Implementation of a process bus based feeder protection and measurement system operating as alternate protection at CTEEP's Embu-Guaçu substation

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Abstract: This study describes the main results obtained from the deployment and commissioning of the feeder's protection and measuring system based on analogue and digital acquisitions by concentrator Merging Units. The presented project is installed at the Embu-Guaçu substation, owned by CTEEP, on the AL-60 feeder. The system architecture, protection functions used, and bus process. To put simply, the bus station is the interaction/communication between devices inside the control room, allowing the replacement of cables for signalling and interlocks. On the other hand, the bus process enables the interaction/communication of the equipment installed in the substation patio (switches, circuit breakers, instrument transformers etc.) with the control room. The data available in the patio are acquired through devices called Merging Units that scan measurements of analogue and digital values, as well as signal states, and then sends them to the network through the standard protocol.

Since the IEC61850 standard is based on communication networks, questions about the performance of the communication architecture that supports the substation's automation, control and protection have become frequent. The correct planning, design and deployment of this communication architecture are of crucial importance. The equipment that makes up this architecture is now considered as critical infrastructure in a substation. On this new architecture, the switch is presented as key equipment, requiring more attention to its specification and design during the preparation of the proposed architecture. Application of some already recognised techniques in order to ensure the high performance of communications networks are being carried out on the substation environment, such as the use of Virtual LANs (VLANs), which is a traffic segregation technique recommended by the IEC61850 standard [1] and traffic prioritisation [2]. Within this context, in order to gain practical experience in measurement and protection solutions using the IEC 61850's concepts, CTEEP – Companhia de Transmissão de Energia Elétrica Paulista, deployment, by means of a pilot project, a measurement and protection system based on analogue and digital signal acquisition through Merging Unit. On this project, in addition to verifying the IEC 61850 system, an RDP will also be deployment, which acquires signals by conventional means, for performance comparison. With this, CTEEP is training its team to specify equipment and to design measurement and protection architectures based on the standard, as well as to enable maintenance crews to perform interventions on these systems.

The project features a system fully in compliance with the IEC 61850 standard operating as AC feeder protection at the Embu-Guaçu substation. One of the objectives of deployment equipment such as the AC protection feeder is the factual demonstration that there is no loss of performance on the protection system when using a system based on Merging Units over the conventional system. Configuring of the IEC 61850 relay was carried out according to the conventional relay settings (main protection) deployed at the substation for protection of bay AL-60.

2 61850 system for AL-60 feeder protection

On IEC 61850 systems, the entire interfacing of fiend signals is performed through the Merging Units. Analog and digital signals from the patio's equipment are encapsulated in Ethernet frames and sent through the Merging Units' network interfaces as GOOSE and Sampled Values messages to bus processes or MMS messages to bus stations. Thus, the substation's electrical signals are limited to the substation's patio and the connection originating from the Merging Unit is carried out through optic-fibre cables connected to switches that manage message traffic from communication buses. Signals originating from control relays or systems, such as circuit breaker opening and closing commands, are received by the Merging Units' network interfaces and then sent by the Merging Units to the field as digital signals through its output contacts. Therefore, all the measurement and protection architecture proposed for the AC protection feeder AL-60 was made based on these concepts, as shown in the following topics.

2.1 Deployment architecture

A Merging Unit MU320 was deployed at the Embu-Guaçu substation patio. It sends analogue field signals (voltage and current), as well as breaker status, circuit breaker fault signal and local/remote key for the system's bus processes by means of an
optical Ethernet connection. As output, the MU320 sends physical opening and closing commands from the circuit breakers coil 1 without the use of auxiliary relays, with its outputs connected directly to terminals on the circuit breaker's command panel. In turn, these outputs' commands are sent by the protection relay when some protection or rewiring command is performed.

The manageable switch is installed at the relay room. It is responsible for managing the communication bus, the GPS clock that synchronises the system, the IEC61850 protection relay and an IEC61850 RDP to monitor the entire system. Additionally, since the RDP used on the design is of distributed acquisition, a remote acquisition module has been installed, in order to compare the RDP oscillograms between conventional signals and digitised signals received from the Merging Unit. Fig. 1 shows the equipment deployment on the substation architecture.

2.2 Communication architecture

Bus processes and station segregation are carried out through the use of VLANs on the switch. With this technique, it is possible, even on a switch, to connect various equipment without the interference of interest messages from one to the other. This one of the traffic segregation techniques recommended by the standard, however, it is important to note that it must use only manageable switches [3].

With traffic segregation, relatively high message traffic, such as Sampled Values, are limited to the ports which are connected to the devices that use them. Segregation of GOOSE messages to travel over an exclusive VLAN, where a protection signal may travel over with reliability and low latency, is carried out in a similar way. Figs. 4–7 show the project's communication architecture and, in sequence, the way how messages are directed on the different VLANs used in this project is shown.
On the communication, architecture used, although only one relay and one Merging Unit are connected to the switch, traffic prioritisation is used, as recommended by the standard. The priority of Sampled Values and GOOSE messages on their respective VLANs were maintained at the equipment's default values (priority four for Sampled Values messages and priority to GOOSE messages), wherein priority queues were maintained the same as the value contained in the frame.

Traffic prioritisation is an indispensable tool for IEC 61850 protection systems because this technique causes the switch to forward priority messages before less critic messages, ensuring high performance of the protection system. It is important to highlight that this technique that will require the use of manageable switches for forwarding of messages to the correct switch priority queues.

