Mini – Substation Monitoring System

Devin King, John Blackburn, Steve Johnson, Anish Raj Pant

School of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — The objective of this project is to build a device that is self-contained unit providing substation monitoring and wireless communications that is designed to be easily installed or integrated into substations. The system also consists of a small, exterior mounted liquid crystal display (LCD) so real-time conditions of the substation can be observed. The exterior of the housing will also contain a light emitting diode (LED) incorporated with an audio alarm. A relay is also incorporated into the device to serve as a breaker should a fault condition occur.**

***Index Terms* — Microcontrollers, current sensor, voltage sensor, driver circuits, relays, voltage dividers.**

I. Introduction

As the world becomes increasing more dependent on electricity, the need for reliable power distribution has practically evolved into a necessity of life. For many Americans even a short-lived power outage feels like a major disaster. After all, how can we possibly expect to survive without air conditioners, televisions, computers, microwaves, refrigerators, stoves, and ovens? While that may seems like a disaster to many, imagine the impact that power outages have in other situations. How can retail locations conduct business without lights and without electricity to power their cash registers and computers? What does the daily commute turn into without traffic lights? How about factories, banks, and grocery stores? It seems as if the world comes to a stand-still without electricity.

To aid in successfully delivering continuous power to the consumer, our goal is to develop a substation monitoring device. This device consists of monitoring chips that can accurately measure current consumption and voltage across the output of the power substation and includes a protection relay to prevent damage or suspend further damage to the system. Information gathered by these devices are then automatically and wirelessly relayed to a computer containing user friendly interface software that displays the information graphically, computes trend information, and can even send email and text message alerts to warn of occurring fault conditions or a developing problem. The software can also be used to activate the protection relay manually from a remote location. All of these functions come in a small weather proof enclosure that can easily be retrofitted to any existing substation.

As substation monitors become more widely implemented, power outages and system down-time will be reduced, maintenance and repair costs will be kept to a minimum, and fault conditions can be more quickly recognized and located so that the system can be brought back on line in the shortest amount of time possible.

Why conduct remote substation monitoring? In the electric utility industry the distribution system reliability and operational efficiency is of the utmost importance. The increasing reliance on electrically based technology means that it is more important than ever that power system interruptions are kept to a minimum. Substation monitoring is crucial to reaching this goal. By implementing effective substation monitoring devices, the overall efficiency of power distribution can be maximized. For example, load monitoring allows the substation to deliver a maximal amount of power without out exceeding its limitations. Another advantage of power monitoring is to keep maintenance and repair costs to a minimum.

Our system draws on data from electronic sensors to accurately assess the condition and capacity of a transformer substation unit. Factors important to this achievement include monitoring changes in output current and voltage to evaluate transformer loading, providing information on current and impedance during operation to determine how the system protection circuitry is performing, as well as analyzing fault conditions. Monitoring all of these conditions allow power system personnel to develop trend data and improve reliability and performance. Automated early warning devices alert the user to developing fault conditions that could lead to equipment failures and power outages. This allows providers to remotely monitor substations saving on maintenance cost, manpower, and service down time.

II. System Components

A. Microcontroller

The microcontroller will be the most important component in our project. It will interact with most of the modules that will have to do with control; as to say, the main system, wireless system, and LCD. In order to get data converted, wireless data transmission and LCD display a microcontroller will have to be present for the functionality mentioned. The different type of microcontrollers for use on our project is overwhelming. The categories go from the number of pins to the type of architecture for that typical microcontroller. For our project we will use a 40-pin PIC microcontroller.

B. *Wireless communication*

Wireless interaction between the module and the host computer will play a big role in this project. In the wireless world there is an abundant amount of technology that is placed to our disposal. For this project however we find Zigbee to be a very appealing solution to interact our module and computer. Zigbee is different from other wireless protocols and standards because it is design to serve a variety of market applications that requires low cost and low power when compared to Wimax and wifi devices.

C. *Relay*

As we have described earlier, we want to be able control a circuit wirelessly from the computer. We want to use a small automatic relay that can be integrated inside the panel. The relay we will use in our project was provided by BCI tech with the proper specifications.

