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Smart Pressure Power Generation

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❖ **Abstract:** In last few decades, the need for electricity is increased exponentially and directly effects upon the economy of countries. Developing countries are facing load shedding issues. The natural ways of producing electricity are decreasing day by day. There is need of natural resources to produce and fulfill the needs of electricity. Currently, the solar panels are widely used for producing electricity from sunlight. But the main hurdle in the implementation of solar panel is that they need to fit in open spaces where the light of sun directly falls on it. World moving towards automation and various sensors available to sense and automate the daily life processes. Piezoelectric sensors are special type of sensors that produce energy by pressure, force or load. Smart cities and societies are key components of automation and main area of research. Street lights are essential part of smart streets. We have proposed an IoT based scheme for street light automation that uses the electricity produced from piezoelectric sensors. It will bring redemption from traditional electricity needs that lead to minimizing the load shedding.

The main aim of this project is to design and develop a sustainable system that utilizes piezoelectric technology to generate electrical energy from mechanical vibrations caused by vehicles and pedestrians, and to use the harvested energy to power street lights and wireless charging stations, thereby promoting clean energy and enhancing smart city infrastructure.

❖ **Index Terms – Street Light System, Piezoelectric Sensors, Wireless Charging system.**

➢ Piezoelectric Sensors:-

❖ Introduction

Piezoelectric Effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. The word Piezoelectric is derived from the Greek piezein, which means to squeeze or press, and piezo, which is Greek for "push".

One of the unique characteristics of the piezoelectric effect is that it is reversible, meaning that materials exhibiting the direct piezoelectric effect (the generation of electricity when stress is applied) also exhibit the converse piezoelectric effect (the generation of stress when an electric field is applied).When piezoelectric material is placed under mechanical stress, a shifting of the positive and negative charge centers in the material takes place, which then results in an external electrical field. When reversed, an outer electrical field either stretches or compresses the piezoelectric material. The piezoelectric effect is very useful within many applications that involve the production and detection of sound, generation of high voltages, electronic frequency generation, microbalances, and ultra fine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution, such as scanning probe microscopes (STM, AFM, etc). The piezoelectric effect also has its use in more mundane applications as well, such as acting as the ignition source for cigarette lighters.

❖ Sensors

The principle of operation of a piezoelectric sensor is that a physical dimension, transformed into a force, acts on two opposing faces of the sensing element. The detection of pressure variations in the form of sound is the most common sensor application, which is seen in piezoelectric microphones and piezoelectric pickups for electrically amplified guitars. Piezoelectric sensors in particular are used with high frequency sound in ultrasonic transducers for medical imaging and industrial nondestructive testing. Based on piezoelectric technology various physical quantities can be measured; the most common are pressure and acceleration. For pressure sensors, a thin membrane and a massive base is used, ensuring that an applied pressure specifically loads the elements in one direction. For accelerometers, a seismic mass is attached to the crystal elements. When the accelerometer experiences a motion, the invariant seismic mass loads the elements according to Newton's second law of motion . The main difference in the working principle between these two cases is the way forces are applied to the sensing elements. In a pressure sensor a thin membrane is used to transfer the force to the elements, while in accelerometers the forces are applied by an attached seismic mass. Sensors often tend to be sensitive to more than one physical quantity. Pressure sensors show false signal when they are exposed to vibrations. Sophisticated pressure sensors therefore use acceleration compensation elements in addition to the pressure sensing elements. By carefully matching those elements, the acceleration signal (released from the compensation element) is subtracted from the combined signal of pressure and acceleration to derive the true pressure information.

Vibration sensors can also be used to harvest otherwise wasted energy from mechanical vibrations.

