RS Based SCADA System for Longer Distance Powered Devices

Harkishen Singh, Gavin Mangeni

Abstract—This project aims at building an efficient and automatic power monitoring SCADA system, which is capable of monitoring the electrical parameters of high voltage powered devices in real time for example RMS voltage and current, frequency, energy consumed, power factor etc. The system uses RS-485 serial communication interface to transfer data over longer distances. Embedded C programming is the platform used to develop two hardware modules namely: RTU and Master Station modules, which both use the CC2540 BLE 4.0 microcontroller configured in slave / master mode. The Si8900 galvanic ally isolated microchip is used to perform ADC externally. The hardware communicates via UART port and sends data to the user PC using the USB port. Labview software is used to design a user interface to display current state of the power loads being monitored as well as logs data to excel spreadsheet file. An understanding of the Si8900's auto baud rate process is key to successful implementation of this project.

Keywords—SCADA, RS485, CC2540, Labview, Si8900.

I. INTRODUCTION

SCADA is a simple acronym for "Supervisory Control and Data Acquisition". As the name suggests, it is not a full control system, but rather concentrates on the supervisory level. It is purely a software package installed on networked computing platforms, such as personal computers (PC) or small dedicated embedded devices that are hardened to operate in industrial environments. Most of the actions in a SCADA system are performed automatically by the RTU or PLCs. The host control functions are normally restricted to basic overriding or supervisory level interactions.

This paper describes the work done in implementing the power monitoring system. Both software and hardware sub systems are developed.

II. LITERATURE REVIEW

Incidentally, various aspects in the SCADA world have evolved over the years, as previous SCADA engineers were concerned with selecting the best system among a wide number of choices, comparing functionalities, characteristics, interfaces, and components. Today, focus has shifted towards guaranteeing interoperability among systems, and developing the most open system possible that may not necessarily be the most complete at the initial stage. [1] The following work shows a review of some of the various types of SCADA systems with emphasis in the field of electric power monitoring applications.

Reference [2] has introduced the design of a SCADA system used in distribution automation for quality power. The designed system's RTU is introduced at Sub-stations rated at 440/220/110/66 KV, in order to continually monitor the power flow and send the information to the Master Control Center. The SCADA framework is then used to remotely control and operate the substation's electrical components as breakers, and relays and its EMS monitors the energy consumption of receiving stations.

Reference [3] proposes a SCADA based Fault Isolation system on low voltage 415/240V distribution system. He presents a customized distribution automation system (DAS) for secure fault isolation tested in the Malaysia's open loop type, TNB distribution system. The fault is detected, identified, isolated and cleared in few seconds by just a mouse click on a computer connected to the system.

Reference [4] demonstrates the practical implementation of SCADA system for Falluja substation, Iraq. The system is made up of 3 RTU devices that are used to collect data from ION 6200 devices installed inside incoming and outgoing panels for low Voltage, 33KV and 11KV. The data gathered is then sent to a Control Centre's computer via special router, for power monitoring, control and energy management functions.

In a paper entitled "Basic SCADA Communication Design", business development manager Gardner, [5] provides an overview of the various aspects that make up a SCADA system. He highlights that is begins with defining SCADA communication systems where six fundamental areas are discussed. Thesis areas include: volume of data received each time a remote site is interrogated, frequency of polling, location of the master control, location of slave devices and repeaters, total number of remote sites, and cost one is willing to pay so as to have "near real time" data from the remote sites.

Reference [6] presents a cost-effective PC based automated monitoring and control electric system, based on Open Modular Controllers (OMC). The PC in this paper used as a visual based human machine interface and for data acquisition. The system is an intelligent SCADA platform, providing economical and user-friendly solutions to the electric power facility management. The data from this platform is then distributed over the Internet or Intranet.

There are many SCADA system manufacturers and most provide a multitude of SCADA systems. Table I shows some of the major SCADA systems manufacturers and their currently used SCADA frameworks. [7]

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Manufacturer	Current SCADA system
ABB	Process Portal A/Operate IT, Ranger
ACS	Prism
Alstom	ESCA
Foxboro	Invensys I/A series
Motorola	MOSCAD
GE Network solutions	XA21, Swift
GE Fanuc Automation	iFix 32
Citect	CitectSCADA
QEI, Inc	TDMS - 2000

A. RS-485 (Recommended Standard – 485)

Also known as TIA/EIA-485-A, it is a standard maintained by Electronics Industry Alliance (EIA). The RS-485 standard was developed to meet the needs of electronic component design for longer cable lengths, increased throughput and control multiple devices and thus it is the preferred standard in this research for longer distance communication over serial lines.