D. *Current Sensor*

For this project we are using a current transformer to measure current. This is the most commonly used current sensor in today's current energy meters. It is extremely useful when dealing with large currents or high voltage in the primary circuit. The current transformer allows the current to be stepped down so it is possible to directly apply measurement devices. This also allows the measurement device to be placed at a distance from the primary circuit keeping it away from what may be high voltages. Current transformers, like any other transformer, contains a primary winding, secondary winding, and a magnetic core.

E. *LCD*

The LCD is an important part of this project. This is the part that will relay information to the user. The LCD will display the power, current and voltage that are being transmitted from the substation. The overall status of the substation will also be shown in the LCD.

F. *Power Supply*

Many of the components in our project will have to be powered up to be able to work. For instance the LCD and the pic-microcontroller require 5V dc to operate, and the Xbee needs 3.3V dc. To obtain all these different voltages we decided to use a voltage transformer. The voltage transformer will step down the voltage, send it to a rectifier. The rectifier will convert the AC voltage to DC which in turn will be stepped down by a regulator before it goes to the component.

G. *SCADA*

SCADA (Supervisory Control and Data Acquisition). A monitoring system that is used for controlling and gathering data usually in an industrial setting has come to be known as SCADA. SCADA is used in many industries. Broken down, this is Supervisory Control and Data Acquisition. The term SCADA describes the entire system as a whole. A SCADA system is made up of many components that communicate together in order to monitor and control particular pieces of equipment or a type of station.

H. *Station Alarm*

Having several different methods of alarming the monitoring personnel of a substation is very important. A visual alarm is very useful when there are loud noises present in the surrounding environment. An audio alarm is also very useful when no visual contact of the substation is available and can make a powerful on site notification system. These two methods are among the most effective alarm systems and combined with one another creates a very convenient way to alert someone that a relay has been energized.

III. System Concept

The Mini-Substation Monitoring System will have various inputs and outputs, which can be seen below in

Figure 1: Mini-Substation Monitoring System Input/**Outputs**.

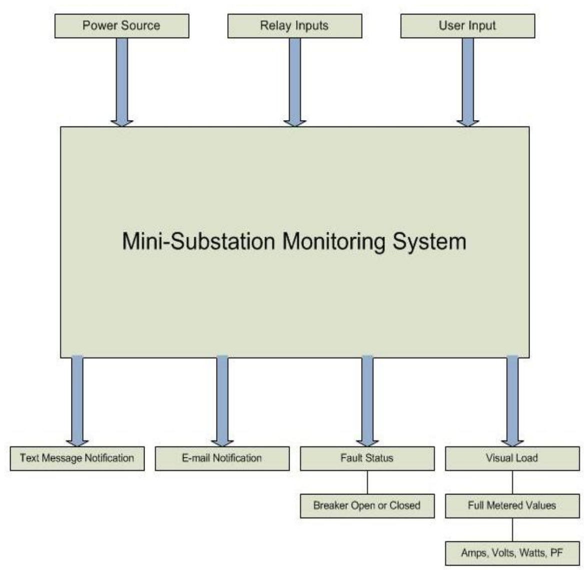

Figure 1: Mini-Substation Monitoring System Input/Outputs

Along the top there are three inputs to the system, a power source, relay inputs, user inputs. Shown along the bottom are the system outputs, which include text message notification, E-mail notification, fault status, full metered values (current, voltage, power, etc.).

There is more to this monitoring system then the inputs and outputs. The system contains a lot of components inside that build up to the big picture. The actual sub-station will contain components such as relays, integrated circuit chips, microcontrollers and many more as seen in **Error! Reference source not found.**. Then on the Laptop computer side there are a couple of things that are of great importance, which consist of the software, user interface, wireless communication with the station. These diagrams are only a basic interpretation of the system; much more detail will be discussed and shown in the upcoming sections of this paper.

