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Hybrid of Solar Energy Harvesting using IoT and WSN Technology

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Abstract—Many experts consider WSNs to be one of the most important scientific topics. To fully utilize WSNs to increase the lifespan of sensors, however, is challenging due to the significant energy limits. Numerous methods for energy collecting, energy transfer, and energy conservation have been proposed. The internet of things (IoT) manages a vast infrastructure of web-enabled smart devices. It does this by using data collected from its surroundings. Therefore, such devices are composed of scalable, light, and power-efficient storage nodes that, in order to operate practically, need electricity and batteries. The effectiveness and durability of IoT devices are undoubtedly greatly influenced by energy harvesting. The LEACH protocol is used along with the solar EH approach. The battery's charging and discharging curves as well as the nodes' energy state are depicted graphically. The converter receives switching pulses from the microcontroller, which also displays output current, solar panel voltage, and supercapacitor voltage. The simulation findings show that after using the solar EH approach, the battery and network lifetimes are increased.

Keywords- Energy harvesting; IoT; Photovoltaic; Solar energy; Wireless Sensor Network

I. INTRODUCTION

A Wireless Sensor (WSN) is a collection of several geographically scattered sensor nodes, wirelessly interconnected and at least one sink node, known as a base station (BS) [1]. Sensor nodes seek to analyze and exchange the pertinent data with other nodes. For example, to monitor and collect data about the ambient circumstances that exist in a field of interested networks. "Fig.1" depicts the architecture of a typical WSN.

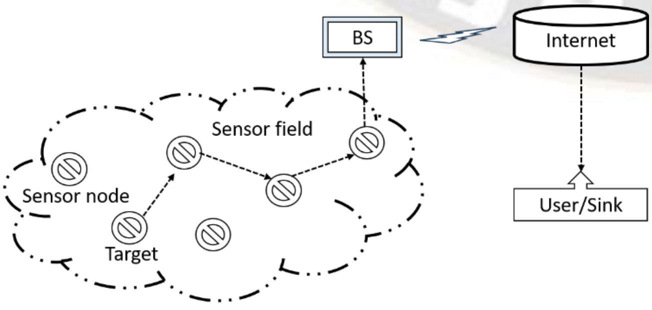

Figure 1. WSN basic communication architecture [1]

The BS is the network's master node and collects data from all other nodes because it also handles data transfer to the end user or sink node. WSN technology is now used more and more in areas such as industrial automation, agriculture, smart cities, target tracking, structural health monitoring, healthcare, civil and military applications, and so on [2].

Wireless sensor network interaction is now possible through the Internet of Things (IoT), a new technology. The four components of an Internet of Things device are a gateway, a processor, an actuator or sensor, and an application. The brain of an IoT system is a processor. IoT is essential to future technologies because so lots of companies are focusing on it. So, the IoT offers to move traditional industry to the emerging Industry 4.0. The WSNs and Wireless Sensor and Actuator Networks (WSANs) are the foundation of Industry 4.0. Many wireless devices that can connect to the internet are currently under the management of the IoT for their networking infrastructure. For Industry 4.0 to be possible, the networking, deployment, and monitoring of numerous different sensors must be dependable, flexible, and scalable [3, 25].

One of the main obstacles to the successful adoption of WSNs is energy conservation because the tiny sensor nodes have limited energy, memory, and computing capabilities. Supercapacitors and rechargeable batteries are the two most cutting-edge energy-storage technologies for energy-harvesting systems in sustainable wireless sensor nodes [4]. Today's WSNs can use a variety of EH approaches, but the solar EH technique is widely used since solar cells have the maximum power density of 15 mW/cm2. As a result, it is sufficient to meet the WSN's power needs [5]. However, the little batteries have a constrained amount of energy storage, and replacing them is both expensive and difficult. WSN-enabled devices Both renewable and non-renewable energy sources are used as power sources. Thermal, mechanical, and radiant energy are three types of renewable energy. Batteries and fuel cells are non-renewable energy sources. Harvesters for renewable energy sources have the advantage of low volume, low weight, minimal environmental effect, and extended life [6]. To reduce the amount of energy used by the WSN as much as feasible, ultra-low power techniques are used. Several difficulties and obstacles must be solved for WSNs to actually become pervasive and autonomous.

