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WIRELESS SENSOR NETWORK BASED REAL TIME MONITORING SYSTEM FOR ELECTRICAL POWER DISTRIBUTION NETWORK

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Abstract- This paper presents the design and development of a real-time monitoring system for monitoring electrical power distribution systems. The developed system monitors electrical parameters like voltage, current and frequency at the distribution points and calculates apparent power drawn from the distribution point. This work is targeted on the use of open source tools and open standards for the development of the system. The developed system does not require any third party services for its operation and is a low-cost system. Its modular structure makes it flexible to implement and use. The developed prototype has been tested under various operating conditions and optimistic results have been obtained.
Keywords – Real-time monitoring; Open Source tools; Open Standards; Arduino Uno; ZigBee; Linux; MySQL; Python.

1. INTRODUCTION

The increased complexity of electrical power distribution systems has a direct impact on the reliability of the power supply and on the power quality. The main cause behind the inefficient operation of the power distribution systems can be attributed to overloading of the power supply feeders, line losses and uneven loading of the feeders. To take care of these situations which eventually lead to a condition of under voltage or over voltage in a power distribution system and affects the reliability of power supply, we need to continuously monitor the system parameters like voltage, current, power and frequency in real time. As in a power distribution system the distribution points are sparsely distributed, it becomes difficult for the operators to monitor all the distribution points within the system in person. This raises the requirement of a system that can monitor the electrical parameters at all the distribution points and enable the remote monitoring of the condition of the distribution system. The available monitoring systems like SCADA and those implemented using PLC are being used widely for monitoring and control of large scale power distribution systems and the industrial setups. But the high cost involved in the implementation and the need of skilled manpower for the operation of these systems make them unsuitable to use in small power distribution systems like that of an educational organization or small industrial setups. Apart from above discussed options we do have many metering devices already available in the market and theses devices can be coupled with specified third party service for communication and data transmission. But the problem with such an arrangement is the high cost of the available measuring devices and also they do not have an integrated communication unit which leads to the need of external devices and service provider for all kind of communication and data transmission.

These issues of high cost associated with the use of SCADA and PLC based systems and the problems related to reliable and low cost communication can be very well addressed by the emerging concept of Wireless Sensor Network and ad-hoc network. A wireless Sensor Network (WSN) is a system that consists of multiple sensing nodes connected with each other and/or to a central unit over a wireless communication link. The systems based on WSN find their application specifically in situations where the system under observation is sparsely distributed.

Most of the systems based on WSN are used for data acquisition. And to handle such a large volume of data we need a database management system that can handle large chunks of data received from the sensor nodes. As the sensor nodes are continuously sending the data to the central unit, therefore it is nearly impossible to regulate the data flow between the nodes and central unit manually. Also we need to continuously log the received data to the database. The best solution to this problem is to automate the task. So we automate the job of regulating the data flow and data logging at the central unit using a python script.

The power monitoring system developed in this work is based on Wireless Sensor Network. The major components of a wireless sensor network include a sensor node, a wireless communication link and a host computer system. The sensor node is realized using Arduino Uno microcontroller board which measures the electrical quantities at the distribution point using the signals obtained from the Hall Effect current sensor ACS712 and other sensing circuits realized for sensing the voltage and frequency. Xbee modules are used to create a communication link between the nodes and the host computer. The

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communication channel works using ZigBee protocol which is an open standard. The central computer receives the data measured by the nodes over a wireless medium and loads that data into a database created using MySQL.
The presented work has focused on the maximum possible utilization of open source tools whether it is software or hardware, for the development of the system. The system has a modular design which provides the flexibility to use it as a whole or a part of it depending on the needs of the user. The presented work can act as a guide in application of microcontrollers in electrical power systems monitoring and also on the use of open source tools for the development of a functional system.

