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Prototype of human footstep power generator using ultrasonic sensor

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Abstract

Nowadays, the human need for electrical energy is getting higher. Due to the declining supply fuel, many efforts have been studied to find renewable energy. One of the studies is building a power generator system that comes from daily human activities. This paper proposes a human footstep power generator using ultrasonic sensor HC-SR04. Only by doing a simply walking on the ground floor, electrical energy can trigger. An HC-SR04 sensor measuring the spring distances from the footstep and activates the motor drive relay and generator that converts mechanical energy into electrical energy and stored in a battery. The test results state that the deeper of a footing step on the floor surface, the greater distance produced and the higher voltage can be generated. The footstep can trigger 7.5 V-8.8 V. Full battery condition can be used to turn on two pieces of 2-watt LED lamps for approximately 5 hours.

Keywords*: human footstep, power generator, renewable energy, ultrasonic sensor*

1. Introduction

The increase of human population has influenced by the enhancement of technology. This symptom leads to an escalation in demand for global energy use which derived from fossil fuels. The fossil fuels increased to exceed the needs of more than seven billion people in the world. This situation will undoubtedly cause an adverse impact on the environment. The excessive burning of fossil fuels not only depletes natural resources but also produces carbon dioxide emissions and causes an increase in the global average world temperature [1].

Some efforts have been studied by researchers to find the renewable energy that used as alternative energy that comes from nature such as solar cell, wind, water, wave, geothermal, and plants. The technology of renewable energy can convert any energy into the form of electrical power, heat, chemicals or mechanical [2]. The portion of total world energy consumption for renewable energy shown in Figure 1. The most of renewable energy comes from traditional biomass (9%), and the rest comes from various other energy sources (10%).

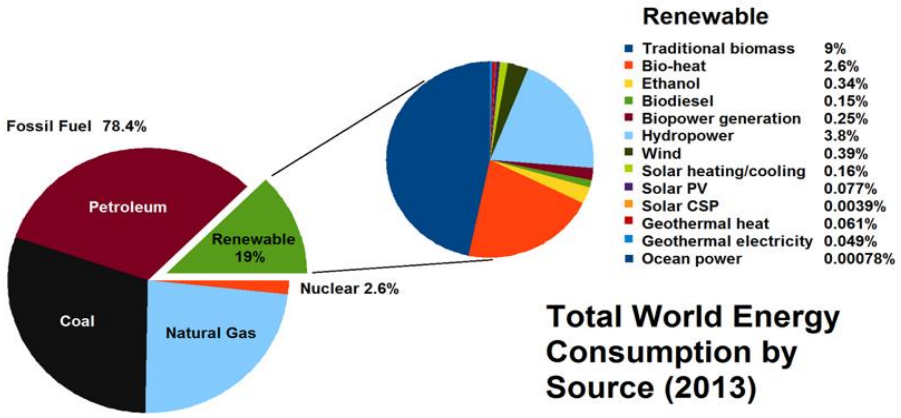

Figure 1. Total World Energy Consumption by Source 2013 [3]

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Based on the description above, efforts made to find and develop a natural fuel derived from renewable energy to be able to minimize the use of fossils as a primary fuel. One of the renewable energies is the energy which gained from the human activities. Walking is one of the events that can be produced and formed to be electrical energy [4]. The utilization of footsteps into electrical energy implemented on the floors in the mall, staircase, bus stair, dance floor, aisle or sidewalk, where a lot of pedestrians found, since the more pedestrians walk, the more electrical energy will be generated.

Many researchers have been developed power plant generator system for footstep by using a piezoelectric crystal as a pressure transducer, which is utilizing pressure and vibration on human footsteps [5]. Mathane Nitashree et al. [6], used many of piezoelectric sensor in each tile of dimension 26cm x 20cm x 0.08cm otherwise Nakirekanti et al. [7, 8], do research using pressure transducer to give the power for the street light. It is also the same construction with Mathane that they are using a lot of sensors to gained energy. Omkar et.al. also doing the same research using piezoelectric for floor dance [9].

There are other researchers doing research using an electromagnetic sensor. Kishore et.al. [10] using the electromagnetic induction by a moving magnet and Lenz's law to measure the electromagnetic induction. Joydev Ghosh et.al. [11] designed an electrical power using a construction of coil and gears using CAD tools and utilized electromagnetic induction using faradays law. But both of them, unfortunately, has the complex construction for designing tile.

