

Economics and Environment Assessment of A Coupled Solar-Piezo Electricity Generation for Environmentally Friendly Hybrid Charging System

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Abstract

In this paper, a combination of renewable and free energy sources is proposed and studied to implement an efficient way to power generation. The energy harvesting plays a vital role in supplying the energy to various applications compared to conventional works. Footstep's pressure and photovoltaic (PV) panel are the input sources for proposed converter. This paper presents the simulation and prototype consideration and reliability of a coupled solar and piezo electricity generation for hybrid charging system. This project also designs a Simulink model of Solar and Piezoelectric Hybrid Charging System for simulation and data analysis. Due to their accessibility and inexpensive price, renewable resources such as solar energy have seen a growth in demand in recent years. The goal of this project is to find a method to overcome smartphones charging problem when people are spending time outdoors or when they are on the go, with an economical approach.

Keywords: Harvesting Energy, Hybrid Charging, Photovoltaic (PV), Piezoelectric Energy, Power Generation, Cheap, Economical Approach

Introduction

On a typical shine day, the Earth received energy on a surface perpendicular to the Sun's irradiation is around $1000\text{W}/\text{m}^2$. Solar energy always plays their roles as the prominent source. Nowadays, energy is a massive need in the present and future world. As energy is limited, there is alternatives and research on renewable energy which could contribute for greener environment. Solar Panel are widely used in the industries, commercial purpose and even for residential used. Solar energy system is meant to collect maximum power from sun and to convert into wattage (Govind et al., 2015). The system for hybrid generation system combines solar power from solar panels and battery energy. This technology contributes to low power consumption, easy to program, stable during operation and affordability (Jonas, 2019). Despite the fact that we tend to use batteries powered electrical devices in our daily lives especially when going outdoors, this project helps to overcome these problems. During

the day, the solar could also be the prominent source, the battery are going to be being either charge state or disconnected.

In much research, various approaches have been applied in this area of energy harvesting but still the gap is there as it needs improvement in using free renewable resources. Piezoelectric sensor is a device that converts changes in pressure, acceleration, temperature, strain, or force into an electrical charge via piezoelectric effect. The prefix piezo is Greek for 'press' or 'squeeze' (Dertien & Regtien, 2018). The sensitivity of such sensors are determined by the elasticity of the spring element (Panthi et al., 2018). The piezoelectric used for power generation that convertsthe applied pressure into electrical energy and vice versa. These properties allow the material to function as an influence harvesting medium. Piezoelectric plates are embedded with piezoelectric crystals and indigenous circuit was designed thatstores the generated energy in batteries. When the piezoelectric material sheet was pressed, then the positive charge is produced and once we release it then the negative charge is produced (Wall, 2013). Nowadays, they are often solar energysystems connected to batteries to store the energy that was generated (Dewangan & Dubey, 2017). The system handled the effectively produce power with none of fuel, like coal in thermal power plant, nuclear fuel in nuclear energy. Combination of electricity generation from solar and vibration used to reduce the utilization of fuel as well as to achieve maximize generation of electricity during daytime (Floess, 2019).

In this project, the study will specialize in the reaction of acoupled solar and piezo electricity generation for hybrid charging system. This paper presents the design, prototyping and testing of facilities electric hybrid energy charging systemcapable to use the solar energy and the kinetic energy from footsteps of people walking over piezo based footboard. The development of idea in this project deals with the need of usingpiezoelectric transducers to design an energy by harvesting it from the footsteps. A microcontroller is employed by applyinga specified program such as Arduino and Raspberry Pi to ensure the machine to operate automatically. In this project, Arduino will be used as the microcontroller to generate microenergy from vibration and pressure using piezoelectric and solar energy. Every system required power to be generated, the proposed idea in this project use harvest energy to supply the power to the microcontroller to monitor the system. For simulation part, the simulation of Solar and Piezoelectrictransducer was build and run in Simulink model. PV array represents the solar energy and Piezo Stack block represent the piezoelectric sensor. Next, I-V and P-V curve was observed on different value of irradiance (W/m^2) and temperature ($^{\circ}C$).

