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RF and Solar Energy Scavenging For IoT: A Survey

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ABSTRACT

IoT is causing a huge economic and technology wave in various sectors like automation industry, healthcare, physical security, building management, waste management, vehicle monitoring and many more. IoT connects billions of "things" which communicate with each other. Supplying continuous power to these "things" which are essentially devices is a big challenge. Major research is happening in this direction in terms of improving battery capacity, improving microcontroller clock cycles and so on. Self sustainable system is a key issue of IoT. Energy harvesting is fundamentally a different approach of addressing this problem. The development of efficient energy generation or harvesting method will prove instrumental for IoT. There are several energy harvesting techniques however RF and solar energy are more viable since they are available in abundance. So these sources are discussed in detail here. The energy harvested can then be stored using supercapacitors.

Keywords: IoT, energy harvesting, RF, solar energy, Supercapacitors

I. INTRODUCTION

IoT(Internet of Things) can drastically change the world by smartly connecting things, saving time and effort. IoT has vast applications in many fields however; several issues like lack of end – to –end standards, cyber security and lack of business model limit the scope of IoT [1]. In IoT, sensors are small and cheap, which can be placed everywhere. For better efficiency of the system, more sensor data is required. The advantage of IoT is that this sensor data can be shared and reused between different partners. The challenge lies in deploying large number of sensors and actuator nodes and to connect them in suitable manner. Another challenge in IoT is the interconnection between "Things" while taking energy constrains into account since, all the sensors and actuators will require continuous power supply. Main requirements for such deployment are discussed below:

A. Key requirements for deployment:

IoT requires its wireless sensor terminal to be placed at all kind of location to collect the data. The requirements such deployment are given in table 1[2].

Installation effort	Many new sensor and actuator nodes are to be deployed with minimum installation complexity and there should be scope for upgradation as well.
Service and maintenance effort	While creating large scale networks, the service and maintenance required by individual nodes has to be minimal. Also the communication between all parties involved has to be rolled out.
Battery cost and its replacement	To ensure continuous operation, constant battery supply is required and hence it has to be recharged or replaced from time to time, which increases

	the cost.
Reliability	When sensor information and actuator commands are exchanged over the Internet reliable data exchange is necessary.
Total cost of ownership	The total cost of ownership such as unit cost, installation cost, operation cost and maintenance cost, must be low.

Table 1: Key requirements for deployment of wireless sensor nodes

These requirements can be met by energy harvesting wireless sensor nodes which use ambient energy as power source where cables or batteries fail.

B. Ambient sources for energy harvesting

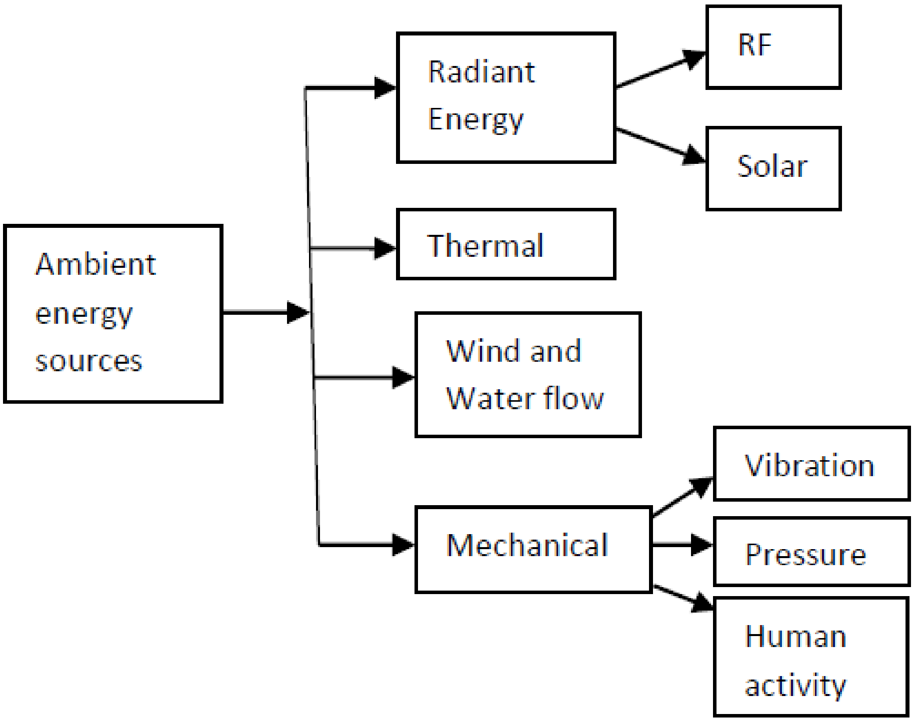

Fig. 1: Energy from ambient environment

Various ambient sources shown in fig.(1) [3] which can be used for energy harvesting are mentioned below:

