Intelligent Energy Harvesting and Magnet Induction for Mobile Phone Charging

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Abstract*—In this paper, we introduce an innovative piezoelectric material designed for efficient energy harvesting and charging of mobile phone batteries. This system offers intelligent control of the power generated from external excitation. A novel alloy has been built with advanced properties such as transparency and flexibility. The chemical composition contains mostly SiO2, ZnO, and Pb(C2H3O2)2. Thereon, the result is an efficient piezoelectric material that permits to harvest as possible the energy due to the applied mechanical force. Furthermore, the system incorporates an appropriate rectifier and amplifier circuit to efficiently store the harvested energy in a mobile phone battery. Additionally, the system is boosted with a magnet induction to ensure a powerful energy source. The proposed hybrid system effectively meets the charging requirements of mobile phone batteries. To validate the functionality of the system, we integrated it into a sample shoe, connected it to a phone battery, and conducted real-time measurements in parallel. The system demonstrated satisfactory performance and met the required specifications. This study highlights the adaptability of our innovative system to various phone battery models, showcasing its high efficiency and potential as a promising alternative for mobile phone charging.

Keywords—***Piezoelectric material; magnet Induction; Energy harvesting; Mobile phone charger.***

I. INTRODUCTION

Mobile phones have become an integral part of modern life that are serving as our constant companions in an increasingly connected world. These compact devices, packed with features and applications have revolutionized the way in which we communicate and entertain ourselves. Yet, behind the sleek screens and powerful processors lies a critical component that powers our mobile phones and makes their portability possible which are the advanced batteries. As mobile phones continue to evolve and become even more integral to our daily lives, the demand for better and more efficient battery let the technology always on the move [1]. However, the factors that impact the quality of these batteries and energy resources pose a significant challenge to their advancement. Thereby, many factors such as energy density, lifespan, environmental sustainability, and charging efficiency are paramount in determining the quality and effectiveness of batteries for mobile phones and automobiles [2, 3]. In addition, the adopted materials to supply these technologies must meet the latest performances requirements and integrating the newest intelligent alloys. As modeling for piezoelectric energy harvesting, it is crucial that the model exploits all piezoelectric effects. Therefore, it is required that it shows both direct and reverse interaction between the electrical and mechanical effects [4]. Furthermore, the model should behave as a piezoelectric transducer that presents an effective electrical circuit [5]. Therefore, to optimize the behavior, it is privileged to adopt an electromechanical model [6]. The famous piezoelectric functioning modes are transverse mode, longitudinal mode and piezotronics model [7, 8]. A given piezoelectric transducer contains several layers of piezoelectric especially elastic, conducting and insulating materials. The working mode is based on a transducer with several piezoelectric thin film connected in parallel. However, the mechanical connection is serial, layered upon each other. Moreover, thanks to the combination of thin films, the total displacement of the piezoelectric transducer is the product between the total number of films and the movement of each film [9]. For the case of longitudinal mode, the most used transducers are cymbal, unimorph and bimorph. In this mode, piezoelectric thin films are fixed upon a supporting structure and placed between layers that play electrodes roles. Then, when an electric field is applied in a vertical direction a stress strain is generated along the horizontal direction. The last functioning mode is piezotronic which is a result of discovering ZnO nano wires with n-type conductivity [10]. In this working mode, especially under an applied piezoelectric potential we observe the formation of Schokley barrier between the piezoelectric nanowire and the electrode that controls the electron flow.

