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A Comparative study of Light- Harvesting Low-Power Wireless Sensors for Indoor Lighting Control

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Abstract - Light energy harvesting is an emerging trend in the field of wireless technology. Optimizing this trend for indoor lighting control is a major challenge because of its very low indoor light energy density and the conversion efficiency. This paper presents a brief comparative study of two different systems, one being the MPPT (Maximum Power Point Tracking) and another embedded design using MSP430 microcontroller for low power wireless sensor node. It has been found that the deployment of WSN (Wireless Sensor Network) control system can lead to around 20% savings in light energy. Both the systems in this paper use photovoltaic cell, energy storage units unique in their design. The paper gives a conclusion with evidences of comparison and with selecting the best available resource, making the solution suitable for practical indoor lighting applications.

Index Terms – *Light energy harvesting, Photovoltaics, Low-power, MPPT, MSP430, EnerChip, WSN, indoor lighting control.*

I. INTRODUCTION

The history of energy harvesting dates back to the windmill and the waterwheel. People have searched for ways to store the energy from heat and vibrations for many decades. One driving force behind the search for new energy harvesting devices is the desire to power sensor networks and mobile devices without batteries. Energy harvesting is also motivated by a desire to address the issue of climate change and global warming.Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of cells containing a photovoltaic material. Photovoltaic energy harvesting wireless technology offers significant advantages over wired or solely battery-powered sensor solutions, virtually inexhaustible sources of power with little or no adverse environmental effects. Solar energy harvesting is a fledged technology for WSN used for outdoor application [1]. For indoor applications, it is to note that efficiency of photovoltaic cell (PV cell) is very low because of its low light intensity. WSN has great potential to enable personalized smart lighting systems for real-time model predictive control of integrated smart building systems. In this paper, two different systems for indoor light energy harvesting meant for low-power WSN are studied [1]-[3].

II. LIGHT HARVESTING SYSTEM USING MPPT

Fig.1 shows the block diagram of the power management system containing Maximum Power Point Tracking (MPPT), energy storage unit, hysteresis comparator and DC-DC boost converter. The idea of design is to store the generated power from PV cell in supercapacitor and deliver it when it is sufficient as a load for certain amount of time [1].

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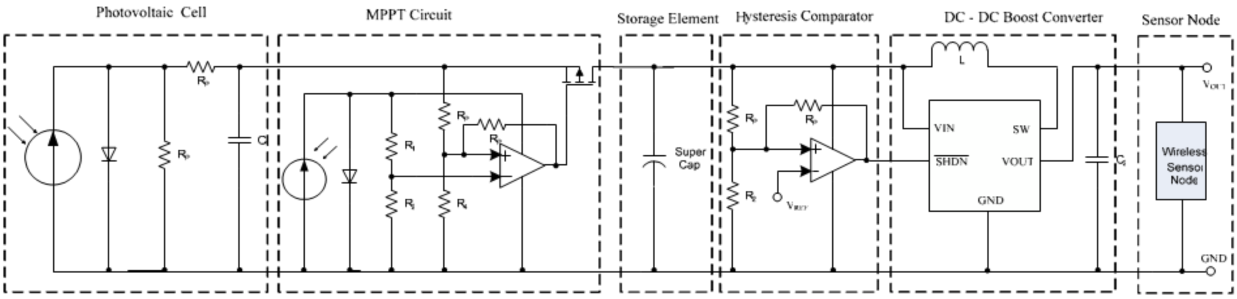
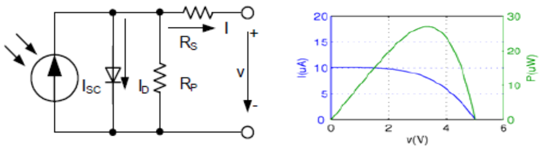


Fig.1: The block diagram of the proposed power management system.

