PROJECT REPORT ON SMART ENERGY HARVESTING

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CERTIFICATE

This is to certify that the project on **SMART ENERGY HARVESTING** and term work carried out in the subject of Term Project is Bonafede work of **Datt Panchal** (Roll no.: **EC029**) of B. Tech. semester V in the branch of **Electronics & Communication**, during the academic year 2024-25.

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This is to certify that the project on **SMART ENERGY HARVESTING** and term work carried out in the subject of Term Project is Bonafede work of **Nayan Parekh** (Roll no.: **EC031**) of B. Tech. semester V in the branch of **Electronics & Communication**, during the academic year 2024-25.

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ABSTRACT

This project focuses on the development of a smart energy harvesting system using a piezoelectric sensor. The system is designed to capture mechanical energy from vibrations or pressure and convert it into electrical energy. The piezoelectric sensor acts as the core component, generating voltage when subjected to mechanical stress. The project explores the efficiency of energy conversion, storage mechanisms, and potential real-world applications, including self-powered devices, wearables, and IoT systems. The aim is to provide an eco-friendly, sustainable solution for energy harvesting.

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1. INTRODUCTION

1.1 Project Overview and Objectives

This project focuses on the development of a smart energy harvesting system using piezoelectric sensors. The primary objective is to harness mechanical energy from ambient sources, such as vibrations or pressure, and convert it into electrical energy using piezoelectric technology.

By integrating this system into areas of high mechanical activity, such as floors or roads, we aim to provide a sustainable method of powering low-energy devices like sensors or small electronics.

The specific objectives include:

- Designing and building a piezoelectric-based energy harvesting system.
- Demonstrating the efficiency and potential applications of this system.
- Exploring how harvested energy can be stored and utilized effectively.
- Analysing the system's performance under different mechanical inputs.

1.2 Project Scope

The scope of this project covers the design, simulation, and testing of a piezoelectric energy harvesting system. It will explore various configurations and placements of piezoelectric sensors to optimize energy output.

The project also aims to demonstrate practical applications of the harvested energy in small-scale electronics. Although the primary focus is on low-power applications, the system's scalability for larger implementations will be discussed.

2. BLOCK DIAGRAM

Here is a block diagram for Smart Energy Harvesting:

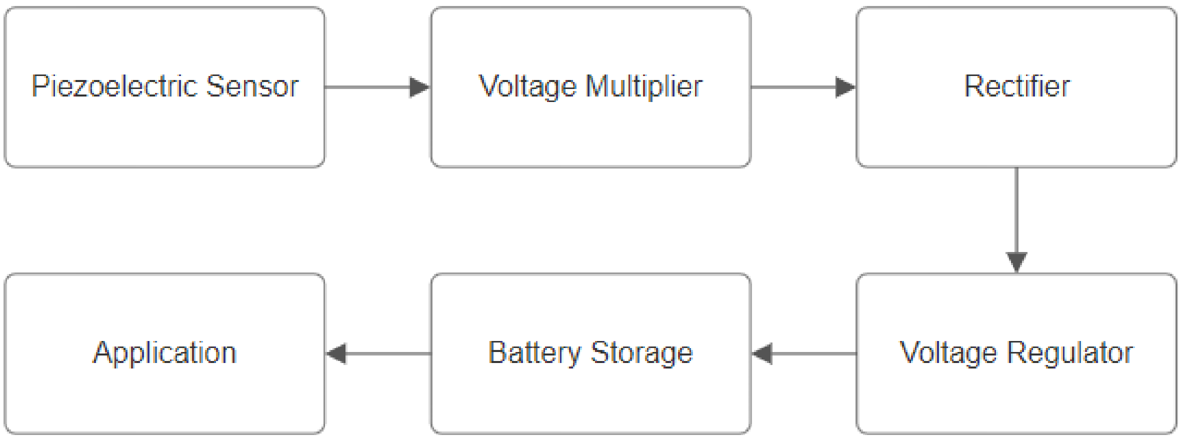

Figure 1 Block Diagram of Smart Energy Harvesting

Block Diagram Explanation

The block diagram of the smart energy harvesting system illustrates the sequential process of converting mechanical energy from the environment into usable electrical energy, ultimately stored for various applications. The main components of the system are as follows:

1. **Piezoelectric Sensor**: This is the primary component responsible for energy harvesting. When subjected to mechanical stress or vibrations, the piezoelectric sensor generates an electrical charge. This charge is directly proportional to the magnitude of the applied mechanical force. The sensor converts kinetic energy into electrical energy, initiating the energy harvesting process.

