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DIGITAL COMMUNICATIONS INFLUENCE ON TOTAL FAULT CLEARING TIME

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The aim of this article is to evaluate the performances of digital communications in terms of total fault clearing time. Protection and control systems, along with communications links are directly responsible for overall fault clearing time. Nowadays, the interest on digital communications is growing due to adoption of digital substations configuration and introducing IEC 61850 standard into the switchyard. This paper studies the fault clearing time of a 220 kV substation from Romanian Transmission Grid in different design configurations: conventional configuration and digital configuration. There are performed different transient stability simulations for each configuration to study the system time response.

Keywords: transient stability, digital substations, IEC 61850, protection and control system, fault clearing time

1. Introduction

The international communication standard IEC 61850 had a major impact on Intelligent Electronic Devices' (IEDs) developing. Digital communications, along with IEC 61850 standard is a novel concept that facilitate the transition from conventional, non-refurbished substations towards digital substations [1], [2].

The IEC 61850 "Communication Networks and Systems for Utility Automation" standard was introduced to enable the communication between different IEDs. To achieve this goal, this standard is divided in 10 main sections, as presented in [3].

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This paper focuses on introducing process bus along with sampled values at process level. IEC 61850-9-2/2LE standard defines process bus and sampled values (SV). In order to facilitate the transition to digital Ss, power utilities must be proper informed about the performance level of the new technology.

In [4] are presented some specific substation applications based on sampled values and the benefits of introducing IEC 61850-9-2 process bus-based substations. In [5] is presented an example of a digital substation project developed by Energinet, Denmark.

Figure 1 presents the simplified architecture of a substation based on IEC 61850 [6] (NCC – National Control Center; RCC – Regional Control Center).

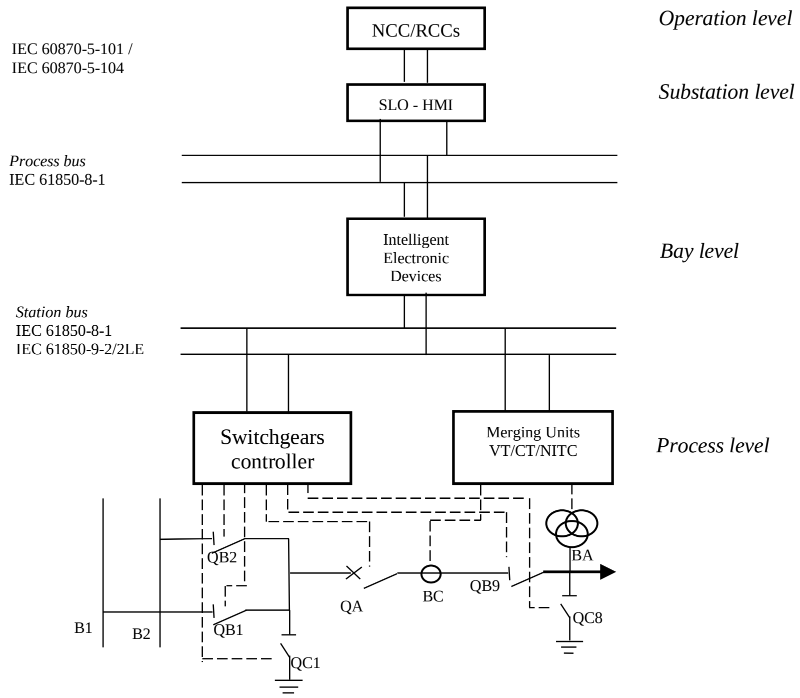

Fig. 1. The simplified architecture of a substation based on IEC 61850

In Fig. 1, primary equipments together with switchgear controllers and merging units are located at process level. They are exchanging information with IEDs located at bay level using process bus based on IEC 61850-8-1, respectively IEC 61850-9-2/2LE. Human Machine Interfaces (HMIs) located at substation level are exchanging information with process level and bay level using IEC 61850-8-1 substation bus. Furthermore, the entire process is observed at operation level (NCC and RCC), by using IEC 610870-5-101/104 communication protocol.

Even if the main advantage by introducing digital communication based on IEC 61850 standard consist of elimination the interoperability barriers between devices from different manufacturers, this still represent a challenge for protection engineers due to the substations' unicity. In [7] is presented a methodology to obtain interoperability.