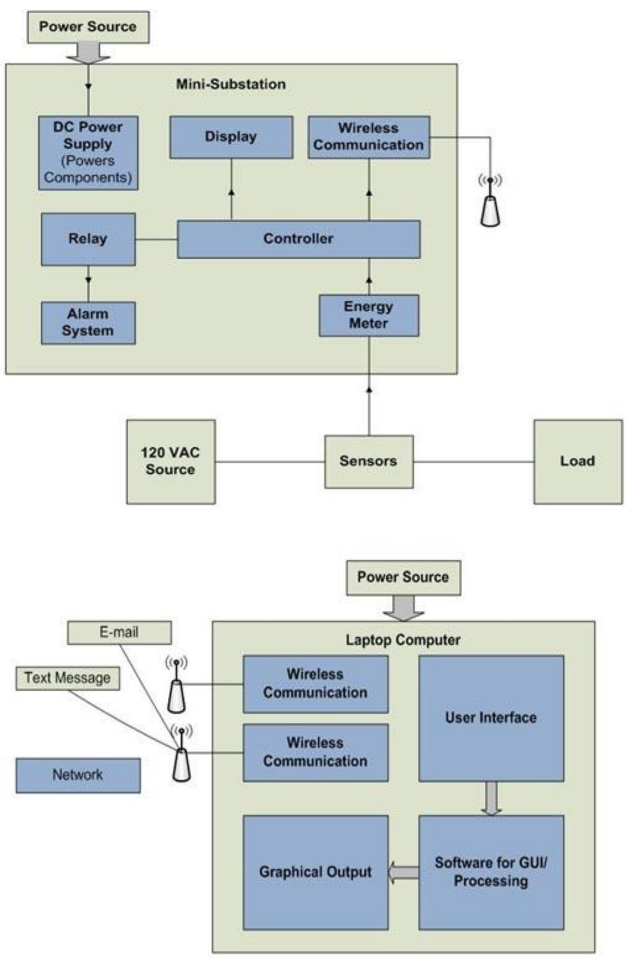

Figure 2: Mini-Substation Monitoring System Block Diagram (Detailed)

IV. Hardware Details

A. Microcontroller

For our project we will use the PIC18F4550. The microcontroller seen in figure 3 is the heart of the project. This model was chosen because of the number of pins available. Being afraid we could run out of pins for our application, we decided that we would use the ones with most pins available. The PIC18F4550 has an operating voltage of 2V to 5.5 V; it has a flash memory of 32 Kbytes and a data EEPROM of 256 bytes. Since this microcontroller also has its own integrated A/D converter, it makes a little bit more attractive knowing we don't have too much space inside our box to add too many components.

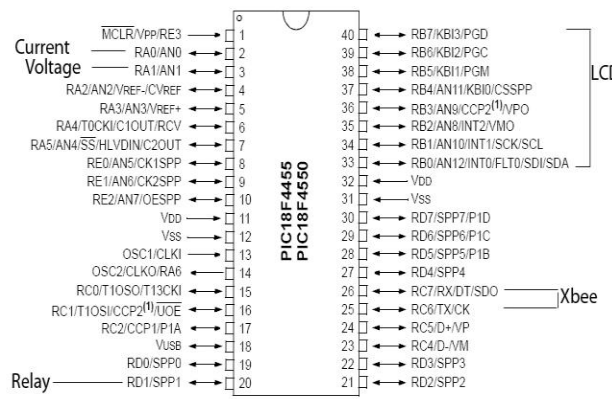

Figure 3: Microcontroller Diagram

The microcontroller is powered with a 5V power supply at pin 32. Our Xbee module is hooked with the microcontroller at pin 25 and 26. Our LCD is connected with the microcontroller from pin 33 to pin 40. We are getting our inputs current and voltage at pins 2 and 3.

B. Wireless Communication

The XBee device as shown in Figure 4 has a 50mW power output, an industrial temperature rating of -40C to +85C and is approved for use in the United States, Canada, Europe, and Australia. Included are 128-bit AES encryption and a data rate of 250 kbps. There are three options available as far as the antenna is concerned for the XBee RF module. The first option is a chip integrated antenna. This option provides about 470 feet of line-of-sight transmission distance on the standard XBee and approximately 1690 feet on the XBee-Pro. The PCB chip antenna does not have any problems transmitting through a plastic enclosure. The second antenna option is the Whip antenna which is a small antenna built into the module. This increases the line of sight range to 845 feet on the standard XBee and 4382 on the XBee-Pro. As with the integrated chip antenna it can be fully enclosed in a plastic box, but does not provide the same range if a metal enclosure is used. With a metal enclosure, the manufacturer suggests using the U.FL antenna connector with a dipole antenna. This provides approximately the same range as the whip antenna without the attenuation problems associated the metal enclosure. Some of the key features of the XBee are listed below.

