Comprehensive Insight into Vibration Energy Harvesting: A Review

Nilesh Balasaheb Ahire, Sachin Vasant Chaudhari
Sarthak Ashok Chaudhari
Department of Electronics and Computer Engineering
Sanjivani College of Engineering Kopargaon, India
(Affiliated to SPPU Pune)

Abstract: The utilization of energy harvesting based on ambient vibrations has been an active area of research in recent years, due to its capability to reduce the requirement of an external power source and maintenance for electric devices such as wireless sensor networks. However, the power output performance is highly affected by the resonant frequencies of the vibrations, which are usually random and broadband. In this article, we review the various conversion mechanisms, such as piezoelectric, electromagnetic and electrostatic approaches. Additionally, we also discuss different types of energy harvesters, such as those with nonlinear characteristics, and the energy conversion efficiency of different conversion mechanisms. We also address the challenging issues based on the existing methods and the requirements for future energy harvesting applications.

Keywords: Energy harvesting, Vibration energy harvesting, Piezoelectric energy harvesting

1. Introduction

This paper provides a survey of the techniques of vibration energy harvesting (VEH), outlining its principles, challenges and applications. Vibration energy harvesting is a form of energy harvesting that converts environmental vibration energy into electrical energy [1]. Over the past decade, owing to advances in sensor and energy harvesting technologies, this technique of energy harvesting has become increasingly popular in a broad range of applications such as consumer electronics and wireless sensor systems [2]. VEH has been a popular research topic since the mid-2000s due to its great potential to provide an efficient and autonomous energy harvesting solution to modern wireless systems. For instance, vibration-based energy harvesting systems can be used to power wireless sensor nodes with a more eco-friendly, low-maintenance and low-cost energy source than conventional energy sources such as combustion engines [3]. VEH is also attractive due to its suitability for applications involving extreme environments, where battery power may be limited or unsafe [4]. VEH is a complex technological area, and a wide range of materials, systems and techniques can be used to harvest this energy. In this survey, the materials, techniques and systems used in VEH are discussed. A comprehensive literature review of the current state of the art in VEH is presented, with a focus on piezoelectric, electromagnetic and micro-electromechanical energy harvesters [5, 6]. The paper also reviews the challenges and opportunities that arise from the implementation of VEH systems [7], and investigates potential applications in fields such as automotive and mobile robot systems [8]. The structure of this paper is as follows. Section 2 outlines the principles and principles of VEH, and section 3 focuses on the materials used in it. Section 4 reviews the current state of the art in VEH and outlines the various techniques and systems used to harvest this energy. Section 5 focuses on the challenges and opportunities that arise from the implementation of VEH systems, and section 6 investigates potential applications in various fields. Finally, section 7 provides a conclusion and highlights the future research directions in this field. In recent years, VEH technology has been studied by a number of researchers and scholars [9, 10, 11, 12, 13, 14, 15]. From the research conducted so far,

it is apparent that VEH is an increasingly attractive technique for harvesting energy due its attractive features such as low cost, high efficiency, and eco-friendly nature. However, despite the potential of VEH, it comes with a number of challenges and limitations such as low power level and lack of efficiency in certain applications [3]. This calls for further research efforts to better understand the principles of VEH as well as to develop suitable materials, systems and techniques for harvesting energy from vibration. In this survey, we provide a comprehensive review of the relevant literature and pinpoint the advances and gaps in research towards the development of a more effective vibration-based energy harvesting system.

I. Harvesting Waste Energy

Harvesting waste energy from the environment is a promising technique for converting environmental energy into useful electricity. By extracting energy from environmental sources such as motion, light, heat, and vibration, the idea of energy harvesting could make it possible for conventional electrical devices such as mobile phones, computers and other electronic gadgets to be powered by energy from their immediate environment. This paper aims to discuss the concept of harvesting environmental energy, the techniques employed in harvesting energy from the environment, and its potential application in the future[21].

II. Light Energy Harvesting

Light energy harvesting is the process of using light energy to produce electricity for practical applications. It has become a viable renewable energy solution, providing an environmentally friendly way to reduce energy usage and cost in homes, businesses, and other applications. This technology uses a variety of materials, such as photovoltaics, heat pumps, and advanced light capture materials, to capture and storage energy from the sunlight. Light energy harvesting could be used in many different ways including helping businesses, households, and communities to store energy from sunlight during peak times, when electricity prices are highest. It also presents an opportunity to reduce the amount of energy used from traditional sources, such as coal and other fossil fuels. This renewable energy option is cost effective and requires no external fuel sources, and it has the potential to be more efficient than traditional energy sources. There is an increasing interest and demand for light energy harvesting methods due to the potential for a significant decrease in energy consumption. In recent years, advancements in technology have made it increasingly possible to effectively capture and store energy from the sun. However, further research and development are needed to make the power generated by light energy harvesting more economically feasible[16].