Thereon, we implement in this work smart samples of materials precisely SiO2, ZnO and $Pb(C_2H_3O_2)_2$ to build an innovative piezoelectric transducer. Above that, to boost our system we integrate a magnet induction based on Neodymium material (Nd). Indeed, this hybrid system permits to a given mobile phone battery to be charged. Hence, the performance of this intelligent system depends on a piezoelectric material quality and efficiency of implemented magnet induction. However, due to the variety of battery brands, we intend to ensure compatibility of charging with majority of models. The majority of batteries require as minimum input the current intensity around 1.2mA and a voltage at order 3.7V as power requirements. Moreover, traditional chargers are typically designed for domestic use or inside a car to provide a consistent charging. This work is an alternative among other developed methods where the goal is to establish an intelligent energy resource for smart applications such as phone battery charging and miniaturized smart devices [11- 17]. The system circuit comprises various essential parts precisely the rectifier and the amplifier before storing the harvested energy in a battery. The charging process performance is depending on the battery model and the developed system enhances the quality of charging state efficiency. Mainly, the system scheme highlights three essentials parts: hybrid energy source, rectifier and amplifier. The integration of both the piezoelectric effect and magnet induction is a pivotal factor that significantly boosts the system's power generation capacity and ensure a high-quality charging. It is mandatory to verify the output power characteristics under different external excitation [18]. In this context, we take the measurement in real time to predict adequate system model. The results obtained are particularly meaningful as they required computational analysis to account for the intricacies of the hybrid energy source. The proposed model and autonomous approach permit to enhance the efficiency of mobile phone charging whatever the ambient conditions. The objective is to develop a charger that is susceptible to be installed in human parts such as shoes to generate energy from induced vibration [19]. Consequently, the system presents innovation thanks to newest energy resource and the optimization of charging process. Finally, the use of an autonomous and smart battery charger is a challenge due increasing of intelligent devices and wide exploitation of newest materials. As result, many possibilities are encountered such as integration of these energy systems in advanced generators. However, the majority of systems require a voltage source converter, amplifier and stabilizer to obtain adequate output power [20]. Referring to the piezoelectric effect [21], a voltage signal is generated from an accumulation charges on both sides of the conductor material plates. Therefore, numerous researches are investigating models to control the generation, conversion and transmission of energy. Above that, to enhance advanced energy system we implement an hybrid system that permits to harvest the energy efficiently before feeding the goal device [22]. More specifically, the choice of a suitable voltage source converter [23] is leading to an efficient system that exploits successfully applied pulses on the piezoelectric transducer. The harvested voltage is then rectified and amplified before being stored in a battery [24]. In addition, some researches are looking for wireless charging solutions. The prototype schematic is based on a diode bridge, to avoid the reverse current, and capacitors to ensure filtering process and stabilization. Above that, we adopt amplifier circuit using a bipolar transistor to get required energy and a sufficient current intensity. The function of the system is to grab the energy from developed piezoelectric sensor then amplify the power and ensure the loading of a mobile phone battery. The proposed system has been developed through numerous iterations especially power amplification. The process starts from applied pulses on the developed piezoelectric transducer and concludes with the charging of the goal battery.

The paper presents the study's design and functioning. Furthermore, we provide details on the construction and testing of the system. Finally, we conclude with a discussion of the results and the system's performance.

II. System design and functioning principle

The system is based on a piezoelectric sensor that requires the integration of various materials to enhance its quality by result the system performances. The schematic depicted by the Fig.1 illustrates the interconnexions for monitoring the harvested energy efficiently. The sensor under the external excitation generates the alternative signal which is converted in DC thank to the diode bridge. The system platform is equipped with many blocs to ensure efficient energy transmission. Additionally, the sensor built from adequate alloy to handle its sensitivity and reliability. To obtain enough power required for mobile phone battery charging we implement capacitors and amplifiers to stabilize and amplify the energy before transmitting into the goal battery. Moreover, the system is a combination of two-sensor energy source so this hybrid state enhances the accuracy and reliability of the concepted charger thank to its efficient power which is suitable for any phone battery model. As we take in consideration that the battery is installed on a phone so the system becomes autonomous thank to its ability to inform about state of charge at any moment. Thereon, the system allows to know the charging performance and it behaves to improve the charge process while the energy is being stored. Furthermore, this conception exploits two principles that are piezoelectric effect and magnet induction together. Thus, with a simple external excitation the generated energy is significant and efficient thank to its power to start the charging process. The system presents an alternative charger for smart devices as it is interacting due its ability to be installed and repaired easily. The measurements during the test on old Nokia model are verifying the functioning and its effectiveness. This valuable result is a great validation to enhance more the system quality and make it smart as possible. This section concerns the design components to harvest the energy from innovative piezoelectric material as we boost its efficiency with magnet induction. The system is based on an intelligent material alloy that plays the role of piezoelectric sensor from applied pulses. The generated power needs many operations to be handled. To reach this achievement we use basically these outlined components in the table Tab.1.

