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Implementation of Piezoelectric Energy Harvesting with Buck-Boost Converter

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Abstract- This paper presents the implementation and analysis of a piezoelectric energy harvesting system integrated with a Buck-Boost converter. This system efficiently converts and regulates the variable low-voltage output from piezoelectric transducers into a regulated electrical Energy Supply. The proposed system addresses the problem of fluctuating input voltage caused by varying mechanical vibrations using the advantage of a Buck-Boost converter to both increase and decrease the output voltage levels. This confirms steady power supply to low-power electronic devices as well as high power A.C. appliances. Experimental results validate the efficiency of the converter in exploiting energy extraction and maintaining stable output voltage. This highlights its latent for powering wireless sensor nodes and other autonomous systems. This work contributes to improving sustainable green energy solutions by making piezoelectric energy harvesting technologies more reliable and effective and a step towards the green energy.

Keywords- Piezoelectric transducer, Super Capacitor, Buck-Boost converter, power management, voltage regulation, smart grid.

I. INTRODUCTION

Recently the demand of sustainable, green, and autonomous energy sources has driven important advancements in energy harvesting technologies. Amongst these, the piezoelectric energy harvesting has gained attention for its ability to convert ambient mechanical vibrations into electrical energy. This capability is especially valuable for powering low-power devices like wireless sensor nodes, wearable electronics, and remote monitoring systems. A key challenge in piezoelectric energy harvesting is efficiently managing the variable and often low-voltage output from piezoelectric transducers. The output voltage heavily depends on the frequency and amplitude of mechanical vibrations, which can change significantly. To tackle this, power regulatory circuits are used to regulate and stabilize the

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harvested energy. This ensures a consistent and usable output. The Buck-Boost converter has emerged as a auspicious solution. Its sole ability to increase or decrease the input voltage makes it suitable for situations where the input voltage may be above or below the desired output level. By incorporating a Buck-Boost converter, the harvested energy can be effectively hardened to meet the energy requirements by improving the overall system performance. This paper explores the implementation of a piezoelectric energy harvesting system integrated with a Buck-Boost converter. The main goals are to design and analyze the piezo electric based energy harvesting circuit's performance, to evaluate the efficiency of the power regulation stage as well as assess the system's ability to supply power to a wireless sensor node. Through this study, we aim to aid the development of more efficient and reliable energy harvesting solutions, paving the way for self-powered electronic systems in various applications.

II. WORKING OF THE SYSTEM

1) Piezoelectric source: Piezoelectric materials are defined as a class of quartz crystalline materials that generate an electric charge in response to applied mechanical stress or strain. Here, this device is providing a very low value of AC voltage in response to the applied mechanical force which is assembled beneath the populated road side pavement.
2) Bridge rectifier: A bridge rectifier is designed with four diodes in a bridge connection to accomplish full-wave rectification. It converts the A.C voltage of the piezo- electric transducer in to a rippled DC voltage.
3) Filter Unit: A super capacitor is used here to store the DC voltage during pulses. The use of a super capacitor of value nearly 10 F, this system provides a measurable storage of energy.
4) Buck-Boost DC-DC converter: A variable low input voltage from a capacitor produces a regulated DC voltage of about 12 V.

   Specifications are:-

   Input range: e.g., 2–30 V with respect to the matched rectified voltage range

   Output: regulated 12 V

   Efficiency: approximately>85%
5) Charge controller: This unit prevents overcharge of the battery with simple current limiting depending on the battery.
6) Storage battery: A Li-ion battery is used here to store the energy required (see sizing example).
7) Inverter: DC 12V to AC 230 V, true sine or modified sine depending on loads. Size by peak and continuous power of loads (fan motor inrush).
8) Automatic Transfer Switch (ATS):To manage connection to the Smart-Grid , when the battery and inverter cover the load ,the surplus energy is transmitted through ATS to the smart grid . It also includes isolation and protection.

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9) Energy meter: This measures instantaneous AC voltage and current and integrates to kWh. A commercial single-phase energy meter is used here.

