Design of RTU & SCADA

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Abstract: *This work aims at designing a system with which the various parameters viz. Frequency(Hz), Bus-bar Current(kA),Bus-bar Voltage(kV), Reactive Power(MVAR),Active Power(MW) and equipments like Isolator ,Relay ,Circuit Breaker of Sub-Station or Generating Station can be monitored and controlled from a remote location . To achieve the desired output Remote Terminal Unit(RTU) will be placed in the Sub-Station or Generation Station which will acquire the various data and these data will be transmitted to the SCADA(Supervisory Control and Data Acquisition) station of RLDC (Regional Load Despatch Centre) . In this work, Arduino integrated with Step Down Voltage Transformer , ACS712 Hall Effect Current Sensor and SPDT Relay is configured as RTU and a PC loaded with a GUI is configured as SCADA(Supervisory Control and Data Acquisition).*

Keywords: RTU,SCADA,Arduino,PC,GUI,ACS712 Hall Effect Current Sensor, RLDC.

1. Introduction

American National Standards Institute(ANSI) states that Remote Terminal Unit(RTU) is a remote station equipment of a supervisory system. The term supervisory system encompasses all control, indicating and associated telemetry equipments at the master station and all the complementary devices at the remote station or stations. RTU is called as the eye, ears and hands of the master station.[1]

There are various modules in a Remote Terminal Unit viz. Analog Input Modules, Analog Output Modules, Digital Input Modules, Digital Output Modules, Data Processing Module, Control Processing Module, Communication Interface Module etc. The data from Current Transformers , Potential Transformers and Transducers are fed into Analog Input Modules as milliamp or voltage values. In order to process the obtained values in RTU & SCADA system they are converted to digital values using ADC(Analog to Digital Converter). Analog output Modules send a constant milliamp signal proportional to a digital quantity specified in a command from the master. Controllers, Recorders and Meters are connected to Analog Output Module. Analog Output Module is the least often used of the basic RTU Input /Output functions. Contacts from Circuit Breakers , Switches and Relays are connected to Digital Input Modules .

The SCADA system monitors these digital data continuously and keeps a track record of contact changes each time it changes which is known as SOE –Sequence of Events Log . An accurate clock and an interrupt driven processor is required in order to time tag the events to within 1 millisecond. The Digital Output Modules send signals to Circuit Breakers, Tap Changers ,Relays, Phase Shifters , Generators,

Switches. Select Before Operate(SBO) security provision and a circuitry is there in order to ensure that only one Control Relay in the RTU is operated at a time . The Control Processing Module helps in achieving closed loop control based on comparing the measured quantity to a set value received from the master SCADA station. If the measured value is less or more than the set value then control action is taken in order to achieve the set value. Data Processing Modules collects and reports two types of data : Analog and Digital. Analog data are obtained from transducers and digital data are obtained from Switches, Tap Changers, Circuit Breakers , Relays etc. The Communication Interface Module looks after setting a link between the RTU & Master SCADA station.

Arduino is an open source platform which helps in faster developing of interactive projects. Arduino is programmed using Arduino C . The program is known as Sketch and its written on the IDE(Integrated Development Environment) of Arduino similar to that of Processing.

Microsoft Visual Basic is the third generation of event driven programming & IDE which is derived from BASIC. Microsoft Visual Basic is often referred as VB which is used for developing Graphical User Interface(GUI). VB has features like - "IntelliSense" and "Code Snippets," which automatically generate code for visual objects added by the programmer.

2. Background

RTU and SCADA are used for Industrial Monitoring & Control. Numerous number of substations and power generating stations are spread all over the country. It is important to maintain a track record of the power being distributed all over the country and outside the country.

