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An extension to IEC 61850 for solving selectivity problem in electrical substations

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Abstract: This paper presents a study concerning the implementation of the 61850 standards (TCP/IP based standards for electric substations). The integration of communication networks in critical or safety applications is nowadays a strategic research problem. The approach consists of the proposition of new architectures according to the new standard IEC 61850. We also present the development of new devices in electrical substation domain. OPNET is used as a simulation platform for evaluation of message timing.

Keywords: IEC 61850, Selectivity and Interlocking problem, Electric substation, Ethernet, SCADA

1. INTRODUCTION

Communication networks are used within electrical power plants and substations. Due to the critical aspects of electricity generation, distribution and particularly the need to provide the system with real time information about shortcuts, the networks used in this kind of applications need to be conformed to specific standards. Anderson et al. (2005), Laderach et al. (2006) give some requirements for the implementation of networks, based on the TCP/IP protocol, proposing some extensions based on the IEEE 802.1p/q priority mechanisms for treatment of critical information. More details are available in International electrotechnical Commission standards IEC 61850 part 8.1 and 7.4.

In our previous paper Haffar et al. (2007), we proposed a solution for fast signal transmission via serial link based on high voltage detection. Thus, on the reception of this transmission, the backup system enters into an interruption subroutine to treat the cause of interruption or fault in the electrical substation. A lot of studies have been carried out and successfully applied in the field of real time transmission over Ethernet bus using TCP/IP protocol. Pritty et al. (1995), Shin et al. (1996), Shimokawa et al. (1985) provide similar approaches as a solution to this problem. The proposition of a successful solution has vast applications in real time fault detection and monitoring in substation electrical power network where the notion of time is one of the most important factor for optimal output of power plant.

On the other hand, usage of computational and memory intensive user friendly applications in the higher OSI layer of TCP/IP based protocol makes the interaction between network components very difficult. This is because of the reason that code function, address memory and communication protocols all differ from one element to another. Methods like Pre-emptive thread scheduling and memory management is needed for predictable response times by assigning priorities, control memory usage and timing as well as controlled access to system resources. Due

to the difference in behaviour of different devices. This disadvantage eliminates the possibility to use different type of off the shelf equipments in electrical power substation. These hurdles in real time communication have led to the development of a new specific protocol of communication for substation power plants, known as TCP/IP based IEC 61850 compliant communication protocol.

This paper briefly explores this protocol concentrating on the problems mentioned above. A solution is proposed for the design of equipment which is able to support IEC 61850 compliant TCP/IP protocol and at the same time taking care of the problems in the existing scenario by the implementation of the IEC standard in data concentrator equipment.

2. PROBLEM DESCRIPTION

In today's substation automation, SCADA (Supervisory Control and Data Acquisition) system does all the monitoring and control function to avoid blackouts and load unbalancing of power networks as shown in Fig. 1. Intelligent electronic devices (IEDs) are commonly used in SCADA which allows getting analogue measurements such as voltage, current, power and energy values as well as discrete status signals to control e.g. numeric Protection Relay or multifunction electronic meter. These devices incorporate one or more processors, with capability to send/receive data to/from an external source and permit the visualization of the real time process. An IED may have connection as a client or as a server or both with other IEDs. Two types of IEDs are as follows:

- In this type of IEDs, TCP/IP protocol and Ethernet communication is used as shown in Fig. 2. All these IEDs are linked to one another through the Ethernet Bus network and communicate with each others and with the supervisor communicating via TCP/IP protocol.

- The second type shown in Fig. 3, is very widespread among industry, uses MODBUS/Serial protocol and serial link

communication, which requires the existence of a data converter/concentrator to communicate with the supervisor.

Hence, this data concentrator/converter act to concentrate the most useful data in the intelligent switch, and to convert the serial protocol to Ethernet protocol for the communication with the supervision as referred by Fong et al. (2006). The notion of concentration is used to allow the optimization of the network bandwidth utilization. This is achieved by reducing the number of messages sent over the network by grouping the most useful data of many IEDs in a specific location in the concentrator's RAM (priority based storage). As shown in Fig.1, the most useful data has the highest probably to be exchanged with the SCADA system.