Along to the interoperability challenges, digital communication also introduce challenges related to time synchronization. In IEC 61850-9-2 process bus substations measured data are digitized in the field, next to primary equipments. In order to have a secure protection system it's important to proper synchronize the SVs, keeping the time delay at minimum. According to [8], time delays consists of: "cable delays, switch fabric latency, store and forwards of switches, queuing from switches". IEC 61850-9-2 SVs are synchronized according to IEEE 1588 "Precision Time Synchronization Protocol", as it provides accuracy at nanosecond level.

Another important issue related to process bus is Ethernet network bandwidth. It is important to send only relevant information from process level to SCADA to avoid overcharging the process bus as may lead to additional delays of SCADA [8].

This article aims to study the performances of digital communications based on IEC 61850 process bus from total fault clearing time point of view. There are computed different transient stability studies considering a 220 kV substation from Romania Power System in different configurations: classical, non-refurbished configuration and in digital configuration. It is evaluated the power transfer response of a synchronous hydro-generator located in close proximity to the studied substation.

In this paper, Section 2 presents the architecture of digital substations, Section 3 presents the time performances needed to be acquired by digital equipments and an example of an IEC 61850-9-2 process bus architecture, Section 3 presents the case study and the simulation results while Section 4 presents conclusions and propose future works.

2. Digital substation architecture

Digital substations design is divided into three levels: digitalization at process level, digitalization at bay level and digitalization at station level. Furthermore, to have a full digital substation, the following concepts must be adopted: cyber security, grid operation support, asset management support, integrated substation engineering.

2.1. Digitalization at process level

Process level in traditional substation is formed by primary equipments (unit transformers, instrument transformers, switching equiments, etc). Digitalization at process level facilitate the introduction of nonconventional instrument transformers (NCITs), together with merging units and breaker controller devices [9].

In digital substations, both analog and binary data are digitized at switchyard level, next to primary equipments and transmitted to IEDs (from substation level) through digital communication, using IEC 61850-9-2/2LE, respectively IEC 61850-8-1. Process bus is the interface between primary equipments and protection and control system.

Breaker controller devices represents the interface between protection and control system and switching equipments. They receive and transfer switching equipment's status and operating commands via process bus, using IEC 61850-8-1 standard protocol.

According to [10], merging unit is a "*physical unit used to do the time-coherent combination of the current and/or voltage data coming from the secondary converters. The merging unit can be part of one of the transformers in the field or may be a separate unit*."

Merging units are placed at switchyard level, in proximity of instruments transformers and sends sampled measured values (SVs) via process bus, using IEC 61850-9-2/2LE. Measured values are transformed into sampled digital values keeping the accuracy of the measured data.

2.2. Digitalization at bay level

Bay level is formed by Intelligent Electronic Devices (IEDs): protection and control devices, metering devices, etc. Merging Units devices removes the need to equip IEDs with binary inputs, contributing to minimize both protection and control devices' size and protection and control cabinets' size.

To ensure the communication network redundancy criteria, it is common to use IEC 62439-HSR (eng. High-Availability Seamless Redundancy) or IEC 62439-PRP (eng. Parallel Redundancy Protocol). The PRP standard is mainly used in Romanian transmission substation.

2.3. Digitalization at substation level

The substation level is formed by HMIs, ethernet switches, engineering and configuration tools, asset management tools, data concentrators, etc. Communication between bay level and substation level is realized by substation bus, using IEC 61850-8-1 protocol. Substation bus enables communication between different clients, allowing the implementation of tools like Wide Area Monitoring Systems (Eng. WAMS).

Different manufacturers from power energy field had developed multiple software applications to increase the observability of both substation and power system: WAMS application, asset management applications, SCADA applications (eng. Supervisory Control and Data Acquisition).

Digital substations bring major benefits not only in terms of operation and commissioning, but also in terms of designing and engineering tests.

3. Total fault clearing time in IEC 61850 process bus-based substations

According to [10], [11], [12], IEC 61850 based devices must have a common model of performances. The performances of the IEC 61850 based devices are strongly influenced by measurement data accuracy, time stamp and time model.

IEC 61850-5 [11] defines transfer time as time interval between the moment when the information is transferred to the stack by the sender device and the information is recovered from the stack by the receiver device.

Figure 2 shows the transfer time between two IEDs, according to [11]. Transfer time is calculated taking into consideration the processing time of each IED, respectively the communication network transfer time, including waiting time.

