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Flexible Hybrid Kinetic-Solar Energy Harvesting: Performance Analysis of Multi Configuration Integrations

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Abstract: - Clean energy is obtained from generation systems that do not emit any pollutants, particularly greenhouse gases like CO^2, which contribute to climate change. As a result, increasing acceptance of clean energy promotes innovations aimed at protecting the environment and reducing the issue caused by non-renewable fuels such as gas and oil. However, excessive depletion and waste of energy resources create serious issues. To address this issue, various strategies have been proposed and implemented. For instance, researchers have introduced new, more efficient and environmentally friendly ways of consuming energy by utilizing renewable sources. This study investigates the performance analysis of multi-configuration integrations for flexible hybrid kinetic-solar energy harvesting systems. With the increasing demand for sustainable energy solutions, the integration of kinetic and solar energy harvesting technologies offers promising opportunities for enhanced efficiency and flexibility. Electricity is generated through a combination of photovoltaic (PV) panels installed along walkways and multiple series-parallel configurations of piezoelectric devices. The generated electricity charges a rechargeable battery, which can be utilized to power low-voltage applications during emergencies. Furthermore, studies were undertaken to improve the input voltage from solar panels and the efficiency configurations of piezo buzzers in slabs in order to measure the charging system efficiency from these two sources. The study explores the synergies between kinetic and solar energy harvesting components, considering factors such as energy output, system adaptability, and cost-effectiveness. Furthermore, an examination of the charge created by various body masses as they move across the piezo buzzers was conducted. Each solar panel and footstep will include a 16 x 2 LCD display that will show the solar panel's output performance and the piezo buzzer when pressure is applied. Power hybrid harvesting is simulated with Multisim and Proteus software, which monitor input and output parameters. Multisim software is used to create AC-DC circuits for solar and piezoelectric systems, and Proteus simulates hybrid power harvesting and energy storage circuits controlled by Arduino Uno R3. In summary, this product can provide considerable output up to 5 V and send notifications via the Blynk app. This research contributes valuable insights into the design and optimization of flexible hybrid energy harvesting systems, advancing the development of sustainable energy solutions for diverse applications.

Keywords: Kinetic energy, Solar energy, Piezoelectric analysis, hybrid energy harvesting, power generation

I. INTRODUCTION

Harvesting energy from human motion is an innovative research field aimed at generating power for wearable sensors, devices, and batteries. On average, men take around 7152 steps and women take about 5210 steps per day.

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This kinetic energy production is a continuous process, unaffected by geographic location or weather conditions, and holds promise for electricity generation. Studies have shown that the energy generated from walking and running can be harnessed to power microdevices. However, the feasibility of using such power harvesting to charge larger devices is still uncertain [1]. Consequently, alternative energy generation and energy saving technologies are required in order to meet the projected increase in the demand in coming years. Many researchers have shown that walking and running have great potential for energy harvesting. Energy harvesting, the process of capturing and converting ambient energy into usable electrical power, stands as a pivotal technology in this endeavor [2-3]. Its importance lies not only in its ability to provide a reliable and renewable source of energy but also in its capacity to reduce reliance on finite fossil fuels and mitigate the detrimental environmental impacts associated with traditional energy generation methods. The global shift towards renewable energy is driven by the urgent need to address climate change, air pollution, and resource depletion. Renewable energy sources, including solar, wind, hydroelectric, and biomass, offer a clean and sustainable alternative to fossil fuels by harnessing naturally occurring energy from the sun, wind, water, and organic matter [4-6].

Energy harvesting technologies enable the efficient capture and utilization of these renewable resources, making it possible to generate electricity without emitting harmful greenhouse gases or depleting finite natural resources. One of the key advantages of energy harvesting is its ability to tap into diverse energy sources that are readily available in the environment. Solar energy, for example, is abundant and inexhaustible, with the potential to power entire cities when harnessed through photovoltaic (PV) systems. Wind energy, similarly, offers a clean and scalable source of power, particularly in regions with strong and consistent wind patterns [7-8]. Kinetic energy harvesting, which captures energy from motion or vibrations, presents another promising avenue for generating electricity from everyday activities such as walking, cycling, or vehicular traffic [9-11].

Piezoelectric materials act as transducers, converting the pressure exerted by moving people into electric current [12-14]. This research presents the design of power generation using footstep-based piezoelectric sensors [15-18], with a detailed study of their merits, demerits, and the sub-equipment and requirements involved. Many research groups are actively working in the area of footstep power generation using piezoelectric methodology [19-22]. Teh and Zuraini (2018) [23] described an energy harvester driven by human foot strikes. Results indicate that the MCFT–41T–1.0A1–141 piezoelectric ceramic, with its thinner profile and larger diameter, generates the highest electrical energy output at 30.97 μW, particularly in a series connection configuration. Moreover, individuals with greater body weight and faster walking speeds produce more electrical energy. Putri et al. (2019) investigated the utilization of human steps as a potential energy source to power low-voltage loads. A tile composed of piezoelectric transducers, specifically Lead Zirconate Titanate type, was designed and implemented to generate electrical pulses and harvest energy from human footstep activities. The piezoelectric floor energy harvester system, comprising 20 parallel-connected piezoelectric transducers, can produce an AC voltage of up to 71.20 V, with an average voltage of 63.98 V. The average power output is 0.0604 watt per 10 footsteps. Ganesh et al. (2021) [24] suggested that voltage should be produced using footstep power in public situations where people are walking, and they have to ride on this device in order to pass through or live. Such systems will then produce voltage about each and every move of a foot [25-26]. The output power generated from its sensor is used to move DC charges. Here we use AT89S52 to demonstrate how much battery gets charged. Furthermore, a Wi-Fi-enabled IoT system uses how often voltage generation from the source of the signal. Using the users' IoT-based tracking, the data can be used to gain power they intend [22, 27-28]. Others proposed footstep generation through walking and its mechanical impact during piezoelectric operations [29-30].

