in power-grid networks (2021).
GitHub: https://github.com/fmolnar-notredame/csb_powergrid
DOI: 10.5281/zenodo.4437866

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Author contributions

F.M., T.N., and A.E.M. designed the research, analyzed the results, and wrote the paper. F.M. performed the simulations. All authors approved the final manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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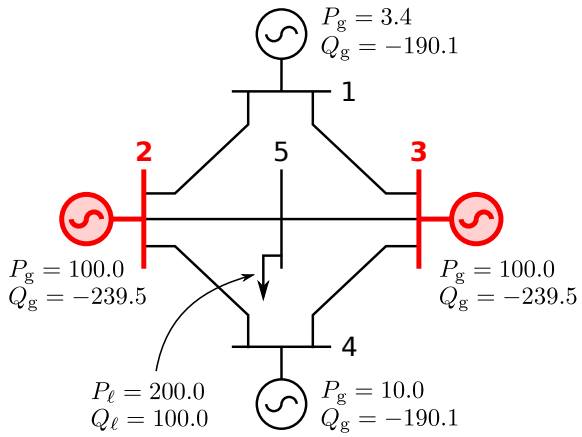
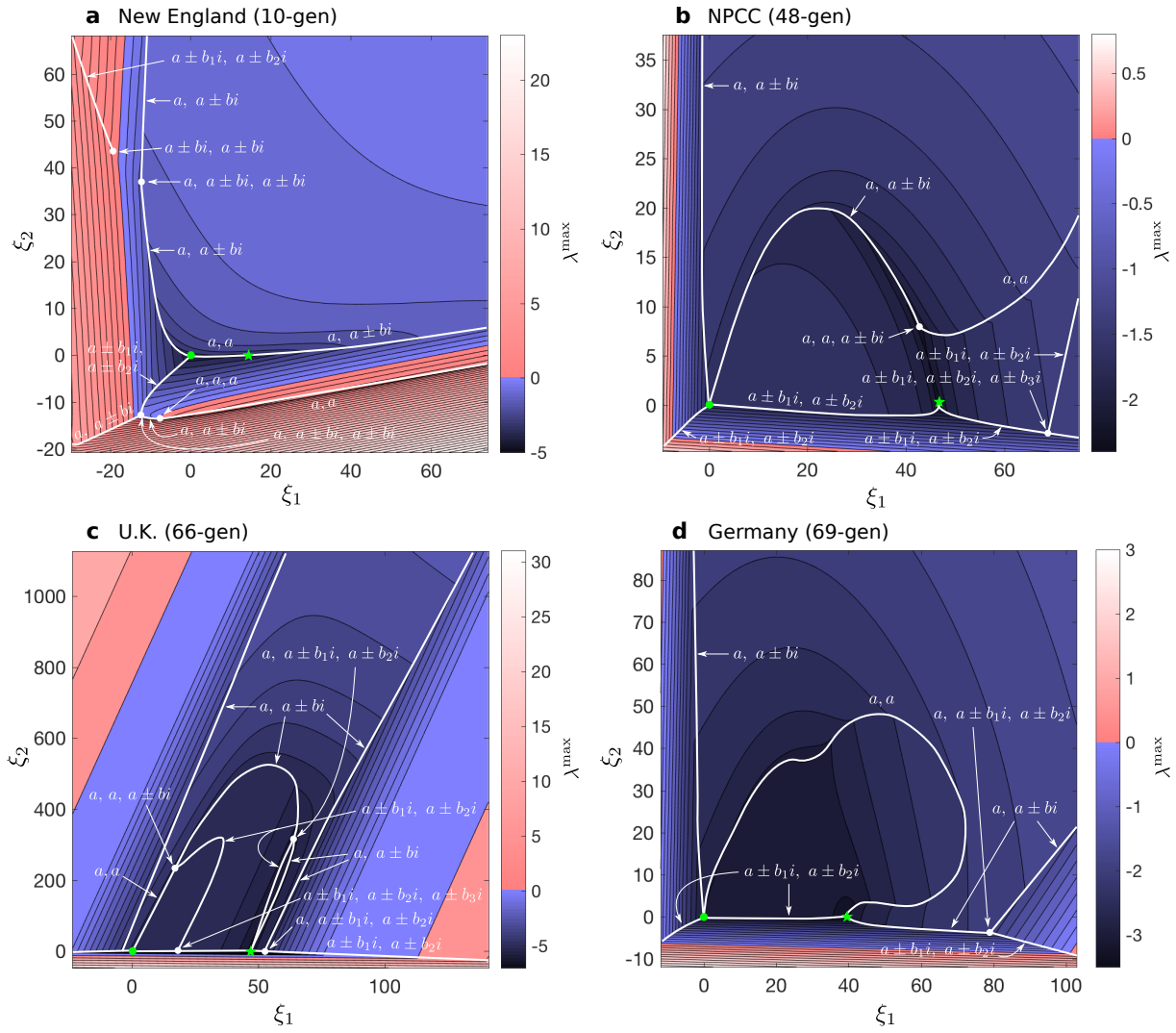
Supplementary Information

Asymmetry underlies stability in power grids

Supplementary Figures



Supplementary Fig. 1: **System diagram for the 4-generator example system in Fig. 5.** The generators at nodes 1–4 produce active and reactive power P_g and Q_g (in MW and MVAR, respectively). The load at node 5 consumes active and reactive power P_ℓ and Q_ℓ. The other generator parameters are identical among nodes 1–4, except for the tunable damping parameters β_i, while the power line parameters are identical among all six lines connecting the nodes.



Supplementary Fig. 2: **Cusp hypersurfaces in the stability landscape of larger networks. a–d** Contour levels of $\lambda^{\max}$ on the plane M, defined as the hyperplane perpendicular to L that contains $\boldsymbol{\beta}_=$ and $\boldsymbol{\beta}_{\neq}$ (as in Fig. 2), for the four systems used in Fig. 6. The horizontal coordinate ξ_1 represents the Euclidean distance from the point $\boldsymbol{\beta}_=$ along the line connecting $\boldsymbol{\beta}_=$ to $\boldsymbol{\beta}_{\neq}$, and ξ_2 is the distance along the line orthogonal to the ξ_1-axis. A white curve indicates the (one-dimensional) cross section of a codimension-one cusp hypersurface and corresponds to single degeneracy of the real parts of the eigenvalues of the Jacobian $\mathbf{J}$, such as two identical real eigenvalues $\{a, a\}$, two pairs of complex conjugate eigenvalues with matching real parts $\{a \pm b_1 i,\ a \pm b_2 i\}$, and one real eigenvalue matching the real parts of a conjugate eigenvalue pair $\{a,\ a \pm bi\}$. The green dot and star indicate $\boldsymbol{\beta}_=$ and $\boldsymbol{\beta}_{\neq}$, respectively. These two points and the white dots correspond to the cross sections of cusp hypersurfaces of higher codimensions, each representing specific double or higher degeneracy of the real parts of the eigenvalues.