ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 5, Issue 4, May 2016

Li-ion Battery Supercapacitor Based Hybrid Storage System in Wireless Sensor Networks

Vaddi Naga Padma Prasuna, Monika Jai CM, Manasa.S, Sujay A.K, Harshitha B.S

Abstract**—*****Hybrid system that increases the efficiency and lifetime of a battery using Li-ion battery and super capacitor, which finds applications in photo-voltaic based wireless sensor network. Longer life time in terms of charge cycle is provided by super capacitor. Also disadvantage in super capacitor is low energy density and high cost. The disadvantage of super capacitor is overcome by lithium-ion battery, but it requires an accurate charge profile in order to increase the lifetime of a battery. The disadvantage here is this feature cannot be easily obtained by providing the wireless node with a fluctuating power source as the PV one combining the above two concepts it is possible to provide a better energy profile.***

Index Terms**— *****Battery, battery management system, hybrid power systems, photovoltaic systems, power management, solar cells, super capacitor, WSN.***

I. INTRODUCTION

Wireless sensor networks (WSN), sometimes called wireless sensor and actuator networks (WSAN) are spatial distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; [1] today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so a wireless sensor network consists of a large number of microsensors distributed in environment. Each node shares information with the other neighbouring node by a wireless link.

Solar cells exhibit a strong nonlinear electrical characteristic. Variable operating conditions can be associated with the weather change and ageing effects or efficiency degradation in the solar panel. The energy transfer mechanism is strongly influenced by the illumination condition such as the angle of incidence of the sunlight that varies along the day especially if the sensor node is in a mobile system, besides shadows that depend also on the instantaneous position of the sensor. The simple and low cost way to extract and store energy from a PV source is to connect the solar panel directly to a battery with a diode [3]. The main disadvantage of this solution is that the system does not always work in the optimal condition to convert the available solar energy.

Two types of energy storages [2] are available they are, batteries and electrochemical double layer capacitors.

Rechargeable (i.e. secondary) Lithium ion battery are now our everyday companions, powering our laptops, cellular phones, tablets, portable audio players, etc. Due to their high energy efficiency and outstanding cycle life compared to earlier battery systems, Lithium ion batteries quickly conquered the battery market for consumer electronics and are at present the power source of choice for these applications. Lithium ion battery technology is currently facing a new great challenge. The conversion of electrical energy to chemical energy (and vice versa), corresponding to the charge (and discharge [12]) of a Lithium ion battery, is a complicated process.

A super capacitor is a high-capacity electrochemical capacitor with capacitance values much higher than other capacitors that bridge gap between electrolytic capacitors and rechargeable batteries. They typically store 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerate many more charge and discharge cycles than rechargeable batteries. They are however 10 times larger than conventional batteries for a given charge. Supercapacitors are used in applications requiring many rapid charge/discharge cycles rather than long term compact energy storage: within cars, buses, trains, cranes and elevators, where they are used for regenerative braking, short-term energy storage or burst-mode power delivery.

II. Related Work

1. DEVELOPMENT OF SECONDARY LITHIUM BATTERY

The anode material for lithium-based batteries is obviously metallic lithium, which has been used for primary (i.e. non-rechargeable) batteries. By possessing the lowest standard potential (–3.05 V *vs.* a standard hydrogen electrode (SHE)) and the lowest atomic weight among all metals, the utilization of metallic lithium as an anode offers the realization of galvanostatic cells having an extremely high energy density [6]. Lithium metal cells have one severe drawback, namely, inhomogeneous lithium plating. The uneven deposition of lithium onto the anode surface upon charge results in the formation of so-called dendrites [7]. These dendrites consist of high surface area, highly branched lithium metal structures, which continuously grow, eventually penetrate the separator and electrically connect the anode and cathode leading to a short circuit of the cell. This spontaneous and uncontrolled event results in local heat evolution. In the course of these developments Scrosati and Lazzari proposed the 'rocking chair battery', which marked the first practical realization of two host materials reversibly shuttling lithium-ions from the anode to the cathode upon discharge and vice versa upon charge [4][5]. The first commercial secondary LIB, released by Sony Corporation in 1991,comprised LiCoO2 as cathode and a soft carbon as an anode (**figure1)**. This Lithium ion battery provided an energy density and specific energy of 200 Wh l–1 and 800 Wh kg–1, respectively, outperforming all other battery technologies present in the market at that time. This battery showed a highly reversible and stable cycling behavior and an extremely high cell voltage of about 4 V. The replacement of soft carbon by hard carbon (**Figure 1**)) , offering enhanced specific capacities, led to an increase of the achievable volumetric and gravimetric energy density up to 295 Wh l–1 and 120 Wh kg–1, respectively . The hard carbon anode facilitated the increase of the upper cut-off potential to 4.2 V, while presenting excellent cyclability in the – at that time – commonly used PC-based electrolytes [4][5].

