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Improving the Lifetime of WSNs using Energy Harvesting Techniques

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Abstract: ***Wireless sensor networks (WSNs) play a pivotal role in the practical implementation of the IoT across various domains such as smart agriculture, intelligent buildings, urban infrastructure, and industrial monitoring. Typically, these nodes rely on limited energy sources, often in the form of non-rechargeable batteries. The duration for which a WSN can operate, usually measured in days, depends on several factors, including the duty cycle, deployment scenario, and state of charge (SoC) of their batteries. To deal with the challenge of constrained energy availability, an innovative solution that harnesses ambient solar energy to recharge the batteries of WSN nodes has been suggested. However, the successful implementation of solar energy harvesting faces numerous challenges, including variations in temperature, solar panel efficiency, difficulties in solar energy forecasting, power interruptions, and various environmental and natural factors. The primary purpose of this study is to extend the lifespan of WSN networks through the application of solar energy harvesting techniques. MATLAB simulations has been done to prove the suggested solution for reliability and energy efficiency of wireless sensor networks by effectively utilizing solar energy resources.***

Keywords: Wireless sensor networks (WSNs)s, Solar Energy Harvesting (SEH), Internet of Things (IoT)

1. Introduction

Wireless Sensor Networks (WSNs) are specialized networks comprising of numerous compact, self-reliant sensor devices. These sensors are outfitted with various sensor types, possess wireless communication capabilities (such as Wi-Fi, Zigbee, or Bluetooth), and often operate with limited processing power and constrained energy resources. These sensors are specifically engineered to observe and gather data from the physical environment, encompassing parameters like temperature, humidity, light, sound, motion, and additional variables. The data collected by these sensors can be used for a wide range of applications, including environmental monitoring, industrial automation, healthcare, agriculture, and more. The application of WSNs makes it possible to implement practical applications including habitat monitoring, air quality monitoring, natural disaster avoidance, smart agriculture, and smart buildings. However, traditional WSN nodes often run on limited-capacity, non-rechargeable batteries. A solar energy harvesting (SEH) technique is recommended in this study as a way to extend the longevity of each sensor node in a WSN. In a perfect world, the implementation could have an indefinite lifetime. However, there are also a lot of other challenges to overcome and factors to take into account while harvesting solar energy, difference in temperature variations, solar panel conversion efficiency, problems with solar energy (SE), forecasting, power outages, and other environmental or natural phenomena issues. Hence, the objective of this study is to investigate contemporary research related to harnessing solar ambient light energy for WSNs. The objective of this project would be to use MATLAB simulations to achieve energy efficiency and dependability in WSNs.

Sources for Harvestable Energy

The energy source is a crucial part of any EH design since it defines the quantity and pace of energy that is usable. The axes of controllability, predictability, and magnitude utilised to describe the traits of different energy sources. An energy source that can be controlled can deliver usable energy whenever we need it Consequently energy availability is not required foreseen prior to harvesting. Energy must simply be harvested whenever it is available while using uncontrollable energy sources. If the source of energy is predictable, then following recharging cycle can be predicted using a forecasting model that forecasts its availability. Additionally, Different energy sources are typically categorized into two groups below:

a) Ambient source of energy: A source of energy derived from the natural environment, such as RF, solar, and wind energy.
b) External (Human power): Power generated from the movement sources of human force that cannot be regulated by the user are considered passive. Examples include breathing, body heat, and blood pressure.

