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Comprehensive Review of Energy Harvesting Optimization Techniques

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Abstract- This paper aims to present a report on the study of the various energy harvesting techniques and the applications of various power electronics control devices to optimize the performance of energy harvesting systems. Energy-harvesting technologies with power management ICs eliminate the need for batteries, removing an obstacle to the success of the Internet of Things. The proliferation of devices and equipments requiring individual energy sources in the society at large creates a demand for continuous studies regarding enhancement of the energy harvesting systems.

Index Terms- Energy harvesting, Energy sources, Internet of Things, piezoelectricity, Smart Grid

I. INTRODUCTION

Energy harvesting (EH) also known as power harvesting is the process of capturing small amounts of energy [1] from external natural energy sources, accumulating and storing them for later use. The external sources could be solar, wind and light, from which the thermal energy, kinetic energy, heat energy and potential energy can be converted to electric energy. In many cases, EH devices convert ambient energy into electrical energy.

Energy harvesters provide a very small amount of power for low-energy electronics. The energy source for energy harvesters is the natural ambient environment. Energy sources are the by-products or waste components extract of other systems. For example, temperature gradients exist from the operation of a combustion engine and in urban areas, there is a large amount of electromagnetic energy in the environment because of radio and television broadcasting. One of the earliest applications of ambient power collected from ambient electromagnetic radiation (EMR) is the crystal radio.

The Energy Harvesting device depends upon the type of energy to be collected from the surrounding environment [2], whether vibration, light, or heat. The most common elements used are solar, piezoelectric, or thermoelectric. The various Energy Harvesting devices are : Ambient-radiation sources, Fluid flow, Photovoltaic, Energy from smart roads and piezoelectricity, Smart transportation intelligent system, Thermo-electrics , Electrostatic (capacitive),Magnetic induction, Metamaterial , Atmospheric pressure changes.

By combining suitable electronics, EH devices [3] can be used for creating a self-sufficient energy supply system. The merits of the system include the replacement or supplement of the batteries and the minimization of the associated maintenance expenditure, and the replacement of the power supply cables.

The paper is organised as : Section 1: Introduction, Section 2: Energy Harvesting Techniques, Section3: Energy Harvesting Applications and Advantages, Section 4: Energy Harvesting System Section 5: Survey on Energy Harvesting Optimization Studies Section 6: Conclusion and Future Scope

II. ENERGY HARVESTING TECHNIQUES

The energy harvesting techniques depend upon the type of source. The various energy sources are depicted in the Figure 1 below.

The actual technique to be employed will obviously vary according to the source and the form of energy to be harvested and also the load to be supplied - some will be very small (e.g. remote wireless sensors, etc.) others will be much larger (e.g. to provide energy for motors, etc.).

There are many technologies that can be used for energy harvesting.

- RF energy harvesting: This form of energy harvesting utilizes RF energy in the environment and converts into energy to power a small device.

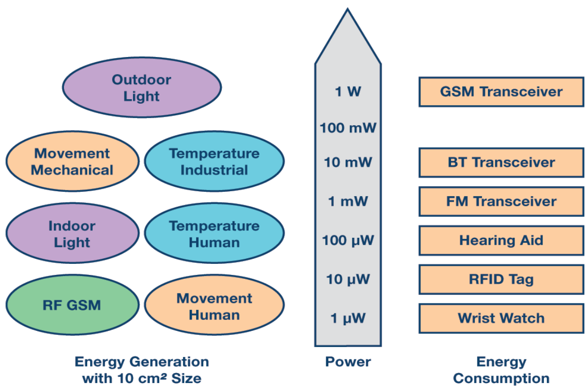

Figure 1. Different sources of energy and the required energy requirements for different applications.

