Enhancing Aeroelastic Wind Energy Harvesting Using Quasi-Zero Stiffness

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Abstract. A quasi-zero stiffness (QZS) two degree-of-freedom (DOF) galloping piezoelectric energy harvester (GPEH) is proposed for efficient energy harvesting in the ultra-low wind speed range. At low wind speeds, traditional 1DOF and 2DOF linear harvesters are not capable of generating enough voltage to power microelectronics, while the bistable harvester tends to be trapped in intrawell motion, which is unfavorable for wind energy harvesting. With the feature of a low dynamic frequency, the QZS nonlinear mechanism is applied to remarkably decrease the onset galloping wind speed and boost the power generation. The simulation result shows that the 2DOF QZS-GPEH has the best output performance at low wind speeds, outperforming its 1DOF linear, 2DOF linear and 2DOF bistable counterparts. This work opens new opportunities for efficiently harvesting wind energy at the ultra-low wind speed region.

Introduction

With the development of wireless sensor networks and Internet of Things, vast sensor nodes are deployed in harsh circumstances for monitoring purposes. However, how to provide a reliable and long-term power supply to these sensors is a big challenge. Currently, wind energy harvesting based on galloping become a viable solution due to its large outputs in an infinite wind speed range [1]. Researchers have mainly focused on decreasing the cut-in wind speed, broadening the operational wind speed range, and improving the power output performance [2]. Because the cut-in wind speed is highly related to the oscillation frequency of the structure [2], manipulating the oscillation frequency is essential to decrease the cut-in wind speed and enhance the power performance at low wind speeds for galloping energy harvesting. 2DOF systems provide more flexibility to adjust the galloping frequency for enhanced outputs by modifying the model frequencies [3]. Besides, quasi-zero stiffness (QZS) nonlinearity has been proved to provide a low dynamic resonance frequency at equilibrium [4]. We propose a 2DOF quasi-zero-stiffness galloping piezoelectric energy harvester (QZS-GPEH) for dramatically enhancing the wind power extraction performance at ultra-low wind speeds.

Results and discussion

We design a practical prototype as shown in Fig. 3. The bluff body oscillates horizontally when subjected to the incoming flow. The piezoelectric transducer attached to the primary beam converts the strain energy during oscillation into electricity via piezoelectric transduction. A secondary beam with a tip mass is added at the free end of the primary beam as the second degree-of-freedom. The quasi-zero stiffness is achieved via magnetic interaction between magnets A, B and C to achieve optimal galloping energy harvesting performance.

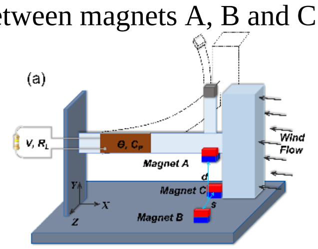

Fig. 1. Configurations of 2DOF QZS-GPEH

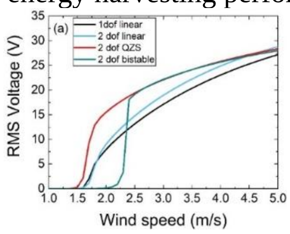

Fig. 2. RMS voltage as a function of wind speed

Figure 2 compares the RMS voltage versus wind speed for the four configurations, including 1DOF linear, 2DOF linear, 2DOF QZS and 2DOF bistable GPEHs based on simulation. Firstly, the cut-in wind speed of the 2DOF QZS-GPEH is reduced to 1.5 m/s, smaller than that of other three configurations. Besides, the output voltage is remarkably larger than that of the other three counterparts, especially at low wind speeds. For instance, the 2DOF QZS-GPEH increases the voltage by 95% and 72% in comparison to the 1DOF linear GPEH, and the 2DOF linear GPEH at 2.0 m/s, respectively. Moreover, below 2.4 m/s, the bistable GPEH is trapped into the intrawell oscillation with very low voltage output. Apparently, the 2DOF QZS-GPEH has the best voltage output performance at low wind speeds, outperforming the other three counterparts.

References

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