TABLE.I Components list.

Component	Description
Diode	1N4148 x (4)
Capacitor	C1= 100nF C2= 2200uF
R1	1KΩ
R2	470Ω
Displayer	LCD
T1 / Operational Amlifier	Transistor NPN / MC1458CD
Load (Battery)	3.7V/1.2A

The scheme that describes different blocs of our system are designed in the figure Fig.1.

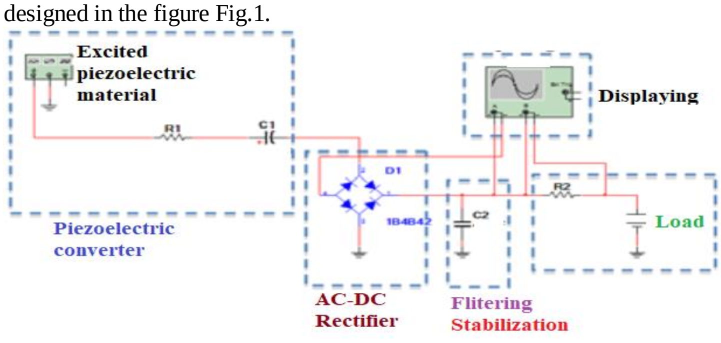

Figure 1. System main design.

The goal of the system circuit is to charge mobile phone battery thank to applied pulses on the piezoelectric material. The excitation is obtained from the motion or any forms of beats thereat we get a permanent stream of energy. However, the system should be provided with adequate components and auxiliaries blocs. Indeed, the produced energy depends on the quality of piezoelectric material and the capacitance of mobile phone battery that influence on the system performances. Moreover, a specific amplifier circuit using either a bipolar transistor or any suitable amplifier circuit to enhance the generated voltage from a piezoelectric material as depicted by the Fig.2.

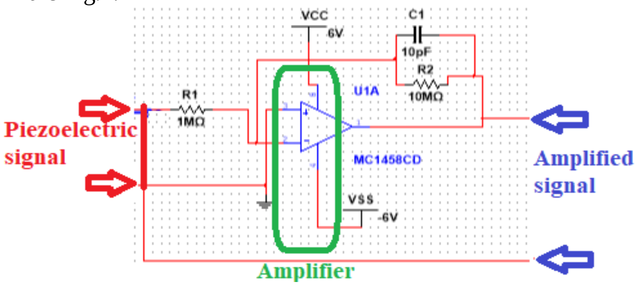

Figure 2. Amplification of generated signal.

III. Modeling and Simulation

To analyze the system circuit, an equivalent scheme is simulated using the Multisim software. The simulation process shows how the harvested voltage of the goal load is varying. Indeed, the charging operation should be fast as possible as it is mandatory to obtain desired current intensity and enough voltage tension. The rectifier bloc schematic is given by the Fig.3.

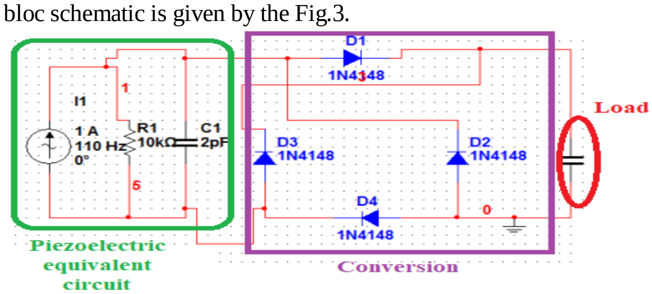

Figure 3. Piezoelectric signal rectifier using diode bridge.

