Energy Harvesting From Electric Power Line: A Brief Review

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Abstract
Energy harvesting systems are used with or instead of batteries to provide energy to low power devices such as sensors and sensor nodes. The most commonly used energy harvesting systems are those that obtain electrical energy from vibration. Because vibrations can be found intensively in the environment. In this study, the systems that produce energy by means of various circuits attached around wires carrying electrical energy are examined. These are generally piezoelectric and electromagnetic energy harvester systems. In the studies, the effects of the distance, the magnitude of the current flowing through the wire and the load resistance to be connected to the energy harvester were investigated. In addition, permanent magnet arrays have been used to increase the amount of power to be obtained in some applications.

Keywords: Energy harvester, power line, piezoelectric, electromagnetic

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1. Introduction

With the development of the Internet of Thing (IoT) system, there is a growing interest in low-power devices. Low-power sensor and sensor nodes have become very important in the recent years. These devices consume very low levels of power and are usually powered by chemical batteries. However, chemical batteries have some disadvantages, such as having limited life and leading chemical pollution. Wireless sensors and sensor nodes are often used in hard-to-reach places. In this case, replacing an exhausted battery can be quite difficult and sometimes even impossible. In order to cope with all these problems, the studies have been focused on batteryless systems. The general name of these systems is energy harvesting system (EHS). Energy harvesting is the process of obtaining energy from the solar (Song et al., 2019, Silva-Leon et al., 2019, Sharma et al., 2019), RF signals (Hameed et al., 2017, Uzun, 2016, Shie et al., 2018) heat changes (Kong et al., 2019, Hyland, 2016) and mechanical vibrations. Mechanical vibrations can be found in nature at very different amplitudes and frequencies. Electrical energy can be obtained many different methods from mechanical vibrations such as triboelectric (Song et al., 2019), wind (Silva-Leon et al., 2019, Raouadi et al., 2018), piezoelectric (Zhang et al., 2017, Bolat et al., 2019, Kurt et al., 2017), electromagnetic (Bolat et al., 2019, Fan et al., 2019), and electrostatic (Guo et al., 2019, Truong et al., 2019). Each of these systems has different advantages and limitations. For example, piezoelectric energy harvester circuits have advantages such as high energy density, high output voltage and high capacitance, but have disadvantages such as costly materials and coupling coefficient. The piezoelectric energy harvester requires specially made piezoelectric materials. It is also possible that these materials can be deformed over time. Electromagnetic energy harvester circuits have advantages such as high output current, long life, durability and cheapness. On the other hand, these circuits have disadvantages such as low output voltage and difficult adaptation to MEMS circuits. In addition, electromagnetic energy harvester requires permanent magnets and coils. That’s way, they can be bulky. Electrostatic energy harvester circuits have advantages such as high output voltage, easily adjustable coupling coefficient and cheapness, while have disadvantages such as low capacitance and start voltage are required. In these energy harvester systems, there are difficulties for controlling of gaps between layers.

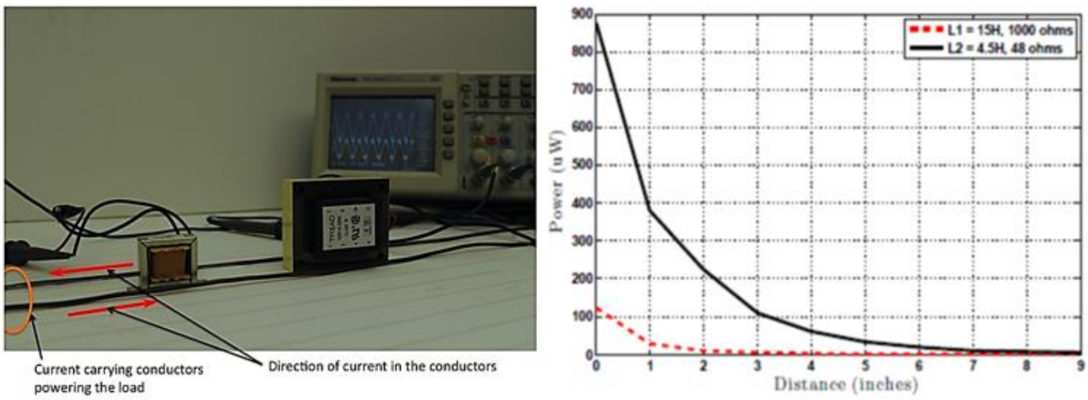
The voltage to be obtained from the vibrations will always be alternating. Therefore, it must be usable with an energy management circuit. In this process, voltage multiplier as rectifiers, impedance matching circuit and power control unit are generally used. The efficiency values of the elements to be used for the circuit are of great importance in determining the obtained electrical power.