Energy-Harvesting in Wireless Sensor Networks (EH-WSNS)

In recent years, WSNs have received a great interest. They have spread widely and utilised in numerous applications, including internet of things, cyber-physical systems, and other developing fields. Energy becomes a significant barrier for applications when the system goal is to run continuously for a long time. Network lifetime and energy performance have emerged as the major factors for measuring wireless communications' energy efficiency. Recent techniques that aim to reduce energy usage and increase network lifetime. The placement of WSN nodes makes it difficult or impossible to recharge or replace exhausted batteries. Unless the source of energy is renewed or a harvesting mechanism to be added in bridge and the energy deficit, a node that is dead will fade out and disengage from the network. Batteries can be drained although they are not in use due to current leaks, and packaging flaws from constant use could have an adverse effect on the environment. The sensor node lifetime may vary from months to years based on requirements of the application. The three operating modes for the sensor node are active, idle, and sleep. It is a priority to develop EH to a solution for the limited node lifetime issue. It is among the most current and promising techniques. technological developments in communications. Any energy-harvesting using a communication system or a specific power emitter, the surroundings is known as operating without a wire or batteries wireless communication that harvests energy.

Energy-harvesting solar system

A fundamental SEH system consists of a solar panel, rechargeable battery, DC-DC converter, battery charge protection circuitry known as battery management system (BMS), and DC-DC converter control unit. The schematic block diagram of a SE harvester (SEH) system controlled by Incremental Conductance (IncCond) MPPT. MPPT controller, a rechargeable battery, a solar panel, a DC-DC buck converter, and a WSN sensor node linked being a DC load make up the SEH system. Utilizing a solar panel, the energy according to the natural sunlight is captured and converted into electrical energy. The amount of this gathered voltage that presented to the battery that can be recharged is scaled back and regulated by using a DC-DC converter. The MOSFET's duty cycle in the DC-DC Buck converter is adjusted in accordance with the solar panel's current and voltage by the MPPT controller. Finally, the wireless sensor node is powered by the battery voltage. The WSN carries out the tasks of sensing, computing, and communicating with other nodes that share similar features. The result is, the SEH-WSN nodes can operate autonomously to monitor and control any physical phenomenon, such as a change in humidity, pressure, temperature, or acceleration. The effectiveness of the SE harvester circuit is crucial to this entire situation. The battery won't receive a sufficient recharge. if the SEH system is inefficient, which will shorten the lifespan of the WSNs.

Maximum Power Point Tracking (MPPT) Technique

When designing photovoltaic (PV) solar systems, the MPPT techniques are frequently employed to maximise obtaining energy from the Sun under a variety of solar irradiation situations. It is a method that continually calculates the duty cycle (D) to be supplied to the DC-DC buck converter's MOSFET switch according to the current (Ipv) and voltage (Vpv) originating with the solar panel.

Principles of the Incremental Conductance Algorithm:

a) Conductance and MPPT:

- Conductance, denoted as "G," is a fundamental electrical parameter representing how easily electric current flows through a component or material. It is the opposite. of resistance (G = 1/R).
- In the context of PV systems, conductance characterizes The connection between the voltage (V) and current (I) at any given moment.
- MPPT algorithms aim to maximize the power output within a solar panel by adjusting its operating point. Incremental Conductance utilizes conductance to accomplish this goal.

b) Incremental Conductance (G_inc):

- The key concept in the IncCond algorithm is the incremental conductance (G_inc), which measures how quickly the change of conductance with respect to voltage.
- G_inc is calculated utilising formula: G_inc = (dI/dV) - (I/V) * (dP/dV)
- Where dI/dV is the shift in current in relation to voltage. I/V represents the instantaneous power-to-voltage ratio.

dP/dV is the shift in power in relation to voltage.

2. Simulation Results

This INC algorithm produces a variable duty cycle (D) that is within the irradiation of the sun (W/m2) input. sun Changes in panel current and voltage as a result of alterations in duty cycle brought on by variations in sun irradiation. Therefore, even if the intensity fluctuates, the solar panel may still provide the maximum power. Matching the load's and the solar panel's impedance is the basis for how the (IncCond) algorithm operates. The matching impedance is required for optimal power transfer. Utilising a DC-DC converter allows for the matching impedance that is required. By adjusting the duty cycle (D) of the MOSFET switch when utilising a DC-DC converter, the impedance can be matched. As a result, if the D varies, so does the solar energy harvester's output voltage (Vo). As the D is increased, the output voltage (Vo) rises, and vice versa.

