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Solar Energy Harvester for Industrial Wireless Sensor Nodes

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Abstract

Advancement in recent wireless technology has triggered the need for devices to run on independent power sources. This is evident especially with the wireless sensor network (WSN). This can be accomplished via harvesting energy from the surrounding environment such as solar, wind etc. These enery harvesting devices can power the wireless sensor nodes either directly of in conjunction with a battery. This paper presents the development of a solar energy harvesting mechanism for WirelessHART sensor node using photovoltaic (PV) cell array. Experimental results on the WirelessHART nodes proved that the developed harvester is capable of powering the nodes.

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Keywords: Wireless Sensor network; Solar energy harvester; photovoltaic array; WirelessHART

1. Introduction

An essential part of Internet of Things (IoTs) is the wireless sensor network (WSN)[1]. These networks have been widely used in various applications such as rescuing in military, emergency recovery, patient health monitoring, air quality monitoring etc.,[2,3,4]. At the moment, the important function of the WSN is for monitoring physical conditions such as temperature, pressure, level, etc. Typically, in the network, the data are transmitted wirelessly[2]. A typical industrial WSN is shown in Fig. 1(a)[5].

The available standards for WSN are ZigBee, Wi-Fi, Bluetooth, Z-wave, etc. Two more industrial wireless standards namely WirelessHART and ISA100 Wireless were introduced recently specifically targeting industrial applications[6]. In this work, the Linear Technology Evaluation Kit based on WirelessHART standard is used. WirelessHART offers mesh network topology, self-healing, self-organizing capabilities, and operates on the traditional industrial, scientific, and medical (ISM) band of 2.4 GHz[7]. This provides maximum interoperability since it is based on HART standard, the most widely used standard in industry[7]. With the mesh topology, the WSN is highly reliable.

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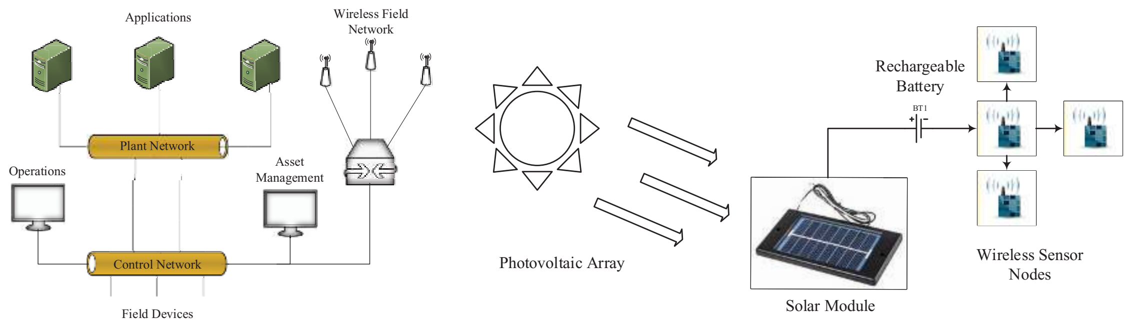

Fig. 1. (a) Wireless sensor network system in a typical industrial setting; (b) Solar energy harvester for WirelessHART mote.

Presently, there are various energy harversting techniques available for WSN. Usually, the main task for energy harvesting in WSN is to transform other forms of energy to electrical energy which can be used to supply the power for wireless sensor nodes. In order to measure the wind speed and to sense the local wildfire, a WSN was deployed at ground level[8]. Here, the wind turbine generator is used to harvest wind energy to power up the wireless sensor node which measures the wind speed. In another energy harvesting approach, mechanical energy of a rail wagon's suspension was harvested to supply power to a sensor mounted on the device for monitoring the railway's condition[9]. Harvested energy distribution was studied with object to distribute concurrent multiple transmitters' energies to recharge wireless sensor nodes in both 2D and 3D environments[10].

Wireless sensors are characterized by their small size, autonomous power supply, and ability to sense environmental phenomena and transmit data. Due to the sensing and transmitting components continue to be scaled down, the size of the nodes in WSNs is mainly determined by the size of the battery. Most of the commercial nodes use two AA batteries as their power sources. Therefore, the life time of each node relies on its duty cycle and the amount of sensed and transmitted data. When the lifetime of the battery comes to an end, the battery need to be replaced or recharged.

