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FPGA Based Remote Monitoring System in Smart Grids

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Abstract

Objectives: Continuous monitoring and automation of the system is required for improving the efficiency and safety of the grid. This paper implements a remote monitoring system for smart grids using Field Programmable Gate Array (FPGA) based Wireless Sensor Networks (WSN). **Methods:** A wireless data logging system which monitors current, voltage and frequency of a micro grid prototype including grid, wind and solar is designed and implemented. The data is acquired and sent wirelessly to a personal computer. **Findings:** The experimental results show that the measured parameters match the rated quantities of the miniature smart grid. The calibrated module along with the wireless node communicates the monitored parameters to the base station at periodic intervals. **Applications:** Presently, wind and solar power generators are available in small ratings and this has created a new revolution in the field of energy production and distribution. So there is a need for determining the various parameters such as voltage and current of these small scale generators simultaneously for the purpose of monitoring and analysis.

Keywords: FPGA, Remote Monitoring, Smart Grid, Wireless Sensor Networks

1. Introduction

The Smart grid is a technology that makes electric grid control, automate and manage the growing demands and needs of electricity, allowing two-way communication between the utility and the customers. Smart grid improves power quality, provides efficient transmission, quicker rerouting when equipment fails or when outages occur and reduces peak demand. An essential feature of a smart grid is to improve the efficiency, economics, and sustainability of the generation, transmission, and distribution of electricity by the use of information and communications technology. The smart grid, being a vast system, utilizes various communications and networking technologies with its applications, which include both wired and wireless communications. Short range wireless communication technologies such as WiFi and ZigBeeare used in smart grid applications, such as in Home Area Networks. Various other networks such as Neighborhood Area Network (NAN) and Wide Area Network (WAN) are available for communication purposes[1–7].

Operating conditions, signal interference, noise levels and vibrations are the major challenges faced in data transmission in communication networks. The technologies currently used in smart grids are GSM (Global System for Mobile communications), GPRS, 3G, WiMAX, PLC, Zigbee etc. Zig-Bee is relatively low in power usage, data rate, complexity, and cost of deployment. It is suitable for smart home and smart metering applications[8,9]. ZigBee, an IEEE 802.15.4 standard, has emerged as a communication and networking standard to meet the requirements of WSN. It is a low power, low data-rate, fault tolerant, scalable short range wireless protocol suitable for personal area network and peer-to-peer networks[10,11].

Advancement in integrated circuits technology, sensors technology and wireless communication have seen new developments in use of wireless sensor networks for smart grids. As these sensor networks require effec-

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tive integration, onboard processing, and less power consumption, field programmable gate arrays (FPGAs) appear to be the suitable technology that provides an optimal balance between performance, power requirements and flexibility. FPGA gives the flexibility of reprogramming and have high level parallelism[12–14].

This paper presents architecture for WSN based remote monitoring system implemented using FPGA for smart grids. Zigbee is used as the mode of communication protocol. A sensing module is designed and implemented to measure the line parameters and transmit the information to a central monitoring system wirelessly. This smart-grid prototype with wireless sensor networks can be implemented for a real time substation and the customer nodes for a safe and reliable operation.

Section 2 of the paper describes the wireless sensor node based monitoring system, section 3 presents the proposed FPGA based sensor nodes, section 4 discusses the hardware details and implementation results and section 5 concludes the paper.

2. WSN based Monitoring System

The miniature smart grid prototype[15] as shown in Figure 1, consisting of ac grid, solar node and wind turbine node is used for data acquisition. Solar node in the system measures the line parameters from the solar panel. The wind energy node, located at the generation side of the micro-grid monitors the parameters such as voltage and current. Each node in the setup consists of Current Transducer, Voltage Transducer and circuit for frequency measurement. Total of 8 such sensor nodes are used to showcase the wireless sensor network. The acquired data is sent to the central station, which monitors the data in real time.

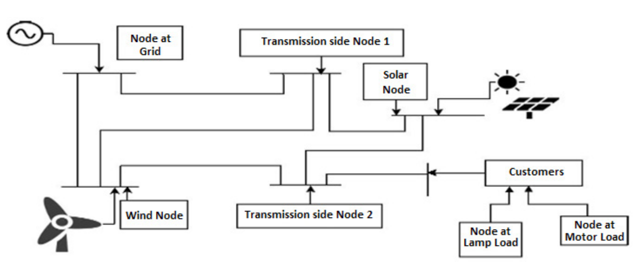

Figure 1. Miniature smart grid prototype.