Methodology

A little device called a solar-piezo can generate electricity right from sunlight and pressure energy from piezoelectricity. When exposed to sunlight, it will generate electricity. Meanwhile, piezoelectric which called as 'piezoelectric effect' able to produce an AC voltage when put through mechanical stress or vibration. The entire system as well as the design and prototyping of solar-piezo hybrid charging system will be discussed. Figure 1 below shows the block diagram of the system.

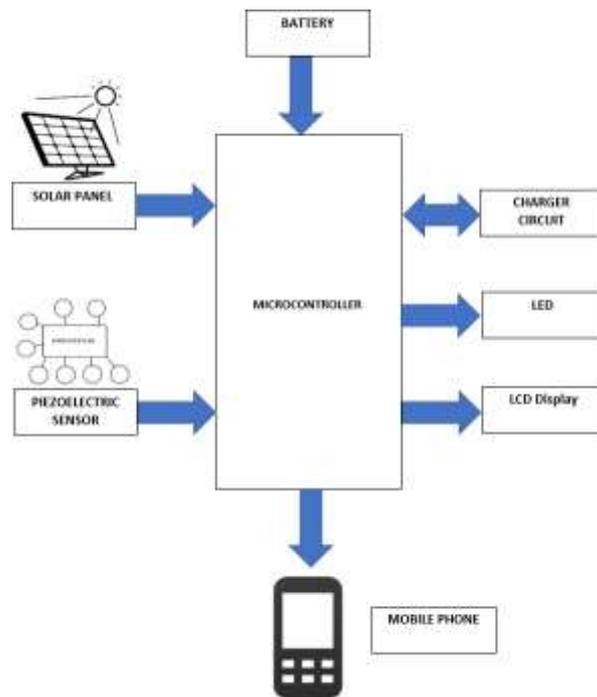


Figure 1: Block diagram of Solar-Piezo Hybrid Charging System

This project designed with Arduino Uno as microcontroller to monitor the pressure sensed by using the piezoelectric sensor and supplied voltage to the load when there is solar energy or pressure from the piezo footsteps board. The voltage and current generated through the solar panel are sensed by Arduino Uno which it displays on the LCD. Similarly, the current and voltage generated through footsteps over Piezo Footboard is shown on the LCD. In this case, the power generated can be calculated based on voltage and current available by using formula $P=IV$. This project also comes with current sensor, voltage sensor, LCD, LED, and DC-DC converter to generate and supply electricity to the load, resulting the device are going to charge the mobile phones as the output load.

A. Solar Panel

Solar is known as an irregular power source that works when the sun is shining. On the solar panel's surface, these photovoltaic cells are sort in a grid arrangement. During the day, these solar panels capture sunlight arrangement. The main source of power for the sensor module is a solarpanel. Using the Arduino Uno, this harnesses the energy from solar cells to charge batteries and raises the voltage from solar to 5V battery. So, solar panel must be capable of both powering the Arduino and charging the battery pack during the day.

B. Piezoelectric Footsteps Board

The piezoelectric footsteps board consists of 12 piezoelectric crystals are used as shown in Figure 3. These 12 crystals are arranged in 3*4 set of crystals that are connected in parallel. This is due to parallel connection of piezo sensor gives maximum power and less voltage. The piezoelectric used in this project is made up of Lead Zirconate Titanate. The piezo sensor also small in size which fits comfortably in the shoes. During walking, the pressure energy applied on the piezo is converted into electrical voltage which is given to an energy storage device.

