Perfomance comparison between traditional hardwired and IEC 61850 protection system using RTDS

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***Abstract* – The evolution of the protection systems that was seen over the past few decades, with the incorporation of microprocessing technology to the relays, brought these systems to a new scenario. The automation and protection systems were integrated in one and some protocols were created to allow the communication between the IEDs (Intelligent Electronic Devices). IEC 61850 is a standard which aims to define one single protocol through which devices from any manufacturer can change data between each other. This paper proposes a system to compare the time delay of a trip signal on a traditional hard-wired connection and on one IEC 61850 based system.**

***Index Terms*— Power System Protection; Automation Systems; Real Time Digital Simulator; IEC 61850**

I. INTRODUCTION

The first relays used for protection of electrical systems were the electromechanical ones, which relied on the interaction between electromagnetic fields, in order to find any abnormal situations on the system. Over the last decades, the strong development of electronics in general affected the protection equipment as well.

First, the static relays emerged as a new alternative, with the advantages of representing lighter loads to the instrument transformers and not having moving parts (which incurred in less maintenance), as presented in [1]. The problem with this technology was its undesirable sensibility to external interferences, which resulted in inappropriate operations like false trips.

Only after the creation of the digital relays, the electromechanical technology really started to be fully substituted. Nowadays, we live on a scenario where no more electromechanical relays are produced, although lots of them are still operating, mainly due to their high reliability and durability.

One can say that the digital relays, also known as IEDs (Intelligent Electronic Devices), have merged the automation and protection systems in one. This incorporation of many protection and monitoring functions in one device, brought this systems to a new level. The possibility of exchanging data between devices in real time, made it possible to shorten the coordination times between equipment, which was previously made basically based on time delaying between tripping times.

Moreover, the possibility of sending/receiving data to/from a central station (local or remote) and programming complex switching operations (avoiding human errors), for instance, incorporated automation and even control field to the protection systems.

Although they are still seen as separated fields of study, the currently close relationship between them can be illustrated by technical papers and even standards, which handle them together, such as [2] and [3]. The impact of these new devices on the protection system itself can also be seen by the revision of the standard [4], which is reported on [5].

The first protection and automation systems that incorporated the IEDs as their main devices applied the traditional hardwired connection between then. This means that each digital information that should be sent from one device to another had to be wire-connected between one output of the first device and one input of the other. And this was a one-way communication channel.

Giving the issue a brief thought, one is able to see that the a huge amount of cables is needed to construct all the necessary channels between equipment. Given this, one could choose to make a simpler (but less protective) system, with less wire connections, or deal with long commissioning times and more maintenance problems. The number of digital inputs and outputs of each device is also a limiting factor to be considered.

At this point, the automation systems were more strongly integrated with the protection ones. The idea of creating a Local Area Network (LAN) to provide the desired communication between equipment emerged soon and each manufacturer started developing its own communications protocol. Applying the LAN concept, the devices can be integrated using one wire connected to each of them. The data is sent to a central device (a switch), which is the responsible for managing the information and delivering it to the right receiver.

The incorporation of the local network overcame plenty of the problems faced until that point. However, the individually developed protocols created a problem related to the use of IEDs of different manufactures on the same system: they could not talk to each other. In other words, whether the client chose only one manufacturer, or was he obligated to use gateways (equipment dedicated only to translate information between protocols), which made the overall system slower.

These new issues brought up the necessity of one single protocol, which should be followed by all manufacturers in order to make it possible to integrate different IEDs in one LAN, without the need of gateways. This is the IEC 61850, which has as main guidelines the search for interoperability and interchangeability, which means that equipment from different manufacturers should communicate directly through the local network and, if needed, one device could be replaced by another from other manufacturer, which should behave exactly as the first one did [6]. Reference [7] brings a practical example of how the application of an IEC 61850 network reduced the amount of copper wires used on a substation. Reference [8] brings another example of real project, which utilizes the standard.