The acquired data from the miniature smart grid prototype are sent to the server or coordinator node using wireless node. This node uses ZigBee modules and GSM modules for wireless communications. The system includes data acquisition from 6 Real-Time Data Collection Units (RTDCU). Each node is capable of sensing the signal, processing and transmitting the data wirelessly. All the nodes are interconnected using wireless Zigbee and GSM modules. Zigbee networks are used for close range communications and GSM module has been used for long range communication process. This sensor node is located at the transmission side of the developed micro-grid. The acquired electrical parameters are sent to the server, at periodic intervals.

A star topology prototype consists of a central computer developed for customer side load management which transmits data to the other nodes. This node serves as the hub and the interconnection between the nodes are done wirelessly. The system shown in Figure 2, consists of 4 nodes in which 3 nodes are termed end devices(slaves) and one of them termed the coordinator (master). The end devices acquire the line parameters from all the 3 nodes and the data acquired is transmitted wirelessly using ZigBee module. The coordinator receives data from all the end devices at the same instant and communicates with the main server.

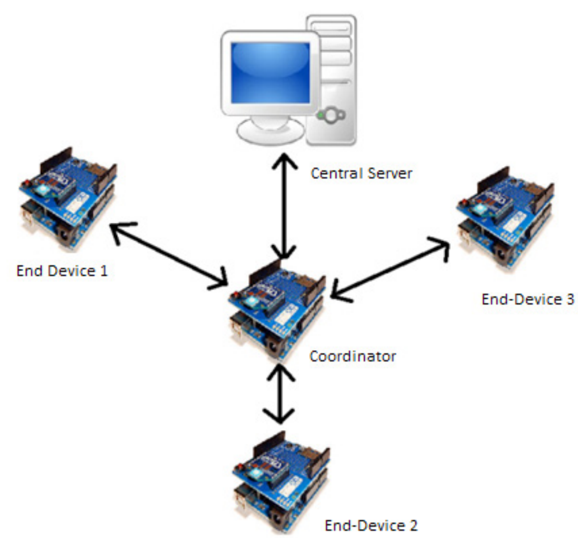

Figure 2. Star Topology of the remote monitoring system.

3. FPGA based Sensor Node

The modular architecture of FPGA based remote monitoring system using WSN is shown in Figure 3. The main function of the sensor node is sensing, processing and communication tasks.

Sensor board consists of transducers, signal conditioning circuit and ADC to acquire the required parameters.

The sensor node, shown in Figure 4, consists of sensors with both analog and digital interfaces. Signals from analog sensors are connected to A/D converter and the signals from digital circuit are directly connected to the FPGA.The output of the analog sensors will be accompanied with unwanted distortions and are conditioned using Op-amp circuits with appropriate gain adjustments. Zero Crossing Detector (ZCD) is used to determine the frequency of the system, by counting the generated pulse and this being a digital signal is connected to the FPGA directly.

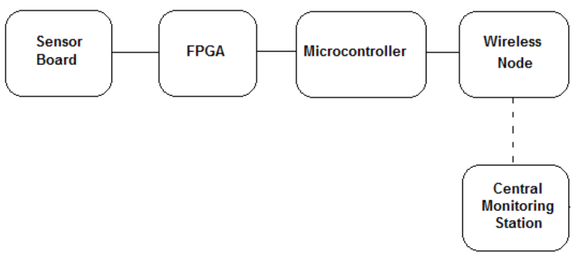

Figure 3. FPGA based sensor node.

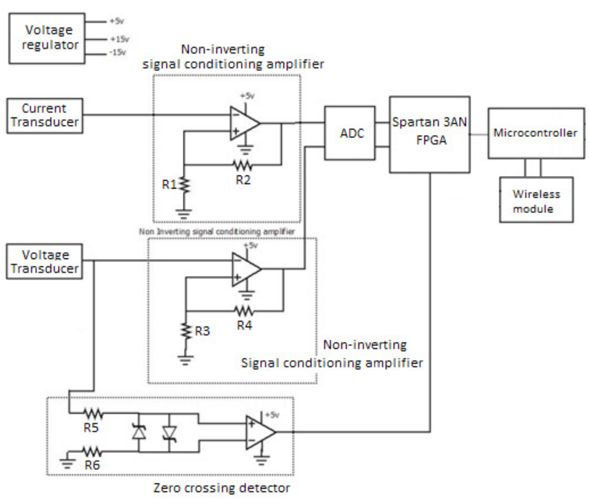

Figure 4. Block diagram of individual sensor node.

