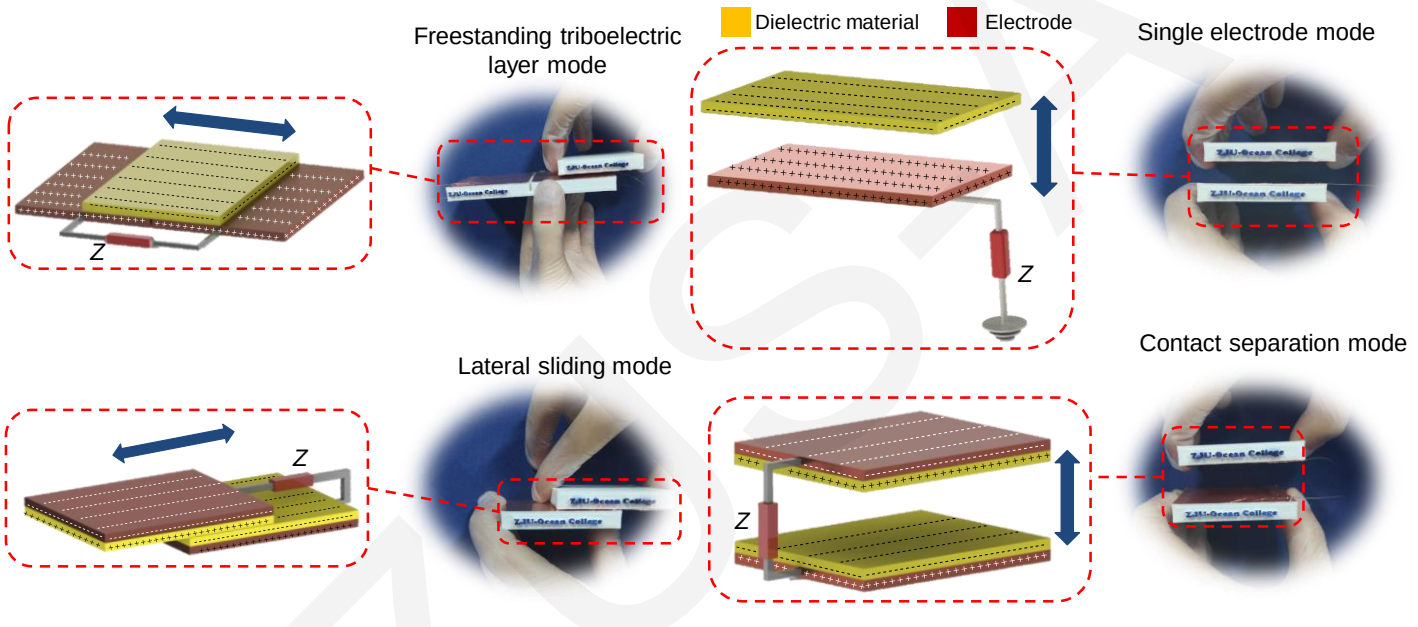
Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Revolutionizing wind energy: exploring triboelectric and piezoelectric nanogenerators for sustainable power generation

