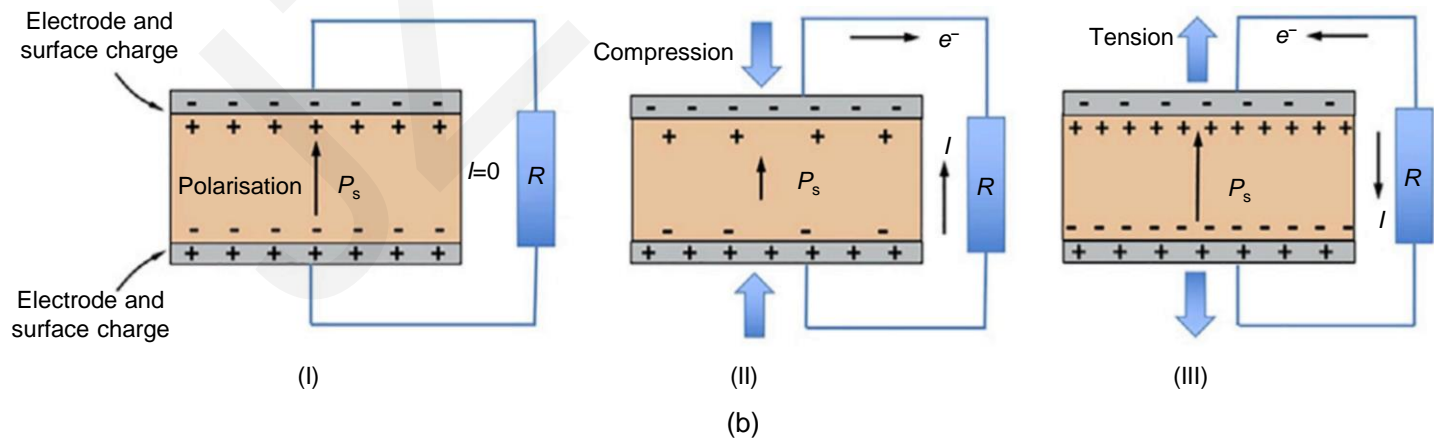
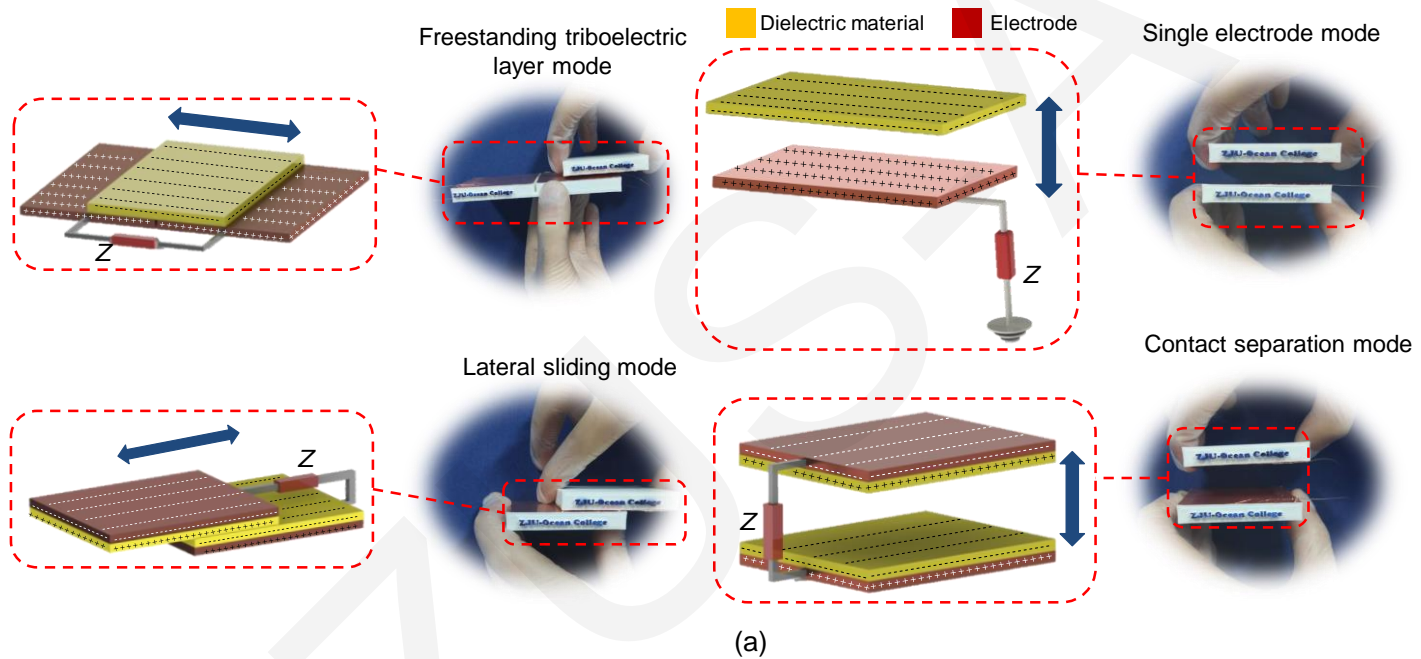