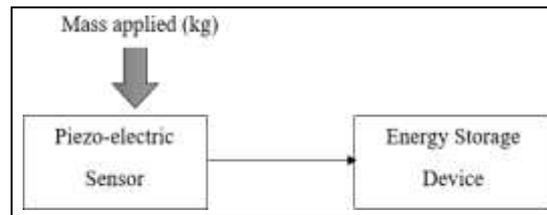


Figure 2: Piezoelectric energy harvesting process

Energy generation by piezoelectric transducer device related to the stress which is the source for stress. The increment in power generated can be done by increasing the concentrated load. Whenever the pressure is applied on piezoelectric, it will provide energy thus it is independent of weather. This system ensure that no fossil is used. Piezoelectric energy harvesting presents a various benefit such as simple structure, high energy, and power density, and it can be meshed into hybrid materials to produce a wide range of voltages.



Figure 3: Connection of Piezoelectric Footsteps

C. Simulation Resources

For simulation part, Solar and Piezo Hybrid Charging System was programmed in Matlab version R2019a for simulation and result analysis. The architecture of solar energy(PV) module is shown in Figure 4.

translational motion sensor is clamped to the left end of the piezo stack, driving the motion. An extra mass is linked to the right end of the piezo stack. The right end's motion is not synchronous with the left end due to the piezo bender's elasticity, mass, and inertia. The distortion generates a charge and voltage across the piezo stack's electrical terminals, which is then converted into electricity.

D. Prototype Design

For hardware part, the prototype design consists of Arduino Uno, Solar Panel, Piezoelectric Footsteps Board, Voltage Sensor, Current Sensor, LED, and LCD as shown in Figure 7. This project is a dedicated project that used to power mobile phone or power bank by generating power using solar and piezoelectric energy sources. The hybrid generated power is stored in a battery through a charging circuit. Two rechargeable batteries are used in this project to recharge the battery during daytime, and it may be used during night.

The prototype design used Arduino Uno as microcontroller to monitor the system in C++ language Arduino IDE. Solar cells are connected to the TP4056 lithium battery charger, which is connected to the 18560 rechargeable lithium battery via its output. To convert from 3.7V dc to 5V dc, the battery is also connected to a 5V step-up voltage booster. Some pins were soldered simultaneously with both modules such as TP4056 and step-up boost to allow easier connection to a breadboard. The solar panel was placed under hot day at 12pm and the result was taken. Next, the voltage and current generated by solar energy or piezoelectric footsteps will display on the LCD. LED will also light up when the voltage above 3.8V or vice versa. As a result, Arduino will give instruction to supply voltage to load and then mobile phone is charging.



Figure 6: Prototype for Solar-Piezo Hybrid Charging System

Results and Discussions

The proposed project is evaluated, and the experimental results are discussed in this section. The result obtained from this project was divided into two parts: simulation and prototype part. The purpose of this topic is to analyze the power generated with solar energy, without solar energy, with piezoelectric sensor, without piezoelectric sensor, and with both combinations of solar energy and piezoelectric sensor, and without both solar energy and piezoelectric.

A. *Simulation Part*

For the simulation part, the coding was programmed in Arduino IDE and Simulink model was simulated in Matlab 2019 which is for simulation testing and prototype consideration of Solar-Piezo hybrid charging system.

Table 1

Data collected from simulation of solar at difference irradiance (W/m²)

Time	Temp (°C)	Irradiance (W/m ²)	PV voltage (V)	PV current (A)	PV power (W)
8.00 AM	23	250	12.91	1.951	25.58
12.00 PM	33	1000	12.92	7.876	108.0
6.00 PM	27	450	12.91	3.533	46.87

Table 1 shows the result from the Matlab simulation, in the morning at 8am, the irradiance received at the PV array quite low which result a low output power generated. The sun is low in the sky in the early morning and late afternoon. Meanwhile, during afternoon at 12pm, the irradiance recorded at the highest values since the Earth was very closetowards the Sun and the output power generated was maximum. During noon, the sun is at its highest position, its rays travel further through the atmosphere (Covaci & Gontean, 2020). On the other hand, during evening at 6pm, the irradiance is low. In this condition, the power generated also low due to the low irradiance received by the PV array.

