Energy Harvesting for Remote Wireless Sensor Network Nodes

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***Abstract*—Wireless Sensor Network (WSN) technology is widely used for controlling and monitoring purposes. Advancement accomplished in the past era in wireless communications and microsystems have allowed the change of minor degree and least effort sensor nodes outfitted with remote correspondence abilities ready to manufacture a wireless WSN node. Each sensor node is ordinarily outfitted with one or a couple of detecting units, information preparing units, remote correspondence interface and battery. WSNs have discovered application in an extensive variety of various spaces like home and biomedical health monitoring. Providing continuous supply of energy to these nodes at remote locations is a major concern. The aim of this paper is to provide un-interrupted supply of energy to remote WSN nodes. Solar energy is expected to provide the required energy; however, photovoltaic (PV) based system are not able to operate at night. This may influence the operation of WSN nodes, rendering them useless for that instant. Several techniques have been proposed to provide satisfactory energy storage. However, the utilization of a suitable device to provide the required energy storage and operate WSN node for all day long is an open issue. A complete WSN node is developed for flood monitoring with sensing capacity along with energy harvesting using PV system and storage unit, which is able to harvest and store energy for un-interrupted operation of WSN node at remote sites.**

Keywords*—*Wireless sensor network (WSN); photovoltaic (PV)

I. INTRODUCTION

Flood is becoming a major natural disaster in different areas of Khyber Pakhtunkhwa (Pakistan), resulting in significant amount of damage including homes, crops, cattle and human lives. Flood control and monitoring is a major problem in Pakistan, owing for the most part to the consumption and maintenance of the equipment utilized in this regard. At dams and rivers, different water level strategies are executed however tragically; we don't have a warning system for continuous checking and controlling in flood prone zones where human access is constrained. Collecting and processing continuous information has been an interesting subject of installed system design. In any case, to gather information utilizing normal wired sensor systems has dependably been troublesome and costly. The wired system frequently goes excessively too crowded and creates an obstacle to mobility requirements of the applications. In this way, WSN has turned into a head research point in the installed fields is a term used to present a class of implanted specialized communication devices that give dependable remote associations between sensors, processors and actuators. It is developing as an answer for an extensive variety of information assembling and handling applications [1]. A WSN is comprised of nodes that have processing units, sensors, antenna, power source and radio frequency integrated circuit (RFIC) as radio transceivers [2].

WSN typically use battery power as a power source while energy harvesting wireless sensor network (EHWSN) use an energy harvesting system (EHS) as a power source, converting energy from nature to electrical energy using different energy harvesting (EH) techniques. For example electrical energy is converted from solar energy by Photovoltaic cell is most widely recycled in our daily life. Although the output power from the EHS is extremely low (μW-mW) and various over time with the development of low power electronics and energy storage techniques (e.g. low leakage super capacitor), EHWSN becomes reality and attracts more and more researchers attentions [3].

WSN technology is generally utilized for controlling and observing purposes. However, providing continuous supply of energy to these nodes is a major concern. This research aimed to provide un-interrupted supply of energy to remote WSN nodes. Solar energy is expected to provide the required energy with minimum expenses of resources. However PV based system are not able to operate at night. This may influence the operation of WSN nodes, rendering them useless for that instant. A few procedures have been proposed to give satisfactory energy storage. However, the use of a reasonable device to give the required energy storage and work WSN node for throughout the day is an open issue [4].

This paper aims to build up complete WSN nodes that will be fit for sensing (based on specific sensor) and transmitting data, with the assistance of PV based system. The proposed system will also be fit for giving the required energy even at the absence of sun (evening time). This would not just encourage the continuous flood checking process with the use of ease and self-supported assets. In addition, this will likewise help in saving valuable lives by conveying earlier data about any unfortunate flooding events.