Revolutionizing wind energy: exploring triboelectric and piezoelectric nanogenerators for sustainable power generation

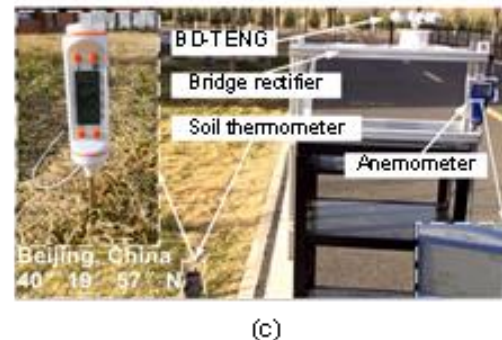
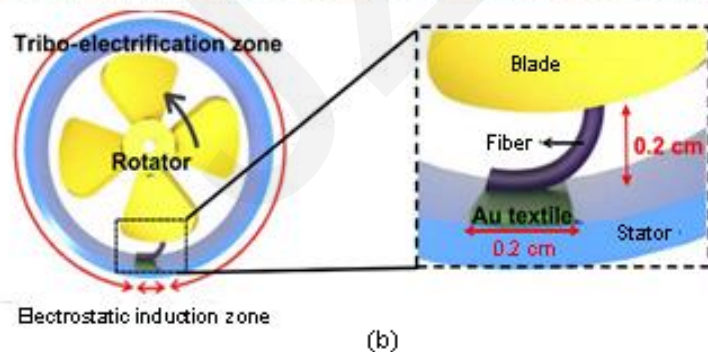
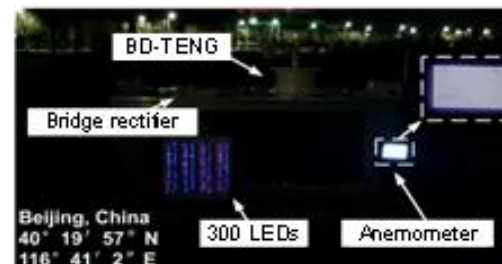
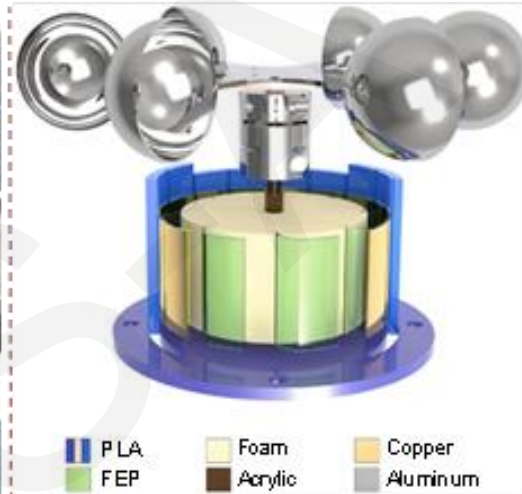
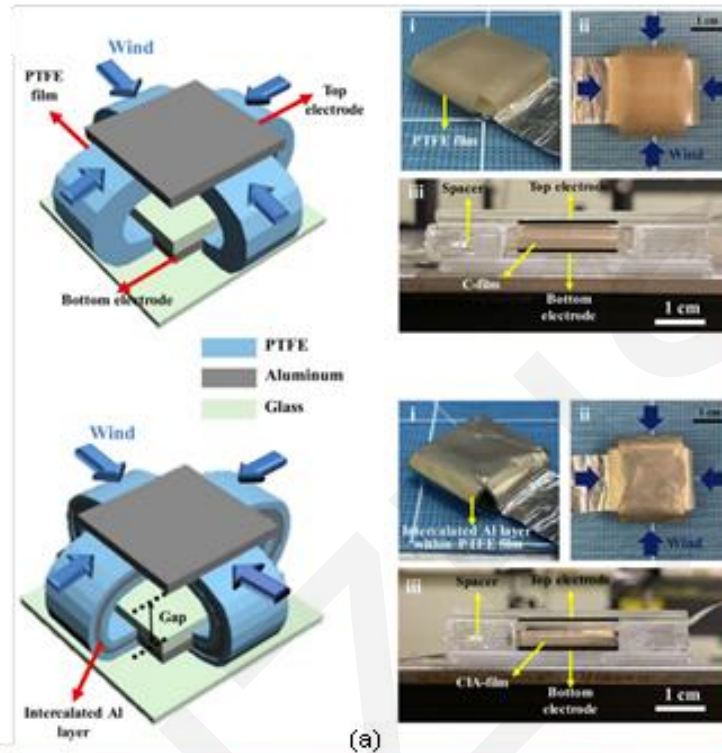
Ali MATIN NAZAR, Haiwei XU, Mingfeng HUANG

