

# *Investigation of Thermal and Solar Energy Harvesting Systems for WSN Nodes*

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## **Abstract**

*Wireless Sensor Network (WSN) node can be described as infrastructure with fewer sensors that are connected wirelessly, forming a network that is used to gather important data/information from a difficult reach environment. These WSN nodes transmit the required data according to the injected queries wirelessly. These WSN nodes are generally applied in many applications, including military surveillance, agriculture, buildings, universities, dams, under the sea, high altitudes, etc. Since some of these areas are difficult to approach and reach, it is difficult to replace or recharge their battery manually, due to which their lifetime suffers, which ultimately causes interruption and unnecessary delay in the research work. So to overcome this issue, the idea of self-powered WSN nodes came into play. The self-powered WSN nodes recharge itself using the natural sources of energy that are openly available in the environment, and the two most commonly available sources of energy are solar and thermal energy. In this paper, some of the energy harvesting models/systems are discussed, which uses thermal and solar energy as the main source of energy in powering the WSN nodes. In this paper, some important conclusions are made by comparing different energy harvesting model.*

**Keywords:** - *Wireless Sensor Network (WSN), Solar Energy Harvesting, Thermal*

## **INTRODUCTION**

WSN node is a device used to gather data from different environments. A WSN node contains a sensor node that is used to sense the physical or chemical characteristics of that environment and a battery that supports it to complete its tasks, but since the size of the WSN node is very small, the battery capacity is also very low. This issue of the WSN node reduces its life, which ultimately interrupts the objective of applying it.

Generally, these WSN nodes are applied in difficult to reach environment such as high altitude mountains, underwater or sea, inside volcanoes, etc. for applications related to military work, research work, smart buildings, navy ships, wildlife researches, etc. due to which it is very difficult to replace or recharge the battery manually in regular intervals of time. This issue could be solved by using a self-powered wireless sensor node. This self-powered energy harvesting system harvests energy from the surrounding atmosphere by using natural energy as a source. The energy sources which are openly available in

the environment are solar energy, thermal energy, RF energy, wind energy, water energy, acoustic energy, electromagnetic energy, etc. The solar and thermal energy harvesting systems are found popular among these energy harvesting techniques as they harvest a great amount of energy, but there are some problems associated with them. Solar energy is widely used for energy harvesting; a great amount can be harvested using it, but only in the day time as in the night, no sunlight is available, so no amount of energy is harvested. In thermal energy harvesting, Thermoelectric Generator (TEG) is used that works on the principle of the Seebeck effect, which requires a great temperature difference across the material. This temperature difference is difficult to maintain in some regions due to the surrounding atmosphere.

For designing an energy harvesting model, it is very important to first estimate the amount of energy used by the WSN node to function properly, as this would be the target value of the harvesting model. The energy harvesting model should be able to harvest energy surplus to this

target value as the battery also drain its energy even when the sensor node is not in an active state due to some physical conditions. From [1], the amount of energy that is estimated for a 3.6V Li-ion battery to work properly for 24 hours is about 105.5J. So this is the target amount of energy needed by the battery to function properly, and while designing any energy harvesting model, this is the prime factor to be taken into consideration.

In this paper, energy harvesting systems that use solar and thermal energy as a main source of energy are briefly explained and discussed. Different models with different techniques are discussed, which are already designed.

**SOLAR ENERGY HARVESTING SYSTEMS**

Solar energy is the most popular form of harvestable energy source as it is the most commonly available renewable source of energy. Solar energy can be harvested using Photovoltaic cells (PV cells). These PV cells work on the basic principle of the photovoltaic effect, which shows that when light rays fall on semiconductor material, a DC is generated, and this can be easily stored using a battery. Using PV cells, only 380 to 750 nm of the wavelength of solar radiation can be transformed into electrical energy that means only visible spectrum radiations can be used to convert into electrical energy whose energy density is about certain factors, which are cloud coverage in thatut 1120W/m<sup>2</sup>.

Using PV cells, solar or light energy is harvested, and a maximum of 0.6V can be generated when it is applied in the regions where solar light intensity is maximum. The solar or light energy harvesting efficiency also depends on region, solar energy intensity this is also the major factor, the moisture content in that region, temperature and pressure in that area, wind speed, etc. In the midday, when the sun is on the top, more energy is harvested as compared to the morning or the evening time.

When the clouds are present less amount of solar energy is harvested as clouds reduce the solar intensity, which is the major factor responsible for solar energy harvesting. In the summer season, the temperature is high, which is not a good sign in solar energy harvesting as the semiconductor material conductivity also increases due to heat which balances the charge and weakens the electric field that ultimately reduces almost 10-25% of the energy harvesting efficiency. A PV cell circuit diagram is explained in fig. 1.