RS-485 is the only interface capable of internetworking multiple transmitters and receivers in the same network. When using default RS-485 transceivers with input resistance of 12k ohms, it is possible to connect up to 32 drivers to the network. Currently available high resistance RS-485 inputs allow this number to be expanded to 256. RS-485 repeaters are also available, thereby increasing the number of nodes to several thousands, spanning multiple kilometers

All senders on the RS-485 bus can operate in three states (called tri-state operation), namely logic '0', logic '1' and 'high-impedance', where it draws virtually no current and appears not to be present on the line. Therefore, there is no need for the senders to explicitly turn the RS-485 driver on and off. RS-485 drivers automatically return to their high impedance tri-state within a few microseconds after the data has been sent, thereby minimizing delays between data packets on the RS-485 bus.

III. METHODOLOGY

The design of a SCADA system is demonstrated for monitoring of the electrical parameters of high voltage powered devices by acquiring the data from different sensors at a remote location and communicating with the operator via RS-485 communication.

A. General Design Procedure

A microprocessor based Remote Terminal Unit (RTU) is fabricated with the help of Embedded C programming and Si8900 Isolated ADC chip to convert the AC mains analog voltage to a digital format that is processed using the CC2540 microchip IC. A relay added to the unit adds remote power on/off capability to the designed system. With the feasibility of the power on/off control, adding more complicated control mechanisms should not be a problem. However, as a result of the limitations in time and resources, this design will only concentrate on the power on/off control mechanism. The RTU shall have an AC mains power supply outlet as well as the AC load outlet to which the powered device is connected, so that its power consumption is measured.

A Human Machine Interface (HMI) is developed using Labview to display the measured data from the RTU designed as well as calculate related power quantities. The AC electrical parameters measured and controlled in real time include: RMS voltage, RMS current, Frequency, Power Factor, Real Power, Apparent Power, Reactive Power and energy consumption. These parameters were computed from the ADC voltage and current values converted by the Si8900 microchip.
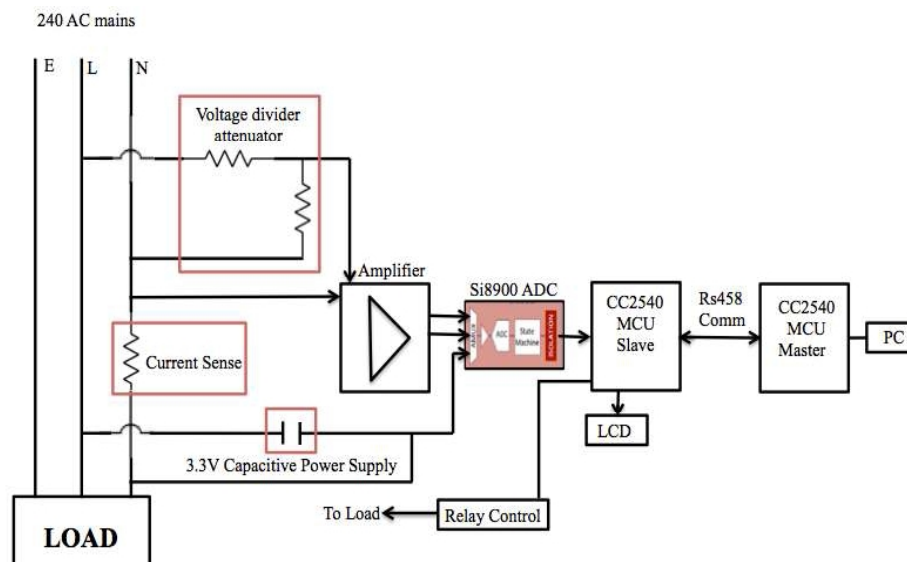