The generated voltage from developed piezoelectric film is then amplified with as simple circuit schematic under Multisim software interface as depicted by the Fig.4.

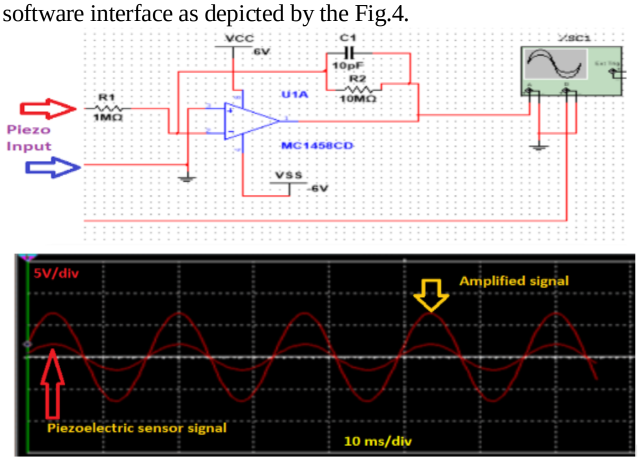

Figure 4. Amplification of the generated signal from piezoelectric film sensor.

The system model simulated under Matlab Simulink is shown in the Fig.5.

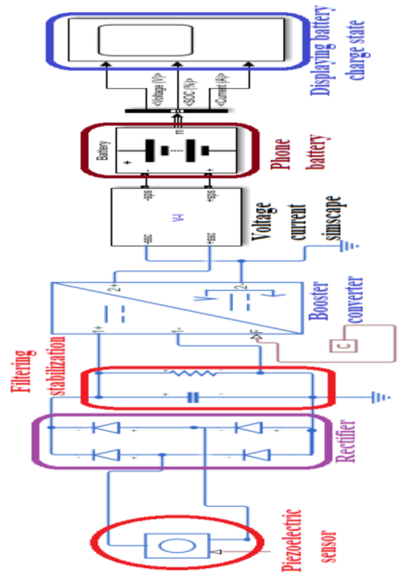

Figure 5. System model interconnexions in Simulink interface.

The most piezoelectric materials don't generate enough energy specially to charge a battery phone. To resolve this shortage, we adopt hybrid material to ensure an efficient generator as we handle it with induction bloc. Moreover, as the model describes we enhance the performance using auxiliaries' parts to obtain the required power for mobile phone battery charging. The piezoelectric effect is a mechanical process where the intensity of applied force is very significant to generate more charges by result a difference of potential. The simulation under Simulink describes the frequency of applied force. We note that the mass and the frequency are the privileged parameters on piezoelectric energy harvesting system as we see obviously in the Fig.6.

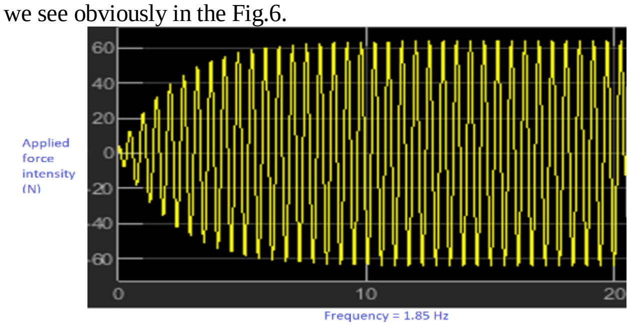

Figure 6. Simulation of applied force on developed piezoelectric sensor.