❖ Construction of piezoelectric:-

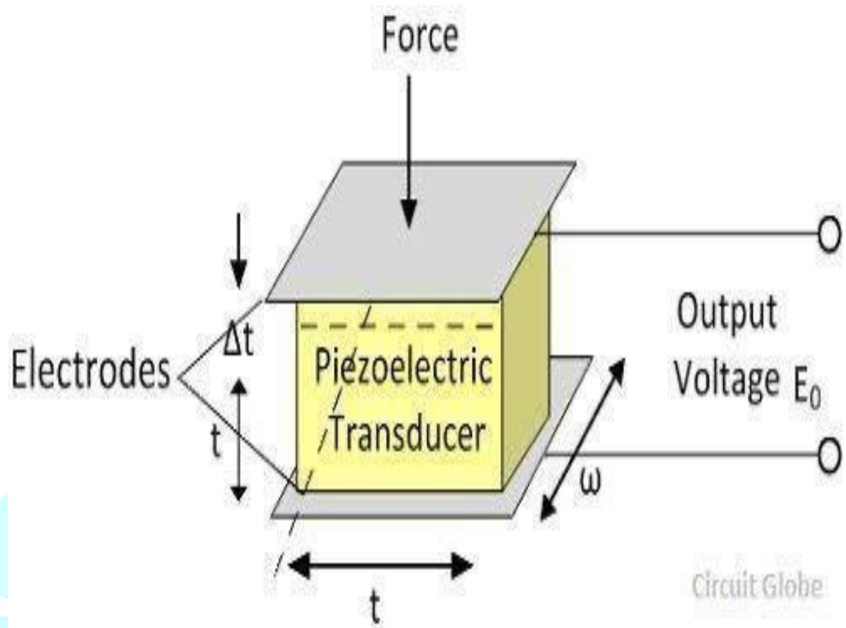

Fig: 1 construction of piezoelectric transducer

Main Parts:-

1. Piezoelectric Transducer:

This is the core material (typically quartz, PZT, or similar) that converts mechanical force into electrical energy using the piezoelectric effect.

2. Electrodes:

Two conductive plates are attached on either side of the piezoelectric material. These collect the electric charge generated when the material is deformed.

3. Force Input:

A mechanical force or pressure is applied to the sensor, which compresses or stretches the piezoelectric material.

4. Output Terminals:

The generated voltage (denoted as E_0) is collected across the electrodes and sent to external circuits via output terminals.

5. Dimensions:

The thickness t and deformation \Delta t are indicated, showing that deformation causes a change in geometry, which is essential to generating a voltage.

6. **Angular Frequency \omega:**

Indicates the sensor may be subject to oscillatory or dynamic forces (like vibration), a common use case for piezoelectric sensors

➢ Wireless Charging system:-

In today's fast-paced digital world, staying connected is more important than ever. As the number of smart devices continues to grow, so does the demand for more convenient and efficient charging solutions. Wireless charging stations have emerged as a modern alternative to traditional cable-based charging, offering users a cable-free, clutter free, and user-friendly experience. Using electromagnetic fields to transfer energy between two objects, these stations provide seamless charging for smartphones, smartwatches, earbuds, and other compatible devices. Whether in homes, offices, public spaces, or vehicles, wireless charging stations represent the future of mobile power, blending innovation, convenience, and sustainability.

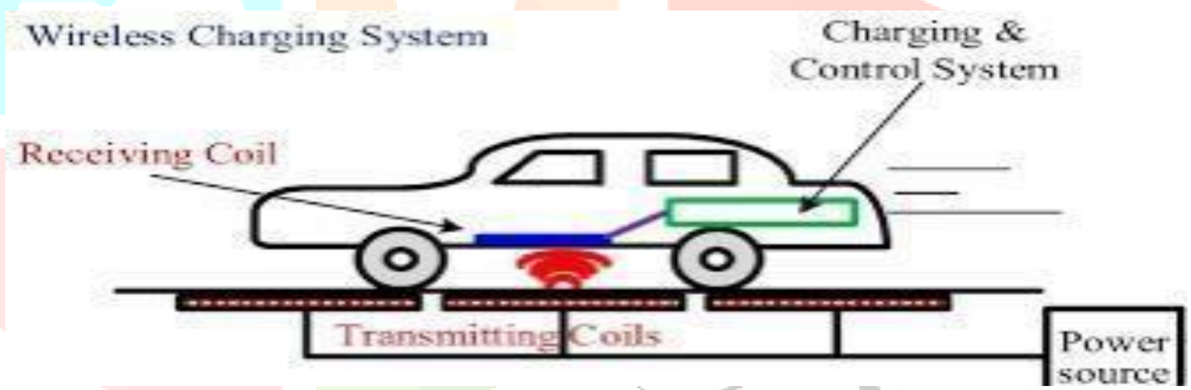

Fig : 2 E-Vehicle charging system

Working:-

A wireless charging station works on the principle of electromagnetic induction. It transfers energy from a power source to a device without the need for physical connectors or cables. The system mainly consists of two sides: the transmitter side (charging station) and the receiver side (device being charged).

Step-by-Step Working:

1. **Power Input:**

- The main power supply provides electrical energy to the system.

- This power is conditioned by the power supply unit, which delivers the correct voltage and current to the transmitter components.

2. **Control System:**

- A microcontroller monitors the system's operation.

- It ensures proper power delivery and safety, and can also communicate status information to an LCD display.