The relationship between the PV module voltage and current at different solar irradiance levels as shown in Figure 7 below. P-V and I-V curves has been constructed from the data collected on the Matlab simulation. Based on the observation, the voltage generated are increase when the irradiance from solar energy is increase. Therefore, the higher the irradiance, the greater the output current. As a result, the greater the power generated.

Meanwhile, Table 2 shows the result from the Matlab simulation, in the morning at 8am, the temperature received at the PV array quite low which result a low output power generated. Meanwhile, during afternoon at 12pm, the temperature recorded at the highest values and the output power generated was maximum. On the other hand, during evening at 6pm, the temperature recorded is high.

Table 2

Data collected from simulation of solar at difference temperature (°C)

Time	Temp	PV voltage(V)	PV current(A)	PV power(W)
8.00 AM	23° C	12.91	1.951	25.58
12.00 PM	33° C	13.03	7.876	108.0
6.00 PM	27° C	12.91	3.533	46.87

Regarding to the temperature, the result obtained shows the higher the temperature the higher the voltage. Furthermore, if the temperature increases with respect to the original conditions, the PV output increase in voltage and power. The relationship between the PV module voltage and current at different solar temperature values as shown in Figure 8.

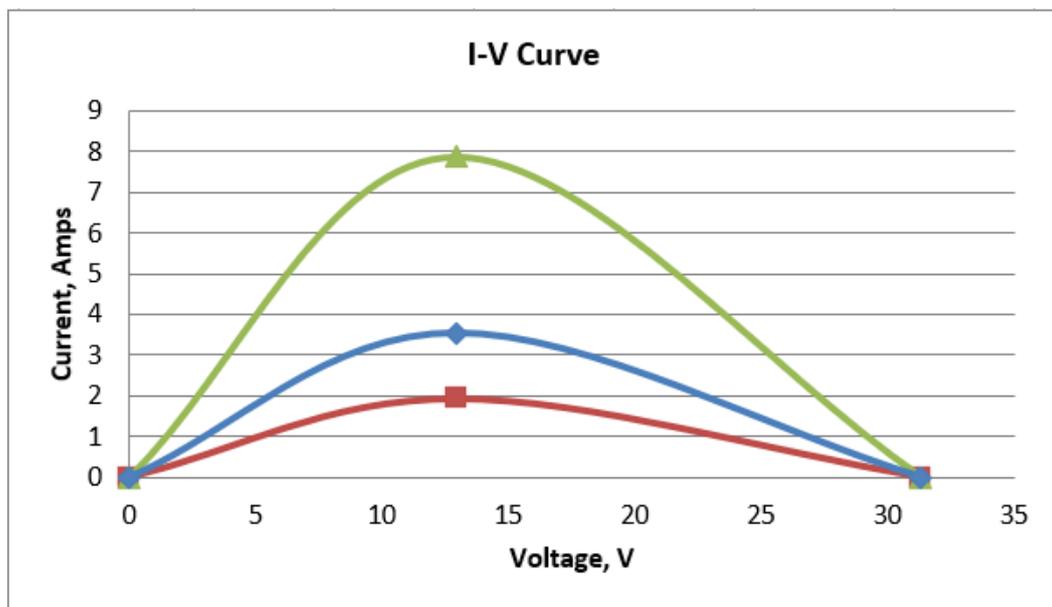


Figure 7: Voltage versus Current at difference irradiance

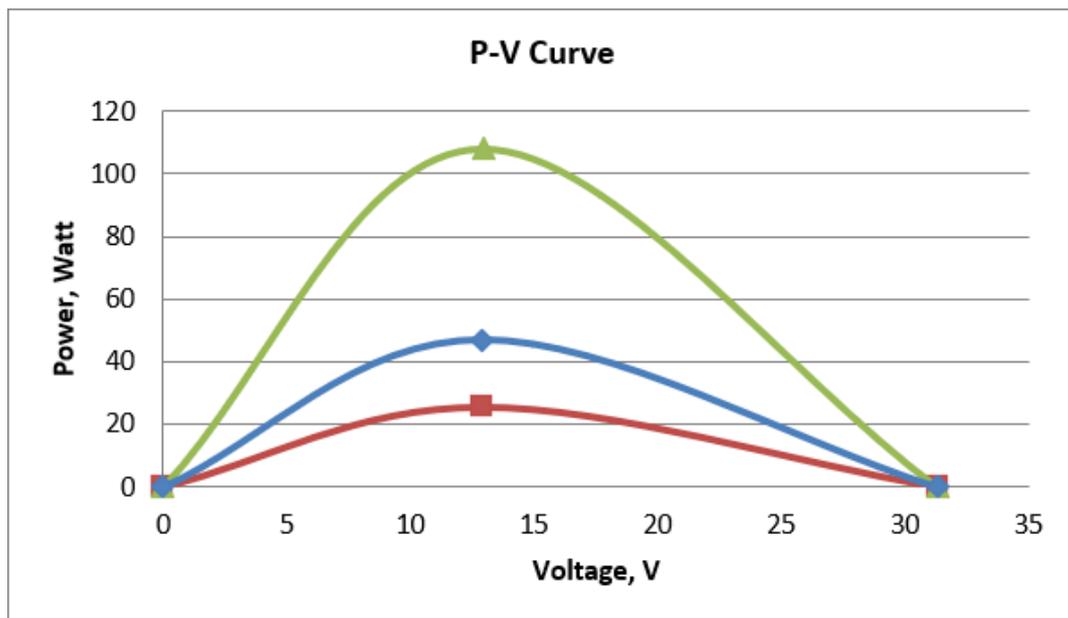


Figure 8: Voltage versus Power at difference temperature

For piezoelectric energy harvester simulation, the P-V graph was observed. During vibration energy harvesting, piezoelectric materials convert mechanical strain to an electrical charge or voltage via the direct piezoelectric effect. Piezoelectric vibration-based energy harvesting systems have been employed as actuators and portable devices as well as an attractive alternative power source. The relationship between the voltage and current in piezo stack module as shown in Figure 9. Based on the observation, the output power generated produced are high when the mass applied (kg) from human's footsteps are high. Therefore, the higher the voltage, the higher the output power produced.

Table 3

Data collected from simulation of piezo stack

Mass applied (kg)	Voltage (V)	Current (A)	Power (W)
0	-	-	0
5	7.5	2.5	18.75
10	7.7	2.78	21.41
15	7.9	3.05	24.10
20	8.1	3.85	31.19
25	8.3	4.04	33.53
30	8.5	4.40	37.40