- Piezo-electric energy harvesting: The piezoelectric effect converts mechanical strain into electrical voltage. This strain can come from many different sources. Human motion, low-frequency seismic vibrations and acoustic noise are a few examples. The piezoelectric effect can be implemented to harvest mechanical energy from walking. This energy can be converted into useful electrical energy that can be used to power wearable electronic devices such as sensors and Global Positioning System (GPS) receivers. Piezoelectric energy harvesting can also be used to power some consumer electronic devices directly such as cellular phones, two-way communicator
- Wind generators: Wind generator is a rotating machine that transfers kinetic energy from the wind into mechanical energy, which is converted to electricity. While large wind turbines can be used for the large scale harvesting of energy, small micro-generators can also be used. This form of energy harvesting is increasingly being used for powering small remote systems - some roadside signs and sensors use this form of energy harvesting.
- Solar cells: Collecting sunlight and converting it into electrical energy is a long known form of energy harvesting. Solar cells rely on the photoelectric effect, the ability of matter to emit electrons when a light is shone on it. Often they are seen with wind generators powering small roadside street lights, signs and sensors.

Researchers in Japan have set a new record for the efficiency of mass-produced solar panels, meaning even more of the Sun's energy can now be converted into electricity. The efficiency record for solar panels now stands at 26.6 percent - breaking the previous record established in 2015.

III. ENERGY HARVESTING APPLICATIONS AND ADVANTAGES

Energy harvesting is a rapidly growing industry. It is estimated that energy harvesting components will exceed $4 billion by 2020, which is significant considering that the market was $79.5 million in 2009 resulting in an average annual growth rate of over 73%. The current market leaders are Europe, North America, Japan and China.

There are a number of reasons why companies are investing in energy harvesting. They could be to reduce the cost of conventional energy drawn from the grid, utilize the energy available from the environment as heat, light; miniaturizing the equipment, increase efficiency, and above all using it for a wide range of applications within the organization by integrating with software and IoT technologies. Depending on the life expectancy of the system an upfront cost to use energy harvesting could pay off in the long run, even if the energy generated is not substantial.

One of the key applications for energy harvesting is wireless sensors. These are already deployed in many areas, specifically for smart meters, but the applications are growing as the technology develops and new ways to use the power are devised.

There are many applications based on EH in various domains like WSN (wireless sensor network), industrial applications [4] and biomedical applications etc., the concept of vibration energy been used to develop a piezoelectric shoe [5]. A 1 KW Thermoelectric Generator for low temperature geothermal resources was developed by Changwei Liu [6].

In Figure 2 the share of energy from various areas like traffic, transportation, residencies, public utility and service areas over the sensor network is depicted.

Major application of EH is for independent sensor networks. The aspect of the sensor network is illustrated in Figure 2. The sensor network consists of wireless sensors placed at various places, such as human body, vehicles, and buildings, in order to monitor the physical or environmental conditions, such as temperature, humidity, sound, pressure, etc. The data are gathered from the sensor nodes and communicated to data center through the gateway sensor node. The compositions of the sensor node are illustrated in the upper right side of the Figure 2. Sensor node consists of a radio transceiver with an antenna, a microcontroller, an electronic circuit for interfacing with the sensors, and an energy source. EH is attracting an attention for the embedded energy source of sensor nodes and is considered to be one of the key technologies of Internet of things (IoT)

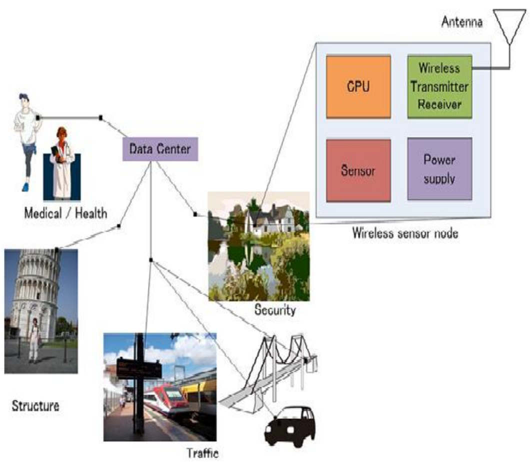

Figure 2. Energy harvesting applications

Other applications of energy harvesting include:

i. Remote corrosion monitoring systems.
ii.Implantable devices and remote patient monitoring.
iii. Structural monitoring.
iv. RFID.
v. Internet of Things (IoT).
vi. Equipment monitoring.