1. Radiant energy: It comes from EM waves such as radio frequency signals, Ultra violet waves, visible light etc.

a. RF energy: It can be harvested from RF source like RF transmitter, base station antenna, radio and TV signal, mobile devices and Wi-Fi.

b. Solar energy: It is a huge energy received by the sun and is always available. It is gaining popularity nowadays and can be harvested by photovoltaic cell or solar cell.

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2. Thermal energy: Thermal energy can be harvested by using thermoelectric transducer. Human body and environment always have difference in temperature, which can be used as a source of thermal energy.
3. Water flow energy can be used to harvest energy using turbine or piezoelectric. Typically impulse or reaction turbines are used. Whereas the vertical or horizontal axis wind turbines are used to harvest the energy from wind.
4. Mechanical energy: It is based on motion or kinetic energy of an object. Vibrations, pressure or human motion can be used to generate energy. This kinetic energy can be converted into electrical energy using piezoelectric transducer or electromagnetic converter.

In this paper, energy harvesting using RF energy and solar energy are discussed in detail.

The paper is organized as follows:

Section II discusses the operation of energy harvesting terminal. Section III describes how energy can be harvested from RF energy and Section IV describes solar energy harvesting. Section V analyses the storage of harvested energy using supercapacitors. Section VI is the conclusion of the paper.

II. ENERGY HARVESTING TERMINAL

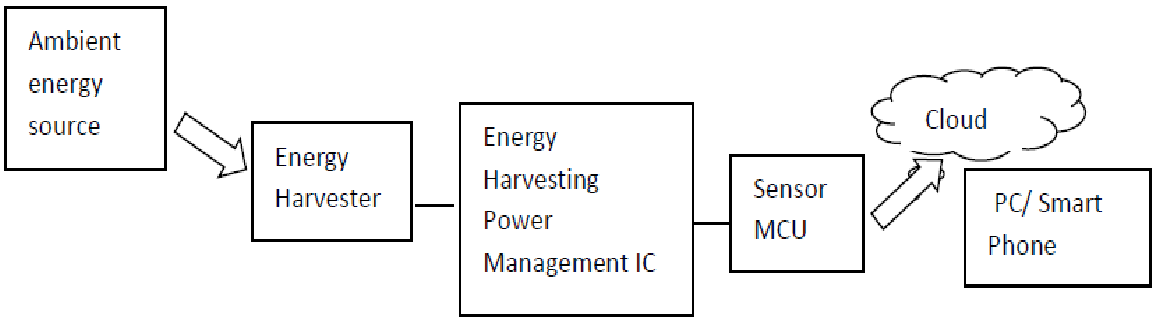

Fig.2 Wireless Sensor Network with energy harvesting

As shown in figure 2[4], energy harvester receives energy from ambient energy source. Sensors are used to sense the surrounding environment. MCU processes the collected data and it is used for system control. Wireless chip is used for wireless communication. Energy harvesting power management IC replaces conventional battery.

The energy harvesting element should be suitable selected depending on the type of energy to be collected from the surrounding environment, whether RF energy, vibration, light, or heat. The most common elements used are solar, piezoelectric, or thermoelectric. The power IC should collect the power efficiently from that element without any loss and it must supply the stabilized power.

Further, the selection of energy harvesting element also depends on distance of communication, the type of network to be built, the application, the data transmission amount, and the power consumption. Power generation and power consumption should be balanced. To determine optimal size of power collecting element(capacitor), power collection time and the usable electric load should be analyzed.

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III. ENERGY HARVESTING USING RF ENERGY

Radio spectrum is becoming highly populated due to new technologies like GPS, Wi-Fi, Radar, cellular and satellite among others. Every frequency band used in these technologies, has a standard, which decides how it is used and RF power to be transmitted. Unlike other energy sources, RF signals are purposely generated and regulated. With the advent of growth of smart phones and tablets, RF energy density will continue to increase every day and hence harvesting RF energy from Wi-Fi, cellular networks can offer a very good solution to power low energy IoT devices. Sufficient level of RF energy is required to harvest energy from it [5][6].