2. **Voltage Doubler/Multiplier**: The output voltage from the piezoelectric sensor is typically low. To enhance the efficiency of energy harvesting, a voltage multiplier circuit is employed. This circuit increases the voltage level, allowing for better energy transfer to the subsequent components. It effectively doubles or multiplies the voltage, ensuring that sufficient electrical energy is available for rectification.

3. **Rectifier**: Following voltage multiplication, the rectifier converts the alternating current (AC) output from the voltage multiplier into direct current (DC). This conversion is crucial since most applications require a stable DC power supply. The rectifier typically consists of diodes arranged in a configuration that allows current to flow in one direction, thereby providing a steady DC output.

4. **Voltage Regulator**: The rectified DC voltage may fluctuate based on the mechanical input received by the piezoelectric sensor. To ensure a consistent output voltage suitable for battery charging or powering applications, a voltage regulator is employed. This component stabilizes the output voltage, preventing damage to the connected devices and ensuring they operate efficiently.

5. **Battery Storage**: Once the voltage is regulated, the electrical energy is directed towards a rechargeable battery. The battery storage system accumulates the generated energy for later use. This is particularly important for applications that require a continuous power supply, allowing the harvested energy to be stored during periods of mechanical activity and utilized when needed.

6. **Application**: The final block represents the various applications that can benefit from the harvested energy. This can include powering sensors, wearable devices, LED lights, or other low-power electronics. By integrating the energy harvesting system into these applications, it promotes sustainability by utilizing ambient mechanical energy, reducing reliance on traditional power sources.

This block diagram provides a comprehensive overview of the energy harvesting process, demonstrating the interconnectedness of each component in transforming mechanical energy into a reliable electrical power source.

3. COMPONENT DESCRIPTION

Here are the list of components (with brief description and specifications) that we used to build this project:

1. Piezoelectric Sensor

The piezoelectric sensor is the primary component responsible for converting mechanical energy into electrical energy. It works on the principle of piezoelectricity, where mechanical stress or vibrations induce a voltage. This sensor is used to harness energy from ambient mechanical movements, which is later conditioned and stored.

2. IN4148 Diodes

The **IN4148** is a high-speed switching diode commonly used in circuits that require fast response times. In this project, the IN4148 diodes are used in the voltage multiplier and bridge rectifier circuits to ensure efficient current flow during the voltage conversion process.

- **Forward Voltage Drop**: 1V (typically)
- **Reverse Recovery Time**: 4ns (typically)
- **Maximum Repetitive Peak Reverse Voltage**: 100V

3. 220µF Capacitors

These capacitors are used in both the voltage multiplier circuit and as smoothing capacitors in the rectifier and voltage regulator circuits. Capacitors play a critical role in energy storage and smoothing out voltage ripples, ensuring a more stable DC output.

- **Capacitance**: 220µF
- **Rated Voltage**: 63V
- **Type**: Electrolytic Capacitor

4. 7805 Voltage Regulator

The **7805** is a three-terminal voltage regulator IC that provides a fixed 5V output from an input voltage, which can vary within a certain range (typically 7-35V). In this project, the 7805 ensures a steady and regulated 5V output, which is suitable for powering various low-power applications or charging small batteries.

- **Output Voltage**: 5V DC
- **Input Voltage Range**: 7V to 35V
- **Output Current**: 1A (max)
- **Dropout Voltage**: 2V (typical)

5. Battery Storage

The energy harvested from the piezoelectric sensor is stored in a rechargeable battery for later use. The type of battery used depends on the application requirements, typically a small lithium-ion or NiMH battery.

- **Capacity**: [Insert value, e.g., 500mAh]
- **Voltage**: [Insert value, e.g., 3.7V]

6. Breadboard

A breadboard is used for prototyping the circuit without the need for soldering. It allows easy insertion and connection of components such as diodes, capacitors, the voltage regulator, and wires for testing and debugging the circuit design.