In order to do this a system known as SCADA (Supervisory Control and Data Acquisition) System is made which work in co-ordination with the RTU (Remote Terminal Unit). As an example the Indian Grid Control Hierarchy chart for load scheduling diagram is shown below.
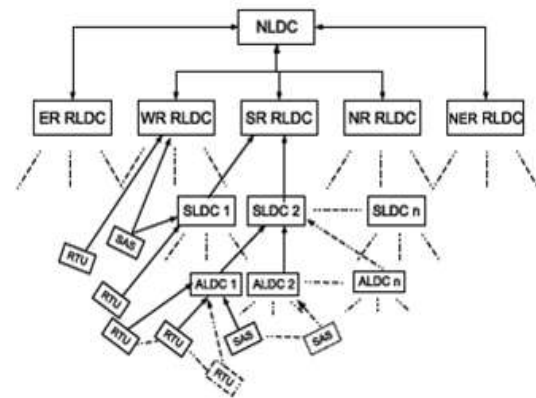

Fig 1: Indian Grid Control Hierarchy

The RTU senses the various parameters such as Voltage, Current, Power etc and the operation of the various components such as Circuit Breakers, Isolators, etc through the help of various sensors and transducers connected to it. The data received by the RTU is then transmitted through PLCC (Power Line Carrier Communication) or Fiber Optic communication to the master SCADA of the ALDC (Area Load Despatch Centre) for that particular area. The ALDCs then keeps a track record of the parameters and forward it to the SLDC (State Load Despatch Centre) where the various parameters are being monitored and the data for each second is recorded and stored in the hard drives for months. The SLDCs then forwards the data to the RLDC (Regional Load Despatch Centre) which takes the data for the entire region comprising of various

states. As shown in the Fig 1 there are five RLDCs in India namely ER RLDC (Eastern Regional Load Despatch Centre), WR RLDC (Western Regional Load Despatch Centre), SR RLDC (Southern Regional Load Despatch Centre), NR RLDC (Northern Regional Load Despatch Centre) and NER RLDC (North-Eastern Regional Load Despatch Centre). All of these RLDCs then forward the data to the NLDC (National Load Despatch Centre) where the load consumed and sent out of the country are calculated in real-time and recorded for each and every second. All these data which is received in the NLDC are monitored at the master PC and are recorded in the hard drive for months. In our project we have proposed to used Arduino as the RTU, since Arduino uses simpler language namely Arduino C and is inexpensive too, therefore programming with Arduino is user friendly and for transmission of the data from the RTU to the SCADA USB cable will be used which is light, efficient and cost effective.

3. Problem Formulation

A Distribution Automation(DA) system will be designed using Arduino & PC . RTU and SCADA system will be used to achieve the desired output. Using this proposed system we can monitor Bus Bar voltage(KV), Reactive Power(MVAR), Active Power(MW), Frequency(Hz) , Isolator status, Circuit Breaker(CB) status of various substations from a remote location. Automatic and manual tripping of CB's will be incorporated in the proposed system.

4. Methodology of Proposed System

In this work Arduino and PC will be integrated to form a new system which will be efficient for designing a Distribution Automation(DA) system.

Arduino will be used as a Remote Terminal Unit(RTU) & a PC will be used for development of a SCADA (Supervisory Control and Data Acquisition) system. Arduino which is configured as RTU will be placed in the substation or generating station , it will take the following inputs from the substation : Bus Bar Voltage using Potential Transformers(PT), Bus Bar Current using Current Transformers(CT) ,Isolator & Circuit Breaker status; the relays will also be connected to the Arduino board . For prototype design purpose step down voltage transformer will be used in place of PT and ACS712 Hall Effect Current sensor will be used in place of CT, SPDT relay will be used for switching purpose(it will serve the purpose of Circuit Breaker) whenever there will be any fault condition the coil of the relay will be energized and as a result of which it will break the circuit in order to protect the power system. Once V,I

are taken from the system the other parameters like frequency, power factor, real power & reactive power will be found/calculated. The RTU's normally use Power Line Carrier Communication(PLCC) or Fiber Optic Communication to send the data from the substation to the Regional Load Despatch Centre(RLDC). On the contrary , in this work we have used USB cables to set up a communication link between the RTU and RLDC, RLDC will have the SCADA system to monitor the various parameters of the substation as mentioned above. In order to boost the current output of the Arduino pin which is required for energizing Relay ULN2803 is used.
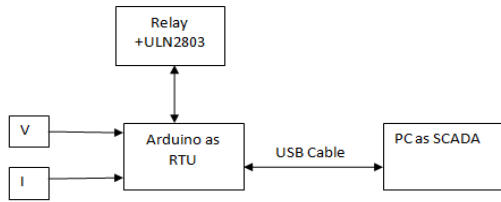
Fig 2: Block Diagram of the Proposed System