The standard itself is a very long and complex one and there are lots of papers and studies to guide the understand of it, such as [9]. Another interesting guideline is to read the manufacturers' network configuration instructions, which can point to the main concepts related to the standard.

This paper proposes the use of one Real Time Digital Simulator (RTDS®) to compare the performance of a hardwired system and the one of an IEC 61850 network. The delay time between the emission by the IED of a trip signal and its reception by the RTDS may be a good indicator of the advantages and disadvantages of each system.

II. RTDS

The Real Time Digital Simulator is a simulator developed with the aim to enable tests of real equipment, such as digital relays, before they are commissioned and used in a real substation. A real time simulator is one in which one second of simulation is equals one second in real life. This means, that by simulating with RTDS it is possible to emulate situations almost identical to the ones faced by the equipment in a real system.

Given this situation, the whole project of a protection system may be tested on a laboratory environment, before commissioning. This can be used to increase the quality of the project itself, avoid errors on it and decrease commissioning times.

RTDS is also compatible with IEC 61850 networks, enabling tests on systems that utilize this standard as well. The website of the manufacturer itself brings some other feasible simulations, that can be made using this simulator [10].

III. IEC 61850

As stated in the introduction of this paper, the IEC 61850 standard is a very long one, with lots of concepts and definitions on it. One of the key tools of the standard are the GOOSE Messages (*Generic Object Oriented Substation Event*), which are the focus the present work.

The standard defines different type of messages inside the network. As one may understand, there are some messages in one substation whose fast delivering is essential for the right performance of the whole system. For example, tripping messages must have priority among all the others: as soon as they are sent, they must have the higher priority in the communication system, in order to guarantee the fastest extinction of the detected problem.

These high priority messages are the GOOSE ones. These messages – which are multicast ones – can carry a number of digital and analogical information and are recognized by its receivers through a MAC address given to the GOOSE package. The project of the communication network consists on associating the right data and its receiver(s) to this package address.

For example: one defines a GOOSE package with the address "go_A" that carries a digital blocking signal. The device(s) that should be blocked by this signal are them configured to listen to GOOSE packages which have the "go_A" id.

On the proposed system, only the GOOSE messages were configured. Other concepts defined by IEC 61850 are out of the scope of this paper and should be found on the standard itself or on other papers related to the topic.

IV. PROPOSED SYSTEMS

To evaluate the performance of the traditional hardwired connections and the one of the GOOSE messages of an IEC 61850 network the systems of Fig. 1and Fig. 2 are proposed. On this proposed cases, the configuration of the hardwired system is much simpler than the one based on the network communication standard.

On the hardwired system the trip signal of the IED is simply associated with one of its digital outputs and also with one of the RTDS digital inputs. This configuration is very simple and also visible through the wire connection, which is an advantage in such a simple system. On the other hand, this connection allows the sending of only one bit from the IED to the simulator. Any other implemented function should have one dedicated pair of copper wire for itself.

By looking at the Fig. 2, one may argue that the insertion of the switch only to send this trip signal is not worthy, given the negative impact on the reliability of the whole system and also the additional delay a local communication network may add to the communication.

Although this statement is correct, a first point to be highlighted is the fact that this link through a LAN is a bidirectional one and that digital and analogical data may be exchanged through it. Furthermore, this may become a huge advantage on more complex systems which are common on real electrical plants.