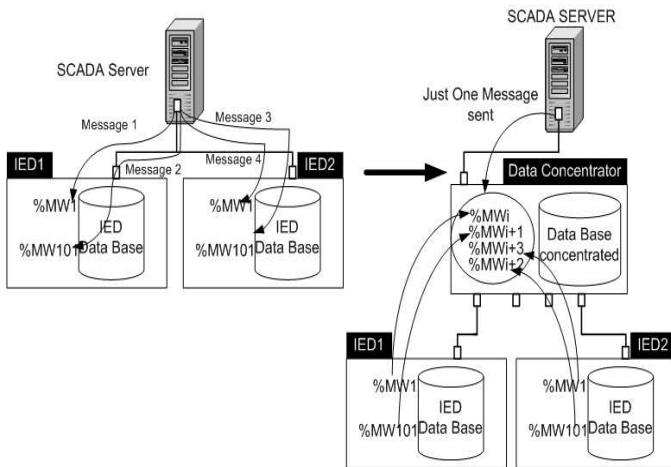


Fig. 1. Data flow in the SCADA system including databases

The reason of sending two messages at the left hand side in Fig. 1 is that the protocol does not allow reading non-contiguous data. Hence to read the data located in address 1 and the other located in address 101, SCADA server must send two different messages. In this example, we can easily notice that the number of messages sent over the bus is reduced from 4 to just only one message.

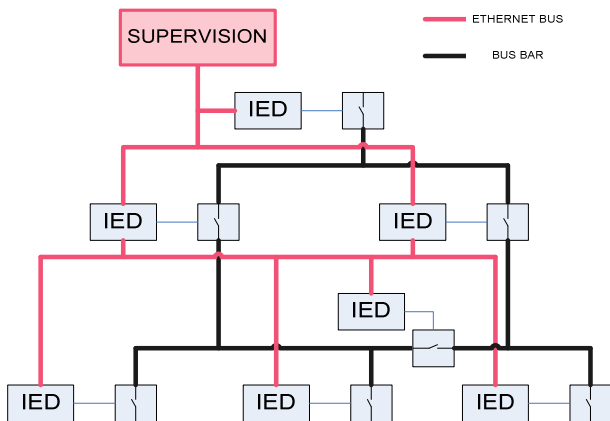


Fig. 2. Architecture showing Ethernet Bus (in red) and High Voltage Bus bar (in black)

Notion of time has been the most basic notion in both architectures to increase the substation output. Consequently, we should completely avoid the failure of one substation

branch because of a failure in another one. This is called the 'selectivity problem'.

One can guarantee a solution for this problem in both architectures using the standard IEC 61850 which is a protocol that permits to solve this problem by introducing the notion of sending real time message over the Ethernet. The result shown in this paper consists of developing new extension card to benefit of the real time Ethernet messages in an architecture containing serial IED and respecting the IEC 61850 standard.

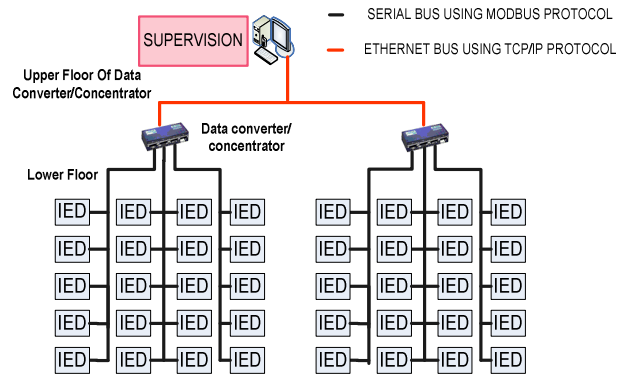


Fig. 3. Architecture with serial IED and data concentrator

3. ADDITION TO IEC 61850

We propose new architectures using the standard IEC 61850 for electric substations. Specifically, these new architectures are composed of new equipments according to the implementation of this standard as the communication protocol in the network of electrical substation. Our proposed solution consists of modifying existing equipments to make them compatible with the new standard.

Let us make a brief description about the evolution of our design. Fig. 4 represents the architecture of CN32 concentrator equipment.