Performance

- Transmit power output: 1mW (0 dBm)
- Indoor or urban range: up to 100 ft (30 m)
- Outdoor/RF line of sight range: up to 300 ft (100 m)
- RF data rate: 250 kbps
- Operating Frequency: 2.4 GHz
- Interface data rate: up to 115.2 Kbps
- Receiver sensitivity: -92 dBm

Power

- Supply voltage: 2.8-3.4 V
- Transmit current: 45 mA at 3.3V
- Receive current: 50 mA at 3.3V
- Power down sleep current < 10 µA

Physical Properties

- Size: 0.960 in x 1.087 in
- Weight: 0.10 oz
- Antenna options: U.FL. RF connector, RPSMA, chip antenna, or whip antenna
- Operating temperature: -40° C to 85° C

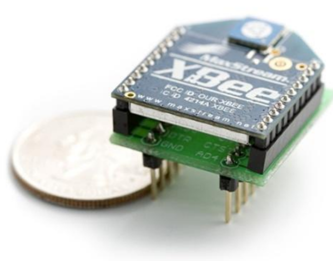

Figure 4: Xbee

C. Relay

Using an automatic relay to shut our device is one of the better alternatives to control our device. However, knowing that the relay has to fit inside the box with all the other components makes it a little bit demanding. We had to find a small enough relay that takes little space and rated with a minimum of 120 Vac. From our research as well as the components given to us by our sponsor BCI Technologies we found a double pole double throw relay RY2LS-U shown in figure 5. It's a small industrial GP signaling relay. The minimum load it can take is 10mA at 5volt DC. It consumes a relatively small amount of power. Its frequency response is 1800 operations/hr. It has a great electrical life expectancy at about 200,000 operations at 120v. Its mechanical life expectancy is over 50,000,000.

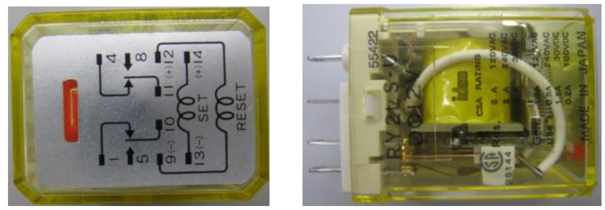

Figure 5: RY2LS-U Relay

D. Current Sensor (Current Transformer)

The current sensor that we will be using is an AC1020 20amp current transformer shown in Figure 6**: AC1020 Current Transformer** . This is a low cost current transformer which operates both on 50Hz and 60 Hz.

Figure 6: AC1020 Current Transformer

E. LCD

When using a LCD screen several precautions are to be remembered. The module is really fragile and cannot take more than it supposed to. The LCD works with 5 volts to 3.3 volts. The LCD can work in a maximum of 70 degree Celsius and -20 degree Celsius. We researched different LCD displays to be used in our project and finally we settled for SSC2F16DLNW-S shown in Figure 5, which uses a HD44780 controller, has 16X2 dispaly with black text on blue background. The advantages of this LCD screen seen in Figure 5 includes: low power consumption, internal oscillator with external resistors and high speed MPU interface of to 2 MHz when Vcc = 5V.

Figure 7: SSC2F16DLNW-S LCD

F. Power Supply

The power supply will need to convert a 120 VAC signal to several DC voltages. The DC voltages are needed to power the different components and chips in the monitoring system. The substation monitoring system is something that needs to have constant power without the risk of a battery dying. This opens up the idea of converting an AC source into a DC source. There are many different variations of converting an AC signal into a DC signal depending on the application. In most DC power supplies that use an AC input use a similar process to the one shown in Figure 8: Block Diagram of a Power Supply System. Starting from the left is the transformer, then rectification, smoothing and regulation. All of these steps lead to a clean DC regulated output voltage.

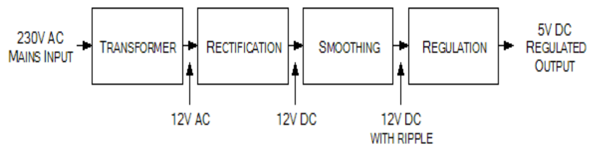

Figure 8: Block Diagram of a Power Supply System

Each section in the block diagram contains certain components that do the job stated. Figure 97 below shows the basic components of each section which may vary from design to design.