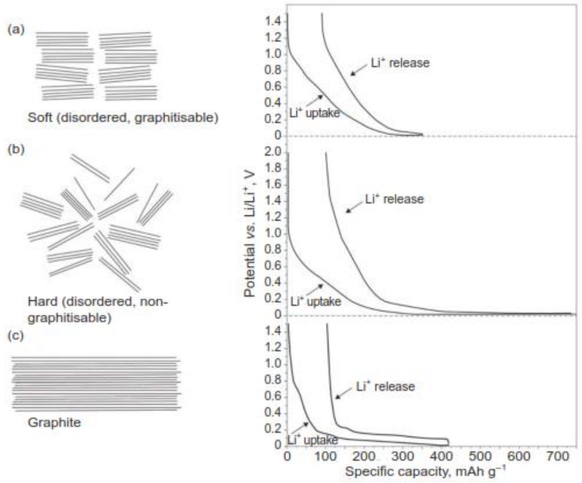

Fig 1. Schematic illustration (left side) of: (a) soft carbon; (b) hard carbon; and (c) graphite structures and (right side) their typical potential profiles

1. MECHANISM OF LITHIUM ION BATTERY

Four types of rechargeable batteries are commonly used: nickel cadmium (NiCD), nickel metal hydride (NiMH), lithium. Effect of constant voltage charge period at 4.2 V on cycle performance. Test cells charged at constant current at 1-C rate to 4.2 V followed by the constant voltage float charging at this voltage for various periods and then discharged to 2.75 V at 1 C rate. The choice between NiMH and Li+ batteries became evident: Li+ batteries are more efficient than NiMH, have a longer cycle lifetime, involve a lower rate of self-discharge, and its cycle-life is independent of the Depth of discharge problem that is present in NiCD batteries [9].The charge strategy used in the proposed architecture is useful to explain the mechanism that affects the lifetime of the Li-ion batteries. In general terms, the charge procedure consists of two phases: a constant current phase and a constant voltage phase; the charge current is expressed as a rate of the nominal capacitance, for example, charging a battery of 1000 mAh with a current of 1 A, means charging at 1 C; this phase requires the 20–30% of the charging time and allows the 70–80% of the total charge. This state ends when the maximum cell voltage is reached (generally4.2 V), and the second phase starts. In last phase (constant voltage phase), the cell voltage is maintained until the current drops under the minimum current, that depends on the C rating of the battery or for a certain period of time. This last stage requires the 70–80% of the total time and allows the 20–30% of the total charge, but a long float-charge period at 4.2 V or above is one of the causes of the lifetime reduction of the cell. Another factor of mechanism in Li-ion batteries is the high charge rate.