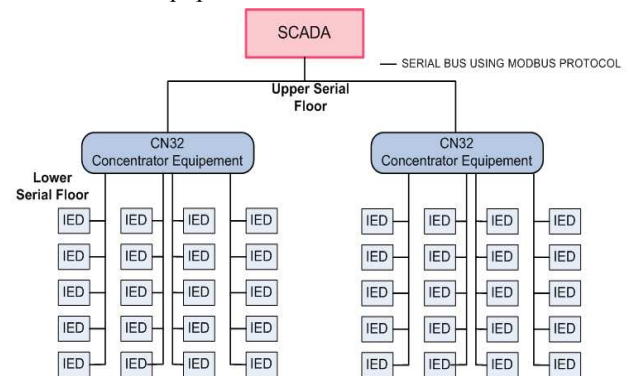


Fig. 4. CN32 inside an electrical substation

This product consists of an assembly of many cards aiming to guarantee the concentration of data coming from several Schneider Electric SEPAM protection devices. The concentration of data permits to reduce the time of communication with the Power Distribution Control System (PDCS). This product is modified to the CN2000 product by introducing Ethernet and TCP/IP protocols. The CN2000

gives functionality in addition of concentration to make a bridge from serial network to Ethernet network and ensure the conversion from serial to Ethernet protocols. The existence of the new IEC 61850 standard providing new time performances in term of sending real time message over the network and ensuring the interoperability between all equipments from any manufacturer by requiring modification. A brief description is given in Fig. 5, which gives a short overview about the logical distribution of data according to the standard.

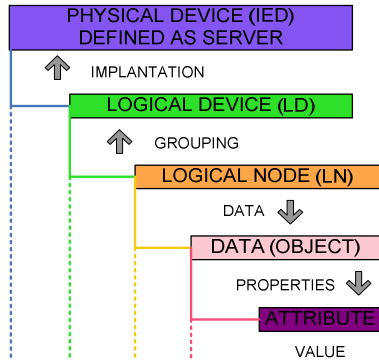


Fig. 5. Logical View of a Physical Device in IEC 61850

A physical device represents the external visible behaviour of the IEC 61850 server. We can consider our concentrator as a physical device according to the standard. A logical device contains the information produced and consumed by a group of domain-specific application functions, which are defined as ‘logical node’. Hence we can consider each IED linked to the concentrator as a logical device respecting the standard.

This paper permits to propose new architectures based on new devices. These equipments aim to preserve the utilization of existing IEDs while topping the network’s communication to IEC 61850. Actually the future architecture using the standard IEC 61850 consists in replacing all existing IED by ones supporting the IEC 61850 as shown in Fig. 6.

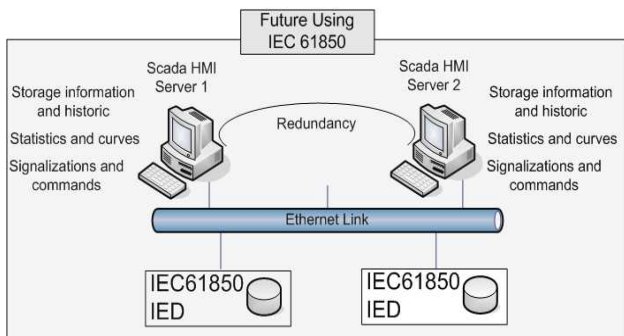


Fig. 6. Actual architecture using IEC 61850

The first proposed architecture, shown in Fig. 7, introduces a new network’s device having same characteristics as a switch adding new functionalities in term of converting existing industrial Ethernet protocols to IEC 61850 compliant protocol. It is important to notice that due to this architecture, we will guarantee the optimization for network’s bandwidth by reducing the number of process messages ‘message exchanged between IEDs’, and the number of SCADA

messages i.e. ‘messages exchanged between each IED and the SCADA server’. This architecture will serve the purpose of our future research.

The second architecture shown in Fig. 8 is taken into consideration to modify our current concentrator by integrating IEC 61850 into it. The concentrator is placed in this architecture in a substation containing serial IED. To preserve all time critical performance ensured by the protocol, we developed new extension card which permit to send the real time Ethernet messages over the serial bus.

