Full Length Research Paper

Monitoring and Configuration of Energy Harvesting System Using WSN

Kodegandlu Venkatarayappa Narayanaswamy
Senior Member IEEE; Professor & Head of EEE, MSRUAS, Bangalore, India; Email: drkvn21@gmail.com

Received 15 May 2013; Accepted 12 June 2013

Abstract. Energy harvesting (EH) system is a new concept introduced for capturing or reusing energy from natural resources like solar energy and wind energy. The EH system consists of two key components i.e. an EH unit and an energy storage device. Monitoring and control of EH system is essential for its efficient and effective functioning, and reduces the cost required for replacement of damaged storage devices caused due to overcharging. This research article propose an architecture for monitoring voltage / state of the charge of EH system during charging and discharging process i.e. essential to protect the storage device from overcharging / deep discharging using Wireless Sensor Network (WSN) technology. A prototype of voltage monitoring slave sensor unit is designed to monitor overcharging / deep discharging of EH system. The monitored voltage is communicated to the sink at periodic intervals. Master slave wireless communication is set up using Zigbee wireless module to enhance communication between the monitoring slave sensor unit and master. The system is also scaled using remote configuration capability to extend the monitoring of EH system by setting up threshold limit to protect the storage device from over charging. By setting up the threshold limit an alert is generated by the monitoring unit and communicated to master over Wireless Network (WN), the remote configuration also provides to put the monitoring unit in low power mode to extend the monitoring unit life.

Key words: Energy harvesting, Wireless Sensor Network, Wireless Network, Cluster Heads

1. INTRODUCTION

The emerging technology has brought new opportunities in EH system and WSN for data monitoring and has given rise to expand WSN potential prospects for monitoring and processing various sensor information through wireless communication. Improvements in EH system technologies and utilization of renewable energy source for power generation has attracted the young researcher to expand the EH systems. EH system has been in rapid development for renewable power generation and monitoring EH system over WSN technology is the fastest and most effective way to reduce cost and man power required for maintenance of these systems. The monitoring and configuration of EH system over WSN has following advantages. Used for remote monitoring of renewable harvested energy. Remote configuration for setting charging threshold limits of storage device that in turn reduce cost and man power required for manual work. The overcharging / deep discharge alerts reduces the storage device replacement and maintenance cost. Particularly suitable for industrial monitoring application in distributed power generation plants.

Fig. 1: System Architecture of WSN for Monitoring of EH System

Most recently the wireless communication ability has made the embedded applications world by leading to the development of sensor networks. In any monitoring and control application the sensor nodes is composed of small wireless sensor node. These nodes are randomly deployed and distributed in a designated region where humans may have limited access to the area/location. This means that once sensor nodes are deployed it should be able to self-organize into a wireless network to identify its connectivity and
distribution without human intervention. The typical arrangement of WSN architecture for collecting information about the region and transmits the monitoring information to the centralized monitoring station / base station (BS) through multi-hop communications. Then the centralized monitoring station then sends the data/information to any remote user for monitor and control application.

Industrial Control and Monitoring: Wireless sensors can be used to monitor the state of machinery, measure the performance of machine or to environmental parameters in harsh environments. With this remote monitoring capability the maintenance cost can be reduced and also deployment cost required for wiring connections to these sensing devices is reduced.

2. LITERATURE REVIEW

In literature review the previous research efforts to understand the concepts in the areas of monitoring and control application using WSN. In remote monitoring application, water environment monitoring plays an important role in environment protection and management in the field of large-scale water quality measurement. The traditional method requires man power to collect the water sample and perform manual testing in the laboratory. This is a labor intensive and time-consuming task to meet the water environment protection and management objective these issues were addressed by the authors (Jin et al., 2010).

The author (Biyabani, 2009) proposes design considerations for an embedded WSN for periodic monitoring of civil infrastructure using an on chip integration of solar energy harvesting super-capacitors for extra power along with batteries powered source when mains power is not available.