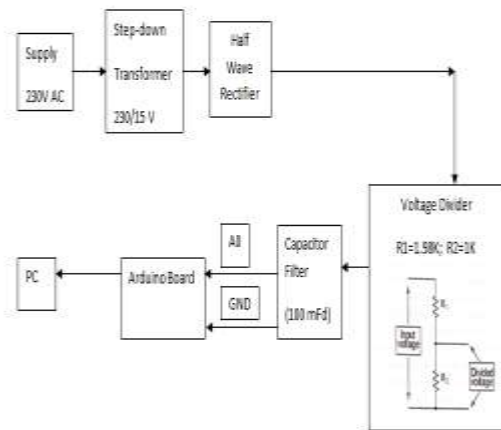## 5. Voltage Measurement Methodology

Fig 3: Block Diagram of Voltage Measurement Methodology

The voltage from the line is first stepped down with the help of a step down transformer then it is fed to a half wave rectifier. In order to further step down the voltage , voltage divider is used and at the output of the voltage divider a small value Capacitor Filter circuit is connected. As we are cognizant that the Arduino board will get damaged if voltage input to the board exceeds +5V hence in order to protect the board a +5V Zener Diode in reverse bias mode should be connected at the output of the Capacitor Filter circuit. The output of the Capacitor Filter circuit is connected to an Analog Pin of the Arduino Board, these Analog data are then converted into Digital data with the help of the 10 bit ADC of the Arduino Board.

In order increase accuracy ,40 samples of voltage were taken after that average of the samples were found out then it is multiplied by the step size (0V is represented by 0 and +5V is represented by 1023), at last it is multiplied by the multiplying factor since calibration was done . The multiplying factor was found out to be 73.30 . The voltage thus obtained was the RMS Voltage of the system.
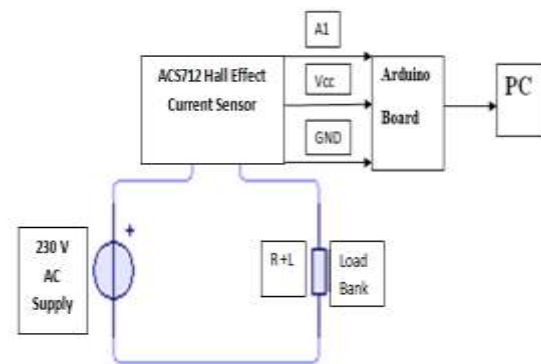
6. Current Measurement Methodology

Fig 4: Block Diagram of Current Measurement Methodology

ACS712 Hall Effect Current Sensor(20A) was used to find out the circulating current. It gives output in terms of voltage which is proportional to the amount of current flowing in the circuit. When it is connected to a DC circuit it gives output in DC and vice versa. This has been proven in the laboratory while testing the Sensor. The output terminal of the ACS712 was connected to an Analog Pin of the Arduino Board, after that it gets converted into Digital data with the help of the 10 bit ADC of the Arduino Board; the value thus found out should be multiplied by the step size i.e. 5.0/1023 . From the data sheet it is found that if $I_P = 0$ then $V_{out} = 2.5$ hence we have to deduct that value from the measured output voltage. The sensitivity of 20A ACS712 Hall Effect Sensor is 100 milli-volt/Ampere. Hence the measured voltage multiplied by 1/sensitivity will give the output

current(Instantaneous current). Using these formulas we have found out the RMS current :

Average Squared Current =

∑ (Instantaneous Current)^2/Samples

RMS Current = sqrt(Average Squared Current)

Using the pulseIn( ) function the Time Period of the signal was found out(For a 50Hz signal ,T =20 ms). Frequency was found out by using this formula,
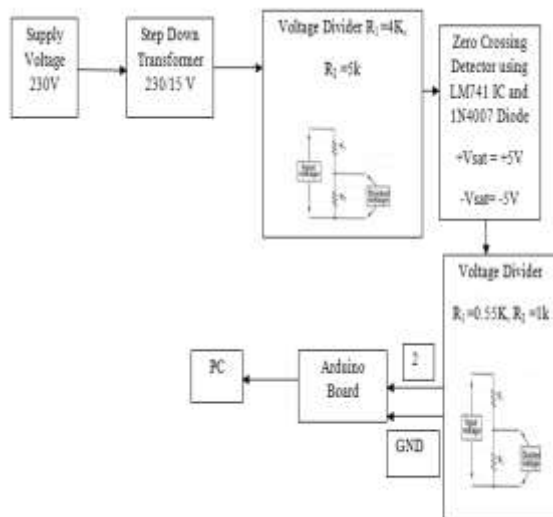
f = 1/ T.

