Development of a Novel Fault Indicator for Distribution Automation

Shang-Wen Luan, Jen-Hao Teng, and Chao-Shun Chen

Abstract—**The paper develops and implements a novel fault indicator for distribution automation to achieve significant and immediate improvement in reliability and hence service to the electricity customers. The proposed fault indicator is designed based on ZigBee communication. ZigBee has been designed to possess general-purpose protocol with low cost, low power consumption and self networking; and therefore, it is very suitable for constructing the communication network in distribution automation and therefore smart grids in the future. A fault detection and identification system is also designed to find out the fault location effectively and efficiently after a fault occurred. Experimental results demonstrate the validity of the proposed system.**

Index Terms—**Fault indicator, Distribution automation, ZigBee, Smart gird.**

I. INTRODUCTION

Distribution networks are important parts of the total electrical supply system, as it provides the final link between the bulk transmission system and the customers. In order to improve service reliability, in many countries the concepts of distribution automation and smart grid has been applied to distribution networks to improve reliability and hence service to the electricity customers. Generally, distribution automation includes the functions of substation automation, feeder automation, automatic meter reading and automatic build-up of geographic information system and so on. The concept of smart grids which features higher utilization of power grid, demand reduction, and extensive usage of renewable energy source, is accepted and implemented all over the world recently. Smart grids are used to accomplish an advanced power system with automatic monitoring, diagnosing, and repairing functions [1-11].

Communication network deployment is one of the most import footstones for distribution automation, since it provides signal exchanges media between different devices installed in different locations. Recently, many governments deploy ubiquitous IT project, which aims to combine the latest wireless network and wide-band technologies etc. to accomplish a ubiquitous wireless communication network. There are many kinds of wireless network, and ZigBee, a low-speed LR-WPAN (Low-Rate Wireless Area Personal Network) based on IEEE 802.15.4 standard, is one of them. ZigBee has been designed to possess general-purpose protocol with low-cost and low-power- consumption wireless communication. The ZigBee application profile includes home automation, industrial plant monitoring, commercial building automation, automatic meter reading, telecom services/m-commerce, wireless sensor networks, personal home and hospital care and so on In power engineering applications, the use of wireless technology can profit distribution automations and smart grids by integrating ZigBee networks into Advanced Metering Infrastructure (AMI), fault monitoring, and the like [12-22].

Most of customer service interruptions are due to failures in distribution branches; however, distribution automation is mainly focused on distribution feeders. In distribution automation, the fault section can found out by protection equipment composed of supervisory control and data acquisition system, feeder remote terminal unit, remote terminal unit, feeder terminal unit, directional over-current device and so on. The protection devices cannot mount densely on the feeder due to the higher building cost. In order to improve reliability, some fault indicators with mechanical flag change or LED display flashing while over-current occurred are mounted on distribution branches instead. Although the fault indicators are useful, it needs the repairers along the distribution branches to check the mechanical flag change or LED display flashing to find out the fault location. Therefore, the paper integrates the ZigBee communication interface into the traditional fault indicators to reinforce their capability. A fault detection and identification system is also designed; thus, the fault location can be found out effectively and efficiently after a fault occurred. Experimental results demonstrate the validity of the proposed system.

II. NOVEL FAULT INDICATOR

Fig. 1 shows the hardware architecture of the proposed novel fault indicator. The novel fault indicator can be divided into three parts: fault current detecting module, ZigBee module and Micro-Controller Unit (MCU) module. The RF transceiver used in the ZigBee module is Microchip MRF24J40MB which is compatible with IEEE 802.15.4 Standard and has the transmitting range up to 4000 fts. The MRF24J40MB is a surface mount module composed of crystal, internal voltage regulator, matching circuitry, power amplifier, low noise amplifier and PCB antenna. The module operates in the non-licensed 2.4 GHz frequency band and is based on the Microchip Technology MRF24J40 IEEE 802.15.4™ 2.4 GHz RF Transceiver IC. The MRF24J40MB module interfaces to microcontrollers via a 4-wire serial SPI interface as shown in Fig. 2. The MRF24J40MB module has low-current consumption and the typical current

Manuscript received June 22, 2011; revised July 20, 2011.
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consumption in receiver mode, transmitter mode and sleep mode are 25 mA, 130 mA and 5 μA, respectively [23-25].