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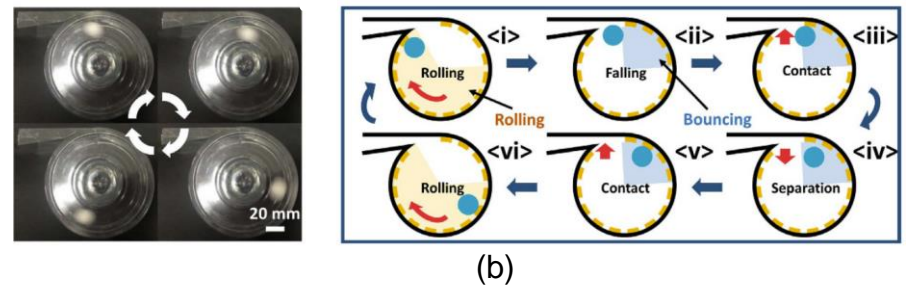
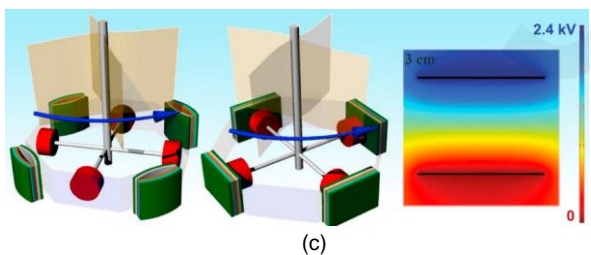
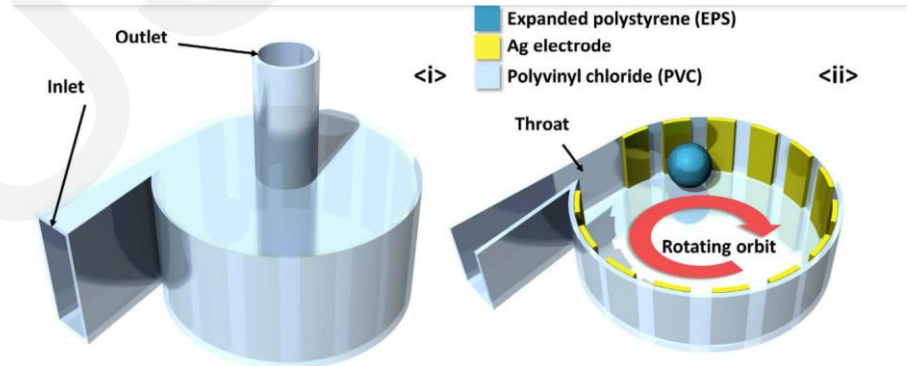
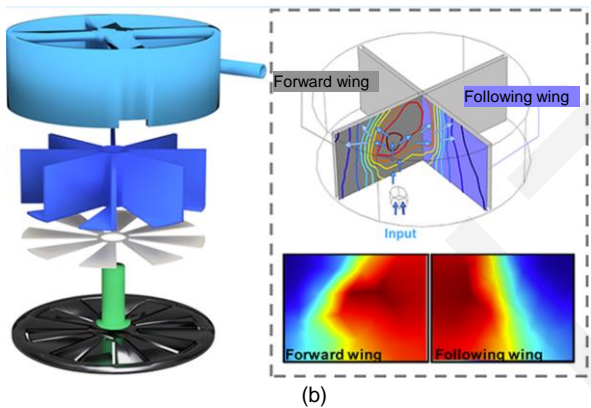
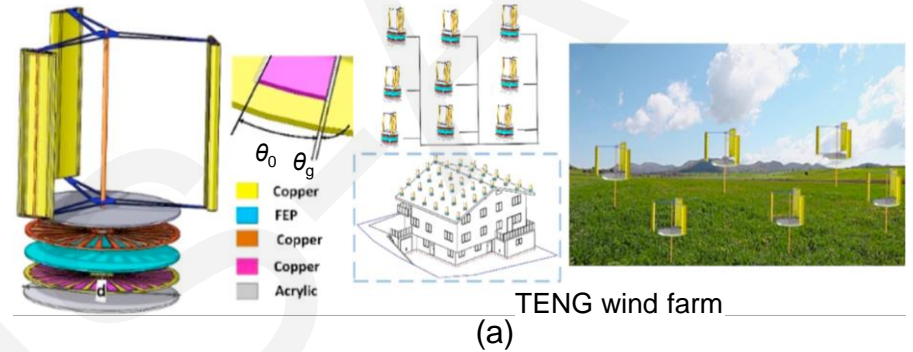
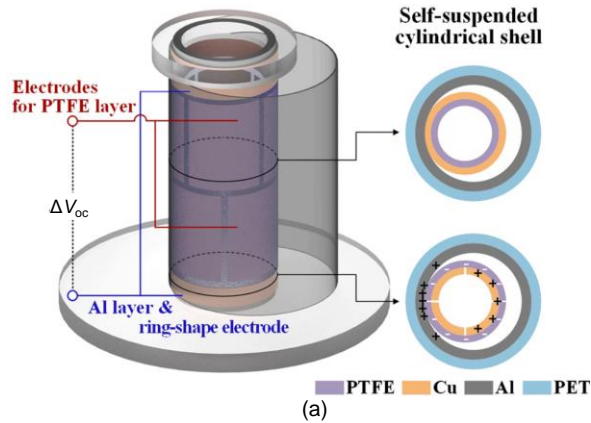
Concepts of triboelectric and piezoelectric nanogenerators