II. LITERATURE SURVEY

Researchers have been attempting to use renewable energies like RF, thermal, wind, solar, and wind energy as a source of power for WSN in recent years. A variety of harvesting models are proposed by researchers. A sensor node with an energy-harvesting source was explored by Sharma et al. [7], and the energy produced was stored in a buffer. For the purpose of monitoring the environment, Minami et al. [8] created a solar block, a wireless system without batteries. Chuang WY et al. suggested [9], a solar-powered sensor module with inexpensive capacitors acting as storage buffers was examined so that the energy-charging time was reduced to less than a second. The Everlast wireless sensor node was introduced by Simjee et al. [10] and uses a Supercapacitors to operate. A solar power system with a lithium battery and a Supercapacitors has been proposed by Alberola et al. [11]. According to Jiang et al.'s method, [12] the system should charge the lithium battery if the voltage falls below a predetermined level. Utilizing maximum power point tracking (MPPT) for WSNs, Yin et al. [13] created an intelligent solar EH system.

Low energy adaptive clustering hierarchy (LEACH) protocol is a hierarchical network protocol that allows for direct communication between the sink (base station) and the cluster heads' aggregated data and data from the nodes [14].

An EH model for solar-powered WSN and the energy management system model's analytical behavior were proposed by Abbas et al. [15]. To display the current-voltage (IV) and photovoltaic (PV) characteristics of the solar cell, numerical simulations were also carried out. The authors of Yildiz et al. [16] created a hybrid EH model that makes use of electromagnetic and solar energy.

TABLE I. HARVESTING TECHNIQUE POWER DENSITIES [5]

Sr.	**Methods**	**Present value**
1.	Solar cell	15 mW/cm^3
2.	Thermoelectric	40 μW/cm^3
3.	Vibration	116 μW/cm^3
4.	Piezoelectric	330 μW/cm^3
5.	Acoustic noise	960 nW/cm^3

In order to reduce the energy dissipation of the sensor nodes the MICAz nodes and LEACH protocol are used to combine the Solar EH technology and lower the power consumption of the nodes. "Table 1." lists the various power densities of EH sources.

This paper is organized as follows for the remainder. Current energy harvesting methods are described in section 2. Furthermore, basic mathematical model expressions and assumptions of low-energy approaches are described. Future simulations are outlined in Section 3 along with the result and its analysis. The conclusion appears in Section 4 last.

III. ENERGY HARVESTING

Energy harvesting, in general, is the practice of capturing and storing energy for the purpose of supplying power to small electronic devices. Energy scavenging technologies that can be installed in the sensor nodes are used in WSNs to accomplish energy harvesting. These energy harvesting systems frequently use power management modules (PMM) to boost the level of captured power and limit energy inconsistencies between the harvester and the node. A harvester or harvesting system, independent nodes, or nodes with inbuilt energy storage devices, are typically required for the harvesting process [18]. "Fig.2" presents a general overview of the energy collecting process.

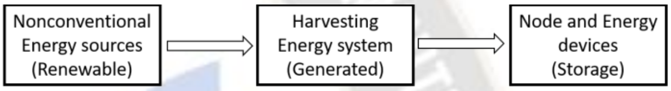

Figure 2. Energy harvesting block [18]

A. Architecture for Energy Harvesting.

"Fig.3" depicts the energy architecture that collects energy, with a photovoltaic (PV) cell serving as the basis for the energy conversion process. The storage components, such as Supercapacitors and rechargeable batteries, need to be chosen based on the environmental circumstances as the energy is harvested from the surrounding energy.