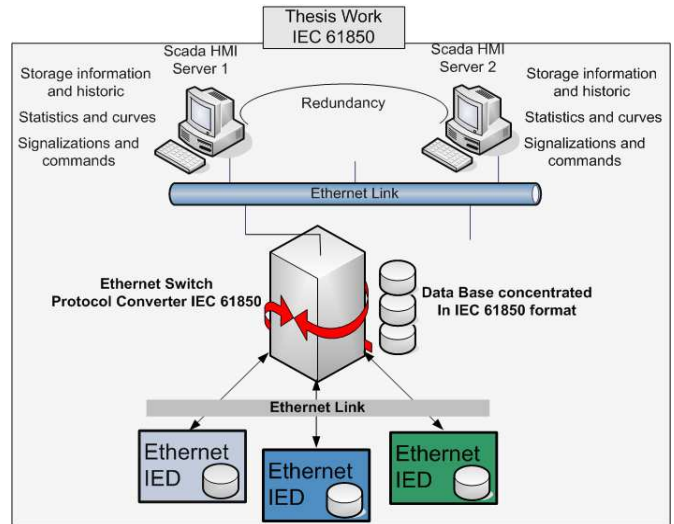


Fig. 7. Architecture proposed using IEC 61850 and Ethernet IEDs

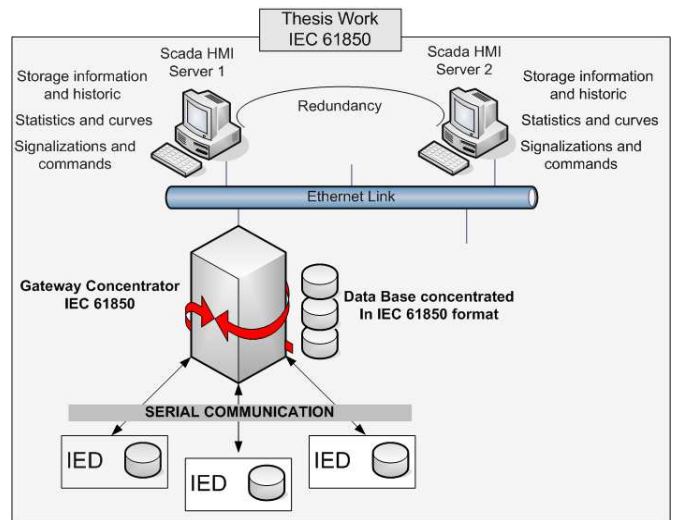


Fig. 8. Architecture proposed using IEC 61850 and serial IEDs

4. SELECTIVITY PROBLEM

As explained in the introduction, the IEC61850 protocol comes to solve the essential problem that exists in electrical substation i.e. Interoperability and selectivity problem. ‘Selectivity’ is the coordination of all circuit breakers in a substation, in order that a fault occurring in any point of the electric network is eliminated by only the circuit breaker placed immediately in the hierarchy of the fault.

There are two methods which permit to solve this problem:

- a) Logical selectivity shown in Fig. 9 consists in making physical links between IED of the circuit breaker. This means that if a fault occurs in a circuit breaker, the IED linked to this circuit breaker sends (via the physical link shown in green in the Fig. 9 below) a signal to the uphill IED and prevents its trigger. This method needs installation of a lot of physical links in a substation making it more complicated and increasing its price.
- b) Chronometric Selectivity shown in Fig. 10 consists of differentiating the time of the two curves of power cut to select the circuit breaker concerned to trip. The main inconvenience posed in this method is that it requires time for studying and programming IEDs.

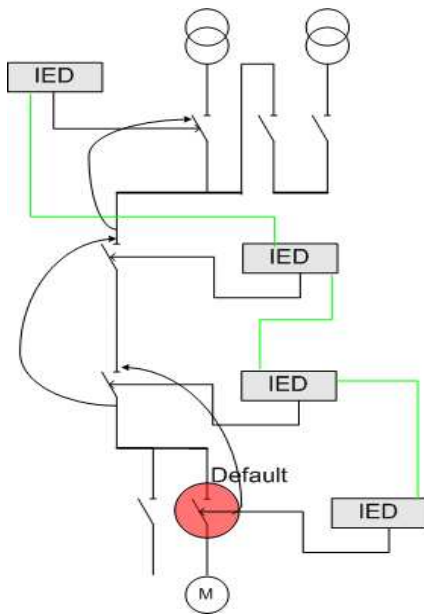


Fig. 9. Critical data flow in IEC 61850 based Ethernet

These two methods of selectivity requires a lot of time for integration and associated costs which leads to introduce another method that takes advantage of the IEC 61850. The solution proposed by the standard ensures the selectivity of the installation by sending real time messages with a high level of priority and reliability over network permitting to reach their destination. This functionality of the protocol is based on the norm 802.1p/q of the stack TCP/IP as described by Priddy et al. (1995).