The Energy harvesting setup with six hours of adequate sunlight to harvest solar power to recharge battery to its full capacity every day increases the lifetime of the Wireless networks (Musiani et al., 2007) explored the active sensing platform for wireless structural health monitoring of batteries were discussed. (Piorno et al., 2009) Management of solar harvested energy in actuation-based and event-triggered the systems. (Staszewski, W. J., Lee, et al., 2004) Structural health monitoring using scanning laser vibrometry concept were presented.(Steck, 2009) Energy and Task Management in Energy Harvesting Wireless Sensor Networks for Structural Health Monitoring were dealt.

(Taylor et al., 2009) A mobile-agent based wireless sensing network for structural monitoring applications, has explored scenarios in which nodes can harvest energy from their environment (Jiang et al., 2005) perpetual environmentally powered sensor networks. Existing approaches to the problem of dynamic duty-cycling of nodes with energy harvesting capabilities attempt to model the energy source and adjust the node’s duty cycle in anticipation of expected incoming energy or lack thereof (Voigt et al., 2003) Utilizing solar power in wireless sensor networks and health monitoring is carried out.

Lifetime Maximization in Clustered WSN: The sensor nodes are grouped into cluster and it comprises of Cluster Heads (CH) and Non-Cluster Heads (NCH). The cluster head processes the data of each non cluster heads and transmit the whole cluster information to base station. The energy consumed by the cluster head to do the processing is higher compared to non cluster heads thereby it drains its battery energy quickly. Thus the authors (Zhang et al., 2011). Presented the single cluster algorithm for life time optimization in homogeneous WSN with one solar powered sensor node. In this technique the cluster heads listen on the network for the non cluster head nodes to transmit the data in the specified time slot. On the receipt of the NCHs data, cluster heads process and routes through the shorter distance energy harvesting node to relay information to the Base Station (BS) thereby increase the network life time and minimizing the energy required by cluster head.

Monitoring systems are widely used in industrial applications and the review shows how wireless sensors can contribute to monitoring systems; however it does not take into account the need of intelligent wireless monitoring systems that can minimize the cost required for maintenance increase the operational efficiency of the system i.e. monitored.

3. MONITORING EH SYSTEM

Energy harvesting is a process by which energy is derived from external sources (e.g., solar power, thermal energy and wind energy) captured, and stored in energy storage devices Example: lithium-ion (Li-ion) / nickel–cadmium (NiCd) Battery.

The monitoring of any energy harvesting system plays an important role to provide reliable operation of the systems that utilizes the energy from energy harvesting storage device, it is important to know the factors that affect the storage device (battery) life and the amount of energy remaining in the storage devices at any point of time. The factors that affect the storage devices (battery) life are (a) Deep discharge of the energy reduces the life of the battery; (b) Frequent overcharging has a damaging effect on the battery.
4. SYSTEM ARCHITECTURE FOR WSN FOR MONITORING AND CONFIGURATION OF EH SYSTEM

Figure 1 forms the basic setup of WSN and the communication between monitoring unit, master and slave node forms WSN for any monitoring application. In this case WSN for monitoring of energy harvesting system the output of the system i.e. to be monitored is given as input to signal conditioning circuitry.

5. DESIGN SPECIFICATION

The monitoring and configuration of EH system consists the following stages:

(a) Monitoring unit needed to monitor the EH system
(b) Monitoring unit integrated with wireless slave node required to transmit the monitoring data to the master over WN
(c) Master node communicates with the slave node to gather data and present them to the end user over USART communication
(d) A user interface over HyperTerminal for displaying data and giving the user the ability to configure the EH System over WN

5.1. Development of WSN Monitoring and Configuring EH System

The hardware development of the system mainly includes Monitoring slave sensor node and sink node. They are composed of the control and wireless communication module and the related functional module.

5.2. The Monitoring Slave Sensor Node

Figure 2 shows the hardware structure of sensor node. It mainly consists of monitoring and control unit, and wireless communication module.