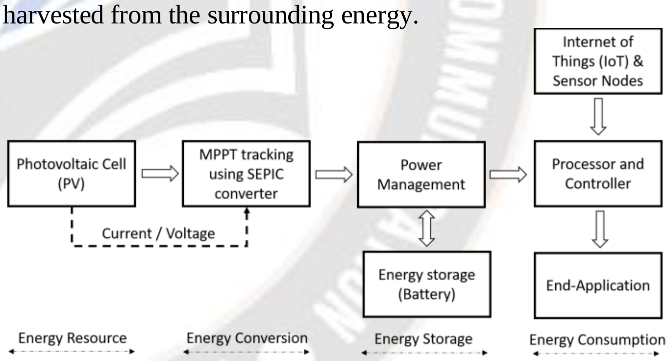

Figure 3. An energy harvesting system architecture [18]

The solar energy harvester is one of such forms of harvesting architecture. Voltage regulator, maximum power point tracking (MPPT) converter, and solar cell make up the harvester. The MPPT tracking in a PV system uses a SEPIC converter to track the maximum voltage. While the voltage regulator is used to charge batteries, the other is utilized to supply steady power to IoT devices [18]. The system lowers the cost of the devices and may lead to an increase in system efficiency. To reduce the amount of energy used by the WSN as much as feasible, ultra-low power techniques are used. A new class of network known as the energy harvesting wireless sensor network (EHWSN) [19].

B. Solar Energy Harvesting

The wavelength of solar radiation that is transmitted ranges from 0.25 micrometers to 3 micrometers (for space outside the earth's atmosphere) and from 0.32 micrometers to 2.53 micrometers (for space inside the earth's atmosphere) [20]. The conversion of solar energy into electrical energy is made possible by photovoltaic cells. Based on the technique used in production, different types of solar cells are categorized. Monocrystalline are pure silicon crystal bars that have been thinly sliced. Polycrystalline is created by melting multiple silicon crystal rods and then pouring the molten material into a square mold. The best photovoltaics are amorphous silicon and copper indium gallium selenide, which operate well outdoors but poorly indoors [21]. Using ambient PV cells, autonomous IoT devices can run on artificial intelligence that is built into the hardware.

IV. METHODOLOGY ENERGY MODEL

The amount of incoming intensity (I) of solar energy (P_{in}) on (A_{Panel}) panel surface area is given by:

$$P_{in}=\mathrm{I}*A_{Panel} \tag{1}$$

The quantity of energy produced by solar panel (P_{out}) by measuring voltage (V) and current (I) is:

$$P_{out}=\mathrm{V}*\mathrm{I} \tag{2}$$

Efficiency (ŋ)value of solar panels is the ratio of maximum power (P_{out}) to input solar radiation to panel power (P_{in}):

$$ŋ = \frac{P_{out}}{P_{in}} \tag{3}$$

Maximum power (P_{max}) calculation is the product of open circuit voltage (V_{oc}), short circuit current (I_{sc}) and fill factor (FF).

$$P_{max} = V_{oc} * I_{sc} * FF \tag{4}$$

Sandhu et al. [22] evaluated an analog-to-digital converter (ADC) that makes use of the signal acquisition power (SAP) of digitizing the obtained signal. The features of the transducer and the application context will determine whether this SAP is higher or lower than the power received. The following is a description of the Acquisition Power Ratio (APR).

$$APR = \frac{P_{harvested}}{P_{acquisition}} \tag{5}$$

The quantity of energy gathered by energy negative sensing (if APR < 1) is less than the energy needed for digitization. Energy gathered for energy-positive sensing (if APR > 1) is greater than the energy needed to acquire a signal. If APR = 1, energy neutral sensing has very little overlap with energy positive and negative sensing.