Shin et al. (1996), Shimokawa et al. (1985) and Shadham et al. (1982) describes IEEE 802.1p standard works on the MAC sub-layer and do not depend on the upper layer transport. It provides to guarantee bandwidth with zero frame loss for mission-critical transmission. It also brings Quality of Service (QoS) to the MAC level and defines how a switch deals with prioritization, priority determination, queue management, etc. This is achieved by adding a 3-bit priority field to the MAC header, giving 8 (0-7) different priority levels for use by switches or hubs.

As shown in Fig. 11, in normal transmission, the protocol uses TCP/IP layers which are mapped under the MMS (Manufacturer Message Specification) application layer, otherwise in critical transmission – GOOSE (Generic Object

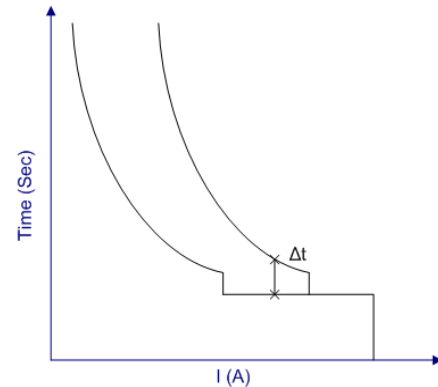


Fig. 10. Critical data flow in IEC 61850 based Ethernet

Oriented Substation Event) messages and sampled values messages; the protocol shortcuts MMS and TCP/IP layers and uses directly the Ethernet Link layer and Ethernet Physical Layer with Priority tagging by shortcutting application, Transport and Internet layers as proposed in IEC 61850 standard.

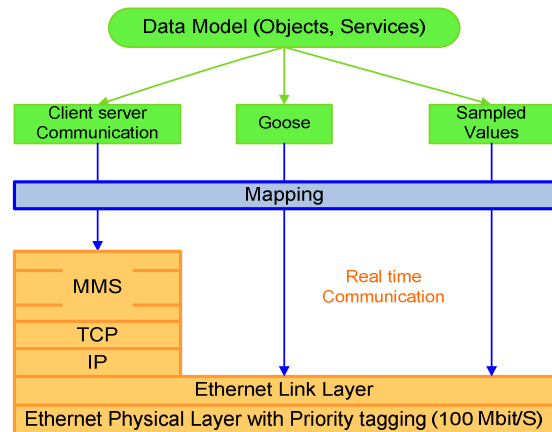


Fig. 11. Mapping layers in IEC 61850

5. SIMULATION SCENARIO

This section shows the communication need in terms of the time critical performance in an electric substation that uses the serial IEDs. It consists of simulating the time between the transmission of two packets from one IED and to compare it to experimental interlocking time.

5.1 Converter/Concentrator description

The data converter/concentrator used in this architecture collects data from all serial IEDs through its serial port. The protocol communication between the data concentrator and the IEDs is the MODBUS serial protocol.

This protocol forces to have one master and 255 slaves coded in 8 bits address. Experimentally, only 12 slaves are used per serial port due to the fact to enter in an admissible margin time, which should be taken as a compromise between the

speed of the data acquisition of the supervisor and the data collection on the data concentrator.

Generally, IEDs put their data in the data concentrator flash memory and the supervisor dislocates this data and refreshes the memory. In this approach, the functionality of the data concentrator may be considered as a FIFO queue.