II. Energy Harvesting

Batteries are normally used to power the WSN nodes. The node will be dead when their energy is exhausted. Just in exceptionally specific applications batteries can be recharged/replaced. Be that as it may, notwithstanding when this is conceivable, the energizing or replacing operation is moderate, costly and it also drops the network performance. Renewable energy sources are proposed to power WSN nodes at remote sites. Solar energy is a suitable candidate; however, sun is not present at night. Therefore, it is imperative to design a suitable circuit that can harvest and store enough energy to operate WSN node throughout the day. Several energy storage units are proposed to operate with PV system; however, the use of a suitable source for flood monitoring applications is still an open issue.

III. Hardware Design

The main goal of this paper is to create WSN node, which are small devices that collect and transmit data and are often placed in remote areas with the capability to extract energy from ambient sources to last eras of time. The goal of this research is to produce such a WSN node that will make use of a unique energy management scheme to ensure long-lasting operation. A solar cell will be the primary energy source with secondary energy storage devices being a rechargeable battery and super capacitor (Fig. 1).

1) *Functions*

- Collect on-board electrical data including: solar cell open-circuit voltage, battery voltage and current and super capacitor voltage.
- Transmit and receive the collected data wirelessly.
- Program the microcontroller for testing and final operation.
- Allow the on-board microcontroller to Communicate with each other.
- Recharge the energy storage devices with surplus solar energy.
- Execute a power management program to maximize the operational lifetime of the WSN node.

2) *Constraints*

The wireless sensor node must adhere to the following constraints:

- Use a super capacitor as an energy storage device.
- Use a rechargeable battery as an energy storage device.
- Operate outdoors during the day under varying lighting conditions and during the night.
- Operate autonomously once deployed.

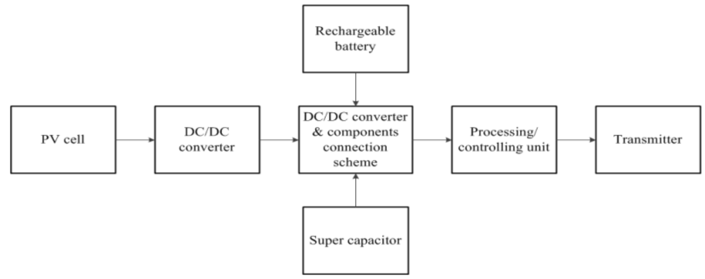

Fig. 1. Higher-level blocks required for the Wireless Sensor Node.

The DC/DC Converter with MPPT Functionality interfaces with the photovoltaic cell to extract solar energy [5]. The component connection scheme contains hardware that will charge and discharge the energy storage devices. The yield of the component connection scheme powers devices, specifically the sensors used to collect data, the transmitter and the controlling units. Data is likewise exchanged among the sensors, transmitter and logic units [6].

IV. Energy Storage and Delivery Module

The Energy Storage and Delivery Module are responsible for:

- Storing input energy from the Solar Boost Converter into either of the onboard energy sources.
- Transferring energy from the Solar Boost Converter or the onboard energy sources to the load on regulated 5V providing signals for the battery voltage, battery current and super capacitor voltage to be used.
- Managing energy viably to guarantee the WSN manages operation once conveyed.

TABLE I. WSN Power Management Operating Modes [7]

Operating Mode	**Energy Source Available**	**Conditions**
Normal Day.	Battery, Super Capacitor, PV.	Sufficient ambient light to power the PVs.
Normal Night.	Battery, Super Capacitor.	Insufficient ambient light to lower the PVs.
Charge Battery.	Super Capacitor, PV.	Day operation, PVs Provide enough power to support load and charge both Super Capacitor and Battery.
Charge Super Capacitor.	P.V and /or Battery.	Insufficient power from PVs to support load from PVs and Capacitor only.
Converter Off.	P.V and/ or Super Capacitor.	Super Capacitor has sufficient energy to support load.
Emergency.	P.V and/ Battery or Super Capacitor.	All energy devices unable to support load.

V. Bi-Directional Non-Inverting Buck-Boost Converter

This converter transfers energy between the battery and super capacitor and supports bidirectional power flow. The converter regulates the battery current for charging and discharging purposes (Fig. 2).