Pavegen, a company in London, UK, initiated by Laurence Kemball-Cook, has produced floor tiles that generate electrical energy, but the production and the selling price are still high, it is above $100 per tiles in dimension 45 cmx60 cm [12, 13]. Meanwhile, in Dubai, there is also a researcher, Elhalwagy et al. [14] who is doing a study to increased the energy produced by piezoelectric tiles. Since the power that comes from piezoelectric tiles only 0.1 Joule of energy per second, he is doing a hybrid system using piezoelectric tiles and solar cell. The hybrid system produces 3.53 Joule of energy per step.

In this research, there will be designed an alternative construction of a prototype in dimension tile of sized floor tiles 50 cm x 50 cm x 10 cm that can be generate electrical energy which is derived from human footsteps using ultrasonic HC-SR04 Sensor, embedded with Arduino, relays, DC motors, generator, transformer step-down, balance charger and batteries. This prototype hope will be constructed from a low-cost production and gained more electrical energy from a human footstep. This simple prototype tested into several electrical devices like a LED lamp and a fan.

This paper organized as follows: chapter 1 explains the condition of energy nowadays and the need for renewable energy. Chapter 2 discusses the research method. Chapter 3 is the proposed system, which idescribes the architecture, dimension, flowchart of the proposed system. Section 4, discusses the testing scenarios to test the system and the discussion of the implementation system. Finally, the last section is a conclusion.

2. Research Method

This chapter discusses the research method for this study to achieve the objectives. According to the literature review on the introduction chapter, most of the researcher using multiple piezoelectric transducer and electromagnetic to trigger the system [15]. This research was trying to implement the combining of the ultrasonic sensor HC-SR04 and the spring compression as a trigger to generate the power to change the use of piezoelectric transducer.

The basic principle is needed to configure an efficient design. Figure 2 shown that sensor HC-SR04 is placed under the surface tile and designed with four compression springs. Sensor HC-SR04 was placed about 8 cm from the surface and located in the middle of the compression springs. When someone is stepping on the surface of the tile, the surface will slightly decrease down, because of the load. The sensor HC-SR04 generated. The surface pressed by the footstep and the length of the spring compression will be yield variation distance (x) between 0.5 cm until 1.5cm depend on the load of the footstep.

This research uses compression spring that has spring Constanta around 467 newton/meter, spring free length 3 cm, outer diameter 2 cm, inner diameter 1.7 cm. The correlation from the spring compression force in Hooke's Law [16, 17] into the voltage [18] calculated from the following equation:

$$F = k \text{ (Newton/meter)} \times x \text{ (meter)} \quad (1)$$

where:
F = Spring Compressing Force (Newton)
K = Spring Constanta (Newton/meter)
x = distance that yield by the spring (meter)

$$P = W \text{ (Joule)}/t \text{ (second)} = V \text{ (Volt)} \times i \text{ (Ampere)} \quad (2)$$

where:
P = energy of power (watt)
W = energy released by the voltage or Work (Joule)
V = voltage (Volt)
i = current (Ampere)
t = time (second)

Besides that, the combination of the DC motor and the generator also implemented into this system. The DC motor used to convert electrical energy into mechanical energy, and the generator used to convert the mechanical energy into electrical energy. The formula [19, 20] calculated as follow:

$$Pin = I \text{ (Ampere)} \times V \text{ (Voltage)} \quad (3)$$

where:
Pin = input power (watt)
I = current (Ampere)
V = voltage (Volt)

$$\omega = rpm * 2 \pi / 60 \quad (4)$$

Where:
W = angular speed (rad/s)
rpm = rotational speed in revolutions per minutes
phi = mathematical constant pi (3.14)
60 = number of seconds in a minute

After doing study literature and defined the correlation between the sensor, spring, motor, and generator the research will be proposed in the form of a prototype as the proposed system in chapter 3. The system will be testing the performance of the system related to the human footstep, analyze and discuss it to the previous research performance, such as the generated power in KWH, cost and complexity design. Other than that, this prototype also being tested to distribute the power into several electrical equipments.