5.2 Experimental evaluation

This simulation gives the delay values in the old architecture shown in Fig. 2. The data concentrator normally interrogates its slaves IEDs with 10 requests per second, and then all IEDs return their inside analogue and status values to the data concentrator as a response for its request. Hence, we can calculate the time between two responses of one slave according to the statistics below:

$$N: \text{Number of IEDs per channel} = 12 \text{ IEDs/channel}$$

$$S: \text{Speed of interrogation} = 10 \text{ requests/second}$$

$$T: \text{Time for 1 interrogation} = 1 \text{ req}/(10 \text{ req/s}) = 100 \text{ms}$$

If it takes into consideration that the response of a slave takes 100 ms in average, we conclude that the time between two responses of one IED is equal to:

$$T_{IEDs}: \text{time between sending two packets of 1 IED} = 12 * 200 = 2400 \text{ms.}$$

In this time we should add the queue delay time and then estimate the maximum time between sending two states of one IED.

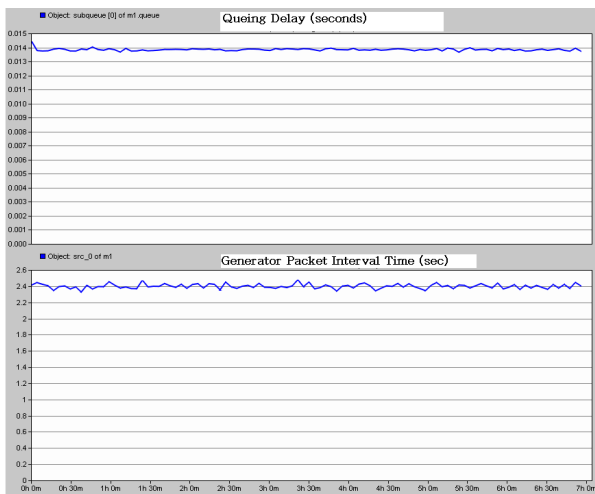


Fig. 12. Queuing Delay and Packet Inter Arrival Time

5.3 Simulation

In this simulation, every IED is modelled as a simple source that generates packets. Every simple source has 2 characteristics which follow Gaussian laws whose parameters have been experimentally determined:

- a) Packet inter arrival Time $\sim N(2.4, 0.1)$
- b) Packet size $\sim N(256, 100)$

The data concentrator is modelled as a FIFO queue that receives the packets and resends them with 19200 bauds which is the speed of the serial transmission.

5.4 Interpretation of Results

As shown in Fig. 12, the average of maximum time between two status transmission is around 2414 ms. The interlocking time is experimentally measured around 80 ms, this means that if an incomer circuit breaker feels a shortcut, the feeder circuit breaker nourishing this incoming signal feels the shortcut after 80ms. Therefore, because of this time delay, the incomer switch cannot transmit an order to omit the tripping of the feeder switch, and so the problem persists.

6. SOLUTION FOR OLD ARCHITECTURE

As it is a protocol converter, data concentrator includes an Ethernet port that communicates, at its high floor, with other data concentrator and supervisor via TCP/IP protocol. The main idea of implementing IEC 61850 in the data concentrator is to consider this data concentrator as a collection of many virtual IEDs. IEC 61850 specifies the time transfer of GOOSE signal as less than 10ms (IEC61850 part 8.1), which mean that at the high floor of data concentrator, the notion of time performance is always respected. In consequence, we still have to conceive a method for transmitting these kinds of signals through the lower floor of the data concentrator toward its IEDs, always respecting the time performance criticality. To deal with this, serial to serial case named EXT850 MOD and EXT850 DEMOD shown in Fig. 13 were developed. The transmission of real time message via serial link is done using an amplitude modulation that may be shifted depending on the voltage level signal initially existed in the serial bus.

A bit '0' will be transmitted at voltage V1 and can vary up to V1+5 due to the normal transmission, however bit '1' will be transmitted at voltage V2 and can vary up to V2+5 due the normal transmission see Fig. 14. This transmission uses the same channel for sending two different messages differed by their modulation Chou et al. (1997).