3 Results of laboratory system test

Prior to the field installation, Factory Acceptance Tests were performed on the system in order to assess the operating and performance of the protection system before deployment at substation. On these trials, in addition to checking the entire communication project, the IEC61850 relay's performance curves were raised in order to ensure that the functions' operating times are in accordance with the design values. All settings and configuration of the protection relay were made based on the conventional relay, which was already installed and being used for the protection of the AL-60 feeder at the Embu-Guaçu substation.

For feeder protection, we used the over-current functions of instantaneous (PTOC1) and timed (PTOC2) phase according to the much reversed ANSI curve, as well as neutral instantaneous (efdPTOC1) and timed (efdPTOC2) over-current according to the extremely inverse ANSI curve. Finally, the rewiring function (RREC) is used at intervals of 1–25 s, and the maximum number of attempts allowed is 2. Figs. 8–11 show the results of the Factory Acceptance Tests on the system.

It was possible to demonstrate, through the results obtained in the tests, that the performance of fully digital protection system behaves similarly to the conventional system, so degradation in system performance times, when compared to the conventional system, is not expected.

4 System results after occurrence in AL-60

After installation and commissioning of the pilot project equipment, the system was in operation at the substation. A few days after the system started its operation, the feeder suffered a fault, which triggered the instantaneous neutral over-current function. The following shows the oscillography of this fault taken from the RDP and the pilot project's protective relay.

First, we analyse the equivalence between the conventional analogue signals and Sampled Values at the time of occurrence of the fault. Fig. 12 shows the conventional current signals (I_AL60 IC) and Sampled Values current signals (IC SV_I_AL60) of phase C. It is possible to that the signals have equivalent magnitude and delay. These signals are from the IEC 61850's RDP, which is
monitoring the entire system in a conventional manner and through process bus.

Starting the protection function's performance analysis by the system based on bus processes, the setting of the neutral instantaneous over-current function (efdPTOC1/50N) parameterised in the protection relay is shown in Fig. 13.

In Fig. 14, the red and black vertical lines indicate the moment of sensibilisation of the protection function (IN > 1 Start) and the performance (IN > 1 Trip), respectively.

On the oscillographic analysis, it was possible to verify that the protection relay indicates the function's sensibilisation (IN > 1 Start) when the current value exceeds the adjusted value of the current pickup for a longer time than one cycle. It is possible to note when the first overshoot occurred, however the time in which the current is maintained above the pickup value was 8.378 ms, in other words, less than one cycle, therefore it was not considered as a violation, as shown in Fig. 15.

Then the value was below 1300 A for about 50 ms. The pickup value was exceeded again and remained at this value for more than one cyclic (17,453 ms – Fig. 16) and then sensitised and acts after 50 ms (Fig. 14).

- IN > 1 Start = 1322 A.
- IN > 1 Start up to IN > 1 Trip = 50 ms (40 ms adjustment).

Regarding the rewiring, it is possible to verify from Figs. 17 and 18 that the operating times of the fault detection up to the circuit breaker's closing performance command (see Table 1).

From the results, it can be seen that the digital protection system worked as expected, within its selectivity curve and with the proper rewiring operation.

5 Conclusion

From the installation point of view, interconnection of the Merging Unit with the protection and measuring equipment only through optical fibre is a point that draws attention by requiring less installation effort. Moreover, the protection system of the panel has a number of cables dramatically lower than conventional systems, which makes the panel's installation and maintenance significantly less expensive than conventional systems, as well as safer for maintenance crews.

For factory and field tests, it is possible to verify that, until now, the Merging Unit and the IED for bus processes have greater or equal strength in comparison to the conventional digital relays. This means a breakthrough for the application of this new technology.

Another important point is the constant concern inherent to the saturation of current transformers and its electromagnetic interference since the short-circuit levels in substations are increasingly higher. For this and other reasons, the optical current transformers used these digital systems need to be developed and tested, and the teams need to be trained.

With the implementation of this bus process technology, there has been a significant increase in safety for maintenance crew during interventions in voltage circuits and especially the current ones, as these analogue signals do not travel over the panels and substation channels.

Regarding the designs, the traditionally used drawings will need to be adapted in order to comply with the GOOSE digital standards.
and the Sampled Values analogue values. In addition, the development of this pilot project demonstrated the need to prepare drawings that detail physical infrastructure and logical network, which are traditionally little detailed in communication architecture projects.

The use of switches between patio equipment and relays, and no direct connection of relay with field signals is a point that draws attention, because it is a novelty inserted by IEC 61850. The use of new equipment switches involving protection systems will be one of the great reviews for this Project, as well as the point of attention regarding the MTBF gap rates between these digital devices. Although the technique of sending analogue and digital values to the network benefits from the point of view of installation and system configuration is a practice that differs from traditional systems. The results so far have shown that from the point of view of application, this new concept offers no degradation in the protection and measuring system [4].

Results obtained in tests on laboratory and field showed that, from the protection system user point of view, both systems have the same result, so the quality of the protection system or oscillograms generated by the measuring system for analysis shortages is maintained when using systems fully compliant with IEC 61850.

Both holder manufacturers of this new technology and user customers will have to organise in order to develop these types of projects and train their teams.

6 References

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