Communication Network for a Wide-Area Special Protection System

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***Abstract*— Special Protection Systems' requirements define the communications scheme so that the power system protections inside work. An Internet-based communications architecture with two level hierarchy is presented. The upper level is a broad-band SDH/SONET network, and the lower network is an IEC61850 standard based Ethernet. The protocols required in each of the layers are determined. The SPS traffic and background traffic of the communication system are also displayed. Finally, a simulation of a hypothetical network based on the Colombian power system is performed, and the network's performance and the transport protocols are evaluated as a function of the delays and dropped packets inside the protocols.**

***Index Terms*—IEC61850, Communications System, Special Protection Systems SPS, Background Traffic, Phase Measurement Unit PMU, Wide-Area Monitoring Systems.**

I. Introduction

Special Protection Systems (SPS) incorporate modern sensor equipment, communication systems and computer networks. The goal is to improve reliability levels, network security and Wide-Area power system stability.

The communication scheme can benefit the SPS by increasing its accuracy and reliability [1], [2]. Furthermore, the development of communications positively impact performance and quality monitoring processes, state estimation, control, operation and management of power systems. [3]

The SPS obtains information from several locations that are distant from the power system using wide-area measurements with time-labels and communications technology, by organized measurements that are arranged into time-labeled measurement sets. The measured information is used for power system estimation and forecast if such is possible, in order to identify disturbances in the power system. In the case that a disturbance is detected, the SPS performs a series of scheduled actions and performs an action information collection in order to adjust subsequent actions until the disturbance is mitigated [5]. This process is executed in real time.

This paper presents the SPS communications requirements for adequate operations. Such requirements, define communications infrastructure that include: structure, media, network topology and protocols. Finally, a simulation of the proposed communications network is executed in order to evaluate the performance of the network in terms of the delay and packet loss.

II. Communications Network

The basic components of a SPS include: Phasor Measurement Units (PMUs), System Protection Terminals (SPTs), a Phasor Data Concentrator (PDC), the PMU-based applications and, finally, the communication system [6], [5]. As shown in the block diagram in Fig. 1.

The communication system is an essential element of the SPS, since it distributes and manages remote information Such importance relies in the fact that the optimal decision is made by collecting global data that depends on the communication system performance [5].

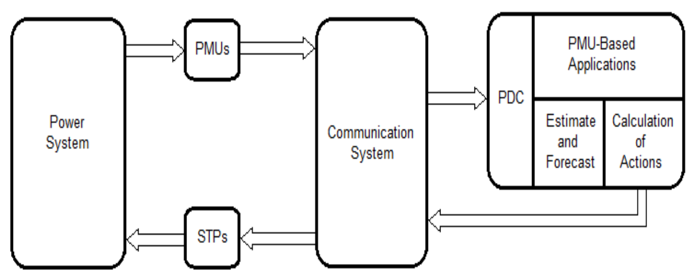

Fig. 1: Conceptual diagram of a SPS.

A. Communication Requirements

There are several communication requirements. However, delay and packet loss rate requirements are the most critical, since SPS operates in real-time. Such condition defines the protocol selection as the critical element of the design in the transport layer.

The power system state estimation and forecast application determines the tolerance for packet loss. In this case, state estimation and forecast is made by a Kalman-filter implementation as shown in [3]. Such strategy results in acceptable values when the three second forecast has been performed. Hence, this methodology tolerates a maximum of three second period for packet loss.

The disturbance inside the power system that demands a higher speed requirement is the transient instability, specifically the power angle stability loss. The oscillation detection can be obtained with at least two phase samples [1]. In the worst case scenario, the system stability can be maintained only if the protection scheme actuates before 0.5s. [1], [5].

The times involved in the disturbance detection and subsequent actions to mitigate the disturbance are: T_s as PMU sampling time, T_1 as sample's transmission delay, T_{PDC} as the time to sort measurements in the PDC, and T_{Dec} as the time required to detect disturbance and determine actions against disturbance. Finally T_2 is protection order transmission's delay. As two measurements are required for oscillation detection, the transmission delay is assumed to be the same for the two samples (T_1). The timing diagram is depicted in Fig. 2.