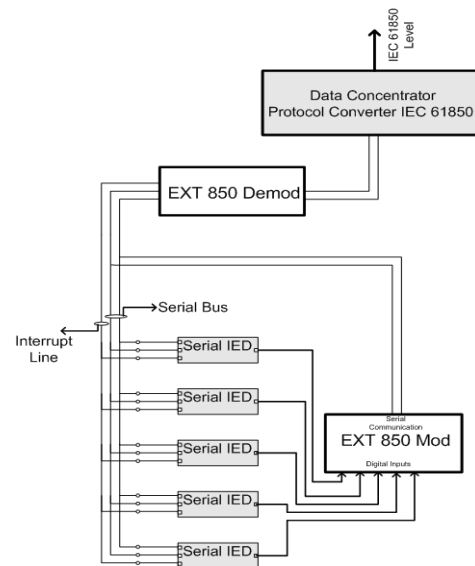


Fig. 13. Serial Architecture design using EXT850 ext. Card

The circuit modulator is implemented in the EXT850 card. The main message will be transmitted using RS232 protocol

of transmission; however the second message will use an amplitude modulation to be transmitted. Fig. 14 gives an example of the result of transmission through the serial bus. The green and purple frame will be the one sent through the bus and the black frame is the initial frame transmitted through the bus. The voltage level V1 corresponds to the logic '0' of the extra data modulated, shifted with the voltage level '0' of the initial transmission or without any shifting due to the absent of the initial signal transmitted. The voltage level V2 corresponds to the logic '0' of the extra data modulated, shifted with the voltage level '1' of the initial signal transmitted. The voltage level V3 corresponds to the logic '1' of the extra data modulated, shifted with the voltage level '0' of the initial transmission or without any shifting due to the absent of the initial signal transmitted. The voltage level V4 corresponds to the logic '1' of the data modulated, shifted with the voltage level '1' of the initial signal transmitted. It should be noted that the four level voltages of the modulation are under industrial test.

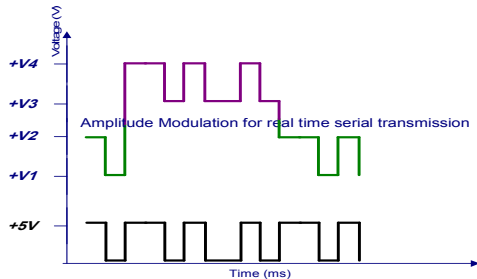


Fig. 14. Signal transmission in multi-access channel mode

The demodulation circuit in Fig. 15 is meant to separate the two messages sent through the same channel. It is divided into three blocs: comparator bloc, logical bloc and data concentrator bloc. At the comparator bloc level, the modulated signal will be compared with 5 voltage levels. As results, 5 logical signals (S0...S4) will be generated. These 5 signals will be transferred to the logical bloc, where the two messages will be separated.

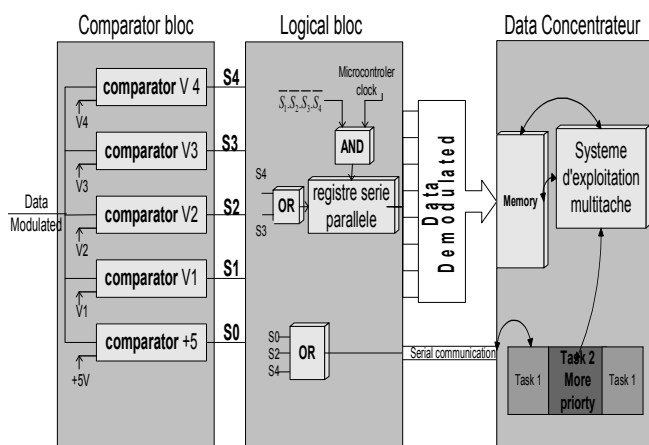


Fig. 15. Demodulator circuit blocks

The AM modulated signal will be considered as the sum of S4 and S3 when at least S1 or S2 or S3 or S4 is set. Then, each 8 bits value will be parallel transmitted to the main data concentrator's memory through a serial to parallel register. The synchronization with the emitter is done by an external

microcontroller clock synchronous with the emitter clock. When the transmission is complete, an interruption bit will be transmitted to the data concentrator like what the extra transmission is completed. In interruption subroutine, the operating system interrupts the message in progress and gives the hand to the real time message to be treated. After finishing its operation, the old message is retreated.

6. CONCLUSION

A solution has been proposed for the actual implementation of the IEC 61850 standard. This solution is compatible both for a complete TCP/IP architecture and for a hybrid architecture consisting of TCP/IP and ModBus. Some preliminary simulations have been achieved. This solution is now at the prototype phase.

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