Design and Development of Communication Adapter for Legacy Substation Devices

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Abstract- The work was carried to integrate the legacy substation devices with the modern substation system. Since the new standardization recently introduced requires all existing substation devices to be replaced with the new ones. But for the developing countries, it is not feasible to completely replace the substation devices all at once due to involvement of huge investments. As a result, the Power System Operation cannot be improved due to non-availability of information regarding the status, history, fault report, etc. of such legacy substation devices.

A communication adapter needed to integrate the substation legacy devices i.e. without communication capability, with the modern utility information retrieval systems. This paper will present the design and development of low cost optimal communication adapter which will be based on both hardware and software implementation. It will serve a lot keeping in view the new open energy market demands, low cost, interoperability, and computational speed, permitting sharing of data and computing resources across Power System. The results of processing and related reports are concisely displayed on the user interface screen and exported through data files.

I. INTRODUCTION

Power System Automation is the act of automatically controlling the power system via automated processes within computers and intelligent electronic devices [1]. The processes rely on data acquisition, power system supervision, and power system control all working together in a coordinated automatic fashion [2] [3]. The commands are generated automatically and then transmitted in the same fashion as operator initiated commands. In developing countries, most electric utility companies have means to monitor their power system activity and control substation equipment from a central location.

Since the new standardization recently introduced requires all existing substation devices to be replaced with the new ones [5] [6] [9]. One of the main requirements for such an implementation to take place in the existing scenario is to integrate the legacy substation devices with the new system. As for the developing countries, it is not feasible to completely replace the substation devices all at once due to involvement of huge investments. As a result, the Power System Operation cannot be improved due to non-availability of information regarding the status, history, fault report, etc. of such legacy substation devices [4].

In order to implement the power system automation completely and to cop up, a communication adapter based hardware module is needed to integrate the substation legacy devices i.e. without communication capability, with the modern utility information retrieval systems [10]. In this paper, the design and development of a low cost optimal communication adapter is discussed, which is based on both hardware and software implementation. It will serve a lot keeping in view the new open energy market demands, low cost, interoperability, and computational speed, permitting sharing of data and computing resources across Power System.

II. SYSTEM HARDWARE DESIGN AND DEVELOPMENT

The scope of the work is to take the snapshot of a power line upon the occurrence of an event that may contain a fault or at a particular time when it is required by the operational wing of Power System to perform steady state analysis. The system has been designed based on the assumption i.e. Power Transmission Line is taken as 220V Power Line as shown in Fig 1. The major hardware components used in the design process are: Step down Transformer that converts 220V to 5V, the purpose of Selector Switch is to select either type of inputs e.g. current, voltage or any digital input, Sampler is implemented via Analog to Digital converter (ADC) to convert the analog signal to digital signal. The hardware section is developed by using C-Language software embedded inside a Microcontroller working as a central processing unit of this system [13] [14]. Serial Communication based on RS-232 to carry data serially between local and remote end via modems and software used at the far end is developed via MATLAB for event analysis.

Fig. 1. Overall System Design
A. Working Principle
During Normal operation, microcontroller is working in an infinite loop and continuously taking samples from sampler and stores these raw samples in SRAM. Upon occurrence of an event, interrupt is generated upon which microcontroller stops the sampling after ten power system cycles to record the post-event conditions. It takes the event time stamp information from Real Time Clock module initially, and then get the stored raw sample data from SRAM to its internal flash memory and prepare data packets that are ready to send corresponding to the event occurring instant. The microcontroller then instructs the modem to establish a serial connection with the remote modem so that data could be transmitted to the other side for analysis and processing as depicted in the flow chart shown in Fig. 2. MATLAB Software part has been divided into two parts i.e. one that takes the data from the remote modem via serial port, and the other part performs FFT on the received data. The results of FFT is then plotted and used to analyze the fault or the event.

B. Overall System Software Design
For System Software development, the system has been divided into two parts Substation Area and Control Centre.

<table>
<thead>
<tr>
<th>Substation Area</th>
<th>Control Centre</th>
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<tbody>
<tr>
<td>Data Acquisition Unit</td>
<td>Data Acquisition Unit</td>
</tr>
<tr>
<td>Data Management Layer</td>
<td>Data Management Layer</td>
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<tr>
<td>Protocol Development Layer (PDL)</td>
<td>Protocol Development Layer (PDL)</td>
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<tr>
<td>Connection Management</td>
<td>Connection Management</td>
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<tr>
<td>Data Publishing Unit</td>
<td>Data Publishing Unit</td>
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Substation Area is the location where the event related information is acquired, processed and prepared for transmission along the long distance serial communication medium.