IV. ENERGY HARVESTING SYSTEM

A. *Energy Harvesting System Structure*

. The main elements of energy harvesting system are outlined in the Energy Harvesting System Architecture block diagram shown in Figure 3.

Energy Source: There are various energy sources for energy harvesting system. The energy harvesting system requires a source of energy such as heat, light, or vibration. Sources such as wind energy, solar energy, electromagnetic waves, thermal energy etc. are used.
Energy Harvesting IC: This IC converts ambient energy into some of energy which can be stored in energy storage devices. For example mechanical stress into electrical signal, temperature difference into electric voltage etc.

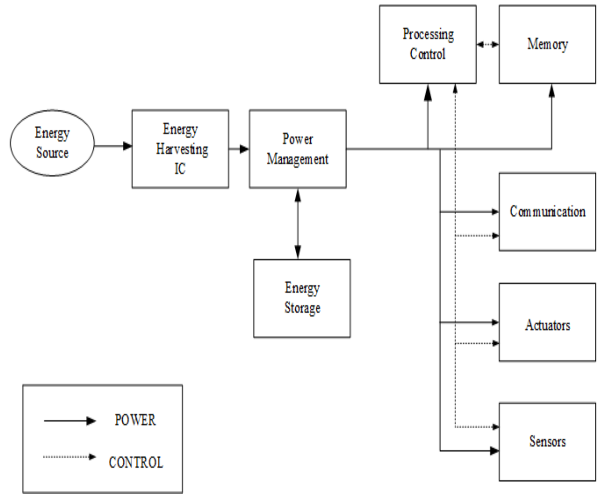

Figure 3. Energy harvesting system architecture

The power-management IC (PMIC) supports and manages the transducer and energy-collection channel, the energy-storage element (battery, conventional capacitor or super capacitor), and the processor/wireless link. This critical block of any energy-harvesting design implements several major functions:

- Captures and extracts the random, miniscule energy from the source transducer.
- Transforms that extracted power into energy for the storage element, usually via a DC/DC converter.
- Manages the outflow of power from the storage element, while ensuring that power is not drawn when the stored energy is below a threshold value and would be wasted.

Power management: This conditions the electrical energy into a suitable form for the application. Typical conditioners include regulators and complex control circuits that can manage the power, based on power needs and the available power.
Energy Storage: There are different ways to store energy which include rechargeable batteries, traditional capacitors, super capacitors etc. Super capacitors have characteristics viz. smaller size, higher efficiency, higher capacity etc.
• The other components are memory, actuators, communication interface, sensors, processing and control device such as microcontroller etc.

B. *Energy Harvester Properties*

The power consumed by the harvester should be very small so that its efficiency is high.
Efficiency of the Energy Harvester = Energy Output per unit time *100/ Energy input from ambient sources per unit time.

$$\eta = \frac{Po * 100}{Pin}$$

Energy harvesting circuits should have high retention, due to irregularity and infrequency of energy capturing activity. Low harvesting activity levels mean that it may be many hours before enough energy has been stored by the energy harvesting circuit to trigger some activities of SNs, such for example data transmission, sensing data, collecting data, etc.

V. SURVEY ON ENERGY HARVESTING OPTIMIZATION STUDIES

Yin-Jyun Hu et-al [7] have proposed a novel maximum power point tracking (MPPT) theorem for piezoelectric (PE) energy harvesting system. They have implemented double sampling technique and the Voc is predicted on the basis of point slope formula. The power electronic capability from piezoelectric harvesters is improved over the fractional Voc method.