7. Frequency Measurement Methodology

Fig 5: Block Diagram of Frequency Measurement Methodology

The voltage from the line is first stepped down with the help of a step down voltage transformer after that its further reduced with the help of a voltage divider in order feed the voltage to the voltage zero crossing detector designed using LM741 IC.

As we know that Microcontrollers cannot read negative voltages hence a half wave bridge rectifier was connected at the output of the zero crossing detector ; as we cannot give input to a Microcontroller beyond +5V hence another voltage divider was used after that it was fed to a Digital Pin of the Arduino Board .

8. Power Factor, Active Power, Reactive Power, Apparent Power Measurement Methodology
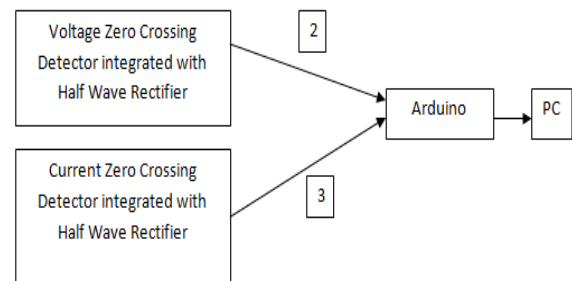

Fig 6: Block Diagram of Power Factor Measurement Methodology

The voltage from the line is first stepped down after that it is fed to a Half Wave Rectifier after that the voltage is again stepped down to a safe level as it is to be fed to the IC's . This voltage is then fed to the Voltage Zero Crossing Detector which converts the sine wave in to square wave ,in order to clip off the negative half cycle of the square wave a Half Wave Rectifier was used. ACS712 Current Hall Effect Sensor gives an output voltage which is proportional to the current flowing through the line.

This voltage is then fed to a Zero Crossing Detector(Current Zero Crossing Detector) which converts the sine wave in to square wave ,in order to clip off the negative half cycle of the square wave a Half Wave Rectifier was used.

The output of both the zero crossing detectors are fed to Digital Pins of Arduino ,with the help of coding we have found out the time duration(t) for which the Ex-OR output of the two signal is HIGH (Ex-OR operation was performed in Arduino code and using timer of the Arduino, time(t) was found). Synchronization of the two signals was done in Arduino Code in order to give correct and accurate results.

In order to convert this time(t) in degree we have used the formula: D= (360/T) * t where T is the Total Time Period of the Line voltage(for 50Hz ,T=20 ms). In order to find Power Factor we have used cos(D),where D is the Phase Angle between V & I . As Power Ractor , RMS Voltage ,RMS Current has been found, those values were used to find out Apparent Power, Real Power and Reactive Power.

Real Power = Vrms * I rms * Cos(D)

Reactive Power = Vrms * I rms * Sin(D)

Apparent Power can be found by vectorically adding Real Power & Reactive Power.

9. Hardware Used

9.1   ACS712 20A Current Hall Effect Sensor
It was used for measuring the circulating current. It can be used for both AC and DC circuits.

The sensitivity of ACS712 20A Hall Effect Sensor is 100mV/A. The internal resistance of the current conduction path is 1.2 mΩ typically , in order to provide low power loss.

Fig 7:ACS712 20A Hall Effect Sensor

9.2 Arduino Uno
Arduino Uno was used to collect and process the data from various sensors and circuits; it served as RTU. The Microcontroller of the board was ATmega 328P. It has 14 Digital Pins and 6 Analog Pins. SRAM ,EEPROM, Clock Speed are 2KB, 1KB and 16MHz respectively.

Fig 8: Arduino Uno

9.3   Step Down Voltage Transformer
As we know that electronic circuits operates on low voltage hence in order to feed the line voltage to the electronic circuits a step down voltage transformer was used (230 V/15V).

9.4   Half Wave Rectifier
As we know that Microcontrollers can't read negative voltage hence in order to clip off the negative half cycle a signal diode, 1N4007 was used as Half Wave Rectifier.

