Journal of Advances and Scholarly Researches in Allied Education
Vol. 20, Issue No. 1, January-2023, ISSN 2230-7540

https://doi.org/10.29070/7zfj4584

A comprehensive review An Optimization of the different green energy harvesting sources for the Wireless sensor networks (WSN's)

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Abstract - Wireless Sensor Network (WSN) is an important consideration of collecting the data from the various field of application. The very basic unit of WSN is sensor node which source of energy is usually battery power. Sustainable energy is an important consideration because sometimes it becomes very hard and expensive and may be threat to human life to change the batteries of sensor nodes every time. Energy harvesting (EH) is the promising solution to this problem and is always a point of interest for re-searchers and scientists. In this paper, various energy harvesting has been discussed and investigated. Researchers are continuously working in new, optimized, and efficient working of various energy harvesting. This study may help the researcher to find the new paradigm of research in the field of energy harvesting systems. A survey of solar, thermal, Wind, piezoelectric, RF energy harvesting has been considered due their popularity. A comparison of various energy harvesting systems has been also considered and discussed in this paper.

Keyword: WSN, Energy Harvesting (EH), Sustainable energy, Solar, Wind, RF energy, piezoelectric

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INTRODUCTION

Wireless Sensor Networks (WSNs) have become increasingly important in various applications, including environmental monitoring, healthcare, and industrial automation. However, the limited battery life of sensor nodes remains a significant challenge. Green energy harvesting has emerged as a promising solution to address this issue. This review focuses on optimization techniques for different green energy harvesting sources, including solar, wind, vibration, and thermal energy.

A keen interest of researchers and scientists has been noticed in Wireless Sensor Network (WSN) in last decades. It is due to its wide area of application and also due to a great part of Internet of Things (IoT). The WSN can be easily used to monitor the environment and can provide event based monitoring [1][2]. WSN also has a great role in Internet of Things (IoT) and it also enhance its popularity in research community. From Fig. 1, we see that WSN has one sink or base station unhitch is connected to one sink node in the sensor field with numerous wireless sensor nodes.

WSN comprise of some main units i.e. microcontroller, Radio Unit (e.g. Zigbee), Different types of sensors, power management unit (battery etc.). There are so many applications where human intervention is very hard e.g. volcanoes etc. and may be a life risk. For such application the designed WSN systems are low power and an energy harvesting is extremely required. The WSN unit is able to collect and manipulate the data which it collects from the sensors, prepare a usable information with the help of microcontroller and able to communicate with its neighbor nodes. All these things require energy and so energy may be required either from battery, or energy harvesting devices. Researchers and scientist are continuously finding the solution for perpetual lifetime of the sensor which is very important [3].

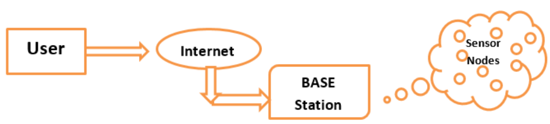

Figure 1: Architecture of WSN

The Energy Harvesting (EH) sensors have been proposed to overcome the above mentioned problem. These sensors harvest the required amount of energy from the environment, resulting in a longer lifetime. The energy harvested WSNs can operate for years without any human need for battery replacements. But the energy generated by these harvesters is not that high to power commercial WSNs as they are power hungry. Hence, it is important to deal with this mismatch by increasing the harvested power and decreasing power consumption [4].

To deal with the mismatch mentioned above, we need to ensure that maximum power is transferred from these harvesters to the load for all the energy harvesting techniques like solar, wind, hydro, vibrational, electromagnetic, piezoelectric and thermoelectric [4].

ENERGY HARVESTING TECHNIQUES

Various energy harvesting techniques are available for WSN node and need to be investigated. Energy consumption of the sensor node depends on the duty cycle. Higher the duty cycle lowers the lifetime of the sensor node. Energy harvesting from natural sources for large scale production may be used without significant considerations but for production of energy of the order of Micro Joules to some Joules, a form factor is a big constraint. Many solutions and systems have been proposed by many authors in last decade out of which some of them are as follows:

A. Solar Energy

Solar energy is one of the most popular and widely researched green energy sources for powering WSNs due to its availability and relatively high energy density. Let's dive into the key aspects:

- **Photovoltaic Technology:** Solar energy harvesting for WSNs primarily uses photovoltaic (PV) cells. These cells convert light directly into electricity through the photovoltaic effect. When photons from sunlight hit the semiconductor material in the PV cell, they excite electrons, generating an electric current.