2. Energy Harvester Systems for Power Lines

Monitoring of electrical power lines is vital for more secure and continuous operation. Measuring the amount of current flowing through the line, determining the probability of error by measuring the temperature of the conductor, determining the corona discharge by measuring the humidity, determining the breaks that may occur by measuring the ice load and taking precautions are some of these measurements. These measurements are made by sensors and transmitted to the related units. Batteries are generally preferred for energizing the sensors. Energy harvesting systems can be used instead of batteries or as additional power for continuous monitoring. Many studies have been carried out on the subject and are still being done. Some studies will be briefly mentioned here.

Gupta et al. (2010) conducted a feasibility study to obtain electrical energy from the electromagnetic energy of AC power lines. They have done many experiments with using various coils and current carrying conductor combinations. In the experiments using simple elements, they were able to obtain power in the order of 1-2 mW.

Figure 1(a) shows, experimental set-up with inductors placed between two parallel conductors carrying live and return current. They measured the voltage on the inductors to estimate the maximum available power from the magnetic field.



(a) (b)

Fig. 1. (a)Experimental design to obtain power from the magnetic field, (b) The obtained power depends on the distance (Gupta et al., 2010)

The power measured from a single current carrying conductor is shown in Figure 1(b). The inductor is placed in the same plane as the wire. The obtained power from the inductor varies inversely with the distance between inductor and wire. In addition, if the position of the inductor relative to a single cable is fixed, the voltage on the coil drops as the return current wire closes the other wire. If the conductors are close to each other, the magnetic fields destroy each other. This leads to a decrease for the obtained power.

Bhuiyan et al. (2010) obtained AC voltage by means of conductor layers placed on a current carrying cable using the transformer principle (Figure 2(a)). They converted the obtained voltage to DC with the help of a voltage doubler and used it to charge a battery. As seen in Figure 2(b), the battery was charged in normal large within one hour and fully charged in three hours. Their energy harvester harvests AC power and converts it into DC with voltage multiplier circuit. This energy harvester can provide 10 mW of DC power to a 50 Ω load. In addition, they presented an analytical which agrees well with measurement results with only error of 10%.

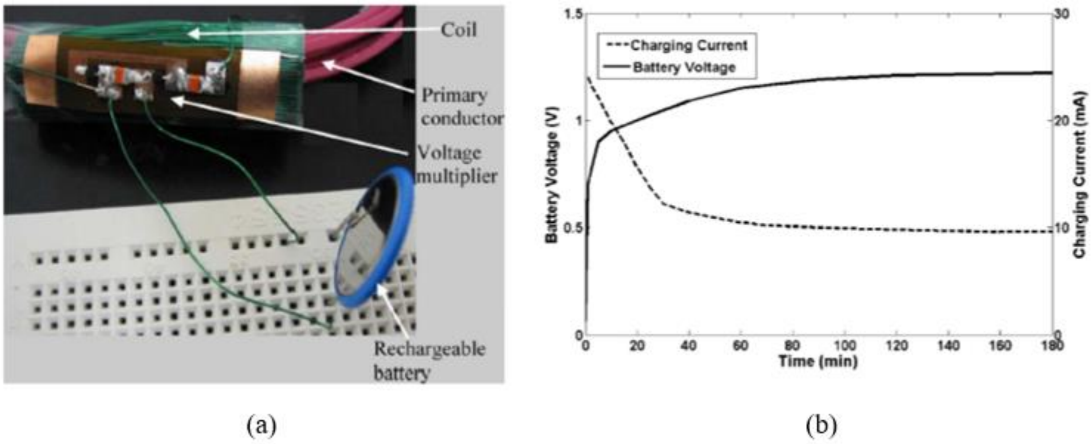


Fig. 2. (a) Energy harvester system, (b) Battery charge graph depends on time (Bhuiyan et al., 2010)