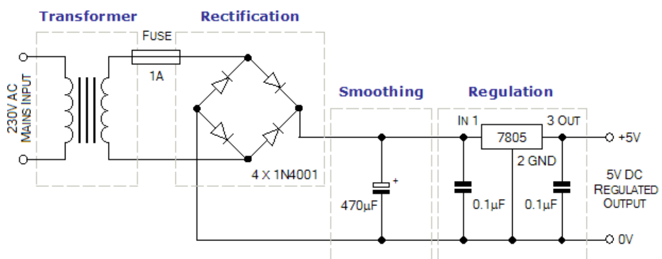

Figure 9: Simple 5V DC Regulated Power Supply System

G. Station Alarm

The alarm is an important part of the substation monitoring system. It needs to be efficient and alarming enough to alert servicing personnel. The response time will be immediate. Once the relay trips, the alarm will immediately activate alerting any nearby personnel.

- The circuit will be powered by 12 VDC coming from the power supply
- 12 VDC Buzzer
- 3200 HZ audio supplied by buzzer
- Buzzer Intensity level of 100dB
- Red LED for Relay Open
- Greed LED for Relay Closed
- Switch to disable alarm

IV. Software Details

SCADA will be used to monitor our device. The software portion of our project will consist of several subsections. It is possible to use assembly; however C will be used for all the microcontrollers. The compiler that we are using right now is the C18 compiler and the program that we are using to program the microcontroller is the MPLAB program. The microcontroller in our box will do all calculations once it received the input current and voltage. Following lines of codes wore used to program our micro controller.

```
//Initializing the ports
TRISDbits.TRISD0 = 0;
TRISDbits.TRISD1 = 0;
PORTDbits.RD1 = 0;
PORTDbits.RD0 = 0;
OSCCON = 0b01100000;  //4 MHz

//---------------------------------------------------------------------
//Set up LCD and Output titles
//---------------------------------------------------------------------
OpenXLCD( FOUR_BIT & LINES_5X7 );  //Initialize
                                     LCD
Delay10TCYx(100);  // Delay for 100TCY
while( BusyXLCD() );
WriteCmdXLCD(CURSOR_OFF);
WriteCmdXLCD(BLINK_OFF);
while( BusyXLCD() );
data = ("Working");
putsXLCD(data);
SetDDRamAddr(0x00);
putrsXLCD("                ");
SetDDRamAddr(0x40);
putrsXLCD("                ");

//---------------------------------------------------------------------
//Configure A/D Converter
//---------------------------------------------------------------------
OpenADC(ADC_FOSC_RC &
                    ADC_RIGHT_JUST &
                    ADC_0_TAD,
                    ADC_CH1 &
                    ADC_INT_OFF &
                    ADC_VREFPLUS_VDD &
                    ADC_VREFMINUS_VSS,
                    0b0110);

//---------------------------------------------------------------------
//Configure USART for initializing xbee
//---------------------------------------------------------------------
OpenUSART(USART_TX_INT_ON &
                    USART_RX_INT_ON &
                    USART_ASYNCH_MODE &
                    USART_EIGHT_BIT &
                    USART_CONT_RX &
                    USART_BRGH_HIGH, 25 );
//---------------------------------------------------------------------
//Display the Voltage and Current values to the LCD
```

```
//------------------------------------------------------------------------
for(i = 1; i<50; i++){
USART();
SetDDRamAddr(0x00);    //Set cursor to first line
putrsXLCD("Voltage:");
SetDDRamAddr(0x40);   //Set cursor to second line
putrsXLCD("Current:");  //Read in Data

SetChanADC(ADC_CH0);   //Set channal to ADC0
Delay10TCYx(100);         // Delay for 50TCY
ConvertADC();                // Start conversion
while(BusyADC());          // Wait for completion
result1 = ReadADC();       // Read result
Delay10TCYx(100);

voltage  = (result1 * 4.46)/1023; //Calculate real voltage value from ADC value
result1 = voltage;
data = itoa(result1, data);
SetDDRamAddr(0x08);
putsXLCD(data);
putrsXLCD(".");
result1A = (voltage - result1)*1000;
data = itoa(result1A, data);
```

SCADA

In today's world there are lots of issues in how to manage, control and monitor energy usage and consumption. In order to stay ahead of the game many companies today have to keep up with the competition, keep customer satisfaction, and keep the customer coming back. The market is always changing with new technology and requirements. These companies must be flexible in how they react and must act quickly. Many companies already use software to help accurately control and monitor their systems or they are in the process of converting older system to new up to date monitoring software.

