A Survey of Energy Harvesting Sources for IoT Device

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***Abstract*— *Environmental Energy is an alternative energy for wireless devices. A Survey of Energy Harvesting Sources for IoT Device is proposed. This paper identifies the sources of energy harvesting, methods and power density of each technique. Many reassert have carried to extract energy from environment. The IoT and M2M are connected through internet or local area network and these devices come with batteries. The maintenance and charging of batteries becomes tedious due to thousands of device are connected. The concept of Energy harvesting gives the solution for powering IoT, M2M, Wireless nodes etc. The process of extracting energy from the surrounding environment is termed as energy harvesting and derived from windmill and water wheel, thermal, mechanical, solar.*

Keywords*— *Energy harvesting, Environmental energy, Mechanical Turbine, MPPT, Piezoelectric material, Power management, Thermoelectric Generator.

I. INTRODUCTION

The main focus of WSN (Wireless Sensor Network) is energy efficiency as nodes of networks are powered by batteries. The recharging operation of batteries is slow, expensive and also decreases the performance of the network. The battery operated WSN fail to provide the requirements of many emerging applications for the network. The energy harvesters combined with the use of rechargeable batteries and super capacitors for energy storage are suitable for WSN operations. The nodes of the WSN are capable of extracting energy from the surrounding environment.

The Energy harvesting is also playing an important role in providing energy to IoT (Internet of Things) devices where billions of wireless sensor nodes are deployed. The Energy harvesting also known as power harvesting or power scavenging or ambient energy is a process by which energy is derived from external source i.e., solar energy, mechanical energy, thermal energy and wind energy are captured and stored for later use. IoT and M2M (Machine to Machine) are mainly with wireless sensor terminals located to collect data. Powering these devices is a big challenge. Using conventional batteries is not always advantageous since they require human intervention to replace them. Hence acquiring the electrical power needed to operate these devices is a major concern. An alternative type of energy source [1] to conventional batteries is the energy harvesting. Energy harvesting technology uses solar cells, piezoelectric elements and thermoelectric element to convert light vibration and heat energy into electricity to the IoT devices.

In this paper we discussed the various types of energy harvesting, types of energy source available for harvesting and comparison of all methods. The major components of IoT and M2M devices are wireless sensors, energy harvesting transducer, energy processing sensor, microcontroller and wireless radio.

II. SOURCES OF ENERGY HARVESTING

The four main ambient sources of energy harvesting are Solar, Mechanical, Thermal and Wind energy.

Table.1: Comparison of power outputs from energy harvesting technologies.[2]

Type of Energy	Harvesting Method	Power Density
Solar	Solar energy-out doors Solar energy-indoors	15mW/cm^3-bright sunny day 0.15mW/cm^3-cloudy day 10-100µW/cm^2
Mechanical	Vibrations (piezoelectric-shoe insert) Vibrations(electrostatic conversion) Vibrations(electromagnetic conversion)	330µW/cm^3 0.021µW/mm^3-105Hz 184µW/cm^2-10Hz 306µW/cm^3-52Hz
Thermal	Thermoelectric—5°C gradient	40 μW/cm^3
Wind	Wind flow	16.2 μW/cm^3 —5 m/s

These harvestings which is used to replace or charge batteries includes electrodynamics, Photovoltaic, Piezoelectric, radio frequency and thermo voltaic. The power densities of the above techniques are given in Table1.

III. SOLAR ENERGY HARVESTING

In solar energy harvesting, solar cells collects the sunlight and convert into electricity. Under optimum condition solar panel are rated at 15% to 20% efficiency and varies under optimum conditions. The solar panel reduces its efficiency of conversion during rain, cloudy skies. Sun is the most rich in renewable energy source in the world. The earth receives solar energy in an hour is greater than the energy consumed in a year. This makes the photovoltaic materials one of the most significant alternative energy harvesters.

Energy harvesting techniques (thermoelectric, piezoelectric, photovoltaic, etc.) requires additional components that increase the circuit complexity and cost of the device. Because of this wireless image sensor with on-chip array is used [3]. This paper focuses on the design and operation of the power management system including the pixel array. The CMOS Active Pixel Sensor (APS) array operates in photoconductive mode when imaging and photovoltaic mode when harvesting. The power management is performed using a single inductor boost/buck regulator. The boost regulator harvests energy from the sensor to charge onboard storage using maximum power point tracking.