3. Transmitter Circuit and Coil:

- The transmitter circuit converts the power into a high-frequency alternating current (AC).
- This AC is fed into the transmitter coil, which generates an oscillating magnetic field.

4. Wireless Power Transfer:

- When the receiver coil (in the device) is placed near the transmitter coil, it picks up the magnetic field.
- This induces an alternating current in the receiver coil via magnetic induction.

5. Power Conversion in the Device:

- The receiver circuit converts the induced AC into DC.
- A voltage regulator then adjusts the voltage to a suitable level for charging the battery of the load (e.g., smartphone or device).

6. Output:

- The device receives regulated DC power and begins to charge.
- The microcontroller continues to monitor and display the status on the LCD screen.

➢ Objective:-

The objective of a street light and wireless charging station powered by a piezoelectric system is to harness the mechanical energy from road traffic to generate electricity, which can then be used to power streetlights and wirelessly charge electric vehicles, promoting sustainable and efficient energy solutions.

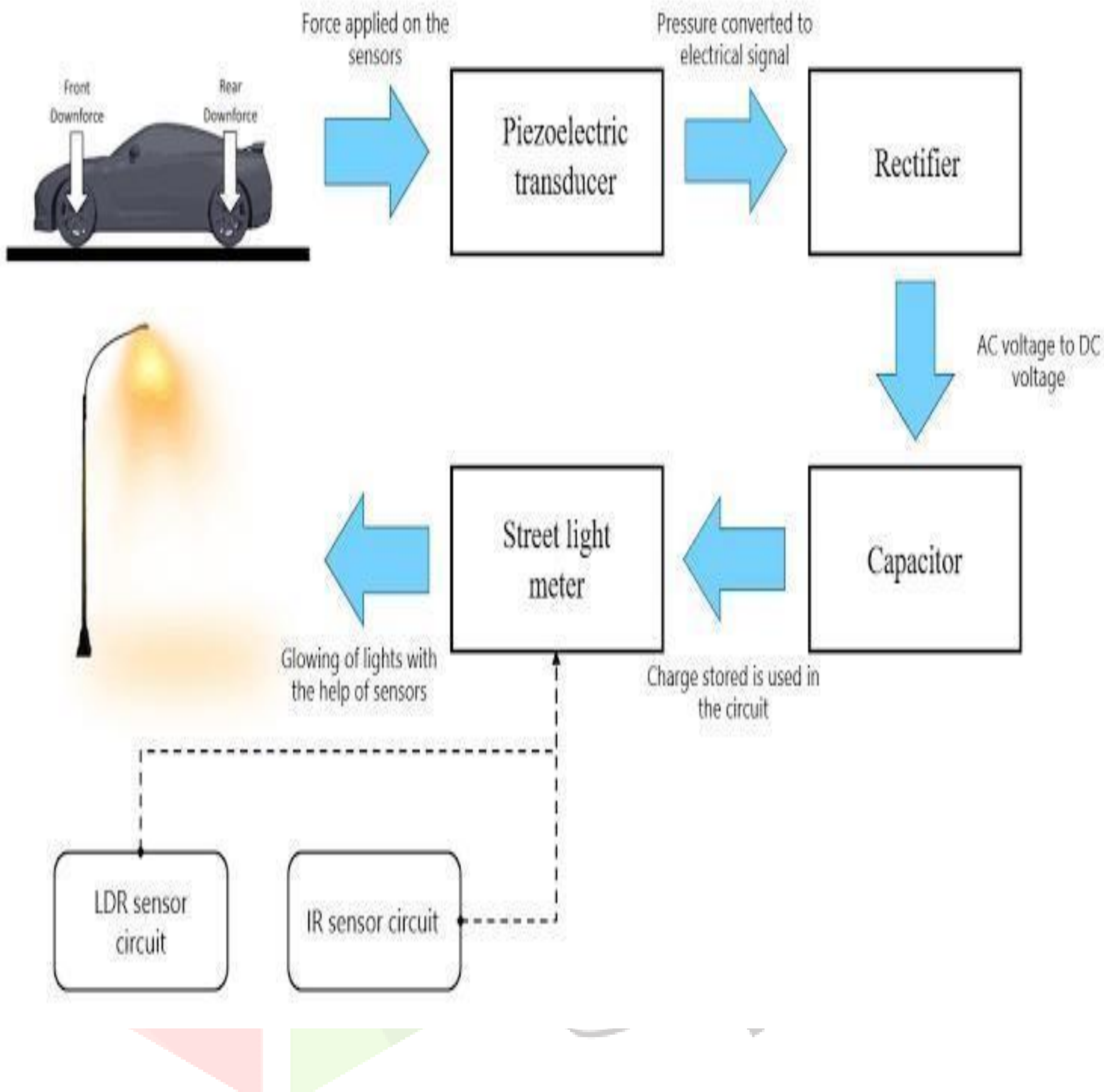

Fig : 3 piezoelectric power generation system

Energy Harvesting:

Piezoelectric materials, when subjected to pressure or vibration, generate electricity. By strategically placing piezoelectric sensors beneath roadways, the energy from passing vehicles can be captured and converted into usable electricity.