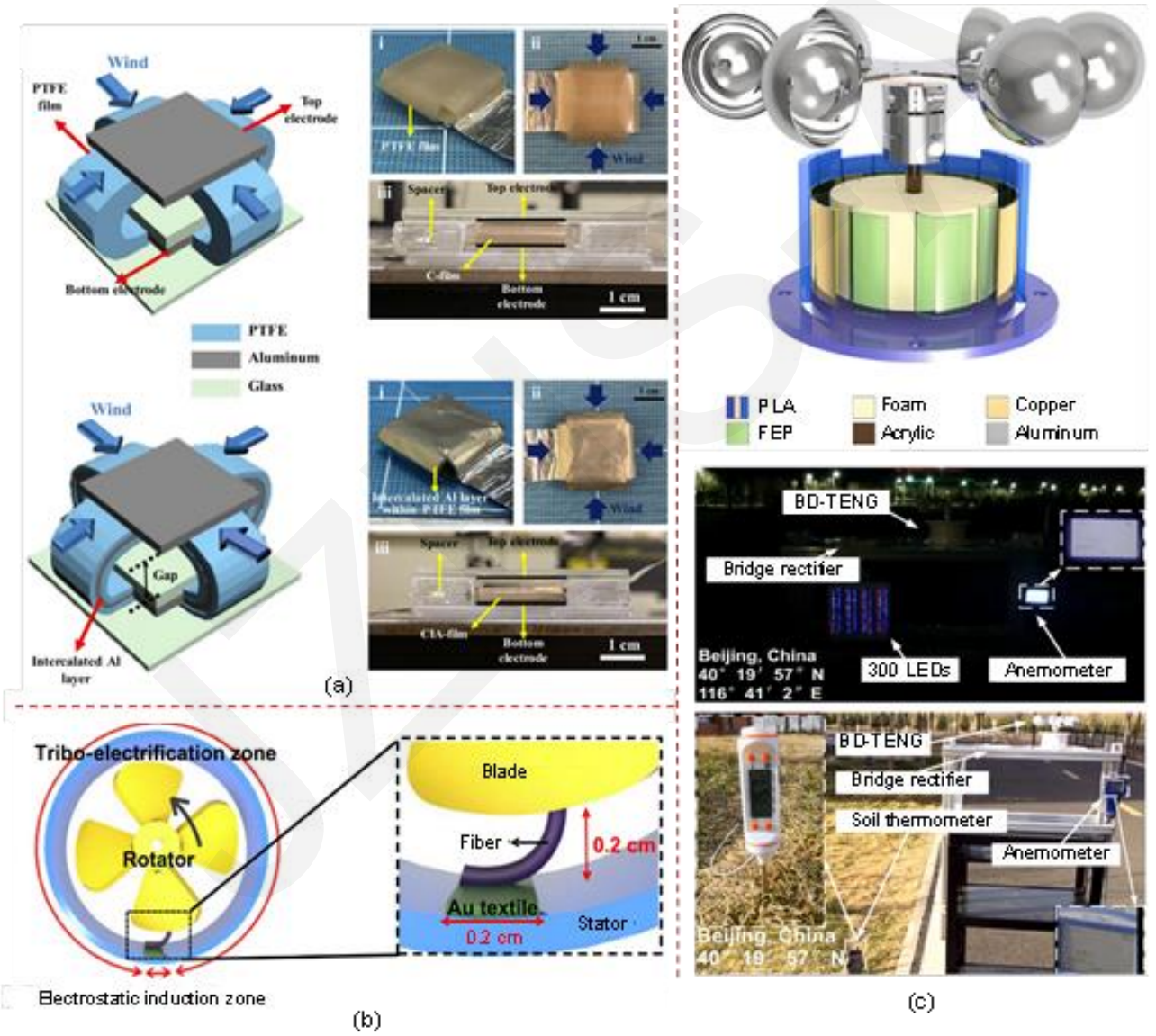
Ali MATIN NAZAR, Haiwei XU, Mingfeng HUANG

Cite this as: Ali MATIN NAZAR, Haiwei XU, Mingfeng HUANG, 2024. Revolutionizing wind energy: exploring triboelectric and piezoelectric nanogenerators for sustainable power generation. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 25(11):889-907. https://doi.org/10.1631/jzus.A2300530

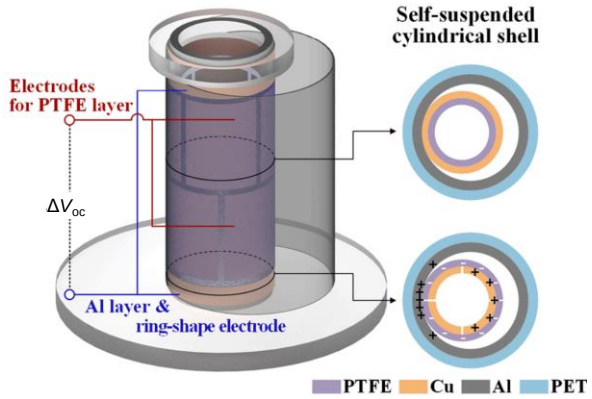
Concepts of triboelectric and piezoelectric nanogenerators



