Micro Scale Energy Scavengers for Low Power Applications in Rural Areas

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***Abstract* — The country like India where majority of the population still lives in rural area, energy crisis is the issue which needs to be resolved at earliest. This paper discusses about the various techniques of energy scavenging in rural areas. Two smart methods of energy scavenging for low power applications are discussed in detail which includes MEMS based energy scavenger using piezoelectric effect and other method includes pedal power generation using exercise cycle. Output of 5.5V was generated using Piezoelectric Scavenger arranged in cantilever geometry and voltage around 5V was generated using pedal power generator. The proposed methods are eco-friendly, simple and will definitely help in solving the energy crisis issues.**

Keywords— Energy Scavenging, Piezoelectric, MEMS, Eco-friendly, Generation, Energy.

I. INTRODUCTION

According to a survey done by the World Bank in 2020, the world will face serious energy scarcity issues by 2030 [1] which will definitely lead to serious downfall of the human race. To prevent such difficult events the world needs to implement methods to generate energy which must be green, clean and eco-friendly. Energy should be widely available in emerging nations like India since it is one of the fundamental necessities for maintaining our civilization [2]. India where majority population lives in rural areas currently, 2.9 billion people still cook with harmful and inefficient fuels, while 1.2 billion people in the Least Developed Countries (LDCs) lack access to electricity [3]. Most developing nations now rely on fossil fuels like coal and natural gas to meet their energy demands, and as countries' energy consumption rises, so do their carbon emissions[4]. 60% of all greenhouse gas (GHG) emissions are caused by energy use [5]. Nearly a quarter of all global CO_2 emissions are produced by the energy industry for power systems[6]. Many times, due to lack of resources the most of the energy generated by conventional methods is utilized in urban development. Hence, we need to find solutions to harvest energy in remote locations from the resources available there. In this paper two smart methods of renewable energy generation are discussed including MEMS-based energy generation and dynamo-based energy generation. These two methods are very efficient for low power and point of care applications in remote and rural locations. Broadly there are two popular methods of energy generation depending upon the resources available: non-renewable and renewable energy sources.

II. NON-RENEWABLE ENERGY RESOURSES

Globally, non-renewable energy dominates the energy consumption profile[7]. Traditional non-renewable energy generation methods include the use of fossil fuels such as coal, oil, and natural gas to generate electricity as shown in fig.1. These energy production techniques have been used extensively for many years and are still crucial sources of power around the world, but they also have negative environmental effects and are not thought to be sustainable in the long run, the reasons we will understand one by one.

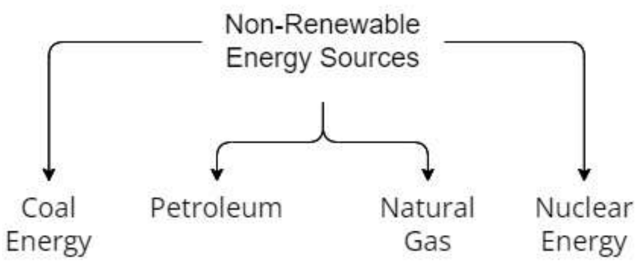


Fig.1. Classification of Non-Renewable energy Sources

Due to its accessibility and low cost, coal-based energy generation is widely employed, but it also significantly contributes to air pollution, greenhouse gas emissions, and poses threats to the environment and public health [8]. Similar issues arise when using petroleum-based energy sources, and the extensive usage of these sources can cause unstable economies owing to rising oil costs. Natural gas-based energy production is thought to be more efficient and cleaner, however fracking techniques can be harmful to the environment and water supplies, and natural gas resources are limited, making it less sustainable. Nuclear energy production is a safe and effective means to generate power, but it has dangers related to handling radioactive material, disposing of nuclear waste, and the potential for accidents[9]. Nuclear energy has some substantial limitations, including expensive construction, maintenance, and decommissioning costs as well as limited scalability and flexibility. Hence, even if each energy generating technique offers benefits, it is crucial to take into account any negative consequences on the environment, human health, or long-term sustainability before choosing the best energy generation method.