Piezo footstep power and solar panels are two different technologies that can be used to generate electricity, often in off-grid or sustainable applications. Piezo footstep power involves harnessing mechanical energy generated by footsteps, usually through piezoelectric materials, to generate electricity. This technology has gained popularity in areas with high foot traffic, such as public spaces, where it can be used to power small devices or lighting systems. On the other hand, solar panels utilize photovoltaic cells to convert sunlight directly into electricity. Solar panels are widely used to generate renewable energy in various settings, including residential, commercial, and industrial applications. While piezo footstep power has gained attention for its innovative approach to generating electricity from human motion, solar panels remain a more established and widely adopted technology for renewable energy generation. The choice between the two technologies depends on factors such as location, available resources, and specific application requirements. This project focuses on the development of a smart energy harvesting system that utilizes both footstep and solar panel power to produce electricity efficiently. Traditional energy generation methods often rely on non-renewable sources such as fossil fuels, which contribute to environmental pollution and climate change. In contrast, renewable energy sources offer a promising alternative by tapping into naturally occurring resources such as sunlight and kinetic energy. Solar panels have been widely adopted as a means of harnessing solar energy, while recent advancements have explored the potential of kinetic energy harvesting from human footsteps. The concept of footstep energy harvesting involves converting the mechanical energy generated by human movement into electrical energy through specialized devices such as piezoelectric materials or kinetic energy harvesters. Similarly, solar panels convert sunlight into electricity using photovoltaic cells, offering a reliable source of renewable energy.

Therefore, by combining these two renewable energy sources into a hybrid smart energy harvesting system, this project aims to enhance energy efficiency and sustainability. The integration of footstep and solar panel power allows for continuous energy generation, making it suitable for various applications, including powering low-voltage devices or providing backup power during emergencies. In summary, a hybrid approach combining piezo footstep power and solar panels offers several advantages, including maximizing energy harvesting capabilities, diversifying energy sources, optimizing space utilization, and enhancing sustainability. In summary, Section I discussed the concept and background of piezoelectric footstep and solar energy harvesting devices for generating electricity. These systems were created to generate renewable energy by embedding piezoelectric materials in flooring to capture mechanical energy from footsteps and incorporating solar panels to turn sunlight into power. Section II described the experimental setup and modeling technique, as well as the selection criteria for the piezoelectric array configuration, the AC-DC harvesting circuit, and the solar panel. Additionally, it described the integration of Blynk apps for controlling and monitoring the energy harvesting output performance. Section III provided a detailed analysis of the results and discussions, including the performance and efficiency of the system. Finally, the research concluded with a summary of findings and discussed the implications in the concluding section.

II. METHODOLOGY

Figure 1 illustrates block diagram of renewable energy sources take center stage in this system, showcasing a combination of solar panels and footsteps contributing power to a DC-DC and AC-DC circuit. The energy generated from these sources is efficiently stored in a battery, guaranteeing a reliable and sustainable power supply. An Arduino Uno microcontroller plays a pivotal role in monitoring both the number of footsteps and voltage levels, with this data being displayed on an LCD screen for user convenience. Designed with portability in mind, the system incorporates a power bank for additional backup power. Furthermore, integration with the ESP32 and Blynk platform allows users to remotely access real-time data via a mobile app. This app not only presents information regarding step count and voltage but also sends notifications based on battery percentage, thereby ensuring efficient energy management and enhancing user engagement.

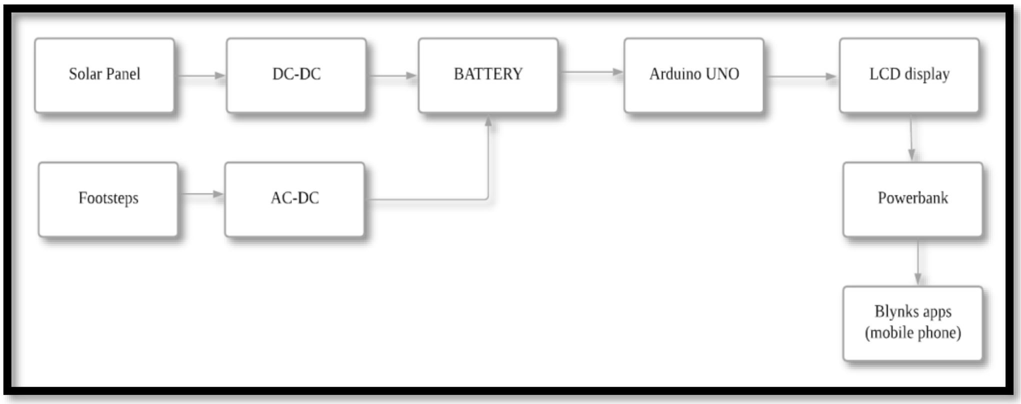

Figure 1: Block Diagram of Modelling the Smart Energy Harvesting System with Footsteps and Solar Panels

A. Equivalent Circuit of Piezoelectric Energy Harvester

The circuit connection has been simulated using the PSIM program, as illustrated in Figure 1, utilizing the provided connection layout and derived parameter values. This simulation involved the integration of a current source and capacitor to replicate the behavior of the piezoelectric equivalent circuit, as depicted in Figure 2. Through this simulation process, the value of the current source was adjusted to achieve the desired output. In order to accurately model the piezoelectric system, the specifications of the 27 mm piezoelectric disc were utilized. These specifications provided crucial information regarding the capacitance, resonant frequency, and resonant impedance of the piezoelectric element. By incorporating these values into the simulation, a more precise representation of the system's behavior was achieved, enabling a thorough analysis of its performance characteristics.

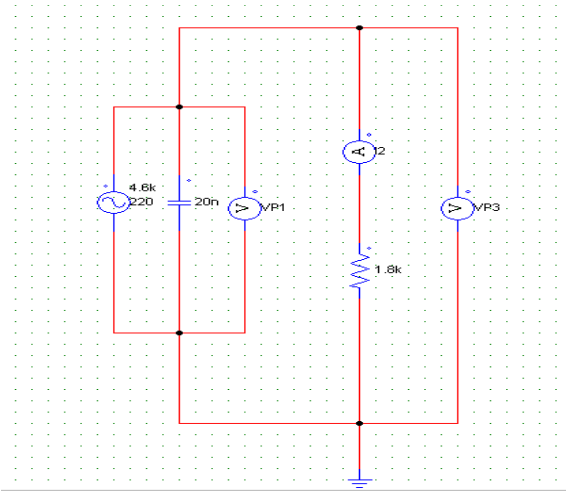

Figure 2: Single Piezoelectric Equivalent Circuit using PSIM

B. Piezoelectric Circuit into Series Array Configurations

In a series array setup, the effect of output voltage, current, and power is investigated by incorporating a current source, capacitor, and resistor combination to represent a single piezoelectric element connected in series. This configuration allows for a comprehensive analysis of the behavior of the piezoelectric system under varying conditions. This simulation provides valuable insights into the performance of the series-connected piezoelectric elements. Figure 3 illustrates the connection of five piezoelectric transducers in series, enabling a comparative analysis of the output characteristics with respect to a single piezoelectric element. This examination sheds light on how the output differs when multiple piezoelectric elements are connected in series. Moreover, eight circuits featuring piezoelectric equivalents are constructed to facilitate a comparison among different array topologies. These circuits allow for a thorough evaluation of the effectiveness of various array configurations in achieving desired output characteristics. To further explore the capabilities of series array design, a total of 32 piezoelectric transducers are simulated in Figure 4 to determine the maximum number of piezoelectric equivalent circuits that can be created in series. This analysis provides valuable insights into the scalability and performance limitations of series-connected piezoelectric arrays.