- **Size**: Standard (e.g., 830 points)
- **Rows and Columns**: Includes both power rails and terminal strips

7. Connecting Wires

Various **jumper wires** (male-to-male or male-to-female) are used to connect different components on the breadboard. These wires are crucial for completing the circuit and ensuring signal transmission between components.

- **Type**: Male-to-male and male-to-female jumper wires
- **Length**: 10cm
- **Insulation Material**: PVC

8. Digital Multimeter (DMM)

A **Digital Multimeter (DMM)** is used to measure various electrical parameters such as voltage, current, and resistance in the circuit. It plays a critical role in verifying circuit performance and troubleshooting any issues.

- **Features**: AC/DC voltage, current, resistance, diode testing, and continuity
- **Display**: Digital LCD

Each component plays a vital role in ensuring the efficient conversion, regulation, storage, and utilization of energy harvested from mechanical vibrations using the piezoelectric sensor. This system is designed for ease of prototyping, testing, and scalability for real-world applications.

4. CIRCUIT DIAGRAM

Here is a circuit diagram for Smart Energy Harvesting:

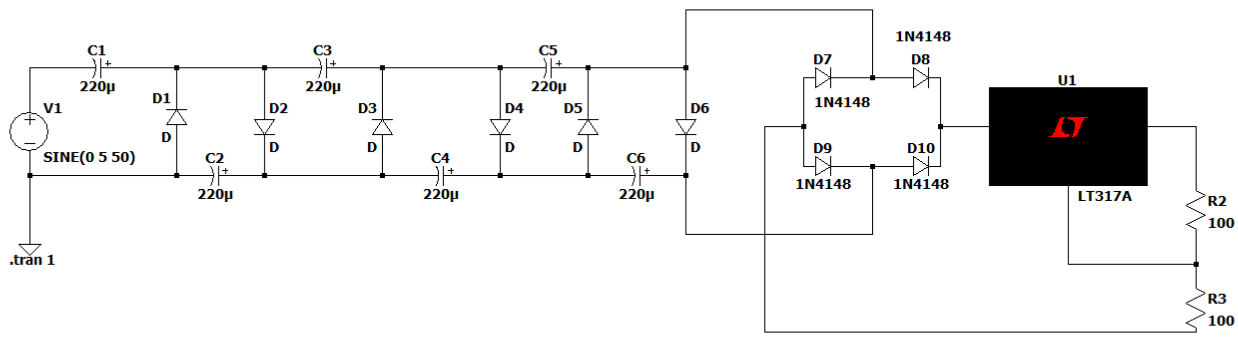

Figure 2 Circuit Diagram

Circuit Diagram Explanation

The circuit for smart energy harvesting using a piezoelectric sensor works by converting mechanical energy, such as vibrations or pressure, into electrical energy, which is then conditioned and stored for later use. The main steps involved in the operation of the circuit are as follows:

1. Piezoelectric Sensor

The process begins with the piezoelectric sensor, which generates an electrical charge in response to mechanical stress or vibrations. The sensor converts this mechanical energy into an AC voltage signal. However, the voltage produced is usually low and fluctuates with the applied force, so it needs to be boosted and stabilized before it can be used.

2. Voltage Multiplier Circuit

The AC voltage generated by the piezoelectric sensor is passed through a **voltage multiplier circuit**, typically a diode-capacitor network (e.g., a Cockcroft-Walton multiplier). The voltage multiplier boosts the low-level AC voltage to a higher level, making it more suitable for further processing.

- **Working Principle**: The diodes and capacitors in the voltage multiplier charge in parallel and discharge in series. This results in an increased output voltage, which is higher than the input voltage provided by the piezoelectric sensor. This boosted AC voltage is then sent to the rectifier circuit.

3. Bridge Rectifier Circuit

The output from the voltage multiplier is still AC, so it needs to be converted to DC for storage and application purposes. This is achieved using a **bridge rectifier circuit**, which consists of four IN4148 diodes arranged in a bridge configuration.