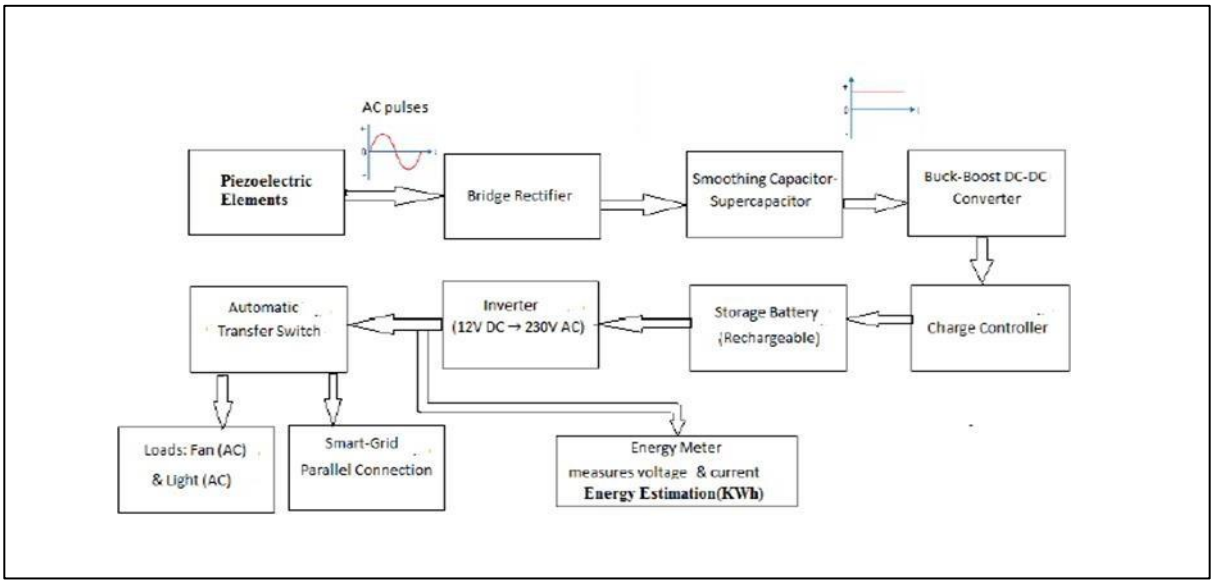


Fig.1. Block Diagram

Explanation of each part:

1) Piezoelectric Elements is a transducer convert mechanical vibrations that is strain or stress into electrical energy as alternating current (AC) pulses. Serve as the main energy harvesting source, capturing nearby mechanical energy.

2) Bridge Rectifier changes the AC pulses from the piezoelectric elements into direct current (DC). Uses diodes arranged in a bridge layout to allow current flow in one direction, giving a pulsating DC output that is suitable for further processing.

3) Smoothing Capacitor / Super capacitor This unit soothes the pulsating DC from the rectifier by filtering out voltage ripples. Offers a more stable DC voltage to ensure a steady input to the voltage regulator stage. Super capacitors can also momentarily store a small amount of energy to cover power gaps.

4) Buck-Boost DC-DC Converter: This part adjusts the DC voltage level by either boosting or bucking based on the input voltage level. Makes sure the voltage supplied to the battery and load stays within safe and optimal limits, regardless the changing piezoelectric output. Improves energy harvesting efficiency by responding to varying input voltage conditions.

5) Charge Controller : This unit monitors and controls the charging of the rechargeable battery to avoid

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overcharging, which can harm the battery. Also prevents deep discharge, which helps extend battery life and keeps the system reliable. Regulates the energy flow from the converter to the battery.

6) Rechargeable Storage Battery holds the harvested electrical energy for use when mechanical vibrations are low or absent. Provides a steady and reliable DC power source for downstream conversion and loads. Ensures energy availability regardless of real-time harvesting conditions.

7) Inverter (12V DC to 230V AC) changes the DC voltage stored in the battery into AC voltage that works with standard household or industrial AC loads. Supports the powering of AC devices like fans, lights, and other appliances. Offers voltage transformation and waveform shaping for a stable AC output.