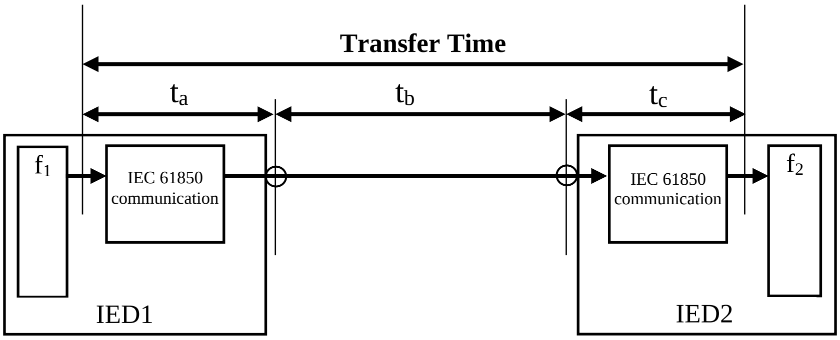

Fig. 2. Transfer time diagram [6]

In Figure 2,

- t – transfer time

$$t = t_a + t_b + t_c \qquad (1)$$

- t_a – IED1 stack processing data time and transmitted it over the communication network;
- t_b – communication network transfer time;
- t_c – IED2 receiving and processing data time.

There are multiple data transmitted in electrical substations with different levels of performances.

In [11] are defined two independent performance classes groups: one for protection and control and the other one for metering and power energy quality. The aim of this article is to study the protection and control devices performances from total fault clearing time point of view. Therefore, below it will be presented the performance classes for protection and control devices.

Additionally, [11] defines three performance classes for protection and control devices:

- Performance class P1 - distribution data or where low performances are accepted;
- Performance class P2 - transmission data or where there is no additional information about the data type;
- Performance class P3 – transmission data with high level of performances.

Time transfer performance is also influenced by the message type. In [11] are defined seven message types: *Type 1* – fast messages (it is divided in two categories: Type 1A "Trip" and Type 1B "Others"), *Type 2* – medium messages, *Type 3* – slow messages, *Type 4* – messages that contain row data (ex.: instrument transformers measurements), *Type 5* – transfer files data, *Type 6* – time synchronization (ex.: time stamp, sampled values synchronization), $t \geq 1$ s and *Type 7* – command messages with control request.

Protection and control devices must meet the standard specifications of Type 1, Type 4 and Type 6 messages, as shown in Table 1.

Table 1

Total transfer time, according to IEC61850-5-2003 [12]

Message Type	Performance class	Total transfer time, in ms
Type 1A	P1 P2 P3	≤10 ≤3 ≤3
Type 1B	P1 P2 P3	≤100 ≤20 ≤20
Type 4	P1 P2 P3	≤10 ≤3 ≤3

Figure 3 shows a simplified block diagram of an IEC 61850 process bus substation. In Figure 3, total fault clearing time is influenced by merging units operating time, process bus operating time, IEDs operating time and circuit breaker operating time.

In Figure 3,

- t_{total} – total fault clearing time;

$$t_{total} = t_{SM} + t_{CI1} + t_{LAN} + t_{CI2} + t_{PA} + t_{trip} + t_{CB} \quad (2)$$

- t_{SM} – merging unit processing time;
- t_{CI1} – communication interface operating time;
- t_{LAN} - process bus operating time;
- t_{CI2} – communication interface operating time;
- t_{PA} – process algorithm operating time;
- t_{trip} – tripping module operating time;
- t_{CB} – circuit breaker operating time.