Therefore, for using renewable energy effectively many factors to be considered such as energy source characteristics, storage device type, wireless nodes' power management functionality, wireless communication protocol, and detail application's requirements[2]. This project focused on the utilizing solar energy to power WirelessHART nodes as it is located in the open area. For example, at the top of buildings or industrials areas. Although harvesting electricity through vibrational energy is also a good idea. However, there are few consequences that need to be considered before implemented the source energy as the vibration will produce noise. Noise is harmful when taking the data because, the noise will affect the information gathering. Thus, additional circuit need to be added to filter the information before transferring through the entire network. Fig. 1(b) shows a PV array serving as a secondary energy module for WirelessHART nodes.

The rest of this paper is organized as follows. Section 2 describes the methodology for developing the energy harvester for WirelessHART sensor nodes. Section 3 presents the results and discussion of this work. Finally, conclusion is drawn in Section 4.

2. Methodology

This section focuses on the detail work flow for the development of renewable energy for WirelessHART mote. This project development is divided into two parts. The first part solar energy harvesting system and the second part describe the project tools.

2.1. Sun hour daytime

During sunrise and sunset, the sunlight is weak and the incidence angle (θ) is less direct. Since θ, is low, the power generated is also less. At high noon, sun rays have close to right angle with the earth's surface, thus resulting in peak

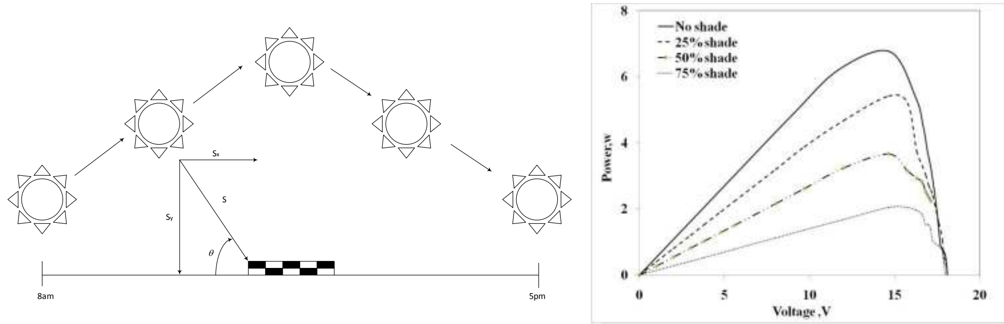

Fig. 2. (a) Sun hour angle; (b) P-V characteristic of PV module

generated electricity during this period. The movement of sunlight changes overtime is shown in Fig. 2(a). In Fig. 2(a), S represent the solar radiation comes from different axis.

$$\omega = \frac{d\theta}{dt} = \frac{\pi}{9}(rad/hr) \tag{1}$$

where, ω is angular velocity.

Table 1 shows the angle of incidence (θ) change over the daytime. The data of the angle will be used later on for the calculation of power generated from the PV module.

Table 1. Sun angle based on time.

Time	Angle of incidence θ
08:00	0^o
09:00	20^o
10:00	40^o
11:00	60^o
12:00	80^o
13:00	100^o
14:00	120^o
15:00	140^o
16:00	160^o
17:00	180^o

As the PV module has been tested under condition of $1000W/m^2$, thus the power generated by the PV module can be calculated as shown below.

$$P = AS_y \tag{2}$$

where, S_y is solar radiation perpendicular to the PV surface module, A is area of PV module.

Given the solar radiation, based on the sun angle in Table 1 and equation (2), the power generated from the PV module can be calculated. The calculated power will be used to find the voltage generated from the PV module by referring the P-V characteristic graph of the PV module shown in Fig. 2(b)[11].

2.1.1. Design consideration

The design of renewable energy for WirelessHART sensor nodes depends on the PV module electrical parameters and also the voltage supply for the sensor node. The design will be further explained in the next section.

2.1.2. WirelessHART and PV module specification

The current consumption of the WirelessHART node is 103.3A. The calculation is shown in Table 2. The PV module electrically performance parameter is shown in Table 3.

Table 2. Wireless sensor node current consumption.

Equipment	Current consumption
Heat sensor	35mA
Arduino Mega [12]	50mA
WirelessHART Mode-on-Chip (LTC 5800- WHM + LTC2379-18)	9.7mA+8.6mA =18.3mA
Total Current Consumption	103.3mA

Table 3. PV Module parameters.