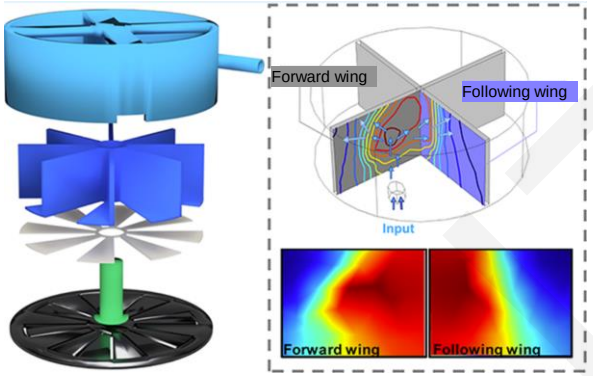
Harnessing wind-powered TENGs for energy harvesting



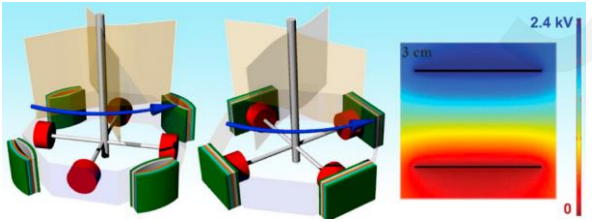
Wind-powered TENGs for energy harvesting



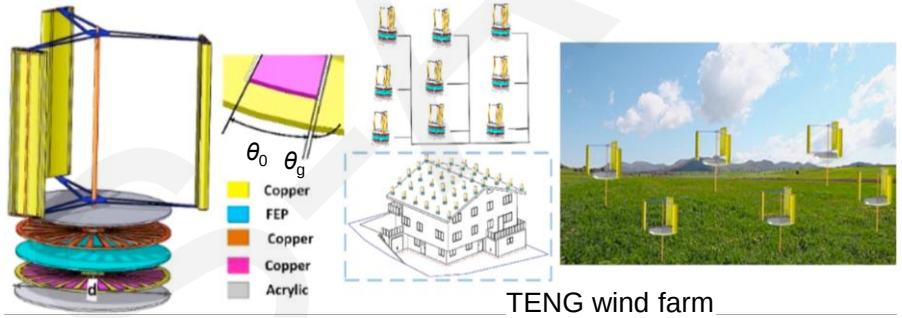
(a)



(b)

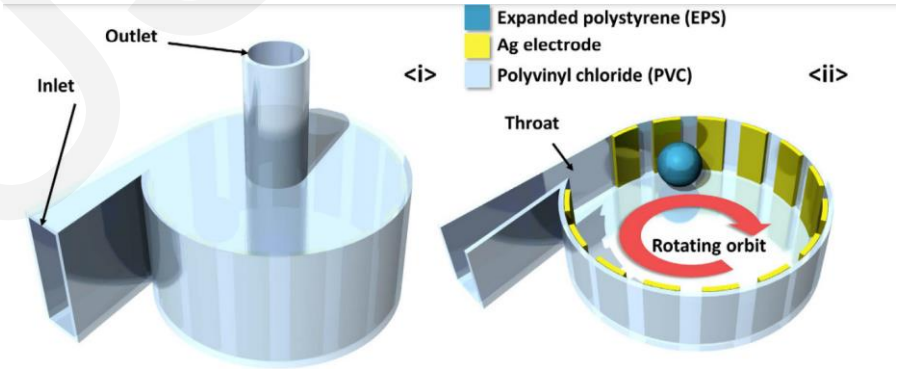


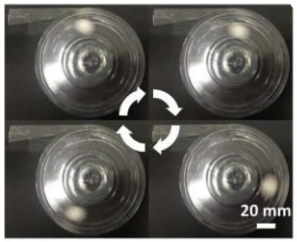
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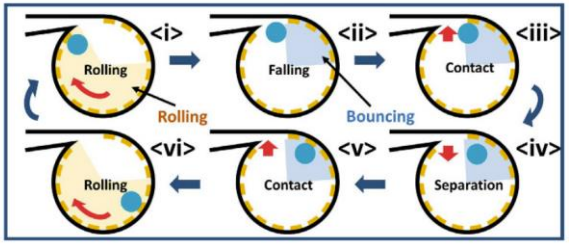