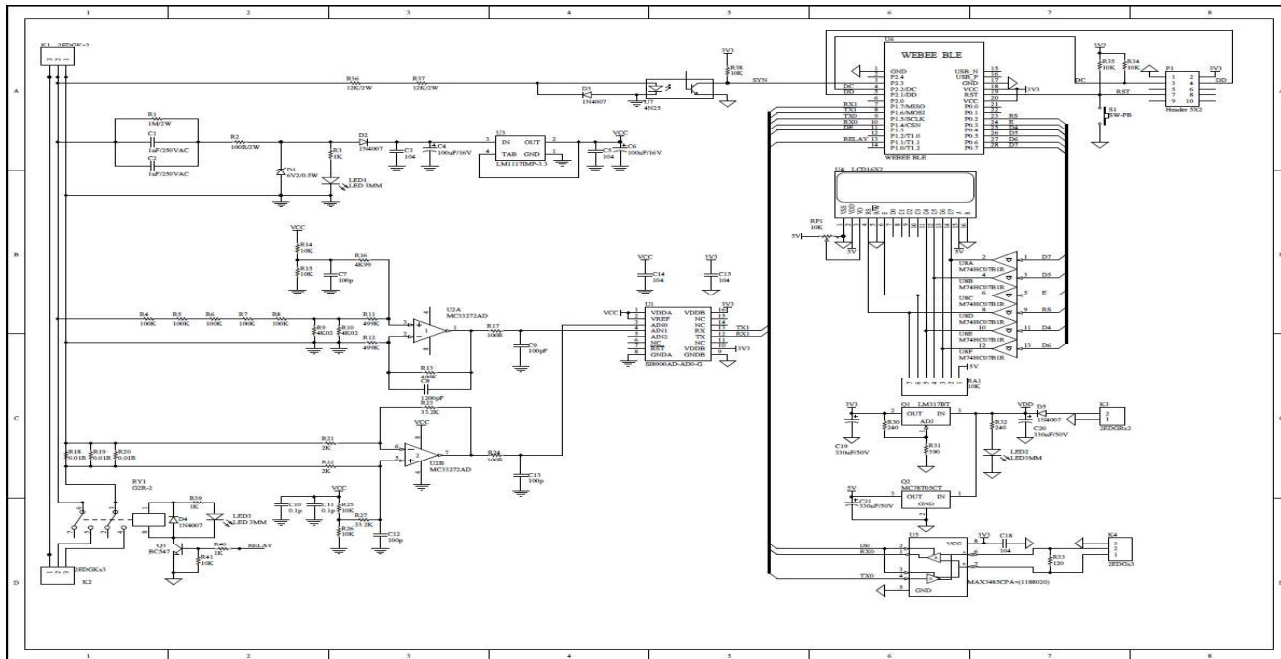Fig. 1 Detailed block diagram of the proposed SCADA system

Fig. 2 Schematic diagram showing the Remote Terminal Unit (RTU) module

B. Hardware Design

The first step undertaken in designing the hardware was to create and develop a schematic diagram to show detailed electrical connection of components in the system. Altium Designer version 14 is used to create the schematic circuits.

1. Power Supply

The microcontroller and other devices get power supply from the 12V AC to DC adapter or from direct 240Vrms AC line. The LM7805 regulator provides fixed positive regulated 5V DC and LM317 regulator provides fixed positive regulated 3.3V DC for low voltage side components from the 12V adapter.

3.3V regulated DC for the high voltage side is tapped directly from the mains AC supply using capacitive power supply principle. This is achieved by reducing the line voltage using a series capacitor between the live and neutral AC lines.

Advantages of using capacitive power supply include:

- The power supply size is smaller.
- The transformer is not required and thus significantly reduces the design cost.

In summary, the CC2540 microchip, Si8900 isolated ADC chip, and Max3485 transceiver consumes 3.3V DC, while the LCD consumes 5V DC and 12V DC powers the relay.

2. Voltage Measurement

Voltage measurement is achieved using a voltage divider network and level shifted using MC33272AD operational amplifier with a reference voltage equal to VCC/2 where VCC equal to 3.3V DC, so as to divide the 240Vrms signal down to a level that can be sampled by the ADC chip.