5.3. Monitoring and Control Unit

The characteristics of the system that is to be monitored are voltage / state of charge in the EH system’s storage device. In monitoring and control unit block the microcontroller has the limitation on the inputs that can be given to it. The monitoring systems voltage is stepped down using signal conditioning circuit then its output is given as the voltage input to the 10 bit Analog to Digital Converter (ADC) of the microcontroller. The value from the signal conditioning circuit and ADC are sampled, and processed using the microcontroller to determine the voltage / state of charge of the system that is monitored. This information is displayed on LCD and also packetized, and transmitted to the master over WN by the wireless communication module.

5.4. Control and Communication Module:

The control and communication module is the core unit that forms slave sensor node, which is responsible for obtaining the data from the monitoring and control unit, and perform wireless communication with other nodes/master using 2.4GHz IEEE 802.15.4 compliant RF transceiver. Below are the following task that are initiated by the slave node, when the master node sends a data request to the slave node:

- Receive and decode the master request
- Send command to the monitoring unit
- Receive the data over USART communication line.
- Packetizes the data with IEEE802.15.4 compliant frame and transmit over WN.
- Go back to monitoring mode and put the RF radio in receiver mode.
5.5. The Master Node

The key device is Zigbee module with 2.4GHz IEEE802.15.4 compliant low power consumption Yoda RF transceiver with an enhanced USART interface and microcontroller from Si2 Microsystems Pvt. Ltd. Figure 5 shows the master node structure, where the Zigbee acts as main communication module to transmit the data request to the slave nodes based on the Zigbee protocol for monitoring of EH system.

![Sink / Master Node Diagram]

**Fig. 3: The Structure of Master Node**

5.6. Software Design of WSN for Monitoring and Configuration of EH System

The self-organization and data transmission of the wireless sensor networks are based on Zigbee protocol stack. The Zigbee IEEE 802.15.4 protocol on 2.4GHz (license free for personal area network) is most suitable for the short range data communication and provides good coverage for industrial monitoring applications.

5.7. Establishing WSN over Master Node

Figure 4 shows the logic flow to form WSN with the slave nodes over master node. Here the master node broadcasts association request command to all the sensor nodes over WN and waits for a specified interval of time for the nodes to respond back. The master node saves the address of all nodes to form a wireless communication network for monitoring application. If the slave node doesn’t respond then the network search time is incremented and trial counter is incremented. If number of trials is completed then the master node goes into the power saver mode and puts the radio into sleep mode. The master has a wakeup counter to wake up the radio and start the new search to establish the WSN.

5.8. Event based algorithm with Periodic Sleep and Communicate Mode

The event based algorithm is an energy efficient algorithm by configuring periodic sleep and communicate method, the RF radio is put to sleep and periodically the radio is made to wake and transmit the data to master thereby minimizing the power consumption and increasing the WN life time.

Figure 7 shows the logic flow diagram of event based algorithm with periodic wake up and communicate mode. In this algorithm certain events are initially configured before deployment in the EH monitoring system by setting up the battery threshold levels for certain types of events. When the events occur in the node or the node sleep time is finished the monitoring node sends a wake up command to the RF module and establishes the wireless communication to notify the monitoring status of EH System to the master. Thus by increasing the sleep time of the slave node and wakeup the RF slave node on event minimizes the energy consumption that is required for data communication.
5.9. Remote Configuration Capability

The Master can configure the slave node remotely to set the upper and lower limit threshold parameters of the EH system for monitoring purposes, if the data sensed by the monitoring unit is out of the limit it triggers the alarm.
Monitoring and Configuration of Energy Harvesting System Using WSN

6. IMPLEMENTATION

Figure 6 shows the logic flow of the remote configuration of EH system over master, the slave receives and decodes the configuration parameters, and then sends a command to the monitoring unit to update the new monitoring configuration parameter of the EH system. The monitoring unit then updates with the new parameters and starts monitoring. This design eliminates the manually updating monitoring parameters and also minimizes the cost involved for manual work.

