Robustness of Cross-Well Dynamics in Multistable Energy Harvesters Under Parameter Mismatch

T. Burzyński, P. Brzeski and P. Perlikowski*

Division of Dynamics, Lodz University of Technology, Poland
e-mail: przemyslaw.perlikowski@p.lodz.pl

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This study investigates the influence of parameter mismatch on the stability of cross-well motion in four nonlinear vibration energy harvesters, including two electromagnetic and two piezoelectric designs [1]. Instead of evaluating performance solely through generated power, a basin-stability-based metric with parameter mismatch is employed to quantify the probability of reaching and maintaining the desired high-energy cross-well response. The analysis is conducted in the excitation amplitude-frequency space using Monte Carlo sampling and up to 200,000 simulations per system [2]. Parameter uncertainties of ±2.5%, ±5%, and ±10% are introduced in damping, electromechanical coupling, stiffness, and potential-related parameters. Results demonstrate that electromagnetic harvesters are substantially more sensitive to parameter mismatch than piezoelectric systems. For the investigated electromagnetic devices, a 10% mismatch may reduce the probability of achieving stable cross-well motion from nearly 1.0 to approximately 0.5–0.7, accompanied by pronounced erosion of safe operating regions. Although the more complex electromagnetic configuration extends the region where cross-well motion can occur, it also introduces wider areas characterized by moderate stability levels. In contrast, piezoelectric harvesters preserve high basin stability even under significant parameter uncertainty, with maximal changes in stability not exceeding approximately 23–30%. The two-degree-of-freedom piezoelectric harvester exhibits the broadest operational bandwidth and the highest robustness. The findings indicate that basin-stability analysis provides an effective framework for assessing practical reliability of nonlinear energy harvesters and identifying excitation conditions that remain safe despite unavoidable parameter uncertainty. The results further suggest that piezoelectric multistable designs offer superior resilience and operational reliability for real-world energy harvesting applications.

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