The acquired signals conditioned for noise removal, processed and converted to digital form are handled in FPGA. The FPGA sends results of the measured parameters in 16-bits, thereby acting as a reconfigurable coprocessor for the microcontroller. The microcontroller transmits the data stream to the central monitoring station by IEEE 802.15.4 standard ZigBee.

The ZigBee module is connected to the microcontroller serial port. Searching of neighbour sensor nodes, establishing and breaking links, and managing all the tasks within the network are controlled by sending commands to the ZigBee module. The microcontroller sends commands to the ZigBee module to manage the communications and also interprets commands from the ZigBee module and other network sensor nodes.

4. Implementation Results and Discussion

A completely wireless smart grid network, consisting of 6 nodes are designed, implemented and tested for real time on a single phase load. Spartan 3AN FPGA is used to implement the sensor node and MSP430F5438 microcontroller with Zigbee is used for wireless communication between the sensor nodes and central controller. Sensor node is designed with current transducer LEM LA-25 and voltage transducer LEM LV-20 for current and voltage measurements respectively. All wireless nodes are designed with Xilinx XC3S50Spartan 3AN FPGA, a Texas Instruments MSP430microcontroller and a CC2420 ZigBee module for wireless communication. The synchronous peripheral interface (SPI) module of MSP430 is used for communication with the ZigBee module CC2420.The CC2420 is IEEE 802.15.4 standard and has a transfer rate of up to 250 kbps.

After acquiring the voltages, and currents, the data are converted to digital form using two channel ADC MCP3202 and sent to FPGA. SPI bus is used to interface FPGA with ADC. Spartan3AN is the master and the MCP3202 is slave on the bus. The measured parameters are sent to the microcontroller in a specific format of 16-bits and are transmitted to the central monitoring station. The implemented prototype of smart grid with FPGA based wireless sensor node is shown in Figure 5.

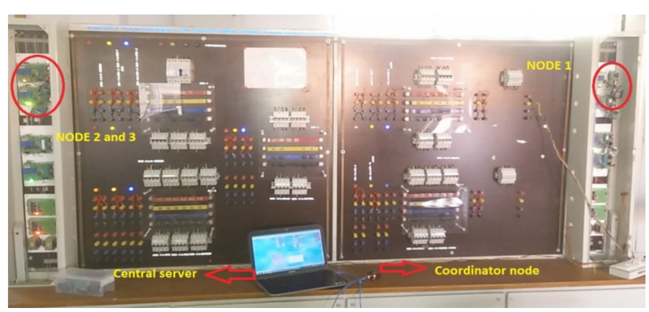

Figure 5. Smart grid prototype with FPGA based wireless sensor nodes.

The data logging graphical user interface is developed using LabVIEW for monitoring the real time values. The parameters are measured through the developed system and monitored in central station. The values are received in real time at periodic intervals and are verified with manual measurements.

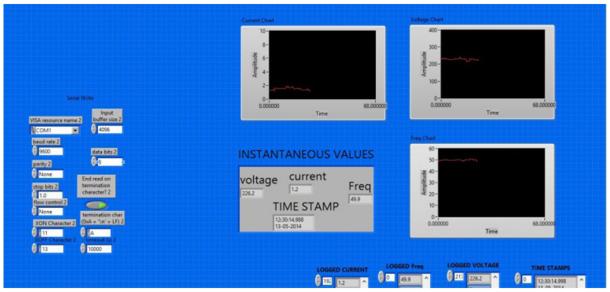

Figure 6. User interface at Central monitoring unit.

The user interface developed for monitoring is shown in Figure 6. The system was able to log the data continuously. However, there is one limitation with the system. The nodes must be within a range of 30m of the base station computer so that the Zigbee module is able to receive the values. To extend the range multi-hop wireless network architecture needs to be used.

5. Conclusion

FPGAs have emerged as a technology that strikes an optimal balance between processing power, energy requirements, and flexibility. In this paper, an implementation of remote monitoring system for smart grids using FPGA based wireless sensor network technology has been implemented. A prototype for wireless sensing module with FPGA coprocessors was designed and implemented for monitoring line parameters. The sensor node is programmable using low power FPGA and a microcontroller. The experimentation results show that the measured parameter matches the rated parameters in the smart grid hardware prototype. The calibrated sensing module along with the WSN node communicated the monitored parameters to the central server at periodic intervals. By implementing the sensor node in FPGA, even complicated tasks can be performed on a sensor node and dynamic configurable wireless sensor network system can be implemented.

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