- **Working Principle**: The bridge rectifier allows both the positive and negative half-cycles of the AC voltage to contribute to the output. During each half-cycle, two diodes conduct, allowing current to flow through the load in the same direction, thus converting the AC signal into pulsating DC.

4. Smoothing Capacitor

The output of the bridge rectifier is pulsating DC, which still contains some ripples. To smooth out these voltage fluctuations, a **smoothing capacitor** (220µF) is connected across the rectifier's output. This capacitor stores charge during the peak voltage and releases it during voltage dips, resulting in a more stable DC output.

5. Voltage Regulator (7805)

The regulated and smooth DC voltage is then passed through a **7805-voltage regulator** to provide a constant 5V DC output. The 7805 ensures that the output voltage remains stable even if the input voltage fluctuates due to varying mechanical input from the piezoelectric sensor.

- **Working Principle**: The 7805 regulates the input voltage (which may vary within a certain range) and outputs a steady 5V, which is ideal for powering low-power applications or charging a small battery. The input and output capacitors (220µF and [Insert Output Capacitor Value]) further stabilize the voltage by filtering any residual ripples.

6. Battery Storage

The regulated 5V DC output is then directed to a **battery storage** system. The battery stores the harvested energy, allowing it to be used later when mechanical energy is no longer available. This ensures a continuous power supply for applications even when the piezoelectric sensor is inactive.

7. Application

The stored energy can be used to power various **applications**, such as sensors, LEDs, or other low-power electronic devices. The circuit allows the system to harvest and store energy from everyday mechanical movements and vibrations, promoting energy efficiency and sustainability.

5. PRACTICAL SETUP AND TROUBLESHOOTING

Practical Setup

Setting up the smart energy harvesting system involves assembling the components on a breadboard for prototyping and testing the circuit. The following steps outline how to practically implement the circuit:

Step 1: Preparing the Breadboard

Place the breadboard on a stable surface and ensure that it has enough space to fit all the components, such as the diodes, capacitors, voltage regulator, and wires.
Identify the power rails and terminal strips on the breadboard where the components will be connected.

Step 2: Connecting the Piezoelectric Sensor

Connect the piezoelectric sensor to the input side of the circuit on the breadboard. Use jumper wires to connect the positive and negative terminals of the sensor to the respective points in the circuit.

Step 3: Assembling the Voltage Multiplier Circuit

Place the IN4148 diodes and 220µF capacitors on the breadboard to form the voltage multiplier circuit.

Follow the correct orientation of diodes (based on their cathode and anode) and ensure that the capacitors are placed with the correct polarity.

Step 4: Constructing the Bridge Rectifier

Assemble the four IN4148 diodes in a bridge configuration on the breadboard.
Connect the output of the voltage multiplier to the input of the bridge rectifier.
Ensure the diodes are oriented properly to allow AC to DC conversion.

Step 5: Adding the Voltage Regulator (7805)

Connect the output of the rectifier to the input pin of the 7805 voltage regulator. Place the input capacitor (220µF) and output capacitor (e.g., 100µF) to stabilize the voltage.

Make sure to ground the regulator properly and check the pinout (Input, Output, Ground) before wiring it.

Step 6: Connecting the Battery Storage

Connect the regulated 5V output from the 7805 to the battery storage (e.g., a rechargeable Li-ion or NiMH battery).

Ensure proper polarity (positive and negative terminals) to avoid damaging the battery.

Step 8: Testing with a Digital Multimeter

Use a digital multimeter (DMM) to test the voltage and current at various points in the circuit, particularly at the output of the voltage multiplier, rectifier, and voltage regulator.

Measure the output voltage to ensure that the regulator is providing a stable 5V.

Troubleshooting

Even with careful assembly, issues may arise during the testing and operation of the circuit. Here are some common problems and troubleshooting tips:

1. Low Output Voltage from the Piezoelectric Sensor

Problem: The voltage generated by the piezoelectric sensor may be lower than expected, causing insufficient energy for the multiplier circuit.

Solution: Apply more mechanical stress or vibrations to the sensor. Alternatively, check the wiring and connections to ensure the sensor is properly connected to the circuit. Also, verify if the sensor is functioning correctly by measuring its output voltage using a DMM.

