IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

HYBRID SOLAR PIEZO SMART ENERGY TILE WITH LOCAL DC-DC AGGREGATION AND INTELIGENT POWER MANAGER

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DOI: https://doi.org/10.56975/ijcrt.v14i7.309973

Abstract— The increasing demand for renewable and sustainable energy sources has encouraged the development of smart energy harvesting systems. This paper presents a Hybrid Solar–Piezo Smart Energy Tile integrated with Local DC–DC Aggregation and an Intelligent Power Management System. The proposed model combines solar energy and piezoelectric energy harvesting techniques to generate electrical power efficiently from both sunlight and human footsteps. Solar panels convert solar radiation into electrical energy, while piezoelectric sensors generate electricity from mechanical pressure applied on the tile surface. The generated energy from multiple sources is aggregated through a DC–DC converter circuit to maintain stable voltage output and improve power efficiency. An intelligent power management unit is incorporated to regulate, store, and distribute the generated energy effectively. The system ensures continuous energy generation even when one source becomes unavailable, thereby increasing reliability and efficiency. This project can be implemented in smart cities, railway stations, shopping malls, pedestrian pathways, and public areas where human movement and sunlight are abundantly available. The proposed hybrid system promotes green energy utilization, reduces dependency on conventional power sources, and supports sustainable development.

I.INTRODUCTION

The increasing demand for electrical energy and the rapid depletion of conventional energy resources have created a strong need for sustainable and renewable energy solutions. In recent years, renewable energy technologies such as solar energy and piezoelectric energy harvesting have gained significant attention due to their eco-friendly nature, energy efficiency, and ability to reduce dependence on fossil fuels. Smart energy harvesting systems play an important role in modern smart city infrastructure by converting naturally available energy into usable electrical power.

The proposed project, **"Hybrid Solar Piezo Smart Energy Tile with Local DC–DC Aggregation and Intelligent Power Manager,"** is designed to generate electrical energy by combining solar energy and piezoelectric energy harvesting techniques. The system utilizes solar panels to capture sunlight and piezoelectric sensors to generate electrical energy from mechanical pressure produced by human footsteps or vibrations. By integrating multiple renewable energy sources, the system improves overall energy generation efficiency and ensures continuous power availability.

II.LITERATURE REVIEW

The increasing demand for renewable and sustainable energy systems has encouraged researchers to develop innovative energy harvesting technologies using solar and piezoelectric sources. Several studies have focused on combining renewable energy harvesting techniques with intelligent power management systems to improve energy efficiency, reduce dependency on conventional power sources, and support smart city infrastructure applications.

Renewable Energy Engineering plays an important role in the development of hybrid energy systems. Solar energy harvesting has been widely used due to its high availability, clean energy generation, and low maintenance requirements. According to Solar Energy Engineering: Processes and Systems, photovoltaic systems are efficient and environmentally friendly solutions for sustainable electrical power generation.

However, solar energy generation depends heavily on weather and sunlight availability, creating the need for hybrid energy systems with additional energy sources.

Piezoelectric energy harvesting has emerged as an effective method for generating electrical energy from mechanical vibrations and human footsteps. S. Priya and D. J. Inman explained that piezoelectric materials generate electrical voltage when subjected to mechanical stress. This technology is highly suitable for smart flooring systems, public pathways, railway stations, and smart transportation applications where continuous mechanical pressure is available.

III.METHODOLOGY AND SYSTEM

1. METHODOLOGY:

This project follows a structured and systematic approach to develop a smart hybrid renewable energy tile system for sustainable power generation and intelligent energy management. The system integrates solar energy and piezoelectric energy harvesting with local DC–DC aggregation. **Phase 1: Requirement Analysis and System Design**

Target Application: Smart renewable energy tile for sustainable power generation in public pathways, smart roads, railway stations, shopping malls, and smart city applications CoreComponents: Arduino Nano, solar panel, piezoelectric sensors, bridge rectifier, capacitors, DC–DC converter, relay module, voltage sensors, rechargeable battery, and intelligent power manageArduino

Architecture: Solar Panel + Piezoelectric Sensors → Rectifier & DC–DC Aggregation → Battery Storage → Arduino Nano
→ Intelligent Power Manager → Load Output

Phase 2: Hardware Prototyping and Power Integration

Component Assembly: The solar panel is connected through a DC–DC converter for regulated voltage output. Piezoelectric sensors are installed beneath the tile structure to generate electrical energy from human footsteps. The piezoelectric AC output is converted into DC using a bridge rectifier.

Monitoring System: capacitor Solar voltage sensor, wind voltage sensor, and battery voltage sensor interfaced with Arduino.
motoroperation.
Power Supply: 12V DC battery used for energy storage and continuous power delivery.