8) Automatic Transfer Switch Automatically switches the power supply between the inverter and the utility smart grid. It ensures uninterrupted power delivery to connected loads by switching to the grid when harvested energy is low or the battery is drained and makes it easy to integrate with existing power infrastructure.

9) Loads: Fan (AC) & Light (AC) represent the practical devices powered by the harvested and conditioned electrical energy. Show the system's ability to support real-world applications and loads.

10) Smart-Grid Parallel Connection allows the system to connect in parallel with the utility grid for backup power or to send excess harvested energy back into the grid. Supports grid-tied operation, improving energy reliability and potential energy credits or savings.

11) Energy Meter measures electrical parameters like voltage and current to calculate energy generation and consumption. Provides energy usage data in kilowatt-hours (kWh) for system monitoring, optimization, and reporting. It helps assess the performance and efficiency of the energy harvesting system.

III. CIRCUIT DIAGRAM

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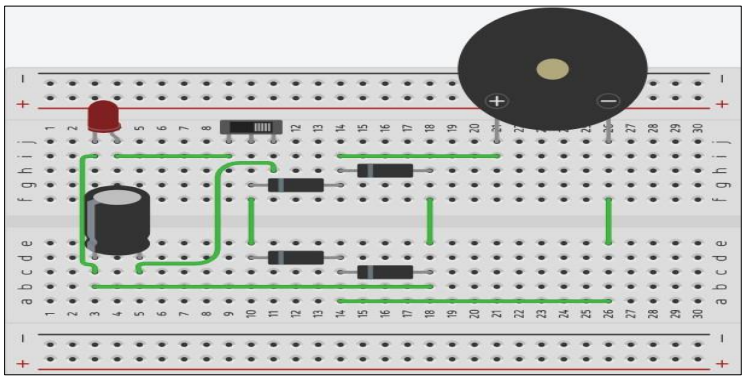


Fig.2. Circuit Diagram part1

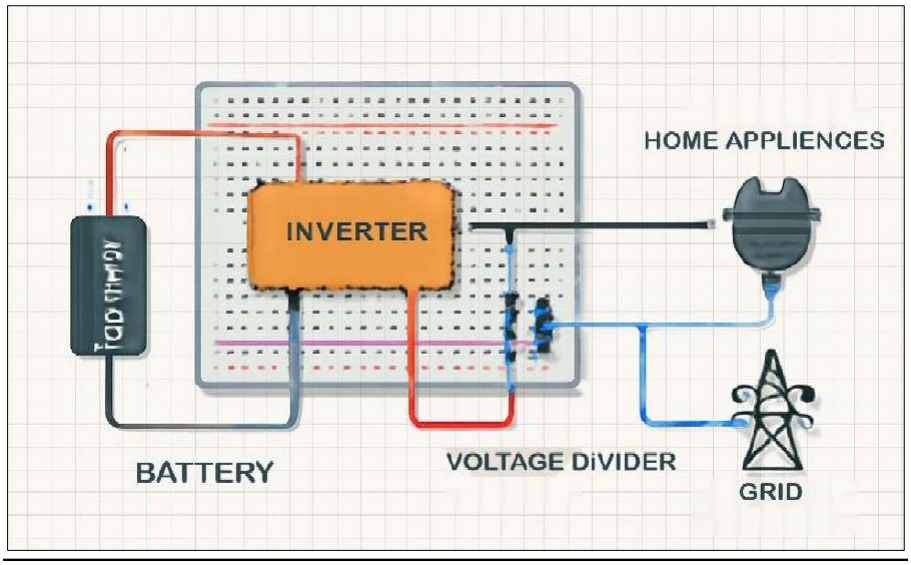


Fig.3. Circuit Diagram part2

IV. ANALYSIS OF DIFFERENT PERFORMANCE PARAMETERS OF THE PIEZO ELECTRIC ENERGY COVERTER SYSTEM

Table1: Performance parameters of the piezo electric energy converter system

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Energy estimation & Energy metering:-

DC Voltage if VDC(t) , DC Current IDC(t), as well as AC Voltage if IAC(t) , AC Current IAC(t), after the inverter is measured.