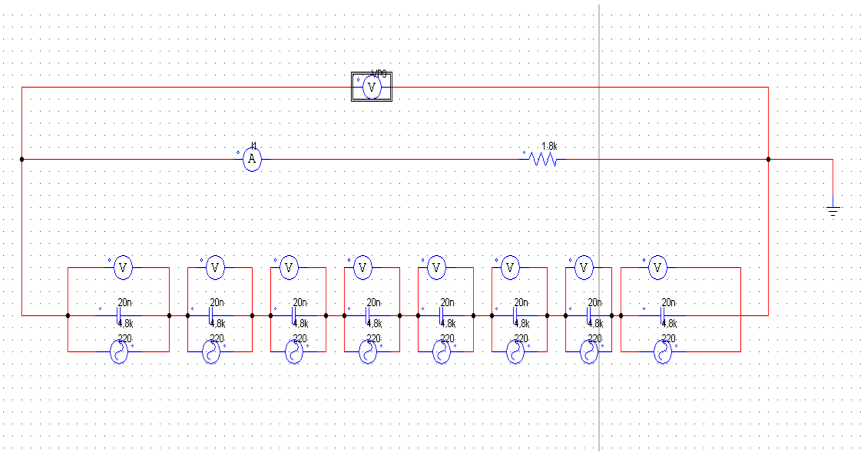

Figure 3: Series Array Configuration of 8 Piezoelectric using PSIM Software

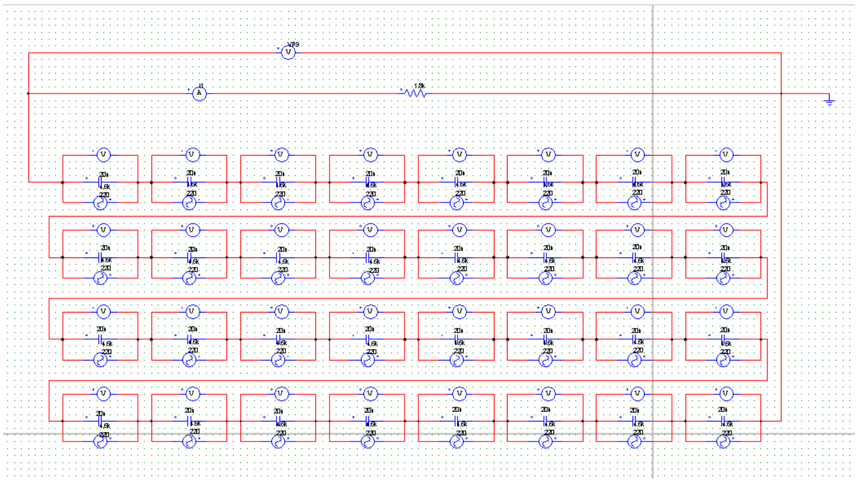

Figure 4: Series Array Configuration of 32 Piezoelectric using PSIM Software

C. Piezoelectric Circuit into Parallel Array Configurations

A single piezoelectric equivalent circuit is constructed by serially connecting a current source, capacitor, and resistor to evaluate the impact of output voltage, current, and power in a parallel array design. This setup enables a comprehensive examination of the behavior of the piezoelectric system under various conditions. To analyze the output characteristics in comparison to a standalone piezoelectric element, a total of eight piezoelectric transducers were initially simulated. Figure 5 illustrates the arrangement of these eight parallel-coupled piezoelectric, providing insights into how the output differs from that of a single piezoelectric element. This investigation aids in understanding the collective behavior of multiple piezoelectric elements in a parallel configuration.

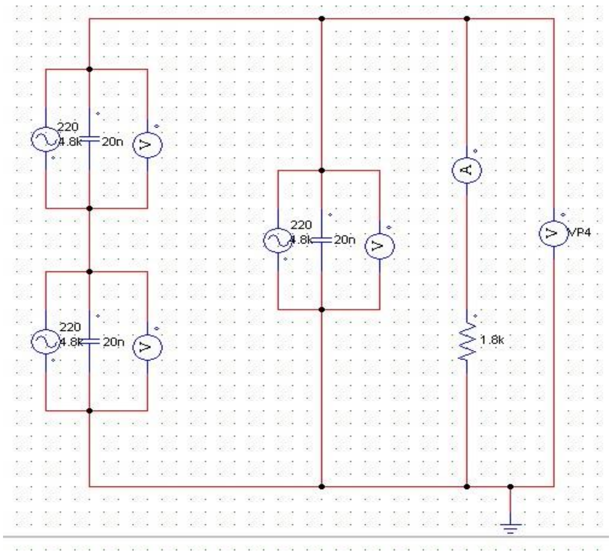

Figure 5: 2S1P Array Configuration of Piezoelectric Equivalent Circuit using PSIM

D. Piezoelectric Circuit into Parallel-Series Array Configurations

The arrangement of the current source, capacitor, and resistor, collectively representing a single piezoelectric element, has been configured in a two parallel and one series (2P1S) arrangement to explore the effects on output voltage, current, and power in a parallel series array layout. This configuration enables a detailed investigation into the behavior of the piezoelectric system when multiple elements are connected in both parallel and series configurations. The PSIM simulation of the series-parallel circuit combination is depicted in Figure 6, showcasing the layout and connections of the 2P1S configuration. This simulation provides valuable insights into the performance characteristics of the series-parallel arrangement, including output voltage, current distribution, and power consumption. Furthermore, the 2P1S configuration serves as the model for the circuit design in the three parallel two series (3P2S) arrangement. By extending the 2P1S layout, the 3P2S configuration enables the exploration of more complex array topologies and their impact on output characteristics. This comparative analysis allows for a comprehensive understanding of the trade-offs and advantages associated with different series-parallel array layouts in piezoelectric systems.