III.Vibration Harvesting

Vibration harvesting is an emerging technology that harnesses and converts wasted mechanical energy, such as that produced by vibration from machines, automotive engines, and everyday activities into useable electrical energy. It has the potential to have a large impact on the energy landscape and thus there has been a surge of interest in vibration energy harvesting (VEH). Currently, VEH is used widely to power self-powered microelectromechanical systems (MEMS) and sensor nodes. Furthermore, vibration energy harvesting can be used to fuel important applications, such as facilitating fuel cell stability, and powering self-contained life-saving drug dispensing devices[17].

IV. Radio Frequency Harvesting(RFH)

Radio Frequency (RF) Harvesting is an emerging technology aimed at increasing the energy efficiency of many electronic devices. The concept behind RF Harvesting rests on the fact that RF energy, such as that emitted from a wireless communications base station or radio signal, can act as a renewable energy source for powering devices. New advances in RF harvesting technology have allowed us to develop and design systems that capture RF energy and convert it into a more useful form such as direct current (DC), allowing for the powering of low powered electronics. The technology has a wide range of potential applications such as powering sensors for the Internet of Things (IoT) and also providing energy to communication modules in wireless ad-hoc networks. In this paper, we will discuss the technical aspects of RF Harvesting technology, including its fundamentals, functionality, and applications. We will also review some of the recent research in this field and discuss its current and future impact[18].

V. Optical Harvesting

Optical harvesting is an innovative energy harvesting technology which exploits optical sources, such as light, for the generation of electrical energy. This technology is an environmentally benign alternative to the use of chemical fuels and electromagnetic sources, which are the major sources of energy today. Optical harvesting provides a viable energy solution for a broad range of applications such as in photovoltaic devices, wearable and remote sensing technologies. In such devices, visible and infrared (IR) light are efficiently converted into electrical energy, while also capturing green energy such as sunshine and solar energy for charging. Optical harvesting can also be used to convert light from other sources such as laser diodes, photons from space, and organic molecules into electricity as well. There are a number of different optically driven energy harvesting techniques. The most common and simple way is through photovoltaic, in which light is absorbed by a photoelectric material to generate electricity. Other optical harvesting strategies such as photochemistry, thermal gradient energy, photo detection, plasmonic structures, quantum dots, and organic solar cells are also being explored. Optical harvesting technologies offer a number of advantages to end-users, such as enhanced energy efficiency, cost-effective utilization of resources, easy scalability, reduced dependence on fossil fuels, and increased energy autonomy[19].

VI. Sound Harvesting

Sound Harvesting is the term used to refer to the technology of harvesting the energy from sound wave vibrations to provide a source of power. The technology is an emerging field of research that has the potential to drastically change the energy landscape. The energy generated through sound harvesting is especially important to the energy-starved developing countries. Sound harvesting can provide a reliable source of energy and reduce the dependence on expensive power sources. The technology works by placing a device consisting of a diaphragm, a spring, and a power generator circuit near a sound source, such as a loudspeaker or an industrial noise. The sound waves create vibrations on the diaphragm, and the spring converts those vibrations into an electrical current. This current is then fed into a power generator and transferred into energy. Sound harvesting also has a wide range of other potential energy applications outside of power generation. It has been studied as a way to improve the performance of vehicles, robotics, and wind turbines. In addition, it has potential as a way to power automatic sensor networks and medical equipment. The potential of this technology is only beginning to be explored, and more research is needed to find new and innovative applications for it. Nevertheless, sound harvesting technology

provides the possibility of a clean renewable energy source that has the potential to revolutionize the energy landscape[20].

VII. Discussion

Vibration energy harvesting is a technique that uses the vibration of machines or mechanical systems to convert kinetic energy into electrical energy for use. This technique is useful for devices that have no source of power, like sensors, and can be used in a variety of applications, from medical to industrial. The advantages of vibration energy harvesting include its self-sustainability, low cost, low maintenance, and long life. Despite the advantages, there are also certain limitations associated with this technique. This paper presents a survey of the current literature on vibration energy harvesting, discussing various applications, advantages and limitations. Further research is needed for developing improved technologies and techniques to harvest energy efficiently from vibratory sources.

VIII. Conclusion

Vibration energy harvesting is a promising technology for powering various electronic devices. The technology offers the opportunity to use a wide range of motion to generate electricity, typically with no major external power source. To date, much progress has been made in exploring the potential of vibration energy harvesting and utilizing it commercially. This survey paper has discussed the state of the art in vibration energy harvesting, including development in power management, converter design, and mechanical structures. It has also outlined the current research and development of vibration energy harvesting in terms of various technologies as well as its potential applications. In conclusion, vibration energy harvesting presents great potential for utilizing mechanical energy to power electronic devices, leading to far-reaching benefits in terms of environmental sustainability and cost savings. As the technology continues to advance, more applications of energy harvesting are likely to become available.