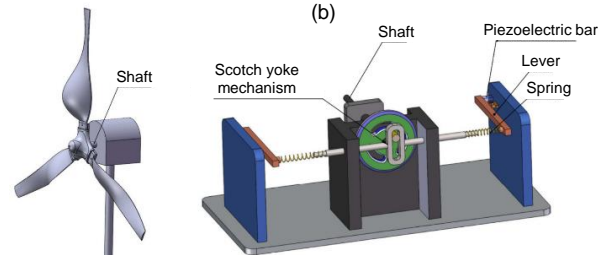
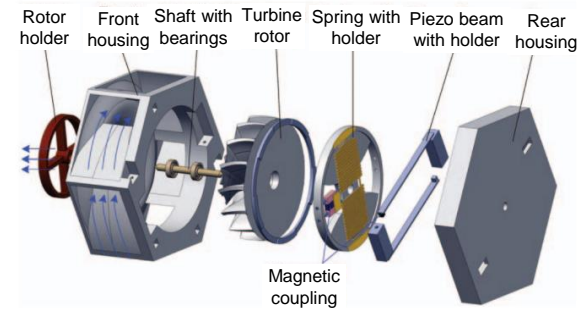
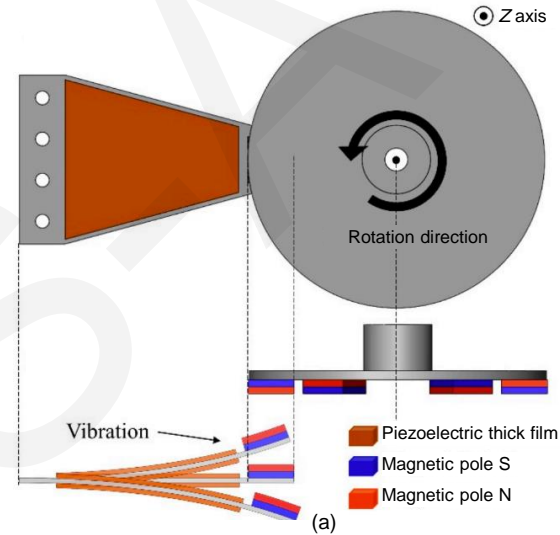
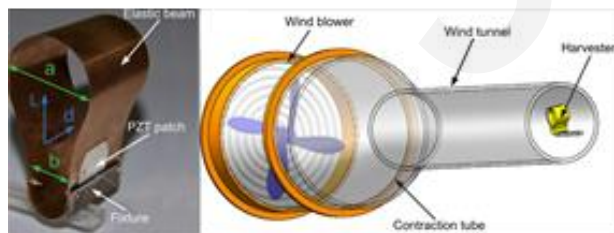
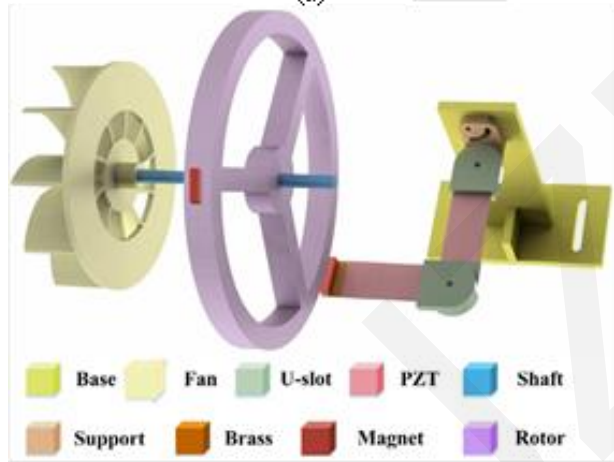
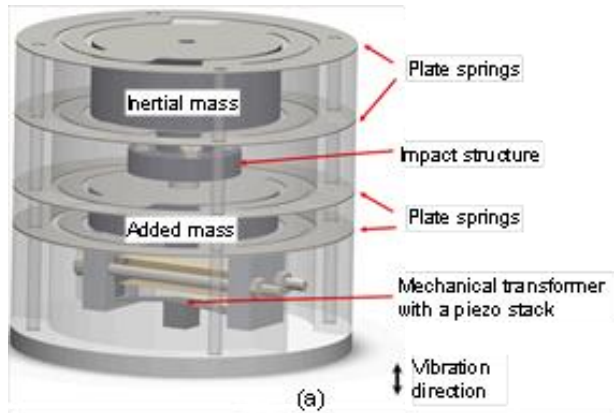
Harnessing wind-powered TENGs for energy harvesting



