Harvesting of Energy through Piezoelectric Effect Technology: Electrical Structure and Applications

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Abstract: In present era wireless data transmission techniques are commonly used in electronic devices. For powering them connection need to be made to power supply through wires else power may be supplied from batteries. Battery requires charging, replacement and other maintenance efforts. For example, in applications such as villages, forest, hilly areas where generally remote-control device are used, continuous charging of microcell is not possible by conventional charging method. So, some alternative method needs to be developed to keep the batteries full time charge and to avoid need of any consumable external energy to charge the batteries. To resolve such problems energy harvesting from piezoelectric effect techniques is the best alternative. In the proposed work energy harvesting through the piezoelectric crystals has been achieved. Mechanical pressure is used as the input to the crystal. The generated emf after the application of pressure on the crystal was utilized for the purpose of charging the 12V battery. The information of generated value of emf at different level of pressure has been displayed continuously by the microcontroller based circuit (Arduino). Further the developed emf was utilized for operating low power load (Lamp of 10W).

Keywords: Energy, Piezo crystal, Inverter, Storage, Piezo electric effect.

1. Introduction

In the current era, which is witnessing a skyrocketing of energy costs and an exponential decrease in the supplies of fossil fuels, there arises a need to develop methods for judicious use of energy which lay emphasis on protecting the environment as well [1-2]. This day most of the research in the energy field is to develop sources of energy for future. It is time to find renewable surceases of energy for the future. One of the novel ways to accomplish this is through energy harvesting. Energy harvesting, or energy scavenging, is a process that captures small amounts of energy that would otherwise be lost as heat, light, sound, vibration or movement [3-4]. It uses this captured energy to improve efficiency and to enable new technology, like wireless sensor networks. Energy harvesting also has the potential to replace batteries for small low power electronic devices [5-6]. Piezoelectric materials can be used as a means of transforming ambient vibrations into electrical energy that can then be stored and used to power other devices. Piezoelectric materials are being more and more studied as they turn out to be very unusual materials with very specific and interesting properties. In fact, materials have the ability to produce electrical energy from mechanical energy for example it can convert mechanical behavior like vibrations in to electricity. Such devices are commonly referred to as energy harvesters and can be used in applications where outside power is unavailable and batteries are not a feasible option. While recent experiments have shown that these materials could be used as power generators. The amount of energy produced is still very low, hence the necessity to optimize them. Piezoelectric materials have two properties that are define as direct and converse effect. Direct effect is the property of some materials to develop electric charge on their surface when mechanical stress is exerted on them, while converse effect is the property of some materials to develop mechanical stress when an electric charge is induced. With the recent surge of micro scale devices, piezoelectric power generation can provide a convenient alternative to traditional power sources used to operate certain types of sensors/actuators, telemetry, and MEMS devices [7- 8].

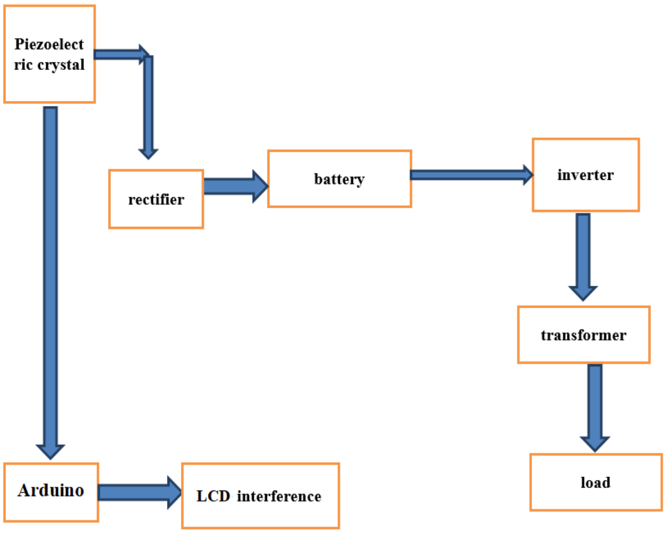

Fig 1 Block Diagram of the proposed work.

The advances have allowed numerous doors to open for power harvesting systems in practical real-world applications. Much of the research into power harvesting has focused on methods of accumulating the energy until a sufficient amount is present, allowing the intended electronics to be powered.