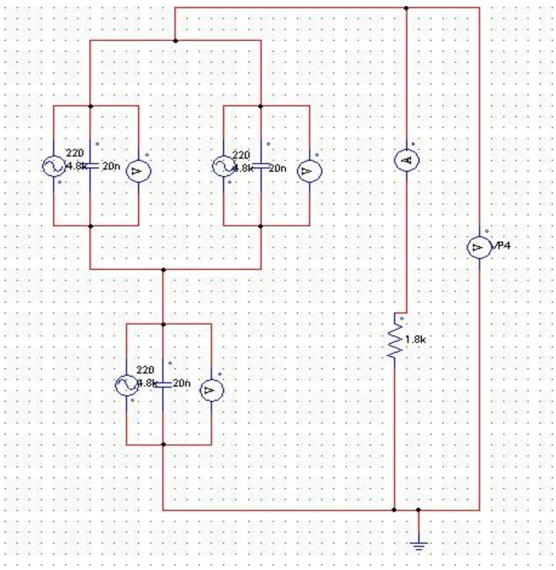

Figure 6: 2P1S Array Configuration of Piezoelectric Equivalent Circuit using PSIM

E. Battery Charger Circuit with Solar Panel

Sunlight is harnessed by the solar panel, where it undergoes transformation into direct current (DC) electrical energy. The efficiency and performance of the solar panel, influenced by various parameters such as its surface area, efficiency rating, and the intensity of sunlight, directly impact the output voltage generated. To regulate the charging process effectively, a charge controller is integrated into the system, directly connected to the solar panel. This charge controller plays a crucial role in managing the charging process by monitoring the level of charge in the battery. It dynamically adjusts the charging voltage and current to ensure optimal charging conditions, preventing both undercharging and overcharging scenarios. Figure 7 illustrates the schematic connection of the battery charger circuit utilizing solar energy, designed using Proteus software. This circuit layout showcases the integration of the solar panel, charge controller, and battery, illustrating how these components are interconnected to facilitate efficient energy conversion and battery charging. Through this design, the circuit ensures the safe and reliable charging of the battery, safeguarding against overcharging and optimizing the utilization of solar energy resources.

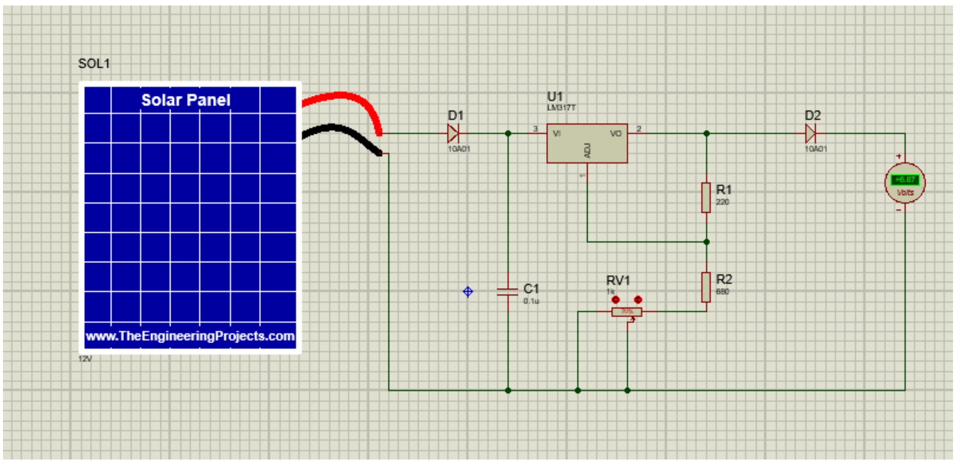

Figure 7: Battery Charger Circuit using Solar

F. AC-DC Energy Harvesting Circuit

The AC-DC converter circuit, also known as a rectifier circuit, plays a crucial role in converting the alternating current (AC) into a direct current (DC) supply. This conversion process is essential for various electronic devices and systems that require DC power for operation. The AC power source serves as the input, providing an alternating voltage to the rectifier circuit. The rectifier circuit, typically comprising diodes, transforms the AC input voltage into a pulsating DC voltage. During the positive half-cycle of the AC input, the diodes conduct, allowing current to flow through the load and charge the capacitor. Conversely, during the negative half-cycle, the diodes block the current flow. A capacitor connected in parallel to the rectifier output assists in smoothing out the pulsating DC voltage. This capacitor stores and releases energy during each half-cycle, reducing the ripple and providing a more constant DC voltage. By minimizing voltage fluctuations, the capacitor ensures a stable and reliable power supply to the load. Figure 8 depicts the connection of the Dickson energy harvesting circuit, while Figure 9 illustrates the Villard energy harvesting circuit connection. These energy harvesting circuits utilize rectification principles to convert AC voltage variations into usable DC power, enabling efficient energy harvesting from ambient sources for various applications.