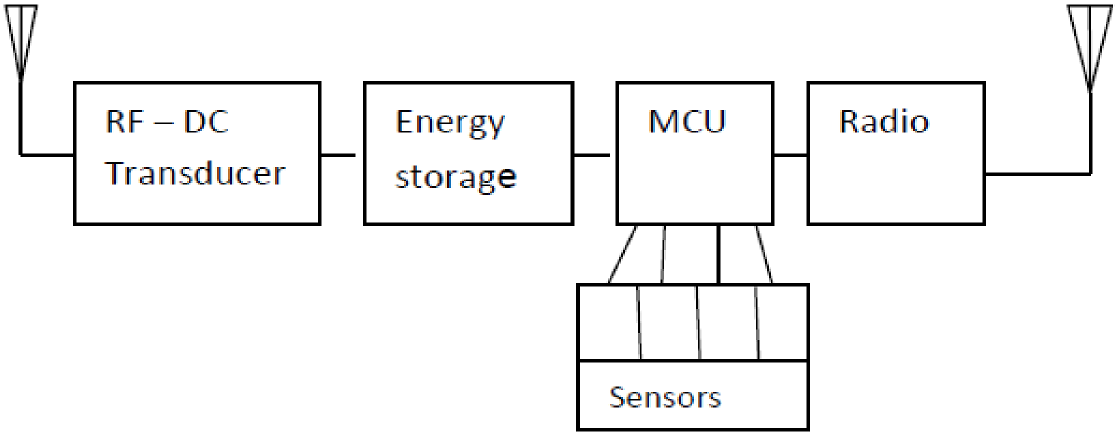

Fig. 3: Energy harvesting using RF Energy

Energy harvesting using RF Energy system is shown in figure.3. Receiving coil or antenna which generates a voltage in response to electromagnetic coupling with RF transmitter, works as an energy source. RF – DC transducer converts received energy into DC. Maximizing the output from the transducer at a given ambient energy level is the main challenge. Super capacitor can be used to store this harvested energy to power MCU. MCU receives data from various sensors. After processing the data, appropriate signals are transmitted.

The efficiency or the effectiveness of the system depends on the type of transducer, the condition under which it operates and on the power levels of the nodes including MCU.

IV.ENERGY HARVESTING USING SOLAR ENERGY

Energy from sunlight is a very good source of clean energy which will never exhaust. It is being used since many years to power small devices such as calculators, wrist watches, etc. Photovoltaic materials which absorb photons can be used in harvesting solar energy. The output from photovoltaic material depends on the intensity of light and hence it should be kept under good lighting environment. With the recent development in manufacturing of optoelectronic components, energy harvesting using solar cell can reduce the cost of overall system [6]. Energy harvesting using solar energy is illustrated in figure.4.

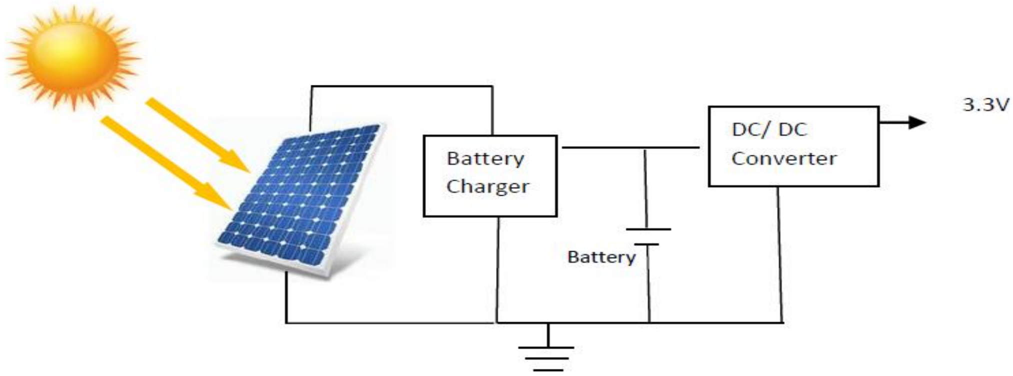

Fig. 4: Energy harvesting using Solar Energy

This system has few limitations as well. As it relies on sunlight, efficiency is low during cloudy days. Further, it is limited to daytime for outdoor environment. Light energy to electrical energy conversion efficiency is low (15% – 20%). Another limitation is that battery is always required to operate the sensors continuously.

To overcome these limitations and to maximize the efficiency, controllers are developed by semiconductor companies. These controllers use Maximum Power Point Tracking (MPPT) technique, in which higher voltage DC from solar array panel is converted to lower voltage DC needed by battery bank. Input current and voltage are monitored by MPPT algorithm. It controls the duty cycle to maintain the MPPT set point needed to maximize the energy output from photovoltaic cell. With this technique, efficiency can be enhanced to around 93% – 97%.