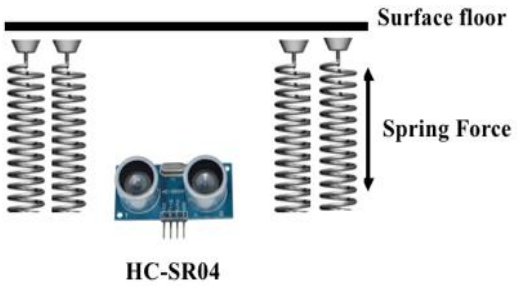

Figure 2. Design Sensor with Spring Compression

3. Proposed System

The system is designed consisting with ultrasonic sensor HC-SR04, DC motor, generator, relay module, spring compression, Arduino UNO, battery Li-Po, step down

transformer, balance charger, and LCD 16x2. HC-SR04 is a distance sensor based on ultrasonic waves, run in 40Khz, and has maximum range detection around 200-300 cm [21]. This parameter (distance) from HC-SR04 will activate the relay, and 9V DC motor will trigger the generator.

The generator then converts the mechanical energy into electrical energy. Relay module is an electromechanical component that consists of a coil and switch. The relay used as a switch contact that can conduct in higher voltage electricity. This system is using three pieces relay. Relay_1 is used to activates the DC Motor while relay_2 and relay_3 used to enable the charging modules (battery_1 and battery_2). Arduino Uno in this system used as processing microcontroller with all programming syntax systems. The lithium-polymer battery chosen as a storage place for electrical power that generated by the generator. This system uses two batteries. Battery_1 is used to provide power to the system itself while battery_2 can be used to provide power to electrical devices. This using of DC motor and generator as a driving force in architecture system is adopted based on the DC motor in PHS (Pico Hydro System) [22].

Figure 3 shown the architecture of the system and proposes into two modules, the charging module, and the power distribution module. The blue line illustrates the charging module while the power distribution module represented by the red line. When human make a step on the floor surface, the HC-SR04 will lit and send data to Arduino. The Arduino will activate the relay_1. Thus, relay_1 will activates DC motor and DC motor will activate the generator. The generator converts the mechanical energy into electrical energy. Since the voltage value that generated by the generator is unstable, the output from the generator inserted into transformation step-down and yield the stable voltage value. When the step-down already sends the stable voltage value, Arduino will activate the relay modules (relay_2 and relay_3).

The relay modules functioned to enable charging on batteries modules (battery_1 and battery_2). Battery charging was done through the balance modules (balance charger_1 and balance charger_2). Balance charging is used to stable the cell on the battery and protected the battery from the damaged and bulged. Battery_1 used as a power supply for the system itself, and the battery_2 is used as a power supply to electrical devices.

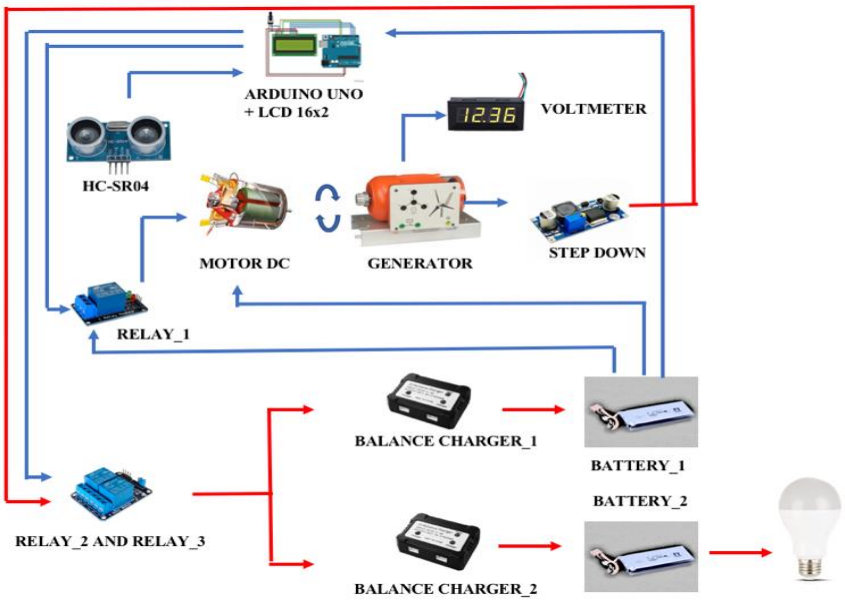

Figure 3. Architecture System

The flowchart of the system shown in Figure 4. On the flowchart, the value of parameter x is set equal to zero as a default when the system starts. Parameter x uses as