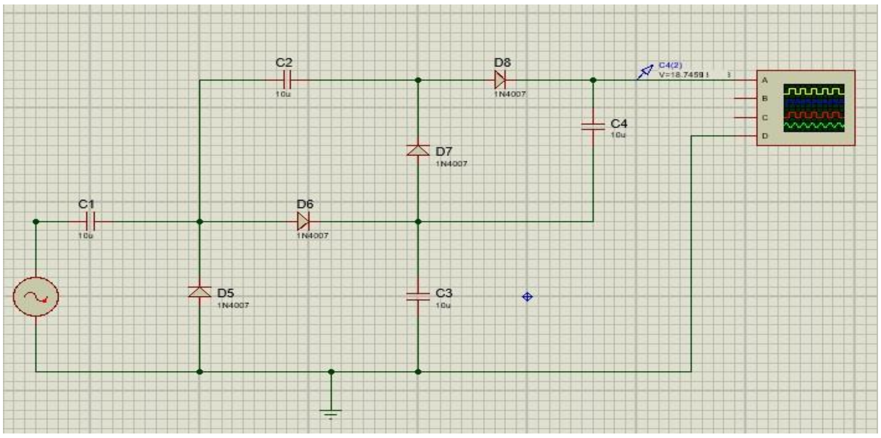

Figure 8: Dickson Energy Harvesting Circuit

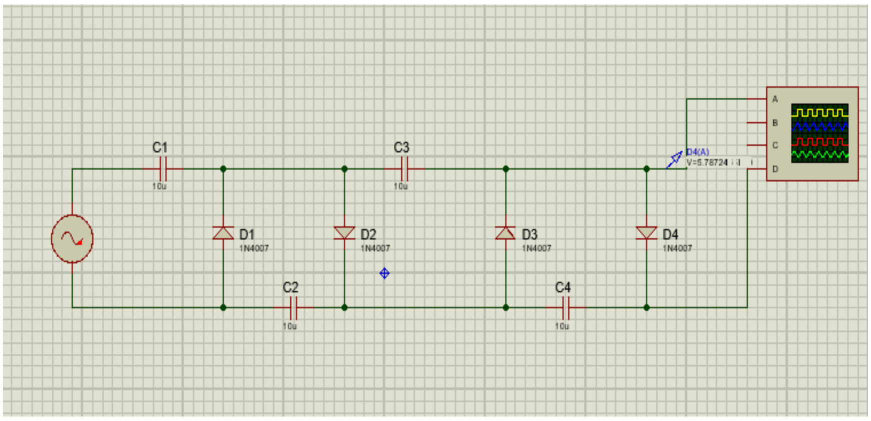

Figure 9: Villard Energy Harvesting Circuit

G. Piezoelectric Equivalent Circuit Setup

In the simulation of the piezoelectric equivalent circuit, several values must be taken into account for constructing the simulation circuit. Firstly, the load resistance (R_L) values have been determined using equation (1), which incorporates the resonant frequency (f) and the capacitance (C) at the resonant frequency.

$$R_L = \frac{1}{2\pi f c} \quad (1)$$

After obtaining the output voltage and current, the output power (P) is calculated using equation (2). This equation involves multiplying the output voltage and current together to obtain the output power.

$$P = IV \tag{2}$$

H. Establishing a Circuit Connection Between Arduino and LCD

To establish a functional link between an LCD display and an Arduino microcontroller, it is imperative to establish both physical and electrical connections as shown in Figure 10. This entails connecting power, ground, and data lines, which typically vary based on the specific type of LCD display (character or graphic) and the chosen interface. These connections form the foundation for enabling seamless communication between the Arduino and the LCD display, ensuring proper functionality and integration within the overall system.

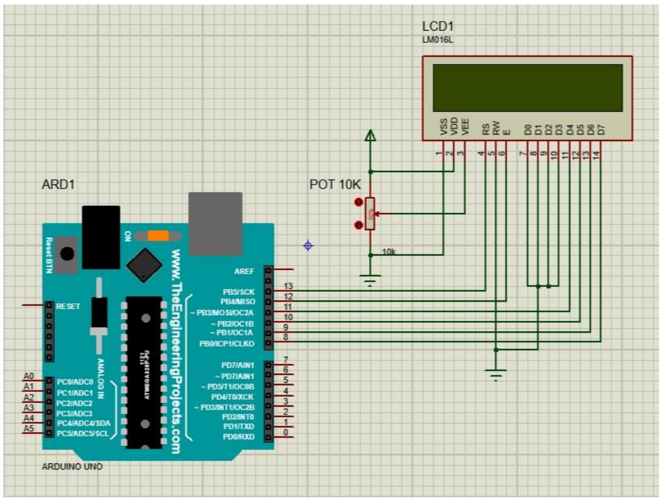

Figure 10: Arduino to LCD connection

I. Experimental Integration of the Blynk Application with ESP32 Development Board for IoT

The utilization of the Blynk application in conjunction with the ESP32 development board for facilitating IoT (Internet of Things) as presented in Figure 11. This section elucidates the seamless integration and operation of the Blynk app, a versatile mobile application designed for IoT control and monitoring, with the ESP32, a powerful microcontroller widely employed in IoT applications. Through an in-depth exploration, we unveil the intricacies of setting up and configuring the Blynk app to communicate effectively with the ESP32, enabling users to remotely control and monitor IoT devices and projects with ease and efficiency.

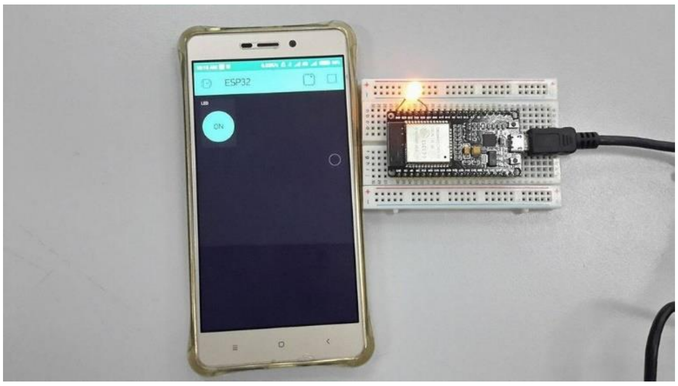

Figure 11: Blynk app with ESP 32

III. RESULT AND DISCUSSIONS

A. Simulation Results of a Single Piezoeletric Equivalnet Circuit

The simulation results obtained from a single piezoelectric equivalent circuit. This analysis provides insights into the behavior and performance of the circuit under various conditions. Through detailed examination of the simulation outcomes, the aim is to illuminate the electrical characteristics and response of the piezoelectric device, shedding light on its suitability for specific applications. These results provide valuable data points for further analysis and optimization of piezoelectric systems in diverse engineering and technological domains. A voltage probe, aligned parallel to the calculated load resistance (Rload) of 1.8 kΩ, as determined by the derivation of equation (1), is employed to measure the output voltage. This probe is strategically positioned to ascertain the voltage differential between the respective nodes. Furthermore, a current probe is affixed to the Rload within an open circuit configuration to gauge the current traversing through it. The sinewave output generated by the piezoelectric equivalent circuit is visually depicted in Figure 12, illustrating the alternating current nature of the output waveform.

