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An Efficient System to Measure and Monitor Voltage in Smart Grid using Zigbee Based Sensor Network

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Abstract

Smart grid is a modified model of the electric power system that aid full duplex communication between the utility and customers. Communication in a smart grid can be improved by advanced measuring and monitoring system through a simpler and cost-effective low power Zigbee based sensor network. This paper presents the architecture and design of an efficient Zigbee based wireless communication system that measures and monitors voltage in a smart grid and shows that the sent data can be received at less time delay compared to other wireless devices. Zigbee has been particularly chosen to monitor smart grid system due to its less latency and duty cycle, high data reliability and low power consumption.

Keywords: *Wireless Sensor Networks, SCADA Systems, Smart Grid, Zigbee, Monitoring*

I. Introduction

With the rapidly developing population, the current electrical power grid suffers from effective communication, monitoring and advanced automation. Tending to these difficulties, another idea of next-generation electric power system has developed which is known as smart grid (SG) (V. C. Gungor *et al.*, 2010).SG is a concept for transforming the electric power grid by utilizing advanced automatic control and communications techniques and other forms of information technology. This concept incorporates energy infrastructure, processes, devices, information and markets into a coordinated and collaborative method which allows energy to be generated, distributed and consumed more effectively and efficiently(C. Cecati *et al*., 2010).

Traditional power grids are generally used to carry power from a few central generators to a large number of distribution networks. The power-system monitoring and diagnostic systems have typically been realized through wired communications. For the present SCADA system, comparatively expensive measuring and communication cables are required to be installed and regularly maintained and thus, they are not widely implemented today because of the older technology and implementation of higher cost. Addressing these challenges, in this paper, a cost-effective, low power Zigbee network-based monitoring of power system parameters (e.g. line voltage) for smart grid is developed and tested. Zigbee (over IEEE 802.15.4) is developed for wireless communication technologies which ensure relatively low power usage, data rate, complexity, long lifetime and minimum cost of deployment.

Fig. 1 describes a conceptual block diagram of the proposed system where voltage can be measured and the data could be sent to SCADA control room.

II. Concept of Zigbee Network

Zigbee is an ideal technology for smart energy monitoring, home automation and automatic meter reading system. Zigbee provides self-organized, multi-hop, and reliable mesh networking along with long battery life. A Zigbee network layer allows a cluster tree, self-healing mesh network, or star topologies, whereby the network gateway and the M2M devices can be flexibly configured. Furthermore, Zigbee devices may take only milliseconds to exit their sleep states compared to Bluetooth or Wi-Fi devices.

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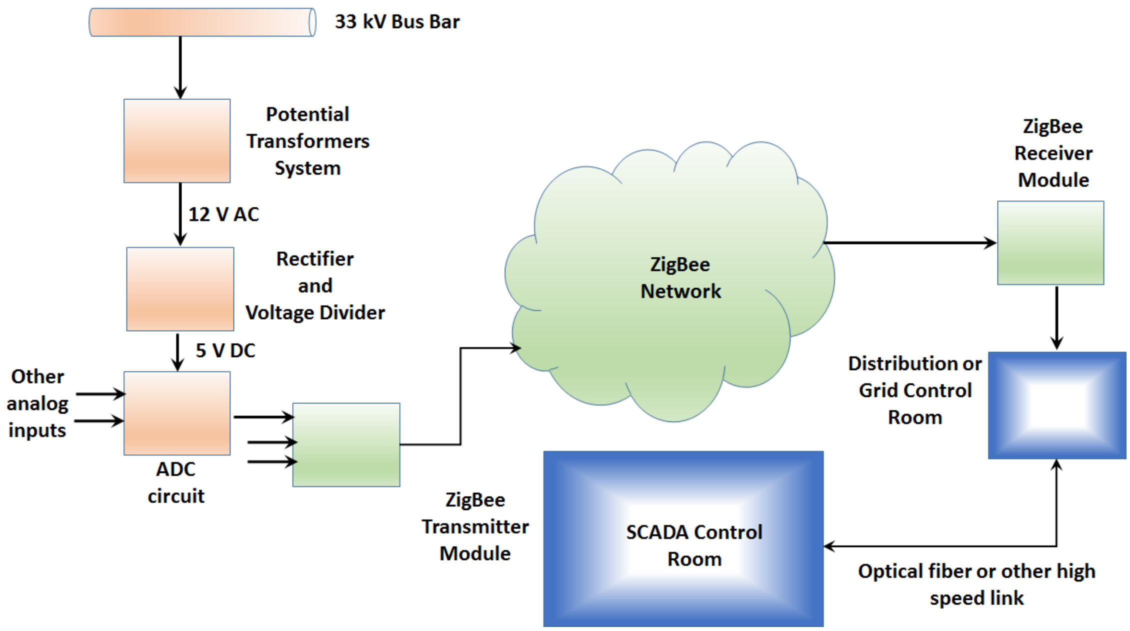