The process is divided into five layers:
- Data Acquisition Unit acquires data from electromechanical device and gives it to Data Management Layer. This process is continuously taking data till the occurrence of event. After pausing for the event during data transmission to the remote end, it will continue again acquiring data.
- Data Management Layer takes data from Data Acquisition Unit and stores it in memory. In case an event occurs, it takes the event-time stamp information from RTC just at the event occurrence.
- Just after the event occurrence, Protocol Development Layer (PDL) requests the data from Data Management Layer and prepares Protocol Data Unit (PDU) by appending proper header, footer and checksum. The PDU is then forwarded to the modem for transmission.
- Connection Management is concerned with the serial connection establishment process between the modems and responsible for reliable data transfer.

Control Center receives the data from the Substation Area and analyzes the data by taking its FFT and plotting results in the form of graphs.

This section is also divided into five layers:
- Connection Management receives the data from the substation area via serial communications.
- Protocol Development Layer (PDL) disassembles the received PDU, calculates and verified checksum. If there is an error, it requests the data to be sent again.
- Data Management Layer extracts the data by removing the header, footer, checksum & other details. Then the data is converted to a matrix form in MATLAB and stored in the memory.
- Data Processing Unit processes the data by taking the FFT of the received data from the Data Management Layer
- Data Publishing Unit layer plots the results in the form of graph accordingly. The plots can be analyzed for event occurrence and different sets of observation

C. Data Transmission via Modems
During the Normal Operation, the Transmission link does not remain active. This becomes active only when there is an event. When the event occurs, after completion of packet formation along with the time stamp, connection management layer starts its process at hardware section side by invoking the master modem configuration module and close itself when the requisite data in the form of packets has been sent reliably.

Both Modems are responsible for data communication between two remote sites based on the V.90 protocol suit that supports max data rate of 56 Kbps and configured in master / slave configuration as shown in Fig. 3. Upon occurrence of event, the master modem is controlled by microcontroller to initiate serial communication with the remote slave modem that is connected with analysis side located at a far distance. The master modem sends dialing request to the Telecom Network to connect with the remote modem and waits for its response. In case the remote modem didn’t respond, it will dial again until or unless the connection is established. Upon getting response and the remote modem hooks up, the microcontroller sends data to other side by appending PAK as header and +++ as footer. The objective of this data is to work as a Flag that allows remote end to understand when the data packets starts, finishes and then connection to be closed by
both ends e.g "+++" is particularly a modem command to change from online Data Mode to command mode, afterwards the master modem got the message from microcontroller to hook up the connection. It then sends the disconnection message to the remote modem. After disconnection, the master modem will remain in the idle and wait state as shown below in Fig 3. The master / slave configuration is set up for optimum use of communication resources and cut down costs.

- As the data arrived at the port, MATLAB arrange this data in the form of matrix for further processing and save in a memory. At this moment the header and footer appended for transmission of data is removed. After receiving the data from serial port, clear the serial port's input buffer, delete it logically and make it available for the next intake of data.
- Checksum calculated and thus reliability of data is checked and verified.

![Fig. 3. Serial Communication between two modems](image1)

**III. MATLAB Modeling**

The MATLAB have been used to perform data analysis i.e. may be fault analysis or harmonic analysis depending on the type of the data arrived [17] [18]. MATLAB implements the layered model as shown in Fig. 2, taking the data from serial port, arrange it, verify checksum and process this data to produce the event analysis in the form of graphs and Event analysis process is developed using MATLAB as shown in Fig. 4.

A number of steps are involved in this side as below:

- Initialization of serial port and checking it continuously if there is data arrived or not. Meanwhile it displays on the user prompt, waiting for the data [18].

![Fig. 4. System Algorithm developed using MATLAB for event analysis](image2)
First row of Matrix is reserved and contains the time stamp taken from the Real Time Clock.

Now from actual data samples headers, checksum values, substation and device ID / tags removed from the data.

Interpolation and FFT is applied on the raw samples to get the time domain as well as frequency domain snapshot of the data. These graphs as a result will provide the basic understanding for fault analysis of the sampled data.

