Journal of Nano- and Electronic Physics
Vol. **16** No 5, 05015(5pp) (2024)

Журнал нано- та електронної фізики
Том **16** № 5, 05015(5cc) (2024)

REGULAR ARTICLE

Design and Analysis of an Innovative Energy Harvesting Solution for IoT Sensor Node Deployment

S. Kalaivani* ✉, C. Tharini†, S.V. Anand

Department of Electronics and Communication Engineering, B.S.A Crescent Institute of Science and Technology, Chennai, Tamil Nadu, India

(Received 15 June 2024; revised manuscript received 14 October 2024; published online 30 October 2024)

Energy consumption is a problem for sensor networks even with different ways to conserve energy. Since their energy reserves run out in less than a year, wireless sensors that rely on batteries will eventually need to be replaced. Longer battery lifespan are made possible by technological advancements like lithium thionyl chloride, however disposing of batteries has an adverse effect on the environment. For wireless sensor networks, energy harvesting especially solar energy becomes a desirable substitute in nations like Finland, Mexico, China, and the United States. Rechargeable batteries and low-energy harvester circuits combined with small solar panels offer a sustainable, self-sustaining option for long-term network viability. Showcasing recent advancements in renewable energy technology, researchers and businesses are currently developing energy harvesting devices specifically designed for traditional battery-operated sensor networks. The focus of the proposed work is to develop a research strategy for assessing both present as well as potential energy harvesting technologies. In order to increase the lifespan of the Wireless Sensor Network, the main goals are to build an effective energy harvesting process and optimize sensor node task schedules.

Keywords: Energy harvesting, Wireless sensor network, Sensor node, Energy efficiency.

DOI: 10.21272/jnep.16(5).05015 PACS numbers: 07.05.Tp, 07.07.Df

1. INTRODUCTION

Energy harvester or power harvester is a method of deriving energy from external sources like solar power, wind power, tidal power piezoelectric energy, etc. The energy derived from these sources can be used for low energy applications. The most used ambient source is solar power. Some systems can derive power from motion, such as that of ocean waves. Fig. 1 shows the various sources from which electrical energy can be harvested. The scavenged energy can also be used to supply power to small autonomous sensors. The harvested energy is generally stored in a battery, capacitor, and supercapacitor. Capacitors are used in applications that require substantial energy spikes. Batteries provide fewer energy leaks and hence used in areas that require a steady energy flow. However, batteries must be replaced or disposed of frequently, sensor nodes that are located in remote areas use supercapacitors as it has infinite charge and discharge cycles compared to batteries. Solar power is an essential form of renewable energy. In the case of a wireless sensor node, solar power is mostly used due to its abundant power source and can be easily transferred into electricity. So, it is necessary to store the solar power in the most efficient way for future usage. An algorithm is proposed for the efficient use of stored energy. The wireless sensor node designed here consists of two SOC which is connected to provide a regulated output of 5 V DC. An Energy-Efficiency algorithm can be implemented to maximize efficiency, and it also helps to reduce the power consumption of the device. To develop the Energy-Efficiency algorithm, the power consumption in each process of a sensor node is calculated.

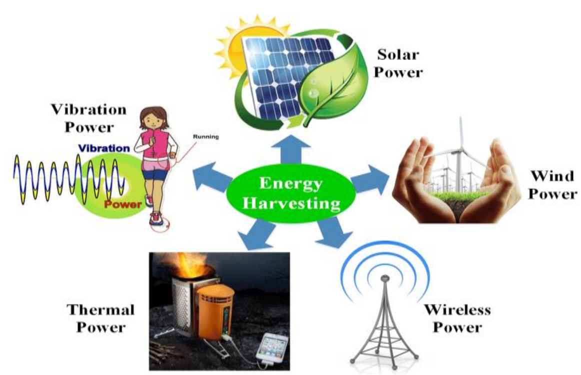

Fig. 1 – Various sources of energy harvesting

The Algorithm is developed to reduce the power consumption of sensors, microcontrollers, and transceiver.