The MCU used in the MCU module is Microchip PIC18LF4620. The power-managed modes of PIC18LF4620 include run, idles and sleep modes and the current of each mode can down to 11 μA, 2.5 μA and 100 nA, respectively. The oscillator structure provides four crystal modes that can up to 40 MHz, 4x Phase Lock Loop (PLL), two external RC modes and two external clock modes etc. Peripheral highlights three programmable external interrupts, four input change interrupts, two capture/compare/PWM (CCP) modules, four PWM outputs with Programmable dead time, enhanced addressable USART module, 10-Bit, up to 13-channel Analog-to-Digital (A/D) converter module etc. Besides, the MCU features 10 MIPS performance, C compiler optimized RISC architecture, 8 x 8 single cycle hardware multiply and so on. Therefore, PIC18LF4620 is suitable to be used in industrial applications [26].

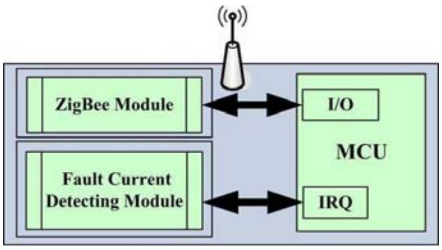

Fig. 1. Hardware Architecture of the Proposed Novel Fault Indicator

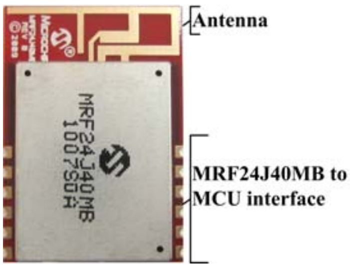

Fig. 2. MRF24J40MB Module

The fault current detecting module is composed of two magnetic reed switches and alarm LED. The magnetic reed switches with higher and lower rated interrupting currents, abbreviated as SW1 and SW2, are used to detect the abnormal and normal currents of a distribution branch, respectively. In general, the higher rated interrupting current is set approximately the rated short-circuit current, such as 1000A or 600A, of a distribution branch, and the lower rated interrupting current is set the minimum recovery current (12A as usual). Three modes can be categorized according to the status of these two magnetic reed switches:

Normal Mode: If the branch current which the proposed novel fault indicator mounted is smaller than the rated interrupting current of SW1, SW1 will remain OFF (open circuit) and the novel fault indicator is in the normal condition. Note that the status of SW2 can be ignored in the normal mode.

Fault Mode: When the branch current exceeds the rated interrupting current of SW1, SW1 will be ON (short circuit) and a fault occurred on the branch. The fault condition will be detected by the external interrupt of the MCU module for SW1 and the fault information including the branch number and location etc. will then be transmitted to the rear-end processing system by the wireless network constructed by the ZigBee modules. The MCU will also enable the alarm LED of the fault current detecting module and the external interrupt for SW2 and the fault indicator will return to repair mode.

Repair Mode: After fault occurred, the fault indicator will be in repair mode. While the fault has been clear completely or the power of this branch section has been restored, the branch current will be smaller than the rated interrupting current of SW1 and higher than the rated interrupting current of SW2, SW2 will be ON. The condition will be detected by the external interrupts of the MCU module for SW2 and then be transmitted to the rear-end processing system. The alarm LED will be turned off and the proposed novel fault indicator will return to normal mode.

The flowchart of different mode exchange is shown in Fig. 3.