2. LITERATURE SURVEY

A wireless Sensor Network (WSN) is a system that consists of multiple sensing nodes connected with each other and/or to a central unit through a wireless communication link. The systems based on WSN find their application specifically in situations where the system under observation is sparsely distributed. Wireless Sensor Network has been successfully implemented in systems used for monitoring of solar panel conditions. WSN based system is also used for power management in intelligent building [1] and for energy management in smart homes [2]. Wireless Sensor Network based systems have also been used for monitoring of smart power grids [3]. The application of Wireless Sensor Networks is not limited to Electrical systems only as presented in a work which uses WSN to develop a system for monitoring the water distribution system [4] and in systems made for ultraviolet detection of flame. WSN is also being used to create wireless sensor actuator network for factory automation application [6].
The vital part of a WSN based system is the wireless communication network that interconnects all the sensing nodes. Theses wireless communication links are established either using the available services like GSM, GPRS and Wi-Fi or in some cases by creating an ad-hoc wireless network. The services like GSM, GPRS etc. are third party services which may not be available at all the places of concern and also they add up a considerable amount to the operational cost of the WSN based systems. These above addressed issues are very well taken care of by the use of an ad-hoc network for the system. An ad-hoc network is created using radio modules which work on a defined protocol and the use of this ad-hoc network makes WSN based systems independent of any third party services. This enables their implementation almost anywhere as an independent system.
For creation of an ad-hoc communication network we need radio frequency modules. Different radio frequency modules are available and used to create the communication network, this includes CC2500 Transceiver, nRF24L01 modules, MC13192 and XBee radio frequency module [7].A communication network requires a set of rules called protocols for its operation and for an ad-hoc network also we need to create a protocol. In this situation use of XBee modules becomes the favorable choice as they work on ZigBee protocol which is an open standard based on IEEE 802.14.5 Standard [8][9]. The work done in [10] presents us the use of Wi-Fi for wireless communication in WSN. The possibility of using both Wi-Fi and ZigBee based network for wireless communication in WSN based systems is presented in [11].

3. SYSTEM DESCRIPTION

The system developed in this work is a based on the concept of Wireless Sensor Network(WSN) hence like all other WSN based systems the structure of our system includes three main units viz. Wireless Sensor Node, Wireless communication link and a central unit which is a computer. The basic structure of the proposed system is given in the Figure 1.

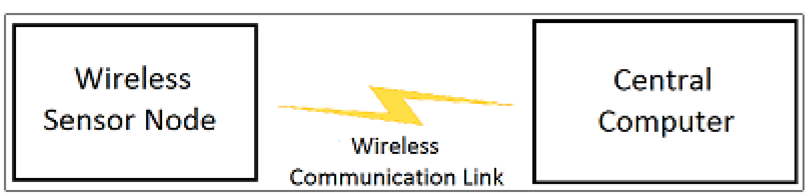

Figure 1: Structure of proposed system

The wireless sensor nodes are the onsite devices which does the measurement of electrical quantities like voltage, current etc at the distribution point. As the electrical quantities to be measured are of high magnitudes therefore depending upon the nature of the quantity to be measured, necessary auxiliary circuits have been developed to step-down and optimize the electrical quantities for measurement. Potential transformers (PT) and current transformer (CT) have been used to step down the level of voltage and current as they have been used widely and for long time which approves their credibility in measurements. A Schmitt trigger circuit is used to obtain the square pulses from the sinusoidal voltage of the power lines and then obtained square pulse is used for frequency measurement. The Wireless Sensor Node is built around Arduino Uno development board which is an open source development board and incorporates an 8-bit microcontroller ATmega328P from Atmel. The general structure of the Wireless Sensor Node is shown in Figure 2.