3. Current Measurement

Current measurement is obtained using a shunt resistor (0.01 Ohm), which is then connected to the MC33272AD operational amplifier for better precision. The neutral phase line is broken and the current sensing shunt resistor placed in series. This creates a small voltage difference across the resistor that is then sampled by the ADC chip.

4. Si8900 Isolated ADC Chip

The Si8900 Isolated Monitoring 10-bit ADC chip from Silicon Labs is used in this project to measure the AC line parameters as voltage and current from the measurement circuits, based on a single chip that contains an ADC subsystem. Voltage is measured on ADC input AIN1 whereas current is measured on ADC input AIN0 as shown in the RTU's schematic diagram. The converted digital data is then transmitted via its UART serial port to the CC2540 master microcontroller for further processing.

5. CC2540 Microcontroller

The CC2540 microcontroller is a cost-effective, low-power, true system-on-chip (SoC) which is compliant with *Bluetooth* low energy (BLE) 4.0 single-mode. It can be operated in either master or slave modes. The CC2540 combines an excellent RF transceiver with an industry-standard enhanced 8051 MCU, in-system programmable flash memory, 8-KB RAM, and many other powerful supporting features and peripherals with very low-power sleep modes. A short transition time between operating modes further enhances low power consumption.

The CC2540 was selected mainly because it had two UART configurable ports to control the Si8900 ADC chip as well as transmit data to the RS-485 transceiver. Both USART ports enable double buffering on both RX and TX and hardware

flow control and are thus ensure a high-throughput. Furthermore, each USART has its own high-precision baud rate generator that determines the rate of serial data transmission.

6. Relay Control

The Omron G2R PCB power relay is used to power on/off the powered device whose power is being monitored depending on the digital output signal sent to energize its contacts from the CC2540 microcontroller.

7. RS485 Transceiver Circuit

The 3.3V powered, low-power MAX3485 transceiver IC is used for RS-485 communication. Each IC contains one driver and one receiver. The MAX3485 IC features 8ns maximum slew rate that enables error-free data transmission up to 10Mbps and configured in half duplex mode.
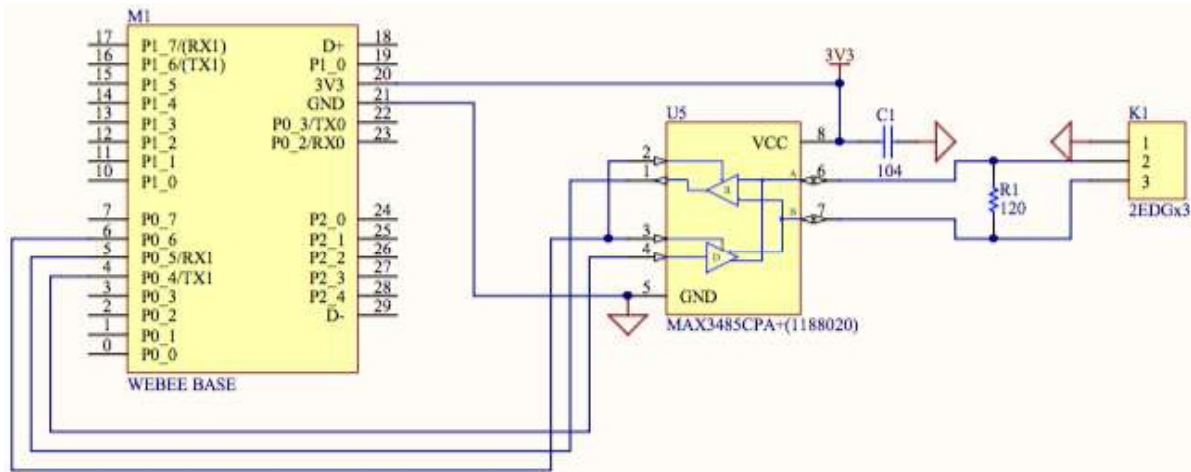
Fig. 3 Schematic diagram showing the Master Station module
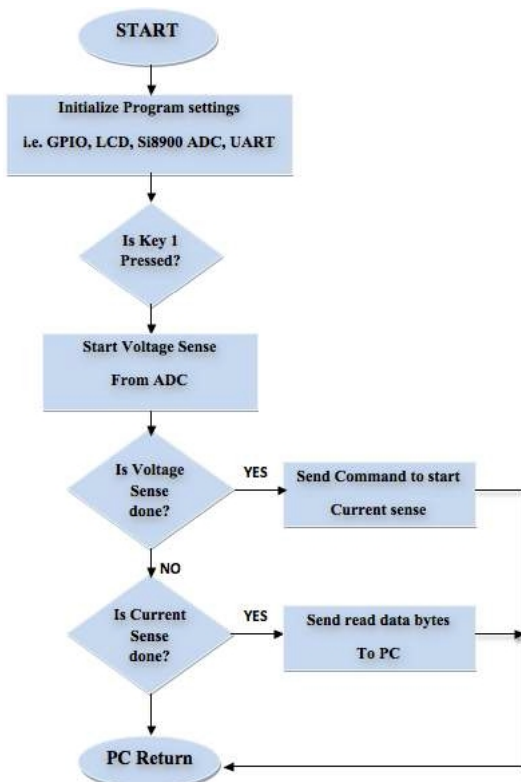
Fig. 4 Flowchart of the RTU module program

