GREEN ENERGY BASED ENERGY HARVESTING TECHNIQUES FOR WSN BASED RAILWAY INFRASTRUCTURE CONDITION AND TRAFFIC MONITORING AND CONTROLLING SYSTEMS

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***ABSTRACT*— The performance of the WSN based monitoring systems in Railway traffic monitoring systems is mainly is limited by the energy efficiency of the WSN nodes. Rechargeable batteries are deployed to supply electrical energy to the WSN nodes. Since the WSN Nodes are deployed at remote places near to the railway tracks or to monitor railway infrastructures like bridges, tunnels or surrounding environmental conditions are often deprived from a grid power. Energy efficiency plays a major role for performance of the WSN networks. Once the power is depleted from the commercially deployed batteries the WSN nodes becomes "dead" temporarily till the battery is recharged again. So different green energy harvesting technologies to be deployed depending upon the actual location of the WSN nodes and the power requirement of the WSN nodes. This paper surveys readily available green energy harvesting technologies and proposes major factors while designing WSN node.**

Keywords—WSN performance, Green energy, Energy storage, battery charging systems.

1.Introduction

Low cost WSN network is the key element of Railway Traffic Monitoring and Control systems in India now.The top ten emerging technologies includes a WSN network which is second largest network after Internet [1].Internet of Things (IOT) based WSN network is a backbone of railway monitoring systems[2].The main factor which limits the performance of the WSN network is Energy efficiency[3].Rechargeable batteries are employed to power the WSN nodes. The battery life can be extended by various techniques [4].It is not always possible to in remote and in accessible locations to change the batteries even in the case of extended life batteries for on board monitoring systems the WSN nodes are embedded in the structure which is monitored. Replacing the batteries requires a special maintenance schedule which is time consuming and expensive and is nearly impossible[5]. WSN node becomes temporarily dead if the energy in the stored battery is fully consumed. In such situation the actual condition monitoring of the infrastructure and or traffic monitoring is at high risk and may cause a fatal accident.

To retain battery energy different techniques has been proposed like recharging operations. The network performance is decreased with these recharging operations since it is slow and sometimes expensive and may have time period in which the recharging is possible. For example Solar Panel based recharging operations has charging window period of 6to 8 hours. The electrical energy harvested from solar energy (sunlight) can also be used directly to power a WSN node. Alternatively, the collected

Energy may be warehoused in a rechargeable battery (or a supercapacitor) for future purposes (e.g., during nighttime when sunlight is not available)[6].

The major problem of the WSN batteries is the leakage current .The depletion of the energy in batteries is to be slow down.The duty cycle based operation and power control techniques plays important role in keeping WSN node active for a longer time .Sleep mode approach plays a major role in retaining the battery power for a longer time and is proven very effective. The sleeping WSN nodes can be activated by simply detecting a pressure signal from a strain gauge [7].Re-chargeable batteries and Super capacitors are the energy –storage systems widely employed in WSN networks.[8].Energy-storage density ,discharging, leakage current, size of the energy –storage device and Life time of it plays major factor for selection as a power source for WSN network[9].Apart from that the batteries used for WSN networks should not affect the environment .Each WSN network may use one or more batteries but the volume of the WSN network is rapidly increasing in every application in Railway systems so the total volume of the batteries after their usage may affect the environment, hence disposal of such used batteries requires a standard procedure and careful methodology to dispose it collectively. Since the WSN network is second largest network other than Internet network the new energy Green energy harvesting and energy storage system is main focus area of the research now. Due to higher leakage current and lower power density Super capacitors are seldom deployed in Railway applications[10].

In impenetrable zones non rechargeable batteries power up the WSN nodes. The life time of such WSN nodes is decided by the battery life time .There is a rapid development in electronics field so day by day most powerful WSN nodes with small size and high data sampling capacities are employed in Railway applications. However the development in battery technology is comparatively is slow and not developing at the same rate as that of electronics field. The discharge characteristics of the battery and surrounding temperature conditions plays a significant role decides the WSN life time [11]. WSN nodes have a limited energy and needs to be optimized in order to increase the operational life time of the sensor nodes.

Energy Harvesting, Energy Transfer and Energy Conservation these are the main factors which determines the performance of the WSN nodes and a base station which is in remote railway field. Dedicated Green Technologies based hardware is required to charge the batteries of the WSN.

For WSN installations at a large scale the energy harvesting and energy transfer increases hardware complexities, size of the WSN nodes and cost hence it is not popular. For WSN energy conservation algorithms are used to optimize the energy requirement.

WSN Batteries are highly non linear devices and their performance largely depends up on the surrounding environmental conditions such as humidity, vibrations, temperature fluctuations and electrochemistry of the battery Therefore for WSN node energy –aware algorithms requires specific battery characterization [12].