9.5 LM741 IC
Its an Operational Amplifier . It's a 8 pin IC. LM741 was used to design Voltage Zero Crossing Detector and Current Zero Crossing Detector.

9.6 Voltage Divider
It was used in order to step down the voltage to a safer level as it has to be fed to the Microcontroller.

Since the voltage input to the board should not exceed 5V.

9.7 Piezo Buzzer & SPDT Relay

A 5V buzzer was used for alarm purpose, whenever any parameter of the substation or generating station exceeds or decreases than the set value of the Master Station an alarm will be raised. A tolerance limit was added to the system i.e. if its within the tolerance limit only then alarm will be raised and if its out of the tolerance limit then automatically the CB will be tripped (in our prototype the SPDT relay will be energized leading to isolation of the line from the Grid, in order to protect the Power System from collapsing).

SPDT Relay stands for Single Pole Double Throw Relay . It has five terminals : two terminals for the coil , one is the Center and other two are NO(Normally Open) & NC(Normally Connected).

The armature of the relay is connected to NC when its not energized, when the coil of the relay gets energized the armature of the relay comes to Normally Open . The phase of the circuit is connected to Center and Neutral is connected to NC whenever any fault occurs the armature gets connected to NO as the coil of the relay gets energized hence isolating the faulty part from the Grid.

9.8 ULN2803 IC(Relay Driver)

It's a Relay Driver IC which has an array of darlington pairs in it. We know that minimum 10mA is required to energise a Relay and Microcontroller output current is in the range of (1-2)mA only hence ULN2803 IC is used in order to boost the current.

10. Software Used

Microsoft Visual Basic 2010 Express was used to develop a GUI i.e. SCADA . The GUI has two buttons : TRIP & RECLOSE , in order to manually control the Relay for connecting/ disconnecting the line.

A Richtext box was added in order to view the data continuously. Automatic Disconnection of the line was added in the SCADA program whenever the parameters are not within the set point.

Alarm Condition are also set in the code according to the set tolerance limit i.e. if the parameter is within the tolerance limit alarm will be raised in order to make the operator aware that they need to take some measures in order to bring those parameters in control.

11. Snapshots

Fig 9: Snapshot of Arduino Code

Fig 10: Snapshot of Output on Serial Monitor

Fig 11: Snapshot of SCADA(GUI)

12. Comparison with the existing systems:

The existing SCADA system comprises of the following elements. Supervisory computer : responsible for communicating with the field installed data acquisition systems and controllers. They gather data, displays them and generate control commands. In this paper this function is accomplished by a PC. The data is displayed on a graphical user interface programmed in Visual Basic. Remote terminal unit(RTU) and Programmable logic

controllers(PLC) : responsible for interfacing sensors and actuators. In this paper this function is accomplished by the Arduino UNO development board . Communication Interface : responsible for connecting RTUs and PLCs to the supervisory computer. For the paper serial communication of PC and Arduino has been used. Hence all the components of the existing SCADA system has been implemented with low cost alternatives.

13. Conclusion & Further Direction

Hence a system has been designed to acquire 8 parameters of a Remote Terminal Unit viz. Voltage , Current, Frequency, Power Factor, Active Power, Reactive Power ,Apparent Power, CB status from the Power System . Results obtained from the proposed system is highly accurate ; efficiency of the system is also high.

Historical Information Management(HIM) can be incorporated in the system by using SD Card Module and in order to give time stamping to each and every obtained data Real Time Clock Module can be used, so that the data can be used for auditing purpose.
Master and Slave Login facilities can be incorporated in the SCADA system so that false operation and mismanagement of the system can be prevented ; and IoT(Internet of Things) can be incorporated by using Ethernet Module and HTML in order to operate the system from any part of the world . Security of the entire system must be given the highest priority in order to prevent the system from collapsing. Security Level of the system must be tracked continuously in order to prevent hackers from performing illegal activities on the system which can lead to collapse of the entire Grid as its an interconnected system.

Lot many parameter control can be incorporated in the system. Raspberry Pi can be used to create a Server in order to connect various RTU's to a Master SCADA station. Frequency Deviation (outbound) charges calculation can be incorporated in the proposed system. Tariff Calculation(Automatic) can be incorporated in the proposed system. Fault Calculation , Automatic Load Despatch etc. can also be incorporated in the system.

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