switch replacement between charging modules (charging battery_1 and charging battery_2). When the system is starting, HC-SR04 is ready to detect the footstep. When the footstep recognized, HC-SR04 send the data into Arduino microcontroller. Arduino will activate relay_1 module and activate the DC motor to rotate the system inside the generator. The generator will convert the mechanical energy into the electrical energy. When the generator has generated the value of electrical power, the system will have checked parameter x. If x is set equal to zero, then relay_3 will do a charging on battery_1 until the DC motor stopped. If DC motor stopped, parameter x will be set equal to 1 and when there is another footstep detected, relay_2 modules will do a charging on battery_2. This condition is continuously performed alternately depending on the value of parameter x that has initialized.

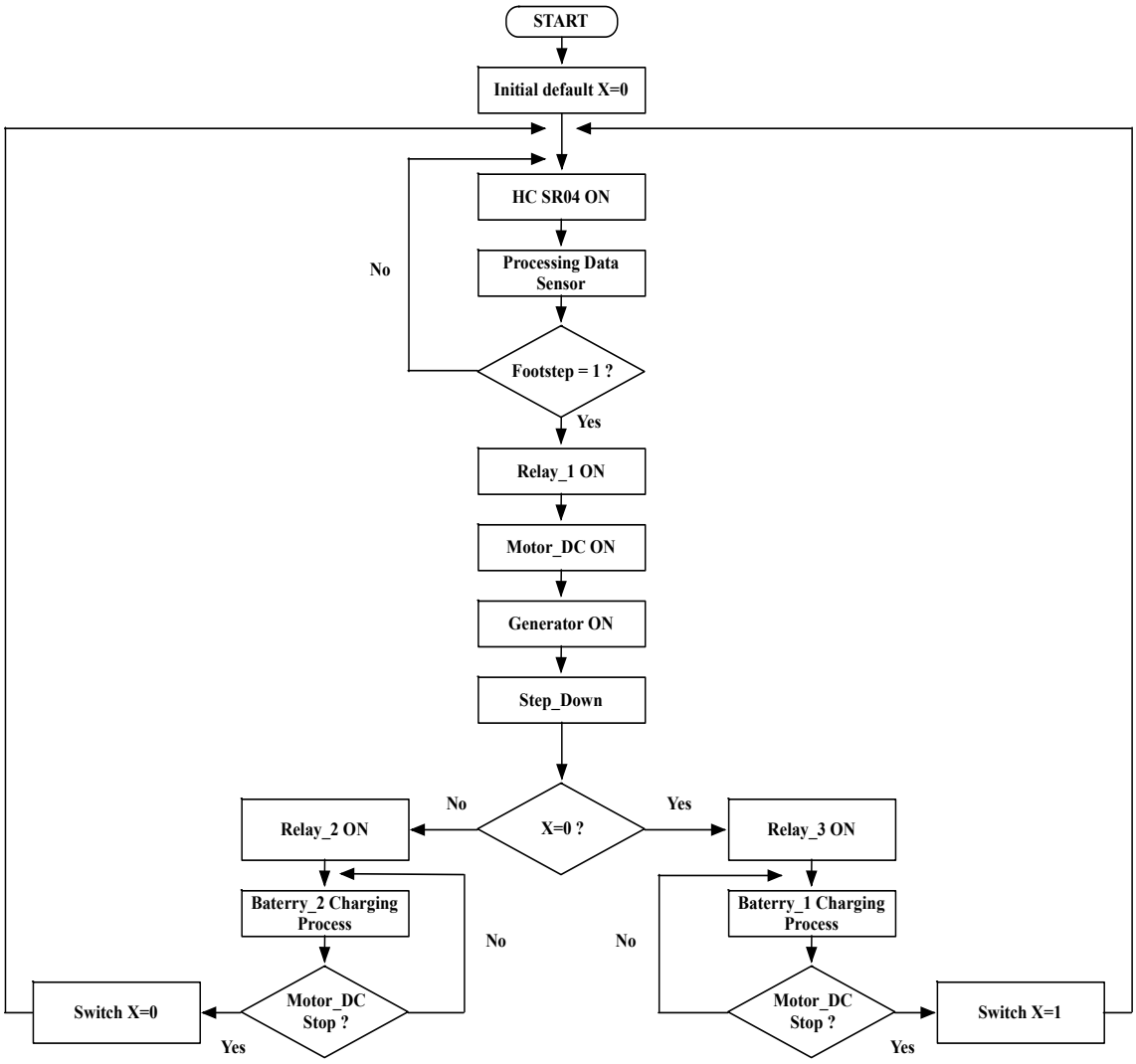

Figure 4. Flowchart System

The prototype of footstep generator system built in an acrylic material with dimension 50cmx 50cmx10cm and shown in Figure 5. It can be seen that all the device configurated in the architecture system above has been installed and embedded. Meanwhile, Figure 6 shown two-pieces of the push button, an LCD display, a voltmeter digital display, and two-pieces USB output line devices the push button is used to start on the system while the other push button functionates to begin the distribution the power supply to electrical devices. An LCD display is used to provide information about the current situation in the system. It could be informed,

"object detected" or "batt_1 active" or other information that has constructed in the system. Other than that, two pieces of USB input lines can be used to channel energy on electronic devices.

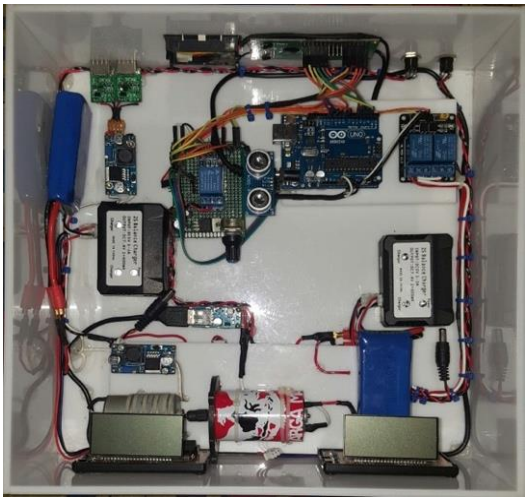

Figure 5. Prototype of Footstep Generation System

Figure 6. The Display System

4. Results and Analysis

4.1. Testing Result

To assess the performance of the proposed system, the testing system is done with two scenarios. The first scenario performs charging tests related to the rotating motor speeds. This scenario aims to find the average voltage value of the system depends on the speed of the DC motor rotation. DC motor rotates at different speeds depending on the load that generated from the footstep. The result of this scenario shown in Table 1.

