A RELIABLE RECHARGEABLE BATTERY FOR A WSN-BASED SOLAR ENERGY HARVESTING SYSTEM

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ABSTRACT

The foundational elements of today's internet of things (IOT) infrastructure in smart buildings, smart parking lots, and smart cities are wireless sensor networks (WSNs). The WSN nodes are severely constrained by their low battery energy, which can only function for a few days depending on the duty cycle of operation. We suggest a fresh approach to this design quandary in this research by utilizing ambient solar photovoltaic energy. Here, we aim to develop a special and highly effective solar energy harvesting system for WSN nodes powered by rechargeable batteries. The optimized SEH-WSN nodes should run continuously in the background for an unbounded network lifespan (in years). In this study, we present a brand-new, very effective solar battery charging technology with maximum power point tracking (MPPT) for WSN nodes. The research focus is on to increase the overall harvesting system efficiency, which depends upon solar panel efficiency, MPPT control DC-DC converter efficiency and rechargeable battery efficiency. Several models for solar energy harvester system have been developed and iterative simulation

Keywords— Smart cities, solar energy harvesting, DC-DC converter, MPPT, battery charging, wireless sensor nodes

I.INTRODUCTION

The most significant technological design challenge of the twenty-first century, caused by the acceleration of global warming and other environmental problems, is the development of renewable energy harvesting systems. ZigBee Green Power (GP), a new standard for energy-harvesting wireless sensor networks (EHWSNs), was just introduced by the ZigBee Alliance in the United States in August 2016[1]. The ZigBee Green Power (GP) standard for EHWSNs and the IEEE 802.15.4 communication standard protocol modifications for low data rate wireless networks make it easier for applications running on low power wireless microcontroller platforms to leverage the Green Power feature [2]. Today, businesses like Texas Instruments and ST Microelectronics and Linear Technology, USA, are offering wireless sensor network power management solutions based on renewable energy harvesting. The design of an efficient solar energy harvesting systems is necessary for the proper planning of solar energy harvesting wireless sensor networks (SEH-WSN). The harvester system extracts the solar Fig.1. Block diagram of Solar Energy Harvesting System using MPPT Control energy into the electrical form by using the Photovoltaic (PV) cells. Then, this electrical energy is used to charge the wireless sensor node battery. It reduces the human efforts to replace the battery of hundreds or thousands of sensor nodes by going out in the remote areas. Therefore, the design problem of limited energy availability of wireless sensor nodes is resolved and the human efforts to replace the battery periodically have been reduced. In the year 2008, Ref. [3] proposed Modelling and Optimization of a Solar Energy Harvester System for self-Powered Wireless Sensor Networks. In 2009, Ref. [4] proposed Design of a Solar-Harvesting Circuit for Battery less Embedded Systems. In this paper, the simulation results show that by using efficient solar energy harvester circuits the sensor network lifetime can be increased from few days to 20- 30 years and higher. Section 1 provides an overview of a basic Solar Energy Harvesting System. Section 2 presents the operation of SEH-WSN Node. Section 3 provides two types of solar energy harvester system most commonly used in practice i.e pulse width modulation (PWM) controlled and MPPT controlled. Section 4 provides simulation parameters and section 5 provides simulation results, section 6 provides efficiency calculations and finally, section 7 provides the conclusion.

BLOCK DIAGRAM

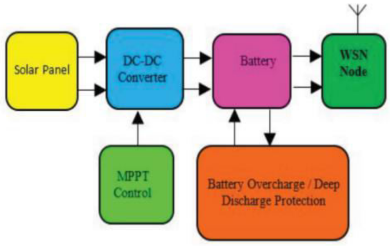

Fig.no.1

II.OPERATION OF AN SEH AND WSN NODES

The internal block diagram of an SEH-WSN node is shown in Figure 1. The solar energy-harvesting system provides a DC power supply (3.6 volts, Tektronix, Inc., Beaverton, OR, USA) to the WSN node. This voltage is harvested from the ambient sunlight by using the solar panels [5]. The solar panel converts light energy directly into the DC electrical energy. The DC-DC converter regulates this DC voltage to charge the battery. The rechargeable battery powers the WSN node. J. Sens. Actuator Net w. 2018, 7, 40 3 of 19 The WSN node measures the desired physical quantity (e.g., temp., light, humidity, and pressure) by using the sensor measurement unit. A microcontroller in computation unit processes this sensed data. The measured or sensed data is sent to the nearby network node wirelessly, in the form of data packets using the transmitter unit. The information is sent to the USB gateway node via cluster head nodes [6] from the end nodes. Finally, the user can remotely monitor & control the application process e.g., temperature monitoring, control of an industrial boiler plant, volcano monitoring, glacier monitoring, forest monitoring, battlefield monitoring applications, air conditioner cooling system control, traffic light management in a smart city.