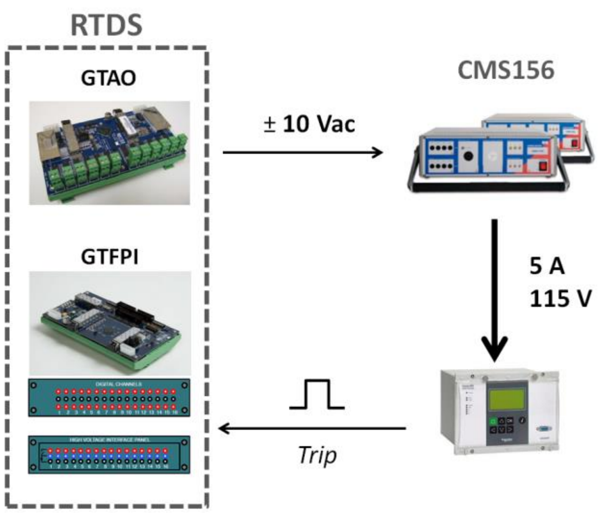

Figure 1. Traditional hard-wired system

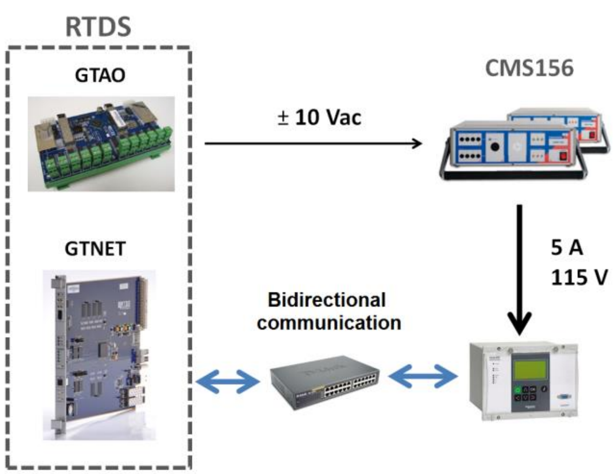

Figure 2. IEC 61850 squeme

The simulated electrical system is a simple generator-load one, as shown in Fig. 3, and it allows one to apply any kind of fault on the terminals of the generators. The current and voltage signals, measured by the modeled current transformer (CT) and voltage transformer (VT) are exported from the RTDS through its analog output card (GTAO) and they have a range of +/- 10V of amplitude. As the input signals of a relay are typically 5 amperes and 115 V_{rms}, one amplifier (CMS156, by Omicron®) must be used to adequate the signal levels.

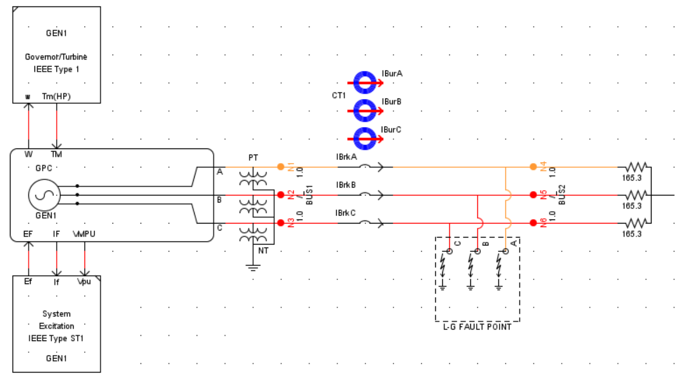

Figure 3. Simulated electrical system

On the hardwired case, the trip signal is received by the RTDS through its front panel interface, which is controlled by the GTFPI card. On the IEC 61850 one, the GTNET card is used, as this is responsible for the network communications. Both of these cards are represented on Fig. 1 and Fig. 2.

All the configuration and connection of the equipment were made based on their manuals: [11], [12] and the IED manual itself.

V. Results

The performance tests consisted on applying a three-phase fault two hundred times on each system and registering the delay time between fault appliance and reception of the trip signal.

In order to illustrate individual cases, the system currents after the appliance of a three phase fault are shown on Fig. 4 and Fig. 5 for the hardwired and the IEC 61850 simulations, respectively. The vertical gray line shows the moment when the IED emitted the trip signal and the black dotted line shows the instant when RTDS receives the signal.

By looking at the graphics, one may see that both of the proposed system connections work properly and may be used to compare the performance of them: by comparing the delay time between the emission of the trip and the reception of it, one is able to evaluate the performance of hardwiring and IEC 61850 GOOSE messages.