Table 1. The Performance of Speed Motor Testing per Step

Variable	Speed (rpm)	Weight (kgs)	Spring Compression (cm)	Voltage (Volt)	Watt (Joule/second)
DC Motor	1600 - 2000	45	0.5	7.5	0.28
	2000 - 3100	55	1.0	8.0 – 8.2	0.35
	3100 - 3355	60	1.5	8.5 – 8.8	0.4

Based on Table 1, the DC motor rotation into generator effects the value of the voltage that has been generated by the generator. On a lite footstep, derived from human footsteps

weighing 45 kg, the generator will produce only 7.5 volts voltage, while on moderate footsteps which are derived from human footsteps weighing 55 kgs, the result is around 8.0-8.2 Volt. Meanwhile, the voltage produced by human footstep who has more than 60 kgs is 8.5-8.8 volt. The rotation of the DC motor also different based on the loaded footstep on the floor.

According to the previous research [14], the average power using piezoelectric sensors that can be generated from a person who has weight up to 60 kg, is 0.1 joule per second (watt) or equivalent with 2-3 volt. If it is compared to the result in table 1 above, it can be concluded that the electrical energy that produces by using HC-SR04 sensor is better than using piezoelectric sensors since it increases three until four times than energy that produced from piezoelectric sensors. For example, one hundred steps of a person that has weighed up to 60 kgs, can produce 10-watt by using piezoelectric sensors meanwhile by using ultrasonic sensor HC-SR04 it can produce until 40-watt. After performing the first scenario, the second scenario is done to test the energy supply from the baterai_2 through the USB line channel into some electrical devices. The result is shown in table 2. In Table 2, testing is done only for two devices. Since the system only provides two different USB line channel to test the power supply. The combination of the test consists of one LED lamp, two LED lamp, one LED lamp, and one fan. This duration tests done for 30 minutes until 60 minutes. Based on the result, it can be stated that if the battery_2 is in full condition (battery_2=100%), it can be used to light on two pieces of 2-watt LED lamps for approximately five hours, while the system lights a combination of a piece of 2-watt LED lamp and a fan in approximately 2.5 hours. The used of balance charger on the system functionated to maintain the Li-Po battery in supplying electrical energy into electrical devices.