The generated voltage by a simple piezoelectric disc is given by the following equation Eq.1.

$$V = P.e.S \qquad \text{Eq.1}$$

Where,
P: Applied pressure (Pa).
e: Thickness (m).
S: Rating of piezoelectric material (%).

The battery charging process is given by various results precisely the charge voltage at order of 3.7V for the most batteries models and bands. However, this innovative piezoelectric transducer requires intermediate capacitor with at least 4.5V. Moreover, the phone battery has three pins where two are feed pins and the third one to describe the state of charge. Thereon, thanks to an indicator circuit we follow the charging performances. Above that, a mobile phone battery requires an intensity of 1A as minimal value as it behaves as capacitor that interrupts the direct current flow when it is full charged.

IV. CONSTRUCTION AND DEVELOPMENT

In this section, we highlight the construction of the part that generates the energy from piezoelectric alloy SiO2, ZnO and $Pb(C_2H_3O_2)_2$. All components are being implemented with respect of the previously mentioned system blocs. More precisely, after integrating the innovated piezoelectric material we integrate a diode directly to avoid the reverse current that discharge the goal battery. To obtain an efficient system we need obtain enough voltage and current intensity at the output. Indeed, we need as the minimum a voltage of 3.7V and a current intensity at the order of 1A to establish a good power of battery charging so we optimize the model as much as possible to prevent any probable malfunctioning. The core of the system is an innovated piezoelectric material transducer built from alloy of Atlas region minerals. After many tests we confirm that it presents accepted performances that generate enough power while applying external mechanical effect or any similar conditional stress. The prototype of developed piezoelectric film is shown in the Fig.7.

Figure 7. Innovative piezoelectric transducer.

To validate the concepted piezoelectric sensor we have checked the charging process of different capacitors using a diode bridge as rectifier. The transmission power line is shown in the Fig.8.

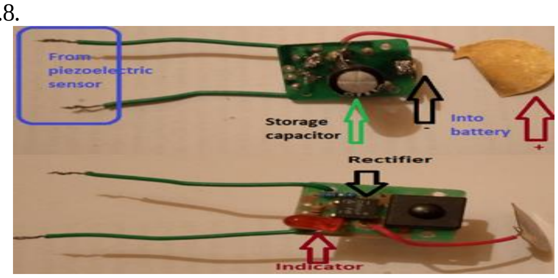

Figure 8. Conversion of the generated signal and capacitor charging test.

V. RESULTS AND DISCUSSIONS

The capacitance of mobile phone battery has a value between 2800mAh and 3000mAh. Thanks to the conversion 1mAh is an equivalent of 0.37uF so the main battery should ensure a capacitance around 111900uF as the minimum value. To answer this mandatory requirement, we adopt a matrix of capacitors where the characteristics are (47uF, 25V). Indeed, a matrix of capacitors connected in parallel is a good solution to get enough power for mobile phone battery charging. Thereon, we use a matrix of six rows and at least 200 columns to satisfy 3000mAh.

After many test, we confirm that each specimen of the developed piezoelectric transducer generates a current intensity varies between 20mA and 50 mA. Thereon, thanks to iteration of applied pulses the voltage of the goal capacitor reaches 11.2V depending on applied stress pressure [2.3KPa, 7.7KPa]. As result we generate easily an accumulation of 12.3mW for each applied pulse. We illustrate the single cell of the developed piezoelectric sensor by the following circuit depicted by the Fig.9.

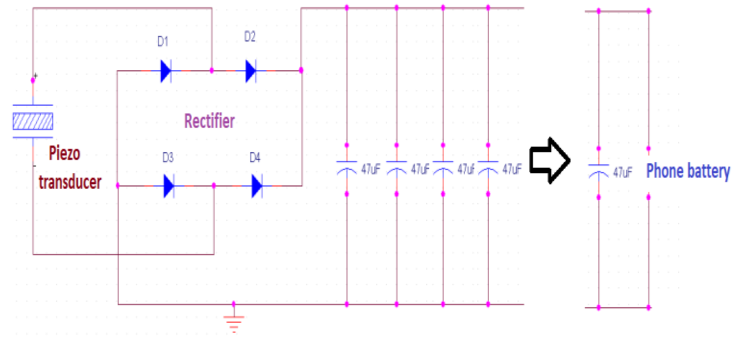

Figure 9. Adopted model for a single cell of piezoelectric transducer.