* Correspondence e-mail: skalaivani@crescent.education
† tharini@crescent.education

Cite this article as: S. Kalaivani et al., *J. Nano- Electron. Phys.* 16 No 5, 05015 (2024) https://doi.org/10.21272/jnep.16(5).05015

2. LITERATURE SURVEY

The purpose of the literature review is to give a brief overview and to establish complete information about the reference paper. The goal of the literature survey is to completely specify the technical details related to the main project, concisely and unambiguously.

Salar Chamanian et al. [1] proposed a method that deals with the objective of harvesting energy from ambient vibrations like Piezoelectric (PE) and Electromagnetic (EM) sources. The energy harvested from EM source is stored in a storage capacitor, and this energy is transferred to the PE harvester as the energy obtained by this method is more efficient than obtained from individual sources. Gaurav Saini et al. [2] focused on building a power management circuit (PMC) that consists of an energy harvester, a DC-DC boost converter, and a DC-DC buck converter. To achieve Maximum Power Point Tracking (MPPT), an open-circuit voltage method is used. This system uses RF energy harvester, Piezo-electric energy harvester and Indoor light energy harvester for harvesting energy.

Zheng Jun Chew et al. [3] proposed a method to transfer the harvested energy directly to the load instead of being consumed by the internal circuit. The Analogue Circuit Control (ACC) and Energy-Aware Interface (EAI) algorithm were used to obtain maximum energy from the solar panel and control the energy flow from the storage element to the load, respectively. Karim Rawy et al. [4] proposed an energy harvesting system that uses 3-D MPPT with Switch Width Modulation (SWM) to improve power efficiency. The SWM eliminates the gate driver/conduction loss tradeoff in a reconfigurable Switched-Capacitor Charge Pump (SCCP). An energy aware algorithm has been proposed to select the harvester and connect it to the EHS.

Engr. Syed Ashraf Ali et al. [5] aims to build an energy harvesting system for a wireless sensor node that can be deployed in a remote area. This system uses both battery and supercapacitor as storage elements. This system provides improved management of uncertainty of energy supply through improved calculations and enhances the energy management procedures. Currently, there are few existing methods to harvest energy from solar power to power the sensor node. Individual systems have implemented different algorithms like Analogue Circuit Control and Energy-Aware Interface to draw the maximum amount of solar power from the solar panel and to control the energy flow from storage elements to the load respectively [6]. So, it is essential to develop a system that prolongs the lifetime of batteries and to power the sensor node even in the absence of sunlight.

3. PROPOSED SYSTEM

The proposed system shown in Fig. 2 consists of Solar Panel, Energy Harvester IC, 3-Channel Buck Regulator IC, Battery, Supercapacitor, Microcontroller, Sensors, and Transceiver. The Energy Harvester IC consists of a Buck-Boost converter, and it can provide a constant 5V output [7]. The output of the Energy Harvester IC is given as input to a 3-Channel Buck Regulator IC, which provides three different regulated outputs to power the sensors, microcontroller, and transceiver. The proposed system uses battery and supercapacitor connected to the Energy Harvester IC to store the harvested energy. The stored energy is used to supply power to the load from the supercapacitor during the daytime, and the load is powered by the battery in the absence of sunlight. The battery is charged when solar power is available. For efficient usage of the stored energy, the Energy Efficiency algorithm is developed that reduces the power consumption in a sensor node.

The main blocks of solar energy harvester [8] are solar panel, energy harvester, switching regulator, sensors, microcontroller, and transceiver. The design idea behind the hardware is to have two different ICs: Energy Harvester and Switching Regulator. The Solar panel is used to convert solar energy to electric energy.

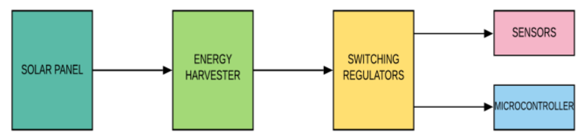

Fig. 2 – Basic Block Diagram of solar energy harvester

The energy harvester does an efficient way of storing, distributing, and powering. The switching regulator acts as a switch that powers the sensor and the transceiver according to the Energy Efficiency algorithm that is programmed in the microcontroller.