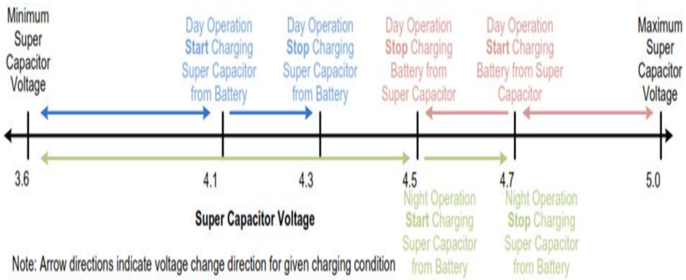

Fig. 2. The voltage conditions that dictate the WSN power management operating mode [11].

VI. Assessment of Proposed Design

The entire design is split into three main sections: energy collection, energy storage and delivery, and energy consumption. Within each of these sections very specific tasks and goals were established to ensure the requirements were met. The energy collection stage needs to efficiently catch solar energy and convey it to the next stage. The Energy Storage and Delivery stage must efficiently and cautiously transfer energy throughout the system. Lastly, the Energy Consumption stage must run the system as proficiently as could be allowed and do its end utilize dependably. A common theme throughout is the careful use of energy: each section is equally responsible for operating efficiently to ensure the WSN node can last for potentially months at a time. Much effort was spent amid the outline/parts-choice stage to secure low power parts that would yield acceptable results. Take note that while the three main sections all depend on each other to work as a whole, each section are modular enough to operate on its own provided suitable input energy is available. To be more particular, there is negligible interconnection between the three modules to ensure successful system integration [8]. Fig. 3 illustrates the relationship between sections: the design leaves little to chance. Each large section can be developed on its own and nearly seamlessly come together. Combining the three large sections was quite trivial relative to the development of every module.

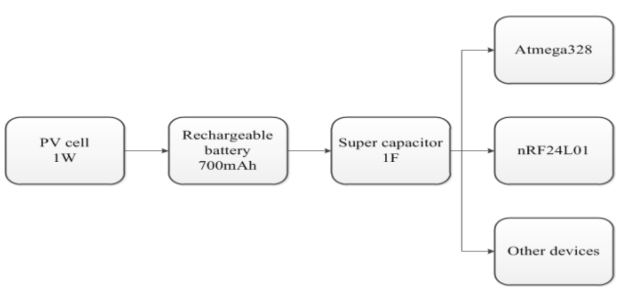

Fig. 3. WSN node design flow.

VII. Power Calculation

To spare restricted power assets, the microcontroller of WSN node remains for huge measure of time in a sleep mode, occasionally changing to an active mode to examine information from sensors or to communicate by means of radio interface. Accordingly, the lifetime of the node for the system without static power supply, would depend also on the node general power utilization and on control source discharge qualities. The power consumption of a node is determined by the consumption of the microcontroller, radio and the peripheral devices for active and sleep modes and on system scheduling. Microcontroller in WSN node is the key part which controls all the work of peripherals and radio communication. Contingent upon application, WSN node is additionally regularly required to make a few information preparing before sending the information to the receiver. In several works it has been shown that in many cases data processing on the node allows reducing the amount of the information, which is required to be transmitted over WSN node. This allows the improvement of the power consumption of the whole WSN node as radio communication usually has higher power consumption than the data processing [9].

The design node has the property that after 1 minute, it goes to sleep mode for 10 minutes. So according to that calculation, the node will be in active mode for 2.4 hours in 24 hours and the remaining 21.6 hours, it will be in sleep mode.

Node has the input voltage=5V.
Current across the node (Active mode) =97.6mA.
Current across the node (Sleep mode) =72.1mA.
For the measurement of power at active mode=97.6mA*5V*2.4h=1,171.2mWh.
For the measurement of power at sleep mode=72.1mA*5V*21.6h=7,786.8mWh.
$Power_{Total} = Power_{Active} + Power_{Sleep.}$
$Power_{Total} = 1,171:2mWh + 7,786:8mWh.$
$Power_{Total} = 8,958mWh.$

The reading of the node active mode and sleep mode are shown in Fig. 4 and 5.