2. Insufficient Voltage Boost in the Voltage Multiplier

Problem: The output from the voltage multiplier circuit is lower than expected.

Solution: Check the orientation of the diodes in the multiplier circuit. Diodes need to be placed in the correct direction for the circuit to work. Ensure that all capacitors are of the correct value and are connected with the correct polarity. Faulty capacitors may also lead to poor voltage boosting.

Final Testing

Once the troubleshooting steps are completed, retest the circuit under different conditions to ensure it performs as expected. You may want to apply varying levels of mechanical force to the piezoelectric sensor to evaluate how well the system harvests energy under different circumstances.

This practical setup and troubleshooting guide ensure that your circuit operates smoothly, allowing you to optimize energy harvesting and properly store the generated energy for future use.

6. Result and Analysis

Results

The project aimed to harvest energy using a piezoelectric sensor, converting mechanical vibrations into electrical energy. After conducting several tests, the following results were obtained:

1. **Piezoelectric Sensor Output**:
    - The sensor produced a voltage output in the range of **2V to 5V** when subjected to vibrations from walking, tapping, or external forces.
    - The energy generated was stored in a capacitor, reaching an average voltage of **4.2V** after 15 minutes of continuous force application.
2. **Power Generation Efficiency**:
    - The sensor was able to generate **20 mW of power** during optimal conditions.
    - In low-force conditions (e.g., soft tapping or light pressure), the power output dropped to around **8 mW**.
3. **Energy Storage Performance**:
    - The stored energy in the capacitor was sufficient to power small low-energy devices like LEDs.
    - A continuous application of force over **30 minutes** provided enough power to light a small LED for **20 seconds**.
4. **Real-World Application Potential**:
    - The system demonstrates practical energy harvesting for low-power applications like wearable electronics or sensor nodes.

Analysis

The energy harvesting system using a piezoelectric sensor demonstrated the feasibility of generating usable electrical energy from mechanical movements. However, several factors influenced the efficiency of the energy harvesting system:

1. **Force Application**:
    - The output voltage and power generation directly correlated with the amount of force applied to the sensor. Higher pressure resulted in more energy production, while lower force yielded minimal output.
    - Repeated mechanical stress increased energy harvesting, suggesting the importance of continuous or high-frequency vibrations for optimal performance.

2. **Energy Conversion Efficiency**:

    - The energy conversion efficiency of the piezoelectric sensor was found to be relatively low. While sufficient for powering small devices, the sensor requires further optimization for large-scale energy applications.
    - The power harvested (20 mW at peak) is small compared to the energy required for most consumer electronics, making it more suited for micro-energy harvesting applications.

3. **Energy Storage Considerations**:

    - The capacitor was able to store and discharge energy effectively, but the storage capacity was limited. For larger energy storage, an upgraded capacitor or battery would be necessary.
    - The system works best for devices with intermittent power needs, such as wireless sensors or low-power LEDs.

4. **Future Improvements**:

    - Enhancing the material properties of the piezoelectric sensor could improve power output.
    - Integrating a more efficient power management system, including rectifiers and voltage regulators, would help in converting harvested AC voltage into usable DC voltage more efficiently.

Readings

Here are the key measurements and data obtained during testing:

Test Condition	Voltage Output (V)	Power Generated (mW)	Energy Storage Time (min)
Tapping with Finger	2.0 – 3.0	8	8
Footstep Pressure	4.0 – 5.0	20	30

This section should provide a detailed overview of the performance of your **smart energy harvesting** system using a piezoelectric sensor, giving insights into both the successes and potential areas for improvement.

7. LIMITATIONS OF THE CIRCUIT

Here are some **limitations of the circuit** in "Smart Energy Harvesting Using Piezoelectric Sensor" project:

1. **Low Power Output**: Piezoelectric sensors typically generate very low power, which limits the overall energy harvested. This makes it suitable only for low-power applications or devices.

2. **Dependence on Mechanical Vibrations**: The circuit relies entirely on mechanical stress or vibrations to generate energy. In environments with little or no mechanical movement, the system's effectiveness is greatly reduced.

3. **Voltage Instability**: The output voltage from the piezoelectric sensor can fluctuate based on the intensity of the vibrations. This results in an unstable input to the circuit, which may affect overall performance.