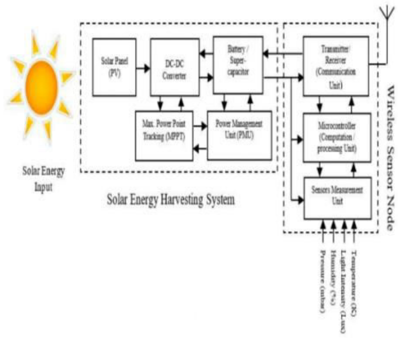

Fig.no.2

The figure 2 shows a block diagram of a maximum power point tracking (MPPT) controlled solar energy harvester (SEH) system. The SEH system consists of a solar panel, a DC-DC buck converter, a rechargeable battery, a maximum power point (MPPT) controller, and a WSN sensor node connected as a dc. load. The ambient solar light energy is harvested using the solar panel and converted into the electrical energy. The DC-DC Buck converter steps down and regulates the magnitude of this harvested voltage, and supplied to the rechargeable battery. The MPPT controller tracks the voltage and current from the solar panel and adjusts the duty cycle accordingly for the MOSFET of DC-DC Buck converter. Finally, the battery voltage is utilized to operate the wireless sensor node. The WSN performs the function of sensing, computation, and communication with other similar characteristics nodes. Thus, autonomous operation of monitoring and control of any physical phenomenon like temperature, humidity, pressure or acceleration can be achieved using SEH-WSN nodes. In this whole scenario, the efficiency of solar energy harvester circuit plays a very important role. If the efficiency of solar energy harvester system is poor, then the battery will not get recharge properly and hence the wireless sensor network lifetime will reduce**.**

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III. SOLAR ENERGY HARVESTING SYSTEM

The figure 3 shows a block diagram of a maximum power point tracking (MPPT) controlled solar energy harvester (SEH) system.

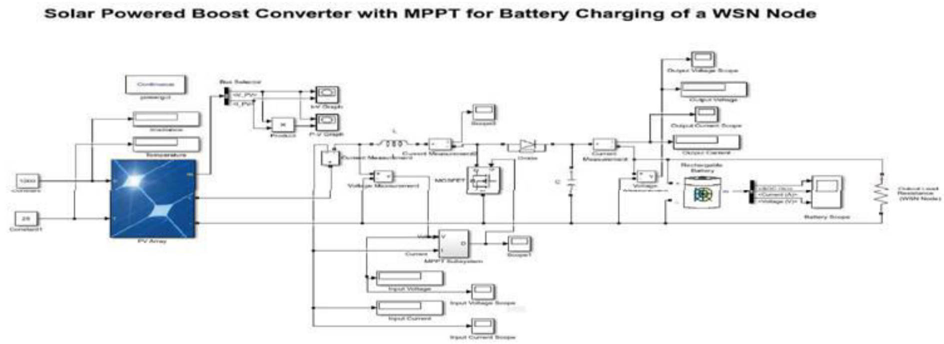

Fig.no.3

The SEH system consists of a solar panel, a DC-DC buck converter, a rechargeable battery, a maximum power point (MPPT) controller, and a WSN sensor node connected as a d.c. load. The ambient solar light energy is harvested using the solar panel and converted into the electrical energy. The DC-DC Buck converter steps down and regulates the magnitude of this harvested voltage, and supplied to t The MPPT controller tracks the voltage and current from the solar panel and adjusts the duty cycle accordingly for the MOSFET of DC-DC Buck converter [7]. Finally, the battery voltage is utilized to operate the wireless sensor node. The WSN performs the function of sensing, computation, and communication withother similar characteristics nodes. Thus, autonomous operation of monitoring and control of any physical phenomenon like temperature, humidity, pressure or acceleration can be achieved using SEH-WSN nodes. In this whole scenario, the efficiency of solar energy harvester circuit plays a very important role. If the efficiency of solar energy harvester system is poor, then the battery will not get recharge properly and hence the wireless sensor network lifetime will reduce.

IV. SIMULATION RESULT

The simulation parameters for a solar energy harvesting system are shown in Table 1. Figure 2 shows MATLAB Simulink model of solar energy harvester system using MPPT control. The solar irradiance of 1000 watts/cm^2 is incident on the solar panel with a constant temperature of 25degree Celsius [8]. The Solar panel can extract only this solar energy into 15 mW/cm^2 with 15% efficiency [9]. For full irradiance on the simulated solar panel, the output voltage of solar panel is 6 volts, 500mA, and 3 watts. Now, this electrical energy from the solar cell is fed to the DC-DC boost converter [10], which increases the output voltage. The

Boostconverter output voltage is used to charge the rechargeable battery. The rechargeable battery is used to operate the WSN node. Here, the WSN load is modelled as output d.c. load resistance of 100 ohms.