Phase 3: Controller Programming and Energy Management

Development Environment: Arduino IDE is used for embedded system programming.
Control functions : Implemented voltage monitoring, local DC– DC aggregation control, intelligent source management, battery charging control, and relay switching using Arduino Nano.
Conditions
Power management: The intelligent power manager distributes regulated energy efficiently to the battery and load while preventing overcharging and voltage fluctuations

Phase 4: System Testing and Performance Evaluation

Performance Analysis: The system was tested under different sunlight conditions and varying footstep pressure conditions. Parameters Monitored: Solar voltage, piezoelectric voltage generation, battery charging performance, relay switching response, and load operation efficiency.

Evaluation: The hybrid energy tile system was analyzed for renewable energy utilization, intelligent power management

2. SYSTEM:

The proposed project, Hybrid Solar Piezo Smart Energy Tile with Local DC–DC Aggregation and Intelligent Power Manager, is designed to generate and manage electrical energy using both solar energy and piezoelectric energy harvesting techniques. The system combines renewable energy generation, power conditioning, intelligent control, energy storage, and load management into a single integrated smart energy platform.

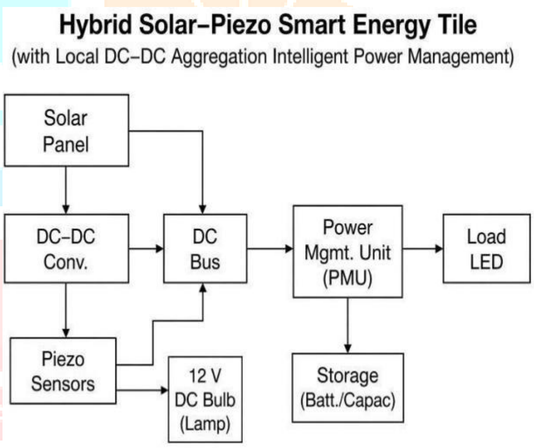

Fig1: system block diagram Of Hybrid solar piezo smart energy Tile

- *System Overview*

The proposed system consists of renewable energy generation, power conditioning, sensing, processing, energy storage, and intelligent power management units. The integration of solar and piezoelectric energy sources ensures continuous and sustainable power generation. The system performs real-time voltage monitoring, automatic energy aggregation, battery charging, and intelligent power distribution for efficient energy utilization

- *Renewable Energy Generation Unit*

The renewable energy generation unit consists of a solar panel and piezoelectric sensors.The solar panel converts sunlight into DC electrical energy using photovoltaic cells.

The piezoelectric sensors generate electrical energy when mechanical pressure is applied through footsteps or vibrations.

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- *Power conditioning and DC-DC aggregation unit*

The power conditioning unit includes:

- Bridge rectifier
- Capacitor filter circuit
- DC–DC converter

- Voltage regulation circuits

The AC output generated from piezoelectric sensors is converted into DC using the bridge rectifier. Capacitors filter voltage fluctuations and store temporary charge. The DC–DC aggregation unit combines and regulates power from solar and piezoelectric sources into a stable DC output for battery charging and load operation.

- *Processing and Control Unit*

The sensing unit consists of:

- Solar voltage sensor
- Piezoelectric voltage sensor
- Battery voltage sensor

These sensors continuously monitor voltage levels from renewable sources and battery conditions. The sensed data is transmitted to the Arduino Nano controller for processing and intelligent decision-making.

- *Energy Storage Unit*

The Arduino Nano acts as the central processing and control unit of the system.

- *Functions of Arduino Nano:*
- Monitoring solar, piezoelectric, and battery voltage levels
- Processing sensor data for intelligent energy management
- Controlling relay switching operations
- Managing DC–DC aggregation and battery charging
- Regulating power distribution to the load

- *Inteligent Power Management Unit*

The intelligent power manager performs automatic energy balancing and source management. Based on energy availability and battery condition, the controller efficiently distributes power between renewable sources, battery storage, and connected loads.

- *Energy Storage Unit*

The Arduino Nano acts as the central processing and control unit of the system.

- *Functions of Arduino Nano:*
- Monitoring solar, piezoelectric, and battery voltage levels
- Processing sensor data for intelligent energy management
- Controlling relay switching operations
- Managing DC–DC aggregation and battery charging
- Regulating power distribution to the load

Load Unit

The regulated DC power is supplied to DC loads such as LED lighting systems, charging circuits, or low-power smart devices. The system demonstrates practical implementation of renewable energy-powered smart flooring applications.