III. Proposed model

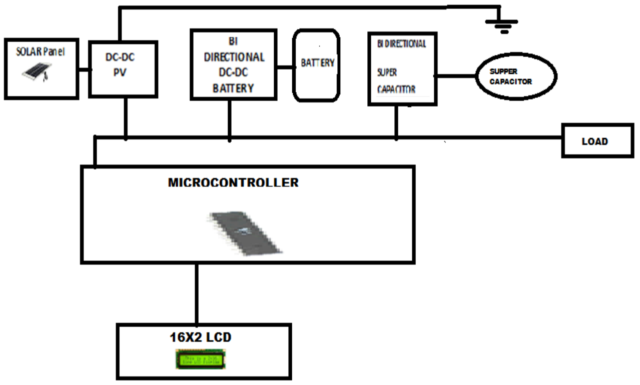

Fig2 Block diagram of the power management

In the proposed power management architecture there are three dc–dc converters are connected in parallel to the dc power bus. The first converter, denoted dc–dc PV, interfaces the PV panel to the dc power bus, the second, is the bidirectional dc–dc battery, connects the dc bus to the battery, and the third, is the bidirectional dc–dc Supercap, connects the dc bus to the super capacitors. The internal power bus is the main power supply of electronic systems utilized by sensor node. The dc–dc PV converter realizes the MPPT of the PV module; the input voltage the converter is controlled by a feedback loop and the reference determined either by the source MPPT or by the control the supercapacitor voltage, depending on the state of the power management algorithm. The dc–dc PV converter is based synchronous Sepic topology this guarantees small input current ripple and it is compatible with the voltage of our PV cell (about 5 V).

The dc-dc supercap converter is a bidirectional converter synchronous buck converter. The converter operates in a step-down mode when the current flows to the supercapacitor and step-up mode when energy from the supercapacitor is needed. The maximum voltage of a typical supercap is about 2.7/2.5 V. This converter controls the dc bus voltage operating as a sink or a source depending on the instantaneous power budget of the system. In the architecture the direct power conversion takes place from the solar panel to load bus. The extra power available on the bus is stored in supercapacitor and can be utilized by the conversion system when a reduction of the available power on the source is present. The stored energy can be designed to manage the variation of the instantaneous power guaranteeing the power to the load in a portable system, to supply the system for many hours without irradiation, or provide the energy necessary for charging the battery in case of fluctuation of the input power. The dc-dc battery converter is a bidirectional boost converter used to charge and to utilize the battery at the same time depending on the working conditions. The lithium battery has a nominal voltage of 4.2 V and the dc-bus voltage is 3.3V. This converter operates like the dc-dc supercap converter, but has a current controlled loop, and the power management algorithm decides the current reference based on the charging/discharging of the battery. To get an operating time of 80-90% a 5W solar panel and a10KJ storage is sufficient for the sensor to be used. The PV module has a 5W nominal power and circuit voltage of 6.6V. The first converter efficiency is set at 80%. The Supercapacitor converter is the only one which runs all the time and is designed to operate with the light load condition with a pulsed frequency modulation, for reducing the auto consumption and increase the efficiency.

IV. Implementation

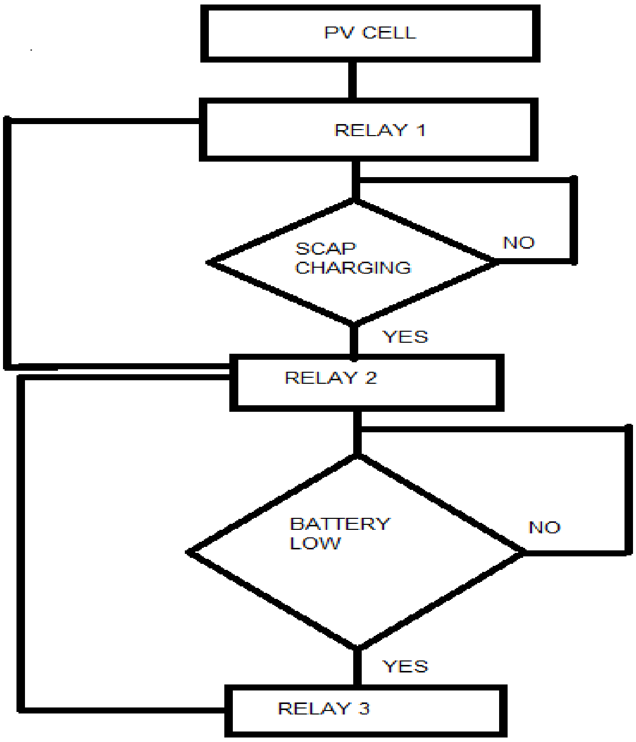

Fig.3 flow chart for the proposed architecture

When the PV cell is charging the relay1 is switched ON the acknowledgement is sent to the microcontroller, if the capacitor needs to be charged it sends the request to the controller and relay 2 is switched ON. After charging to the maximum voltage required to charge the load the relay2 is switched off. If the voltage of the battery is below the threshold voltage then the microcontroller send the request to relay3 to be switched ON. After the battery is fully charged relay2 and relay 3 is switched OFF.