For video monitoring applications energy harvesting power management unit is designed to get high power density. It generates a 1V regulated voltage from external photovoltaic harvester with super capacitor [4]. Here energy harvesting power management unit is based on the direct connection between photovoltaic cells and regulated power supply along with DC/DC converter. To exact the maximum power efficiency energy harvesting power management unit operation uses the Maximum power management technique. DC/DC convertor with MPPT controls the harvester voltage.

Semiconductor companies have developed controllers to optimize energy harvesting from solar panels. One such approach is that using maximum power point tracking (MPPT) technique is applied to control illumination and temperature variation [5]. Also in this paper instead of using frequency modulation scheme the specific impedance tuning method is used. The result that they have achieved 20μW and efficiency of 89%.

An intelligent energy harvesting [6] system is based on MPPT for sensor nodes used in IoT to prolong the life of lithium batteries. This system uses RS triggers, which makes lithium battery charge only when the battery voltage is lower than a specific value.

Another proposes is an energy prediction algorithm that uses the light intensity of fluorescent lamps in an indoor environment [7]. In this propose the algorithm gives accurately estimated the amount of energy that will be harvested by a solar panel.

IV. MECHANICAL ENRGY HARVESTING

Mechanical energy harvesting is also called as waste energy harvesting is low power generations. Energies are harvested by using vibration electricity conversion. This conversion can be realized through these basic mechanisms including electromagnetic, electrostatic and piezoelectric transductions. Among these piezoelectric transductions used widely because of piezoelectric material. This material has large power densities. Solar energy is not suitable or not accessible for mobile and embedded electronics. In such cases mechanical energy in the form of ambient vibrations, machine rotation, bio-motion is representing the source of energy available all the time. Piezoelectric transducers will be used to harvest this energy ability to convert from mechanical to electrical energy.

Piezoelectric energy harvesting devices like MEMS generator or nanogenerators have added advantages of flexible and foldable power source. Which are mainly for biomedical sensors [8]. For Piezoelectric energy harvesting MEMS generator or nanogenerators implementation is by whip element that describes mechanical measurements [9]. Specific fabrication is also described in this paper. Here whip design is also compared with cantilever. The piezoelectric energy harvesting technology is also done based on cantilever structure.

Electrostatic energy harvesting is based on changing the capacitance of a vibration dependent variable capacitor. In order to harvest the mechanical energy a variable capacitor is created by opposing two plates one fixed and one moving is initially charged. When vibration separates the plates mechanical energy is transformed into electrical energy from the capacitance. Energy can be harvested by using electric field which will be used to operate low power wireless sensor nodes. This can be done by using aluminum foil is wrapped cylindrically around an insulated AC power line [10].

Electromagnetic energy harvesting is based on Faraday's law of electromagnetic induction. An electromagnetic harvester uses an inductive spring mass system for converting mechanical energy to electrical. It induces voltage by moving a mass of magnetic material through a magnetic field created by a stationary magnet. Vibration based electromagnetic transducer provides a peak voltage of 3.25v and operated at mechanical resonance frequency about 10.4Hz [11]. The power converter has been designed and this converter transfer harvested energy to a storage capacitor.

V. THERMAL ENERGY HARVESTING

Thermal energy harvesting is the process of converting thermal gradients into electrical energy through thermoelectric generators (TEGs). TEG comes with ceramic plate’s one side warm and other side cold, it generates electrical energy i.e., converting the heat flux into electrical energy. Energy can be generated of a few degrees, for example between a human body and the surrounding air. These sources of energy ranges from microwatts to kilowatts. The dynamic behavior of temperature changes due to evident changes in the surrounding environment between day and night, changing weather and seasonal changes results in varying energy generation. To ensure a stable power source to the various applications, power management circuits are used. Standard components i.e., ICs are available. Further in the case of using a thermal generator to low temperature gradients, the generated voltage is in the 10 mV that needs a very good converter design. Using those power converters ICs power conversions rarely covers below 1V.