Instantaneous power P(t)= V(t). I(t)

P(t)= Vrms . Irms Cos φ

Rated Inverter power

Power in VA = vAC(t) x IAC(t)

Power in KVA = vAC(t) x IAC(t)/1000

Power in Watts = vAC(t) x IAC(t) x Cos φ

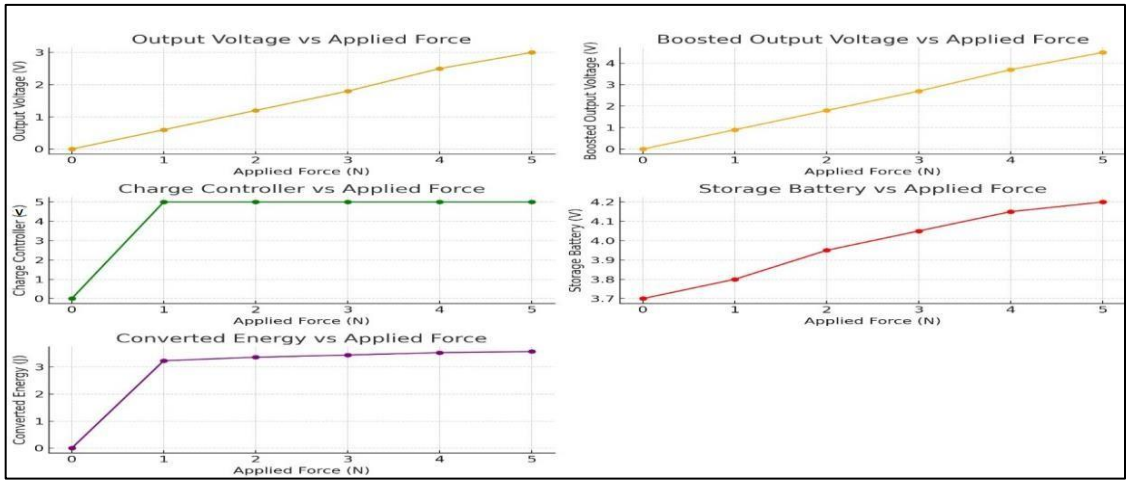
Where Cos φ = power factor

Power in KW = vAC(t) x IAC(t) x Cos φ /1000

Power in W = Vrms . Irms Cos φ

Power in KW = Power in KVA x PF

Power in KVA = Power in KW/PF = Power in KW/0.8 (Nominal Cos φ = 0.8)



Applying Power in KW = Power in KVA x Cos φ

Applied Force(N)	Output Voltage of Super capacitor(V)	Boosted Output Voltage(V)	Charge Controller Output (V)	Output Voltage of Storage Battery(V)	Output Voltage of Inverter(V)	Output Voltage of Converter(V)
0	0	0	0	3.70	0	0
1	0.6	0.9	5	3.80	230	3.23
2	1.2	1.8	5	3.95	230	3.36
3	1.8	2.7	5	4.05	230	3.44
4	2.5	3.7	5	4.15	230	3.53
5	3.0	4.5	5	4.20	230	3.57

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Power in KVA = Power in KW/ Cos φ = Power in KW/0.8 (Nominal PF = 0.8, which is standard for homes)

Fig 4. Characteristic graphs of performance parameters Vs applied mechanical force of the

Calculation of Total KVA requirement:-

Total load in Watts = 2*18 + (2 x 75) = 186W =0.186KW

Power in KVA = 0.186/0.8 = 0.2325

An inverter of standard rating 0.3KVA is used to carry the loads above.

V. CONCLUSION

Combining a Buck-Boost converter with a piezoelectric energy harvesting system improves the efficiency and reliability of turning mechanical vibrations into functioning electrical energy. The Buck-Boost converter efficiently manages the unregulated, frequent low-voltage output from piezoelectric elements. This regulation provides a stable power supply that can charge storage batteries and power electronic devices. This method tackles important issues in energy harvesting, like voltage fluctuations and energy storage management. It offers a strong solution for sustainable and autonomous power generation in low-power settings, like wireless sensor networks and portable electronics. Future work can focus on optimizing the converter design and exploring hybrid energy harvesting systems to maximize energy capture in different environments.

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