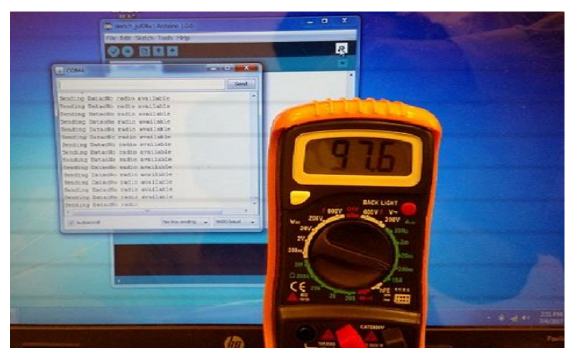

Fig. 4. Active mode.

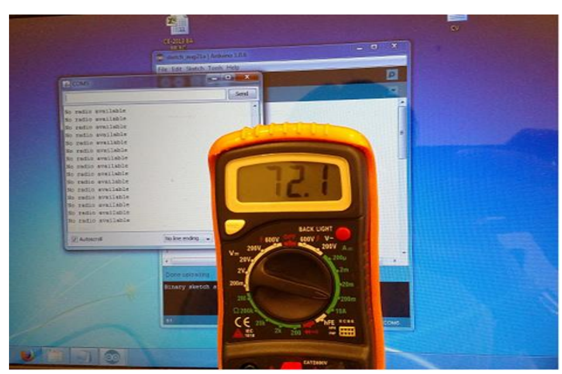

Fig. 5. Sleep mode.

VIII. Design Node

In the design node, the solar cell features open voltage of 6V and short-circuit current at 0.184A (Fig. 6).

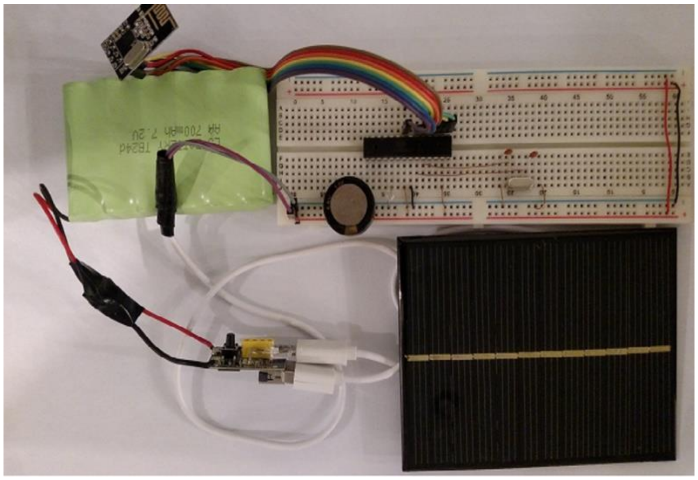

Fig. 6. The implemented WSN node with Solar cell, rechargeable battery and super capacitor.

The individual curves are measured under direct sunlight, on a cloudy day, 1 hour before sunset and under heavily cloudy conditions using different load resistors, which are shown in Fig. 7 and 8.

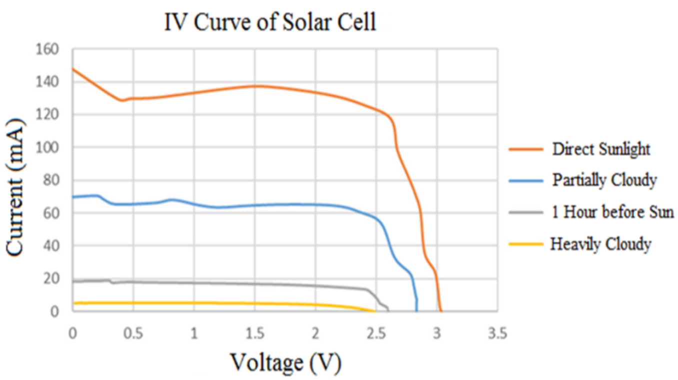

Fig. 7. Current-voltage curve of Solar cell [12].