Figure 1: Block diagram of the proposed Zigbee based system of smart grid system parameter

Indeed, Zigbee provides a decent communication range of 10 to 100 meters while maintaining significantly low power requirement (1 to 100 mW) and thereby, lowers cost and typically operates in the personal operating space (POS) of 10m (Z. M. Fadlullah *et al*., 2011).

There are two different device types which can participate in an LR-WPAN network: a full-function device (FFD) and a reduced-function devices (RFD). The FFD has three modes of operations- serving as a PAN coordinator, a coordinator, or a device. An FFD can communicate with RFDs or other FFDs, while an RFD can communicate only with an FFD. An RFD is designed for applications that are extremely simple, such as a light switch or a passive infrared sensor. They do not require to send large amounts of data and may only associate with a single FFD at a time. Therefore, the RFD can be implemented using minimal resources and memory capacity. After an FFD is activated for the first time, it may establish its own network and becomes the PAN coordinator. All-star networks can operate independently from all other star networks which are currently in operation. This is achieved by selecting a PAN identifier, which is not currently utilized by any other network within the radio sphere of influence. Once the PAN identifier is chosen, the PAN coordinator can permit other devices to join its network. An RFD may connect to a cluster tree network as a leave node at the end of a branch, because it may only link with one FFD at a time. Any of the FFDs may function as a coordinator and provide synchronization services to other devices or other coordinators. Only one of these coordinators can be the overall PAN coordinator, which may have greater computational resources than any other device in the PAN (J.S. Lee *et al*., 2007).

A. Advantages of Zigbee Network

Zigbee has 16 channels in the 2.4 GHz band, each contains 5 MHz of bandwidth. The maximum allowed output power is 0 dBm (1 MW) in Zigbee with a transmission range between 1 and 100 m. 2.4 GHz Zigbee uses OQPSK modulation with a sampling rate 250 Kb/s. It has a good efficiency for data size smaller than 102 bytes. Zigbee is considered as a good option for metering and energy management and ideal for SG wireless monitoring due to its simplicity, mobility, robustness, low bandwidth requirements, and low cost of deployment, operation within an unlicensed spectrum, and easy network implementation.

In (A. Y. Mulla *et al*., 2014) power consumption scenario is analyzed for HAN, NAN and WAN for 802.11, 802.15.1 and 802.15.4 and for every case it is clearly seen that 802.15.4 standard consumes less power than other standards.

B. Disadvantages of Zigbee Network

There are some limitations of Zigbee for practical implementations, such as low processing capabilities, small memory size, small delay requirements and being subject to interference with other appliances that share the same transmission medium, license-free industrial, scientific and medical (ISM) frequency band ranging from IEEE 802.11 wireless local area networks (WLANs), Wi-Fi, Bluetooth and Microwave. Hence, these concerns about the robustness of Zigbee under noise conditions increase the possibility of corrupting the entire communications channel due to the interference of 802.11/b/g in the vicinity of Zigbee. Interference detection and avoidance schemes and energy-efficient routing protocols should be implemented in order to increase the network lifetime and provide reliable and energy- efficient network performance (V. C. Gungor *et.al*., 2011).