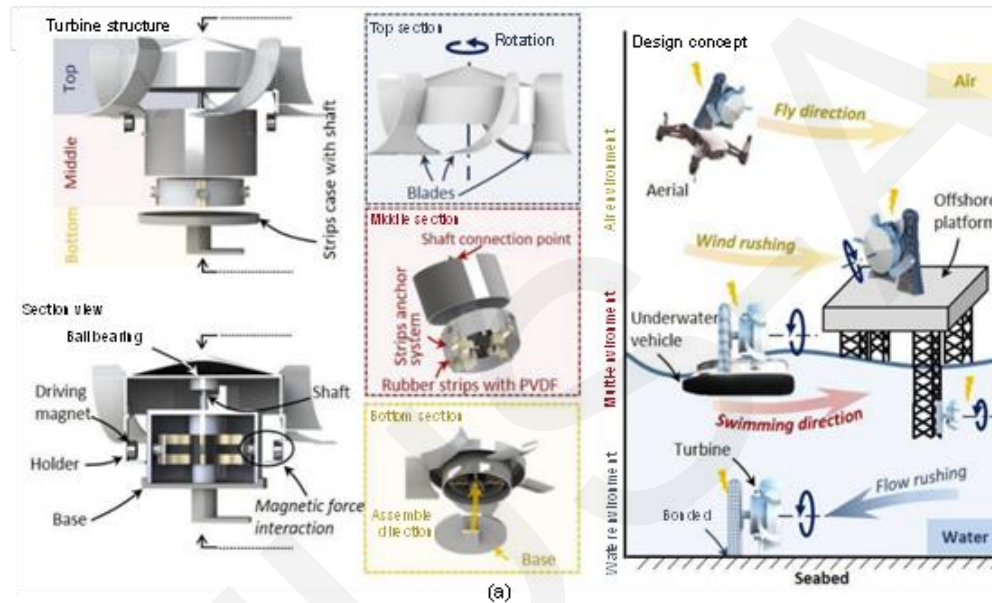
Wind-powered TENGs for energy harvesting