4. PROPOSED SYSTEM DESIGN

4.1 Proposed Work

The main objective of the proposed method is to build an efficient energy harvesting for a WSN module. For a WSN to work for a more extended period, it requires a constant and more reliable power source. To build such a source, the design depicted in Fig. 3 is well suited to provide the necessary supply. It has both battery and a supercapacitor for storing the harvested energy.

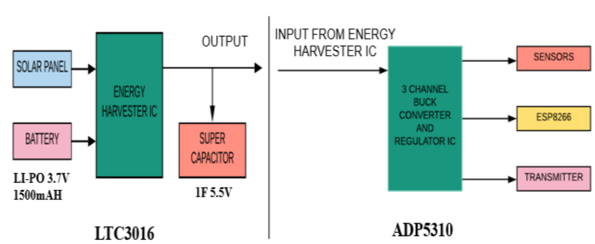

Fig. 3 – Working structure of solar energy harvester

Supercapacitors or Ultra capacitors are new energy storage technology that has been developed jointly in modern times [9].

4.2 Design of Energy Harvester Module and Switching Regulator Module

The LTC3106 is a highly integrated, ultra-low voltage buck-boost DC/DC converter with automatic Power Path management optimized for multisource, low power systems [15]. A basic design produces 5VDC as an output from the energy harvester IC. The schematics of the energy harvester IC is done by using EAGLE software, and the PCB is also designed in it. The diagram in Fig. 4 shows the design for PCB of Energy harvester IC. The ADP5310 combines dual buck regulators and one load switch package that meets demanding performance and board space requirements. The design process of ADP5310 is to provide switching three-channel voltages of 5 V for sensors, 3.3 V for microcontrollers and 3.3 V for transceiver modules [16].

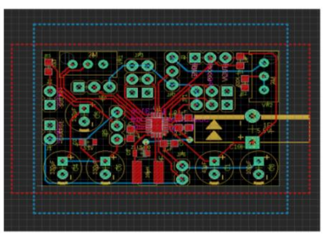

Fig. 4 – PCB Design of LTC3106

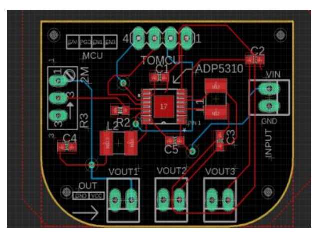

Fig. 5 – PCB Design of ADP5310

The PCB design of ADP5310 is given in Fig. 5.

5. EFFICIENT USE OF HARVESTED ENERGY

The energy consumption of the ESP8266 varies between 15 μA and 400 mA depending on the various applications [17]. An ESP8266, in its idle state, consumes 0.164 mAh per reporting cycle, when it wakes up, the Wi-Fi radio also turns ON that takes about 0.35s. Then the sensors begin to measure data for around 1.2s as the sensors take time to stabilize. Next, the establishment of the Wi-Fi access point takes place for 2.3s. Then, the data is transmitted within 0.3s and the ESP8266 dives into sleep mode. The total power consumption for one reporting cycle is reduced to 0.07 mAh. Energy Efficiency is the main prerequisite to optimize the life of the sensor node [10]. Usually, the sensor nodes are powered by a battery source with a finite lifetime [11]. It is necessary to model the energy consumption for various tasks to design an autonomous sensor node [12]. To optimize the energy consumption of the sensor node, it is necessary to estimate the energy consumed by each sensor unit. The total energy consumed can be estimated from the sum of energy consumed in active and sleep modes [13],

$$E_{Total} = E_{Sleep} + E_{Active} \quad (1)$$

where, E_{Sleep} is the energy consumed in sleep mode, and E_{Active} is the energy consumed in active mode. The energy consumed in sleep mode can be expressed as,