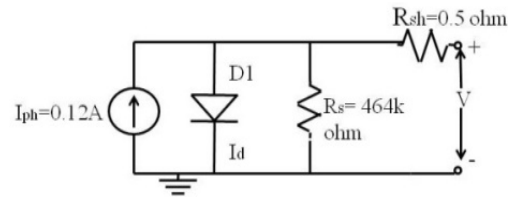


Figure 1: Solar cell circuit diagram

Fig. 1 is taken from [1]. In this figure, ‘I<sub>ph</sub>’ represents the Photocurrent (A), ‘D1’ is the diode, ‘I<sub>d</sub>’ represents the diode current (A), ‘R<sub>s</sub>’ and ‘R<sub>sh</sub>’ represents the series and shunt resistance (Ω) respectively. This I<sub>d</sub> that is diode current (A) can be calculated using the formula given in equation (1).

$$I_D = I_S \left[ \exp\left(\frac{qV_D}{nKT} - 1\right) \right] N_P$$

$$I_D = I_S \left[ \exp\left(\frac{q(V+IR_s)}{nN_SCKT} - 1\right) \right] N_P \quad (1)$$

In equation (1), ‘I<sub>D</sub>’ is the diode current which can be calculated using ‘I<sub>s</sub>’ that is the saturation current of the solar cell in nA, ‘N<sub>s</sub>’ is the number of cells in series, ‘R<sub>s</sub>’ represents the series resistance(Ω), ‘n’ represents the ideality factor, ‘N<sub>p</sub>’ represents cells connected in parallel, ‘V<sub>D</sub>’ is the voltage across the diode, ‘T’ is the temperature, ‘K’ represents the Boltzmann’s constant (1.38x10<sup>-23</sup>), ‘q’ is the electronic charge. The efficiency of this PV cell can be calculated using the formula given in equation (2).

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}} = \frac{V_{mpp} I_{mpp}}{P_{in}} \quad (2)$$

In equation (2), ‘η’ represents the efficiency of the solar cell, ‘V<sub>mpp</sub>’ represents the maximum power voltage, ‘I<sub>mpp</sub>’ represents the maximum power current, ‘FF’ represents the Fill Factor, and ‘P<sub>in</sub>’ represents the input power.

Table 1 is taken from [1]; in this table, the comparison is made on a different type of semiconductor material for solar cells based on some important key parameters such as module efficiency, the area required, and research cell percentage.

In [2], the authors designed a solar energy harvesting model that uses a switch matrix to power each component of the model. According to the authors of [3], first of all, it is very important to estimate the power consumption of the node needed in the future and the parameters of the available energy system. The authors of [4] powered wearable devices of very low power consumption using the energy harvested using these PV cells. In this, they did not use MPPT(maximum power point tracking) for energy harvesting. But the authors of [5] designed an

MPPT model using a supercapacitor for storing the electrical energy. They also used a pulse width modulator (PWM) for power conversion with a power tracking algorithm, and this MPPT based model also needs a microcontroller and some hardware changes. Some more updates in this model were given by [6]. They designed a model that uses a more optimized algorithm and requires less power for functioning as compared to the previous model given by [5]. In [7], the authors' low power consumption model saved energy and used the solar energy harvesting model to power the node.

The authors of [8] implemented a low power consumption system inside a building using an ultra-capacitor as a primary and alkaline battery as a secondary electric energy storage device. The researchers of [9] used small capacitors for storing electric energy harvested using solar cells.

### THERMAL ENERGY HARVESTING SYSTEMS

Energy harvesting using thermal energy as the main source can be done using a device called Thermoelectric Generator (TEG). Thermal energy harvesting is a popular energy harvesting technique as it is used in several applications, including sensor nodes, waste energy harvesting at the microscale level, medical applications, consumer electronics, etc. TEG is used to convert the temperature difference present in any material to electrical energy, which works on the basic principle of the Seebeck effect.

The output power of the TEG can be calculated by taking the product of the potential difference and the current flow of the circuit. The efficiency of the TEG can be calculated using the formula given in equation (3).

$$\eta_{TEG} = \frac{\Delta T}{T_H} \times \frac{\sqrt{1 + ZT} - 1}{\sqrt{1 + ZT} + \frac{T_C}{T_H}} \quad (3)$$

$$Z = \frac{\sigma S^2}{k} \quad (4)$$

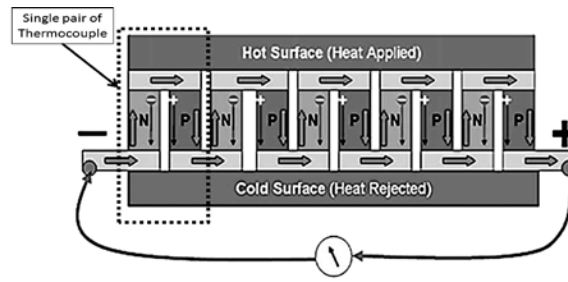
In equation (3), 'η' is the efficiency of the TEG, 'Z' represents the figure of merit, ΔT represents the temperature difference between hot and cold side, 'S' represents the Seebeck coefficient, 'k' represents the thermal conductivity, 'σ' represents the electrical conductivity, and 'T' is temperature equal to 27k.

The most important parameter of TEG is ΔT, as the output power generated directly depends on the temperature difference. Some key parameters defined for optimized power output are the Seebeck coefficient of temperature, thermal conductivity, load and internal resistances used in the circuit, and heat transfer in the device, etc. to increase the temperature difference that is the thermal conductivity of the heat bridge should be more than that of TEG's thermal conductivity. This **fig. 2** is taken from [10](novel), which shows the working of the TEG. This figure shows that thermocouple is applied in the middle of the hot and the cold material, and TEG is applied across it.