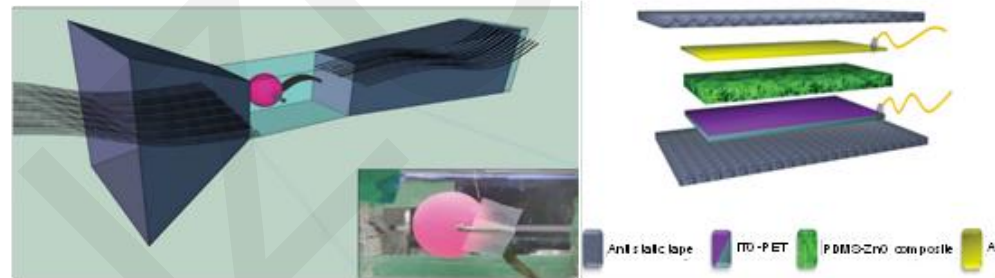
Wind-powered PENGs for energy harvesting



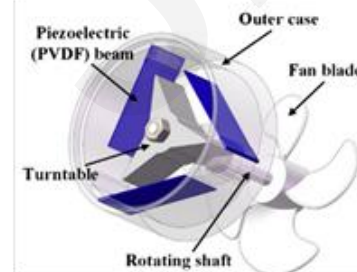
Wind-powered PENGs for energy harvesting



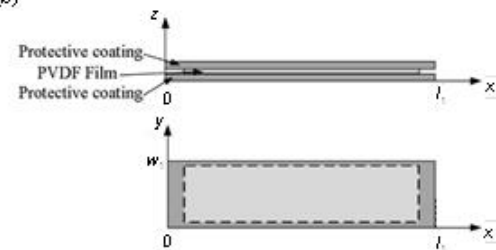
(a)



(b)



(c)



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 μ A | 46.1 W/m ² | – | ~150 V |
| TENG | Park et al. (2017) | 21.6 V | 0.6 μ A | – | – | ~12 V |
| TENG | Li et al. (2022) | 330 V | 7 μ A | – | 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 μ A | 283.95 W/m ² | – | ~60–62 V |
| TENG | Huang et al. (2016) | 206 V | 30 μ A | – | 3 mW | ~120–160 V |
| TENG | Ahmed et al. (2017) | 600 V | 0.38 μ A | – | 0.6 W | ~300 V |
| TENG | Yong et al. (2016) | 11.2 V | 1.86 μ A | – | – | ~9 V |
| PENG | Shan et al. (2022) | 4.01 V | – | – | 6.72 mW | ~1.16 V |
| PENG | Yu et al. (2022) | 120 V | – | – | 563 μ W | – |
| 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 μ W | ~1.4 V |
| PENG | Tao et al. (2017) | – | – | – | 553 W | ~150 W |
| PENG | Egbe et al. (2021) | 15 V | – | – | 9 μ W | ~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 μ W | ~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.