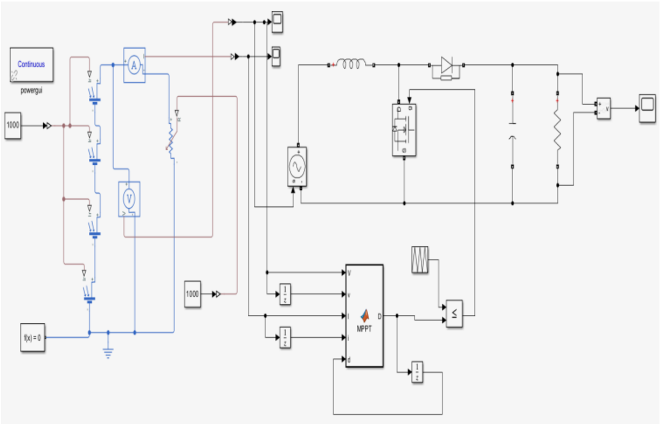

Figure 1: Matlab/Simulink Model For Inc Mppt Seh System For Wsn Node

For the modelling of a solar-powered Boost converter and battery charging of a WSN node, we utilised the MATLAB Simulink 2023 software. The SE system consisted of modelled using MPPT control. The DC-DC boost sun cell provides electrical energy to the converter, which raises the output voltage. The rechargeable battery is charged using the boost converter's output voltage. The WSN node is powered by the rechargeable battery. The WSN load is modelled as output in this case with a 100-ohm DC load resistance.

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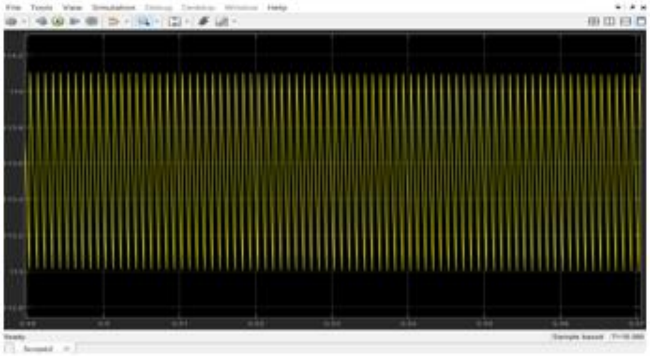

Figure 2: Simulation result on INC MPPT SEH system for WSN Node

Using an IncCond MPPT-controlled SEH(SEH) system, the simulation results with comparisons of battery state of charge (SoC), battery current (IB), and battery voltage (VB).So We are able to see that we are getting a constant of 114 volts.

Wireless Sensor Network Simulation Topology

In the context of designing a Wireless Sensor Network Simulation Topology, there are eight wireless sensor nodes include It is composed of one sink node, and one ad hoc link. A sink node is a device that saves data, whereas an ad hoc link is a device which links each sensor node in a network. It is a sensor node entire collection of information and data in a network. For the purposes of this analysis. In the setup, a programme to send data to the sink node built specifically for each sensor.

Solar irradiance refers to the power per unit area (usually measured in watts per square meter, W/m²) of sunlight that reaches the Earth's surface or any other surface exposed to the Sun. It's the fundamental parameter in SE and climate science. Solar irradiance a measurement of the amount of SE that is received at a specific location and time. It can vary depending on factors such as geographic location, time of day, season, and atmospheric conditions. Solar irradiance is not constant and varies throughout the day and across seasons due to the Earth's tilt on its axis and its elliptical orbit around the Sun. Instruments such as pyranometers or pyrheliometers are used to measure solar irradiance. These devices consist of sensors that measure the incoming solar radiation and provide data for various applications, including the design and operation of SE systems.