The Master station module as shown in Fig. 3 consists of the CC2540 based WeBee 4.0 module, the MAX3485 as a receiver for 485 signals. The CC2540 MCU is programmed as the master controller in this section to control its slave counterpart in the RTU module. The two USART ports are configured as UART 0 and UART 1, where UART 0 communicates to the user PC via its full-speed USB peripheral interface and UART 1 communicates with the Si8900 ADC microchip. Both CC2540 module and MA3485 transceiver are powered with 3.3V DC supply from the USB port connected to the PC or external alkaline battery connected to the WeBee 4.0 module.

C. Software Programming

Two program codes are developed to program the CC2540 microcontroller for the RTU and Master station modules, so that data converted by the Si8900 ADC microchip is received at the operator's PC as well as send commands from the PC back to RTU module. IAR Embedded Workbench IDE for 8051software is the development tool used to build the code. The code is developed using C language. This IDE is the environment where all necessary tools used to build the code are integrated. The build tools include: C Compiler, assembler, editor, linker, project manager with a make utility and debugger.

The flow chart for the RTU module basically starts with initialization of the parameters such as auto baud rate and UART serial port and then scans the status of the momentary push button (Key 1). If pressed, then it initiates the ADC

conversion process from the Si8900 microchip that reads the voltage sense value first and acknowledges it is ready to read the current sense value thereafter. Once both voltage and current values are successfully read from the Si8900, the CC2540 microcontroller then sends these values to the user PC via the Master station module and RS-485 transmission line. UART 0 communicates from the user PC to the Si8900 ADC whereas UART 1 communicates from the Si8900 ADC back to the user PC.

1. Labview GUI Development

Labview VISA program is used to read digital bytes of data available at a user selectable serial port set using the VISA resources name. An I/0 Flush buffer block is used to it clear buffers of any leftovers data at the serial port and therefore enables fresh accumulation of characters each time the program is run.

Voltage and current values are then manipulated so as to calculate parameters such as frequency, power factor, root mean square values, as well as perform data logging function to a spreadsheet file for further analysis.

The final hardware setup of the designed SCADA system prototype is as shown in the Fig. 8. It basically consists of the Remote terminal unit module that interfaces with the desired AC load circuit. The measured data is transmitted over RS-485 recommended Cat 5e cable to the Master station module, which communicates with the user PC via the USB port. The load test circuit consists of 3 light bulbs to provide a resistive load, a fluorescent lamp ballast to provide the inductive load as well as the power factor correction capacitor used as a capacitive load.

V. CONCLUSIONS

The design of an RS based SCADA system design has been successfully implemented both in hardware and software components as per the set project objectives. A fully functional SCADA system consists of two major units namely; SCADA Master station computer systems that continuously polls RTUs for data values in real time or near real time and the Labview based human machine interface (HMI) that presents the measured data values to the human operator in an understandable and presentable format.

The results got using this design were accurate as compared to those from the Fluke 87 IV Digital Multimeter and thus declared satisfactory. The power loads tested were resistive, inductive and capacitive loads whose effect on the AC line was analyzed.