III. Renewable Energy Resourses

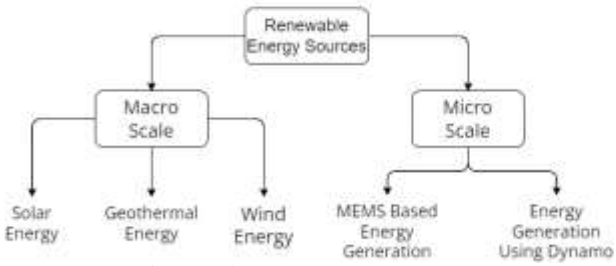


Fig.2. Classification of Renewable Energy Scavenging Techniques

Macro scale Energy generation

The potential of renewable energy sources to displace non-renewable energy sources has attracted a lot of attention in recent years. From the initial discovery of solar energy in 1839, researchers have made considerable strides towards creating solar panels that can transform sunlight into power. Solar energy can't be used as a main source of energy since it fluctuates and is influenced by the weather[10], [11]. On the other hand, geothermal energy uses the heat from the Earth's core to create power. Although it is a clean source of energy, it has the potential to affect the environment through ground instability, air pollution, and water contamination. The creation and upkeep of the infrastructure required for the generation of geothermal energy can also be costly. Another clean and sustainable energy source is wind energy, which produces electricity using the power of the wind. Nevertheless, the installation and upkeep of the required infrastructure may be costly and is reliant on wind patterns. The utilization of wind energy is also constrained in certain locations by its availability. Renewable energy sources have the potential to replace non-renewable energy sources and play a critical role in combating climate change, notwithstanding their shortcomings. Macro-scale energy generation methods are not suitable for low power applications in remote and rural areas due to the high cost of infrastructure and maintenance. Therefore, this paper focuses on micro-scale energy generation such as MEMS based energy generation and Pedal Power Energy Generation using an Exercise Cycle which are more cost-effective and efficient for generating low power in these areas.

Micro scale Energy Generation

In day-to-day life, there are many applications where we need the energy in small quantities like if we need to drive a sensor a very small amount of supply is required. In such applications it is better to choose micro scale energy scavengers instead of macro scale scavengers like solar and geothermal methods. Another advantage of using microscale energy scavengers is that they are efficient sources of instant power; thus, the energy can be harvested at the location of need using some ambient inputs like vibrations or motions etc. In this work, piezoelectric energy generation using cantilever structure and energy generation using dynamo are discussed.

A. MEMS based Energy Generation:

Microelectromechanical system (MEMS) utilizes various microsystem-based methods form energy harvesting. In this paper we focused energy generation using piezoelectric effect which was discovered by French scientists Jacques and Pierre curie in 1880[13]. MEMS is a miniaturization technique that has been widely adopted from the integrated circuit (IC) sector and used to the miniaturization of all systems, including mechanical, optical, fluid, magnetic, and other systems[12]. A piezoelectric energy generation method is utilized for transforming mechanical stress and pressure into electrical energy in the MEMS domain. Utilizing piezoelectric materials, which generate an electrical charge when mechanical force is applied, are used for this. These substances can be employed in many different ways, such as bulk substances, thin films, or fibers. Piezoelectric materials include quartz, lead zirconate titanate (PZT), and zinc oxide, among others (ZnO). Since piezoelectric materials are often brittle, it is more challenging to use them directly for energy scavenging. For capturing energy from background vibrations, cantilever beam structures covered with piezoelectric materials are used.

a) Cantilever based Piezoelectric Energy Generator

A cantilever-based piezoelectric energy generation system is a device that converts mechanical energy into electrical energy using the piezoelectric effect. It works by attaching piezoelectric materials to a cantilever beam, which is then subjected to vibrational energy. In the Cantilever Structure of the Piezoelectric Energy Generator, it can be arranged in two different ways, unimorph structure and bimorph structure. A structure is called a Unimorph if it has only one active and one passive layer[14]. As shown in fig.3, the unimorph structure consists of various layers labeled, such as P Layer, Proof Mass, S Layer and Fixed End.

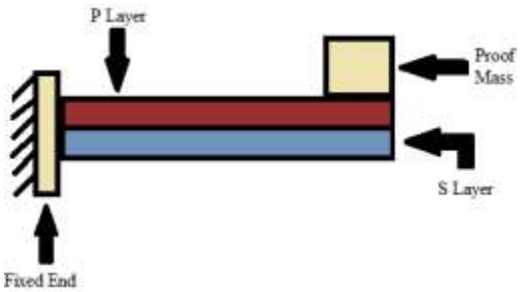


Fig.3. Geometry of Unimorph Structure

Bimorphs are defined as having one passive layer of the substrate material sandwiched between two active layers of piezoelectric material[15] as shown in fig.4 in this geometry there are various layers labeled, such as P1, P2, Proof Mass, S Layer and Fixed End.