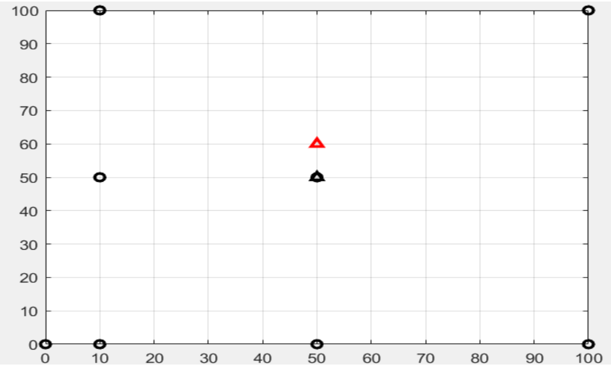

Figure 3: WSNs Simulation Topology

Energy Harvesting Results (Morning)

No	Performance parameters	Without EH	With EH
1	Number of data packet transmitted	4000	5012
2	Number of control packets transmitted	2800	3508
3	Total number of Bytes transmitted (bytes)	400000	501200
4	Number of payloads transmitted (bytes)	160000	200480
5	Number of overheads transmitted (bytes)	240000	260624
6	Number of data packets collided	400	626

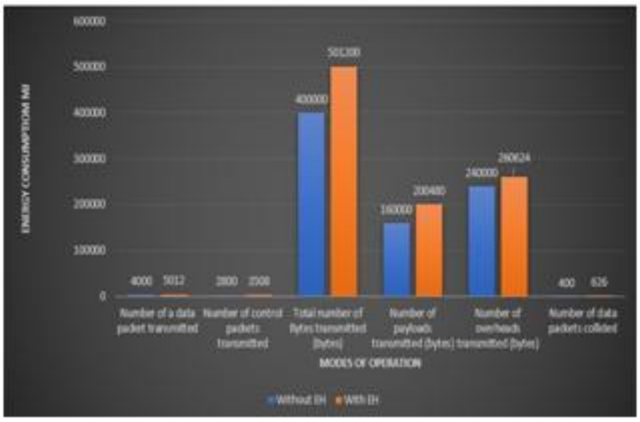

Figure 4: Network layer performance parameters (Morning).

SEH -WSNs involves capturing sunlight, often with photovoltaic panels, to generate electrical energy. Utilizing morning solar energy is crucial for ensuring continuous sensor network operations. Fig. 11 shows a graphical representation of Network layer performance parameters in (Morning) results.

Energy Harvesting Results (Afternoon)

No	Performance parameters	Without EH	With EH
1	Number of data packet transmitted	4000	5609
2	Number of control packets transmitted	2800	4202
3	Total number of Bytes transmitted (bytes)	400000	645100
4	Number of payloads transmitted (bytes)	160000	230018
5	Number of overheads transmitted (bytes)	240000	274870
6	Number of data packets collided	400	863

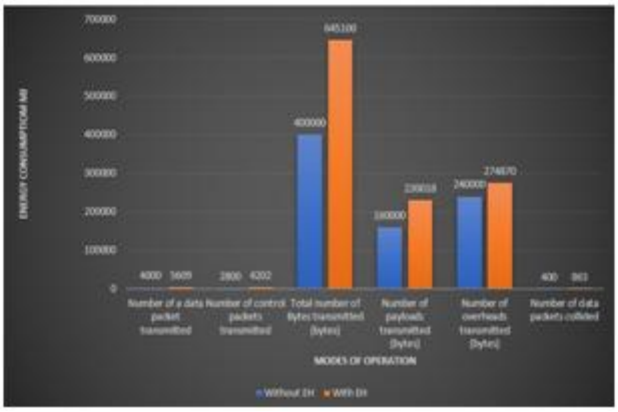

Figure 5: Network layer performance parameters (Afternoon)

SEH -WSNs in the afternoon is a vital strategy to optimize energy collection during peak sun hours. This process relies on advanced technology, efficient energy management, and the integration of energy storage solutions to power sensor nodes and support data transmission. Fig. 12 shows a graphical representation of Network layer performance parameters in (Afternoon) results.