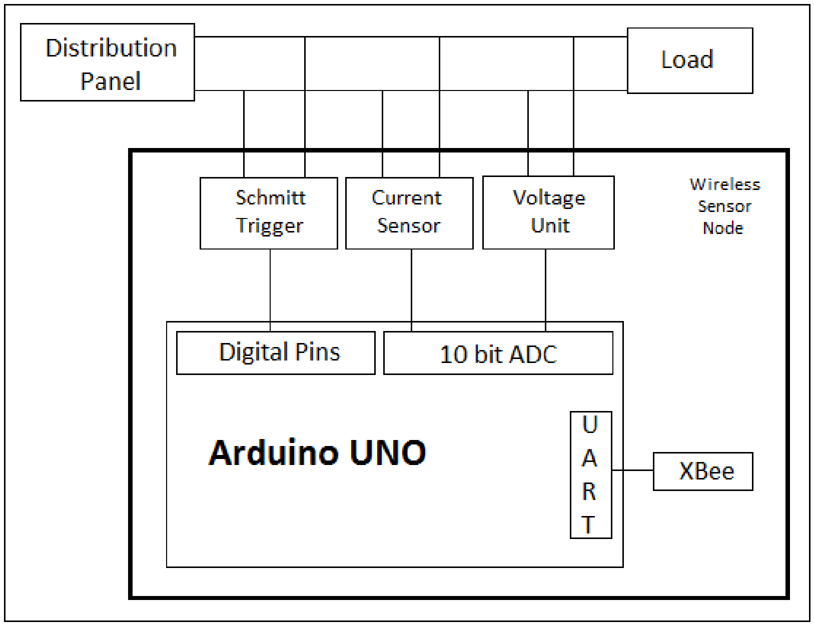

Figure 2: Block Diagram of Wireless Sensor Node

All the measurements done by the wireless sensor node is transmitted in real-time to the central unit over the wireless communication link. The data sent by the sensor node is received at the central unit through the Xbee module and then loaded into the database. This process of reading serial port for data and data logging is done automatically by a python script running in python shell.

3.1 Voltage Measurement –

The supply voltage level is reduced down to 12V by a 230/12V step down transformer. This reduced voltage is rectified using a full bridge rectifier realized using 1N4007 diodes. The output of the rectifier is passed through a capacitor to get a smooth DC signal. Obtained DC signal is brought down to a level of allowable 5V input limit of Arduino analog pins. This DC signal is fed to the analog pins of Arduino Uno where it is converted to digital values by inbuilt 10-bit ADC. The output of ADC is sampled for an interval of 100ms at a frequency of 2.5 KHz. The average of the samples is then mapped to original voltage levels as shown by equation 1

Actual Voltage = (Average value of samples * 270)/1000 (1)

Where 1000 is the ADC value corresponding to an input voltage of 270 VAC. Figure 3 shows the auxiliary circuit used for conditioning voltage signal. The results obtained from our voltage measurement unit are shown in Figure 4.

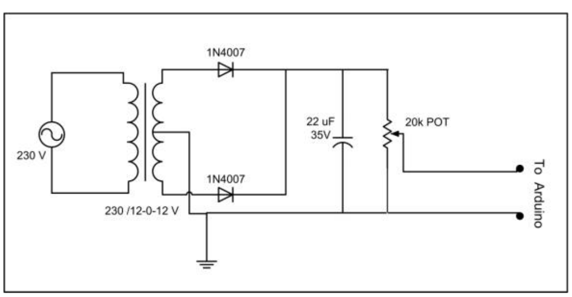

Figure 3: Circuit for voltage measurement.

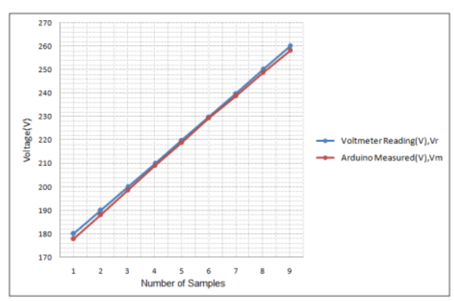

Figure 4: Results of voltage measurement

3.2 Current Measurement –

The current is measured using a Hall Effect current sensor, ACS712. This current sensor produces a voltage in its output corresponding to the input current. Though we can use current sensor directly in line supplying the load but it limits our measurement to the rating of the sensor. So we use a current transformer of CT ratio 30A/5A. The CT reduces the current to lower values which is then measured using the current sensor. The purpose of using the CT with the current sensor is to demonstrate the functionality of the CT and current sensor combination. This combination can be extended to current transformer with any CT ratio.

The output of the current sensor is fed to the analog input pin of Arduino Uno. The input signal is then converted to digital signal by in-built ADC. We take samples of the ADC output for duration of 100 ms at a frequency of 2.5 KHz. RMS values of the samples is calculated and mapped to original current levels by relation given in equation 2.