TENG wind farm

(a)

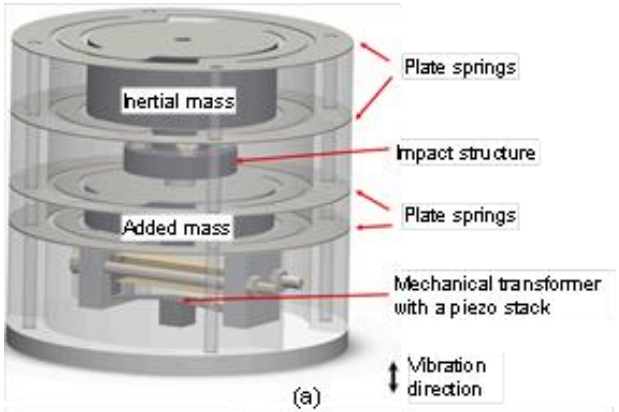




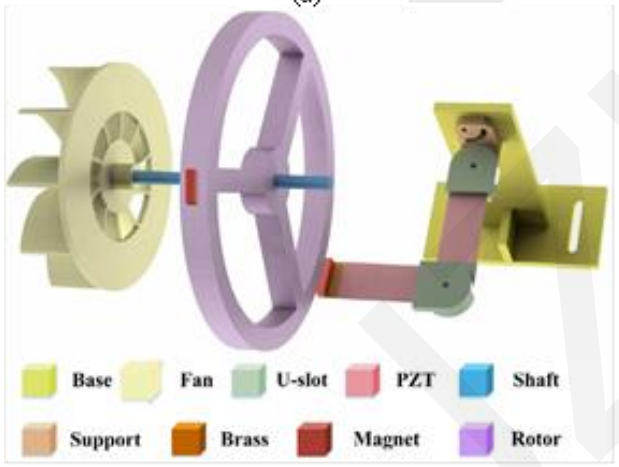


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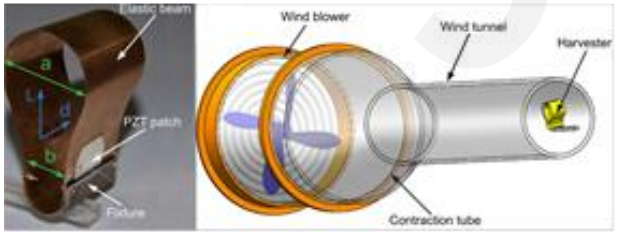
Wind-powered PENGs for energy harvesting



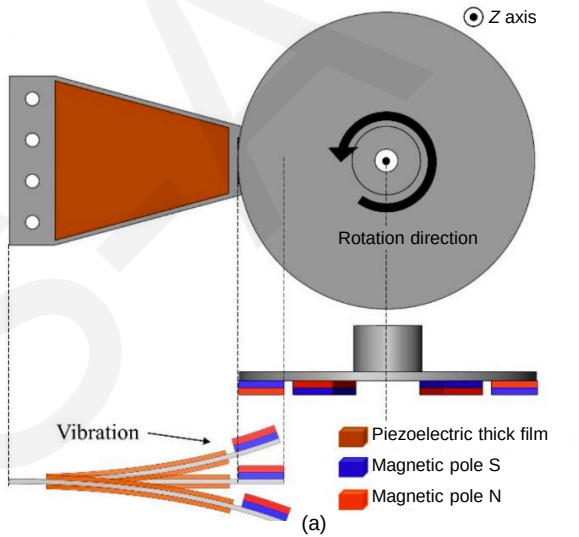
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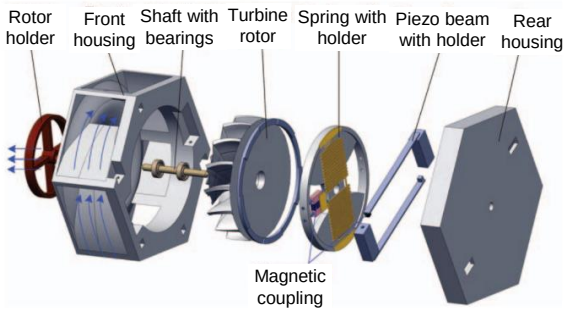
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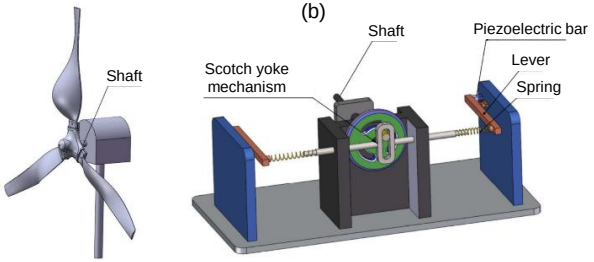
(c)