A low temperature thermal energy harvesting system is designed, which can harvest heat energy from a temperature gradient and convert it into electrical energy. Heat energy from a radiator and use it to power ZigBee electronics. This system gives efficiency and long system lifetimes are two of the main advantages of this design. The results show that[12] a maximum of 150mW power can be harvested voltage is as low as 0.45V.By using two AA batteries this thermal energy harvesting system, a ZigBee Wireless Radiator can operate for more than eight years.

Thermoelectric generators (TEG) are uses thermal gradients in the environment can be converted into electric energy for powering the wireless node. Thermoelectric generator is used to extract the energy from environment for example monitoring the working of the industrial engines which can exploit excess or wasted heat when they are running. Another example is that monitoring health of the patient in hospital, excess heat can be generated from body of the patients [13]. Here the WSN uses the power management. This power management system adapts the system performance by changing duty cycle to consume energy as much as possible. A low power complexity power management reads the voltage of the super capacitor to consider the duty cycle of the wireless sensor node.

The design of thermoelectric generator (TEG) using complementary metal-oxide-semiconductor CMOS-MEMS technology is done [14]. The design consists of p-doped and n-doped polysilicon thermocouple arranged electrically in series and thermally in parallel in order to increase the temperature difference between the cold and hot parts. The simulation result gives the temperature difference of 10k and output voltage of 301mV and 45μW power. These values are suitable for low power devices like wireless sensor node.

VI. WIND ENERGY HARVESTING

Wind energy is extracted from wind using mechanical turbines. These turbines capture the wind energy with the help of two or three propeller-like blade. These turbines are high towers to capture stronger and less turbulent wind. Speed of the wind decides efficiency and economy of the wind energy application. Wind is caused due to uneven heating of earth, irregularities of the earth's terrain and also from the rotation of the earth. Wind which rotates the blade and spin a shaft of the turbine, which produces the electricity through generator. Since wind speed is higher at high altitude and also less turbulent, so wind turbines are to be placed at higher hub heights. The power that turbine generates is a function of the cube of the wind speed.

The model is design to extract the wind harvesting, that translate a weather forecast into a corresponding energy harvesting prediction. Architecture designed here is retrieve the weather forecast from internet and transmit this information to the end device. In this they also propose different power management policies two of them exploiting the use of weather forecast to improve the prediction accuracy for WSN and also they propose Adaptive Response Rate Single Exponential Smoothing (ARRSES)-based power management [15] policies for predicting wind harvested energy in the context of autonomous WSNs.

Pendulum-based generation system is used. Planar device uses the rotation to produce energy for generator. Planar generator extract the kinetic energy which will obtain due to the oscillation of the body motion and also portable biomedical device can extract energy from every day walking to extend life of the battery. The main purpose of this to study is how much energy is generated using pendulum-based generator due to body motion. The produced energy is also depending on location. This uses mainly in bio-medical applications. Theoretical work gives 20X [16] the energy which is available for pendulum-based generators on the elbow while walking and up to 10X at the hip. This is useful for health monitoring applications for biomedical devices.

A wave roller energy harvesting system has been designed and manufactured [17]. This system harvest that the sea wave energy to produce electricity. Wave roller system is a wave energy converter. The simulation result helped in study of undersea conditions. In this they have suggested that the further work can be carried out for hybrid (wind and wave) system is design that generates electricity from both wind and waves. Wind turbines are used to produce electricity from wind in deep sea.

VII. CONCLUSIONS

Internets of things are deployed with billions of devices. To avoid the replacement of batteries and its cost, the WSNs require energy harvesting. The Energy harvesting allows on-site charging of rechargeable batteries, which can be cycled hundreds of times before their performance degrades. With proper hardware and energy management, lifetime of the battery can be extended almost indefinitely. The Energy harvesting harvests or scavenges energy from a various ambient energy sources and converts into electrical energy to recharge the batteries of IoT devices. Solar energy scavenging system consists of an energy source as photovoltaic cell exposed to either direct sunlight or even indoor lighting. These photovoltaic cells are capable of generating very good power. These energies are collected in a good manner using energy harvesting circuits. Since the sun is the richest renewable energy source in the world and the solar energy which earth receives in an hour is greater than the energy consumed in a year. Therefore the solar energy harvesting is the best one to be chosen for IoT device.

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