V. ENERGY STORAGE USING SUPERCAPACITOR

Once energy is harvested for IoT sensors using RF, solar or any other ambient source, it needs to be stored. This is where supercapacitors come in. They provide an easy and efficient way of energy storage better than regular batteries. Supercapacitors conceptually lie between capacitors and batteries [7]. Their power capabilities are higher than batteries but lower than normal capacitors. The energy storage capacity is lower than batteries but higher than regular capacitors. Supercapacitors use activated porous carbon electrode on which electrolyte ions get accumulated [10]. Due to porosity the electrolyte resistance is highest for the current at the bottom of the pores and lowest towards the opening of the pores. An alternate material for supercapacitors is using carbon nano tubes. They provide good conductivity but their solubility is low.

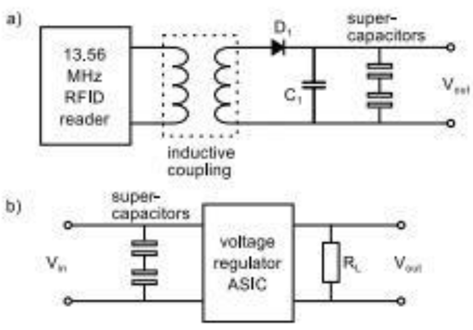

Fig.5 : a) Harvester charging circuit b) Harvester operation circuit [8]

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In [8] a demonstration of energy harvesting from RF energy using supercapacitors is shown. In this RFID reader is used as a source of RF energy which is then transferred to a supercapacitor kept in the vicinity. If higher voltage is required then similar supercapacitors are connected in series. The energy from supercapacitors is then transferred to the sensors using application specific integrated circuit (ASIC).

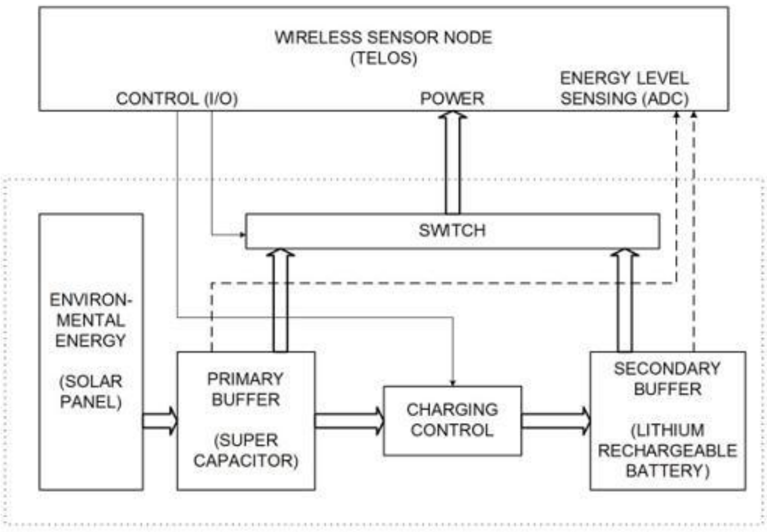

Fig.6: System architecture using solar energy [14]

In [14], a demonstration of energy harvesting using solar energy is shown. In this, a multistage energy transfer system is implemented with super capacitor as the first source of storage from the solar panel. This energy from supercapacitor is then suitably used to power different blocks of the system. A battery is also used but as a secondary source of energy.

VI. CONCLUSION

In this paper energy harvesting using RF and solar energy for IoT have been discussed. IoT requires trillions of sensors and electronic devices to be placed everywhere with self sufficient energy source like harvesting the energy from the ambient environment. Energy harvesting can reduce the requirement of battery and hence can reduce the total cost of the system. The scarcity of energy creates huge demand for energy harvesting and these requirements are met due to development of new products and services. Such development will give rise to battery free IoT connectivity and can be used in areas which are difficult to reach. RF harvesting can be used in wearable smart devices, medical devices and RFID tags. Energy harvesting using solar power is one of the most preferred methods as long as sun light is available. The efficiency of solar/ photovoltaic cell can be enhanced by using MPPT technique. Such systems are simple, efficient and highly reliable for outdoor based wireless sensor nodes in IoT, with low power loss. If various applications of IoT city adopt energy harvesting, it will move the world towards greener technologies benefitting the world globally. Further, various studies have shown that the performance of super capacitor is satisfactory for storing the harvested RF and solar energy.

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