As a result of time constraint, a lot more can be done to further enhance the usability of this project for example, since the CC2540 is a Bluetooth Low Energy (BLE) 4.0 module with RF antenna, the C code developed can be modified so transmit the data to a mobile phone with BLE 4.0 capability.

Webcasting capability can be implemented using Labview software to make the monitored data available online by logging into the project server created from the developed user interface.
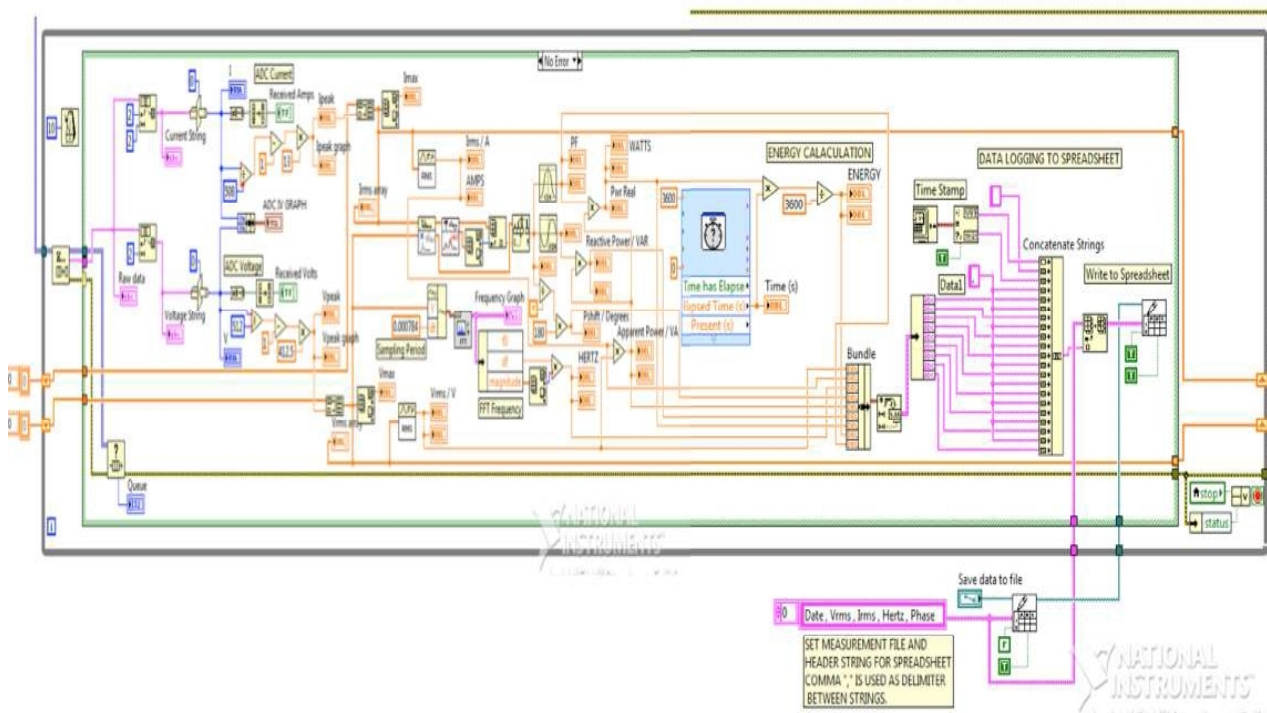