IV. WORKING

The proposed **Hybrid Solar Piezo Smart Energy Tile with Local DC–DC Aggregation and Intelligent Power Manager** works by combining solar energy harvesting and piezoelectric energy generation to produce sustainable electrical power. The complete system operation is explained below:

- *Solar Energy Generation*

At system startup, the solar panel converts sunlight into DC electrical energy using photovoltaic cells. The generated power is supplied to the DC–DC converter for voltage regulation. The regulated power is then supplied for battery charging and load operation

- *piezoelectric energy generation*

When pressure is applied on the smart tile surface through human footsteps or vibrations, the piezoelectric sensors generate AC electrical signals. The generated AC power is converted into DC using a bridge rectifier circuit and filtered using capacitors for stable output generation.

- *Local DC-DC Aggregation*

The regulated solar power and converted piezoelectric power are combined using the local DC–DC aggregation unit. This unit maintains stable voltage levels and improves overall power efficiency by integrating multiple renewable energy sources into a common DC bus

- *Battery Charging and Energy Storage*

The 12V rechargeable battery stores excess renewable energy generated from solar and piezoelectric sources. During low generation conditions, the stored energy is supplied to the load for uninterrupted operation.

- *Voltage Monitoring and Sensor Operation*

Voltage sensors continuously monitor solar voltage, piezoelectric voltage, and battery voltage. The sensed signals are transmitted to the Arduino Nano controller for processing and intelligent control operation

- *Intelligent power management and control*

The Arduino Nano acts as the intelligent power manager of the system. Based on voltage sensor data, the controller automatically manages energy flow, battery charging, and relay switching operation. This ensures efficient renewable energy utilization and stable power delivery.

- *Load operation*

The regulated DC output power is supplied to connected DC loads such as LED lighting systems or charging devices. The intelligent power manager ensures stable load operation under varying renewable energy conditions.

- *System Performance and Energy Efficiency*

The hybrid renewable energy tile system continuously operates by maximizing renewable energy harvesting from solar and piezoelectric source.

V.RESULT & CONCLUSION

- **RESULT:**

The proposed Hybrid Solar Piezo Smart Energy Tile with Local DC–DC Aggregation and Intelligent Power Manager successfully generated electrical energy using both solar and piezoelectric energy sources. The solar panel produced stable DC power under sunlight conditions, while the piezoelectric sensors generated electrical energy from human footsteps and mechanical pressure applied on the smart tile surface.

The generated energy was effectively converted, regulated, and combined using bridge rectifiers, capacitors, and DC– DC aggregation circuits to provide stable DC output. The Arduino Nano continuously monitored solar voltage, piezoelectric voltage, and battery voltage through voltage sensors and efficiently controlled relay switching and intelligent power management operations.

The 12V rechargeable battery successfully stored excess renewable energy and supplied backup power during low energy generation conditions, ensuring uninterrupted load operation. The connected DC loads such as LED lighting systems operated smoothly with regulated power supply and minimal voltage fluctuations.

- CONCLUSION

The proposed Hybrid Solar Piezo Smart Energy Tile with Local DC–DC Aggregation and Intelligent Power Manager successfully generated electrical energy using both solar and piezoelectric energy sources. The solar panel produced stable DC power under sunlight conditions, while the piezoelectric sensors generated electrical energy from human footsteps and mechanical pressure applied on the smart tile surface.

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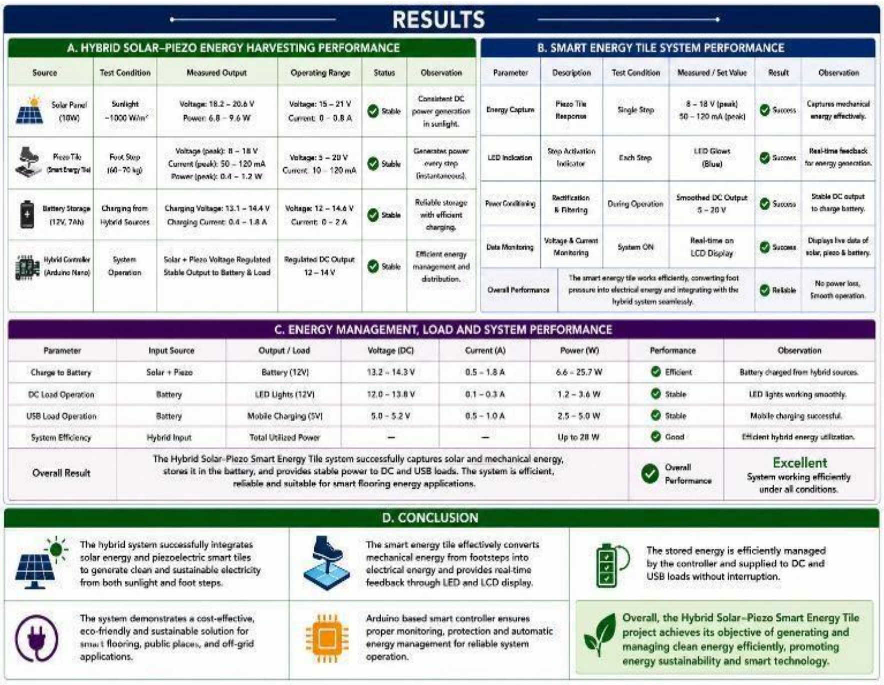