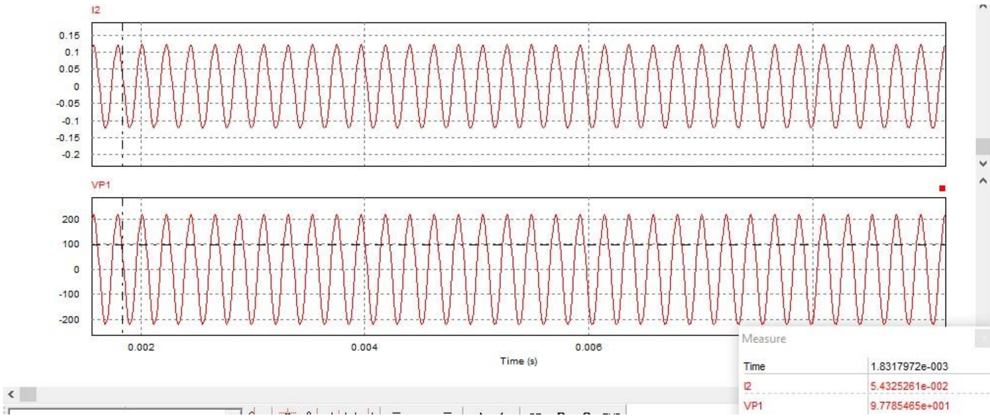

Figure 12: Output Result of the Single Piezoelectric Equivalent Circuit

B. Simulation Performance of 8 Piezoelectirc Equivalnet circuit and Difference Array Configurations

Piezoelectric equivalent circuit arrays can be configured in series or parallel. This examination dives into the arrangement of piezoelectric elements within different arrangements, examining their electrical properties and performance. The goal of investigating the behavior of piezoelectric circuits in series and parallel arrangements is to acquire insight into their applicability for various applications as well as their impact on overall system performance. These discoveries add to a better understanding of piezoelectric systems and help optimize their design for a variety of engineering and technology applications. The overall performance and electrical properties of the piezoelectric device are heavily impacted by its array configuration. Different configurations, such as series and parallel connections, have varying effects on its behaviour. For example, while series connections can increase voltage output, they may also reduce current output. In contrast, parallel connections have the reverse effect, potentially increasing current output while decreasing voltage output. Understanding these distinctions is critical for refining the design of piezoelectric systems to meet specific application needs. The 8-element equivalent circuit model is a standard way for approximating a piezoelectric transducer's electrical activity. This model provides a complete depiction of the transducer's electrical properties, allowing engineers to properly estimate its performance under various scenarios.

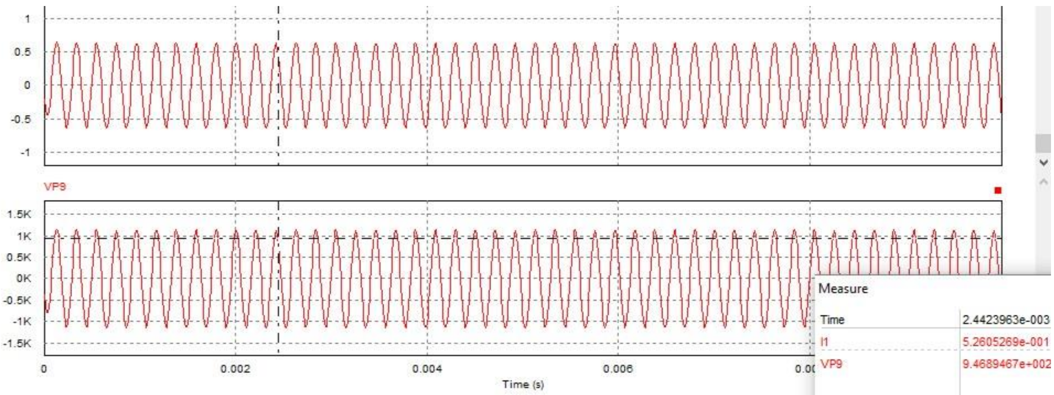

Figure 13: Output Performance of 8 Piezoelectric Equivalent Circuit Arranged in series array configuration

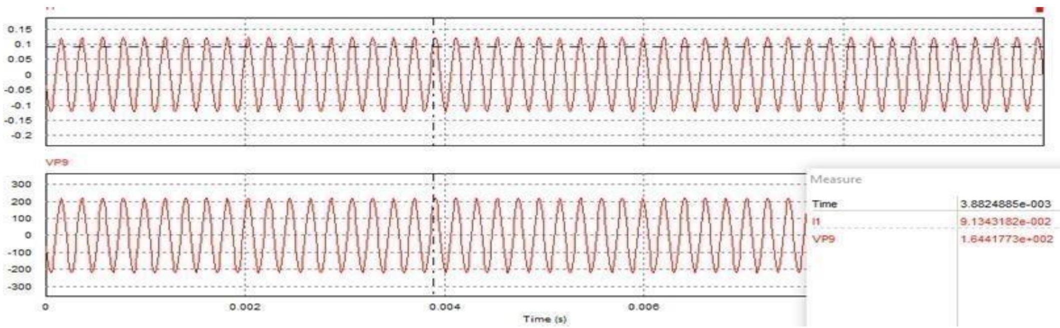

Figure 14: Output Performance of 8 Piezoelectric Equivalent Circuit Arranged in Parallel Array Configuration

C. Simulation performance of 32 Piezoelectirc Equivalnet circuit and Difference Array Configurations

When designing and analyzing a system comprising 32 piezoelectric components using an equivalent circuit and various array configurations, it's imperative to consider both electrical and mechanical interactions within the array. Expanding the original 8-element circuit to a 32-element equivalent circuit by adding components for each piezoelectric element enables a more comprehensive analysis. Incorporating components for each piezoelectric element facilitates a detailed examination of the system's behavior, accounting for nuances in electrical and mechanical interactions. This expanded circuit model allows for a thorough assessment of how different array configurations affect the system's performance, considering factors such as series and parallel connections. Figures 15 and 16 illustrate the output performance of the piezoelectric in series and array configurations circuit, emphasizing that the final outcome is an alternating current.

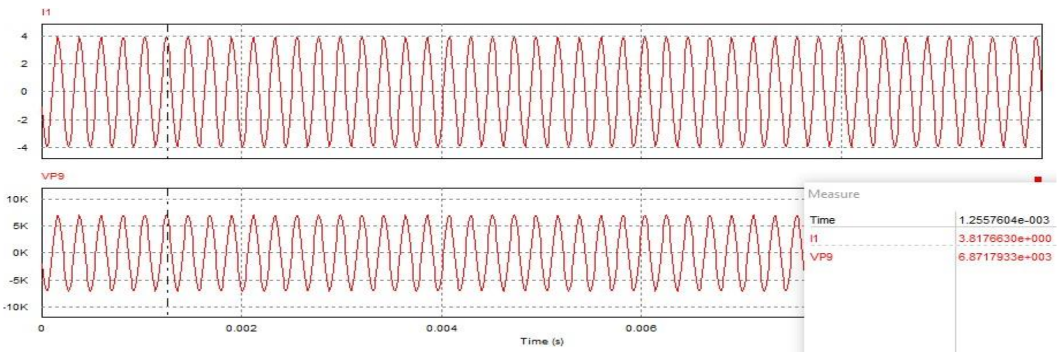

Figure 15: Output Performance of 32 Piezoelectric Equivalent Circuit Arranged in series array configuration

