Sandia National Laboratories

Transient Stability Control with Battery Energy Storage Systems

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Background

When power systems that lack sufficient synchronizing torque are subjected to a severe disturbance they may experience widespread power outages. To mitigate this risk, stability limits are imposed on certain transmission corridors that inhibit the full utilization of existing line capacity. In turn, this increases the investment and operation costs of the transmission system. The combination of utility-scale energy storage and wide-area measurement systems (WAMS) enables new approaches to address these problems [1].

Open-Source Software Release

We released an open-source software package for MATLAB called the Power and Energy Storage Systems Toolbox, or PSTess. It enables system-wide dynamic analysis and control design [2].

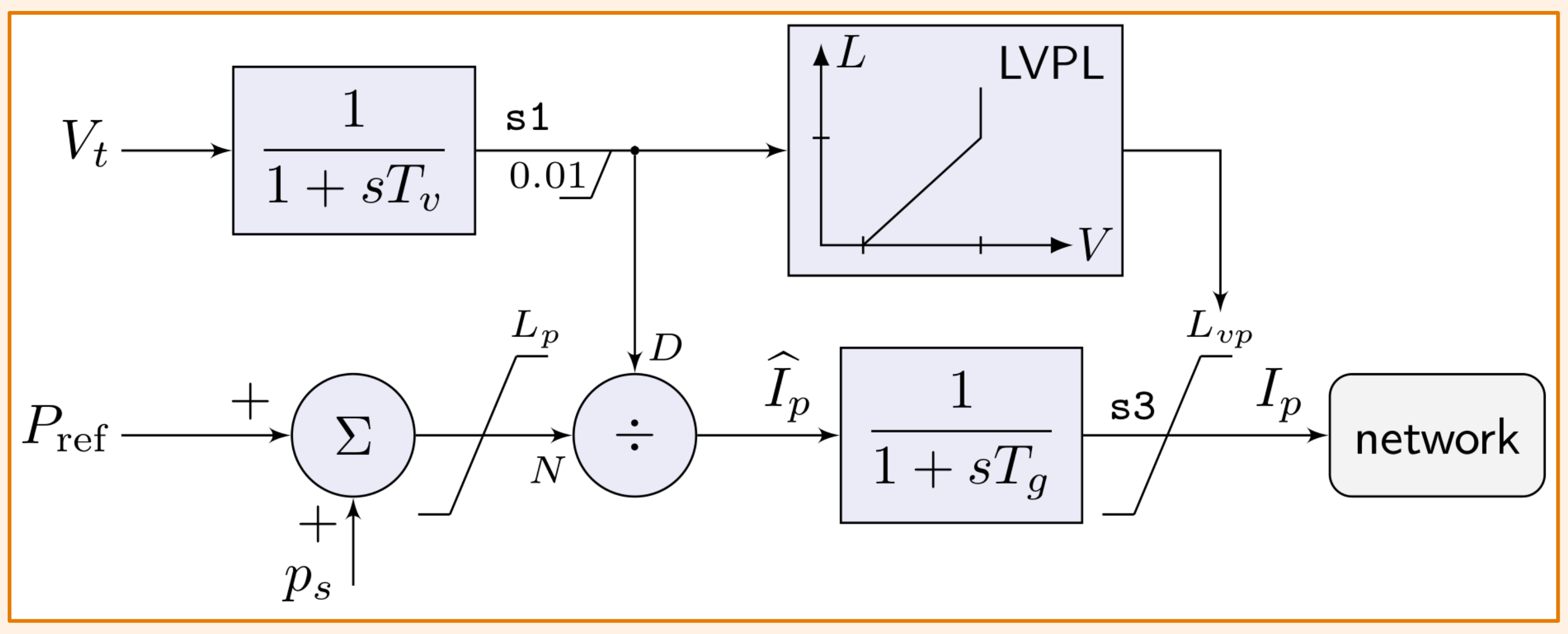


Fig. 1. Converter interface model based on REGC_A.

Reduced-Order WECC Model

Analyses were performed using a reduced-order model of the WECC. An energy storage system is co-located with each generator (power 5% of MVA base). The contingency is a 3-phase fault on one of the branches between buses 7–79. In open-loop, the system goes unstable after 6 cycles. With control, the crit. clearing time increases to 9.5 cycles.