Street Lighting:

The generated electricity can be used to power LED streetlights, reducing reliance on traditional grid power and potentially lowering energy costs.

Wireless Charging:

The same harvested energy can be used to power wireless charging stations for electric vehicles, enabling convenient and sustainable charging solutions.

Smart Street Lighting:

Piezoelectric systems can be integrated with other technologies to create smart street lighting systems that dynamically adjust brightness based on traffic volume and ambient light conditions.

Benefits:

This approach offers several advantages, including reduced energy consumption, lower maintenance costs, and a more sustainable and environmentally friendly energy system.

Examples:

Roadway Energy Harvesting: Piezoelectric materials are placed under the road and generate electricity from the pressure of vehicles.

Wireless Charging: The generated electricity is used to power wireless charging pads for electric vehicles.

Smart Streetlights: Sensors detect traffic and adjust the brightness of streetlights accordingly.

➢ LITERATURE SURVEY:

✧ Piezoelectric Energy:-

1. Introduction

Piezoelectric energy harvesting has gained significant attention as a sustainable method for powering small-scale electronic devices. This technology leverages the piezoelectric effect, wherein certain materials generate an electric charge in response to mechanical stress. The increasing demand for lowpower and self-sufficient systems, such as wireless sensors and wearable electronics, has driven research into efficient piezoelectric materials and device architectures.

2. Fundamentals of Piezoelectricity

The piezoelectric effect was first discovered by Jacques and Pierre Curie in 1880. It is a reversible phenomenon observed in materials like quartz, zinc oxide, and various ceramics (e.g., PZT - lead zirconate titanate). When subjected to mechanical stress, these materials generate electric potential due to the displacement of internal electric dipoles.

3. Materials for Piezoelectric Harvesting

- Ceramics: PZT is the most widely used due to its high piezoelectric coefficient and efficiency. However, its lead content raises environmental concerns.
- Polymers: PVDF (Polyvinylidene fluoride) is flexible, lightweight, and suitable for wearable devices.
- Composites: Combining ceramics and polymers can enhance flexibility and performance.
- Recent Advancements: Research has also explored lead-free alternatives like BNT (Bismuth sodium titanate) and KNN (Potassium sodium niobate).

4. Device Structures and Mechanisms

Common piezoelectric harvesters are based on cantilever beams, diaphragms, and stack configurations. These structures convert vibrations, mechanical pressure, or motion into electrical energy. Enhancements in design, such as multi-layer structures and resonant frequency tuning, have improved energy conversion efficiency.

5. Applications

- Wearable Technology: Powering sensors and health monitoring devices.
- Infrastructure Monitoring: Embedded in bridges and buildings to detect stress or damage while harvesting energy.
- Transportation: Harvesters embedded in roads or railways to utilize vibrations from vehicles.
- Biomedical Devices: Implantable devices powered by body movement or physiological functions.

6. Challenges and Future Directions Key challenges include:

- Low power output for high-energy-demand applications.
- Efficiency losses due to mismatch between vibration frequency and resonator design.
- Durability and long-term performance, especially in dynamic environments.
- Need for environmentally friendly, lead-free materials.

✧ Wireless Charging Station:-

1. Introduction

Wireless charging, also known as inductive charging, enables power transfer without physical connectors. This technology is increasingly applied in consumer electronics, electric vehicles (EVs), medical devices, and industrial automation. The growth of electric mobility and demand for user convenience has accelerated the development of wireless charging stations, especially for EVs.

2. Wireless Power Transfer (WPT) Technologies Wireless charging is mainly based on three technologies:

- **Inductive Coupling (Near-Field):**

Operates on magnetic fields between two coils (transmitter and receiver). Common in smartphones and electric toothbrushes.
References: [Ahn & Kim, 2013], [Wang et al., 2019]

- **Resonant Inductive Coupling:**

An extension of inductive coupling allowing greater distance and efficiency through resonating coils. Applied in EV charging stations.
References: [Sample et al., 2011], [Choi et al., 2020]

- **Microwave or Radio Frequency (Far-Field):**

Transfers energy over longer distances, but with lower efficiency. Still in early research for practical applications.