A WSN's lifetime can be estimated from a stochastic point of view. The rate at which electric energy *e(t)* as a function of time is as the instantaneous electric power, or *p(t)*, is used to assess the energetic cost of transmitting/receiving data [23].

$$P(t) = \frac{d_e(t)}{dt} \tag{6}$$

The total energy E is the instantaneous power's integral is represented by T=$[t_i - t_f]$.

$$E = \int_{t_f}^{t_i} p(t)\,dt \tag{7}$$

Formulas (6) and (7) can be used to compute the mean power E in T.

$$E = \int_{t_f}^{t_i} p(t)\,dt = e(t_f) - e(t_i) = e(t_i) \tag{8}$$

Power in W for the duration of Δt is given as

$$E = \breve{\mathrm{W}}\Delta\mathrm{t} \tag{9}$$

An easy way to determine energy is needed to complete an operation, such as $E_{\mathrm{Tx,slot}}$, $E_{\mathrm{Rx,slot}}$, or $E_{\mathrm{Sleep,slot}}$, per slot, is provided by formula (9).

$$E_{\mathrm{Tx,slot}} = W_{Tx}\Delta t_{slot} \tag{10}$$

$$E_{\mathrm{Rx,slot}} = W_{Rx}\Delta t_{slot} \tag{11}$$

$$E_{\mathrm{Sleep,slot}} = W_{Sleep}\Delta t_{slot} \tag{12}$$

where W_{Tx}, W_{Rx}, and W_{Sleep} are the corresponding amount of power used during transmission, reception, and, in turn, sleep. In most solar harvesting systems, rechargeable batteries are used. There are several different types of rechargeable batteries, including lead-acid, nickel-cadmium, nickel-hydrogen, lithium-ion, and lithium-polymer batteries. The lithium-ion battery used in this proposed work has a capacity of 730 mAH. Its nominal voltage is 3.7 V for lithium-ion batteries. The time needed to charge the battery is indicated in the following equation [24]:

$$Charge\ time = \frac{battery\ capacity\ (mAH)}{produce\ energy\ (mA)} \tag{13}$$

The battery's time to discharge is stated in the equation below [24]:

$$Discharge\ time = \frac{battery\ capacity\ (mAH)}{\text{current drawn}\ (mA)} \tag{14}$$

V. SIMULATION SETUP

In the proposed idea MATLAB R2015b were used in implementation. This work combines the MAC protocol LEACH with the solar EH method. The MICAz nodes were set up in the sensor field are operating in three separate modes: active mode, idle mode, and sleep mode.

TABLE II. MICAZ NODE POWER CONSUMPTION [25]

Mode type	**Present value**
Idle mode	9.16 mA
Active mode	21.7 mA

Sleep mode	17.83 µA

The nodes can transmit or receive data while they are in the active state, but when they are in the sleep or idle states, some of the circuitry on the sensor nodes is turned off. "Table 2." displays the current node usage for each of these several modes.

VI. RESULT AND ANALYSIS

The proposed system implementation analysis in "Fig.4" shows the lifetime of the WSN in terms of rounds using the LEACH protocol. All 100 nodes employ the protocol method to continue for a 2898 number of rounds. Thereafter it starts dying away after 2898 rounds until 4500 rounds. The number of rounds, when compared to the network lifetime before and after utilizing the solar EH technique, gets improved.

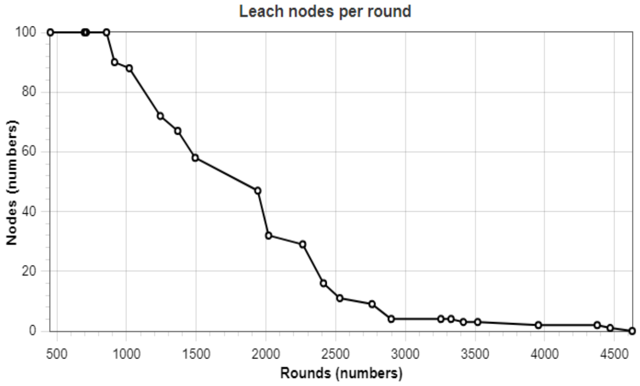

Figure 4. WSN lifetime measured in rounds using the LEACH protocol

Next, to determine how many watts of energy could be extracted from a solar cell, study the PV properties of a solar panel. "Fig.5" shows the solar panel's power-voltage characteristics. The analysis uses a 48-cell monocrystalline Solex module to calculate solar power. SES18220 model specifications are Rated Power (Pmax): 220; Current at Pmax (Imp): 8.13; Short-Circuit Current (Isc): 8.70; Open-Circuit Voltage (Voc): 33.50.