In the proposed work, energy harvesting through the piezoelectric crystals has been achieved. Mechanical pressure has been used as the input to the crystal. The generated emf after the application of pressure on the crystal was used for the purpose of charging the 12V battery. The generated emf has been displayed by the microcontroller based circuit (Arduino). Further the developed emf was utilized for operating low power load (Lamp of 10W).

Full-bridge rectifier was used as rectifier circuits to convert the AC output of a piezoelectric into a DC voltage. The rectifying circuits consist of 4 diodes. The voltage needs to rectify due to the need for constant supply of voltage light up the series of LED placed in parallel. An inverter is designed to convert the DC power stored into the battery to the AC power for operating the AC load. The schematic block diagram of the proposed work is shown in Fig. 1.

2. Literature Survey

Frede Blaabjerg *et. al.* [1]: Continuously expanding deployments of distributed power-generation systems (DPGSs) are transforming the conventional centralized power grid into a mixed distributed electrical network. The modern power grid requires flexible energy utilization but presents challenges in the case of a high penetration degree of renewable energy, among which wind and solar photovoltaics are typical sources. The integration level of the DPGS into the grid plays a critical role in developing sustainable and resilient power systems, especially with highly intermittent renewable energy resources. To address the challenging issues and, more importantly, to leverage the energy generation, stringent demands from both utility operators and consumers have been imposed on the DPGS. Furthermore, as the core of energy conversion, numerous power electronic converters employing advanced control techniques have been developed for the DPGS to consolidate the integration. In light of the above, this paper reviews the power-conversion and control technologies used for DPGSs. The impacts of the DPGS on the distributed grid are also examined, and more importantly, strategies for enhancing the connection and protection of the DPGS are discussed.

M.V.S. Lakshmi *et. al*. [2]: has proposed energy conservation system for mobile phones and laptop keyboards have been presented in this paper. The design presented here will be quite effective in providing an alternate means of power supply for the mentioned devices during emergency. Further, the approach presented in this paper can be extended to many other applications where there is scope for similar kind of energy conservation. The material used for the current application is a PZT with 1.5 MBA lateral stresses operating at 15Hz. The volume of the material used is 0.2cm3. The output power produced is 1.2W. The energy/power density is 6mW/cm3.The output voltage is 9V. This voltage can be used to produce the required amount of charge after being processed.

M.D.A.Al-Falahi *et. al*. [3]: Has proposed that the technology is based on piezoelectric materials that enable the conversion of mechanical energy exerted by the weight of passing vehicles into electrical energy. As far as the drivers are concerned, the road is the same, she says Edery-Azulay added that expanding the project to a length of one kilometer along a single lane would produce 200 KWh, while a four-lane highway could produce about a MWh sufficient electricity to provide for the average consumption in 2,500 households. As the results shows that by using double actuators in parallel we can reduce the charging time of the battery and increase the power generated by the piezoelectric device. In second research where a piezoelectric generator was put to the test and generated some 2,000 watt-hours of electricityThe setup consists of a ten-meter strip of asphalt, with generators lying underneath, and batteries in the roads proximity. So that it is clear by using parallel combination we can overcome the problems like of impedance matching and low power generation. The results clearly show that piezoelectric materials are the future of electric power generation.

MickaelLallart *et. al*. [4]: Energy harvesting using piezoelectric elements received much attention as vibrations are widely available and as piezoelectric transducers feature high-power densities and promising integration potentials. It has also been shown that applying a nonlinear treatment on the output voltage of the piezoelectric material can significantly enhance the performance of the device. This process consists of inverting the piezoelectric voltage when the displacement is maximum, which therefore requires a way of synchronization. In practical applications, however, a delay may happen between the inversion and the actual occurrence of an extremum. The purpose of this paper is to investigate the effect of such a delay on the microgenerator performance and therefore to predict the power output that can be expected under real circumstances. Theoretical analysis validated through experimental measurements shows that the effect may not be the same for positive or negative delays. It is also demonstrated that the effect is not significant as long as the delay is small. The acceptable delay range also increases as the electromechanical system becomes more coupled and/or less damped. Under such configuration, the output power can even be slightly increased as the delay permits controlling the tradeoff between energy extraction and damping effect.