$$E_{Sleep} = P_{Sleep} \cdot T_{Sleep} \quad (2)$$

where P_{Sleep} is power consumption, and T_{Sleep} is the time duration in sleep mode. The energy consumption in active mode is expressed as,

$$E_{Active} = E_{WU} + E_m + E_{WUT} + E_{Tr} + E_R \quad (3)$$

where E_{WU} is the energy consumed in node wake-up, E_m is the energy consumed in measuring sensor data, E_{WUT} is the energy consumed in waking up the transceiver module, E_{Tr} is the consumed energy during data transmission, and E_R represents the energy consumption in data reception. These parameters can be calculated using the following equations,

$$E_{WU} = P_{ON}(f_{MCU}) \cdot T_{WU} \quad (4)$$

$$E_m = (P_{ON}(f_{MCU}) + P_m) \cdot T_m \quad (5)$$

$$E_{WUT} = (P_{ON}(f_{MCU}) + P_{WUT}) \cdot T_{WUT} \quad (6)$$

$$E_{Tr} = (P_{ON}(f_{MCU}) + P_{Tr}) \cdot T_{tR} \quad (7)$$

$$E_R = (P_{ON}(f_{MCU}) + P_R) \cdot T_R \quad (8)$$

The proposed Energy Efficiency (EE) algorithm is mainly focused on reducing energy consumption and utilizing the harvested energy efficiently. The flow diagram of the proposed EE algorithm is given in Fig. 6. Two factors must be considered when designing a wireless sensor node that is the maximization of battery lifetime and reduction of energy consumption [14].

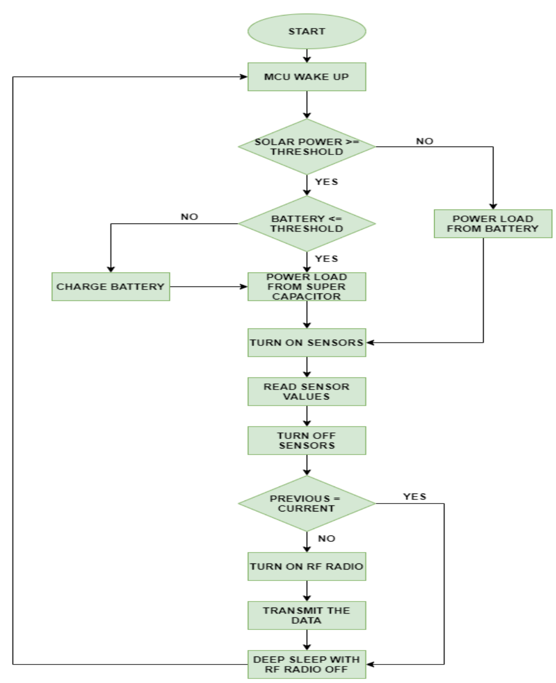

Fig. 6 – EE Algorithm flow chart

6. IMPLEMENTATION OF THE PROPOSED WORK

The schematics of the LTC3106 module and the ADP5310 module have been designed using the Easy EDA tool [18]. EAGLE is a graphical layout editor that saves Gerber and PostScript graph documents used by manufacturing PCB firms [19]. As shown in Fig. 7 the implementation of the proposed work is done in Proteus, a simulation and design software tool [20].

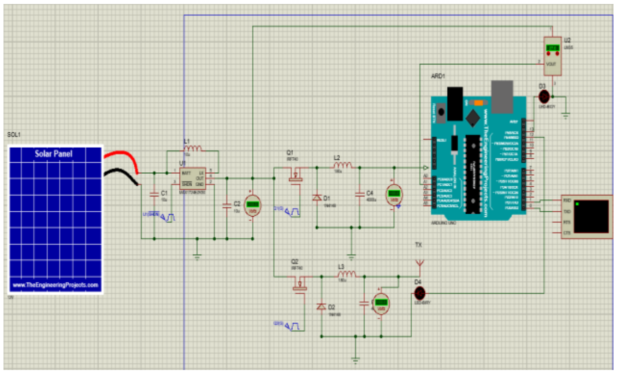

Fig. 7 – Circuit of the proposed system

Table 1 – Energy Consumption of Different Operating Modes of Arduino

E_{WU}	68 mJ
E_{m}	345 mJ
E_{WUT}	290 mJ
E_{Tr}	131 mJ
E_{R}	130 mJ
E_{Active}	964 mJ
E_{Sleep}	696 mJ
E_{TOTAL}	1660 mJ