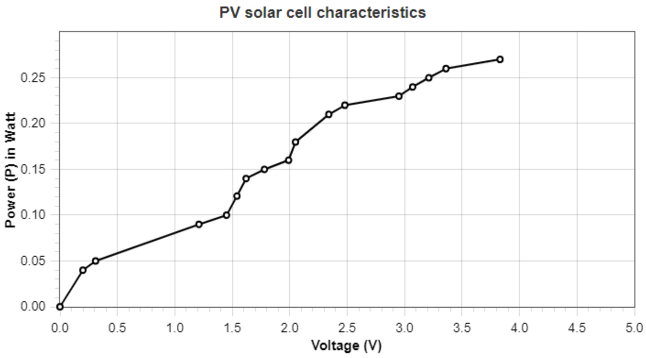

Figure 5. The solar panel Solex SES18220's output power

Next, research was conducted to determine the solar cell's intensity and power. The solar panel produces the highest level intensity of the sun's irradiance at noon and falls by evening. "Fig.6" displays the graph of irradiance intensity versus time of day. The solar panel provides a maximum current of 150 mA at noon with Irradiance 1,000W/m2, based on this diagram. Later the value starts falling down.

The battery's charging and discharging curves are then shown in "Fig. 7" and "Fig. 8" for the active, sleep, and idle states of the sensor nodes. After providing solar energy to the WSN, the nodes' energy status during particular LEACH rounds is mentioned.