Fig. 6 and Fig. 7 show the histograms of the two hundred faults simulated on both systems. They show the time between the appliance of the fault on the simulation and the reception of the trip signal by the RTDS. Table 1 shows the medium times of tripping for each system. P 90 medium is calculated excluding the 5% best and worst response times.

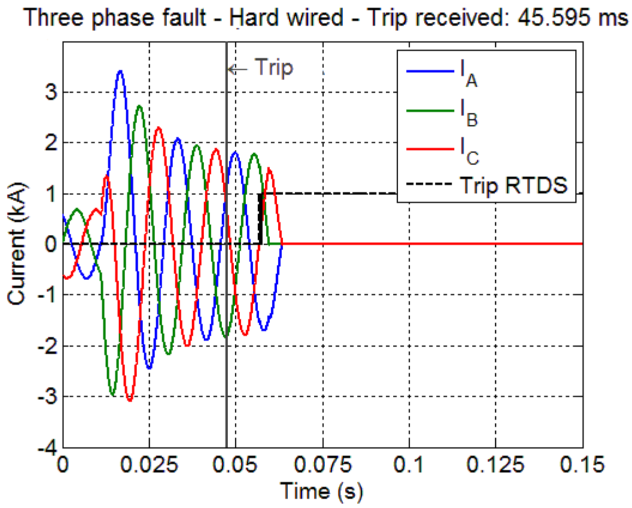

Figure 4. Response to three-phase fault – Hard-wired system

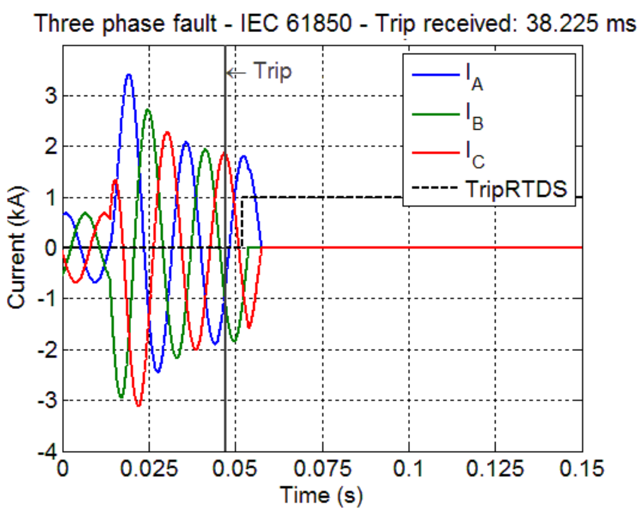

Figure 5. Response to three-phase fault – IEC 61850 system

By analyzing the histograms, one may see that there is a typical delay of 5 ms between the hardwired system and the IEC 61850 one, being the IEC faster. The medium tripping times from Table 1 confirm this difference. Using the whole dataset, the difference is 5.355 ms and the P 90 dataset, 4.83 ms.

By looking at Fig. 4 and Fig. 5 one may also see these typical delays for each case. On the hardwired one sees approximately 10 ms between emission and reception of the trip signal; while on the IEC 61850, the time is approximately 5 ms.

A very interesting point, visible on Fig. 7, is the trip received 48 ms after the fault application. Another feature of a local network is its stochastic nature: as the switch must processes simultaneous messages inside the network, there is the possibility that two packages collide and one of them can be lost or delayed. It seems that this is the case. On the other hand, the hardwired pattern is more concentrated, due to the fact that this is a deterministic event: the energizing of the output contact of the IED.