Adam M. Wickenheiser *et. al*. [5]: This paper focuses on comparing the effects of varying degrees of electromechanical coupling in piezoelectric power harvesting systems on the dynamics of charging a storage capacitor. In order to gain an understanding of the behavior of these dynamics, a transducer whose vibrational dynamics are impacted very little by electrical energy extraction is compared to a transducer that displays strong electromechanical coupling. Both transducers are cantilevered piezoelectric beams undergoing base excitation whose harvested electrical energy is used to charge a storage capacitor. The transient dynamics of the coupled system are studied in detail with an emphasis on their charging power curves and the time to charge the storage capacitor to a specified voltage. An analytic model for the system is derived that takes into consideration the reduction in vibration amplitude of the beam caused by the removal ofelectrical energy.Althoughthismodelmakesthetypicalassumption that the beam is vibrating at its open-circuit resonance, it is shown to predict the charging behavior of the system accurately when compared to experimental results and a complete, nonlinear simulation without this simplification. Finally, the simplifications and discrepancies created by several types of modeling assumptions for a highly coupled energy harvesting system are discussed.

ShaoWeiXie *et. al.* [6]: Low-power electronic applications are normally powered by batteries, which have to deal with stringent lifetime and size constraints. To enhance operational autonomy, energy harvesting from ambient vibration by microelectromechanical systems (MEMS) has been identified as a vivid solution to this universal problem. This paper proposes an automated design and optimization methodology with minimum human efforts for MEMS-based piezoelectric energy harvesters. The analytic equations for estimating the harvested voltage by the unimorph piezoelectric energy harvesters are presented with their accuracy validated by using the finite element method (FEM) simulation and prototype measurement. Thanks to their high accuracy, we use these analytic equations as fitness functions of genetic algorithm (GA), an evolutionary computation method for optimization problems by mimicking biological evolution. Our experimental results show that the GA is capable of optimizing multiple physical parameters of piezoelectric energy harvesters to considerably enhance the output voltage. This harvesting efficiency improvement is also desirably coupled with physical size reduction as preferred for the MEMS design process. To demonstrate capability of the proposed optimization method, we have also included a commercial optimization product (i.e., COMSOL optimization module) in our comparison study. The experiments show that our proposed GA-based optimization methodology offers higher effectiveness in the magnitude improvement of harvested voltage along with less runtime compared with the other optimization approaches. Furthermore, the effects of geometry optimization on mechanical and electrical properties (e.g., resonant frequency, stiffness, and internal impedance) are also studied and an effective solution to producing maximum power from unimorph piezoelectric harvesters is proposed

Christopher Oshman *et. al.* [7]: The recent development and commercialization of microelectromechanical systems (MEMS)/nanoelectromechanical systems (NEMS) has brought the related challenge of independently powering such systems. The concept of the nanogenerator (NG) has shown potential for harvesting energy from the ambient environment to power MEMS/NEMS. Kinetic energy harvesting NGs based on the piezoelectric properties of ZnO nanowires have attracted much interest. In this paper, we have fabricated hydrothermally synthesized ZnO-based NGs following the procedures standardized in the published literature. Likewise, reference NGs without ZnO piezoelectric material were fabricated in parallel with the ZnO NGs. The voltage output of both the ZnO NG and the reference NG was measured given a 10-Hz cyclic vertical load. Unexpectedly, both the ZnO and the reference NG were found to produce 3 mV with 0.451 N of load. A finite-element model was created to determine that the voltage potential of the NG should be about 1 mV with the given load. A possible explanation for this unexpected behavior is that the measured signals are not entirely piezoelectric in nature. Rather, the signals recorded from the NGs may be some alternate phenomenon, such as the triboelectric, flexoelectric, or electret effect

Andalib-Bin-Karim *et. al.* [8]: In this work**,** maximum public movements is observed in railways stations and holy places, hence, such places can be exploited for use of piezoelectric crystals for generation of electricity. Gathering ranging from thousands to millions are observed in holy places, thus installation of piezoelectric crystals at floorings would generate enough power to light up lights of houses as well as air circulation systems. Use of piezoelectric crystals has being started and positive results are obtained. With further advancement in field of electronics, better synthesized piezoelectric crystals and better selection of place of installations, more electricity can be generated and it can be viewed as a next promising source of generating electricity.