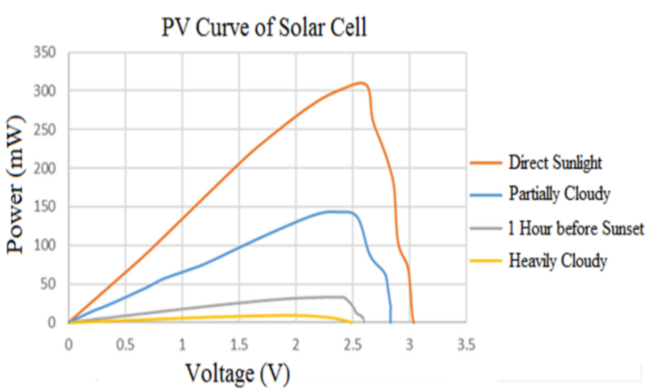

Fig. 8. Power-voltage curve of Solar cell [12].

Fig. 9 shows the Volts-Hours curve of Rechargeable batteries.

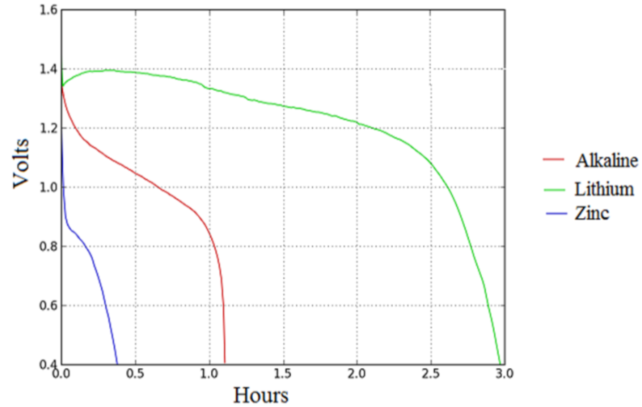

Fig. 9. Volts-hours curve of rechargeable batteries [13].

Fig. 10 shows the measured self-discharge of 1 farad super capacitor.

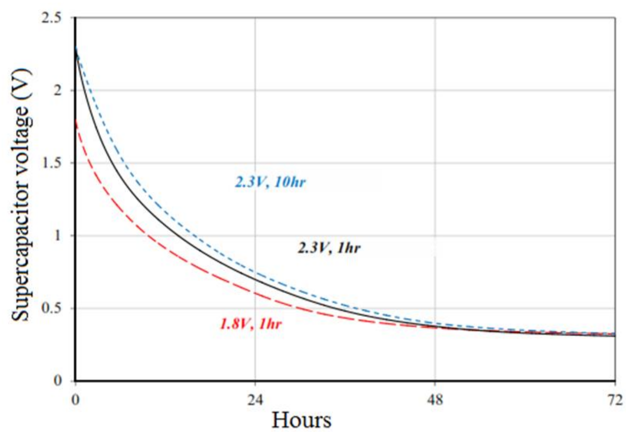

Fig. 10. Measured self-discharge of 1F super capacitor.

Maximum power point tracking circuits, reverse current own protection and charging controller are typically included by the influence of PV cell and energy storages units (rechargeable batteries and super capacitor). The most straightforward of this interface incorporates a turn around current protection diode, which keeps energy stockpiling from compelling current into the PV cell under low brightening conditions yet includes a diode voltage drop between the PV cell and energy storages. This interface can be efficient and even sufficient in the case where the PV cell nominal operating voltage range fall a diode drop above the operating voltage range of energy storage and this arrangement is suitable for systems that are able to select energy storages and PV cell accordingly.

This interface is also the part of maximum power point tracking (MPPT). The main concern of MPPT in case of low-power harvesting is the efficiency of the block and a number of implementations have been proposed. In some cases it is shown that the benefit extended from MPPT is peripheral as given in Fig. 11 matched connection between the maximum power point and PV cell operating time.