Figure 7 shows the hardware prototype setup for WSN for monitoring and configuration EH System. The following are steps are initiated for monitoring the EH System over WSN
(a) Monitor the EH System Continuously
(b) Upon monitoring data request from master node pack the monitoring data in MAC frame and Transmit
(c) Master receives the monitoring data, decode and present the monitoring parameter of the EH System to user over host HyperTerminal
(d) Monitor the data on Hyper Terminal for over charge alert and initiate corrective measure to minimize the damage to the storage devices

7. RESULTS

The Figure 8 shows the monitoring of EH system over WSN. The master sends a request to the monitoring slave and the slave nodes send the data of the battery voltage of the energy harvest device. This enables to monitor the energy stored in the harvesting devices and also enables better utilization of other system to utilize the harvested energy.
8. MONITORING ANALYSIS

To demonstrate WSN for monitoring EH system, the experiment has been set up using monitoring unit, slave node and master node using Zigbee modules and the experiment had been carried out on a sunny day using a solar panel that outputs 18 volts with constant current not exceeding more than 1200mA and Li-ion battery had been used as EH storage device. The EH system data is captured by the monitoring unit and the master request the data at every three minutes form slave and logged for future analysis. The battery characteristic graph below shows the monitoring data collected from EH system over WN the resulting 60 minute for charging and 66 minutes for discharge at different constant discharge currents and the variation of voltage with respect to time is obtained and discussed.

8.1. Monitoring of Storage Device during Energy Harvesting

To determine the time required to fully charge / state of charge, two trials have been conducted one is with
load and other is without the load connected to the EH system and the graph is plotted for monitoring data that is collected over WN from EH system for the resulting 60-minute charge time. From the Figure 10 it can be observed that the voltage of the battery increases with the time. When the load is connected the time required to charge increases compared to that without the load.

![Figure 10: Battery Characteristics while Harvesting the Energy](image)

8.2. Monitoring of Storage Device during Discharging

Figure 11 gives the variation of voltage in battery with time when the battery is discharged at a constant current of 800mA and 1A. From the characteristics Figure 11 it is seen that the terminal voltage of the battery decreases with time till a certain voltage. The battery is considered to be depleted fully when the terminal voltage reaches 6200mV.

The experiment shows that when higher load is connected and the load is kept continuously active results in decrease in battery life time and upon completely depleted the load becomes inactive.

![Figure 11: Battery Characteristic During Discharge](image)

9. CONCLUSION

The proposed method provides low power monitoring unit, master and slave nodes for monitoring of EH system by establishing the communication between master-slave over WSN with an easy to install and setup the monitoring of EH system. The monitoring system provides reliable measurements in a periodic time interval and the system provides remote configuration capability that is capable to configure EH system to provide over charged / discharge alert to minimize the damage to the EH storage devices and also reduces the man power and cost required to set the EH system threshold limit manually. To assure efficient working operation of monitoring unit over WSN allows remote configuration capability to put
the monitoring unit in low power mode to extend the life of the monitoring system / slave node. Further improved by
(a) Multiple numbers of master/slave nodes can be used for better performance.
(b) This monitoring alert can be further enhanced to have a graphical user interface over internet to monitor all system parameters online.
(c) The system can be made still energy efficient with the use of path selection or cluster head selection algorithm to increase the WN life time

REFERENCES

K.V. Narayanaswamy received his Bachelor and Post graduate degree in Electrical Engineering from Bangalore University, and Ph.D degree in Electrical & Electronics Engineering, Specialised in Wireless Communications and Networks from Visvesvaraya Technological University, Belgaum, Karnataka, India. He has more than 22 Years of Teaching & Research experience in the field of Electrical, Electronics & Telecommunication Engineering. His research interests are in the areas of next-generation wireless communication and networks, Mobile Ad-hoc & wireless sensor networks, Advanced optical network design, automotive communication protocols and standards. Carried several research, consultancy and funded projects. Delivered number of corporate trainings in India and abroad, Published more than 16 papers in peer reviewed international journals including IEEE, IJCA, etc., and several conference papers.