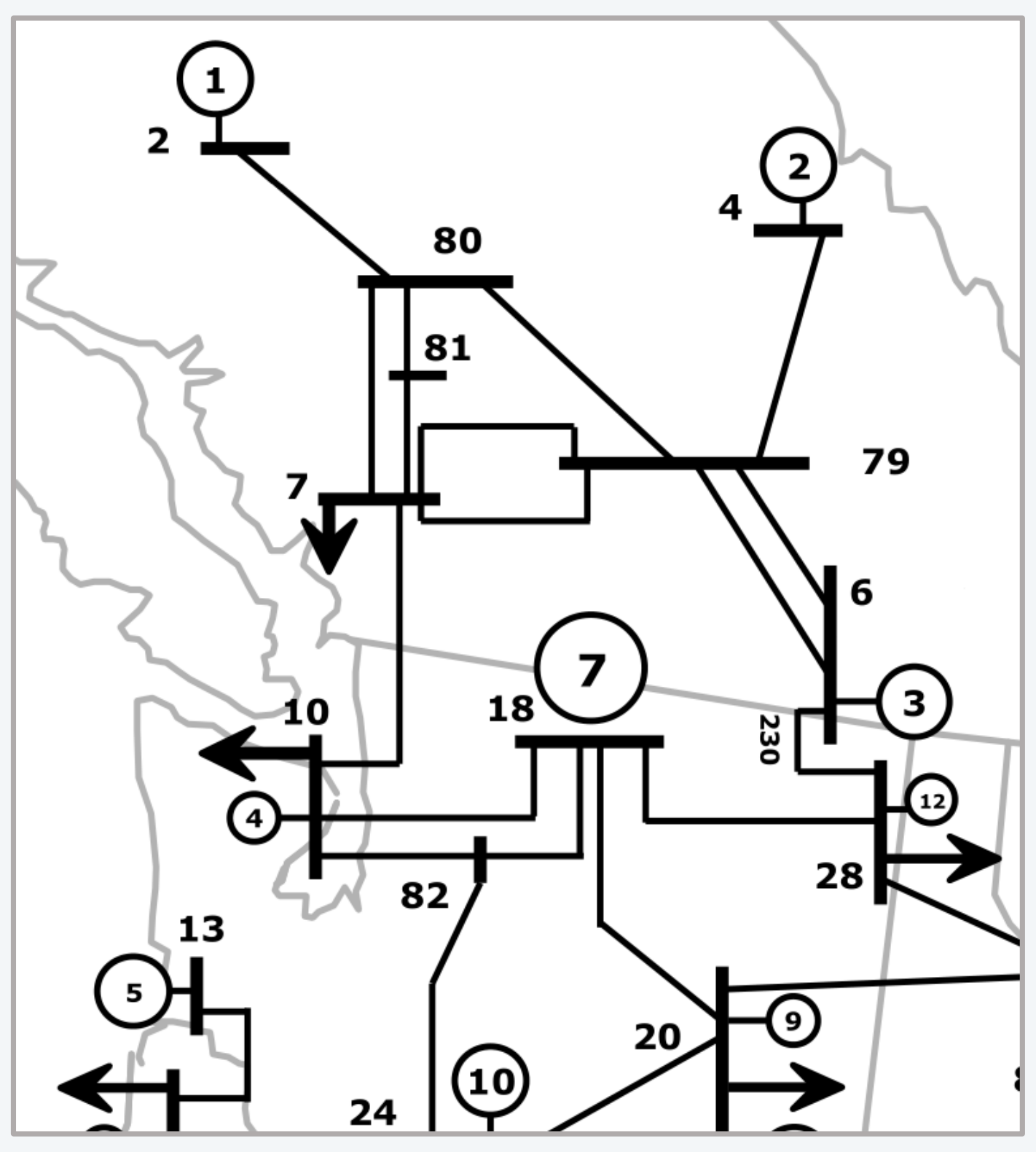


Fig. 2. Section of the reduced-order MiniWECC model.

Trajectory Tracking Control

Our control approach specifies a desired angle trajectory:

$$\bar{\delta}_i(t) = \tilde{\delta}(t) - \tilde{\delta}(t_0) + \delta_i(t_0), \qquad (1)$$

where $\tilde{\delta}(t)$ is the angle of the center of inertia [1]. The control error $\Delta\zeta_i(t)$ is specified to "push" the local voltage angle toward this desired trajectory, i.e.,

$$\Delta\zeta_i(t) = \delta_i(t) - \bar{\delta}_i(t) = \omega_b \int_{t_0}^{t} \omega_i(\tau) - \bar{\omega}_i(\tau)\, d\tau. \qquad (2)$$

Simulation Results

Here the control gain is set to a large value, causing the storage devices to behave like "bang-bang" controllers following the fault.