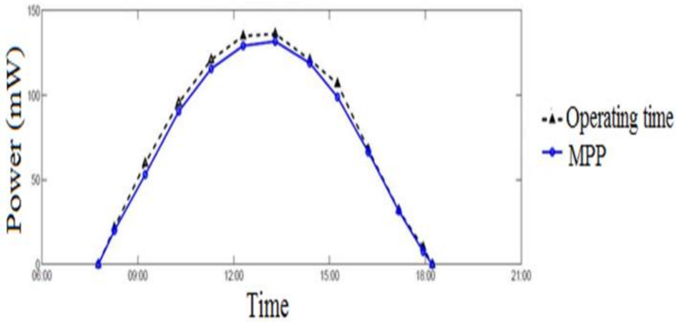

Fig. 11. Comparison of Solar cell output: Operating point verses MPPT.

Then again, when utilizing a super capacitor the subsequent voltage swing as a super capacitor completely releases or charges can make the PV cell go amiss incredibly from its close most extreme power working point as appeared in Fig. 12.

For this situation the MPPT piece can guarantee that PV cell works near its most extreme.

With a completely released super capacitor, an additional issue is cold-booting where the drained super capacitor does not permit the PV cell to energize the super capacitor. A rechargeable based battery charging circuit is recommended that permit the fast charging of a super capacitor contrasted with coordinate charging (Fig. 13).

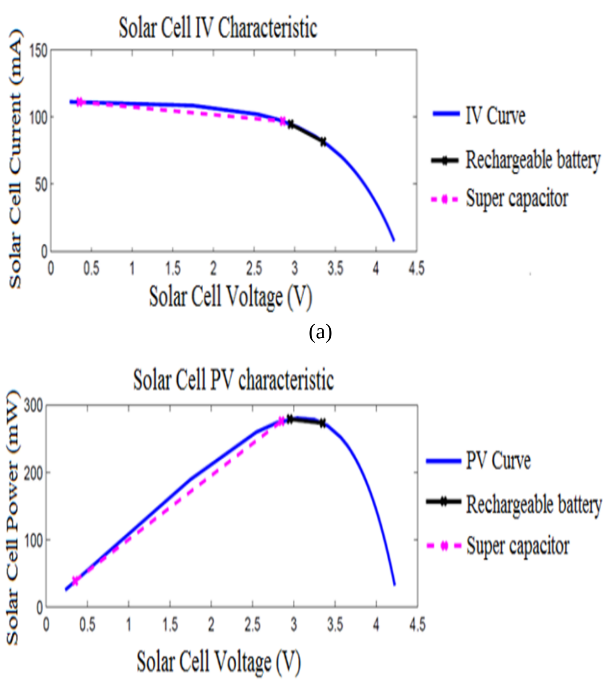

Fig. 12. Operating range of the WSN node.

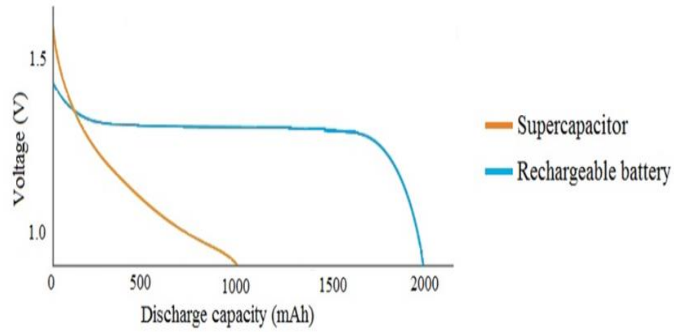

Fig. 13. Voltage-discharge capacity comparison of super capacitor and rechargeable battery [10].

IX. Conclusion

The aids of this paper can be summarized in two phases:

The first phase is improved management of uncertainty of energy supply through improved calculations and using this to achieve low variability in performance of energy harvesting systems.

The second phase is to enhance the energy management procedures that achieve better match of application workload demand with energy supply using system components and practical design.

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