References: [Brown, 1984], [Shinohara, 2014]

3. Wireless Charging for Electric Vehicles (EVs)

Wireless EV charging stations offer contactless charging and are often installed in garages, parking lots, or embedded in roads. Technologies such as **SAE J2954 standard** define interoperability and efficiency for wireless EV chargers.

- **Static Charging:** Car is stationary during charging.
- **Dynamic Charging:** Charging occurs while the vehicle is in motion, using embedded road coils (ongoing research).

References: [Miller et al., 2015], [Heo et al., 2022]

4. Key Research Areas

- **Efficiency Improvements:**

Researchers are developing better coil designs and power management systems to increase power transfer efficiency and reduce losses.

- **Alignment and Positioning:**

Misalignment between transmitter and receiver coils significantly affects performance. New alignment techniques and automated positioning are under development. References: [Bi et al., 2016]

- **Safety and EMI (Electromagnetic Interference):**

Investigations focus on minimizing electromagnetic radiation exposure and interference with nearby electronics or medical devices.

- **Bidirectional Charging:**

Allows energy to be transferred both ways – e.g., Vehicle-to-Grid (V2G) scenarios for power balancing.
References: [Cui et al., 2021]

5. Applications Beyond EVs

- **Consumer Electronics:** Wireless charging pads for phones, wearables, and laptops.
- **Medical Implants:** Charging pacemakers or sensors inside the body without wires.
- **Industrial Robots & Drones:** Enables autonomous, cable-free recharging.
- References: [Zhang et al., 2017]

6.Challenges

- Lower efficiency compared to wired charging.
- High cost and complex infrastructure, especially for dynamic EV charging.
- Interoperability and standardization issues.
- Environmental impact and thermal management.

7. Future Trends

- Development of **multi-device and spatial freedom** charging systems.
- Integration with **IoT and smart grids** for energy optimization.
- Use of **AI for positioning and power control.**
- **Standardization efforts** like Qi (for electronics) and SAE J2954 (for EVs).

➢ RESEARCH METHOD:

1. Problem Identification and Objective Definition

- Define the purpose of the study: e.g., developing a piezoelectric system to harvest energy from vibrations, foot traffic, or machinery.
- Identify the application: wearable devices, smart roads, biomedical implants, etc.
- Set goals such as improving energy output, miniaturization, or integration with IoT systems.

2. Literature Review

- Review past research on piezoelectric materials, device structures, and energy conversion techniques.
- Analyze existing systems for performance, limitations, and areas for improvement.
- Identify gaps in current knowledge (e.g., low efficiency in low-frequency vibration environments).

3. Material Selection

- Choose suitable piezoelectric materials based on the application:
- **PZT** (Lead Zirconate Titanate) – High performance but contains lead.
- **PVDF** (Polyvinylidene fluoride) – Flexible and biocompatible.
- **ZnO, $BaTiO_3$, KNN** – Lead-free or nano-materials.
- Consider properties like piezoelectric coefficient, mechanical strength, flexibility, and environmental impact.

4. System Design and Simulation

- Design the geometry and structure of the energy harvester: cantilever beam, stack, diaphragm, etc.
- Use software tools like COMSOL Multiphysics, ANSYS, or MATLAB to simulate mechanical stress, resonance frequency, and electrical output.
- Optimize for frequency matching, material thickness, and output voltage

5. Prototype Development

- Fabricate the device using microfabrication techniques, 3D printing, or manual assembly.
- Integrate piezoelectric material with supporting structures (e.g., substrate, electrodes, packaging).

6. Experimental Setup and Testing

- Create a test environment to apply controlled vibrations or pressure.
- Use tools like a shaker table, vibration motor, or pressure rig.
- Measure output parameters: voltage, current, power, frequency response.
- Use oscilloscopes, multimeters, and data acquisition systems for analysis.

7. Data Analysis

- Compare measured data with simulation results.
- Analyze performance under various loads, frequencies, and environmental conditions.
- Evaluate efficiency, durability, and consistency of power generation.

8. Integration and Application Testing

- Connect the harvester to storage units (e.g., capacitors, batteries) and power management circuits.
- Test in real-world applications (e.g., shoe inserts, building floors, car suspensions).
- Evaluate long-term performance and reliability.

9. Conclusion and Future Work

- Summarize findings and highlight improvements over existing systems.
- Suggest enhancements (e.g., using hybrid energy sources, improved packaging, wireless data transmission).
- Propose further research directions.