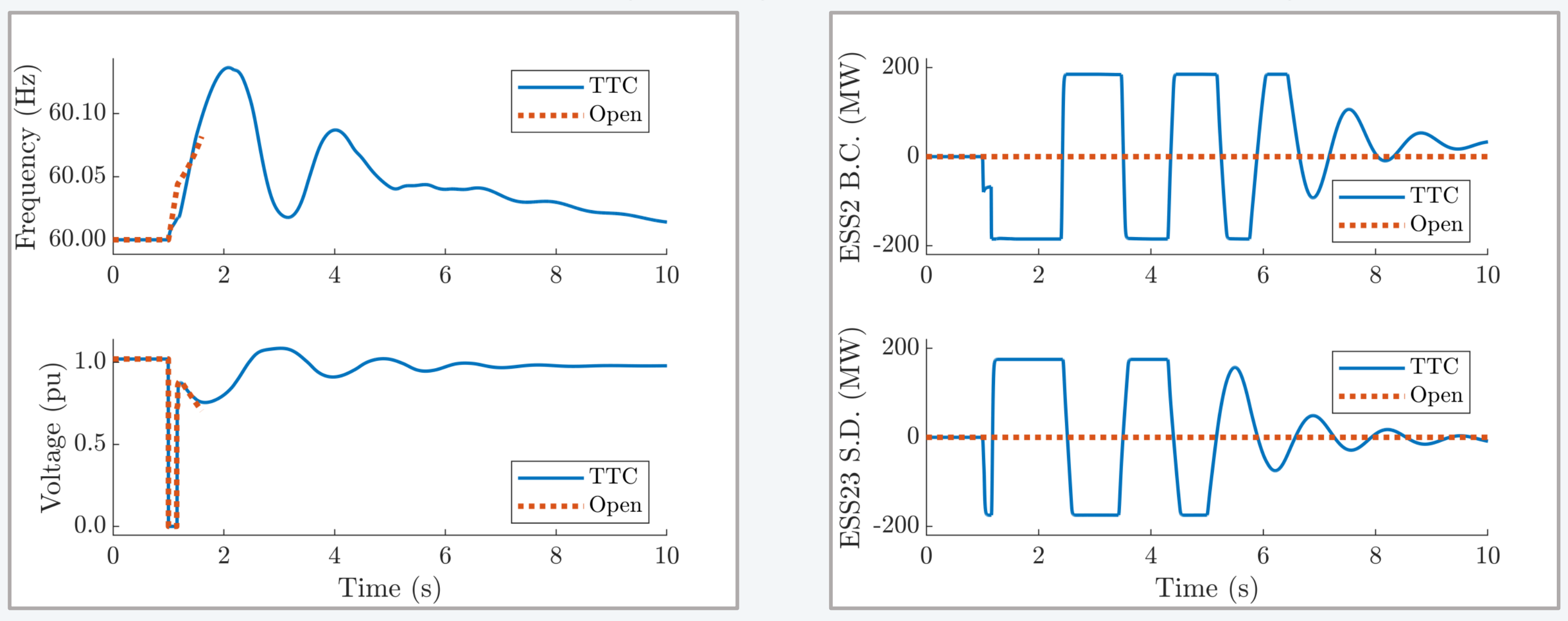


Fig. 3. System response to a 9.5-cycle fault near bus 79.

Koopman Operator Illustration

To overcome the inherent nonlinearity of power systems, we apply a nonlinear coordinate transformation that linearizes the dynamics [3].