3. Theoretical Analysis and Working Principles of the proposed work

3.1 Piezoelectric Crystal

Squeeze certain crystals (such as quartz) and you can make electricity flow through them. The reverse is usually true as well: if you pass electricity through the same crystals, they "squeeze themselves" by vibrating back and forth. That's pretty much piezoelectricity in a nutshell but, for the sake of science, let's have a formal definition: Piezoelectricity (also called the piezoelectric effect) is the appearance of an electrical potential (a voltage, in other words) across the sides of a crystal when you subject it to mechanical stress (by squeezing it).In practice, the crystal becomes a kind of tiny battery with a positive charge on one face and a negative charge on the opposite face; current flows if we connect the two faces together to make a circuit. In the reverse piezoelectric effect, a crystal becomes mechanically stressed (deformed in shape) when a voltage is applied across its opposite faces [9].

3.2 Piezoelectric Effects

The piezoelectric effect occurs due to the materialȇs electric dipoles. Dipoles are represented as vectors pointing from the positive to the negative charges. Groups of aligned dipoles are called Weiss domains. In a piezoceramic material, which are materials that are not inherently piezoelectric like naturally-occurring piezoelectric crystals, but rather can be manipulated to exhibit piezoelectric behavior, the Weiss domains are not aligned, and the overall material has no net polarization. After applying an electric field, the domains align themselves in the direction of the field, creating a polarization. When the field is removed, the material cannot return to its original structure, but rather a more organized structure which allows for the material to exhibit the piezoelectric effects like a normal crystal. Applying mechanical stress to this newly piezoelectric material disrupts the orientation of the dipoles, realigning them as they were during polarization with the applied electric field and bringing about a polarization which creates a potential difference across the material. This voltage drop allows charge to flow between the two poles in order to realign the dipoles, thus generating a current. Additionally, the applied pressure and the generated energy have a direct relationship in which increasing the pressure will also increase the energy output [10].

3.3 Working and Principle of the Proposed Work

The piezoelectric material converts the pressure applied to it into electrical energy. The source of pressure can be either from the weight of the moving vehicles or from the weight of the people walking over it. The output of the piezoelectric material is not a steady one. So a bridge circuit is used to convert this variable voltage into a linear one. Again an AC ripple filter is used to filter out any further fluctuations in the output. The output dc voltage is then stored in a rechargeable battery. As the power output from a single piezo-film was extremely low, combination of few Piezo films was investigated. Two possible connections were tested - parallel and series connections. The parallel connection did not show significant increase in the voltage output. With series connection, additional piezo-film results in increased of voltage output . So here series connection is employed for producing 12V voltage output with high current density. From battery provisions are provided to connect dc load. An inverter is connected to battery to provide provision to connect AC load. The voltage produced across the tile can be seen in a LCD. For this purpose microcontroller based on the arduino uno is used. The microcontroller uses a crystal oscillator for its operation. The output of the microcontroller is then given to the LCD which then displays the voltage levels. The inverter used in this circuit uses the IC CD4047. It is used to convert the DC voltage stored in the battery to AC voltage. IC CD4047 produces two pulse trains phase shifted by 180°. These pulse trains are used to switch transistors configured in common emitter mode producing pulse trains of 12V. These pulses are connected to a step up transformer from whose high voltage side; we obtain the 220V AC supply.

4. Hardware Design and Implementation of the Proposed Work

The electrical circuit of the proposed work is shown in Fig. 2. The components used in designing the electrical circuit has own standard that is recognized by internationally [11-13]. The generated power from the series connected piezo crystal is converted into the DC power by the use of full bridge rectifier. The generated Dc power is stored in The 12 V battery. An inverter is connected with the battery. The Inverter will feed the power from the battery to the Ac- load.

