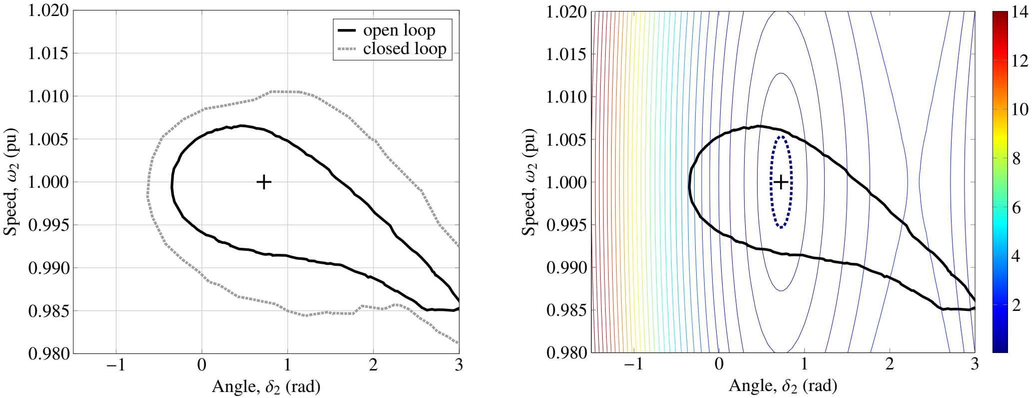
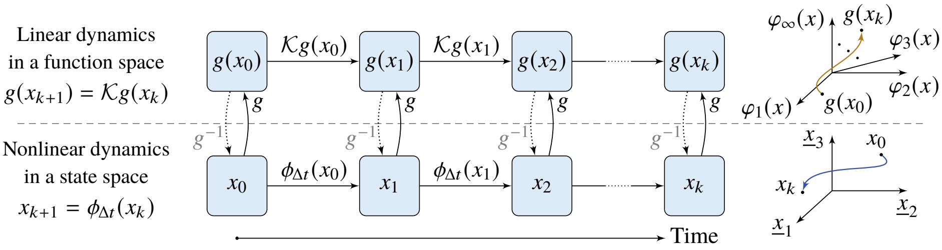


Illustration of the Koopman framework

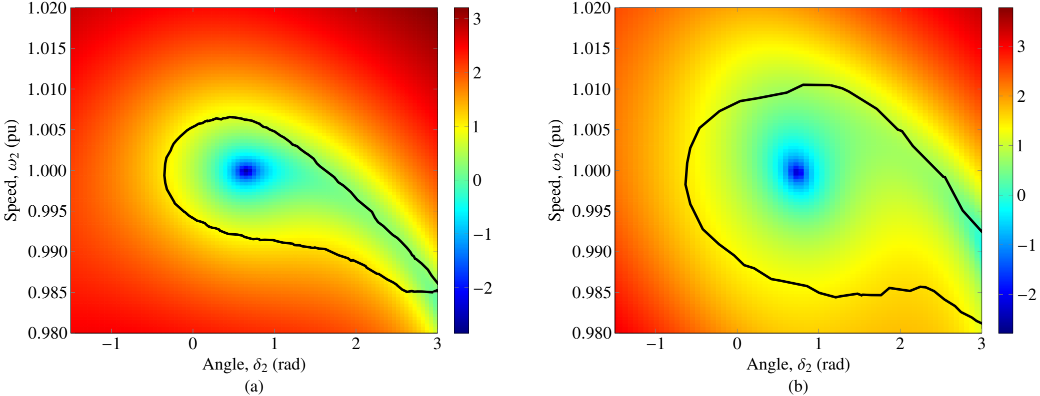


- We an explore a data-driven stability assessment technique based on Koopman operator theory, which does not require a model of the system.
- Basic idea: Determine a type of nonlinear coordinate transformation such that the system dynamics become linear in the new (lifted) space.
- The Koopman operator advances the system in the lifted space, $g(x_k) = \mathcal{K}g(x_k)$. Decomposition of $\mathcal{K}$ provides spatio-temporal insights.

Data-driven ROA estimation

- We estimated the ROA for generator G2 using the Extended Dynamic Mode Decomposition (EDMD) algorithm (Williams, 2015).

- The open-loop case is shown at left, and the closed-loop case at right, where the color map indicates the level sets of the dominant eigenfunction.



Summary

- Data-driven stability assessment techniques do not require an explicit dynamical model of the system.
  - The Koopman operator approach showed promising results, but future work is required for realistic systems (scalability and computational effort).
- Transient stability control schemes based on physics almost invariably use an estimate of the center-of-inertia speed and/or angle.
  - Wide-area measurement systems that are accurate and secure are critical to successful implementation of any of these strategies.
- Simulations and analysis for this work were conducted using the MATLAB-based Power and Energy Storage Systems Toolbox (PSTess).