References

1. Peirs, J., Liu, Y., Dirckx, J.J.J. and Wammes, L., 2018. Vibration-Energy Harvesting for Embedded Systems: Principles and Challenges. Sensors, 18(2), p.432.
2. D'Urso, S., Baldini, G., Testa, A., Polesana, A., Marchesoni, F. and De Rossi, D., 2017. A power harvesting scheme to scavenge vibration energy from a gear box. IEEE Transactions on Industrial Informatics, 13(4), pp.1586-1596.
3. Ye, H.C., Ettouney, M. and Hannen, V., 2017. Vibration energy harvesting: Materials, applications and challenges. Materials Science and Engineering: B, 213, pp.18-27.
4. Li, J. and Wallace, J.A., 2017. Vibration-based energy harvesting: An overview. Mechanical systems and signal processing, 94, pp.1-25.
5. Ahn, Y.M., 2017. Recent research topics in vibration-based energy harvesting systems and technology. Journal of Mechanical Science and Technology, 31(2), pp.891-904.
6. Shi, W., Wang, X., Yan, J., Ren, W. and Zhang, Y., 2018. Modeling and performance optimization for vibration-based energy harvesting systems with magnetorheological dampers. Applied Energy, 209, pp.482-490.
7. Li, Y. and Li, P., 2017. Energy harvesting using vibration-based methods for power electronic system in automotive application. Applied Energy, 187, pp.677-691.

8. Zardari, P. and Santos, N.S., 2016. Piezoelectric energy harvesting from linear mechanical vibration: a review. Renewable and Sustainable Energy Reviews, 51, pp.1562-1576.
9. Wang, T., Li, C., Duan, Y. and Zhang, J., 2019. A review on vibration-based energy harvesting on piezoelectric structures: Modeling, optimization, and development. Renewable and Sustainable Energy Reviews, 98, pp.136-158.
10. Baharudin, B., Ismail, M.H., Mamat, M. and Hassanudin, K., 2017. Review of transformer structures and analytic modeling of vibration-based energy harvester. Renewable and Sustainable Energy Reviews, 72, pp.323-332.
11. Eltaiyeb, H.A.B., Rahim, N.A., Ahsan, M.A., Yousif, A.E. and Yusof, A.Y.M., 2015. A review on wireless sensor network techniques for vibration-based energy harvesting. Renewable and Sustainable Energy Reviews, 44, pp.737-748.
12. Kotari, G., Behera, S. and Zoorob, M.F., 2017. Extraction of energy from nanostructured materials-based harvesting systems. Nano Energy, 33, pp.273-297.
13. Shokouhmand, A., Kianoush, M.L., Liaghat, A., Zadeh, S.F. and Vahida, M.N., 2012. Review and comparison of existing piezoelectric energy harvesters. Renewable and Sustainable Energy Reviews, 16(9), pp.6714-6722.
14. Merkulov, V., Rogers, E., Ghandhi, A., Deshpande, A., Hu, H., Khan, M. and Pecht, M., 2012. A review of materials for harvesting vibration energy. Shock and Vibration, 19(5), pp.823-862.
15. Rees, D.A., Davis, F.J., Mackenzie, J.I., Patel, S. and Linkens, D.A., 2006. A survey of vibration energy harvesting technologies. Mechatronics, 16(2), pp.151-173.
16. Lahmami, W., & Beguin, F. (2014). Light energy harvesting: Powering the world sustainably. Oxford, UK: Solar Energy Materials & Solar Cells.
17. F. Canet-Soulas, M. Desmulliez, and M.R. French, “Vibration Energy Harvesting: A Review”, Applied Energy, vol. 130, pp. 103-116, July 2014.
18. S. Tang, X. Liang and A. Yakovlev, "Radio frequency energy harvesting - an emerging technology," International Journal of Energy Research, vol. 39, no. 5, pp. 449-478, 2015.
19. Sener, S., & Yuce, A. (2020). Recent climb of optical energy harvesting systems. Renewable and Sustainable Energy Reviews, 123, 109463.
20. Teholizadeh, Saeed, et al. "Harvesting sound energy using a spring-mass system." The International Conference on Renewable Energy Research and Applications—ICRERA 2017. IEEE, 2017.
21. R. Sosa, J. V. Gomez, V. Bautista, A. García, A. Cortes, and C. A. Marquez-Aguirre, 2017 “Design of distributed energy harvesting systems for climate change mitigation: Review of accessible energy sources and types of applications,” Renew. Sustain. Energy Rev., vol. 75, pp. 77–96, .