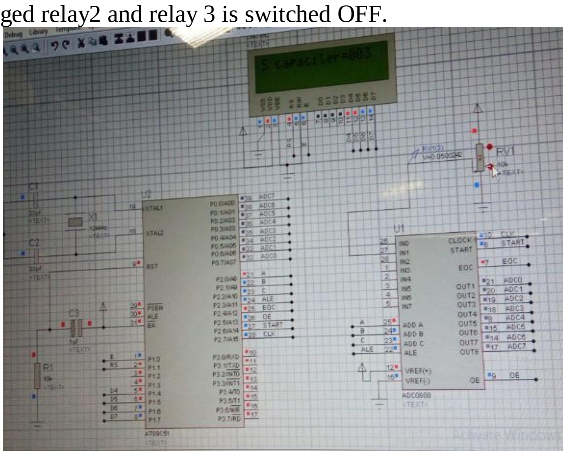

Fig4. Interfacing of supercapacitor

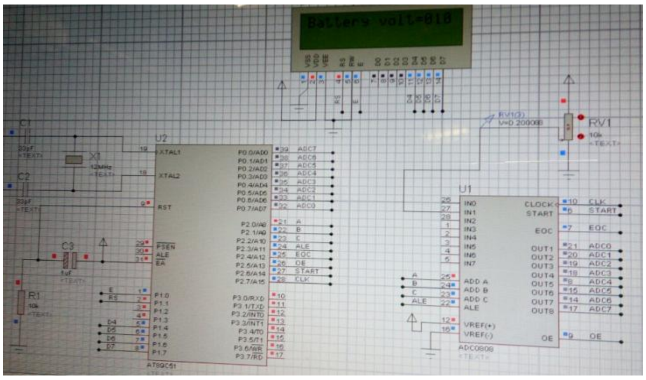

Fig 5 Interfacing of battery

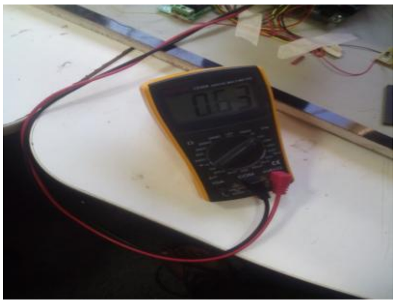

Fig 6 initial voltage of capacitor

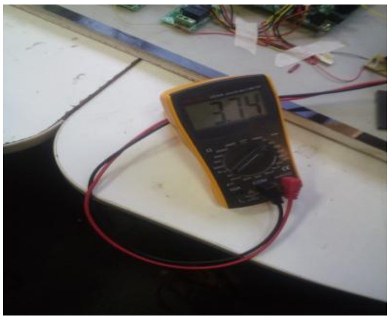

Fig 7 initial voltage of battery

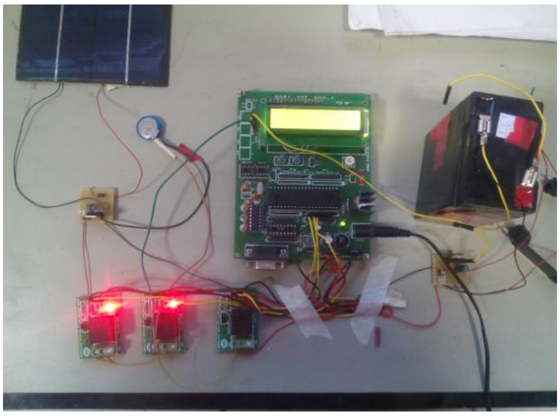

Fig 8 charging of capacitor

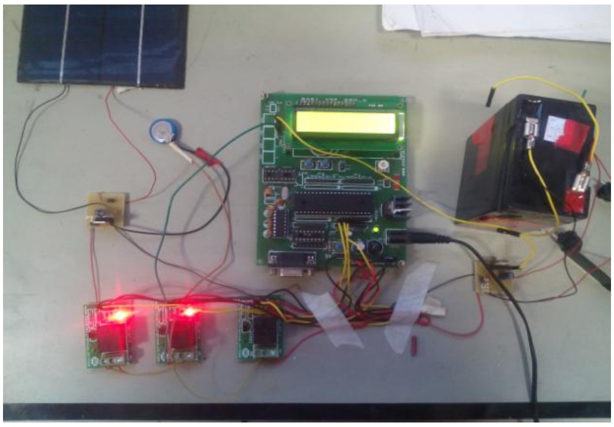

Fig 9 hardware interface

V. Results

The power manager is implemented by a microcontroller 8051 and it work with the crystal oscillator of 11.592MHz. The two bidirectional converter works at the same frequency of 490KHz.

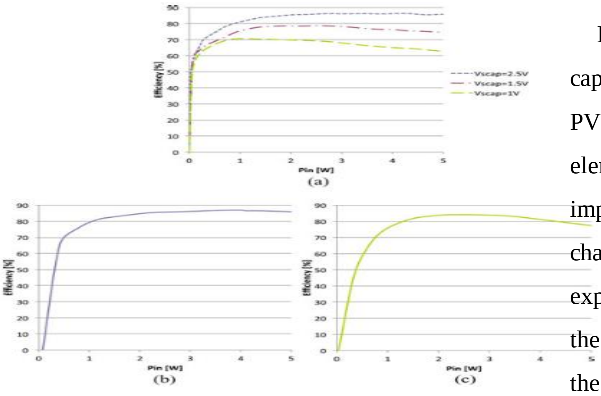

Fig 7 Efficiency of three main converters

The efficiencies of the three main converters are reported in Fig. 7(a)–(c): the measured efficiency of the bidirectional dc–dc Supercap converter in buck mode, at different supercap voltages; the measured efficiency of the bidirectional dc–dc battery; and the measured efficiency of the dc–dc PV converter, respectively. In order to verify, an SPI interface has been connected to the power manager; this communication enables the monitoring of currents and voltages in the circuit and