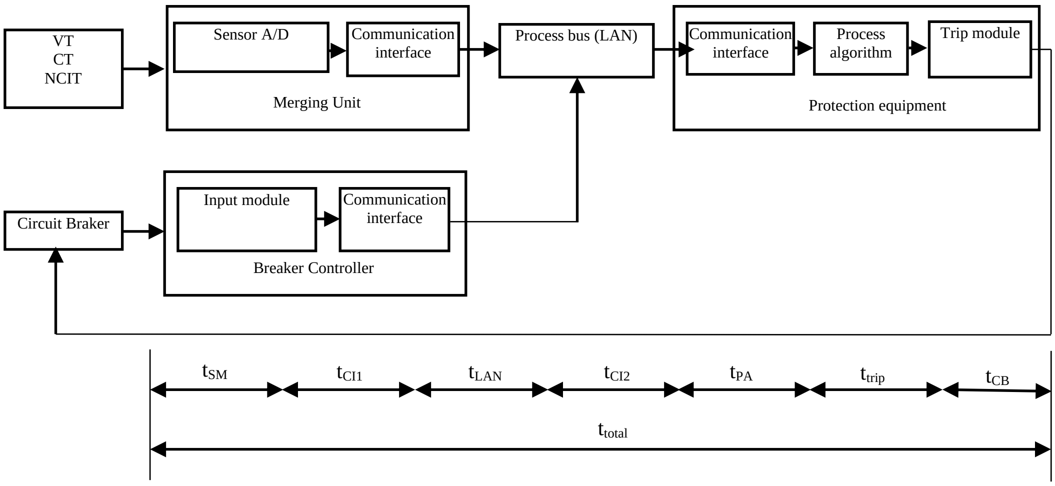

Fig. 3. Simplified diagram of the total fault clearing time in a IEC 61850 based substation [6]

According to [13], total fault clearing time represent "*the time interval between the fault inception and the fault clearance*". The overall fault clearing time must be smaller than the critical clearing time, when system can lose its stability [6], [14].

4. Case Study

The aim of this paper is to present the benefits of introducing the IEC 61850 process bus in a 220 kV substation from Romanian Power Grid in terms of total fault clearing. It is evaluated the time response of synchronous generators located next to the studied substation by realizing transient stability simulations in different scenarios.

Figure 4 presents the single line diagram of the studied network area. The studied substation, 220 kV Substation A, is linked through two 220 kV Overhead Transmission Lines (OHLs) to a hydroelectric power plant. The hydroelectric power plant is formed by four identically generating units, 61 MVA installed power each.

In present, the studied 220/110 kV Substation A is a conventional, non-refurbished substation. The 220/100 kV Substation A equipments are commissioned between 1963-2000 years and designed at the technological level of that time. Therefore, the primary and secondary equipments are obsolete. The 220/110 kV Substation A was recently involved into a refurbishment process at process level, bay level and substation level.

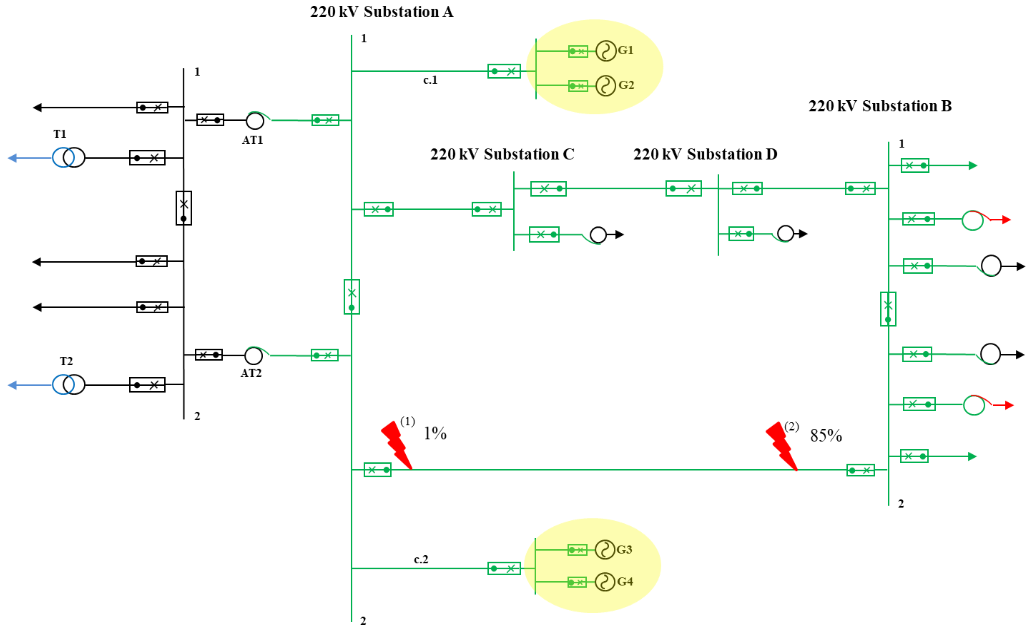

Fig. 4. Framing the studied network area

Transient stability trials are conducted in EUROSTAG software in which is modelled the entire 400/220/110 kV Romanian power grid. There are considered two scenarios: the studied substation in conventional configuration and in digital configuration, having IEC 61850 standard introduced at process level.