(a)

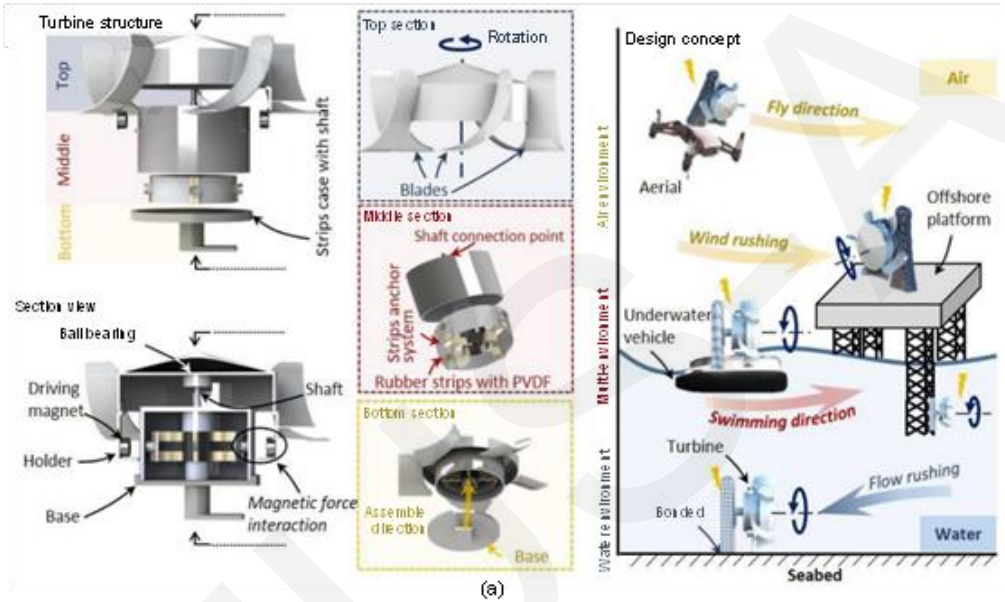


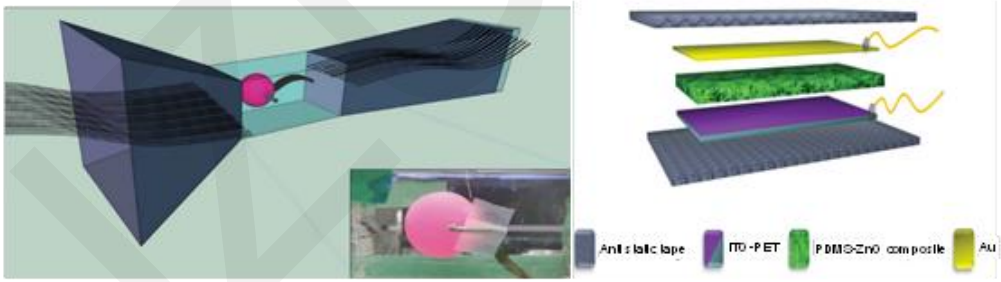
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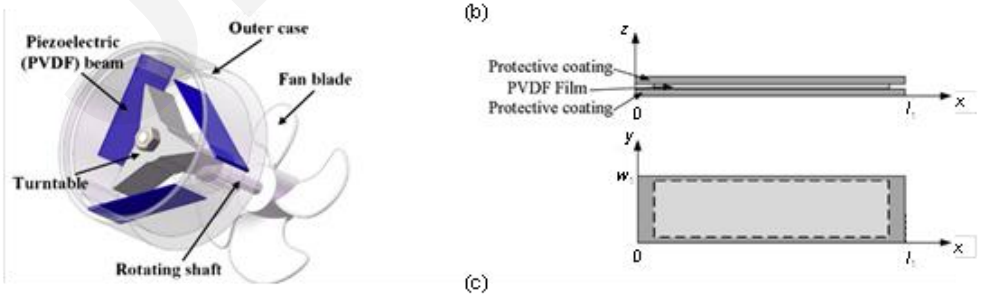