2. Green Energy harvesting for WSN nodes.

Energy can be extracted from surrounding environment and can be transferred to energy storage devices to power the railway WSN networks. The railway network in India has wide variety of environmental conditions. Hence based on geological and surrounding environmental favorable parameters can be exploited to extract the energy for WSN nodes. Today it is possible to to extract energy from surrounding physical parameters due to the developments of sensor and harvesting various technological methods .Some of the challenges and opportunities are mentioned briefly in this paper.

Energy harvesting for WSN nodes can be done from various energy types available in railway field as indicated by Fig 1.

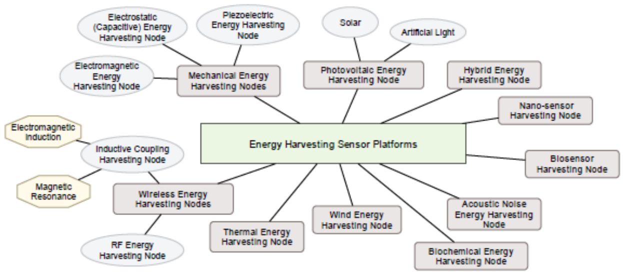

Fig.1: Types of Energies and Sources[13].

2.1 Mechanical Energy Harvesting

As the name suggests the Mechanical energy is converted into Electrical energy .Displacement of and oscillations of the springs converts the mechanical energy into an electrical energy from the surface of the sensors, high pressure motors, waste rotational movements and Force. Mechanical energy harvesting can be: Piezoelectric, electrostatic and electro-Magnetic.

Piezo-electric crystals are able to convert mechanical pressure into electrical voltage at the surface of the piezoelectric crystal is used here. Mechanical energy from pressure, force or vibrations is transformed into electrical power by straining a piezoelectric material such as quartz crystals or Roschell Salts.

A cantilever structure is used with a seismic mass attached into a piezoelectric beam that has contact on both sides of piezoelectric material can convert mechanical energy into an electrical energy. Strains in the piezoelectric material produce charge separation across the harvester, creating an electric field and hence voltage, proportional to the stress is generated.

AC signal is generated whose voltage varies with respect to time randomly as per the mechanical pressure and or stress on the surface of the piezoelectric crystal beam.[14].It is an active transducer hence does not require a separate energy source. The high voltages can be generated for a short time and when used with the low pass filter this energy can be transferred to the energy storage batteries for WSN nodes.

2.2 Electromagnetic energy harvesting

Faradays law of electromagnetic induction. is used to convert mechanical motion into energy harvesting for a WSN node. Inductive spring mass system for converting mechanical energy to electrical energy .The voltage is induced by a moving a mass of magnetic material through a magnetic field created by a stationary magnet. Vibrations of the permanent magnet attached to the spring inside the coil changes the flux and produce an inducedemF as per the faradays laws of electro-magnetic induction. The induced emf is directly proportional to the rate of change of the flux as well as on the number of turns of the coil. Some examples of electromagnetic energy harvesting systems are presented in [15].

2.3Light energy Harvesting:

It is most widely used energy harvesting technique in railway applications not only for powering the WSN nodes butfor signalling Systems also it has been effectively used.Light is harvested into an electric energy using a photovoltaic (PV) cellar a Solar Cell.Solar provides an excellent source of energy for wireless systems or stand-alone device that have no access to fixed power. Given the commercial interest in green technology and alternative energy sourcing, Solar or Photovoltaic (PV) cells continue to improve at a rapid pace, both in terms of higher efficiencies and lower production costs. On an average, the amount of solar energy falling onto a square meter at the equator of planet earth is 1000 w/m2 [16].

When the light falls on the PN junction of a photovoltaic cell it releases electrons. Photovoltaic energy conversion is a traditional, mature, and commercially established energy-harvesting technology. It provides higher power output levels compared to other energy harvesting techniques and is suitable for larger-scale energy harvesting systems. The efficiency of the conversion of the photovoltaic cell depends upon the several factors such as availability of the light, materials used for photovoltaic cells, conditions of photovoltaic cells etc.

2.4 Thermal energy harvesting

It is implemented by thermopile or thermocouple. Thermoelectric energy harvesting is the process of creating electric energy from temperature difference (thermal gradients) using thermoelectric power generators (TEGs). [17].The core element of a TEG is a thermopile formed by arrays of two dissimilar conductors, i.e., a p-type and n-type semiconductor(thermocouple), placed between a hot and a cold plate and connected in series. Recent developments in Thermoelectric energy harvesting is successfully applied in railway applications can be useful in extreme weather conditions such as Himalayan railway stretch.