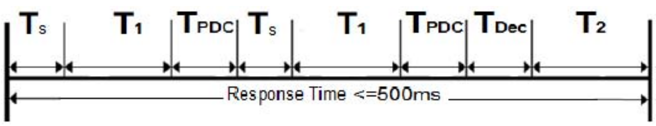

Fig. 2: Timing Diagram SPS Response Time to the transient instability

According to Fig 2, equation (1) shows the total time requirement.

$$T_s + T_1 + T_{PDC} + T_s + T_1 + T_{PDC} + T_{Dec} + T_2 \leq 0.5s \quad (1)$$

Assuming that the sampling rate in the PMU is 30Hz, T_s correspond to 33,33ms. In this case, sort measurements are made by the PDC algorithm presented in [6]. Hence, the maximum time to sort phase measurements is 55ms, which defines that T_{PDC} has to be at least 55ms . Assuming the protection order time, T_{Dec}, is 50ms, equation (2) is obtained.

$$2(33.33ms) + 2T_1 + 2(55ms) + 50ms + T_2 \leq 500ms \quad (2)$$

Thus the delay requirement is given by equation (3).

$$2T_1 + T_2 \leq 273.33ms \quad (3)$$

Evaluating the limit of maximum allowable delays, and assuming that the upload and download delays are the same, $T_1 = T_2 = T$,bounds for the delays are obtained in (4).

$$3T \leq 273.33ms$$

$$T \leq 91.11ms \quad (4)$$

B. *Communications Infrastructure*

An Internet communication standard is chosen, because of its popularity, low cost, and easy migration. However, taking into account that Internet was not designed for time-critical applications, special attention must be taken to ensure that the capabilities of the network, protocols, security and Quality of Service (QoS) are properly managed to ensure that the Internet-based network is capable of meeting the requirements of the SPS [2], [7].

To operate an SPS, the communications network can be seen as a two level hierarchy system, as presented in [4]. The lower level is a Local Area Network (LAN). This level is in charge of the communication between substations and power plants, PMUs, SPTs, the substation host, and other Intelligent Electronic Devices (IEDs) that are directly related to the power equipment of the substation [1]. As defined in the IEC61850 standard [8] [9], the LAN control center is a common network with several hosts. Still, the server that supports the PMU-based applications along with the PDC belong to this network. The substations and control center are nodes in the upper level [1], which corresponds to a Wide Area Network WAN.

The selection of communication protocols is critical to guarantee an adequate QoS of the communications system. The protocol selection in different layers of the stack depends on the fact that the communication network is based on Internet technologies.

The selection of the transport protocol is the most important; Internet has only two transport protocols, Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) [10]. The importance of the protocol selection relies in the fact that each protocol has advantages and disadvantages, which directly affect the final QoS of the system.

III. COMMUNICATIONS NETWORK TRAFFIC

Two types of traffic are generated inside a SPS: "Upload" and "Download" traffic. Upload traffic corresponds to those packets containing phase measurements provided by the PMU and sent to the control center, with data format defined by the C37.118 standard [11], [14]. Download traffic corresponds to those packages with the information required for disturbance mitigation, which are created in the control center and sent to the corresponding STP. These traffic models are presented in Table 1.

The communication network is not only used for the SPS. Data rates, coverage and other benefits make it a general purpose network for the power system. The traffic that is not generated by the SPS is called background traffic, as seen in [2] and [7].

IV. EXPERIMENTAL SCENARIO

The Colombian power system scenario was studied in order to calculate delays and dropped packets from the SPS communication system simulation, by proposing a hypothetical communication network. Only 21 substations and power plants were chosen as base sites in order to generate network measurements and SPS interaction with the power system. The 21 chosen substations and power plants correspond to those with the greatest number of buses and a 90% chargeability in mean operation [12].

TABLE 1: UPLOAD AND DOWNLOAD TRAFFIC PARAMETERS.