Actual Current = (RMS value of samples * 75.75)/1024 (2)

Where 75.75 is the sensitivity of the current sensor and 1024 is the digital value corresponding to maximum rated current of the current sensor that we have used i.e. 30A. The current sensor with higher current rating has better sensitivity which justifies our use of a current sensor of 30A rating. The circuit setup used for current measurement is shown in Figure 5. The results of current measurement are presented in Figure 6.

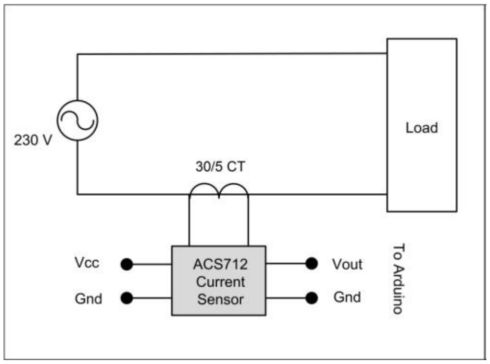

Figure 5: Setup for current measurement

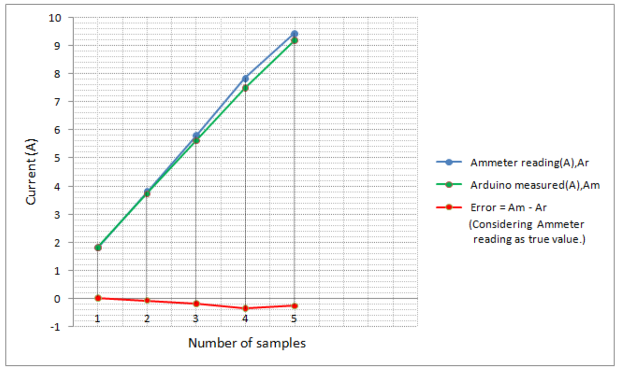

Figure 6: Results of test done on current measurement unit

3.3 Frequency Measurement –

For frequency measurement we have converted the sinusoidal voltage signal into square pulses using a Schmitt trigger. The Schmitt trigger is realized using an operational amplifier, 741. The obtained bidirectional pulses are clipped to get square pulses in positive direction only. The obtained signal is fed to digital input of the Arduino Uno where we measure the time period of the pulse. Time period of the pulse is the addition of the time for which the pulse was high and the time for which it was low. The frequency is calculated using the relation given in equation 3.

Frequency = 1000000/(Pulse High Time + Pulse Low Time) (3)

Where pulse high time and low time are in microseconds. The circuit used for measuring frequency is given in Figure 7. Results of frequency measurement are shown in Figure 8.

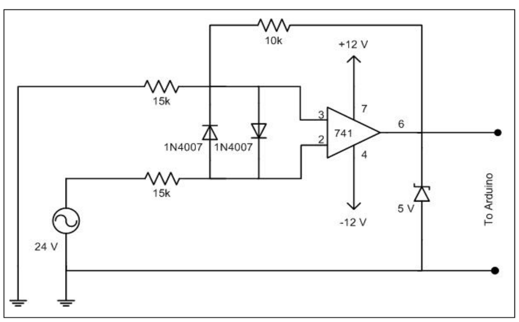

Figure 7: Circuit to convert sinusoidal to square pulse

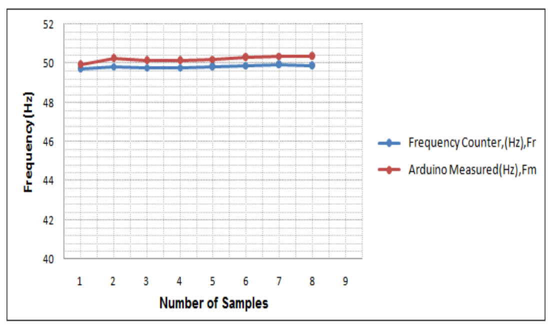

Figure 8: Results of frequency measurement

3.4. Wireless Communication Link –

For end devices to transfer the measurement data to the central computer and to have bidirectional communication between the sensor nodes and the computer, we create a wireless radio frequency link between the sensor node and central computer. This link is made using Xbee radio frequency modules from Digikey, which work at a frequency of 2.4 GHz. The Xbee modules have been configured using XCTU software, to work in AT mode. In this mode a serial link is created between the modules present in a network.