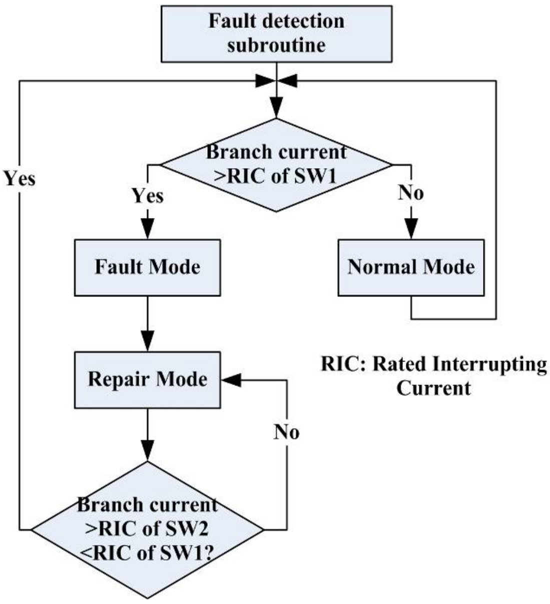

Fig. 3. Flowchart of Different Mode Exchange

III. FAULT DETECTION AND IDENTIFICATION SYSTEM

The concept of integrating the proposed ZigBee-Based novel fault indicators into developing a fault detection and identification system for distribution branches is shown in Fig. 4. The proposed fault detection and identification system are composed of several novel fault indicators and a rear-end processing system. Using Fig. 4 as an example, if a fault occurred on "Fault (1)", the fault current will be detect by fault indicators 2 and 3 and then these two indicators will be in "Fault Mode". Fault indicators 2 will transmit "Fault Information (2)" to fault indicators 3 which is acted as a router in this situation and then re-transmit "Fault Information (2)" to the rear-end processing system. Fault indicators 3 will also transmit "Fault Information (3)" to rear-end processing system. After the fault information are collected by the rear-end processing system completely, the fault location can be identified and displayed in the Human-Machine Interface (HMI) of Fig. 5.