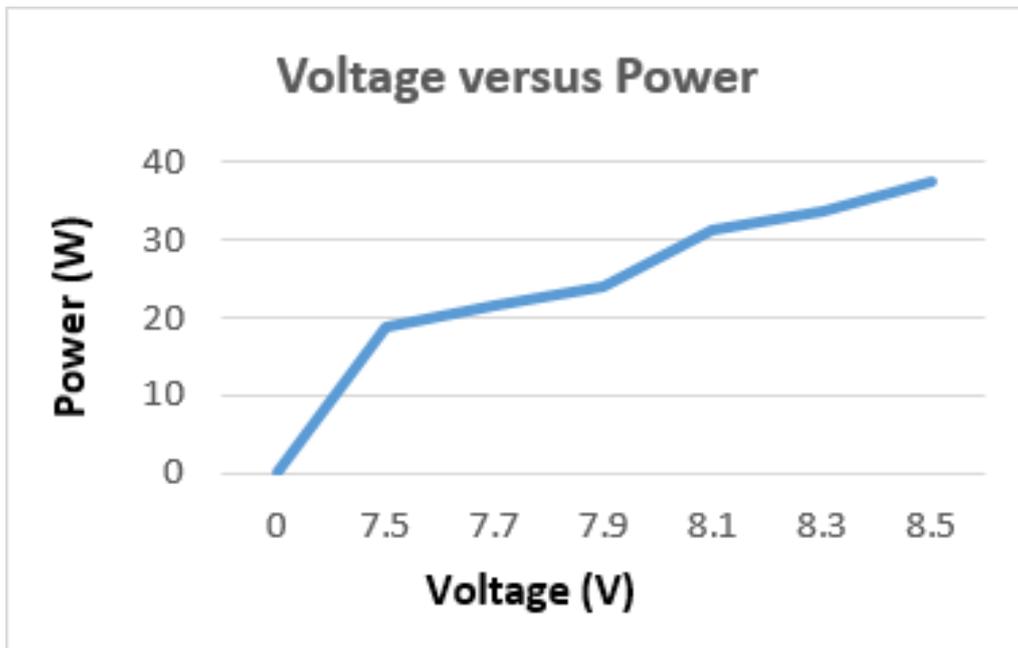


Figure 9: P-V graph

B. Prototype Part

For hardware part, the output result display on the LCD and LED will light up once it reached above 3.8V or vice versa. There are six situations has been investigated, which are during the presence of solar energy, without the solar energy, with the presence of pressure applied on the footsteps, without pressure applied on the footsteps, and with the combining of solar and pressure energy and vice versa. The voltage and current have been generated and display on the LCD. Similarly, the power generated can be calculated by using $P=I*V$

For example, as the value of voltage $V=3V$ and Current= $0.0015A$. Therefore,
 $P=V*I=3*0.0015=0.0045W$,

$$V = 3V \quad I = 0.0015A$$

$$P = IV = 3 \times 0.0015 = 0.0045W$$



Figure 10: Reading when no presence of solar energy and no pressure on footsteps is supplied



Figure 11: Reading when no presence of solar energy and pressure on footsteps is applied



Figure 12: Reading when solar energy is supplied and pressure on footsteps is applied



Figure 13: Reading when no pressure applied on the footsteps and presence of solar energy



Figure 14: Reading when pressure applied on the footsteps and presence of solar energy



Figure 15: Reading when prototype placed under hot sun at 12pm and pressure applied on piezoelectric footsteps board

The experiment was conducted at 8am in the morning, during afternoon at 12pm which is to get the highest source from solar energy and during evening at 6pm. The pressure comes from footsteps of human on the piezoelectric footstepsboard. Figure 10-15 shows the output performance of solar energy and piezoelectric energy.

Table 4

Data collected from prototype part

Situations	Voltage produced by Solar (V)	Voltage produced by Piezoelectric (V)	Current (A)	Power (W)
Without presence of solar and no pressure applied on footsteps	0	0	-	-
Without the presence of solar and pressure applied on footsteps	0	6.15	2.78	17.1
Without the presence of solar energy and pressure applied on footsteps	10.9	4.30	4.41	67.03
Without pressure applied on footsteps and presence of solar energy	5.59	0	4.04	22.58
Without pressure applied on the footsteps and presence of solar energy	5.10	6.37	4.40	50.47
With both solar energy and pressure applied on the footsteps	11.6	3.85	4.04	62.42

Table 4 shows the result taken in six situations that has been investigated in this phase. Based on the observation, Figure 12 shows the highest voltage and current generated from solar energy are 10.9V and 4.41A respectively. Meanwhile, piezoelectric sensor can produce 6.15V with 2.78A. When combining both solar and piezoelectric energy sources, the results show 11.6V of solar and 3.85V of piezo sensor with 4.04A. From repeated experimentation, the results can be concluded that both solar and piezo energy are good combination of

electricity generation hybrid charging system that produce voltage and current to supply to the load. Both solar energy and piezoelectric pressure energy are the efficient way to electrify or generate electricity by harvesting (Govind et al., 2015).