Table 2. Electrical Supply Test

Baterai_2	Time (minutes)	Used Capacity Battery_2 (%)
A 2-Watt LED Lamp	30	9
Two pieces of 2-Watt LED Lamp	60	20
A 2-Watt LED Lamp and a Fan 12 V	30	18
A 2-Watt LED Lamp and a Fan 12 V	60	37

4.2. Discussion

This research may contribute to further research since this project is still in the prototype form that requires further enhance before entered lab test and mass produced. This research also can enhance by doing several prototypes, embed it with the serial circuit between the prototype to have a larger voltage to supply larger electrical devices [23].

This footstep generator system can be implemented in a crowded place with human activities such as a mall, markets, sidewalks, terminals, bus stairs, railway platforms, airport, up and down stairs to MRT station, dance floor, etc. Japanese country has tried to implement electric power generation floors on bus stair using piezoelectric sensor [6]. In addition, some countries in Europe also tried to implement this electricity producing tile on the dance floor and the street lights [7, 24, 25]. Even though in other countries the electrical energy for street lights implemented from the solar cell [26].

According to Table 3, Pavegen, floor tiles from London, UK, this purpose prototype can be built in a low-cost budget. The cost to build this the purposes prototype is only needed around $75 per tiles. While Pavegen price more than $100 per tiles. Meanwhile, the combination system between piezoelectric and solar cell still resulting in the best power system since it produces up to 60KWH per year per tile. The system which was built with piezoelectric design, still the cheaper cost but has the lowest power produced.

Table 3. Comparison the with the Previous Research

Technology	Dimension (cm)	Power Produced	Price (USD)	Ref
Pavegen Tiles	45 x 60	5 W continues step	175.84	[13] [14]
Piezoelectrics	100 x 100	0.4 - 0.8 W per 10 steps	27.87	[22]
Piezo with Solar cell	75 x 75	Up to 60KWH per year per tile	836.07	[12]
Purposed system	50 x 50	2.8 – 4.4 W per 10 steps	75	-

Although this purpose generator system seems to produce less energy than other energy sources (solar cell, wind, wave, etc.), at least in the future, the electrical energy which derived from footsteps can help reduce the using of the fossil as a major energy in the world. The using of combination the ultrasonic sensor and the spring compression can substitute the use of piezoelectric transducer. For example, in the future, the electricity for one mall can be used from electrical energy that collected and generated based on human footsteps who visit the mall and walking on their platform. This research is also needed to be improved by using a hybrid method in order to have more energy produced.

5. Conclusion

This system built in a simple and low-cost construction, using the HC-SR04 which is combined with compression spring in order to activate the DC motor to drive a generator that produces mechanical motion converted into electrical energy based on the load of the footstep. The entire system has its own energy derived from batterai_1 which also comes from the footstep itself. The more footstep pressure you get, the faster the battery will full.

According to the comparison with the previous research, the combination of the ultrasonic sensor and the spring compression can substitute the use of piezoelectric transducer since this purpose system can give more power produced and has a simple design. The Pavegen tiles still produce the highest power production while the piezoelectrics still produces the lowest power. Meanwhile, the combination of hybrid method between footstep generator system with other energy sources like the solar cell, wind, and others, can improve the power produced like the combination of piezoelectric with a solar cell.

Based on the resulting testing, this system can produce the energy three until four times higher than the previous research. The resulting testing of supply energy from the baterai_2, if it is full voltage, can supply the energy for approximately five hours to light on two pieces of 2-watt LED lamp with average decreased battery_2 capacity 20% per hour, while the system needs 2.5 hours to supply energy for a 2-watt LED lamp and a fan. The average decrease of battery_2 capacity is equal 37% per hour.

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