2.5 Pyroelectric energy harvesting

It is the process of generating voltage by heating or cooling pyroelectric materials. These materials do not need a temperature gradient similar to a thermocouple. Instead, they need time-varying temperature changes. Changes in temperature modify the locations of theatoms in the crystal structure of the piezoelectric material, which produces voltage. To keep generating power, the whole crystal should be continuously subject to temperature change. Otherwise, the produced pyroelectric voltage gradually disappears due to leakage current [18].

Pyroelectric energy harvesting achieves greater efficiency compared to thermoelectric harvesting. It supports harvesting from high temperature sources, and is much easier to get to work using limited surface heat exchange[19]. Onthe other hand, thermoelectric energy harvesting provides higher harvested energy levels. The maximum efficiency of thermal energy harvesting is limited by the Carnot cycle [20]. Because of the various sizes of thermal harvesters, they can be placed on the human body, on structures and equipment. Some example of this kind of harvesters for WSN nodes in near future can be deployed in railway fields to power WSN nodes.

2.6 Wireless energy harvesting techniques.

Recently wireless energy harvesting technology has gained lot of attention for low power applications such as human wearable electronic gadgets and also for WSN nodes. With the rapid development of silicon technology, even a tiny amount of energy is able to do plenty of work. Energy harvesting intends to scavenge wasted energy from the ambient environment. Electromagnetic radiation can be utilized to power low-power devices in an eco-friendly manner. EH is a promising solution to power sensors, wearable's, biomedical implants, RFIDs, and so on.[21]

Wireless energy harvesting can be categorized into two main categories: RF energy harvesting and resonant energy harvesting. RF energy harvesting is the process of onverting electromagnetic waves into electricity by a rectifying Antenna, or Rectenna.

Energy can be harvested from either ambient RF power from sources such as radio and television broadcasting, cellphones, WiFi communications and microwaves, or from EM signals generated at a specific wavelength. Although there is a large number of potential ambient RF power, the energy of existing EM waves are extremely low because energy rapidly decreases as the signal spreads farther from the source. Therefore, in order to scavenge RF energy efficiently from existing ambient waves, the harvester must remain close to the RF source. Another possible solution is to use a dedicated RF transmitter to generate more powerful EM signals merely for the purpose of powering sensor nodes. Such RF energy harvesting is able to efficiently delivers powers from micro-watts to few mill watts, depending on the distance between the RF transmitter and the harvester[22].

Resonant energy harvesting,

It is also called as resonant inductive coupling. In this process it transfers and harvests an electrical energy between two coils, which is highly resonating at the same frequency. Specifically, an external inductive transformer device, coupled to a primary coil, can send power through the air to a device equipped with a secondary coil. The primary coil produces time-varying magnetic flux that crosses the secondary coil, inducing a voltage. In general, there are two possible implementations of resonant inductive coupling: Weak inductive coupling and strong inductive coupling. In the first case, the distance between the coils must be very small (few centimeters).

However, if the receiving coil is properly tuned to match the external powered coil, a \strong coupling" between electromagnetic resonant devices can be established and powering is possible over longer distances. Note that since the primary and secondary coil is not physically connected, resonant inductive coupling is considered a wireless energy harvesting technique. Some recent implementations of wireless energy harvesting techniques for WSNs can be found in [23].

2.7 Wind energy harvesting

Energy in the air flow can be converted into electricity. It is the most proven technology in remote areas and also it supplies energy to the power grids in most parts of India now. The most advantage of this technology is that it can be used in the day time as well as in a night time also, unlike solar panels which harvest energy only in a day time Solar panel produces little or less energy in monsoon season due to the lack of clear sun shine.But wind energy harvesting technique is suitable in a region where minimum speed of the wind is more than 40 km/hour and deployed especially in mountain regions. Since Indian Railway is constructing a new railway network in Himalayan region from Banihal to Jammu section as well as in Leh to Bilaspur stretch where the railway shall travel at the height above 10,000 feets above sea level .This technology shall be very useful to harvest the wind energy into an electrical energy for monitoring the railway field in such Himalayan rail network.. Many eco friendly materials are now used and which can be recycled as wind turbine blades and are light weight so they can be transported easily to the remote regions in Himalya.

A properly sized wind turbine is used to exploitlinear motion coming from wind for generating electrical energy. Miniature wind turbines exists that are capable of producing enough energy to power WSN nodes [24].

Aero elastic instabilities such as vortex induced vibrations coupled with piezo electric materials using cantilever beam is one possible solution other than miniature wind mill for energy harvesting. Many new designs has been discussed in various wind energy harvesting survey papers recently [25]

However, efficient design of small-scale wind energy harvesting is still an ongoing research, challenged by very low flow rates, fluctuations in wind strength, the unpredictability of flow sources, etc for railway network other than Mountain region parts of India.