The researchers made observations by changing many parameters such as the layer width, layer numbers and air gap between the layers. If the distance between the layers is increased, the obtained voltage decrease. The increase in the number of layers and the increase of the width of the layers cause increase voltage

Guo et al. (2011) have designed an energy harvester that generates energy from wind vibrations and magnetic fields (Figure 3). The system is designed for HVDC power transmission lines. With the help of the wind, the system moves back and forth, thus generating electrical energy. Although the use of permanent magnets will increase the power obtained, researchers have not used permanent magnets to reduce costs. The power obtained is sufficient to charge the battery for continuous operation of a wireless sensor point.

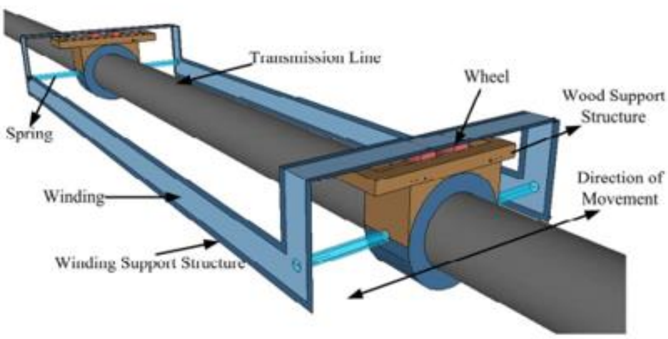


Fig. 3. For DC The proposed energy harvester utilizing from wind and magnetic field (Guo et al., 2011)

Moser et al. (2011) have designed an ice detection system for high voltage power systems using capacitance change. The obtained data transferred to remote computer via GSM network. All power requirements have been supplied from high voltage line by energy harvester. The prototype was prepared for a field test and mounted on a 220 kV line on an Austrian mountain pass at an altitude of about 1000 m above sea level. The field prototype successfully received and transmitted measurement data via a GSM network connection.

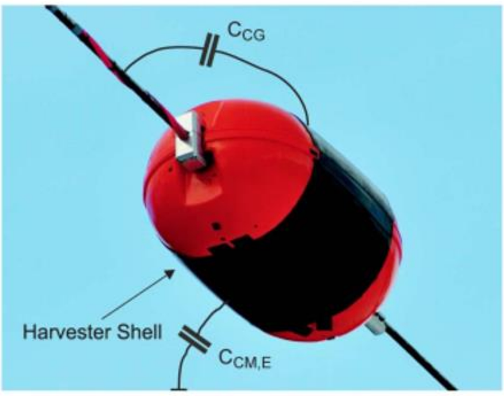


Fig. 4. For DC The proposed energy harvester utilizing from wind and magnetic field (Moser et al., 2011)

Chang et al. (2012) have introduced a new energy collection technology that uses the stray electric field of a power line. They have found that energy is collected and stored in a storage capacitor connected to a cylindrical aluminum foil wrapped around a commercially insulated 220 V power line including neutral, ground and phase wires. The average current flowing to the 47 µF storage capacitor is about 4.53 µA with a 60 cm long cylindrical aluminum foil and it was possible to operate the wireless sensor node to transmit RF data every 42 seconds. In this case, the average harvested power is approximately 47 µW. Since energy can be collected without removing the sheath, the proposed harvesting technology can be applied to the sensor nodes to provide power to the wireless sensor network and the intelligent grid system. Figure 5 shows the energy harvester system that obtains energy from power line using aluminum foil.