- **Types of PV Cells Used in WSNs:**

  a) **Mono crystalline silicon:** High efficiency but more expensive

  b) **Polycrystalline silicon:** Less efficient but more cost-effective

  c) **Thin-film solar cells:** Flexible and lightweight, suitable for certain WSN applications

  d) **Organic solar cells:** Emerging technology, potentially cheaper but currently less efficient

- **Energy Storage:** Solar energy is typically paired with rechargeable batteries or super capacitors to store energy for use during low-light periods or at night.

- **Advantages of Solar Energy for WSNs:**

  a) **Abundance**: Sunlight is freely available in many outdoor environments

  b) **Scalability**: Can be sized according to the energy needs of the sensor node

  c) **Long lifespan:** PV cells can last for many years with minimal degradation

  d) **Silent operation:** No moving parts, ideal for sensitive environments.

The authors in [5] propose a unique and methodical solar powered battery-charging system with maximum power point tracking (MPPT) for WSN nodes. Their objective was to increase the efficiency which depends on various components like solar panel. From the simulations carried, it was seen that the designed solar energy harvesting system has 96% efficiency (sys).

In [6], authors propose a novel solar-powered DC-DC buck converter for energy harvesting WSN nodes. The paper looks into the design of DC-DC converter and has analysis of this low-powered Photovoltaic (PV) harvester. From the stimulation results, it is seen that output voltage ripple is inversely proportional to various parameters like inductance, capacitance and duty cycle.

In [7], the authors take an initiative to combine MPPT technology with solar tracking system to achieve maximum absorption of solar energy by panels. They use various technologies like LDR sensors. This is done to ensure maximum absorption of solar energy.

The authors in [8] propose a highly efficient Radio Frequency RF energy harvester integrated with a solar energy harvester. The ratings of the solar cell are as follows: Voc= 6.30V, Isc = 50 mA, power=292mW and solar irradiance=100mW/cm−2. The integrated model produces a power of 192.9μW

B. Wind Energy

Wind energy is another promising green energy source for powering WSNs, especially in outdoor environments where consistent airflow is available.

Wind energy harvesting for WSNs:

- **Basic Principle:** Wind energy harvesters convert the kinetic energy of moving air into electrical energy. This is typically done using small wind turbines or innovative designs adapted for WSN scale.

- **Types of Wind Energy Harvesters for WSNs**:

  a) **Micro wind turbines**: Miniaturized versions of traditional wind turbines

  b) **Piezoelectric wind harvesters:** Use wind-induced vibrations to generate electricity

  c) **Electromagnetic wind harvesters:** Utilize electromagnetic induction principles

  d) **Tribo electric nano generators:** Harvest energy from wind-driven friction

- **Components of a Wind Energy Harvesting System for WSNs:**

  a) **Rotor or harvesting mechanism:** Captures wind energy

  b) **Generator**: Converts mechanical energy to electrical energy

  c) **Power management circuit:** Regulates and optimizes energy output

  d) **Energy storage:** Usually a rechargeable battery or super capacitor

- **Advantages of Wind Energy for WSNs:**

  a) **Availability**: Can operate day and night, unlike solar

  b) **Complementary to solar:** Often used in hybrid systems

  c) Potentially high power output in windy conditions

  d) Suitable for remote, windy locations

The authors in [10] propose a system specialized in EH circuit for the fluttering wind harvester. The system consists of an AC/DC buck-boost converter. It has a low power microcontroller unit with improved P&O algorithm. This is done to achieve input MPPT. The results conclude the power efficiency reaches 53% while commercially tested systems have efficiency only up to 45%.

The paper [11], represents an efficient design and devel- opment of an ambient wind energy harvesting system based wireless sensor network (WEHSWSN) for Structural Health Monitoring. Supercapacitors are used as storage devices. This is done so that, the need of replacement of a battery is eliminated. This will lead to a better power management system.

