A TELE-PROTECTION IMPLEMENTATION EXPERIENCE AT POWER SUBSTATIONS USING METRO ETHERNET NETWORKS

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ABSTRACT

The present paper describes the experience gained (know-how) while implementing a MetroLAN network. Such a network constitutes the core infrastructure of a complete system that supports all communication services towards a main control center. During the whole implementation, which was carried out by CODENSA (the Colombian capital-city power-distribution company) in 2012, various important challenges had to be faced when designing an IP-wise network to carry tele-protection services associated to electric-power transmission lines. The ultimate challenge was to complete a design that guarantees both the desired reliability and the required availability so as to obtain proper operation of tele-protection services within CODENSA's high-power system, which consists of 65 power sub-stations. This paper describes the challenges and corresponding solutions that led to the fulfillment of current regulations and also to cost-reduction benefits. The flexibility that was achieved allows using ip-metro-lan networks to support critical electric-power infrastructure communications. The final part of this paper gathers a set of recommendations so that other companies (Codensa peers, for instance) can benefit from the experience gained, facilitating their own communication-system optimization while keeping up with high-performance, high-reliability communication standards among power sub-stations, particularly interms of critical services such as tele-protection.

INTRODUCTION

In recent years, CODENSA (a company in charge of electric power distribution in Bogotá-Colombia, with up to 3 million customers) has carried out a project called metroLAN. In completion of such a project various communication services migrated from SDH networks to full-IP deployments. This required updating communications equipment as well as laying 65 km of optical-fiber lines (in addition to the existing 550 km) so as to properly connect 65 high-voltage substations to a control center.

Figure 1. MetroLAN Communication network implemented using optical-fiber links between the power substations and CODENSA's power control center.

The project also involved migration processes of services such as tele-control, remote equipment management and the electronic security service for power substations.

However, tele-protection services represent an important challenge since reliable tele-protection-service transmissions via IP networks still need improvement [1]. Some of the drawbacks include the need to meet requirements according to standard IEC 60834-1, especially in terms of performance, namely:

- Dependability: the ability to deliver a tele-protection information at the receiver's end despite channel degradation
- Security: the receiver's capability to reject false tele-protection information resulting from channel degradation

This paper summarizes a set of results obtained by CODENSA while making use of metro-Ethernet networks for the transmission of tele-protection services. The paper also discusses the experience gained during such practices. The results presented attempt to explain the nature of technical obstacles that are still to be overcome together with various alternative solutions (e.g. the use of passive optical devices, which allowed making up for some of the weaknesses of Metro-Lan networks when carrying the data associated with tele-protection links).

The main problems encountered (and properly identified) when using metro networks to provide tele-protection services [2] are as follows:

- Latency: Maximum delay intervals for the transmission of tele-trigger data over a tele-protection link between two ends must not exceed 16 ms for 60Hz grids. Therefore, the addition of packet delays, routing delays, and buffer-jitter delays must be less than the specified figure (16 ms) plus the time margin of tele-protection equipment.

- Jitter: Under normal operation, this condition results from equipment construction itself and can be regarded as negligible. Jitter becomes noticeable when unusual conditions occur, such as communications-network congestion. In these particular cases it is necessary to resort to QoS (Quality of Service) functionalities.

- Network architecture: response time for main-ring nodes in old SDH networks is about 50ms, and the new Metro-Ethernet networks keep up to such standards. However, on access points, convergence times might result in lower performance, which must be validated prior to actual implementation on tele-protection networks. This should be analyzed thoroughly under testing conditions such as intermediate-equipment failure.

- Synchronization: Because equipment precision is crucial, timestamps are important, thus the use of protocol PTP is highly recommended.

- Protocols: It is suggested that standard IEC 61850 be followed together with a layer-2 network, allowing tele-protection information exchange. However, other protocols (such as Mirrorbit) can be successfully implemented.

CHALLENGES ASSOCIATED TO TELE-PROTECTION-SERVICE IMPLEMENATION VIA IP-METROLAN NETWORKS

Implementation of the metroLAN network implied a migration process, for all existing network communication services that used to be SDH-based, towards IP-based technology. During the project, migration of the whole range of services was performed with some difficulty, but care was taken so as not to put the project's schedule at risk.