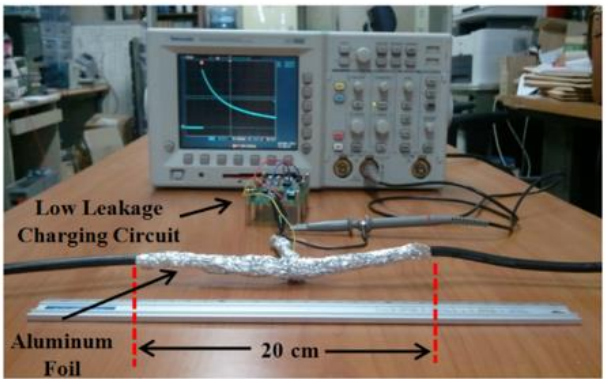


Fig. 5. The energy harvester obtains power from power line using aluminum foil (Chang et al., 2012)

Yao et al. (2013) presented a method of obtaining an electrical energy from the high-voltage transmission line based on the electric current sensor, in order to solve the power supply problem for the equipment or function module mounted in the high-voltage transmission line (Figure 6(a)). They have compared magnetic permeability, loss of hysteresis and other performance parameters of silicon steel and nanocrystalline materials. Then, they have selected the nanocrystalline magnetic material as the iron core of the sensor and calculated the number of turns of the electric current sensor. They proved that the obtained powew is enough for powering a monitoring module, if the current flows in the line between 0.5-40 A.

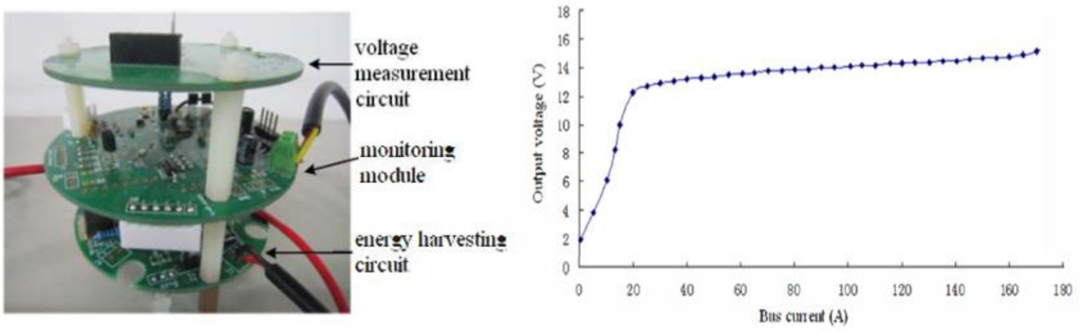


Fig. 6. (a) The energy harvester circuit utilizing from power line, (b) The output voltage depends on the bus current (Yao et al., 2013)

Figure 6(b) shows the obtained voltage depends on the flowing current. For current values below 20 A, the increase in obtained voltage is linear, and the voltage increases very quickly depending on the current for these current values. However, with the effect of the saturation in the core, the increase in the obtained voltage for current values above 20 A slows down.

He et al. (2013a) obtained electrical energy with the help of a piezoelectric energy harvester circuit attached to a conductor carrying energy (Figure 7(a)). Authors make theoretical and experimental works. The energy harvester circuit consists of a piezoelectric layer, a magnetic circuit attached to the end of the layer, and a mass load attached to the magnetic circuit to adjust the resonance frequency.

When the power line is energized, it generates Ampere force. The reaction force of the Ampere force acts on the magnetic circuit and then generates a bending motion on the piezoelectric layer. The bended piezoelectric layer generates an alternative voltage for each alternance. In this system, the frequency of the piezoelectric layer has the same frequency as the flowing current through the conductor, i.e. 50 Hz.