➢ STREET LIGHT SYSTEM:-

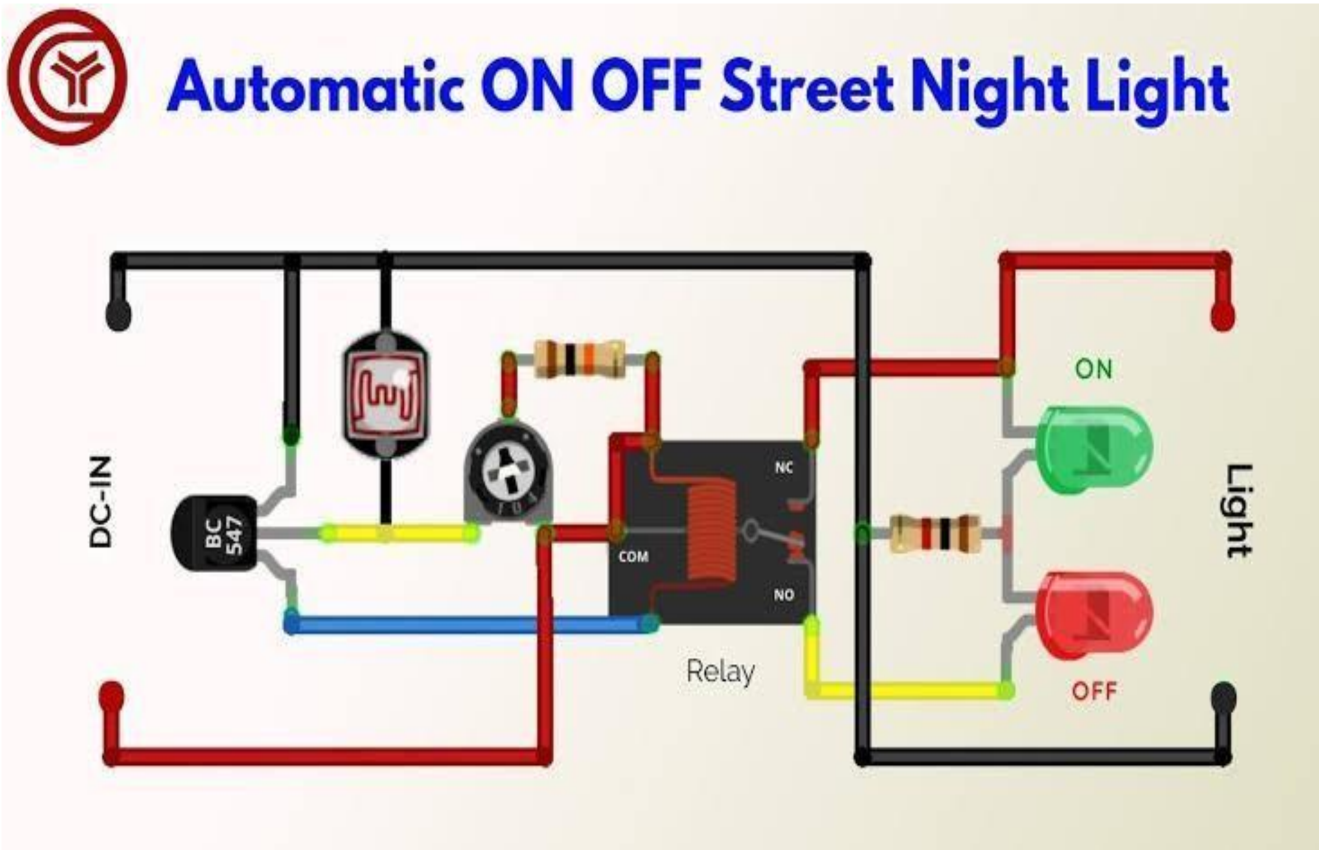

Fig : 4 working of the street light system

An automatic street light system turns on at night and off during the day without human intervention. It is commonly based on a light-dependent resistor (LDR) or photodiode sensor that detects ambient light levels.

During Daytime (Bright Light):

1. LDR receives light → its resistance is low.
2. A higher voltage appears across the base of the transistor.
3. The transistor remains OFF because the base-emitter voltage isn't enough to turn it on.
4. This means no current flows through the transistor → the relay is not activated.
5. The light remains OFF, and the OFF LED (Red) might glow as an indicator.

During Nighttime (Darkness):

1. LDR is in darkness → its resistance increases significantly.
2. This causes higher base current in the transistor.
3. The transistor switches ON, allowing current to flow from collector to emitter.
4. This energizes the relay, which then closes the circuit to the light.
5. The street light turns ON, and the ON LED (Green) glows to show active status.