The authors in [12] design a wireless sensor node which is powered by a micro wind turbine generator. It constitutes an AC-DC converter and MPPT circuit to assist the operation of WSN. Test Results it to be noted that efficiency of energy from the proposed power system is improved by the numeric value of 80%

Table I: Output power of Wind energy

S.No.	Wind speed	Power generated
1	3 m/s	2.9 mW
2	7 m/s	23mW

C. Piezoelectric Harvest Energy

This is an interesting and promising method of energy harvesting that can be particularly useful in certain environments.

Piezoelectric energy harvesting for WSNs:

Basic Principle: Piezoelectric energy harvesting is based on the piezoelectric effect, where certain materials generate an electric charge in response to applied mechanical stress or vibration.

Piezoelectric Materials:

a) Commonly used materials include:

b) Lead Zirconate Titanate (PZT)

c) Polyvinylidene Fluoride (PVDF)

d) Zinc Oxide (ZnO)

e) Barium Titanate (BaTiO3)

These materials can be in the form of ceramics, polymers, or composites

Types of Piezoelectric Harvesters:

a) **Cantilever beams:** Most common design, often with a tip mass

b) **Diaphragms:** Circular or rectangular membrane-like structures

c) **Cymbal transducers:** Two metal end caps with piezoelectric disc in between

d) **Stack actuators:** Multiple layers of piezoelectric material

Energy Harvesting Mechanism:

a) Vibration or stress causes deformation of the piezoelectric material

b) This deformation leads to charge separation within the material

c) Electrodes collect the generated charge d) A power management circuit conditions the electrical output

Advantages for WSNs:

a) Can harvest energy from ambient vibrations in the environment

b) No need for external power sources

c) Compact and can be integrated into MEMS devices

d) Suitable for indoor and enclosed environments where solar or wind isn't available

In [9], the authors focus on power sources based upon piezoelectric energy harvesters. MPPT is employed to achieve a power output which is maximum. Various energy estimation methods are discussed, and this is done by using MPPT algorithm.

The authors in [18], propose an efficient energy harvesting system for potential application in medical electronics. To achieve this component like a low power CMOS and transducers are used. While designing the harvested circuit the following rating is taken resistive load is 45KOhm, rectifier output voltage is 694mV and piezoelectric transducer voltage is 703mV. From the results we conclude that Vout / Vin = 98.7% and power efficiency of 46%.

Table 1 shows the Output power of wind energy harvesters. A very light speed of wind can produce a power of the order of milli watt. The authors in [13], implemented a custom developed vibrational energy harvesting powered WSN. The harvester generates a power of 3.2mW with loading of 600 με at a frequency of 10Hz. This method reduces sleep current of commercial WSN and ensures longer active time of the nodes.

D. Radio Frequency harvesting

This is an increasingly important area of research, especially as our environments become more saturated with RF signals.

RF energy harvesting for WSNs:

- **Basic Principle:** RF energy harvesting involves capturing electromagnetic energy from ambient radio waves or dedicated RF sources and converting it into usable electrical energy for powering WSN nodes.

- **Sources of RF Energy:**

  a) **Ambient RF:** TV and radio broadcasts, cellular networks, Wi-Fi signals

  b) **Dedicated RF:** Purposely deployed RF power transmitters

- **Components of an RF Energy Harvesting System:**

  a) **Antenna**: Captures the RF signals

  b) **Matching network:** Ensures maximum power transfer

  c) **Rectifier**: Converts AC signal to DC (often called a "rectenna" when combined with the antenna)

  d) **Power management circuit:** Regulates voltage and stores energy.

- **Advantages for WSNs:**

  a) **Ubiquity**: RF signals are widely available in urban and some rural environments

  b) **Continuous availability: Can** harvest energy 24/7, unlike solar

  c) Unaffected by environmental conditions like weather

  d) Potential for long-range power transfer

  e) Can be miniaturized for integration into small WSN nodes

In [16], design and optimize antennas for Radio Frequency (RF) harvesting. They design an antenna that has a gain of 4dbi at frequency of 1800Hz. They further say that due to the high availability of RF energy, they can be used in Smart cities.