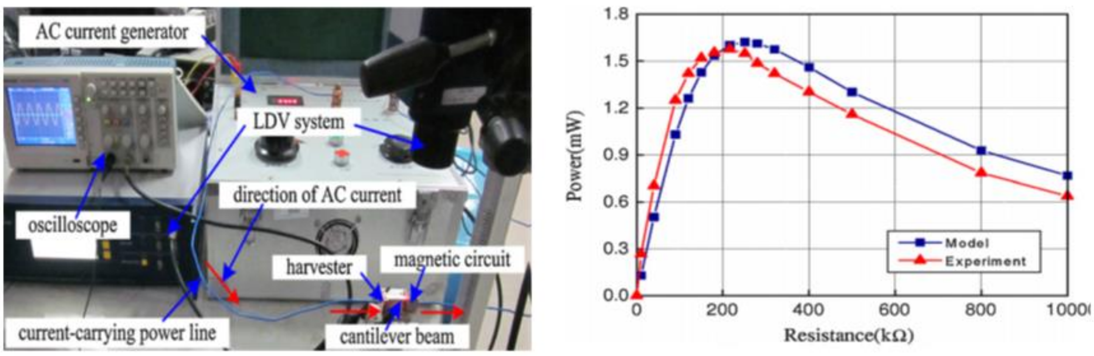
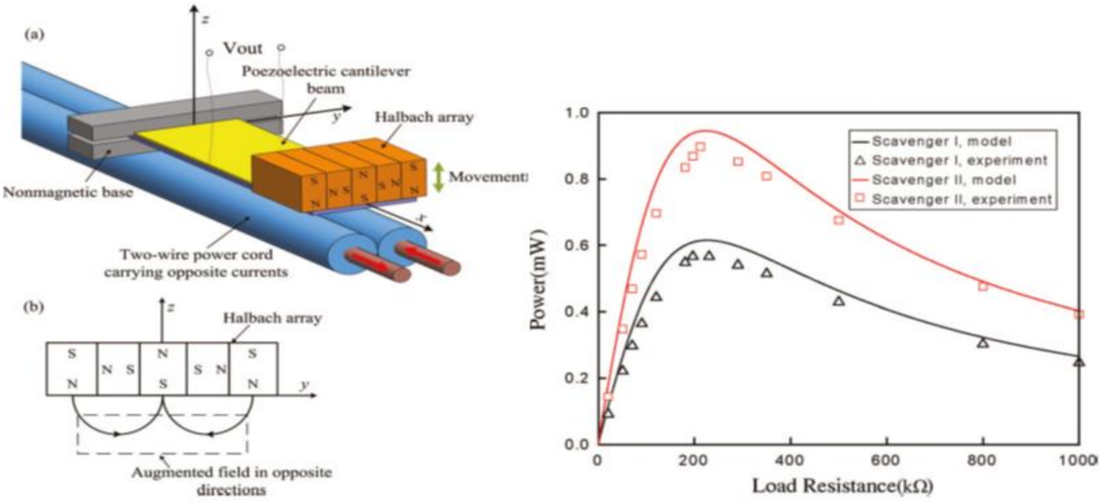


Fig. 7. (a) Experimental setup of piezoelectric energy harvester. (b) The obtained power level versus load resistance (He et al., 2013a)

As can be seen from Figure 7(b), researchers were able to obtain 1.58 mW of power at 216 kΩ resistance for 6 A flowing current. Although this power value is low, it is continuously obtained as long as current flows through the wire and is not very dependent on environmental conditions. However, other vibrations are not continuous and directly dependent on environmental conditions.

He et al. (2013b) have designed a harvester that generates energy by utilizing the alternative magnetic energy of the electric power line (Figure 8(a)). This system consists of a Halbach array with permanent magnets attached to the end of the piezoelectric layer to increase the energy to be obtained from a single conductor or two opposed conductors. Halbach array increases the magnitude of the vibration to be obtained by increasing the magnetic flux density, thus increasing the voltage value to be obtained. The researchers confirmed their theoretical work experimentally. Theoretically, the magnetic flux density produced by the Halbach array is analyzed using the magnetic charge method, and the current density distribution of the power line is obtained based on the solution of Maxwell's equations. It is possible to assume an even distribution of the current density at 50 Hz or 60 Hz on the conductor cross-section of a power line. After the magnetic flux density generated by the array is expressed as a power series of the transverse displacement of the proof mass over the volume of the power line, the electromechanical equations are solved to estimate the voltage and power generated. Other studies using Halbach arrays are available (Zhu et al., 2012, Wang et al., 2012)



(a) (b)

Fig. 8. (a) Piezoelectric energy harvester enforced by permanent magnets. (b) The obtained power versus load resistance (He et al. 2013b).