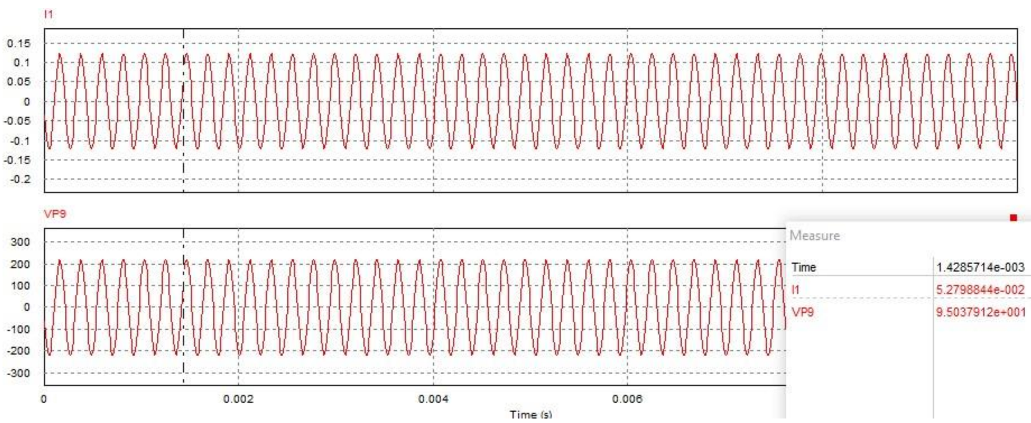

Figure 16: Output Performance of 32 Piezoelectric Equivalent Circuit Arranged in parallel Array Configuration

D. Analyzing the Relationship Between Piezoelectric Parallel-Series Equivalent Circuit and Simulation Performance Across Various Array Configurations

In conjunction with the examination of the relationship between the piezoelectric parallel-series equivalent circuit and simulation performance across different array configurations, it is crucial to consider the actual electrical output of the system. Figures 17 and 18 provide output performance generated by the piezoelectric equivalent circuit, clearly indicating that the resulting output manifests as alternating current. This characterization of the output waveform offers valuable insights into the electrical behavior of the system, complementing the analysis of simulation performance across varied array configurations. Additionally, Table 1 presents a comprehensive summary of the overall output voltage, current, and power for different array configurations. By consolidating this data alongside the simulation results and waveform analyses, a holistic understanding of the system's performance can be achieved. This integrated approach facilitates informed decision-making regarding the optimization of piezoelectric systems for diverse engineering applications, taking into account both electrical characteristics and array configurations.

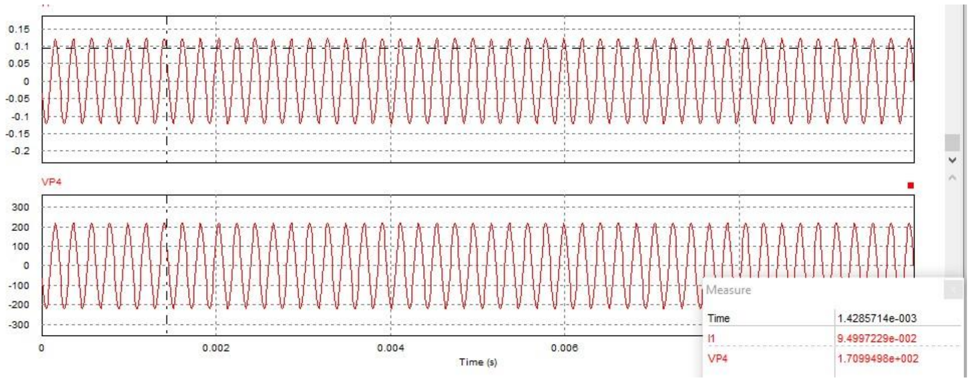

Figure 17: Output Performance of Piezoelectric Equivalent Circuit Arranged in 2S1P Array Configuration

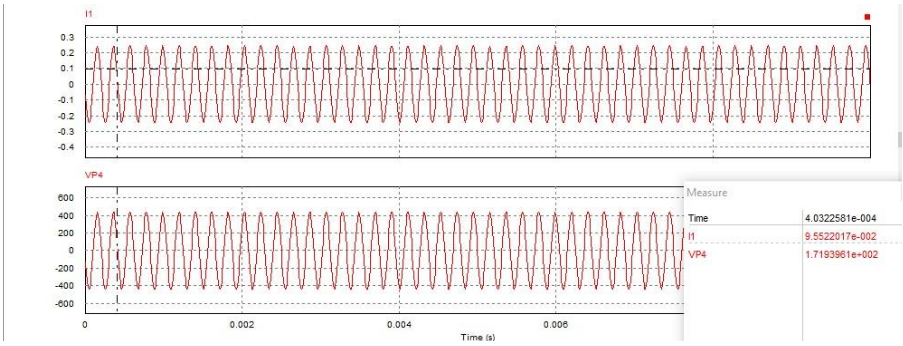

Figure 18: Output Performance of Piezoelectric Equivalent Circuit Arranged in 2P1S Array Configuration

Table 1: Overall Output Voltage and Current in differences Array Configurations

	Voltage Output (V)	Current Output (mA)	Power Output (mW)
Series array configuration of 8 piezoelectric	9.47	5.26	49.81
Series array configuration of 32 piezoelectric	6.87	3.81	26.17
Parallel array configuration of 8 piezoelectric	1.64	9.33	15.30
Parallel array configuration of 32 piezoelectric	9.50	5.27	50.07
2S1P array configuration of piezoelectric	1.71	9.50	16.25
2P1S array configuration of piezoelectric	1.71	9.55	16.33