Relay Role:

The relay acts as an electromechanical switch. When energized (at night), it allows a higher current to flow to power the street light. This keeps the control (low voltage) side isolated from the light load side.

➢ **LDR SENSORE:-**

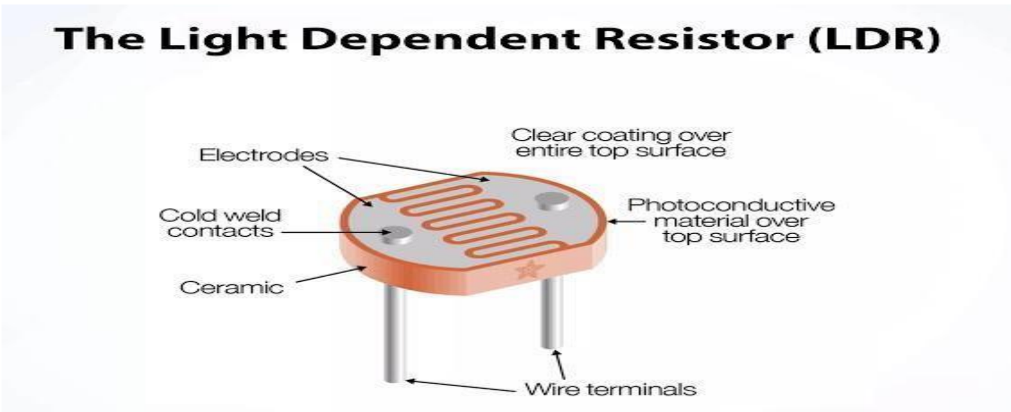

Fig : 5 LDR SENSORS

An LDR sensor (Light Dependent Resistor), also known as a photoresistor, is a type of light sensor whose resistance changes with the intensity of light falling on it.

- The resistance of an LDR decreases as the light intensity increases.
- In darkness or low light, its resistance is very high (in the megaohms).
- In bright light, its resistance is very low (a few hundred ohms).

This property allows the LDR to be used in circuits that need to detect or measure light levels.