The main schematic to harvest the enough power require installation of many piezoelectric sensor as illustrated in the Fig.10. The adopted matrix is an efficient solution to feed small and portable devices thank to accumulation of generated energy from transducers as illustrated in the Fig.10.

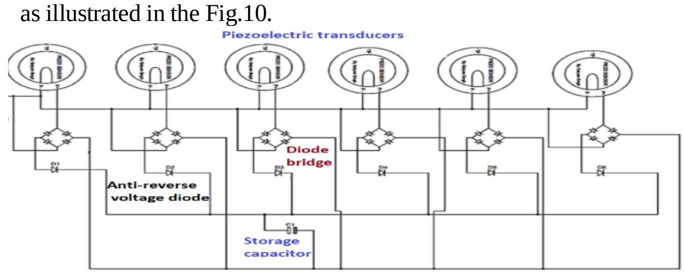

Figure 10.Matrix installation of a piezoelectric transducer.

The realized system is a matrix of many cores from the developed piezoelectric transducer film. To make the installation easy we profit from laptop keyboard where we replace each button with a piezoelectric sensor. We illustrate this process by the Fig.11.

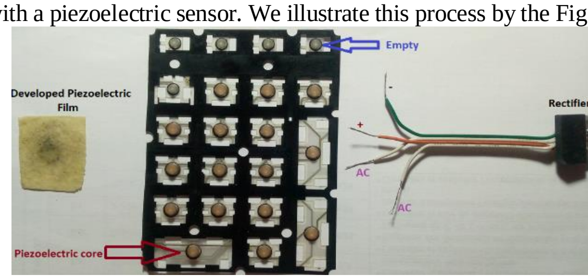

Figure 11. Piezoelectric cores matrix Installation.

Depending to the number of the connected cells in parallel we enhance the conservation of generated voltage but the current intensity is accumulated as sum of different intensities. Thereon, the charging process varies with this current intensity and the charged capacitance. The Tab.2 describe the evolution of charged electric quantity during time.

TABLE.II BATTERY CHARGE PERFORMANCES WITH TIME EFFECT.

ic(mA)	tc(h)	Qc(mAh)	C(uF)
300	2.8	854	315.98
400	2.1	814	301.18
500	1.5	775	286.75

Where,
ic: Charging current intensity.
tc: charging time.
Qc: Electric quantity.
C: Capacitance.

During the discharging process a similar behavior is observed as we illustrate by the Tab.3.

TABLE.III BATTERY DISCHARGE PERFORMANCES WITH ELAPSED TIME.

id(mA)	td(h)	Qd(mAh)	C(uF)
300	3	901	333.37
400	2.2	898	332.26
500	1.7	893	330.41

When the full matrix is installed an amplifier is able to be implemented basing on a simple bipolar transistor circuit to improve the output power especially the current intensity. Then the power is carried out in the battery to charge the goal battery. The amplifier circuit is shown in the Fig.12.

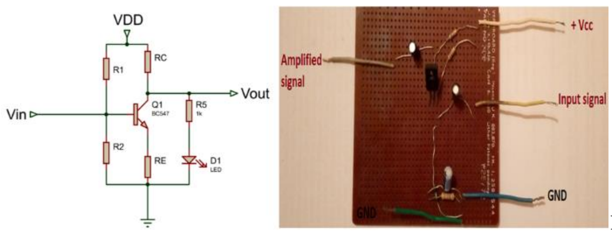

Figure 12. System amplifier circuit.