(c)

Wind-powered PENGs for energy harvesting







Summary of various TENG and PENG techniques for energy harvesting

Structure	Reference	Max-open circuit voltage	Max-short circuit current	Surface power density	Power	Average power or voltage
TENG	Shin et al. (2021)	233 V	348 μA	46.1 W/m^2	–	~150 V
TENG	Park et al. (2017)	21.6 V	0.6 μA	–	–	~12 V
TENG	Li et al. (2022)	330 V	7 μA	–	2.81 mW	~300–330 V
TENG	Ko et al. (2022)	47.68 V	–	8.43 mW/m^2	–	~30–35 V
TENG	Roh et al. (2019)	62.4 V	8.3 μA	283.95 W/m^2	–	~60–62 V
TENG	Huang et al. (2016)	206 V	30 μA	–	3 mW	~120–160 V
TENG	Ahmed et al. (2017)	600 V	0.38 μA	–	0.6 W	~300 V
TENG	Yong et al. (2016)	11.2 V	1.86 μA	–	–	~9 V
PENG	Shan et al. (2022)	4.01 V	–	–	6.72 mW	~1.16 V
PENG	Yu et al. (2022)	120 V	–	–	563 μW	–
PENG	Zhao et al. (2015)	34 V	–	–	1.73 mW	~20 V
PENG	Na et al. (2021)	60 V	2 mA	–	22 mW	~35–45 V
PENG	Fu et al. (2016)	2.64 V	–	–	742 μW	~1.4 V
PENG	Tao et al. (2017)	–	–	–	553 W	~150 W
PENG	Egbe et al. (2021)	15 V	–	–	9 μW	~10–12 V
PENG	Pandey et al. (2019)	1.6 V	–	–	–	~1.0–1.2 V
PENG	Zhang et al. (2017)	160.2 V	–	–	2566.4 μW	~100–140 V

Conclusions

This review has highlighted the advancements and challenges associated with triboelectric and piezoelectric nanogenerators used for wind energy harvesting. The triboelectric and piezoelectric effects which underly these devices' functions were discussed, emphasizing how they enable the conversion of mechanical energy into electrical energy. We provided an overview of the latest research and developments into energy harvesting based on triboelectric and piezoelectric nanogenerators. For both nanogenerator technologies, various optimization techniques and integration strategies were discussed, along with potential applications and associated challenges.

We also identified several challenges that need to be addressed for the successful implementation of wind-driven triboelectric and piezoelectric nanogenerators. These include scalability, durability, power management, and system integration. Future research efforts should focus on developing scalable manufacturing techniques, enhancing the durability of nanogenerators, and implementing efficient power management systems. Despite these challenges, we underscore the great potential of wind energy harvesting based on triboelectric and piezoelectric nanogenerators. These technologies offer sustainable methods for powering autonomous systems, monitoring wind turbines, and providing electricity in remote areas. This review contributes to existing knowledge by providing insights, perspectives, and future directions for the advancement of wind engineering using nanogenerators. By addressing the associated challenges and leveraging the unique capabilities of these technologies, researchers and engineers can unlock the full potential of wind energy harvesting and contribute to a greener and more sustainable future.