➢ FLOW CHART

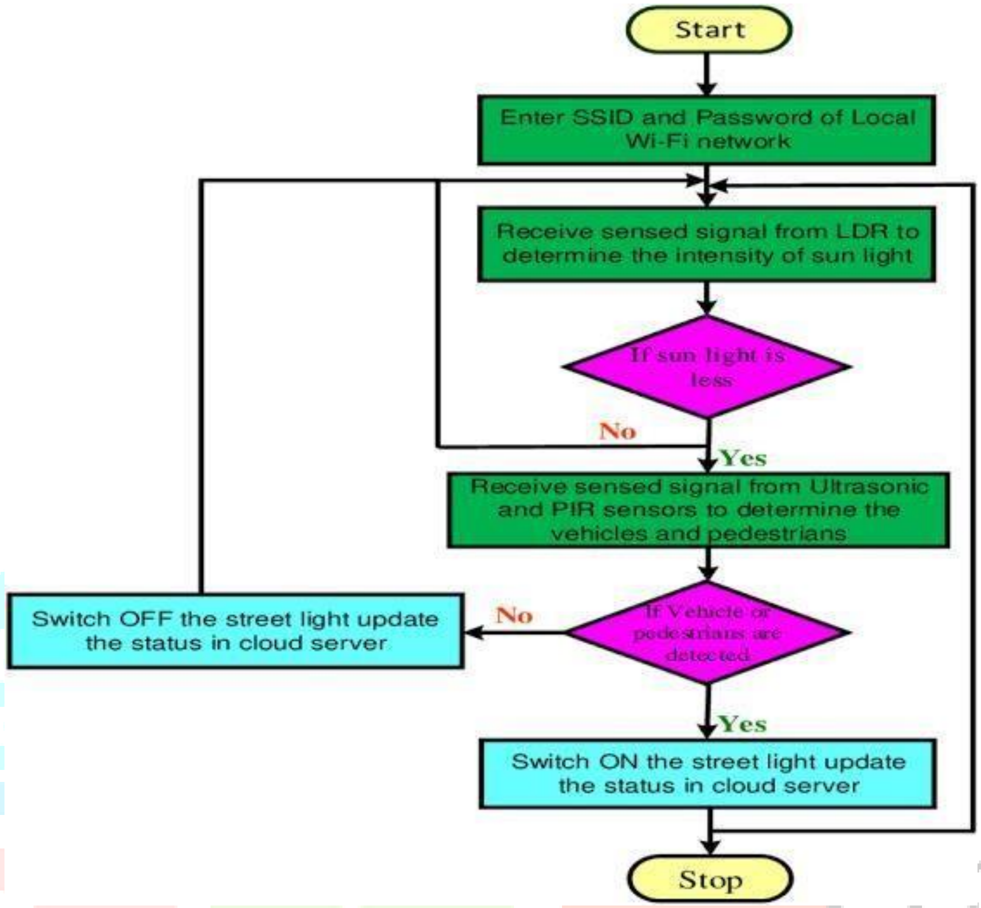

Fig : 6 flow chart

WORKING PRINCIPLE OF PIEZOELECTRIC SYSTEM:-

A piezoelectric sensor works based on the piezoelectric effect, which is the ability of certain materials (like quartz or PZT - lead zirconate titanate) to generate an electric charge when subjected to mechanical stress

Step-by-Step Working:

1. Mechanical Input:

• When a mechanical force (such as pressure, vibration, acceleration, or a tap) is applied to the piezoelectric sensor, the piezoelectric material inside the sensor gets compressed or deformed.

2. Electric Charge Generation:

• Due to the internal crystal structure of piezoelectric materials, the mechanical deformation causes a separation of electric charges (positive and negative) within the material.

3. Voltage Output:

• These separated charges appear across the surfaces of the material, creating a voltage difference.
• Electrodes attached to the piezo material collect this charge and output a measurable voltage signal.

4. Signal Use:

• This output voltage is proportional to the magnitude of the force or stress applied.
• It can be processed using amplifiers, ADCs, or microcontrollers or various applications.

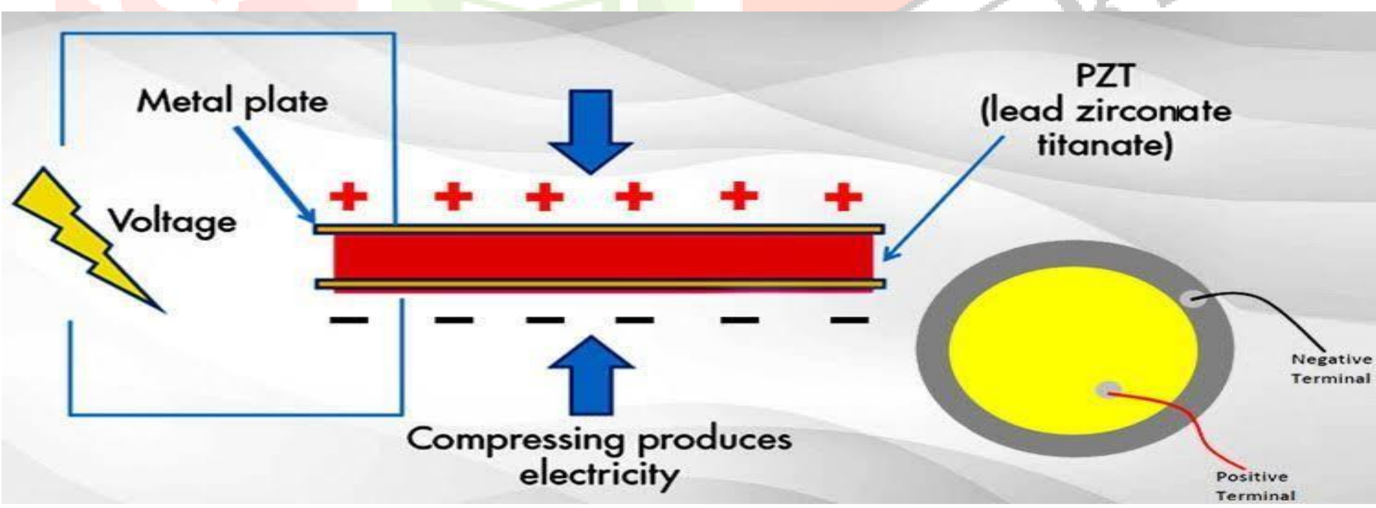

Fig : 7 piezoelectric working diagram

Hardware implementation:-

➢ CONCLUSION:-

The integration of piezoelectric energy harvesting with automatic street lighting and wireless charging stations presents a sustainable and intelligent approach to modern urban infrastructure. The piezoelectric system effectively converts mechanical energy—such as vibrations from vehicles or footsteps—into usable electrical energy, enabling a self-powered solution for low-energy applications.

In the automatic street light system, the use of piezoelectric power ensures reliable nighttime illumination without dependence on the conventional grid, enhancing energy efficiency and reducing operational costs. By employing sensors like LDRs and relays, the system intelligently responds to ambient light levels, providing lighting only when needed.

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