Numerical Modeling of Flow-Driven Piezoelectric Energy Harvesters

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ABSTRACT

A specific class of energy harvester devices for renewable energy resources is investigated, that allow conversion of ambient fluid flow energy to electrical energy via flow-induced vibrations of a piezo-ceramic composite structure positioned in the flow field [3,4]. In this way, potentially harmful flow fluctuations are harnessed to provide independent power supply to small electrical devices. In order to harvest energy from fluid flows by means of piezoelectric materials the kinetic energy of the fluid first has to be transformed to cyclic straining energy of the piezoelectric material which is then transformed to electrical energy under the presence of an attached electrical circuit representing the powered electrical device or charged battery.

This energy converter technology simultaneously involves the interaction of a composite structure and a surrounding fluid, the electric charge accumulated in the piezo-ceramic material and a controlling electrical circuit. In order to predict the efficiency and operational properties of such future devices and to increase their robustness and performance, a mathematical and numerical model of the complex physical system is required to allow systematic computational investigation of the involved phenomena and coupling characteristics. The research is devoted to introducing a monolithic approach that provides simultaneous modeling and analysis of the coupled energy harvester, which involves surface-coupled fluid-structure interaction, volume-coupled piezoelectric mechanics and a controlling energy harvesting circuit for applications in energy harvesting. The weak form of the governing equations is discretized by the space-time finite element method based on a mixed velocity-stress/rate form of the potential-dielectric displacement framework. The space-time finite element [2,3] model incorporates a novel method to enforce equipotentiality on the electrodes covering the piezoelectric patches, making the charge unknowns naturally appear in the formulation. This enables to adapt any type of electrical circuit added to the electromechanical problem. To validate the formulation, the case of piezoelectric triple layer EHD driven by base excitations, as described in [1] is chosen. The closed-form solution from [1] is compared to numerical solution proposed in this work. The variation of the electric potential through the thickness of the piezoelectric patch, assumed to be linear in many closed-form solutions, is shown to be quadratic in nature.

The research contributes to the mathematical modeling and numerical discretization of complex multi-physics system in an efficient way which facilitates an ideal basis for precise and transient coupling. This may lead to improved convergence and numerical efficiency in comparison with portioned approaches. This methodology also provides new insights and in-depth understanding on design requirements on such energy harvesting devices in terms of their robustness and efficiency

References

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