The Photovoltaic cell used here is the amorphous silicon PV cell which has a higher efficiency at low light intensity levels. This is the best suited cell to use for indoor lighting applications [4]. Fig.2(a) shows the electrical model of the PV cell and Fig.2(b) depicts the output characteristic of the PV cell. The output current of this PV cell is given by the following equation

$$I = I_{SC} - I_O\left(e^{\frac{V+R_S I}{V_t}} - 1\right) - \frac{V + R_S I}{R_P}$$

where I_{sc} is the photocurrent, I_o is the saturation current, R_s and R_p are the series and parallel cell resistances and V_t is the terminal voltage [4]



(a) (b)

Fig.2: (a) Electrical model of PV cell (b) Output characteristic of PV cell

MPPT refers to extracting power from energy harvesting source at a point where the maximum power output is obtained. For PV cells, current-voltage combination gives the maximum output for a defined light condition and temperature. The theoretical principle is based on the expression $V_{mpp}=V_{oc}.K$ where V_{oc} is the open circuit voltage, K is the illumination parameter (0<K<1) [3]. The MPPT circuit also consists of a control unit and a MOSFET switch. A hysteresis voltage comparator is used as a control unit. It generates control signals to drive the MOSFET switch by comparing the reference V_{mpp} and the main PV cell operational voltage. By adjusting the hysteresis, the threshold voltage of the comparator can be changed. Thus, the sensitivity of the MPP tracking can be adjusted. The controlled MOSFET can then approach the theoretical maximum power point voltage by oscillating around the required voltage range [3].In the tracking control unit, a reference voltage is required to set V_{mpp}. A secondary PV cell is used to obtain this reference voltage. By using the same photovoltaic technology as the main PV cell, the reference PV cell has the same open circuit voltage V_{oc}. A pair of resistors is then used to divide the open circuit voltage V_{oc} to the required V_{mpp}[3].Here, supercapacitors are used as the energy storage element. They are more efficient than batteries and offer higher lifetime in terms of discharge cycles [4]. The hysteresis comparator can be built using LT6700 single supply IC. The output will have a proper swing to high or low with the reference or threshold values. In this system, it has been set to 1.8V for upper threshold and 1.2V for the lower threshold. The DC-DC boost converter is the LT3525 chip, which is the efficient synchronous step-up

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converter which can start even with low voltages such as 1V. Its quiescent current and shutdown currents are as low as 7µA and 1µA respectively. This MPPT based system can drive the wireless humiture sensor load where the node transmits signal. This wireless humiture sensor works in the burst mode, transmitting and receiving information very fast in very small time slots (1ms). Fig.3 shows the measured output voltage and the node while transmitting data. The output voltage drops from 5V to 3.6V while the voltage of the sensor node is transmitting data [3].

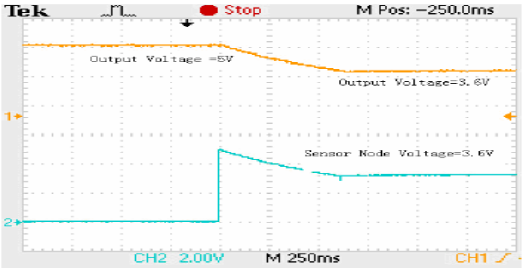

Fig.3: Measured waveform of Output voltage and the wireless sensor node voltage while transmitting signal load.

III. LIGHT HARVESTING SYSTEM USING LOW POWER MSP430

This section considers a zone-based lighting control system with a central controller and distributed sensing modules [5].

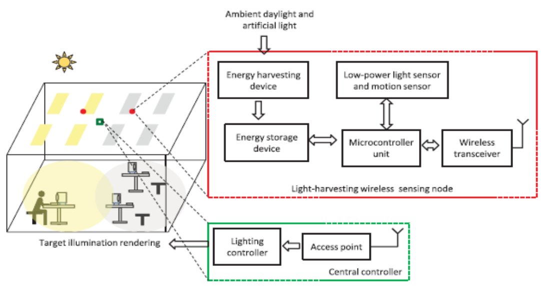

Fig.4: Lighting control system

In Fig.4, the indoor lighting control system driven by light-harvesting wireless sensing module is illustrated [5] [6]. The ceiling-mounted light-harvesting wireless sensing module (eZ430-RF-2500-SEH) development kit consists of a light sensor (APDS9004), a motion sensor, an energy harvesting device, an energy storage device, a micro-controller unit (MCU) (MSP430F2274) and a wireless transceiver. The light harvesting module with light and motion sensors is depicted in Fig.5[5] [8].