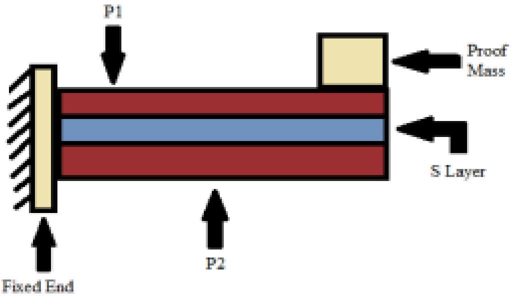


Fig.4. Geometry of Bimorph Structure

Fixed End is used to give a fixed support to the suspended cantilever structure. P Layer is the Piezoelectric Layer which is responsible for the generation of the electricity; it is also called the active layer. S Layer is also called as a Passive layer or Substrate layer; it is responsible to give the mechanical strength to the structure.

The piezoelectric components provide a little electrical charge as the beam vibrates, which may be gathered and stored in a battery or utilized immediately. In distant or off-grid regions, these technologies can be utilized to generate tiny quantities of power. In this work, a bimorph structure is simulated in COMSOL Multiphysics to harvest electrical energy from the applied ambient vibrations. The details about COMSOL Multiphysics and simulated design are discussed in the following section.

b) COMSOL Multiphysics

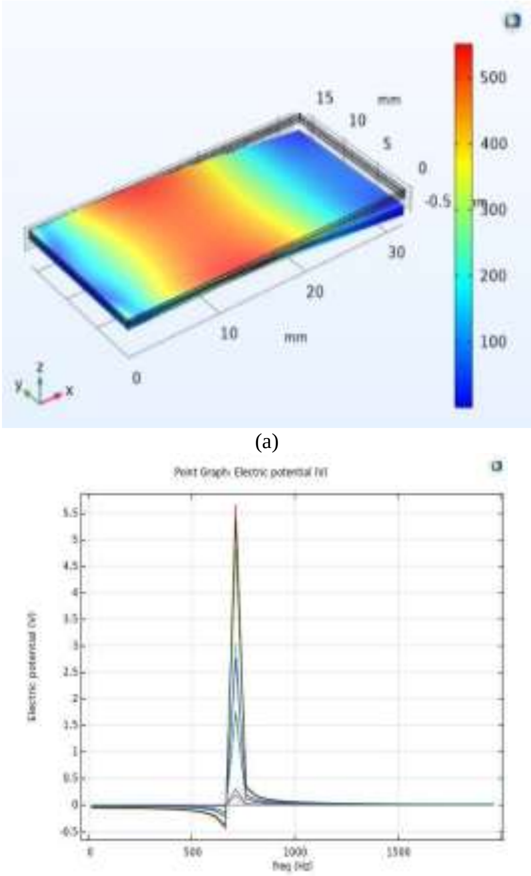
COMSOL Multiphysics is a software tool used by engineers and scientists to simulate designs, devices, and processes in all disciplines of engineering, manufacturing, and scientific research. COMSOL Multiphysics is a simulation platform that allows for both fully linked Multiphysics and single-physics modeling. The Model Builder encompasses all of the modeling workflow phases, such as establishing geometry, material characteristics, and the physics that explain specific phenomena, as well as solving and post processing models to get correct results[16].

c) Simulation details

A Bimorph Cantilever beam was designed and simulated in this work having the geometric dimensions as shown Table 1. ZnO (Zinc Oxide) was used as the piezoelectric layer, length of the cantilever is 32 mm and width were considered as 16 mm and height as 0.3 mm. PET (Polyethylene Terephthalate) was used as elastic layer and the height of this layer was 0.2 mm, the cantilever beam had the boundary load of 0.9 Nm2. The simulated model generated output voltage of 5.5 V at a frequency of 750 Hz as shown in fig. 5 (b).

TABLE.1: CANTILEVER BEAM SPECIFICATIONS

S.N.	Parameters	Details
1	Beam Configuration	Bimorph
2	Piezoelectric Material	ZnO (Zinc Oxide)
3	Length of Cantilever	32mm
4	Width of Cantilever	16mm
5	Height of Piezoelectric Material	0.3mm
6	Elastic Material	Pet (Polyethylene Terephthalate)
7	Height of Elastic Material	0.2mm
8	Length/Width of Elastic Material	Same as Piezoelectric Material
9	Boundary load	9.81 N/m^2



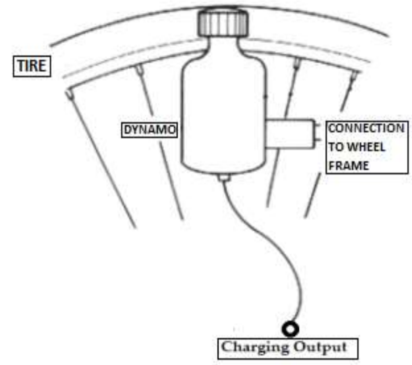
(a)