A monitoring system that is used for controlling and gathering data usually in an industrial setting has come to be known as SCADA. SCADA is used in many industries. Broken down, this is Supervisory Control and Data Acquisition. The term SCADA describes the entire system as a whole. The system might contain components such as: a graphical user interface (GUI) which would run on the main supervisory computer and allow a user to control the system remotely, this is also called HMI (human machine interface), a network of sensors or relays for inputs and outputs of the information that is being monitored, and communications and software to monitor, keep track, and trend data that is being monitored. Each of these types of software does require some sort of license agreement. These licenses keep a count of how many objects or points you are going to monitor and cost accordingly.

There are many types of SCADA systems in today's technological world. Such examples could be in the power industry, water and waste water industry, communication, manufacturing, distribution, auto making and automation. Inside these plants the SCADA system would provide an easy to use interface between human and machine. While these systems collect data, monitor progress using sophisticated charts and wizards, and notify the proper people when alarm conditions can occur, they also many control and safety features to prevent human errors and mistakes. In order to keep things safe and secure, certain parameters are set to allow access or deny access of certain functions, controls, and validations of the systems operations. As you can see there is a wide variety of uses for this type of software in today's society.

MODBUS

Our project is going to be programmed and configured to communicate and understand modbus protocol. Modbus is one of the most popular standard forms of communication in automation. Modbus was created in the late seventies and the design behind it was to create a communication network and interface for a multiple network setup using the master/slave or master/client type computer architecture. Modbus is most commonly run on RS-232 serial but now has become popular on the RS-485 interface which can allow more distance and faster communication speeds. Many types of devices use a modbus interface to send data back to the host or master system because of its flexibility including microcontrollers, Remote Terminal Units (RTU), Programmable logic controllers (PLC) and many intelligent sensors. A common network setup can be seen in Figure9 below.

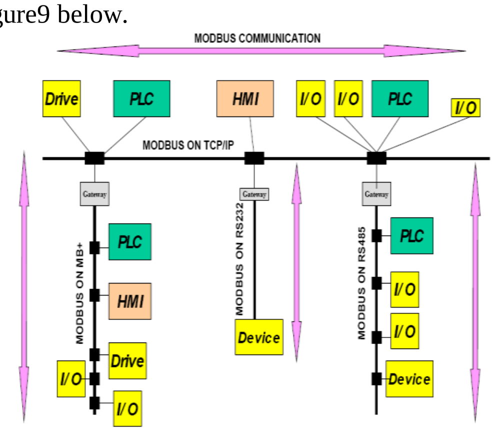

Figure 9: Common Network Communication setup for Modbus

The mapping of Modbus communication protocol is on specific buses of application data. Modbus is set up to communicate through its own messages. A good factor of modbus is the messages are standard no matter what type of physical or virtual connection you may have. This means that whether the system is set up RS 485 or RS 232 or even TCP/IP on an Ethernet connection the messages will have the same type of structure giving the entire communication protocol a long lifespan in the industrial protocol structure. The structure to the modbus messages come in the same standard form every time they are sent. Modbus messages are structured in a plain ASCII or RTU format on some simple systems but may be embedded packets that have the same format that is used in the physical interface. The main message structure is designed to communicate peer to peer, but because of the embedded packet format it can be used in point to point and networked communication. There are four fields associated with every modbus message that have the same sequence each time it is sent. The four basic elements in order of appearance are the device address, function code, data bits, and error check. An example and description of this can be seen in **Error! Reference source not found.** below.