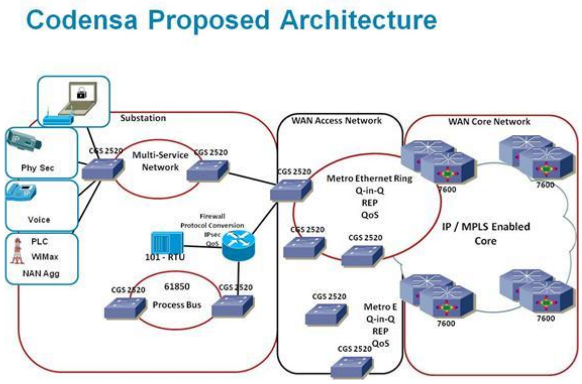

Figure 2. Architecture summary, MetroLAN network implemented by CODENSA

However, in the first stages associated to tele-protection service-migration design, it was soon clear that various requirements, not included in the IP standard behavior, were to be met. A first step towards overcoming this situation was to revise existing literature on the subject, which revealed a set of technical issues such as the unsuccessful timing and poor reliability caused by the probabilistic behavior of such networks and the impact of atypical traffic patterns on the overall performance [3]. In order to solve this situation, it was first decided that high-power-line critical links be identified, that is, it was necessary to identify those high-power lines whose tele-protection services could not be properly provided due to their requirements in terms of trigger timing or function type (Bus bar differential protection), impeding a reliable migration process. For this reason, the communication network design intended for providing tele-protection services was established as shown in Figure 3.

Thus it was possible to avoid failure risks associated to communication equipment as well as avoiding cascade effects resulting from communication-network failure.

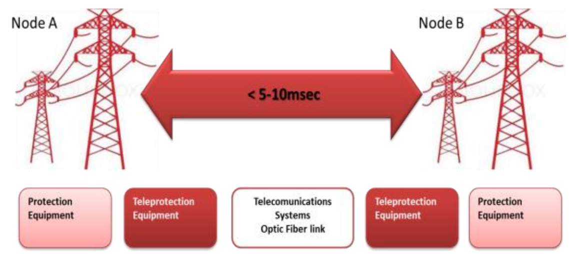

Figure 3. Tele-protection network implemented by Codensa for high-power critical lines.

Using this communication architecture, Codensa implemented 33 links intended for tele-protection, whose purpose was to protect high-power lines. This required a 65-Km optical-fiber lay in addition to the existing 550 kilometers of optical-fiber lines.

INTERNATIONAL STANDARDS

In order to validate the necessary requirements and achieve proper operation of tele-protection services, a comprehensive survey of existing regulations on the subject was conducted.

IEC 60834

Standard IEC 60834 includes the necessary requirements to guarantee proper operation of tele-protection services. This standard presents various requirements to be met in the following contexts

WAN channel typical Degradation: In the case of analog channels, common signal degradations occur due to attenuation, interference, frequency shifts between transmitter and receiver, and noise. In the case of digital channels, bit error rates, jitter and propagation delays may affect signal reception.

Teleprotection-system parameter performance: This standard defines performance parameters such as dependability and security. Each of these parameters involves various restrictions that must be met by any tele-protection-system design. Additionally, tele-protection information must be transmitted within a maximum time interval.

Tele-protection system performance against channel degradation: Standard IEC60834-1 specifies the way tele-protection must occur when dealing with degraded channels. For example, when using a digital channel, it is required that dependability levels should be Pmc= 1e-3 with BER=1e-6, and a maximum transmission time equal to 100 msec for all types of tele-protection applications.

IEC 61850 – GOOSE Messages

In general, tele-protection equipment is similar to the traditional IED found at sub-stations and therefore compliance with Standard IEC 61850 [4] assumes that, whenever necessary, the sub-station's gateway equipment should deal with the conversion process of information from other power sub-stations. Since, in this way, the system deals with a sample value that carries information about a trigger order towards another sub-station, the system must comply with standard IEC 60834-1 as well as meeting the information-wise requirements included in standard IEC 61850, which facilitate such interoperability among different components at substations as well as diagnosis tasks (e.g. communication channel status). It is important to remember that standard IEC 61850 Std2 can be more effective as long as standard IEEE 1588 is adopted, which corresponds to the adoption of protocol PTP. Given the demanding requirements in terms of intervention times, this facilitates sub-station synchronization among sub-stations that use tele-protected lines [5].