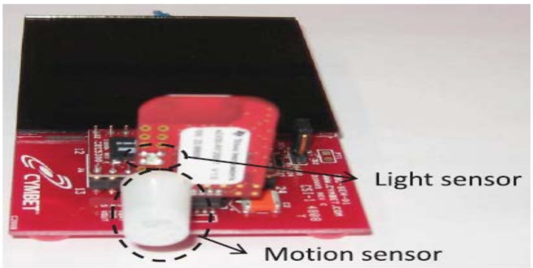

Fig.5: Light harvesting wireless sensor module

The core of the energy harvesting module CBC-PV-01 photovoltaic cell converts ambient light into electrical energy [9]. The energy is managed and stored in a pair of thin film rechargeable 50µAh CBC 5300 EnerChip solid state devices connected in parallel. These EnerChips act as a buffer, storing energy. This also has a very low self-discharge cycle. The voltage from the photovoltaic cells is increased using a boost converter to a level sufficient to charge the EnerChips and power the rest of the system. The output of the boost converter is monitored continuously by a charge control block. The charge controller disconnects the boost converter from the EnerChips if the output of the boost converter falls below the voltage needed to charge the EnerChips, thus preventing them from back powering at low light levels. The development board is equipped with a low-power MSP430 micro-controller unit and a CC2500 2.4

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GHz wireless transceiver and includes a USB to interface between the wireless radio and a PC.

The motion sensor used here is the Panasonic Passive Infrared (PaPIR). This is suitable for low-power designs. It is experimented that the power consumption of the sensor module is around 8µW in standby mode and 700µW in operating mode. Such a sensor module can be driven by the CBC-PV-01 photovoltaic cells as the energy-harvesting device [9]. The communication between the light-harvesting module and the central controller is achieved by describing an application layer wireless sensing protocol SimpliciTI™, a low-power RF protocol for direct device-device low data rate communications [10]. This protocol includes collision avoidance and receiver acknowledgement features for enhanced reliability. The working of a protocol is shown in Fig.6.

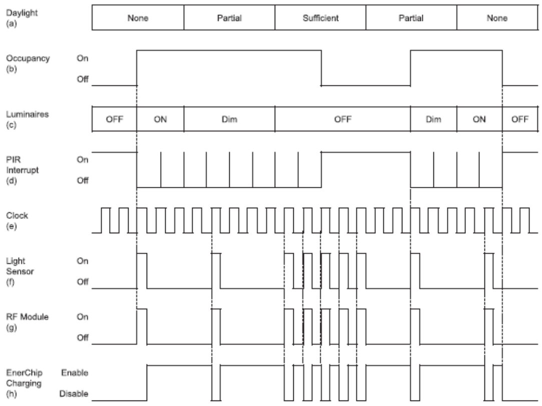

Fig.6: Working of the Wireless sensing protocol SimpliciTI™

An example daylight and occupancy scenario is shown in Fig. 6(a)-(b), where "none", "partial" and "sufficient" indicate the amount of daylight at workspace plane w.r.t. the required level of luminance, and "on" and "off" indicate occupancy and non-occupancy respectively. Corresponding to the daylight and occupancy states, the dimming status of the luminaires is shown in Fig. 4(c), with the three states "OFF", "ON" and "Dim" indicative of the lighting control mechanism. Once occupancy is detected by the PIR sensor, it gives an output as a raise edge which actives a GPIO interrupt on the MCU. The PIR interrupt enable signal is active during non-occupancy and is duty-cycled during periods of occupancy as shown in Fig. 6(d). Within the interrupt service routine (ISR), the PIR interrupt is disabled and the MCU wakes up from low-power mode. The MCU first sets the GPIO pins which are connected to the light sensor so as to measure the current ambient luminance and it resets those pins in order to switch off the light sensor and save power. A timer clock inside the MCU is set to run at 1 Hz, as shown in Fig. 6(e), to synchronize light sensor sampling as well as the updating of dimming levels. The light sensor makes a measurement every 5 s as shown in Fig. 6(f). The light sensor may be made to sample more frequently, as illustrated in Fig. 6(f), when daylight luminance is sufficiently high since the EnerChips are properly charged. This has the advantage that in case daylight levels suddenly reduce significantly, the lighting controller may adapt dimming levels quickly based on luminance readings from light sensors. A bit wise input port named BATOFF receives an instruction from the MCU to either close or open a switch connecting the photovoltaic cell to the EnerChips. The switch is closed if there is enough light energy else the switch is closed. The MCU enables the EnerChips for 1 second and enters low-power mode if the present voltage is less than the minimum voltage. Otherwise, the MCU wakes up the RF module and transmits a packet.