**Table 2** is taken from [10], which exhibits some of the important parameters taken in designing a TEG for a Hybrid energy harvesting system. The authors of [11] designed a model that uses thermal energy harvesting, and they achieved total energy of about 27J at a temperature difference of 40K. The authors of [12] designed a system that uses artificial light supported energy harvesting system for controlling home appliances such as AC, heater, and cooler, basically for room temperature control. In this model, they implemented the MPPT algorithm. Some other physical factors like weather conditions also change the irradiance and illumination intensity. In the afternoon period, maximum power is consumed as compared to other times of the day.

**Table 1: Comparison of type of solar cell material**

Imp. Parameters	Max Module Efficiency (%)	Research cell (%)	Area Required per kW (m <sup>2</sup> )
Monocrystalline	21	25	9-8
Polycrystalline	16	20.4	7
Amorphous	8	13.4	16
CdTe	11	18.7	12
CIS/CIGS	12	20.4	11



**Thermoelectric Generator (TEG)**  
**Figure 2: TEG working diagram**

**Table 2: Parameters related to the TEG**

S. No.	Parameter	Notation	Value
1	Thermal conductivity of Ceramic Substrate	$\lambda_{Sub}$	180W/mK
2	Thermal conductivity Of Thermocouple	$\lambda$	1.5W/mK
3	Substrate Thickness	$L_{sub}$	0.9mm
4	Antimony Telluride (p-type) Seebeck Coefficient	$\alpha_p$	185 $\mu$ V/ $^{\circ}$ K
5	Bismuth Telluride (p-type) Seebeck Coefficient	$\alpha_n$	-228 $\mu$ V/ $^{\circ}$ K
6	The electrical conductivity of n-type	$\rho_n$	12.6 $\mu$ $\Omega$ m
7	The electrical conductivity of p-type	$\rho_p$	12.6 $\mu$ $\Omega$ m
8	Length of the thermal element	L	1.6mm
9	Total number of thermocouples	N	127
10	Thermal conductivity of n-type	$\sigma_n$	1.8W/mK
11	Thermal conductivity of p-type	$\sigma_p$	1.3W/mK

In this model, they achieved an input voltage of 23mV through a temperature difference of 0.6 $^{\circ}$ C, which is used to switch on the harvester in 3 minutes [13]. From this, it is concluded that it can harvest 30mA of current at a 2.2V of potential difference in 3ms for 1 second, and this energy is found to be sufficient for the purpose. The authors of [14] analyzed a mathematical relation for a thermocouple pellet and the total power received and found that a temperature difference of at least 1.2 $^{\circ}$ C was required for data transmission by extensively studying the relation [15].

Some issues faced by the researchers while working with thermal energy harvesters are, first, the prime difficulty was faced in maintaining the temperature difference across the TEG in harvesting energy. Next, according to [16], for applications like heat engine structural monitoring, a substantial temperature difference is not available. Some piezoelectric patches can replace the use of artificial sources in future nodes.

**SOME IMPORTANT CONCLUSIONS MADE ON ENERGY HARVESTING**

- Working on high power consumption devices is much easier as compared to working with low-power consumption devices like WSN nodes because of the congested hardware as they are of very small size.

- As the size of the low-power consumption devices like the WSN node is very small, the battery capacity of the node is also very low, which a drawback of it is.
- The battery of the WSN node drains energy even when the device or sensor node is not in an active state which reduces the life of the WSN node. It is very important first to calculate the target value of the energy required for the WSN to work properly as this will give the idea that any method or energy harvester could be appropriate or not.
- The Duty cycle of the sensor node is one of the prime factors required in the calculation of the active time of the sensor node and its power consumption pattern.
- In solar cell harvesting techniques, a great amount of energy can be easily harvested in the day time when the sun is available with its full intensity, but in the time when the weather becomes cloudy or rainy, very small or no amount of energy is harvested and also in the night zero amount of energy could be harvested, these all factors like weather conditions and night time limits the advantages of solar power harvesting and makes it bit of unreliable in some cases.
- Also, it is found that in the summer, when the temperature is high, the thermal conductivity

of the semiconductor material increases, which makes its charges balance and reduces the electric field, which ultimately affects the energy harvesting pattern of about 10 to 25%.

- In thermal energy harvesting models, it is found that it is difficult to maintain the temperature difference across the thermoelectric material in some regions due to some weather conditions like temperature, wind, moisture, etc.
- In researches, it is also found that uneven temperature distribution may lead to less amount of energy harvesting, and also, its thermal efficiencies are low.
- It is also found that TEG does not require any liquid or fluid thing in performing its tasks, and it also does not need any fuel or cooling, which makes it usable for many applications like zero-gravity or under the sea.
- TEG machinery also does not have any moving part, which makes it proof to any maintenance and makes it live longer.
- From the above points, it is observed that these solar and thermal energy harvesting models can harvest enough energy so that a sensor node can work or perform its functions properly.

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