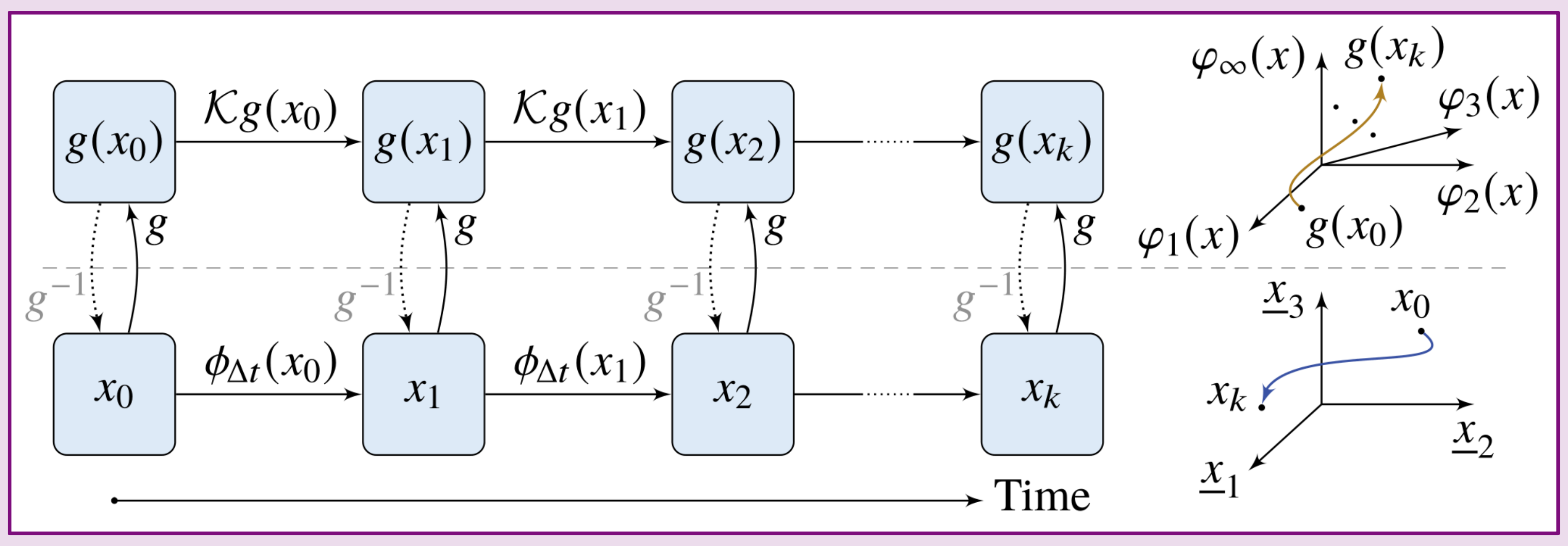
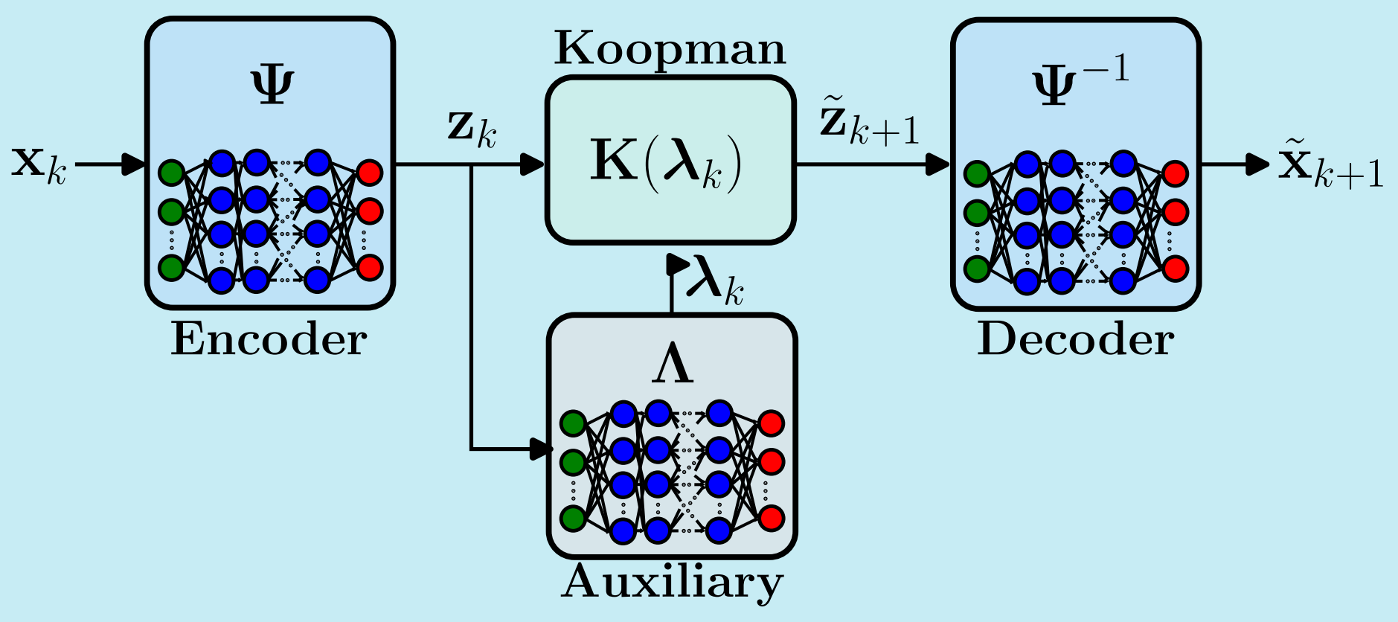


Fig. 4. Illustration of the Koopman operator framework.

Transient Stability Quantification via Koopman

We leveraged machine learning to estimate the Koopman operators using time-series data. We then estimated the region of attraction (ROA) using the Koopman operators to quantify transient stability. The performance of the ESS controls was verified using the ROAs.