Fig. 5 Block diagram showing conversion back to analog signal representation of received data
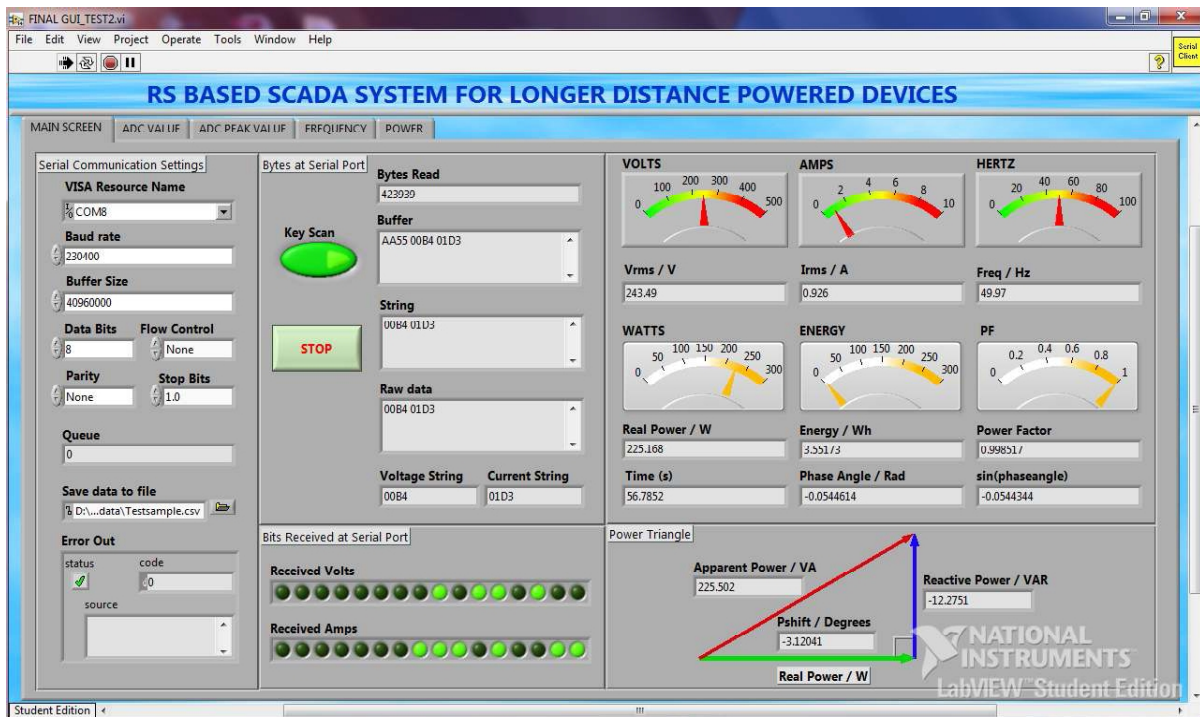
IV. RESULTS AND DISCUSSION

Fig. 6 Labview Main Screen User Interface

Fig. 7 Sampled Data saved to spreadsheet

Fig. 8 Final design Hardware Setup

Fig. 6 shows the usage of a pure resistive load for two 100W light bulbs connected in parallel. As show in Fig. 6, for a purely resistive load, the power factor is almost one, 0.9985 and the phase difference at the instant when the snapshot was taken is -3.12 degrees, implying that current and voltage are in phase. The real power the two bulbs consume at the instant this snapshot was taken is 225.168 W, which is close to rated 200W by hand calculation. The energy consumed was calculated by multiplying the real power by the elapsed time in hours to get energy in Watt-hours and after 56.7852/3600 equal to 3.55 Wh. The frequency is as expected 49.97 ~ 50 Hz. The current consumed is 0.926A while the voltage is 243.49 V.

Fig. 7 shows the data logging to excel spreadsheet functionality added to the designed SCADA system so as the data read during the running of the UI can be available later for further analysis. The Write to Spreadsheet function block in Labview is utilize to ensure proper data logging. The Write to Spreadsheet function accepts data in string format and since our data after the calculations is in number data type; this has to be converted first. The Bundle and Unbundle blocks are used to minimize the block space to create clusters. The Number to fractional string function is used to convert the data to be saved to string data type and the Unbundle block used return the converted data in string format. A concatenate strings function is used to join the data to be saved into a cluster string that is send as 1D array to the Write to Spreadsheet function. Time stamp is added to each of the saved data so as one can know which data value is received at any given time while browsing the spreadsheet file. The file path is set from the front panel and a header string is added at the top of each of the initialized files. New data is continuously appended to the file while the Append to file control is enabled.

The final hardware setup as shown in Fig. 8 of the designed SCADA system prototype to monitor power over longer distances is as shown in Fig. 8. It consists of the Remote terminal unit module that interfaces with the desired AC load circuit. The measure data was transmitted over RS-485 recommenced Cat 5e cable to the Master station module, which communicates the user PC via the USB port. The load test circuit consists of three light bulbs to provide a resistive load, a fluorescent lamp ballast to provide the inductive load as well as the power factor correction capacitor used as a capacitive load.

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