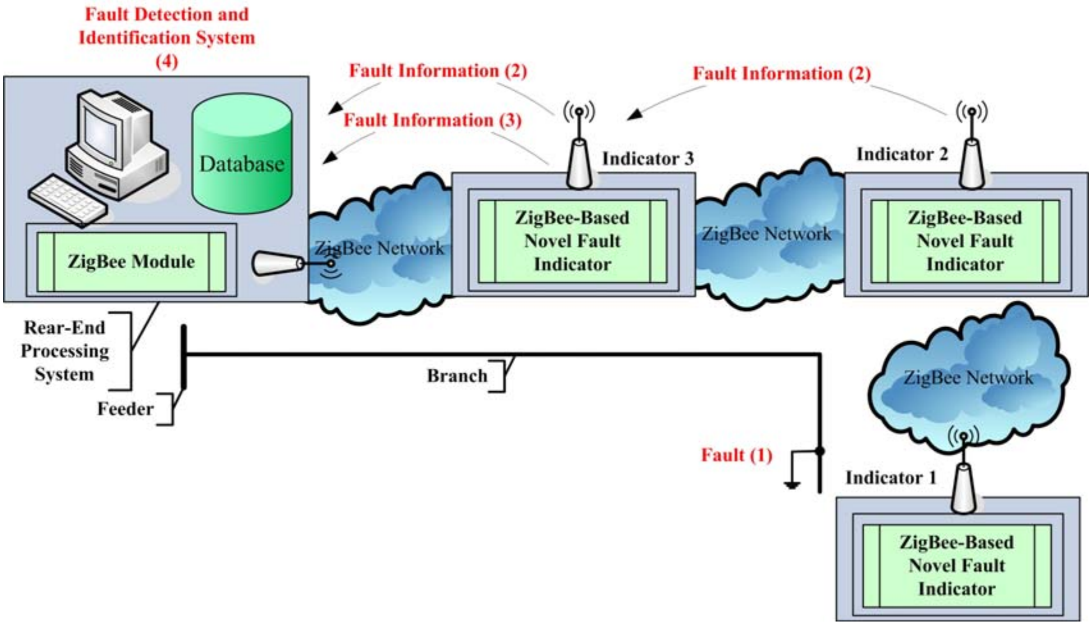

Fig. 4. Concept of the Fault Detection and Identification System

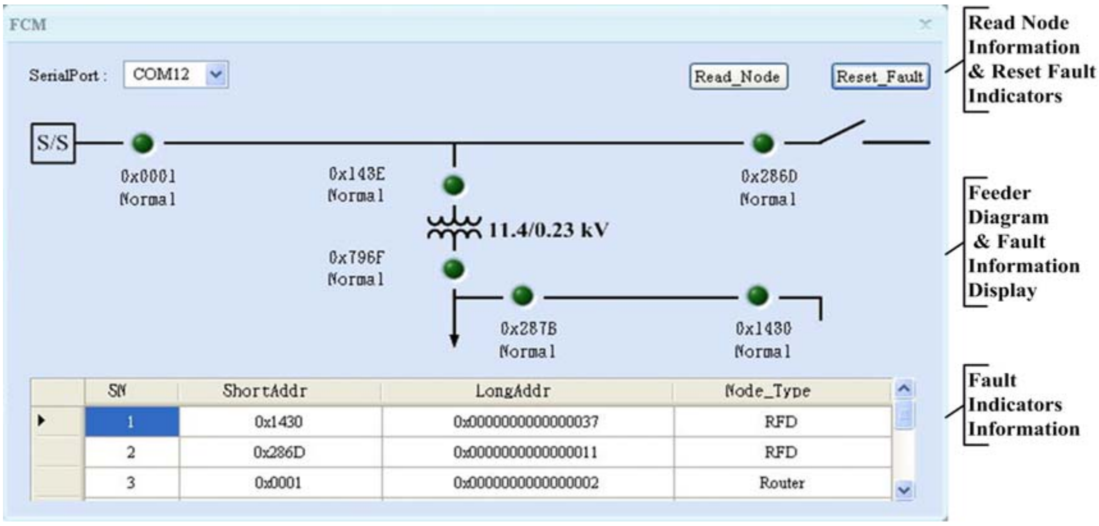

Fig. 5. HMI for the Fault Detection and Identification System

From Fig. 4, it can be seen that it is very important to construct the communication network by the proposed ZigBee-based novel fault indicators. ZigBee Alliance defines three device types for ZigBee network, ZigBee coordinator, ZigBee router and ZigBee end device. ZigBee coordinator and ZigBee router are Full Function Device (FFD), and ZigBee end device is Reduced Function Device (RFD). The FFD is capable of implementing the complete protocol set. The RFD is implemented using minimal resources and memory capacity and can only be used as end device. ZigBee network supports star, tree and mesh topologies. In a star topology, the network is controlled by one single device called the ZigBee coordinator. The ZigBee coordinator is responsible for initiating and maintaining the devices on the network. All other devices, known as end devices, directly communicate with the ZigBee coordinator. In mesh and tree topologies, the ZigBee coordinator is responsible for starting the network and for choosing certain key network parameters, but the network can be extended through the use of ZigBee routers. In tree networks, routers move data and control messages through the network using a hierarchical routing strategy. This paper employs the tree topology. In this paper, the rear-end processing system employs ZigBee coordinator to initiate, construct and maintenance the wireless network for the proposed fault detection and identification system. Other fault indicators employ routers or end devices as required. With the automatic networking characteristic of ZigBee, an novel fault indicator serving as a node will communicate with the ZigBee coordinator of rear-end processing system and then the ZigBee network can be constructed sequentially. After the ZigBee network was constructed, the proposed fault indicators can send the fault information to the ZigBee coordinator and then the information can be displayed on HMI. In order to make sure that the ZigBee network can cover the whole range of distribution branches, ZigBee router and ZigBee end device should be arranged and mounted on the branches carefully.