2.8 Biochemical energy harvesting.

The Railway networks are exposed to variety of environmental variations. coastal railway networks has a vast energy available in sea waters near to the railway tracks, The energy in sea ,ponds and rivers in Bio Chemical l forms harvesting is the most recent energy source can be tapped to harvest for small power applications where the other ambient energy cannot be harvested.

In this the endogenous substances and oxygen is converted into electricity via electrochemical reactions. Biofuel cells acting as active enzymes and catalysts can be usedto harvest the biochemical energy in bio fluids into an electrical energy.T here are many fluid substances in human body can be converted into an electricity using enzymes and catalysts [26].

Research efforts have proposed many innovative prototypes that use biochemical energy harvesting to power microelectronic devices and can be applied in railway monitoring WSN network in near future.

Acoustic energy harvesting:

Railway field WSN requires very less power and this requirement can be easily fulfilled by some acoustic energy harvesting devices, where in railway field the noise level is always more than 80 db in extremely busy tracks and railway yards where electric grid power is not easily available at remote locations.

Here continuous acoustic wave in surrounding railway field is converted into an electric energy by an acoustic transducer or by a suitable resonator. The harvestable acoustic emissions can be inthe form of longitudinal, transverse, bending, and hydrostatic waves ranging from very low to high frequencies[27].

Efficiency of the harvested acoustic power is low and such energy can only be harvested invery noisy environments. Harvestable energy from acoustic waves theoretically yields 0:96_W=cm3 [28], which is much lower than what is achievable by other energy harvesting techniques. Acoustic waves belong to one kind of mechanical waves and utilizing ambient energy sources has always been a hot topic in recent years. Generally, acoustic energy is ultimately dissipated into thermal energy at the propagation stage, and low- and mid frequency sound waves have attracted the most attention.[29]An AEH device has low requirements in terms of installation and operation, and can be integrated into other engineering structures to obtain smart structures.

All previously described harvesting techniques can be combined and concurrently used on a single platform (hybrid energy harvesting).A bird's eye view of the amount of energy harvestable from different sources is given in Table 1.1. For each energy harvesting technique we show its power density and conversion efficiency. The power density expresses the harvested energy per unit volume, area, or mass. Common unit measures of power density include watts per square centimeter and watts per cubic centimeter. Conversion efficiency is defined as the ratio of the harvested electrical powerto the harvestable input power. The energy conversion efficiency is a dimensionless number between 0 and 100%.

Energy harvesting technique	Power density	Efficiency
Photovoltaic	Outdoors (direct sun): 15 mW/cm^2 Outdoors (cloudy day): 0.15 mW/cm^2 Indoors: <10 $\mu W/cm^2$ [9, 21, 105, 126]	Highest: $32 \pm 1.5\%$ Typical: $25 \pm 1.5\%$ [48]
Thermoelectric	Human: 30 $\mu W/cm^2$ Industrial: 1 to 10 mW/cm^2 [53, 126]	$\pm 0.1\%$ $\pm 3\%$ [126]
Pyroelectric	8.64 $\mu W/cm^2$ at the temperature rate of 8.5° C/s [77]	3.5% [125]
Piezoelectric	250 $\mu W/cm^3$ 330 $\mu W/cm^3$ (shoe inserts) [21, 105]	^{a}
Electromagnetic	Human motion: 1 to 4 $\mu W/cm^3$ [88, 121] Industrial: 306 $\mu W/cm^3$ [8], 800 $\mu W/cm^3$ [121]	^{a}
Electrostatic	50 to 100 $\mu W/cm^3$ [124]	^{a}
RF	GSM 900/1800 MHz: 0.1 $\mu W/cm^2$ WiFi 2.4 GHz: 0.01 $\mu W/cm^2$ [9]	50%^{b} [94]
Wind	380 $\mu W/cm^3$ at the speed of 5 m/s [103, 104]	5% [103]
Acoustic noise	0.96 $\mu W/cm^3$ at 100 dB 0.003 $\mu W/cm^3$ at 75 dB [14, 95]	^{c}

CONCLUSION

WSN network is a backbone of the railway traffic monitoring and control which communicates the railway field information with highest speed using integrated IOT technologies. Hence its operation is very crucial for smooth functioning of the railway traffic monitoring and control. Since WSN networks are deployed in remote locations and are exposed to the extreme weather conditions. Since the power grid is not available at such a remote locations energy requirement for smooth functioning of the WSN nodes is a major issue. We can explore suitable methods to power up the WSN Nodes and Sensor nodes using suitable green energy harvesting technologies mentioned above in our paper for future WSN sensor node in specific environmental conditions.

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