III. Zigbee Related Research Work on Smart Grid

Zigbee for SG application is presented in (A. Y. Mulla *et.al*., 2014) where a comparative analysis of power consumption with other standard technologies, for example, Wi-Fi & Bluetooth technologies, is focused. Zigbee topologies that support the case study applications are proposed and performance for each is assessed. In (S.W. Luan *et al*., 2009) the new wireless communication technologies to design and implement a Zigbee-based smart power meter are described. An outage recording system is designed and implemented into the smart meter. The Zigbee technology is used to transmit the detailed power consumption information and outage event data to rear-end processing system. The system can possibly be utilized to manufacture the area based AMI. Test results described in (S.W. Luan *et al*., 2009) showed the legitimacy of the proposed system. The application of Zigbee communication in SG network may, expectedly, prompt to make a distinct contribution to ubiquitous IT project. In (Q. Zhang *et al*., 2010), the applications of Zigbee technology for SG were analyzed aiming at the requirement for monitoring and controlling purposes of SG system such as HAN, fault locating and UHV transmission lines monitoring. In (N. Javaid *et al*., 2012) power utilization, power organizing and power controlling architecture for power saving purpose are discussed and also the role of Zigbee in transmission line monitoring, real time meter reading and direct load controlling of electric home appliances are analyzed. A new geometric structure to improve the formation of large scale Zigbee network and its performance is studied in (J. H. Biddut *et al*., 2015). The author in (J. H. Biddut *et al*., 2015) claimed that the study will create a new opportunity to establish a reliable large-scale Zigbee network.

The communications protocol to be used in SG is analyzed in (A. R. Arias *et al*., 2014). The study mentioned in (A. R. Arias *et al*., 2014) determined the distances where a satisfactory communications response was found, which are within the typical range of distances in distribution systems, resulting in the conclusion that the Zigbee technology can be a good option for SG uses.

In a paper by A. Varghese *et al*., 2015, the communication requirements for observing energy transmission in SG by wireless enabled overhead line sensors and the feasibility of using Zigbee communication for the overhead line monitoring application is studied. The description in (A. Varghese *et al*., 2015) exhibits an analysis on the effective throughput available when using Zigbee for the fault detection application, and determines the maximum sampling rate that the Zigbee communication link can support. In (A. Varghese *et al*., 2015), the results from the theoretical analysis are also compared with lab experiments to show that Zigbee is a feasible technology for overhead line fault monitoring for the planned infrastructure. The reliability of Zigbee-based wireless sensor networks in transforming existing power systems into future SG is investigated and presented in (F. M. Sallabi *et al*., 2014).

IV. Security Issues in Smart Grid

Power system is a very complex interconnected network (Z. Lu *et al*., 2010). It is always necessary to up-grade the present grid system to increase the overall system efficiency and reliability. For extremely large, wide area communication networks the access and communications capabilities require the latest and proven security technology (A. R. Metke *et al*., 2010). From current power systems the SG will further introduce millions of in intelligent computing components that can communicate in much more advanced ways e.g. two- way communication (The Smart Grid Interoperability Panel, 2010). As such, how to address networking security issues is critically important in the design of communication networks for the SG. Potential networking intrusion caused by potential attackers may lead to leakage of customer's information or create massive failures such as power outages and destruction of infrastructures. (Z. Lu *et al*., 2010).

The design of communication networks that are robust to attacks targeting network availability must be a top priority, since network unavailability may result in the loss of real-time monitoring of critical power infrastructure and possible global power system disasters (Z. Lu *et al*., 2010). To address these issues and to satisfy a wide range of applications, Zigbee offers two network architectures and corresponding security models-distributed and centralized. Zigbee security is based on symmetric-key cryptography which means two parties must share the same key to communicate with each other. Zigbee uses highly secured 128-bit AES (Advanced Encryption Standard) based encryption system which meets not only confidentiality, but also low-power requirement, low complexity, and low-cost.

V. Experimental Setup

For testing purpose of a Zigbee based measurement system, first 220V single phase line voltage is stepped down using a transformer. The reduced voltage level is then connected to a bridge rectifier circuit. A linear potentiometer is used in the circuit for changing the output DC voltage level by varying the POT. The DC voltage level is approximately around 17-20V when the POT RV1 (Fig. 2) is in maximum position.

An XBee module was connected to the microcontroller of the arduino board in order to transmit the AD converted data wirelessly to receiving side where another XBee module was connected with a laptop (Fig. 3). The received data values were monitored in the laptop through Xctu. Xctu software is used for data monitoring purposes in both transmitting and receiving cases.