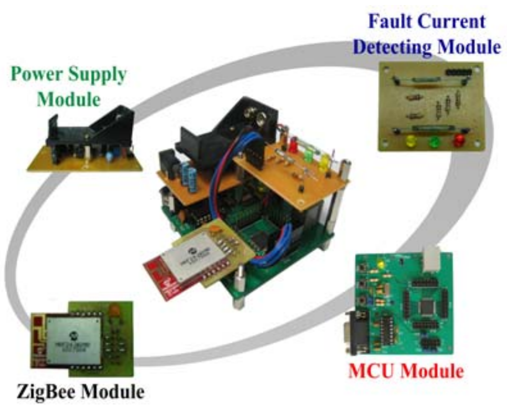

Fig. 6. Hardware Prototype of the Proposed Novel Fault Indicator

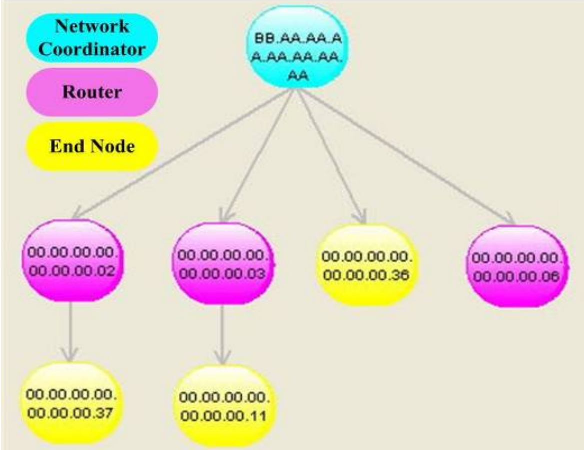

Fig. 7. ZigBee Network Topology of the Proposed System

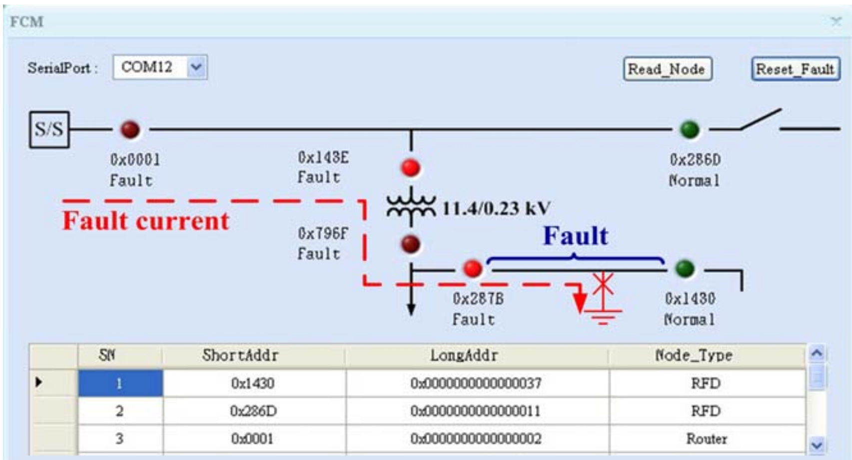

Fig. 8. Fault Information Display

IV. Experimental Results

The hardware prototype of the proposed novel fault indicator is shown in Fig. 6. The experimental branch with six novel fault indicators mounted is shown in Fig. 5. The types of ZigBee devices and their addresses for these six fault indicators are shown in Table 1. The ZigBee network topology is illustrated in Fig. 7. From Table 1 and Fig. 7, it can be seen that one coordinator, three routers and three end devices are used to deploy the ZigBee network. Distance between the ZigBee modules of short addresses 0x0000 (rear-end processing system) and 0x286D (fault indicator) exceeds the transmitting range of a single ZigBee RF transceiver and therefore a fault indicator with ZigBee router (short address 0x143E) is used to extend the transmitting range. The ZigBee network can cover the whole range of distribution branch.

When a fault occurred on the location between the "0x287B" and "0x1430", the fault current will flow from the substation to the fault location. Meanwhile, the fault indicators with short address "0x0001", "0x143E", "0x796F" and "0x287B" will detect the fault current and the fault information will be transmitted to the rear-end processing system immediately. The rear-end processing system can then display the fault information on the HMI of Fig. 8. From Fig. 8, it is can be seen that the fault location can be identified effectively and efficiently.

TABLE I: ZigBee Information of Novel Fault Indicators

Short Address	Long Address	Node type
0x0000	0xBBAAAAAAAAAAAAAA	Coordinator
0x0001	0x0000000000000002	Router
0x143E	0x0000000000000003	Router
0x286D	0x0000000000000011	End Node
0x796F	0x0000000000000036	End Node
0x287B	0x0000000000000006	Router
0x1430	0x0000000000000037	End Node

V. Conclusions

It is reported that most of customer service interruptions are due to failures in distribution branches; however, distribution automation is mainly focused on distribution feeders. Although some fault indicators are mounted on distribution branches, it needs the repairers along the distribution branches to check the mechanical flag change or LED display flashing to find out the fault location. The procedure is time-consuming. A novel fault indicator was designed and implemented in this paper. A fault detection and identification system was also designed to identify the fault location automatically and efficiently. Since the cost of the proposed novel fault indicator is low, it can be densely mounted on distribution branches to reduce the time for fault detection and identification.

ACKNOWLEDGMENT

This work was sponsored by National Science Council, Taiwan, under research grant NSC 100-3113-E-214 -001 - and NSC 99-3113-P-214 -001 -.

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