of the state of the power manager, as well as the verification of the validity of the Simulink model and the proposed design procedure. The sampled values are reported Fig 8: the first image is the solar panel voltage, the second image is the instantaneous input current of the solar panel, the third image is the instantaneous input power, the fourth image is the voltage across supercap, the fifth image is the status of the control state machine.

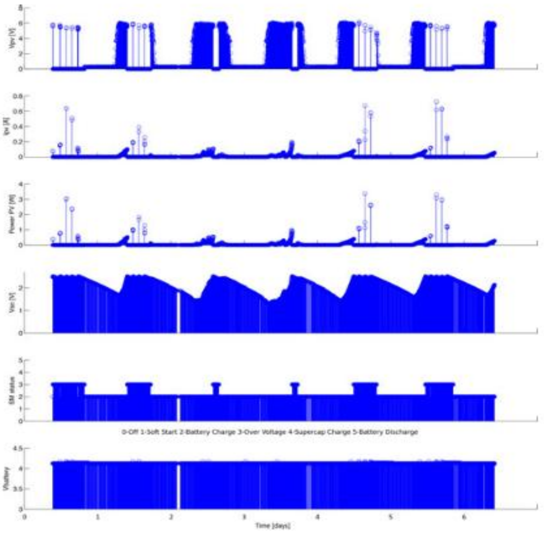

Fig 8 Measured voltages, currents and state variables

VI. Conclusion

In our power management architecture utilizes both super capacitor cells and a Li-ion battery as energy storages for a PV-based WSN. It shows that a combination of both energy storage elements reduces the number of charge cycle of the battery, improving the battery lifetime. The Simulation results show that the charge battery cycles is reduced almost by a factor four. The experimental results have validated the design procedure for sizing the storage elements. The major limitations are auto consumption of the supercap converter, being 37 mW the average absorbed power and 25 mW the one required by the sensor, and the efficiency at low load.