Model	Bn-8D
Rated power	8W
Rated voltage	17.5V
Rated current	0.46A
Short circuit current	0.52A
Open circuit voltage	21.5V
Standard test condition	$1000W/m^2$, AM 1.5, 25^oC

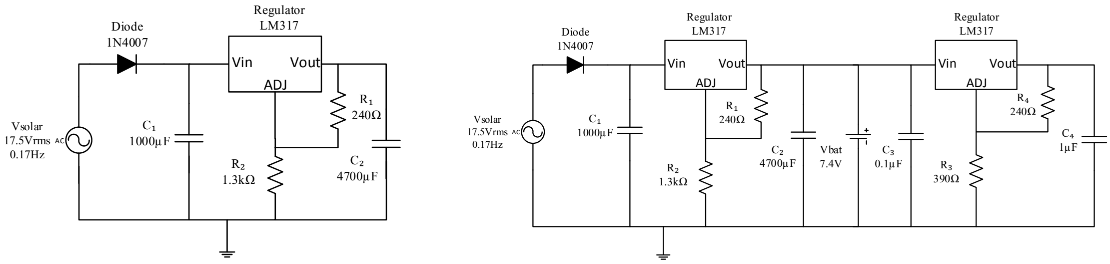

Fig. 3. (a) Voltage regulator circuit for battery; (b) Energy harvester for WirelessHART sensor node circuit.

2.1.3. *Circuit design*

Fig. 3(b) shows the overall circuit design of the renewable energy for WirelessHART sensor nodes. The PV array will be absorb by the PV module. The PV module will convert the solar energy into electrical properties giving a maximum output voltage of 21V. This high voltage will damage the rechargeable battery. Therefore, voltage regulator is required in order to regulate the voltage. This paper [13] used LM317 as their voltage regulator for lithium battery charger. Thus, the concept of voltage regulator by using LM317 as shown in Fig. 3(b) has been used in order to regulate the high voltage coming from PV module. The voltage regulator has been design as estimated in Equation (3). The design will be simulated afterwards by using Multisim Circuit Software. The simulation has been carry out for 9s which represent 9 hours of sun hour from 8 a.m. till 5 p.m. The simulation results as seen in Fig. 5(a), shows that the output voltage is 7.5V and there is slightly voltage ripple at the output voltage.

The output voltage subsequently will be used to charge up the battery. The rechargeable battery used is 7.4V Li-Po battery with capacity of 900*mAh*. The output voltage of 7.4V however is still high to power up WirelessHART sensor mote and able to destroy its functionality. Thus, the voltage need to be regulated again by using voltage regulator. The voltage regulator has been design as estimated in Equation (3). Next, the voltage regulator design will undergo simulation to determine either it gives positive result or not. As presented in Fig. 5(a), the output voltage is constant with value of 3.3V.

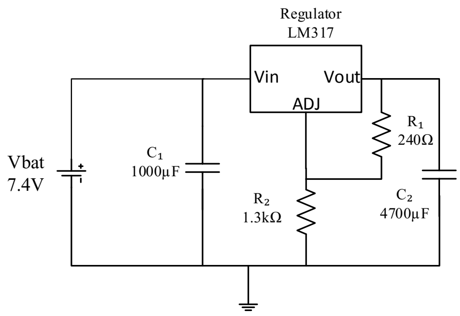

Fig. 4. Voltage regulator circuit for sensor node.

2.2. Voltage Regulator Design

2.2.1. Voltage regulator design for battery (LM317)

The maximum output voltage from solar panel is approximately 21V. Thus, 21V required to be regulated into 8V. In order to have the voltage required, the value of adjustable resistor, R_2 as shown in Fig. 6 need to be calculated by using equation (3) and the value of can be obtained from the LM317 datasheet which is 100μA. The calculation of R_2 is shown below,

$$V_{out} = 1.25[1 + \frac{R_2}{R_1}] + I_{ADJ}R_2$$
$$R_2 = 1346\Omega \approx 1.3k\Omega \quad (3)$$

where, R_1 is fixed resistor, R_2 is adjustable resistor, V_{out} is output voltage, and I_{ADJ} is adjustable current.

2.2.2. Voltage regulator for WirelessHART sensor nodes (LM317)

The amount of voltage supply for the node is 3.3V. However, the voltage from the Li-Po battery is 7.4V. Therefore, as shown in Fig. 4, LM317 and two resistors are required to regulate the voltage. R_1 is 240Ω and the value of R_1 can be calculated by using equation (3).