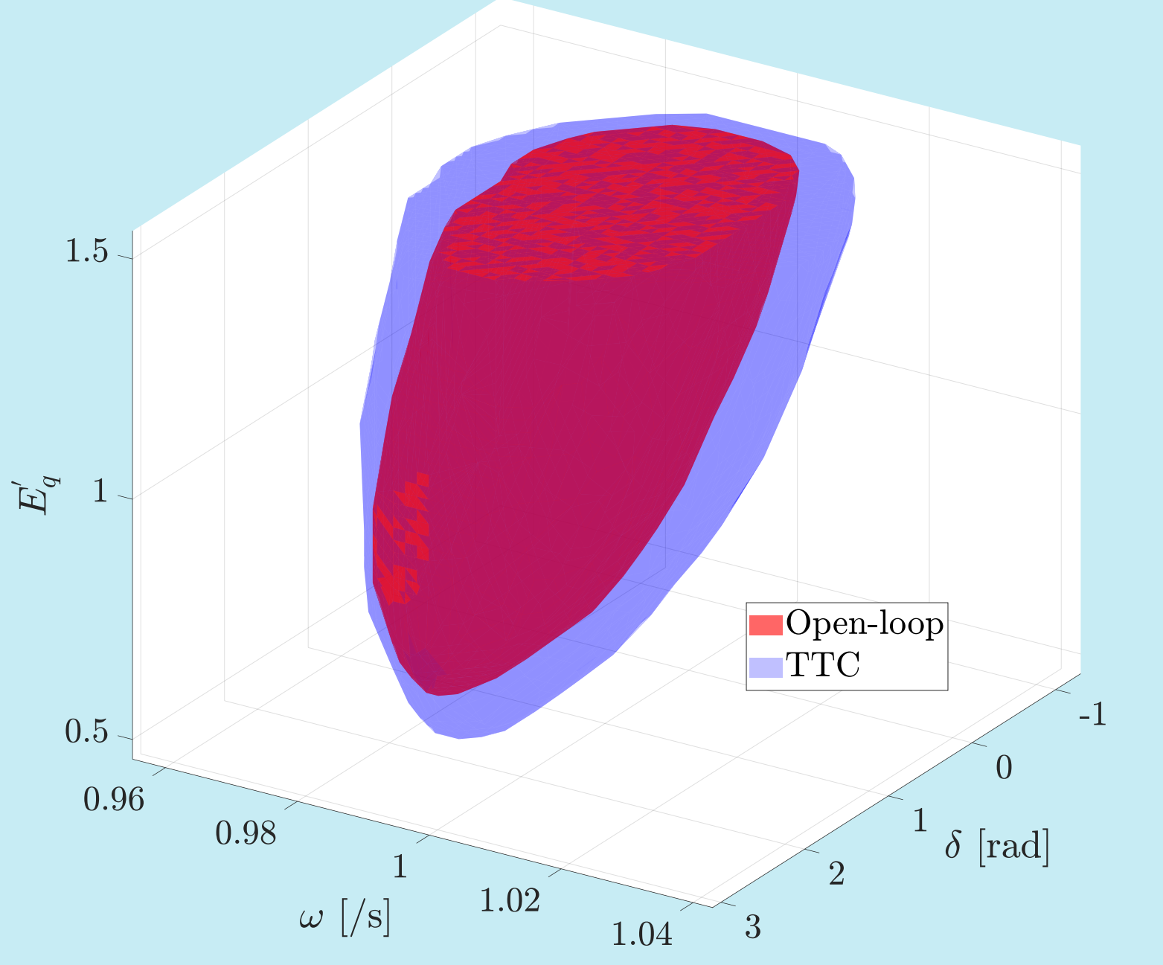


Fig. 5. Koopman autoencoder model

Fig. 6. ROA for OL vs. TTC

Acknowledgment

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References

[1] R. T. Elliott, H. Choi, D. J. Trudnowski and T. Nguyen, "Real Power Modulation Strategies for Transient Stability Control," in *IEEE Access*, vol. 10, pp. 37215-37245, 2022.

[2] R. T., Elliott, D. J. Trudnowski, H. Choi, and T. Nguyen, "The Power and Energy Storage Systems Toolbox–PSTess (V1.0)," SAND2021-11259, United States, 2021. Web. doi:10.2172/1819998.

[3] S. L. Brunton, B. W. Brunton, J. L. Proctor, E. Kaiser, and J. N. Kutz, "Chaos as an intermittently forced linear system," Nature Commun., vol. 8, no. 1, pp. 1–9, May 2017.

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