The created network is verified using the XCTU software by directional data transmission between the Xbee module at senor node end and the coordinator Xbee module connected to central computer. Figure 9 shows the Xbee modules used to create the network and Figure 10 presents the process of configuring Xbee modules.

Figure 9: Xbee radio frequency Module

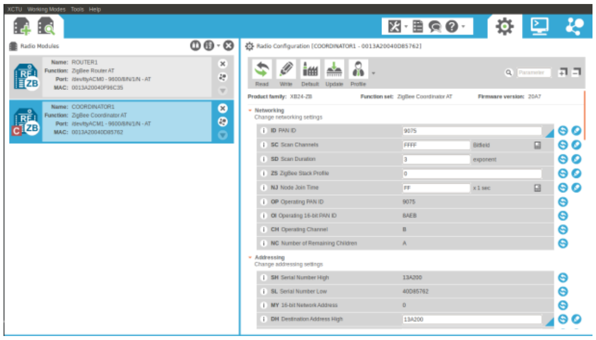

Figure 10: XBee modules being configured using XCTU

3.5. Data Storage –

As the system is doing the measurements in real time hence large amount of data is going to accumulate over time. This data is needed not only for monitoring the system in real time but we also need to store this data for future study of the systems behavior. To handle such large volume of data we create a database using MySQL, an Open Source Database Management Software.

The data is received by the coordinator of the ZigBee network which is connected through USB to the central computer. All the data is received at the serial port of the host computer and we need to read that data and load it into the database. This is done using a Python script. We have used "serial" library to read the serial data and to establish the connection with the database and load data into it, we used "MySQLdb" library. Figure 11 shows the MySQL database management system that we used and Figure 12 presents snapshot of the python script used for establishing connection with the database and reading the serial port.

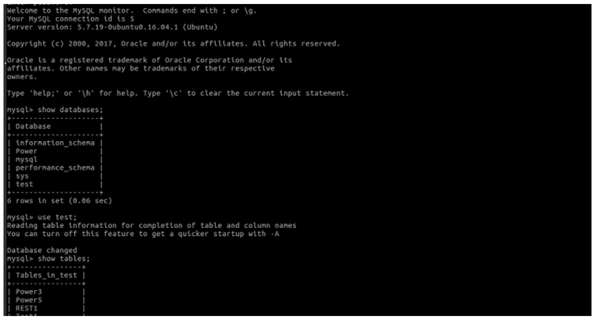

Figure 11: Starting MySQL DBMS

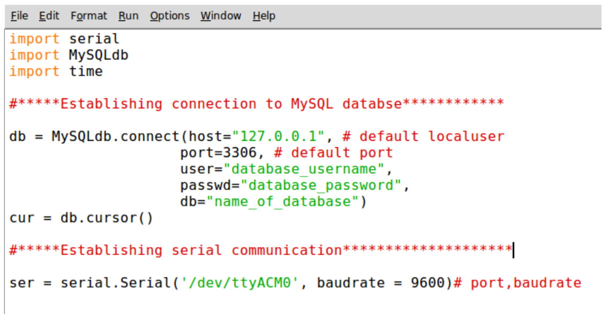

Figure 12: Connecting with database and serial port

4. EXPERIMENT AND RESULT

The developed prototype has been tested under different fixed and variable load conditions. Lamp load has been used as fixed load while for simulating variable load condition we have used heating filament load. Lamp load from 500W to 1200W has been used to test the system response under small load conditions. The heating filament load we used can be changed to different loading levels without cutting off the power supply and therefore has been used to verify the performance of developed prototype under variable load conditions. The final prototype testing setup is shown in Figure 13.