2.2.3. Simulation and modeling

The simulation of this project has been done by using the Multisim Circuit Software. The frequency used for the simulation is 17.5Hz. The reason why this project used 17.5Hz instead of 60Hz because the peak sun hour is generally for 6 hours. Thus, an assumption has been made where the simulation will be run for 6s. Therefore, the frequency that will be used is as calculated below

$$f = \frac{1}{6s} = 0.17Hz \quad (4)$$

where, f is frequency.

2.2.4. Battery performance evaluation

This is an approximate measurement of Li-Po rechargeable battery ability to provide energy

$$Time(h) = \frac{BatteryCapacity(Ah)}{Current(mA)} \quad (5)$$

where, battery capacity is 900mAh and current drawn is 1.162mA.

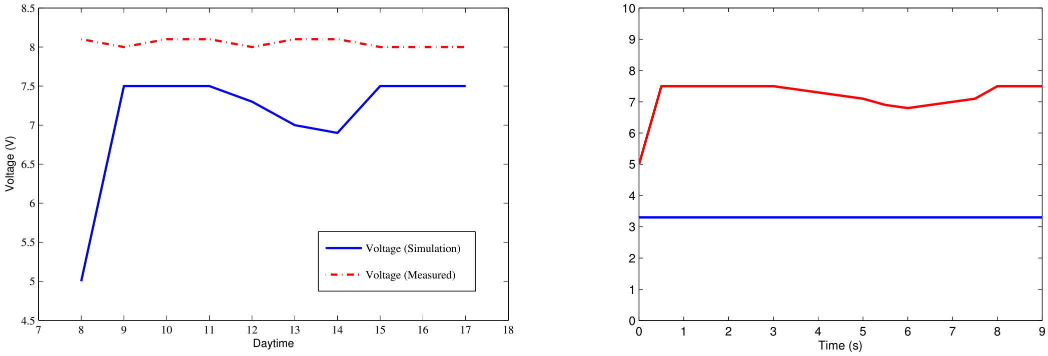

Fig. 5. (a) Simulation result; (b) Comparison between simulation result and experimental result

Thus, the battery discharge time is 32 months. The current drawn by the PV module system can be calculated by dividing the PV generated power to its rated voltage.

$$I(mA) = \frac{P(W)}{V(V)} \tag{6}$$

where, P is power and V is voltage.

3. Results and discussion

3.1. Simulation Results

As shown in Fig. 5(a), the output voltage from the voltage regulator LM317 is 8.4V which will be enough to charge up the Li-Po battery. The voltage supply for the WirelessHART node is 3.3V. The voltage from the battery which is 7.4V will be regulated to 3.3V by using the voltage regulator LM317.

3.2. Data collection

3.2.1. PV module measurement

Table 4. Comparison between measured and calculated voltage.

Day Time	PV module output voltage (V)-Measured	PV module output voltage (V)-Calculated	PV module output power (W)-Calculated
8.00am	20.0	0.0	0.00
9.00am	20.0	5.1	2.74
10.00am	20.0	9.0	5.14
11.00am	20.5	12.2	6.93
12.00am	21.1	14.2	7.88
1.00pm	20.8	14.2	7.88
2.00pm	20.6	12.2	6.93
3.00pm	20.1	9.0	5.14
4.00pm	20.7	5.1	2.74
5.00pm	20.3	0.0	0.00

Table 4 shows the comparison between the measured voltages of PV module and the calculated voltages of PV module. There are huge different between the readings as a result of not every PV module is manufactured with 100% efficiency. Thus, the voltage measured during the testing will be different with the one that has been calculated.

3.3. Comparison between simulation result and experimental results

As shown in Fig. 5(b) the simulated results are not staying the same throughout the simulation. There are voltage ripple in the output voltage and varies differently with the measured voltage. The measured output voltage maintain the same value of 8V. However, the simulated voltage does not giving any values that near to the required voltage of 8V.

3.4. Battery calculation

Battery performances are evaluated by using theoretical equations (5) and (6). The battery able to provide energy for WirelessHART sensor mote for about 32 months. Meanwhile, the rechargeable battery takes 50 minutes to be fully charge with the current drawn of 1.08A from the PV module. The calculations however are for the ideal case. The discharge and charging time of a battery however varies in real world. The battery performances depend on many factors. For example, ambient temperature, battery chemistry, cycling and service. As the performance and safety of the Lithium battery depends on the operating temperature, it must be well controlled. Also, different ambient temperatures will affect the performance of the battery differently, thus resulting in reduced lifetime of the battery [14]. Factors that affecting the performance of the battery should be further study in order to prevent the sensor node from running out of energy and stop working at certain of time which will interrupts the continuous sensing.