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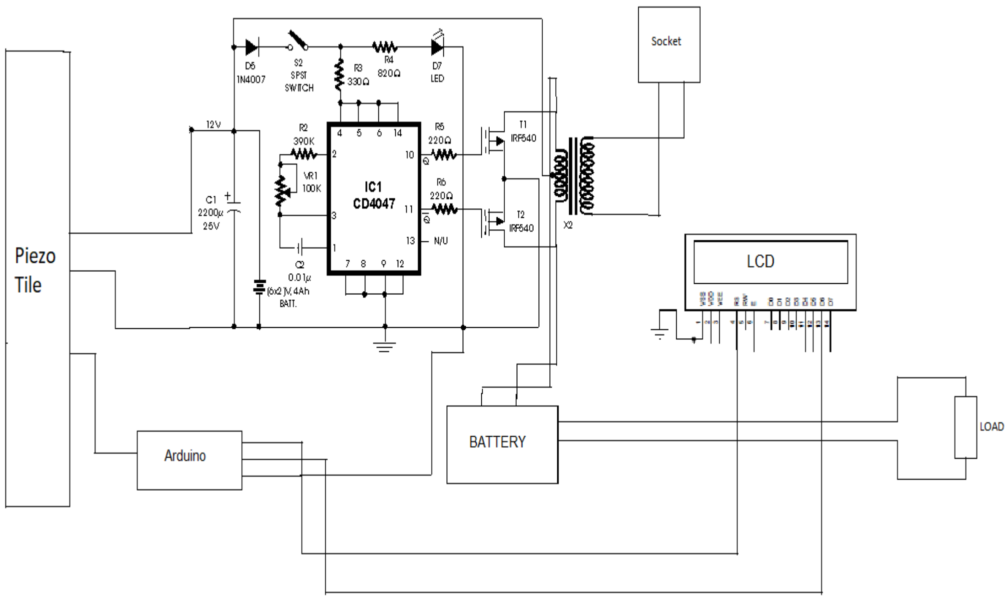

Fig. 2 Electrical circuit diagram of the propsed work.

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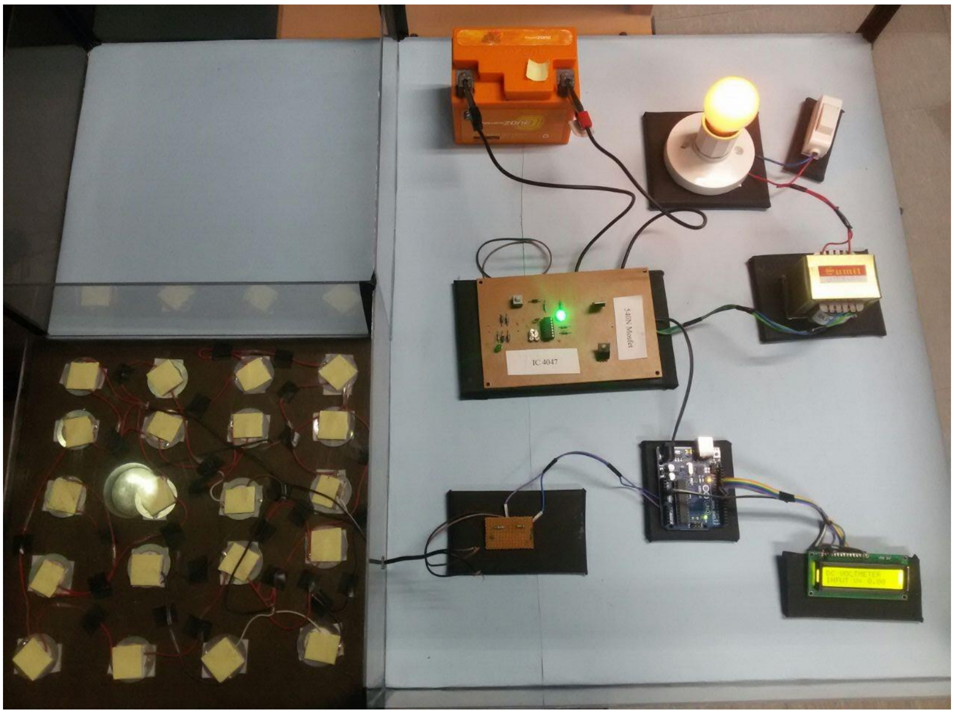

Fig 3 Schemetic diagram of the hardware model.

