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ANALYTICAL MODEL FOR SAMPLING-BASED RELIABILITY ANALYSIS OF OUTPUT ELECTRIC POWER GENERATED BY PIEZOELECTRIC ENERGY HARVESTING SKIN UNDER UNCERTAINTY

Heonjun Yoon[1]*, Byeng D. Youn[2] and Heung S. Kim[3]

[1] Department of Mechanical and Aerospace Engineering, Seoul National University, Seoul, 151-742, Republic of Korea, heonjun@snu.ac.kr
[2] Department of Mechanical and Aerospace Engineering, Seoul National University, Seoul, 151-742, Republic of Korea, bdyoun@snu.ac.kr
[3] Department of Mechanical, Robotics and Energy Engineering, Dongguk University-Seoul, Seoul, 100-715, Republic of Korea, heungsoo@dgu.edu

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Energy harvesting (EH) technology, which scavenges electric power from ambient, otherwise wasted, energy sources, has been explored to develop self-powered wireless sensors and possibly eliminate the battery replacement cost for wireless sensors [1]. As a compact and durable design concept, piezoelectric energy harvesting skin (PEH skin), which consists of piezoelectric patches directly attached onto the surface of a vibrating structure as one embodiment, has been recently proposed [2].

To design the PEH skin and select best sites for its installation, it is of critical importance to preliminarily predict harvestable electric power under a given vibration condition. Furthermore, the uncertainty propagation analysis [3] should be performed to quantify the effect of the physical uncertainty sources (e.g., the material properties, geometry, natural frequency, and loading condition) on the variation of harvestable electric power. Therefore, this study aims at developing an electromechanically-coupled analytical model for the two main purposes: i) quick quantification and ii) reliability analysis of electric power generated by the PEH skin under uncertainty. In this study, the probability that harvestable electric power is larger than the threshold at which it is set to activate the operation of wireless sensors while taking into account physical uncertainty sources is defined as the reliability.

Based on the Kirchhoff plate theory, the Hamilton's principle is used to derive the differential equations of motion. The Rayleigh-Ritz method is implemented to calculate the natural frequency of the PEH skin. The electrical circuit equation is derived by substituting the piezoelectric constitutive relation into Gauss's law. The steady-state output voltage is obtained by solving the differential equations of motion and electrical circuit equation simultaneously. Finally, by applying the Monte Carlo simulation to the analytical model of the PEH skin, the reliability or statistical moments of harvestable electric power are estimated with affordable computational burden.

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