E. Analysis of Input and Output Voltage Results for AC-DC Harvesting Circuit and Solar Charger circuit

This analysis offers insights into the performance of the circuit in converting alternating current (AC) input to direct current (DC) output, which is crucial for harvesting energy from piezoelectric elements. By examining the input and output voltage characteristics, the goal is to evaluate the efficiency and effectiveness of the harvesting circuit in capturing and utilizing piezoelectric energy. The input voltage for both circuits was simulated using Proteus. A sinusoidal waveform was utilized, and the input source was configured in AC mode. From the waveform analysis, the amplitude was determined to be 5 V at a frequency of 1 Hz. Based on the experimental findings presented in Table 2, a solar-powered battery charger has been developed with a primary focus on efficiency and eco-friendliness, promoting sustainable charging practices. This innovative device optimizes energy absorption by leveraging solar power through its 19 V solar input. The outcome is a consistent and environmentally conscious 6 V output, capable of charging batteries and an array of electronic devices. This solar charger not only reduces overall carbon emissions but also ensures a reliable power supply for various scenarios, including emergencies, outdoor activities, and mobile usage. When considering specific energy harvesting requirements, selecting the Villard harvesting circuit over the Dickson harvesting circuit necessitates careful deliberation. This Villard and Dickson circuit is particularly beneficial in scenarios where a modest level of voltage multiplication suffices to meet the desired objectives. In contrast, applications demanding greater scalability and higher voltage multiplication are better suited for the Dickson harvesting circuit. Its cascading design enables it to handle higher voltage levels effectively, making it suitable for precise energy harvesting needs. Ultimately, the decision between the Dickson and Villard harvesting circuits hinges on project-specific considerations, taking into account factors such as voltage scalability, cost-effectiveness, and circuit complexity. In this particular project, based on the insights gleaned from Table 2, the Villard harvesting circuit has been chosen, aligning with the project's objectives and requirements, which could potentially produce a higher voltage of 15.81 V.

Table 2: Overall Input Voltage and Output Voltage for Input Source

	Input Voltage (V)	Output Voltage (V)
Battery charger circuit using solar	21.2	6.87
Dickson Harvesting circuit	5	20.74
Villard Harvesting circuit	5	15.81

F. Analysis Experinental Performance of Piezoelectric in Series Connection

The trend observed in Table 3 illustrates the behavior of a series circuit design incorporating a variable number of pressed piezoelectric components. Each entry in the Table 3 demonstrates an increase in voltage output proportionate to the number of pressed piezoelectric elements. This phenomenon aligns with the characteristics of piezoelectric series arrangements. In series configurations of piezoelectric elements, the voltages across each component combine to produce a cumulative effect. As the number of piezoelectric devices in the series circuit increases, the total voltage across all elements simultaneously rises. This additive nature of voltages in series circuits is commonly associated with this behavior, where the total voltage is the sum of individual voltage contributions from each piezoelectric element. Consequently, by increasing the number of pressed piezoelectric elements, there is a corresponding increase in the number of voltage contributions, leading to a higher overall voltage output. It is worth highlighting that this behavior carries practical implications in applications where higher voltages are desirable. The output of the piezoelectric series circuit is depicted in Table 3. When a single piezoelectric element is squeezed, the output registers at 3.00 V with a current of 3.002 mA. However, upon simultaneous pressing of multiple piezoelectric elements, such as piezo 10, the voltage and current escalate to 3.91 V and 3.909 mA, respectively.

Table 3: Experimental result of piezoelectric in series connection

Piezoelectric	Current (mA)	Voltage (V)
1	3.002	3.00
2	3.088	3.09

3	3.321	3.32
4	3.519	3.52
5	3.643	3.64
6	3.730	3.73
7	3.793	3.79
8	3.841	3.84
9	3.841	3.88
10	3.909	3.91

G. Experimental Results of Piezoelectric Circuit: Assessing Variations in Human Step Performance

The experiment involves randomly selecting 5 individuals, with weight being the sole criterion for selection. This indicates that the weight of these individuals is a crucial variable under scrutiny in the experiment. To assess the impact of various weights on voltage output, a diverse range of weights has been incorporated into the experiment. The objective is to thoroughly analyze and comprehend the relationship between the weight of subjects and the voltage produced during their step. By employing individuals with varying weights, the experiment seeks to uncover any discernible patterns or correlations between weight and voltage output. This systematic approach contributes significantly to a more comprehensive understanding of the phenomenon under investigation. The primary objective of this experiment is to quantify the electrical output of a piezoelectric material when exposed to varying mechanical loads, specifically the weight applied by individuals. The focus lies in gaining insight into how different weights influence the voltage generated by the piezoelectric material. In Table 4, it is illustrated that when a person walks or steps on a surface containing piezoelectric materials, the mechanical force exerted by the foot applies stress to the piezoelectric elements. This stress induces a charge separation within the material, leading to the generation of electrical voltage.

Table 4: Performance of Piezoelectric and difference of human weight steps

No	Weight, (kg)	Voltage, (V)
1.	45	6.28
2.	50	6.99
3.	55	7.09
4.	60	7.68
5.	66	7.89

H. Experimental Results in Blynk Applications

The value display widget in the Blynk app in Figure 19 dynamically presents the current battery percentage of the power bank storage. This connectivity enables customers to conveniently monitor their power bank's condition from a distance using the Blynk platform.

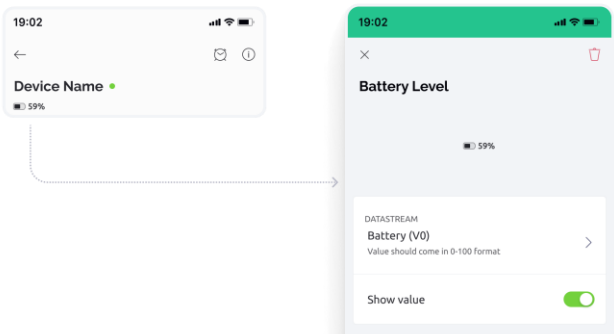

Figure 19: Blynk display battery percentage from power charger during charging

IV. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the goal of research on solar panels and footsteps for smart energy harvesting is to create a system that can mix energy from these sources to power a variety of applications. The primary components of this project are a solar panel array and footstep energy harvesting, which together use energy harvesting to gather and transform ambient energy into useful electrical energy. The mechanical energy of human footfall is converted into electrical power by the footstep energy harvesting system. Furthermore, a simulation with the same resonant frequency has been used to analyze the piezoelectric equivalent circuit in a number of configurations. The goal of this investigation was to ascertain the highest possible output voltage, current, and power. The best output might be obtained with a parallel array architecture, according to the results. In order to improve energy harvesting efficiency, further work on the project will involve investigating various piezoelectric materials and doing additional optimization of the circuit designs that are similar to them. According to the study's experimental findings, a piezoelectric transducer with solar panels that can create 6.87 V may be used as a green energy harvester from human footsteps if it is connected in parallel to produce the most electrical energy. Two to ten pieces of piezoelectric transducers connected in series can produce AC output pulses with an average voltage of 7.89 V and a range of 3.09 V to 3.90 V, with an average of 7.89 V when pressed by a human weighing 66 kg walking in place.

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