Source	Destiny	Traffic Type	Packet Size	Interval Packet	Transport Protocol
Upload Traffic					
Each PMU	Control Center	Constant	38B/Bus	33.33ms	UDP/TCP
Download Traffic					
Control Center	Breaker	Poisson	100B	Random	UDP/TCP

The upper level of the communication system is presented in Fig. 3. The links between each node (substations) of the upper level are implemented with optical fiber as the physical transmission medium, using 155.52Mbps ST1 SDH protocol.

Different size substations are considered for system heterogeneity. The substation LAN is an Ethernet network with links up to 100Mbps transmission rate. The LAN network model in substations and power plants is presented in Fig. 4. The LAN control center is also an Ethernet network but with links up to 1Gbps transmission rate, as shown in Fig. 5.

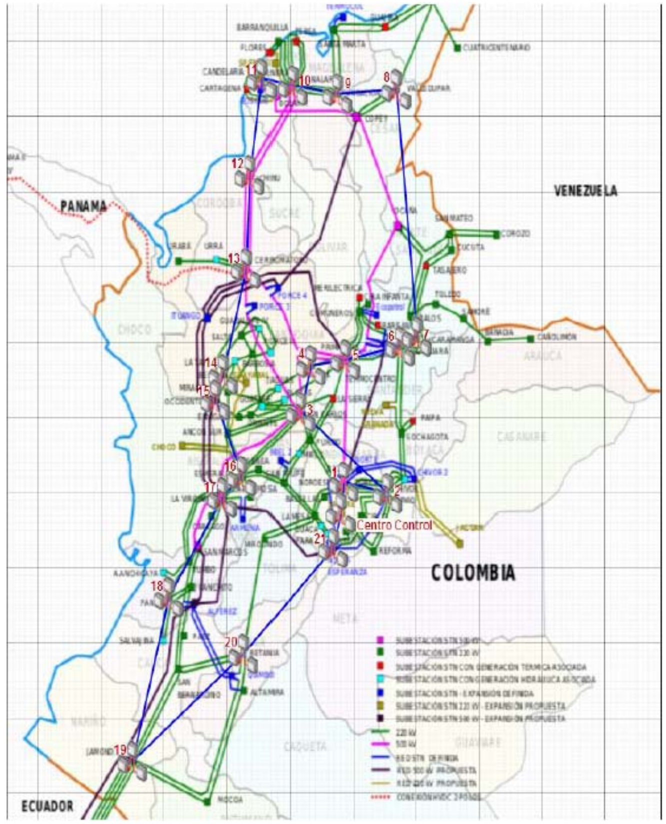

Fig. 3: Experimental Scenario

V. COMMUNICATION NETWORK SIMULATION

The simulations were performed in QualNet ® 5.1 simulation software. The algorithm used for packet routing was RIP version 2 since it presents a simple configuration. It is an open algorithm (supports derivative versions which are not necessarily compatible), and it is widely used. Furthermore, it is supported by most of the manufacturers. Moreover, RIP is the canonical example of the routing protocols, and it is distance vector algorithm based [13]. The first packet stands for five minutes (300 seconds) before it is sent, in order to have an adequate network initialization.

The simulations results of the Upload traffic using UDP without background traffic are depicted in Fig. 6. Upload traffic simulations results using TCP without background traffic are depicted in Fig. 7. In the case where UDP is used as transport protocol, the upload traffic delay constraint given by (4) is met even considering the worst case scenario, in great extent. For example, taking the larger packet delay in the simulation, which correspond to 8.4ms, the 91,11ms constraint is met.