Figure 8(b) shows the obtained power values from a single wire (Scavanger I) and two wires (Scavanger II) consisting of phase and neutral. The graph is valid for 4 mm between the conductors and the energy harvester. For changes in obtained power at different distances, the corresponding paper can be checked. The authors obtained 566 μW with load resistance of 196 kΩ for Scavenger I and 897 μW with load resistance of 212 kΩ for Scavenger II. As can be seen from the figure, when the two conductors are used for this distance value and average optimum load value, the power obtained is 50% higher than the single conductor system.

Li et al. (2015) designed a high-efficiency management circuit using a multi-winding up-conversion current transformer in order to harvest energy from power lines. The management circuit consists of an amplifier matching circuit, two rectifiers, a storage capacitor, a control circuit, a burst generator and an instantaneous pulse discharge circuit (Figure 9(a)). This energy harvesting circuit basically obtains signals by means of a current transformer by electromagnetic induction. The management circuit makes the signal available efficiently. The circuit obtained with this multi-winding current transformer enabled a wireless sensor to be operated without batteries.

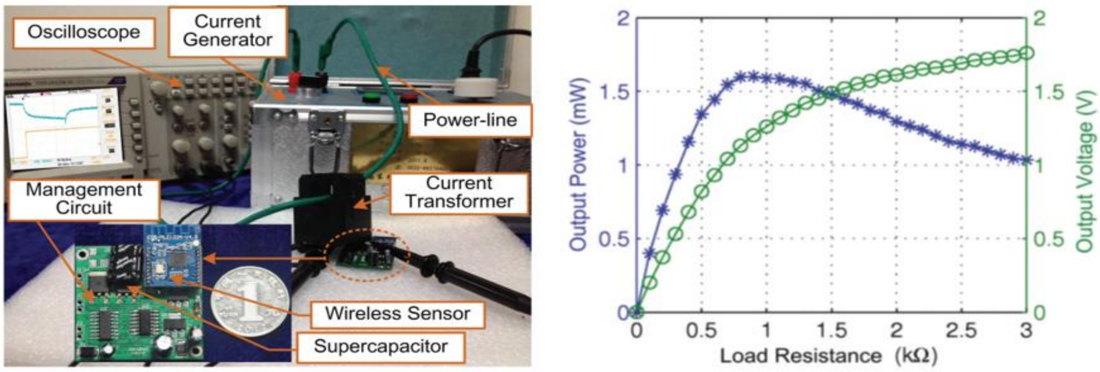


Fig. 9. (a) Overall EH system with management circuit and WSN. (b) The obtained voltage and power of the current transformer depend on load resistance for 1A power-line current (Li et al., 2015).

Figure 9(b) shows the output voltage and power of the current transformer depend on load resistance for 1A power-line current. The obtained energy by the system installed on a power line with a current of 1 A enables a wireless temperature sensor to transmit data in a lossless manner within a distance of 40 m. The authors claimed that using sensors with lower power consumption will increase the distance up to 300 m and this system can be used many different low frequencies EH systems.

3. Conclusions

Energy harvester systems are used in many different fields. It is possible to obtain electrical energy from many sources such as RF, thermal, solar and mechanical vibrations. The studies on obtaining electrical energy from vibrations are discussed to obtain electrical energy from a conductor carrying energy in this work. The general purpose of these studies is to provide the energies of the sensors to be used for monitoring the temperature, humidity and ice load conditions of the energy transmission lines. For this purpose, piezoelectric and electromagnetic energy harvesting are generally preferred. In addition, permanent magnets are used to increase the obtained vibration amplitude and the obtained amount of electrical power. Permanent magnets are an important factor in increasing the amount of the obtained power. The obtained power values are often enough to feed a low-power sensor.

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