We notice that the charge time and obtained electric quantity are the main parameters that exhibit the system performances. Therefore, the generated voltage from the developed piezoelectric film is given by the equation Eq.2.

$$V = Q/C \qquad \text{Eq.2}$$

However, the sensitivity can be expressed by the Eq.3.

$$S = V/P \qquad \text{Eq.3}$$

Where, P is applied pressure and V is the generated voltage.

Moreover, the sensitivity is varying in function of thickness ratio of layers that constitute the pins plates of piezoelectric transducer as shown in the Fig.13.

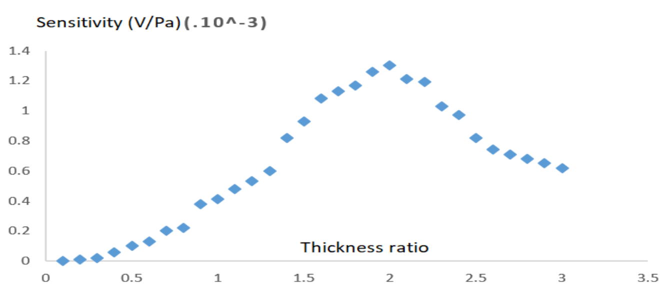

Figure 13.Sensitivity with different thickness ratio of piezoelectric material vs aluminum substrate.

The harvested charge at the output of the developed piezoelectric transducer is given in function of radius ratio by the curve of the Fig.14.

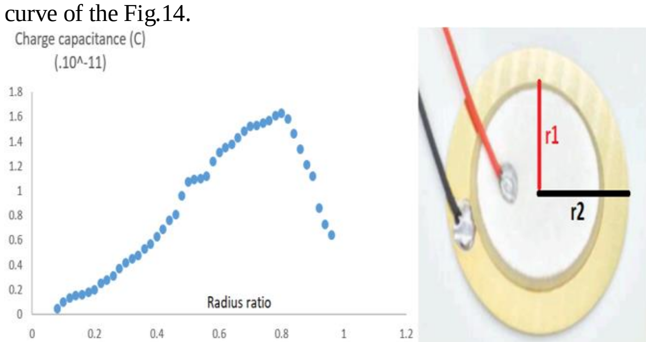

Figure 14. Harvested charge in function of radius ratio.

According to the previous results the built piezoelectric sensor with aluminum electrodes presents a good sensitivity and a competitive charge output. However, these performances are varying in function of thickness and radius ratio. The maximum of sensitivity is 0.00014 V/Pa for a thickness ratio equal to 2 while the charge reaches its maximum at a radius ratio 0.8. Thereon, we take in consideration the thickness and radius during the conception process of a piezoelectric transducer. Furthermore, the frequency response for the developed sensor is privileged for a medium frequency range but not stable for lowest and highest frequencies. As result the sensitivity is measured for the range in which it remains constant as possible. As experimental procedure, the variation of applied pressure generates a signal voltage which we measure at real time thank to the oscilloscope probe. We collect the measurement during pressure variation as resumed in the Tab.4.

TABLE.IV THE GENERATED VOLTAGE WITH APPLIED PRESSURE.

V(mV)	**Pa (Pa)**
285	1400
310	1600
345	1800

We note that the generated signal voltage is proportional to the applied pressure. Thereon, the dynamic pressure causes a given deflection to a piezoelectric material then a potential difference is detected and it is measured easily with an advanced oscilloscope. Above that the power performances are depending on the adopted frequency for our case the privileged is around 8Hz. Referring to measurement we note that the generated voltage is a linear equation of applied pressure where the constant depends on generated pulses frequency. The equation relation is given by the approximation in the Eq.4