(b)

Fig.5. (a) Simulated Cantilever, (b) Output Plot

B. Pedal Power Energy Generation using Exercise Cycle

The process of transforming mechanical energy into electrical energy using a dynamo is very well-known method of energy production. This is commonly accomplished by using a rotating magnetic field to induce an electrical current in a conductor. The electric generator is the most popular form of energy producing dynamo, and it is used in power plants to transfer energy from steam or other fuel sources into electricity. The usage of dynamos to generate energy is a very efficient method [17]. Power is generated by pedaling the exercise cycle and converting the rotational movement into electricity with the help of dynamo. Besides the health advantages of the exercise cycle, it can be used for generating small energy to supply many low power devices like mobile phones, LED displays etc. The prototype model as shown in fig.6 was used for production of electricity using an exercise cycle. The shaft of the dynamo is coupled with the tire of the exercise cycle so that the magnet of the dynamo rotates with the rotation of the exercise cycle tire.



(a)

Fig.6. Practical Implementation of Pedal Power Generation

a) Working Principle of Dynamo

Faraday's concept of electromagnetic generators, often known as Faraday's law of electromagnetic induction, asserts that when an electrical conductor encircles a fluctuating magnetic flux, an electromotive force (EMF) is formed. This implies that when a conductor, such as a wire, is put in a magnetic field and the field changes, an electrical current is generated. This idea underpins the operation of dynamos[18]. The fig.7 depicts the working of the Dynamo, Here the magnet is rotated in the vicinity of coil, the rotating magnetic field thus created causes current to flow through the coil.

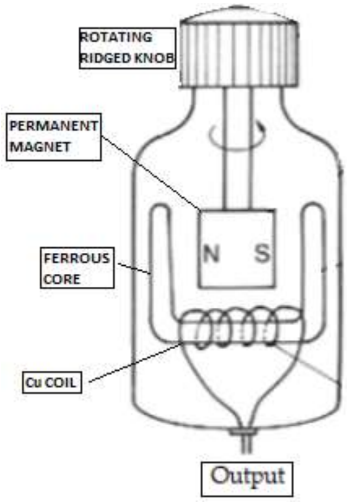


Fig.7: Working Principle of Dynamo

b) Practical Implementation

The model shown in fig.6 was implemented successfully and it was observed that dynamo generated electricity proportional to the angular motion. The output of the model was in the range of 6 to 8 V but was not regulated, so a regulator circuit was used in order to get stable output.

The output of the dynamo was fed to regulator circuit which finally generated a regulated voltage of 5V. This output was stable and can be used for supplying low power applications like mobile charging as shown in fig.8. The Redmi mobile phone with model no Redmi Nine Prime was charged using the pedal-based energy generator.

(a)

(b)

Fig 8. (a) Implemented model, (b) Mobile Charging

IV. Advavtages and Application of Micro Scale Energy Generation

The Cantilever-based Piezoelectric Energy Generator is a passive energy scavenger that does not require an external power source or battery. It is lightweight, small in size, and easy to install, making it ideal for remote and rural areas. It can generate power from various sources such as vibration and pressure, and has a low maintenance cost and long lifespan. It can be used in wireless sensor networks for environmental monitoring and disaster management, health monitoring devices for patients in remote areas, and to power low-power electronic sensors and devices.

The Pedal Power Energy Generation using an Exercise Cycle is a sustainable and eco-friendly method of generating energy that promotes health and wellness. It is easy to operate and maintain, has a low cost of installation and maintenance, and can generate power in real-time. It can be used for rural electrification for lighting and powering household appliances, charging small electronic devices such as phones and laptops, and powering community centers, schools, and health clinics.

Overall, both methods offer advantages in terms of cost-effectiveness, efficiency, and applicability to low-power applications in rural areas, providing sustainable and reliable sources of energy to improve the quality of life for people living in remote and rural areas.

V. Conclusion

Micro scale energy generation methods are efficient and effective ways to tackle the energy shortages; especially in the remote and rural locations to supply low power and low duty cycle applications. Two methods for generating micro scale energy are discussed in this paper, the Cantilever based piezoelectric energy scavenger generated 5.5 V and pedal power energy generator using dynamo generated 5V. Both the methods have several potential uses and constitute an important step toward a low-carbon economy. More study is needed to fully grasp the potential of these approaches as they are already showing considerable promise in fulfilling contemporary society's expanding energy demands. Such type of clever approaches to create electricity by harvesting natural energy sources such as vibration, motion, pressure, and temperature variations will be helpful for future generations working in non-renewable energy harvesting domain.