A Fast Fourier transform (FFT) is an efficient algorithm to compute the Discrete Fourier transform (DFT) and its inverse FFT’s are of great importance to a wide variety of applications, from digital signal processing to solving partial differential equations to algorithms for quickly multiplying large integers [18]. Let \( x_0, \ldots, x_{N-1} \) be complex numbers and the DFT is defined as in (1)

\[
X_k = \sum_{n=0}^{N-1} x_ne^{-\frac{2\pi ink}{N}} \quad k = 0, \ldots, N-1. \tag{1}
\]

As FFT can only process a sampled waveform where \( N \) (number of samples) is a power of 2. Acceptable values of \( N \) include 128, 256, 512 and 1024.

The input signal is assumed to be periodic with a constant frequency. The spectrum was set up so that the first harmonic was the same as the basic input frequency. This straightforward approach is useful when something about the signal ahead of time is known; such as in the case when analyzing AC voltage. In this case, a practical signal was chosen, sampled at a rate of 800/fs samples per sec, samples are collected and pass through FFT.

The spectrum tells us that the original signal is a composite of 1 pure tone. In fact, this tone is at 50 Hz (ideally). FFT used here is taken as 128 point.

The length of the sample period is 0.00125 seconds, so the first harmonic (f1) is 50Hz. There is a spike on 50 Hz shown in the graph.

There is a small leakage / shifting from 50 Hz, is a direct result of using a limited set of sampled data. If one could collect and process an infinite amount of samples, the frequency increment (x-axis) becomes very small and all possible frequencies would be valid harmonics.

FFT is applied in two portions depending on the event type i.e if event is based on fault, then FFT is applied cycle by cycle to observe the faulty cycles and if event is steady state condition, then FFT is applied on the sampled data to observe the harmonics details.

IV. Simulation and Results

With the system developed, following observations have been recorded in two major conditions of Power System i.e.

1. Fault Condition
2. Steady State Condition

A. Fault Condition

During a typical fault condition, threshold of the current or voltage waveform is disturbed and is simulated on the developed system. A disturbed Waveform amplitude wise as shown in Fig. 5 i.e. some cycles before and after the fault is normal and some have large amplitude that simulates the behavior of the fault appearance in the power system, is generated and applied. The developed system detects this and sends this snapshot to the remote end for analysis purposes. During the fault conditions typically threshold type faults, the MATLAB program is designed and developed to apply the Fast Fourier Transform on cycle by cycle basis, those cycles that have large amplitude in time domain, have larger amplitude in frequency domain as shown in Fig. 6 and Fig. 7.
By observing the frequency domain snapshot of fundamental wave of Power System Waveform under fault conditions, Fault can be detected by using the threshold detection algorithm.

B. Steady State Analysis

During Steady State Condition of Power System, several harmonics can be found on the transmission line and needs careful attention as they are not self-initiating the fault but can disturb the stability of the Power System. These harmonics are generated due to different causes, mainly due to the involvement of different electronic components and switching at different stages.

This condition of Power System can be easily observed by our developed system, at any particular time, by sending the raw samples from embedded system side to event analysis section. After getting the samples, FFT can be applied to view its frequency domain snapshot. For this, a time domain Power System Waveform that contains different odd harmonics that are usually available in the transmission line is applied on the input of our developed system and accordingly its Frequency domain snapshot is generated as shown below:

![Frequency Domain Snapshot of Power System Waveform](image)

**Fig. 9.** Frequency Domain Snapshot of Power System Waveform that have fundamental, 3<sup>rd</sup>, 5<sup>th</sup> and 7<sup>th</sup> harmonic

V. Conclusion

In this paper the work has been presented in the design and development of low cost optimal communication adapter, based on both hardware and software implementation. It will serve a lot keeping in view the new open energy market demands, low cost, interoperability, and computational speed, permitting sharing of data and computing resources across Power System. The results of processing and related reports are concisely displayed. The developed system can be enhanced further if ADC Accuracy enhanced in terms of bits per sample. Sampling Frequency can be increased, SRAM size can be enhanced to accommodate for acquiring more types of data, Robust Microcontroller can be used for more processing. Data transmission can be based on wireless communication that will ultimately make this device location independent. GPS system can be utilized to capture the universal timing information.

The developed system is particularly useful in the analysis of Power System Steady State Conditions as well as Fault Conditions while observing at central location. In steady state conditions, the observation of Load flow studies, Network stability, Power Quality Monitoring, Data logging can be made. In Fault conditions, Pre-fault conditions (normal), Fault conditions, Fault inception point, Fault detection point, Post Fault Conditions, Digital Inputs, Relay trip point, Circuit Breaker opening point and Phase involvement can be observed. In addition we can calculate the sequence of events for Fault Conditions that is highly important for protection engineers by sitting in the central location and in the shortest possible time.

References