When considered zone-based lighting control, the light sensor measures light levels in its respective zones, the motion sensor detects occupancy over this zone and the wireless transceiver then sends out the sensing information to the central controller as defined by the wireless sensing protocol.In Figs. 7 and 8, performance of the lighting system for a dynamic occupancy and daylight scenario is shown [5] [7].

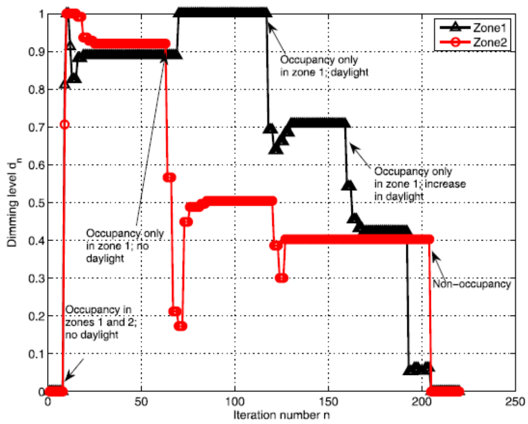

Fig.7: Dimming levels of luminaries in the two zones over control iterations with dynamic occupancy and daylight.

The dimming levels of the luminaires and the light sensor measurements in the two zones are shown respectively in these plots. The valuesL$^{(o)}$= 500 lux and L$^{(u)}$= 300 lux, where L$^{(o)}$ is the average illuminance level over a zone occupied and L$^{(u)}$ is the level if the zone is unoccupied but there is global presence, are chosen. The corresponding set-points were Z$^{(o)}$= 95 lux and Z$^{(u)}$= 61 lux at the light sensors. From Fig. 7, it is seen that as the amount of daylight increases, the dimming level in occupied zone 1 goes lower while the light sensor maintains a steady state value close to the target set-point, as seen in Fig. 8.

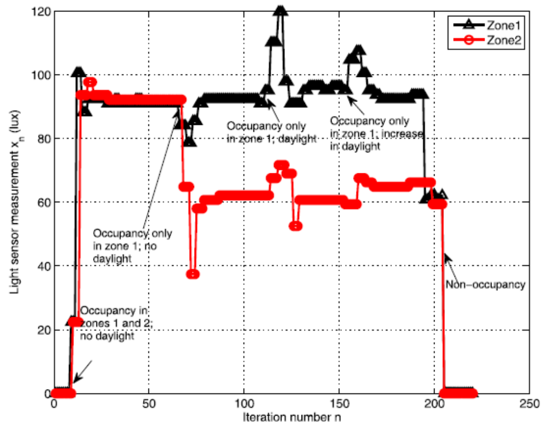

Fig.8: Light sensor measurement in the two zones over control iterations with dynamic occupancy and daylight.

The lifetime of the designed wireless sensing module is said to be working for almost 20 hours with the EnerChip's 50% energy charge. These results were obtained under dark-room and non-occupancy conditions [9].

IV. COMPARISON

The eZ430-RF-2500-SEH development kit is not bulky when compared to the light harvesting module with the MPPT design. The wireless sensing module with MCU holds good for any practical illumination zones even like a zone with partial shadowing whereas the system with MPPT design does not hold good everywhere since the parameter "K" is viable only for uniform illumination. The MCU module was proved for 90%-92% energy harvesting results but the MPPT design yielded only 80% of light energy harvesting. The MCU design is practical because it is capable of delivering enough power for over 400 transmissions but the MPPT system is design dependent [7].

V. CONCLUSION

Experimental result shows that the wireless sensor light-harvesting system using MCU is more implementable and viable. This design also is proved to achieve stable illumination control. MPPT designed system does not appreciate dynamic changes in the lighting systems. Further, the efficiency pertaining to both the harvesting modules is notable. The system design with MCU can be commissioned better due to the usage of the MSP430 microcontroller which bases the features of low-cost and low-power consumption.

VI. FUTURE SCOPE

As more flexible and low-cost light-harvesting devices emerge, embedded integration of battery-less sensors that function particularly on harvested energy into luminaires will become an important challenge. In addition, controlling lighting systems reliably based on sensing information from energy harvesting wireless sensors will be another technical challenge.

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