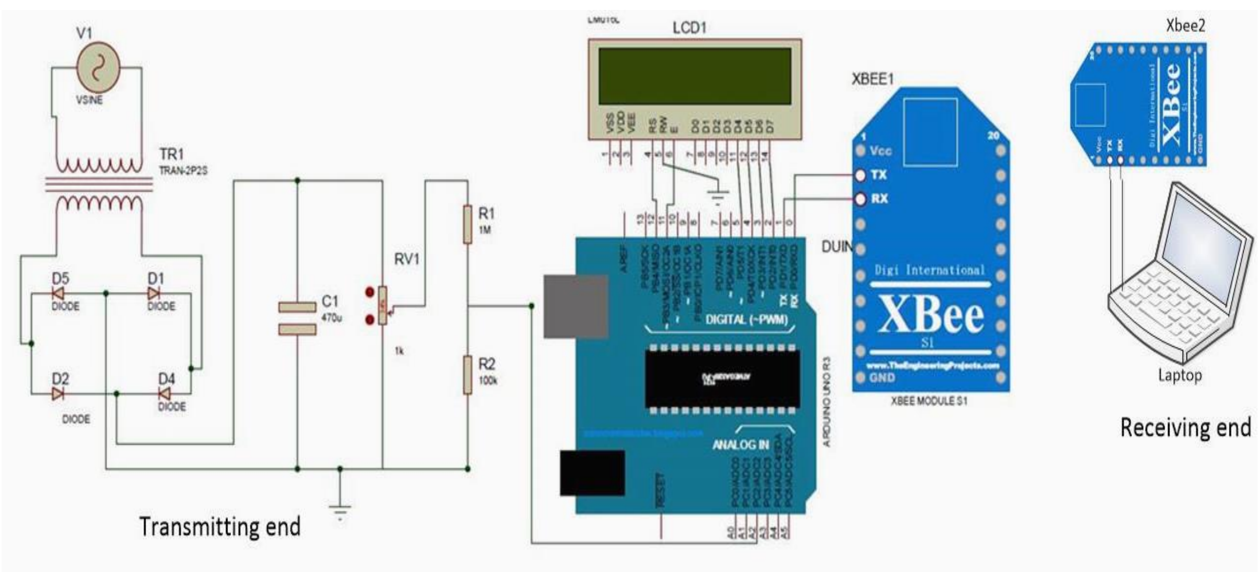

Figure 2: Schematic of experimental setup.