To analyze synchronous generators behavior, there are three stages of time-domain simulations that can be performed during transient stability trials: pre-disturbance, moment of disturbance and post-disturbance. The synchronous generators response to disturbances involves changes in rotor speeds, power angles and power transfer [15]. In this article is studied the synchronous generators response in terms of power transfer after the disturbance occurs.

Transient simulation simulations were realized by simulating a three-phase short circuit on different 220 kV OHL A-B locations: at 1% of the 220 kV substation A and at 85% of the 220 kV substation A.

The total fault clearing time to eliminate the short circuit in conventional substation simulations is considered 130 ms. This time was decided based on a post-event analyze of a fault on 220 kV OHL A-B, near the 220 kV studied Substation A – Figure 5.

Figure 5 shows the protection relays pick-up time (Pick up 51N, Pick up 21) and trip decision (Trip, Trip phase A), the circuit breaker tripping time. 51N represent the ANSI achronym of neutral time overcurrent protection relay, while 21 represent distance protection relay. The total fault clearing time is 128,8 ms.

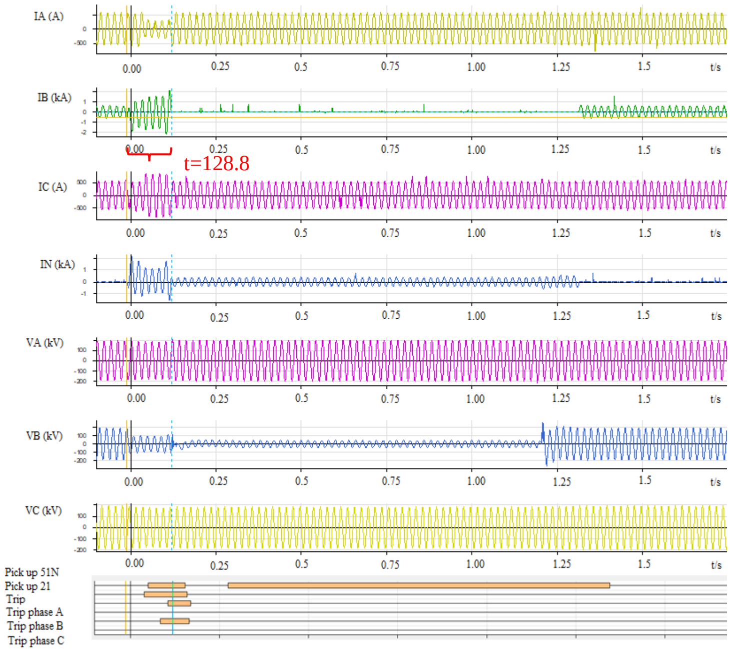

Fig. 5. Oscillography recording to a fault located near 220 kV Substation A

In Figure 6 and Figure 7, red dotted line shows the synchronous generators response in terms of power transfer for the conventional configuration (total fault clearing time is 130 ms), while the blue line shows the synchronous generators response in terms of power transfer for the digital configuration (total fault clearing time is 50 ms).

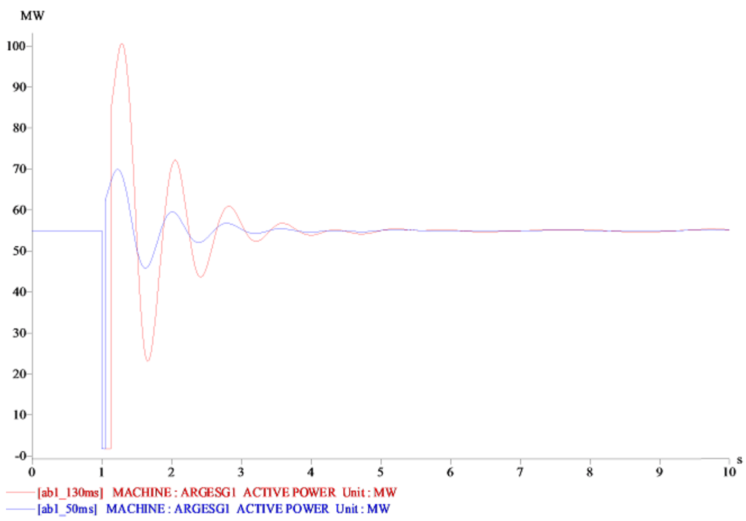

Fig. 6. Power transfer synchronous generators response to a fault on 220 kV OHL A-B located at 1% of the studied substation

Figure 6 presents the power transfer response to a fault located on 220 kV OHL A-B, at 1% of the studied Ss, notated with (1) in Fig. 4. In digital configuration the power transfer ranges to 70 MW and is damped in approx. 3,5 s while in classical configuration the power transfer ranges to 100 MW and is damped in approx. 5 s.