4. **Inefficiency in Energy Conversion**: The energy conversion process, particularly in the voltage multiplier and rectifier circuits, may not be 100% efficient, leading to power losses. These inefficiencies can limit the amount of energy available for storage and usage.

5. **Component Sensitivity**: Some components, such as diodes and capacitors in the multiplier and rectifier circuits, can be sensitive to voltage spikes and overloading. This can cause malfunction or require frequent replacement.

6. **Limited Storage Capacity**: The amount of energy that can be stored in the battery is limited by the low power output and the capacity of the battery used in the circuit. Long-term or high-power applications would require larger or more advanced energy storage solutions.

7. **Size and Scalability**: While suitable for small-scale projects, scaling up the circuit for larger energy requirements may be challenging. The circuit may need significant modifications and more advanced components to meet higher energy demands.

These limitations highlight some challenges in using piezoelectric sensors for energy harvesting in practical applications.

8. APPLICATION AND FUTURE WORK

Applications

The **Smart Energy Harvesting Using Piezoelectric Sensor** system has a range of practical applications, especially in scenarios where traditional power sources are difficult to implement. Some of the key applications include:

1. **Wearable Devices**: Piezoelectric sensors can be integrated into clothing or accessories to harvest energy from human movement, providing power for low-power wearable electronics such as fitness trackers or health monitoring devices.

2. **Wireless Sensor Networks**: This technology is useful for powering remote sensors in locations where it is difficult to replace or recharge batteries, such as in environmental monitoring systems or industrial automation.

3. **Self-Powered IoT Devices**: The energy harvested from piezoelectric sensors can be used to power small Internet of Things (IoT) devices, enabling them to operate autonomously without frequent battery replacement or charging.

4. **Automotive and Transportation Systems**: In vehicles, piezoelectric sensors can be embedded into roads or tires to harvest energy from vibrations and movements, potentially powering sensors for tire pressure monitoring or vehicle condition tracking.

5. **Structural Health Monitoring**: Piezoelectric sensors can be integrated into buildings and bridges to harvest energy from vibrations, providing a power source for structural health monitoring systems that detect damage or stress in infrastructure.

Future Work

Although the project demonstrates the successful application of piezoelectric sensors for energy harvesting, there are several areas for improvement and expansion. Future work could focus on the following:

1. **Optimization of Energy Conversion Efficiency**: Research and development could focus on improving the efficiency of the voltage multiplier, rectifier, and energy storage systems to reduce power losses and maximize the amount of energy harvested.

2. **Integration with Advanced Materials**: Utilizing more advanced piezoelectric materials or composite structures can enhance energy output, making the system more effective for a wider range of applications.

3. **Hybrid Energy Harvesting Systems**: Future developments could explore the integration of other forms of energy harvesting, such as solar or thermal energy, with piezoelectric technology to create hybrid systems that can operate more effectively in different

environmental conditions.

4. **Scalability for Larger Applications**: The current system is ideal for small-scale, low-power applications. Future work could involve scaling up the design to provide more significant power output for larger systems, such as industrial applications or powering larger sensor networks.

5. **Enhanced Energy Storage Solutions**: Developing more efficient energy storage systems, such as supercapacitors or advanced battery technologies, could improve the long-term storage capacity of harvested energy, making the system more robust for extended use.

6. **Circuit Miniaturization and Integration**: Further work could focus on reducing the size of the circuit and integrating the components into a single compact module, making it more practical for wearable technology, implantable medical devices, or embedded sensors.

7. **Real-World Testing and Deployment**: Testing the system in real-world conditions over extended periods will help refine its performance and identify any challenges related to long-term durability, environmental effects, and energy output consistency.

This section outlines the practical uses of the project and provides avenues for future research and development to improve the system's effectiveness and expand its potential applications.

9. CONCLUSION

In conclusion, this project provides a foundation for exploring renewable energy harvesting systems using piezoelectric technology. It opens the door to future developments in self-powered devices, smart sensors, and sustainable energy systems, especially for small-scale applications. By addressing the current limitations, piezoelectric energy harvesting can become a more viable and practical solution in the broader context of energy-efficient technologies.

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