RESULTS

A. HYBRID SOLAR–PIEZO ENERGY HARVESTING PERFORMANCE

Source	Test Condition	Measured Output	Operating Range	Status	Observation
Solar Panel (10W)	Sunlight ~1000 W/m²	Voltage: 18.2 – 20.6 V Power: 6.8 – 9.6 W	Voltage: 15 – 21 V Current: 0 – 0.8 A	Stable	Consistent DC power generation in sunlight.
Piezo Tile (Smart Energy Tile)	Foot Step (60 – 70 kg)	Voltage (peak): 8 – 18 V Current (peak): 50 – 120 mA Power (peak): 0.4 – 1.2 W	Voltage: 5 – 20 V Current: 10 – 120 mA	Stable	Generates power every step (instantaneous).
Battery Storage (12V, 7Ah)	Charging from Hybrid Sources	Charging Voltage: 13.1 – 14.4 V Charging Current: 0.4 – 1.8 A	Voltage: 12 – 14.6 V Current: 0 – 2 A	Stable	Reliable storage with efficient charging.
Hybrid Controller (Arduino Nano)	System Operation	Solar + Piezo Voltage Regulated Stable Output to Battery & Load	Regulated DC Output 12 – 14 V	Stable	Efficient energy management and distribution.

B. SMART ENERGY TILE SYSTEM PERFORMANCE

Parameter	Description	Test Condition	Measured / Set Value	Result	Observation
Energy Capture	Piezo Tile Response	Single Step	8 – 18 V (peak) 50 – 120 mA (peak)	Success	Captures mechanical energy effectively.
LED Indication	Step Activation Indicator	Each Step	LED Glows (Blue)	Success	Real-time feedback for energy generation.
Power Conditioning	Rectification & Filtering	During Operation	Smoothed DC Output 5 – 20 V	Success	Stable DC output to charge battery.
Data Monitoring	Voltage & Current Monitoring	System ON	Real-time on LCD Display	Success	Displays live data of solar, piezo & battery.
Overall Performance	The smart energy tile works efficiently, converting foot pressure into electrical energy and integrating with the hybrid system seamlessly.			Reliable	No power loss, Smooth operation.

C. ENERGY MANAGEMENT, LOAD AND SYSTEM PERFORMANCE

Parameter	Input Source	Output / Load	Voltage (DC)	Current (A)	Power (W)	Performance	Observation
Charge to Battery	Solar + Piezo	Battery (12V)	13.2 – 14.3 V	0.5 – 1.8 A	6.6 – 25.7 W	Efficient	Battery charged from hybrid sources.
DC Load Operation	Battery	LED Lights (12V)	12.0 – 13.8 V	0.1 – 0.3 A	1.2 – 3.6 W	Stable	LED lights working smoothly.
USB Load Operation	Battery	Mobile Charging (5V)	5.0 – 5.2 V	0.5 – 1.0 A	2.5 – 5.0 W	Stable	Mobile charging successful.
System Efficiency	Hybrid Input	Total Utilized Power	—	—	Up to 28 W	Good	Efficient hybrid energy utilization.
Overall Result	The Hybrid Solar-Piezo Smart Energy Tile system successfully captures solar and mechanical energy, stores it in the battery, and provides stable power to DC and USB loads. The system is efficient, reliable and suitable for smart flooring energy applications.					Overall Performance	Excellent System working efficiently under all conditions.

D. CONCLUSION

The hybrid system successfully integrates solar energy and piezoelectric smart tiles to generate clean and sustainable electricity from both sunlight and foot steps.

The smart energy tile effectively converts mechanical energy from footsteps into electrical energy and provides real-time feedback through LED and LCD display.

The stored energy is efficiently managed by the controller and supplied to DC and USB loads without interruption.

The system demonstrates a cost-effective, eco-friendly and sustainable solution for smart flooring, public places, and off-grid applications.

Arduino based smart controller ensures proper monitoring, protection and automatic energy management for reliable system operation.

Overall, the Hybrid Solar–Piezo Smart Energy Tile project achieves its objective of generating and managing clean energy efficiently, promoting energy sustainability and smart technology.

FIG 2: RESULT & CONCLUSION

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