However, piezoelectric transducer produces less power compared to solar energy (Covaci & Gontean, 2020). The output current display on the LCD is negative, but as all knows that current always positive. On the other hand, charge can flow in one direction only or opposite direction (Zhang & Liu, 2022). Therefore, this is the reason when it comes to positive or negative current. A sensor can read negative and positive current that are used to measure rate of charging or discharging a battery.

As the result, the energy stored from solar panel and piezoelectric sensor used to charge the rechargeable battery as well as to store energy (Jamal, Hassan, Das, Ferdous, & Lisa, 2013). Therefore, the device can be used during the night. Next, the voltage is supply to the output load and mobile phone is charging through USB wire.

The efficiency of this project has been calculated to measure the efficiency of Solar-Piezo approach as a charging system. When an input energy was fed into the proposed method, the efficiency detected by the proposed method would be shown by a manual calculating. The efficiency obtained from this project is 91.67%. This result shows that solar and piezoelectric energy are a good combination for electricity generation has been proven.

$$\begin{aligned} \text{Efficiency} &= \frac{\text{Energy added to the battery}}{\text{Energy used by the charger}} \times 100 \\ &= \frac{5.5 \text{ W}}{6.0 \text{ W}} \times 100\% \\ &= 91.67\% \end{aligned}$$

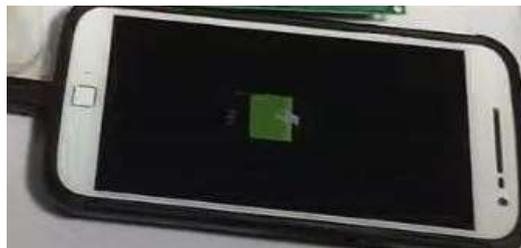


Figure 16: Mobile phone is charging

Conclusion

In this paper, the feasibility of applying a coupled solar energy and piezoelectric sensor has been studied as the electricity generation towards hybrid charging system. Besides, this project focused on the renewable and affordable energy. The simulation part was simulated by using Matlab 2019a. Afterwards, Solar-Piezo pertaining to be a device that help to reduce the electrical consumption by using renewable and free energy resources. After simulation, Solar-Piezo Hybrid Charging System moved to the prototype by using C++ language in Arduino IDE. Therefore, this paper has designed an energy harvesting system from a coupled Solar- Piezoelectric approach. Other than that, this project has developed an integrated prototype of an automatic transfer switching system for energy storage. The impact of this

project is it can be utilized for commercialization. For example, this project can be used at public place such as shopping mall, R&R area, and railway station which can place the solar panel and has a lot of people walking by. So that, people can easily charge their mobile phone when they are on the go. Furthermore, this project applied Atmega as the microcontroller to generate micro energy from vibration and pressure using piezoelectric material and solar energy. Hence, this model is simple and less complex, and it has a vast development scope. Hopefully this project will provide convenience to consumers and move towards clean and renewable energy.

Contribution of this Study

Nation

1. Provide an electrical method for electrical generation with enhanced efficiency through high absorption solar cell.
2. Improves Grid Security with the widespread use of solar energy. The grid is less vulnerable to blackouts.

Economy

1. Increase the generation of electrical energy through solar panel when an anti-reflective top layer coating is applied. Consumer will be protected against rising energy costs.
2. Malaysia's economy can achieve better with solar power. When there is a higher demand for this clean energy, more companies will be needed to install solar panels. As a result, there will be additional jobs for experienced workers, keeping the economy growing.

Society: beneficial towards human society because we do not have to depend on the non-renewable energy

Environment: Solar power in Malaysia represents a clean green source of energy and can reduce carbon footprint. Solar energy does not pollute the environment

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