$$V = 0.18P + 16.07 \qquad \text{Eq.4}$$

The sensitivity of the developed transducer depends on its charge capacitance where 60uF generates 1V as output voltage on the oscilloscope. The developed piezoelectric film connected to a capacitor with 47uF delivers a signal with an amplitude at order 0.78V. As result for each pulse with 1Kpa we generate a potential difference of 200mV so the sensitivity is at 200 (mV/KPa). Moreover, the sensitivity is improved by optimizing the transducer dimensions and the chemical composition. Above that, the sensor has under pulse a voltage fluctuation during 80ms. The standard piezoelectric sensor connected with a capacitance of 25.7pf, has a voltage sensitivity 36.2mV/kPa. The cadence of applied pulses on piezoelectric material has a huge influence on a battery charging response. The prototype is given by the Fig.15.

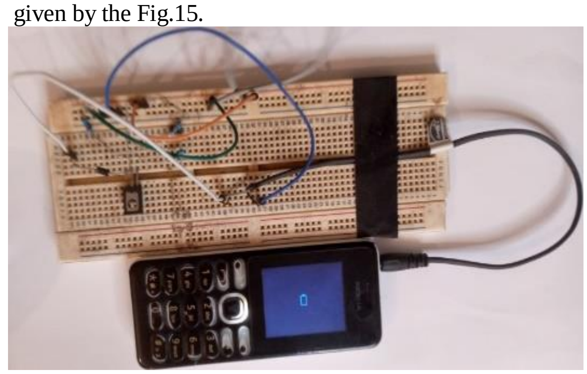

Figure 15. Mobile phone battery charge testing.

Based on the previous results, we confirm that an intelligent piezoelectric material is an alternative energy source for systems with low energy consumption as advanced mobile phone battery, smart watch and Bluetooth kit. Further, we note that the adopted amplifier with a single bipolar transistor has a positive effect on a battery charge time. Above that the system is more performant when it is functioning under adequate pulses frequency which is beyond 8Hz. As result, the connected capacitor at the output system circuit is an intermediate generator. We give here the variation of charge state when the characteristics are (ic=500mA, U=4.2V) by the Tab.5.

TABLE.V STATE OF CHARGE DURING TIME.

Percentage charge state (%)	Elapsed time (h)
35-40	1
55-60	1.5
75-80	2
95-100	2.5

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The percentage of charge state depends on adopted piezoelectric effect frequency. The arterial pulse is characterized with its frequency depending on arterial regions of human body. The pulse amplitude is varying with the beat pressure on the piezoelectric material film. According to test on the developed film the wist generates a voltage between 150mV and 300mV for a pulse with a frequency around 1.1 Hz, which matches the heart rate (65-70 bpm). The developed film bonded on the skin surface, demonstrating its high flexibility and sensitivity. Referring to literature an old piezoelectric sensor under the radial pulse generates a voltage with amplitude between 30 - 40 mV after each time delay step around 65±5ms [28].

VI.CONCLUSION

The ultimate goal of this paper is to establish an alternative way to charge a mobile phone battery and similar portable device. The generated pulses from the motion and similar external mechanical effect are confirmed as competitive solution especially with a booster system based on a magnet induction to ensure a powerful hybrid source. Thereon, this work is a contribution to show that an intelligent piezoelectric transducer constitutes adequate spring of energy for smart and small devices. Overall, we observed that the power can be increased whatever the sort of the utilized amplifier but the efficient slight amelioration is observed for the case of an amplifier with a single bipolar transistor. Finally, the harvested energy from this system is able to charge the mobile phone battery as it seems an effective prototype that we intend, in perspectives, to miniaturize to be installed easily. The developed piezoelectric sensor is a challenge for a human body measurement, including pulse rate detection and related parameters. The piezoelectric film is a competitive sensor due its flexibility and elasticity. Thereon, after bonded on the skin surface such as wrist region it presents a good sensitivity to pulse with low frequency as result it is a reliable sensor. The main future objective is to exploit this innovative sensor for human health monitoring and adopt it to feed miniaturized devices such as smart watches and Bluetooth kit.

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