The authors in [17], present a compact coplanar waveguide with slotted symmetrical M-shape microstrip patch antenna. This improves the gain of the antenna, and the maximum gain= 2.04 dB is observed. It is seen that there is a maximum current distribution at the patch.

E. Hybrid Energy Harvesting

This is an important and growing area of research that aims to overcome the limitations of individual energy harvesting methods. Hybrid energy harvesting combines multiple energy sources to power WSN nodes. This approach addresses the limitations of single-source harvesting, such as the intermittency of solar power or the low power density of RF harvesting. By diversifying energy sources, hybrid systems can provide more consistent and reliable power.

Common Combinations:

Solar + Wind: Effective for outdoor deployments, complementing each other during day/night cycles.

Solar + Piezoelectric: Combines abundant solar energy with vibration harvesting for industrial or urban environments.

RF + Thermal: Useful in indoor industrial settings where both RF signals and temperature gradients are present.

Key Advantages:

Increased Reliability: If one source is unavailable, others can compensate.

Higher Power Output: Combining sources can meet higher energy demands.

Adaptability: The system can switch between sources based on availability and efficiency.

The authors in [14], design, implement and characterize a hardware platform to self-power WSN. It is a multisource platform with various energy harvesting techniques. These may include solar, hydro, wind and thermal energy. It consists of components like MCU module, super capacitors and RF transceiver module. The results conclude that the generating capacity= 7805.09 J

In [15], the authors propose a hybrid energy harvesting model which consists of both solar and electromagnetic energies. They develop a programming method to minimize the loss of energy from the nodes. The results show that when solar energy is completely exploited, there is a maximum energy consumption at node. By proposing a hybrid model, they conclude that they can reduce energy consumption at the node.

Table II: Output power of solar energy

S.No.	Solar atmospheric condition	Energy in Joules
1	Cloudy day generating capacity	6000J
2	Sunny day generating day capacity	9000J
3	Daily power Output	7805J
4	Average power consumption	2979.88J/day

DISCUSSION

The primary objective to design and implement a multi-source energy harvesting system is to increase the working time of WSN nodes. The generating capacity of multisource energy modules is higher than normal WSN nodes. The power consumption of WSN node is tested as 56mW[14].

The results of solar harvest subsystem experiment show that the solar panel maximum power =900 mW when the light intensity=1000W/m2When the light intensity=500W/m2, the power=235 mW. This shows that there is access power than required for the given system.

The results of the wind harvest subsystem show that power harvested by wind system is less than solar. From the heat harvest subsystem, it was evident that the power was very weak, about 3mW. For the tests conducted on self-powered WSN in [14], it is concluded that, self-powered WSN can work regularly

From the comparison Table 1, the output power of solar energy harvesting is better than other harvesting methods mentioned above. It also has a maximum efficiency of about 96% with minimum WSN node. It can be concluded that solar energy harvesting is a better option for energy harvesting.

Table 2 shows the output energy in different weather and atmosphere conditions. A sunny day may provide 9kJ of energy while on average nearly 3kJ of energy can be harvested which may be sufficient for wireless sensor node for perpetual working.

CONCLUSION

Optimization techniques for green energy harvesting sources are crucial for efficient and sustainable WSNs. This review highlights the importance of optimizing energy harvesting techniques for solar, wind, vibration, thermal, and hybrid energy sources. By applying these optimization techniques, WSNs can achieve increased energy efficiency, reduced carbon footprint, and extended network lifetime.

In this paper, we have presented a survey on energy harvesting techniques for WSN. This survey was conducted to understand how to increase the lifetime of the network and hence energy consumption. From the literature review, we noticed that considerable work has been done on various energy harvesting techniques for WSN and a comprehensive survey on increasing power consumption of WSN has been discussed. This survey provides an insight to this issue and identifies potential WSN which provides increasing operational time In this paper, we have presented a survey on energy harvesting techniques for WSN. This survey was conducted to understand how to increase the lifetime of the network and hence energy consumption. From the literature review, we noticed that considerable work has been done on various energy harvesting techniques for WSN and a comprehensive survey on increasing power consumption of WSN has been discussed. This survey provides an insight to this issue and identifies potential WSN which provides increasing operational time.

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