References

[1] "Energy Overview: Development news, research, data | World Bank." https://www.worldbank.org/en/topic/energy/overview (accessed Feb. 14, 2023).

[2] R. Zafar, A. Mahmood, S. Razzaq, W. Ali, U. Naeem, and K. Shehzad, "Prosumer based energy management and sharing in smart grid," *Renewable and Sustainable Energy Reviews*, vol. 82. Elsevier Ltd, pp. 1675–1684, Feb. 01, 2018. doi: 10.1016/j.rser.2017.07.018.

[3] R. Poudyal, P. Loskot, R. Nepal, R. Parajuli, and S. K. Khadka, "Mitigating the current energy crisis in Nepal with renewable energy sources," *Renewable and Sustainable Energy Reviews*, vol. 116. Elsevier Ltd, Dec. 01, 2019. doi: 10.1016/j.rser.2019.109388.

[4] Z. A. Elum and A. S. Momodu, "Climate change mitigation and renewable energy for sustainable development in Nigeria: A discourse approach," *Renewable and Sustainable Energy Reviews*, vol. 76. Elsevier Ltd, pp. 72–80, 2017. doi: 10.1016/j.rser.2017.03.040.

[5] "Refworld | Transforming our world : the 2030 Agenda for Sustainable Development." https://www.refworld.org/docid/57b6e3e44.html (accessed Feb. 14, 2023).

[6] "Master Computer Science A Genetic Algorithm Parameter Control Method using Deep Reinforcement Learning for Offshore Wind Farm Maintenance Planning."

[7] B. Mufutau Opeyemi, "Path to sustainable energy consumption: The possibility of substituting renewable energy for non-renewable energy," *Energy*, vol. 228, Aug. 2021, doi: 10.1016/j.energy.2021.120519.

[8] M. Lakovic *et al.*, "COAL-FIRED POWER PLANTS ENERGY EFFICIENCY AND CLIMATE CHANGE-CURRENT STATE AND FUTURE TRENDS The concept of sustainable energy supply of settlements with energy efficient facilities View project 20th International Conference on Thermal Science and Engineering of Serbia-SIMTERM 2022 View project COAL-FIRED POWER PLANTS ENERGY EFFICIENCY AND CLIMATE CHANGE-CURRENT STATE AND FUTURE TRENDS □," 2015. [Online]. Available: https://www.researchgate.net/publication/299600314

[9] I. Energy Agency, "Nuclear Power in a Clean Energy System."

[10] P. Baidya, "Solar Cell and Solar Energy Harvesting : An Overview," 2021, doi: 10.13140/RG.2.2.15631.10405.

[11] S. R. G. Weliwaththage and U. S. P. R. Arachchige, "Solar Energy Technology," *J. Res. Technol. Eng.*, vol. 1, 2020.

[12] A. Allamin Shaikh, "MICRO-ELECTROMECHANICAL SYSTEM (MEMS) SENSOR," *Int. J. Sci. Eng. Res.*, vol. 3, no. 11, 2012, [Online]. Available: http://www.ijser.org

[13] R. G. Ballas and D. Schoen, "The Piezoelectric Effect - A Descriptive Representation of an Essential Solid Body Effect Enabling Various Sensor and Actuator Applications in Mechatronics and Microtechnology," in *2020 21st International Conference on Research and Education in Mechatronics, REM 2020*, Dec. 2020. doi: 10.1109/REM49740.2020.9313872.

[14] C. Mo, D. Arnold, W. C. Kinsel, and W. W. Clark, "Modeling and experimental validation of unimorph piezoelectric cymbal design in energy harvesting," in *Journal of Intelligent Material Systems and Structures*, May 2013, vol. 24, no. 7, pp. 828–836. doi: 10.1177/1045389X12463459.

[15] Z. Yi *et al.*, "High performance bimorph piezoelectric MEMS harvester via bulk PZT thick films on thin beryllium-bronze substrate," *Appl. Phys. Lett.*, vol. 111, no. 1, Jul. 2017, doi: 10.1063/1.4991368.

[16] "COMSOL Multiphysics® Software - Understand, Predict, and Optimize." https://www.comsol.com/comsol-multiphysics (accessed Feb. 14, 2023).

[17] R. Balakrishnan, B. Rubini, and K. Sasikala, "Power generation using gear setup with dynamo Software Defined Radio Network View project Computational Analysis of CDNA Microarray Image View project POWER GENERATION USING GEAR SETUP WITH DYNAMO," vol. 12, no. 8, 2017, [Online]. Available: www.arpnjournals.com

[18] "Dynamo - Wikipedia." https://en.wikipedia.org/wiki/Dynamo (accessed Feb. 14, 2023).