V. SIMULATION RESULT

The simulation results for the Battery State of Charge (SoC), battery Current (I_B) and battery voltage (V_B) as a function of time
(seconds) are shown in figure 3
A. Battery State of Charge (SoC), Voltage and Current during Charging using MPPT

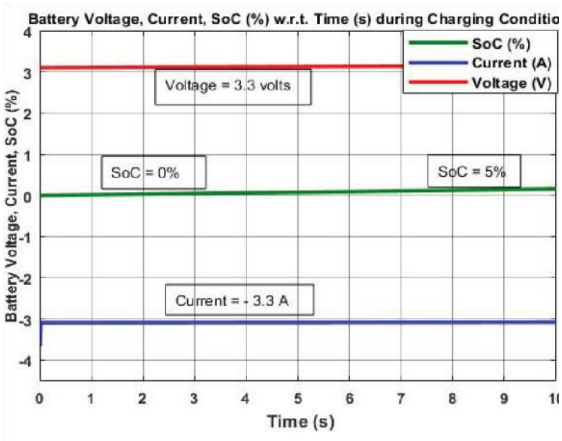

Fig. 4 Simulation results of MPPT controlled SEH system for 10 s.

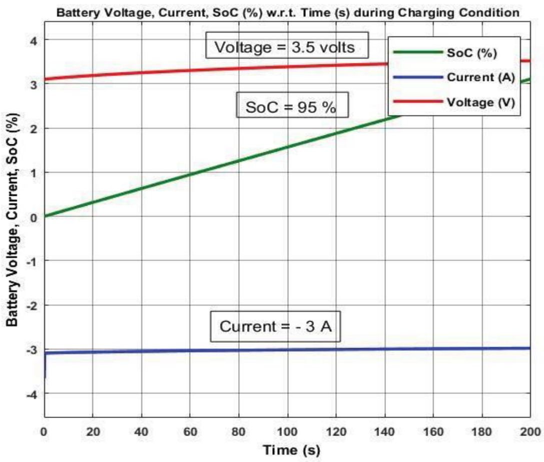

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Fig.5 Simulation results of MPPT controlled SEH system for 200 s.

In figure 3, MPPT controlled solar energy harvesting battery charger (i.e. Battery State of Charge (SoC), battery Current and Voltage) are shown for a simulation time of 10 seconds. Here, the battery SoC reaches from 0 to 5 % Similarly, in figure 4 the MPPT results for 100 s simulation time have battery SoC till 50 %. Finally, in figure 5 the battery SoC reaches till 95 % in just 200 s simulation time. Thus, the battery charging time is dynamically increased by using MPPT controlled solar energy harvesting systems for WSN nodes.

Parameters	Value	Parameters	Value
Irradiance (W/m^2)	1000 $Watts/m^2$	Capacitor (C)	100Uf
Temperature (T)	25 degree Celsius	Inductor (L)	200uH
DC-DC	Boost	MOSFET	5KHz

Converter	Converter	Switching Frequency (f)	
Max. Solar Panel output voltage (V_m)	6 volts	Initial duty Cycle	0.5
Max. Solar Panel output current (I_m)	500Ma	MOSFET Switching Power Losses (P_{sw})	0.5Mw
the rechargeable battery	the rechargeable battery	the rechargeable battery	the rechargeable battery
Rechargeable Battery Type	NiCd	WSN Load Model	10-ohm Resistor
Battery Voltage	3.6 volts	Inductor conduction Power Loss (P_L)	50 mW

VI.ENERGY HARVESTING SYSTEM

The energy harvester system efficiency is calculated for MPPT control methods. By using P&O MPPT the max. Power available from the solar panel is 2.8 watts. From the simulation parameter table 1, the (P_{MPP}) is 2.8 watts and maximum theoretical power (P_m) is 3 watts. Thus MPPT efficiency is calculated as 2.8w / 3w = 93.33 %. Here, the P_{loss} also changes due to MPPT in DC-DC Buck Converter. The $P_{loss}$is the sum of MOSFET switching loss (P_{sw}) and Inductor conduction loss (P_L). From the simulation results table, the output power (P_o) is 1.8 W and MOSFET switching losses are 2 mW and inductor power loss is 20 mW. Thus buck converter efficiency is calculated as 1.8W /1.8 W+ 22 mW = 98.79%. Finally, the overall energy harvester circuit efficiency ($!_{sys}$) is the average of Buck converter efficiency and MPPT efficiency.

Energy Harvester Parameters	**Value**
Max. Solar Panel output Power (P_m)	2.8 watts
Average Buck Converter Output Voltage(V_m)	3.6 volts
Average Buck Converter Output Current(I_m)	500mA
Buck Converter Output Power	1.8 watts
Inductor Loss	20mW
MOSFET Switching Loss	2mW
Harvester System Efficiency $\#_{\$\%\$}\&$	96 %

From the formula of eq.2, the calculated overall energy harvester system efficiency ($_{\$\%\$}$) is (98.79%+93.33%) / 2 = 96.28%.

VII. CONCLUSION

In this study, we used MATLAB/SIMULINK to develop and test an effective solar energy harvester system for WSN nodes using MPPT. The battery is charged extremely quickly by the MPPT-based harvesting technology. While charging, the battery's SoC and terminal voltage begin to rise. The product of MPPT efficiency and Boost converter efficiency is the overall energy harvesting circuit efficiency (!sys). The efficiency of the MPPT-based Solar Energy Harvester system is 96.28 percent, according to the simulation findings.

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