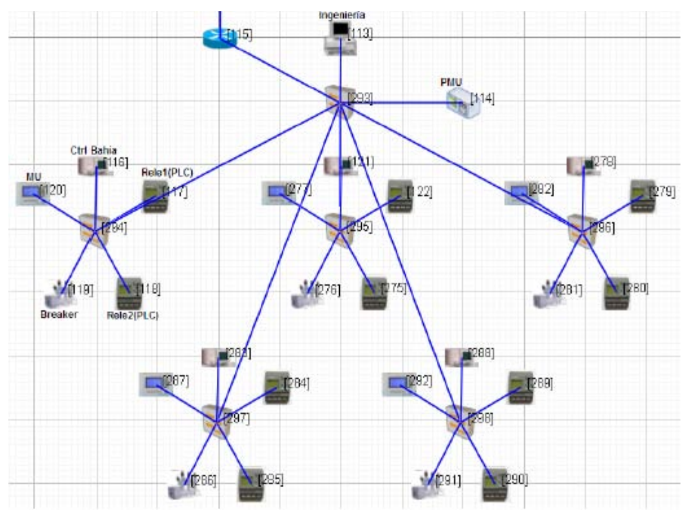

Fig. 4: Substation LAN

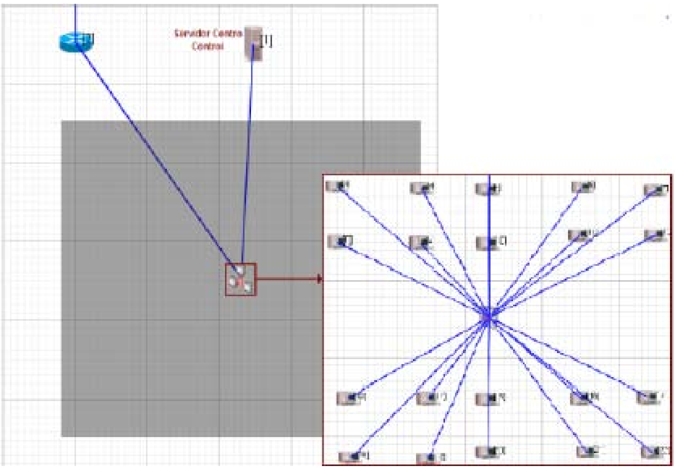

Fig. 5: Control Center LAN

In the case where TCP is used as transport protocol the upload traffic delay boundary given by (4) is not satisfied, because even if the control order delay is neglected ($T_2 = 0$), the Upload packets present delays greater than the 91.11ms, in more than 60% of the cases. Therefore, the chosen upload traffic protocol is UDP.

UDP upload packets are shown in Fig. 8. When background traffic is included, the time window is increased, in order to have a better perception of the effects of background traffic regarding their delays. The maximum delay obtained is twice the delay obtained without background traffic. However, the delay constraint in (4) was met.

The download packets in a background traffic scenario are show in Fig. 9 and Fig. 10. The first graph corresponds to the UDP case and the latter corresponds to the TCP scenario. The graphs show that the Download packet delays are very low. Such packets meet the constraint even under background traffic. In this case, the download traffic is not affected by whether of the transport protocols is used (TCP or UDP).

Finally, packet loss are not presented.. For this particular case, the Internet-based network is not saturated even in the presence of background traffic. The proposed communication network meets both of the requirements: low delay and low packet loss.

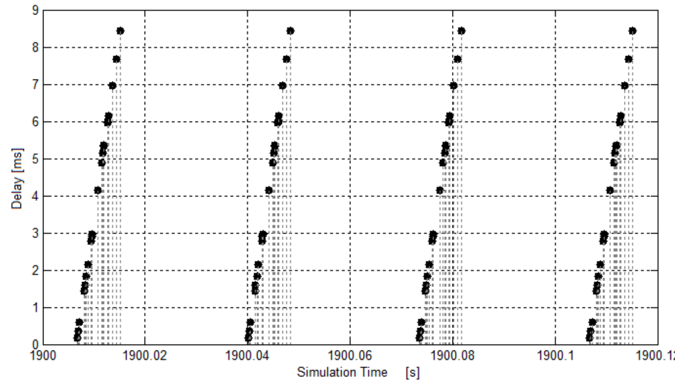

Fig. 6: Upload Packets Delay Using UDP, Without Background Traffic.