With reference to Table 1, the energy consumption of different operating modes of ESP8266 given in paper [13] is used to calculate the energy consumption. For one reporting cycle, Arduino consumes 2215 mJ of energy. Table 2 shows the energy consumed before and after applying EE algorithm in Arduino. The difference between the energy consumed before and after applying EE Algorithm is 1251 mJ which is 43% of the total energy.

Table 2 – Comparison Table of Energy Consumption for Arduino

	Active Mode	**Sleep Mode**	**Total**
Energy Consumption Before Applying EE Algorithm	2215 mJ	696 mJ	2911 mJ
Energy Consumption After Applying EE Algorithm	964 mJ	696 mJ	1660 mJ

7. CONCLUSION AND FUTURE WORK

Harvesting energy from ambient sources is essential because it allows energy to be extracted without using conventional power sources. The inability of current energy harvesting techniques to keep sensor nodes dormant at night is a drawback. The creation of a solar energy harvesting module for wireless sensor nodes is suggested in this research. It will effectively use the energy captured to guarantee a steady power supply. The battery's life is increased by using a supercapacitor during the day and saving the battery for times when there isn't any sunlight. Through deep sleep and wake-up phases, an Energy-Efficient (EE) algorithm enables smooth transitions between the battery and supercapacitor, lowering the total power consumption of the sensor node. The energy harvester is made up of two modules that improve fault identification: LTC3106 and ADP5310, which may eventually be combined into a single module. The extension of this work can be used to power sensor nodes for usage in healthcare, agriculture, and other fields. To get more power from solar energy, utilize a high-power solar panel. For more sophisticated applications, interface units can link a greater number of sensors. Multiple sensor nodes can be powered by a single solar energy harvester. To increase the efficiency of the sensor node, a new algorithm can be created. Power consumption might be decreased by employing timers to schedule the sensors.

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Розробка та аналіз інноваційного рішення для збору енергії, що використовується для розгортання сенсорного вузла IoT

S. Kalaivani, C. Tharini, S.V. Anand

Department of Electronics and Communication Engineering, B.S.A Crescent Institute of Science and Technology, Chennai, Tamil Nadu, India

Споживання енергії є проблемою для сенсорних мереж навіть з різними способами збереження енергії. Оскільки їхні запаси енергії вичерпуються менш ніж за рік, бездротові датчики, які працюють від батарей, зрештою потребуватимуть заміни. Подовження терміну служби батареї стало можливим завдяки технологічним досягненням, таким як літій-тіонілхлорид, однак утилізація батарей негативно впливає на навколишнє середовище. Для бездротових сенсорних мереж збір енергії, особливо сонячної, стає бажаною заміною в таких країнах, як Фінляндія, Мексика, Китай і Сполучені Штати. Акумуляторні батареї та схеми харвестерів з низьким енергоспоживанням у поєднанні з невеликими сонячними панелями пропонують стійкий, самопідтримуваний варіант для довгострокової життєздатності мережі. Демонструючи останні досягнення в технології відновлюваних джерел енергії, дослідники та підприємства зараз розробляють пристрої збору енергії, спеціально розроблені для традиційних сенсорних мереж, що працюють від батарейок. Основною метою запропонованої роботи є розробка дослідницької стратегії для оцінки як існуючих, так і потенційних технологій збору енергії. Щоб збільшити термін служби бездротової сенсорної мережі, основні цілі полягають у створенні ефективного процесу збору енергії та оптимізації графіків завдань сенсорних вузлів.

Ключові слова: Збір енергії, Бездротова сенсорна мережа, Сенсорний вузол, Енергоефективність.