Arish Shareef [8] et-al have proposed a topology to combine multiple low voltage piezoelectric energy harvesters in order to widen its harvesting frequency range and to improve its power output. Shared inductor scheme and a rectifier free approach were used for the architecture. They have implemented multiple harvesters to operate efficiently by harvesting the peak energy from each harvester. They have proposed this topology based on synchronous electric charge extraction. They found that the performance of the SECE circuit was a bench mark against the DBR circuit and they found the same when energy was harvested from very low input voltages. They also found out that the SECE circuit could harvest maximum energy from individual harvesters to achieve an impressive power conversion efficiency of 83%.

Adrian Enrique Aguayo et- al [9] have proposed a self-powered interface circuit for micro machined piezo electric energy harvesters [PEH]. They have implemented this system by using the synchronous electric charge extraction technique. They operated the proposed interface circuit from a low power of about 1.5 micro watts and from a completely discharged state, where PEH open circuit AC voltages were as low as 900mVpk.IT was found that this system could operate up to 7V with a high efficiency of about 86%.This scheme was proven to be a milestone in the non-linear charge extraction schemes for piezo-electric harvester as it can cold start from 0.9V.They have made an automatic selection where the system can start-up in two regimes :low-voltage (0.9-2.5)V using a charge pump and high voltage (2.5-7) V regime using a diode and they have utilized the same electronics.

Kanishka Aman Singh et-al [10] have proposed a non-linear vibration harvester which combines a non-linear bistable broadband piezoelectric cantilever. This cantilever is used to transduce ambient vibration energy with synchronized capture for efficient harvesting over broadband sources. They also proposed an accurate model of the bi stable transducer that augments the Butter worth van Dyke model to capture the external magnetic force which was added as a bias to the external vibrations. They have demonstrated its validity through physical implementation and experimental validation against simulation of the mathematical model. They have employed the SCE and SSHI, two non-linear extraction circuits used for efficient extraction of the transuded energy. The switching in these circuits was implemented using a fully self-propelled, low power electronic breaker circuit, which is capable of detecting extrema in the waveform to perform switching. They have also observed significant gains for broad band excitations.

NavidMohajer et-al [11] have tested and examined an electrical optimization in interference circuit after analyzing and modeling a designed Piezo-Electric Energy Harvesting System. The striking features of this scheme are using off the shelf components and a relatively simple structure of this circuit which was substituted for Standard Energy Harvesting Circuit (SEHC). They have found out that the piezo-electric cantilever can be used as a mechanical part which is the most efficient mechanism that can be used as a PHES due to considerable stress distribution and accessible resonance frequency for environment vibration levels. They have conducted a few experiments to obtain resonance and anti-resonance frequency as short circuit and open circuit condition respectively along with the optimal resistive load in these frequencies for extracting maximum amount of energy. Through these experiments, they have observed that the maximum power at resonance frequency was 24.9mW and at anti resonance frequency it was observed to be 25.15mW. The implemented results show that the net harvested power grows for the ambient vibration level higher than a specific value, though the accessible load voltage declines due to voltage drop in passive components.

Ramesh Vaddi et-al [12] have proposed an enhanced -bias flip rectifier topology that can improve power extraction capability from piezoelectric harvesters. They have found out that the proposed rectifier topology has 4 times more output power over conventional full-bridge rectifiers and voltage doublers. It has also been shown that it has 3.25 times maximum output power in comparison to existing bias-flip topology. It consumes ultra-low power (less than 6 micro watts) and achieves a near ideal inversion coefficient required for perfect bias flipping. For a given piezo device model parameters and load condition, it was observed that the bias flip rectifier reaches nearly 130 micro watts, whereas the existing flip rectified topology had 40 micro watts and the conventional full bridge rectifier topology had around 10 micro watts.

VI. CONCLUSION AND FUTURE SCOPE

Energy harvesting is a potential power generation option for electronic systems in many scenarios, including inaccessible locations, high-density deployments, and long-term applications with no battery replacements. We presented an overview of these considerations.

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