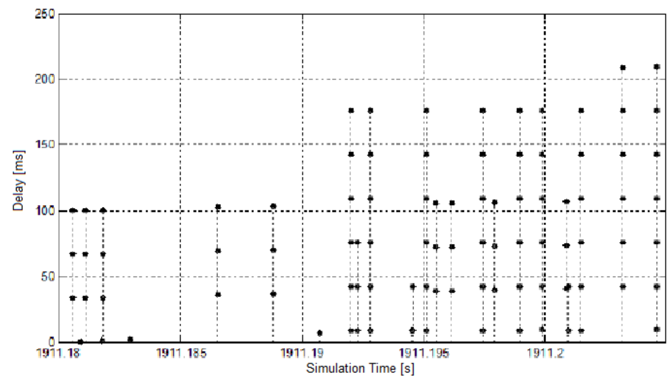

Fig. 7: Upload Packets Delay Using TCP, Without Background Traffic.

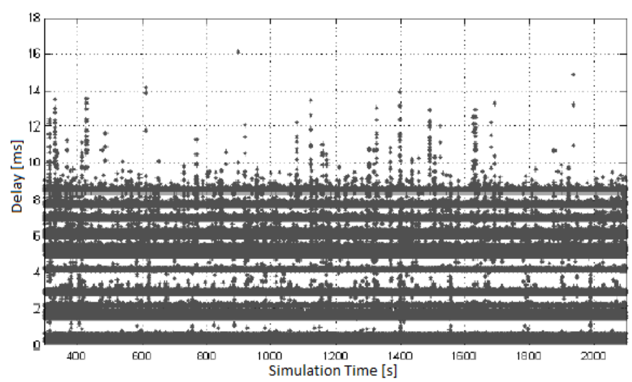

Fig. 8: Upload Packets Delay Using UDP, With Background Traffic.

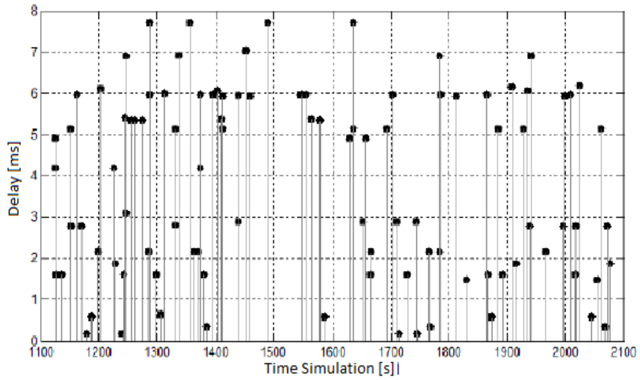

Fig. 9: Download Packets Delay Using UDP, With Background Traffic.

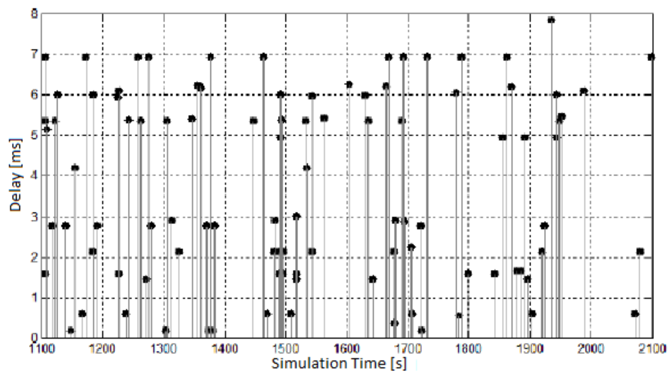

Fig. 10: Download Packets Delay Using TCP, With Background Traffic.

VI. Conclusions and Recommendations

For the hypothetical case presented, the communication network meets all the requirements needed for proper operation over SPS in the Colombian power system for the 21 selected substations under study. Upload packages with phase measurements must be sent using UDP as transport protocol. Since TCP adds very high delays in flow control, which result in a high percentage of failed packets for delay fulfillment, adequate power state estimation and disturbance detection is not well performed.

For Download traffic, the obtained delays are independent of the chosen transport protocol (UDP or TCP). However, TCP is highly recommended, because it provides better delivery reliability in comparison to UDP, thereby meeting the requirement of high reliability of delivery required by download traffic.

In the studied case the traffic due to other power system processes do not greatly affect the behavior of Upload and Download traffics in terms of delay and dropped packet.

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