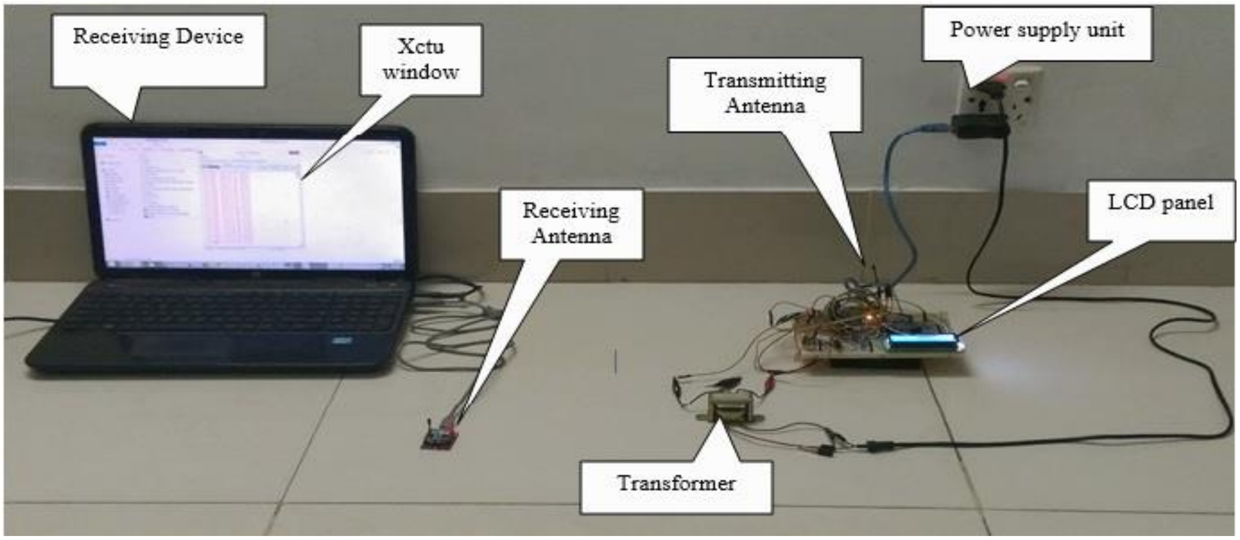

Figure 3: Setup for Zigbee based voltage measurement system

VI. Experimentation and Analysis

The main objective was to develop a prototype system for measuring and monitoring a line voltage wirelessly using Zigbee. Fig. 4 shows the measured input voltage and Fig. 5 shows the output voltage seen in Zigbee. In fig. 6, line voltage versus time plot for input and received output is shown. The input line voltage values may contain noises and interferences due to setup but the received voltage is the same as input voltage. Therefore, our research group has investigated some algorithms for the regeneration of the actual system voltage and minimized time delay. Here, the time delay is 17 ms which is less than other wireless devices.

```
12 VAC
Line Voltage=241 volts
Divider Volt=1.20 volts
Load Voltage=13.32 V
T = 66.89*C
Initializing AES128...
Key:
000102030405060708090A0B0C0D0E0F
Unencrypted data:
0112
Encrypted data:
FFFFFFFEFFFFFFC3
Back decrypted data:
0112
11 VAC
Line Voltage=235 volts
Divider Volt=1.20 volts
Load Voltage=13.52 V
T = 67.87*C
```

Fig. 4: Measured input voltage

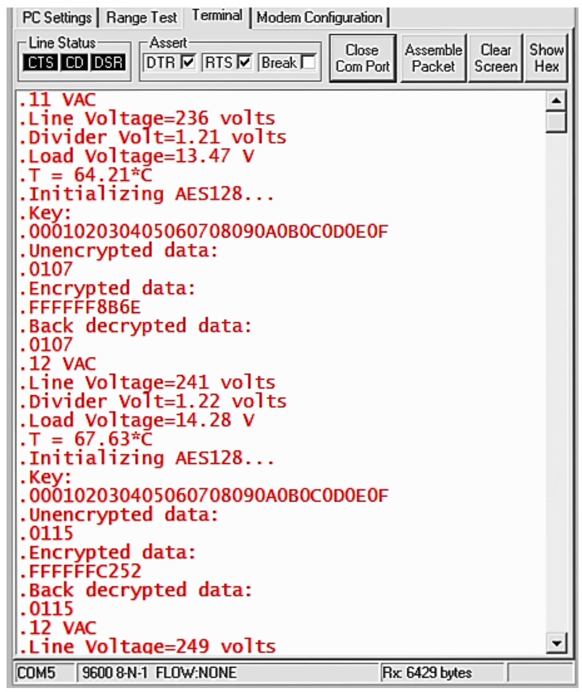

Figure 5: Received voltages via Zigbee

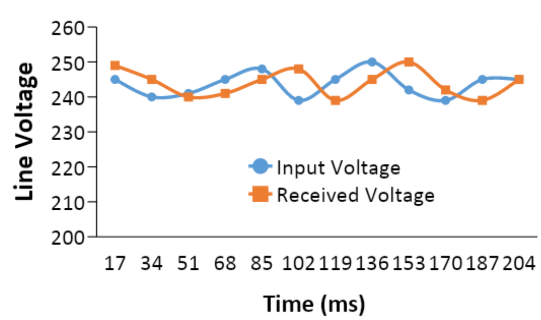

Figure 6: Input vs. received voltage

VII. Conclusions

A prototype of Zigbee based monitoring system for smart grid has been developed and tested in this work. The experiment shows that the sent data is being received at the receiver end with less time delay compared to other wireless devices i.e. bluetooth. The wireless monitoring system described in this paper, using Zigbee technology follows the IEEE standard 802.15.4 and necessary security measures to minimize incoming threats. The proposed system can be implemented in SG-device for measuring and monitoring purposes.

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