VII. **References**

[1] N. Guilar, A. Chen, T. Kleeburg, and R. Amirtharajah, “Integrated solar energy harvesting and storage,” in Proc. Int. Symp. Low Power Electron. Design, Oct. 4–6, 2006, pp. 20–24.

[2] V. Raghunathan, A. Kasal, J. Hsu, J. Friedman, and M. Srivastava, “Design consideration for solar energy harvesting wireless embedded system,” in Proc. IEEE Int. Conf. Inf. Process. Sens. Netw., Apr. 15, 2005, pp. 457–452.

[3] K. Liu and J. Makaran, “Design of a solar powered battery charger,” in Proc. IEEE Electr. Power Energy Conf., 2009, pp. 1–5.

[4]. B. Scrosati, *J. Electrochem. Soc.*, 1992, **139**, (10), 2776

[5]. M. Lazzari and B. Scrosati, *J. Electrochem. Soc.*, 1980, **127**, (3), 773

[6]. Y. Nishi, *J. Power Sources*, 2001, **100**, (1–2), 101

[7]. J.-M. Tarascon and M. Armand, *Nature*, 2001, **414**, (6861), 359

[8]. D. R. Lide, “Handbook of Chemistry and Physics”, 95th Edn., CRC Press, Taylor & Francis Group, Boca Raton, USA, 2014

[9] S. S. Choi and H. S. Lim, "Factors that affect cycle-life and possible degradation mechanisms of a Li-ion cell based on LiCoO2," J. Power Sources, vol. 111, no. 1, pp. 130–136, 2002.
[10] A. F. Burke, "Batteries and ultracapacitors for electric, hybrid, and fuel cell vehicles," Proc. IEEE, vol. 95, no. 4, pp. 806–820, Apr. 2007.
[10] A. F. Burke, "Batteries and ultracapacitors for electric, hybrid, and fuel cell vehicles," Proc. IEEE, vol. 95, no. 4, pp. 806–820, Apr. 2007.

ABOUT AUTHORS

Prof. PRASUNA V N P

Vaddi Naga Padma Prasuna: M.Tech in VLSI and Embedded systems (PhD). Currently working as professor in the Department of Electronics and Communication Engineering at Atria Institute of Technology, affiliated to Visvesvaraya Technological University, Bangalore, Karnataka, India.

MANASA.S

Manasa was born on 8th august 1994, and completed her secondary education from Gulabi girls high school and pre university course from St. Joseph Indian composite PU college and currently pursuing her bachelor degree in engineering in Atria Institute of Technology, Bangalore.

Has taken part in the workshop on "Latest Trends in Wireless Technology. Is an active member of IETE (Institution of Electronics and Telecommunication Engineering).

MONIKA JAI CM

Monika was born on 21st September 1994, and completed her secondary education from Florence public school; and pre university from Seshadripuram composite PU college; currently pursuing her bachelor degree in engineering in Atria Institute of Technology, Bangalore.

Has taken part in the workshop on "Latest Trends in Wireless Technology. Is an active member of IETE (Institution of Electronics and Telecommunication Engineering).

SUJAY A.K

Sujay was born on 9th october 1993, and completed his secondary education from Bhoruka English medium high school; and pre university from Bellary INDP PU college; currently pursuing her bachelor degree in engineering in Atria Institute of Technology, Bangalore. Has taken part in the workshop on "Latest Trends in Wireless Technology.

HARSHITHA B.S

Harshitha was born on 26th October 1994, and completed her secondary education from Sri Vani education center; and pre university from KLE society's S.Nijalingappa P.U college; currently pursuing her bachelor degree in engineering in Atria Institute of Technology, Bangalore.

Has taken part in the workshop on "Latest Trends in Wireless Technology. Is an active member of IETE (Institution of Electronics and Telecommunication Engineering).