Nonlinear Dynamics of Vibratory Energy Harvesting Systems

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Abstract

The technological advances of the past decade have spurred the development of various mobile devices—ranging from smartphones to medical implants and micro-sensors—that rely on dependable, autonomous energy sources. In this landscape, piezoelectric vibration energy harvesters, particularly those operating in nonlinear regimes, stand out for their ability to efficiently convert mechanical vibrations into electrical energy across a broad frequency range, far beyond resonance peaks. This study conducts an in-depth nonlinear analysis of a typical bistable energy harvester, modeled as a Duffing oscillator with harmonic excitation, exploring a range of excitation amplitudes and frequencies. Our analysis reveals complex dynamics characterized by multiple bifurcation mechanisms, hysteresis, and chaos, underscoring the potential for significant energy recovery. To enhance conversion efficiency, we employ classical chaos control techniques, such as OGY and Pyragas methods, alongside innovative control strategies based on fractional operators to stabilize the system along high-energy unstable periodic orbits. Additionally, we extend our investigation to include non-convex optimization, global sensitivity analysis, and uncertainty quantification, addressing both symmetric and asymmetric configurations of the energy harvesting systems. The incorporation of these methodologies provides a comprehensive understanding of the operational dynamics and aids in optimizing the performance of these crucial energy solutions.

About the speaker

Americo Cunha Jr is an Associate Professor of Applied Mathematics at Rio de Janeiro State University (Brazil) and he was Visiting Researcher at Princeton University in 2023. He earned a double D.Sc. degree in Mechanical Engineering from the Pontifical Catholic University of Rio de Janeiro (Brazil) and the University of Paris-Est (France). He serves as an Associate Editor for the Journal of Vibration Engineering & Technologies and an Affiliated Editor of Plos One. His research interests include nonlinear dynamics, uncertainty quantification, mathematical epidemiology, and origami-based engineering. He was the recient of the 2023 ABMEC (Brazilian Association of Computational Methods in Engineering) Award for Young Scientists.