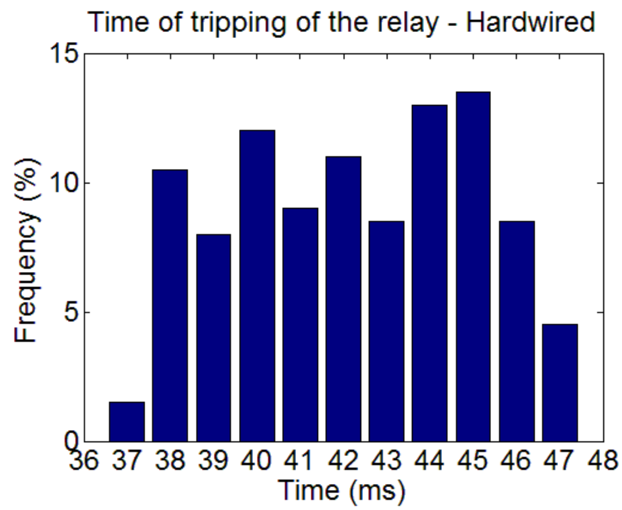

Figure 6. Delay between fault application and trip reception – Hard-wired

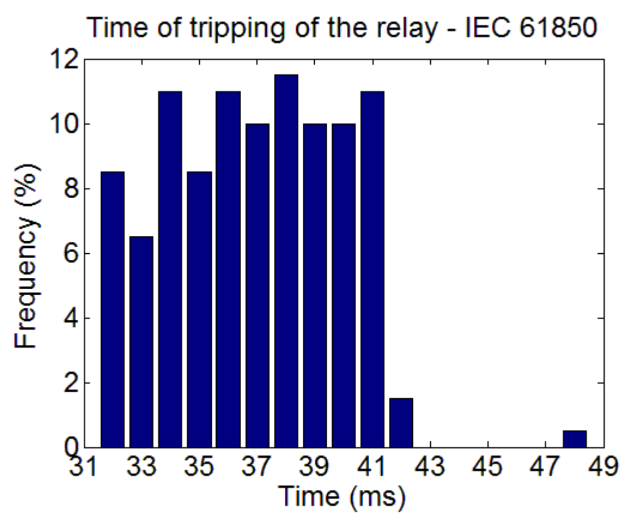

Figure 7. Delay between fault application and trip reception – IEC 61850

TABLE 1. MEDIUM DELAYS OF THE PERFORMANCE TESTS

System	Medium delay	Medium delay (P 90)
Hard wired (HW)	41.250 ms	37.12 ms
IEC 61850	35.895 ms	32.29 ms
Difference (HW – IEC)	5.355 ms	4.83 ms

VI. CONCLUSION

The present work showed the better performance of the IEC 61850 over the traditional hardwired connections on the proposed test system. Besides the advantages such as the bidirectional exchange of data using only one wire per device, the time response of emission of the trip signal was approximately 5ms faster.

The disadvantage of the presented system is the configuration of the local communication network, which demands a considerable knowledge about automation of electrical systems. This is a problem faced by real projects, since the traditional work force, which works with the protection of electrical systems, normally do not have this knowledge.

In such a simple system as the analyzed on this paper, it demands much more effort to configure the IEC 61850 network than to use the traditional hard-wired connection.

However, on real plants – with more devices and logics to be implemented – this may not be such a disadvantaged. The number of cable connections grows exponentially with the number of devices. Therefore, at some level the required work to configure an IEC 61850 network may be smaller than the one required to make all the hardwired connections.

Furthermore, the maintenance and implementing of new logics may be much easier and cheaper on the LAN system than on the hardwired one. These factors may reflect on the reliability of the system, which is very important.

One may still argue that the growth on the number of devices will enhance the chances of a package collision – like the one show on Fig. 7 – which would make the IEC system slower. This is true, but may be mitigated by a careful LAN design. On the presented system, no special effort was made in order to guarantee a good network performance and still the IEC 61850 was faster.

To give an example, in order to improve the proposed system, the use of a multilayer switch would be very interesting. On this devices it is possible to configure VLANs (virtual local area network) enhancing the chance of fast delivering of the GOOSE packages and avoiding the collision seen on Fig. 7. Configuring a VLAN is like breaking the switch into smaller ones, giving priority to some packages over others. On the presented results, no VLAN was configured.

Other factors, like the communication network topology and use of redundancy, among others, may be explored on further studies on the performance of IEC 61850.

ACKNOWLEDGMENT

The authors thank the technical and financial support of PPEE UFJF and the Federal University of Juiz de Fora.

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