5. Result of the experimental work

The simulation results of piezo crystal output in voltage at 10kg of weight for 2 ms are shown in Fig. 4. It is sinusoidal in nature. The amplitude of the generated voltage decrease with the time as the applied pressure over the piezo crystal release.

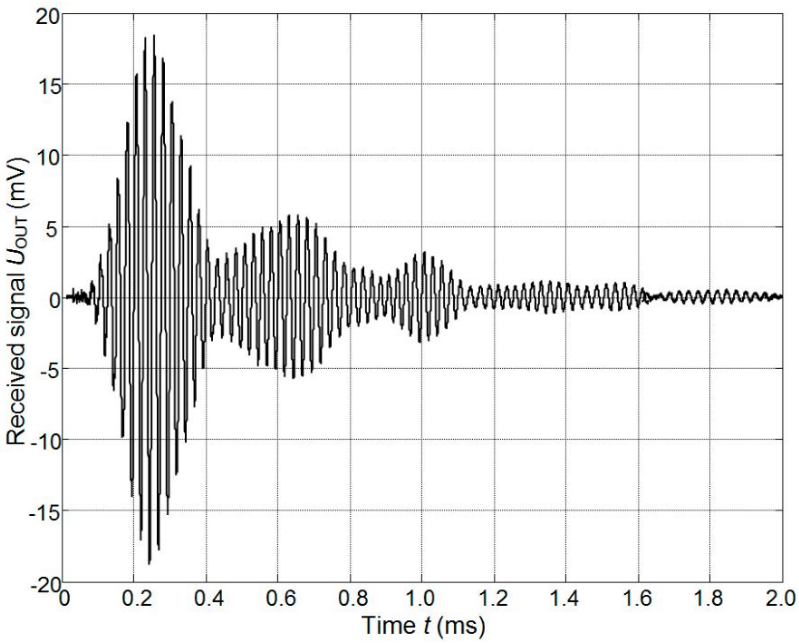

Fig. 4 Waveform of output voltage of piezo crystal.

The inverter output voltage after filtering with the inductor is shown in fig. 5.
It is semi sinusoidal in nature and noise free signal. It if further feed to the step up transformer to step it up up to 220 V AC, which is suitable for driving the single phase AC load.

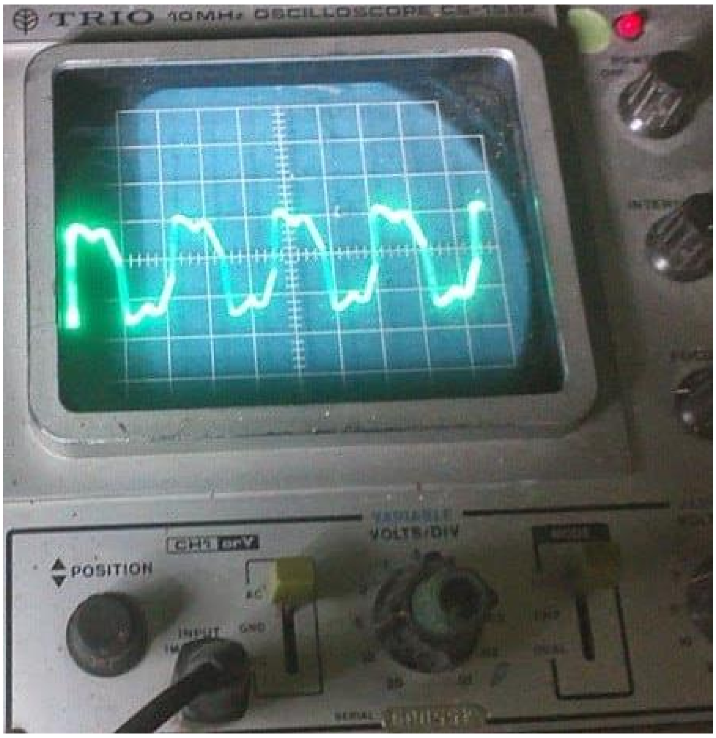

Fig. 5 Output waveform of voltage of Inverter after filtering with the inductor.