Energy Harvesting Results (Evening)

No	Performance parameters	Without EH	With EH
1	Number of data packet transmitted	4000	4414
2	Number of control packets transmitted	2800	3007
3	Total number of Bytes transmitted (bytes)	400000	451080
4	Number of payloads transmitted (bytes)	160000	160360
5	Number of overheads transmitted (bytes)	240000	250600
6	Number of data packets collided	400	716

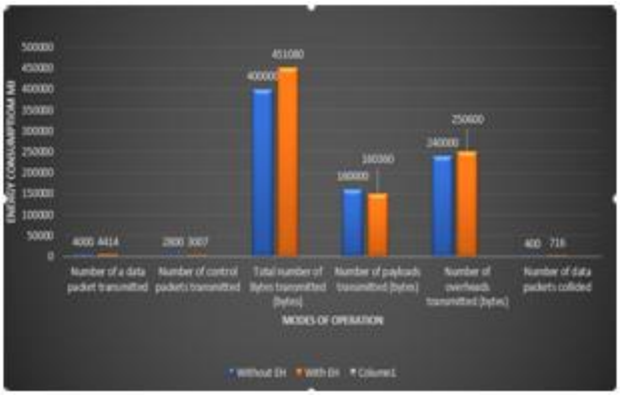

Figure 6: Network layer performance parameters (Evening)

SEH -WSNs in the evening represents a valuable strategy for maximizing energy collection during late daylight hours. This process relies on advanced technology, efficient energy management, and the integration of energy storage solutions to power sensor nodes and support continuous data collection and transmission. Fig.13. shows a graphical representation of Network layer performance parameters in (Evening) results.

Comparison of Average Energy Consumption

No	Energy Consumption	Without EH (mJ)	With EH (mJ)	Improved performance percentage (%)
1	Consume energy	1225	1456	15.85%
2	Transmitting energy	7920	9504	16.66%
3	Receiving energy	3.49	4.16	16.25%
4	Idle energy	4335	5059	14.31%

3. Conclusion

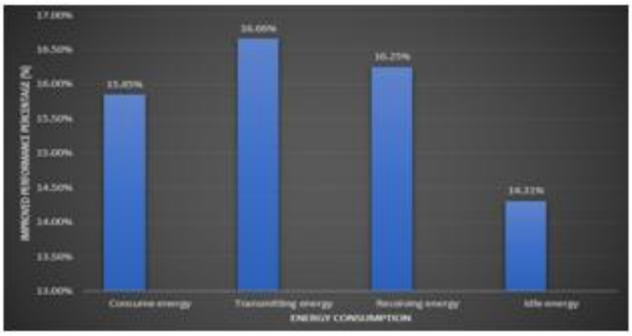

Figure 7: Energy consumption performance parameters

This project has provided an overview of the energy harvesting approach for wireless sensor networks, with the intention of applying it in practical settings such as smart agriculture and other real-world applications. The simulation has been performed for SEH-WSNs and analyzed MPPT INC through MATLAB simulations for WSNs. The ideal outcome of this study would be to use SEH to increase the dependability and energy efficiency of WSNs. Additionally, the total amount of bytes delivered ranged from (400000 to 645100) has been increased. The simulation results indicate that the utilization of solar energy harvesting enhances the analysis of network performance and energy consumption. As a result, it can possibly increase the lifespan of WSNs to infinity. SEH can be seen as a cost-effective approach because it eliminates the need for frequent battery replacements in sensor nodes to sustain the network. The Future Scope this study would be, SEH-WSNs systems are scalable to a number of advanced MPPT algorithms such as those employing neural networks, fuzzy logic, and machine learning techniques, can be applied.

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