CODENSA'S EXPERIENCE ON DESIGNING AND IMPLEMENTING TELEPROTECTION SERVICES VIA METROLAN NETWORKS

Once the tele-protection links that were not crucial were separated, various tests were conducted so as to a enable tele-protection links in a controlled way via metroLAN networks [6]. In the first trials, results were discouraging since communication equipment exhibited poor response times when compares to those required by current standards. Subsequently, attempts at using other information-transmission proprietary protocols were made so as comply with the serial-to-IP conversion function via intermediate equipment. Theoretically speaking, this would yield shorter response times; however, measurements revealed that by using different equipment to perform such conversion, independent from the information-transmission equipment via the switching network associated to the metroLAN network, allowed meeting the desired response times an also improved the overall system performance. By thoroughly revising the logs stored in the network equipment, it was possible to find the most suitable behavior in terms of memory usage. This might account for the performance improvement observed when another piece of network equipment was added. Results showed that metroLAN network response times range from 10 to 15 ms, which is good enough to run applications where there is no critical link.

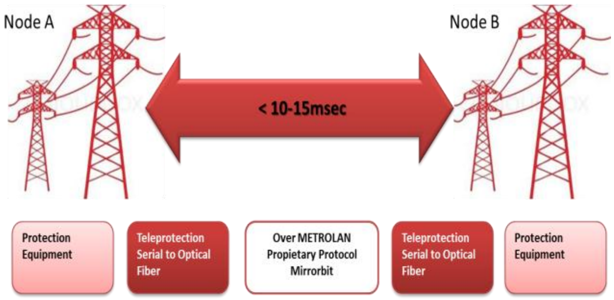

Figure 4. Teleproteccion network implemented by Codensa, intended for high-power non-critical lines.

One of the elements that is still a subject of study and should be further investigated is the understanding of the system's behavior under failure conditions (metroLAN failure [7]). In such situations, network-recovery times ranging from 20 to 50 ms have been experienced. This represents a limiting factor when using the data-transport layers on this type of communication links, where latency is extremely low [8] when compared to most of the commercial applications that run at power sub-stations.

The tests currently being conducted are intended to determine whether synchronization via PTP has a positive impact on the response times associated with these links under failure conditions. It is also expected that the tests help to find a way to reduce latency when dealing with large-scale networks.

The times associated to remote triggers imply that, under normal conditions, the communication system would allow the linking of any tele-protection event; however, under failure conditions or when facing extremely busy communication periods, these times might fluctuate between 21 and 50 ms, which do not guarantee the expected reliability for these type of tele-protection systems associated to high-power lines [9].

CONCLUSIONS AND RECOMMENDATIONS

The results obtained by CODENSA confirm the estimates associated to the ever-closer possibility of using IP networks to carry low-latency services such as tele-protection.

While implementing tele-protection services over metroLAN networks, it is worth mentioning that such an implementation does not cover the entire set of high-power lines. As indicated in the results presented above (regarding CODENSA's metroLAN network), there still exist lines with critical performance levels that cannot carry data via IP networks without compromising the fulfillment of current standards. Unlike other studies, CODENSA's network implementation indicates that under failure conditions, metroLAN networks still have a long way to go in order to guarantee proper network-recovery times that suit critical tele-protection links such as line differential-protection.

The experiences gathered by CODENSA show that using point-to-point links (through fiber optical media) is still a simple and highly reliable solution for critical-link transmissions associated to high-power lines.

Some of the aspects that can be improved in future tele-protection link validations include a proposal to ensure synchronization with protocol IEEE 1588 (PTP). The purpose is to guarantee that delay conditions associated to communication-system (metroLAN) contingency responses are not caused by network synchronization difficulties.

On the other hand, it is recommended that metroLAN networks be used to cover links regarded (by the corresponding risk matrices) as non-critical, since cost reductions represent long-run, long-lasting benefits.

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