Field	Description
Device address	Address of the receiver
Function code	Code defining message type
Data	Data block with additional information
Error check	Numeric check value to test for communication errors

Table 11: Fields and Descriptions of modbus messages

Modbus communications are based on a master and slave type environment. A sequence of steps is carried out each time data and information is sent over the connection. The data message and conversation is always begun with the master device on the modbus network. The master sends the initial message and decides how to handle it based on the contents of the message. Then the slave will respond appropriately. The first part of the message, the device address, calls out to that device for a response to the message. Each of the other slaves that do not match the address given in the beginning will ignore and not respond to the message. When a slave is responding it will repeat the requested address from the master, so the master knows and understands which message the slave is responding to.

All of the data sent by the master to the particular slave has to match in order to continue that message; otherwise the error check will find an error. This may cause the master to send the original message again. In figure it shows the cycle in which a message is sent through modbus from the master and slave. The modbus cycle happens many times a second but the response to a message can take a long time, so to get around the error, a timeout is set. The timeout has to be set in order to allow enough reasonable time to get a response but not tie up all resources in the communications waiting for a message response to occur. Below in Figure **10**10, the cycle of the modbus message is shown.

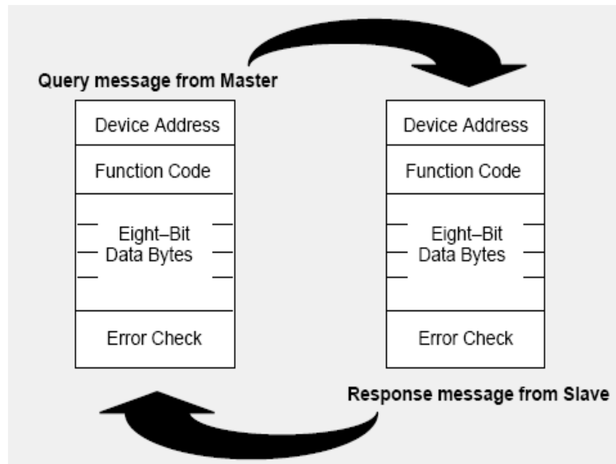

Figure 10: The Cycle of modbus message Path

CONCLUSION

The two semester long project is a valuable experience for us in terms of how to work in group, how to conduct professional meetings and how to professionally write a technical report. While working in groups and the meetings that we had organized, we contributed ideas to the group and discussed various issues with our team mates. We observed the different people have different roles and responsibility in a company. The management works conceptually on projects and the technicians have more on first line information, and can locate the problems deeply.

The components we mentioned above were tested and working as expected. We are still working to put the whole system together. We have decided to create our own PCB board because as future engineers it would be a good design experience.

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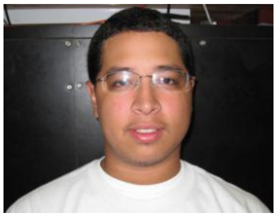
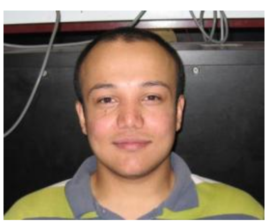
BIOGRAPHY



Devin King is currently a senior at the University of Central Florida and will receive his Bachelor's of Science in Electrical Engineering in December of 2009. He currently holds a position in the UCF/Lockheed Martin College Work Experience Program and plans to obtain a full time position at Lockheed Martin post graduation. He also plans to pursue his Master's in Electrical Engineering in the near future. His Primary interests lie in power electronics and

John Blackburn will receive his Bachelor's of Science in Electrical Engineering in August of 2009. He has attended the University of Central Florida for 2 years after receiving an Associates of Arts in Engineering from Valencia Community College in Orlando, FL in 2007. His primary interests are in the power field, substation engineering, SCADA, and high voltage. His future goals are to become employed with Progress-Energy Florida or Lockheed Martin after graduation.



Anish Raj Pant is currently a senior at the University of Central Florida and will receive his Bachelor's of Science in Electrical Engineering in December of 2009. He has attended the University of Central Florida for 2 Years; he was previously a Student at Valencia Community College for 2 Years. He plans to continue his Masters studies here in University Of Central Florida. His Primary interests lie in power electronics, Nanotechnology and mathematics.

Steve Johnson will receive his Bachelor's of Science in Electrical Engineering in August of 2009. From there he will continue his education at the University of Central Florida towards a Master's Degree in Electrical Engineering in the area of Signal Processing and Systems. His primary interests are in the area of Digital Signal Processing.

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