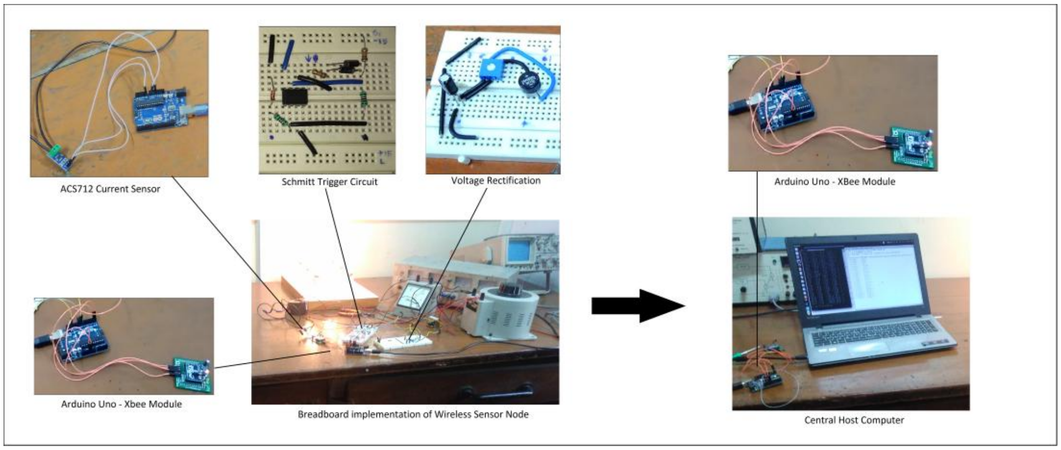

Figure 13: Final test setup of the prototype

Wireless Sensor Node measures the voltage, current, frequency and calculates the power and transmits the processed data to the central computer. Note that all the raw data obtained from the sensor and auxiliary circuits are processed at the node itself and no processing is needed at the host computer. This approach of processing the raw data is referred to as inline processing and it let us to utilize the full processing power of the microcontroller used in Wireless Sensor Node.
\The sensor node continuously transmits the measured data to the host computer and the data received is then loaded into the database. Python script reads the serial port at which Xbee coordinator is connected and loads that data to the database. Figure 14 shows the data received at the serial port and the same being loaded into the database.

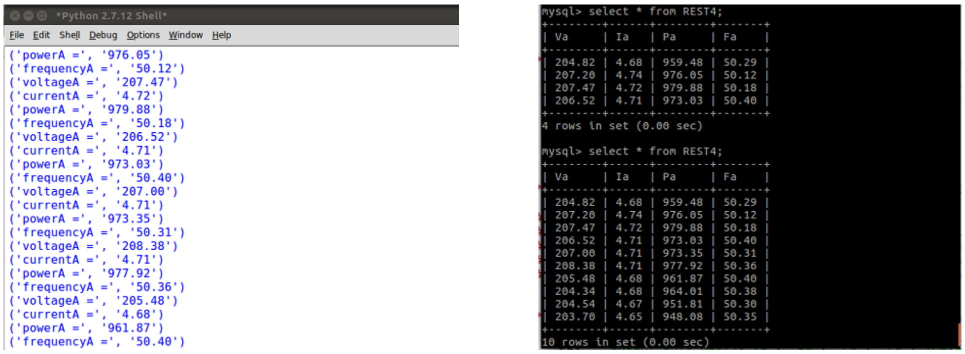

Figure 14: Reading serial data and logging it into the database.

The prototype has been tested at different distances from the host computer and gave satisfactory results in operation for a nearly line of sight distance of up to 70 foots. The system also works well for a no line of sight distance of up to 20 foots. The estimated range of operation for the developed system would be around 100 foots for nearly line of sight distances.

5. CONCLUSION

We have realized a power monitoring system with the use of open source tools. The system has been tested successfully for the measurement of electrical quantities in a single phase system. The measured data has been transferred over the wireless communication link to the central system and loaded automatically to the database using a Python script. The developed system can be extended to monitor the required number of distribution points and all three phases of the power supply.
In future the system can be expanded by addition of following features to it as listed below

1. Implementation of mesh network using XBee modules configured in API mode. The data transfer operations done in ZigBee based network is encrypted by default hence providing the security of the data in exchange operations.
2. Developing a wireless control mechanism to remote control the switching of the load at any distribution point.
3. Development of a GUI based application for presenting data to the end users in easier to understand format and making provisions for accessing the sensed data using a website over the internet.

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