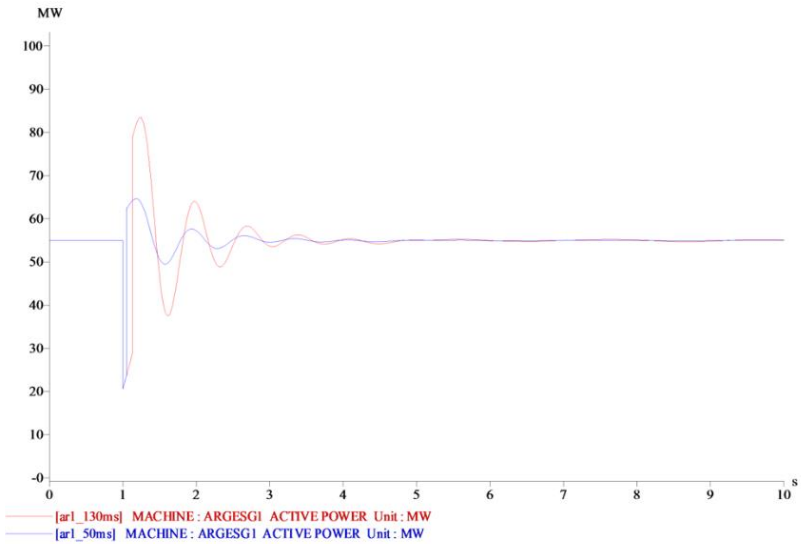

Fig. 7. Power transfer synchronous generators response to a fault on 220 kV OHL A-B located at 85% of the studied substation

Figure 7 presents the power transfer response to a fault located on 220 kV OHL A-B, at 85% of the studied Ss, notated with (2) in Fig. 4. In digital configuration the power transfer ranges to 65 MW and is damped in approx. 3 s, while in classical configuration the power transfer ranges to 85 MW and is damped in approx. 4.5 s.

In Table 2 are summarized the increasing of the oscillations magnitude in relation with initial conditions (τ [%]) and oscillations damping times for both Ss configuration. Despite the fact that in both simulations the initial power transfer in steady state condition is 55 MW, damping time and magnitude of oscillations and are enhanced in digital configuration.

Table 2

Transient simulations results overview

Fault location	Digital configuration ($t_{total} = 50\ ms$)		Classical Configuration ($t_{total} = 130\ ms$)	
	τ [%]	Damping time [s]	τ [%]	Damping time [s]
1 %	27%	3.5 s	82 %	5 s
85 %	18%	3 s	55%	4.5 s

5. Conclusions

Transition towards digital configurations and introducing IEC 61850 process bus at process level introduce several benefits not only in terms of reducing commissioning and maintenance work costs but also by increasing stability of the grid.

Transient stability is directly dependent on the total fault clearing time. The presented paper shows a comparative study of the total fault clearing time considering a real 220 kV substation in different configurations: conventional configuration and digital configuration. It was evaluated the synchronous generators response, located in the proximity of the studied substation, in terms of power transfer to a large disturbance.

Although simulations showed that power system maintains its stability in both configuration (classical, non-refurbished configuration, respectively digital configuration), improvements in both power transfer ranges and oscillations damping time are achieved in the IEC 61850 process bus based configuration.

The synchronous generator response in terms of power transfer corroborated with a three-phase short circuit has an important influence of the frequency deviation. A higher magnitude of power transfer will cause a higher frequency deviation. Thus, may result in using applications like automatic generation control (AGS) to maintain system nominal frequency.

Improvements in power transfer ranges, oscillations daming times, frequency deviations contributes to increasing the overall stability and security of the electrical power system and minimises the impact to the system.

In this paper, transient stability studies were conducted considering a three-phase short circuit. Generally, the magnitude of the three-phase fault current is higher compared to the other types of faults (phase to earth, phase to phase, phase to phase to earth short circuit, etc.). Therefore, improvements to overall stability were analyzed considering the worst-case scenarios.

In order to have a better understanding about power system stability improvements, further work is required to perform stability studies to different fault types and in different power system locations.

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