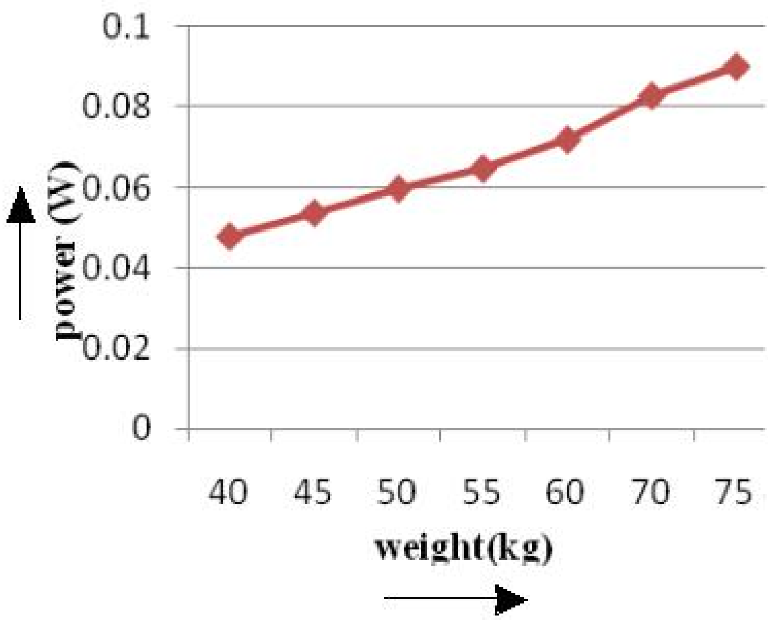

Fig 6. Generated power with different weight.

To validate the suitability of the proposed model, People whose weight varied from 40 kg to 75 kg were made to walk on the piezo tile to test the voltage generating capacity of the Piezo tile.

The relation between the weight of the person and power generated is plotted in fig. 6. From the graph it can be seen that, maximum power is generated when maximum weight/force is applied. Thus, maximum voltage of 0.09 W is generated across the tile when a weight of 75 Kg is applied on the tile. Output power of the crystal linearly increases with the weight.

6.1. Conclusion

The project is successfully tested which is the best economical, affordable energy solution to common people. This can be used for many applications in city areas where want more power. India is a developing country where energy management is a big challenge for huge population. By using this model in large scale. D.C loads according to the force applied on the piezo electric sensor can be drive. Although the theory are obviously some practical limitations to the systems presented. The final prototype design does fulfill the objective of generating electricity from piezoelectric disk. Due to the low cost design of the piezoelectric system it is a practical product which could increase the operating period of most common products. The data collected is capable of extending the operational lifespan per charge of portable electronic devices.

Although the theory developed in this report justifies the use of switching techniques in efficiently converting that energy to a usable form, there are obviously some practical limitations to the systems presented. Measurements of source current into the primary and load current transferred from the secondary reveal that very little current gain truly occurs between the input and output ports of the switch in the forward converter hybrid. Further, similar results were encountered when one examines the energy transferred through the series switch and inductor in the buck converter. In addition, based on the results gathered in this investigation, the final prototype design does fulfill the objective of generating electricity from piezoelectric disk. Due to the low cost design of the piezoelectric system it is a practical product which could increase the operating period of most common products. The data collected is capable of extending the operational lifespan per charge of portable electronic devices.

6.2. Future Work

There are two conditions to be satisfied in order to commercialize piezoelectric harvesting. One is that their energy efficiency should improve, and the other is that their prices must go down. The higher piezoelectric elementôs efficiency gets, the faster and bigger the conversion becomes. Once the technology to improve efficiency at a lower cost is developed, the market will grow much faster. Experts expect the piezoelectric harvesting market to take 28.8% of the entire energy harvesting market soon, as the number of piezoelectric harvesting related productis increasing rapidly. Piezoelectric harvesting will be considered the next generation energy source as soon as these issues are taken care of.

Today, we learned about cases in Korea and around the globe related to piezoelectric harvesting as well as their future prospects. The key to 21^{st} century IT is to show the notion of green IT which strives to solve environmental problems while enhancing technology at the same time. The eco-friendly energy projects such as piezoelectric harvesting are being developed consistently based on the fact that they donôt create toxic waste and that they can be applied to smaller businesses. Other than the examples I shared in this posting, there are diverse attempts to advance the green IT market while solving the energy crisis and preventing possible environmental disasters.

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