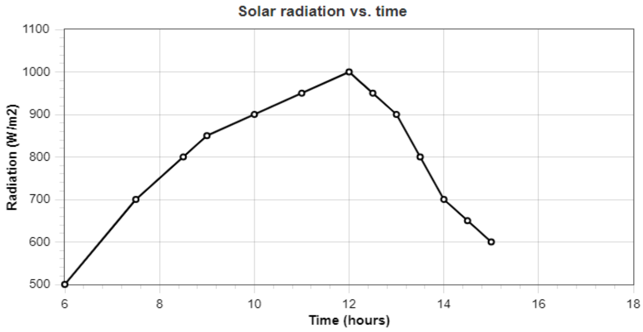

Figure 6. The solar panel irradiance in relation to time of day

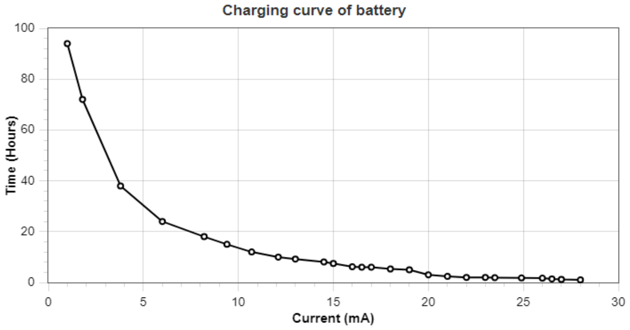

Figure 7. Charging curve of the battery under three states

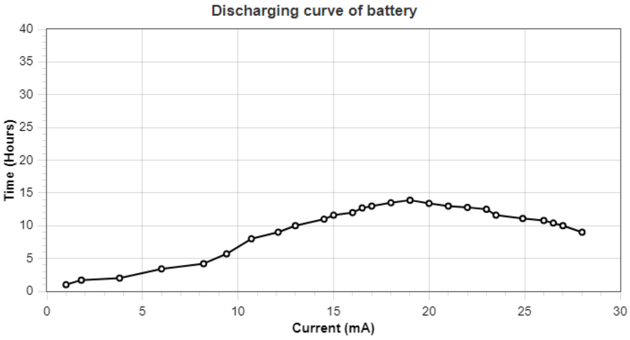

Figure 8. Discharging curve of the battery under three states

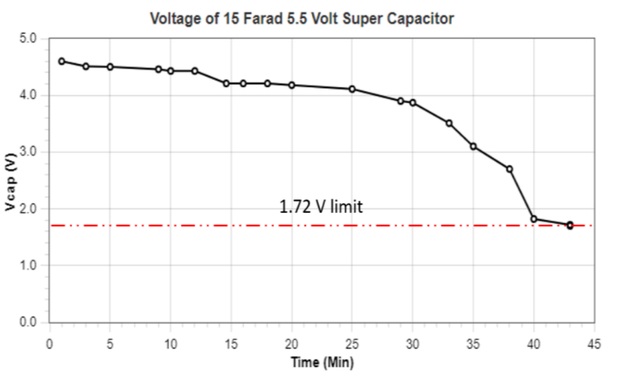

Figure 9. Time-dependent voltage of a 15 F @ 5.5 V supercapacitor

"Fig. 9" illustrates the behavior of a single 15 F @ 5.5V Supercapacitors feeding a wireless sensor that is continuously transmitting. The CHP series, 15 Farad, 5.5 Volt, Supercapacitors model number is CHP5R5L156R-TW. Ideal storage capacity for this Supercapacitors, which the wireless sensor can use, is UE = 1/2CV2 = 220:69 J. It shows that neither the radio chip nor the microcontroller can function properly when the capacitor voltage is below 1.72 volt. Unless the Supercapacitors somehow boosts its energy, if this point is reached, the wireless sensor will be unable to function in the network.

The microcontroller pulse and the TC4427A output pulse are shown in "Fig. 10" and "Fig. 11".

Figure 10. Gate pulse from the microcontroller

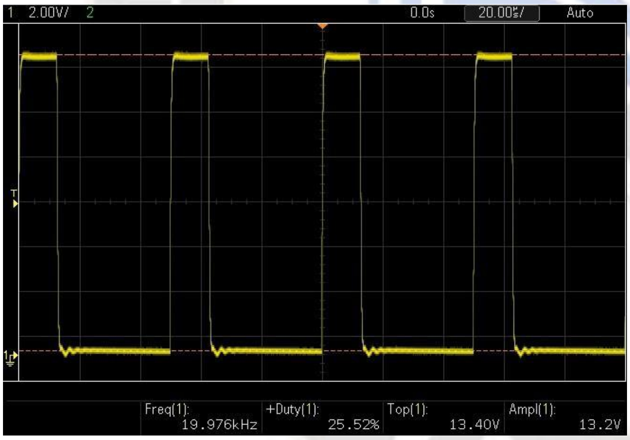

Figure 11. Amplifier enabling the SEPIC converter MOSFET

A gate driver circuit is set up to amplify the gate pulses the microcontroller generates into a voltage level able to trigger the MOSFET (IRFZ44N). The TC4427A driver chip, which offers both amplification and isolation, is employed. The pulse amplitude of the signal after amplification is high in comparison to the gate pulse produced by the controller without amplification. It is 13.51 volt. The converter malfunctions if this amplified pulse is not applied to the MOSFET's gate. As a result, the converter's output will be less precise.

VII. CONCLUSIONS

Energy harvesting is crucial for improving the effectiveness and durability of IoT devices. In this research, a unique intelligent solar energy-harvesting system is constructed employing an MPPT circuit with a SPIC converter. The analysis and design of a WSN device could utilize monocrystalline solar energy sources. Both the hardware and the software involved manage the lithium battery's charging by the addition of Supercapacitors, which considerably increase the system's robustness. Power management integrated circuits play a crucial role in lowering battery power consumption, which extends the lifespan of the system.

Results from experiments show that the system is capable of switching the power supply branch automatically. High dependability, high efficiency, low power loss, and a straightforward composition enable the system to operate safely and steadily. As a result, the proposed solar EH technique's results show that the battery and network's lifetime is extended. Future improvements can be done with the short- and medium-term scope of machine learning.

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