4. Conclusion

This paper has demonstrated the development of renewable(solar) harvesting circuit for the WirelessHART sensor node. Experimental results with the proposed system showed that indeed solar energy can be harvested to power WirelessHART nodes. The performance of the WirelessHART sensor node with the developed harvester has been analysed by connecting it with the network manager. Signals from the node powered by the harvester are recorded in the network manager signifying that the harvester works well with the node. In the future, management module to manage both the charging and discharging processes will be incorporated and the processes will be evaluated, while attempt will be made to explore other harvesting techniques such as piezoelectric for vibration energy harvesting.

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References

1. He, T., Chin, K.W., Soh, S.. On wireless power transfer and max flow in rechargeable wireless sensor networks. *IEEE Access* 2016; **4**:4155–4167.
2. Cui, R., Qu, Z., Yin, S.. Energy-efficient routing protocol for energy harvesting wireless sensor network. In: *Communication Technology (ICCT), 2013 15th IEEE International Conference on*. IEEE; 2013, p. 500–504.
3. Touati, F., Legena, C., Galli, A., Crescini, D., Crescini, P., Mnaouer, A.B.. Renewable energy-harvested sensor systems for air quality monitoring. In: *2014 26th International Conference on Microelectronics (ICM)*. IEEE; 2014, p. 160–163.
4. Mangali, N.K., Kota, V.K.. Health monitoring systems: An energy efficient data collection technique in wireless sensor networks. In: *Microwave, Optical and Communication Engineering (ICMOCE), 2015 International Conference on*. IEEE; 2015, p. 130–133.
5. Chen, D., Nixon, M., Han, S., Mok, A.K., Zhu, X.. Wirelesshart and ieee 802.15. 4e. In: *Industrial Technology (ICIT), 2014 IEEE International Conference on*. IEEE; 2014, p. 760–765.
6. Song, J., Han, S., Mok, A., Chen, D., Lucas, M., Nixon, M., et al. Wirelesshart: Applying wireless technology in real-time industrial process control. In: *Real-Time and Embedded Technology and Applications Symposium, 2008. RTAS'08. IEEE*. IEEE; 2008, p. 377–386.
7. Chung, T.D., Ibrahim, R.B., Asirvadam, V.S., Saad, N.B., Hassan, S.M.. Simulation of wirelesshart networked control system with packet dropout. In: *Control Conference (ASCC), 2015 10th Asian*. IEEE; 2015, p. 1–6.
8. Tan, Y.K., Panda, S.K.. Self-autonomous wireless sensor nodes with wind energy harvesting for remote sensing of wind-driven wildfire spread. *IEEE Transactions on Instrumentation and Measurement* 2011;**60**(4):1367–1377.
9. Hodge, V.J., O'Keefe, S., Weeks, M., Moulds, A.. Wireless sensor networks for condition monitoring in the railway industry: A survey. *IEEE Transactions on Intelligent Transportation Systems* 2015;**16**(3):1088–1106.

10. Naderi, M.Y., Chowdhury, K.R., Basagni, S.. Wireless sensor networks with rf energy harvesting: Energy models and analysis. In: *2015 IEEE Wireless Communications and Networking Conference (WCNC)*. IEEE; 2015, p. 1494–1499.
11. Sathyanarayana, P., Ballal, R., PS, L.S., Kumar, G.. Effect of shading on the performance of solar pv panel. *Energy and Power* 2015; **5**(1A):1–4.
12. Gharghan, S.K., Nordin, R., Ismail, M.. Energy-efficient zigbee-based wireless sensor network for track bicycle performance monitoring. *Sensors* 2014;**14**(8):15573–15592.
13. Rahimi, A.M.. A lithium-ion battery charger for charging up to eight cells. In: *2005 IEEE Vehicle Power and Propulsion Conference*. IEEE; 2005, p. 6–pp.
14. Leng, F., Tan, C.M., Pecht, M.. Effect of temperature on the aging rate of li ion battery operating above room temperature. *Scientific reports* 2015;**5**.