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Protection of single busbar substations through coordination between overcurrent IEDs and the transformer differential based on IEC 61850

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Abstract*– The purpose of this research is to apply the IEC 61850 standard to implement a protection methodology for reliable coordination between overcurrent protections and transformer differential. It solves a typical problem of unwanted operation in a single bar substation protection system. The development of this paper demonstrates that the use of IEC 61850 standard can provide a real-time control system capable of scanning the network every time an event occurs, guaranteeing the selectivity and reliability of the protection scheme, as well as of the whole electric power system (EPS). The scope of the project is limited to the configuration of communication parameters, the IEC 61850 standard, and the protection settings of intelligent electronic devices (IEDs). As part of the setup, development and analysis, GOOSE messaging for decision making stands out over the wired signals during. Therefore, based on the results of simulations and tests, it is recommended to implement the IEC 61850 standard for EPSs in order to improve protection reliability and reduce maintenance costs.

Keywords-- Protection scheme in electrical power systems, substation automation system, IEC 61850 standard, protection relays, GOOSE messaging.

I. Introduction

The protection schemes seek to guarantee that a fault is cleared as quickly as possible, preserving the criteria of selectivity, safety, and reliability. Such protection schemes aim to guarantee the safety of the people, the environment, and the equipment, reducing the impact on the EPS, which are becoming more and more robust and complex [1].

In the particular case of a failure in one of the feeders of a substation, there are normally large short-circuit currents that can generate significant electrical and mechanical stress on all the equipment installed in the substation, but also putting people's safety at risk and endangering the stability of the system. Nonetheless, an internal transformer failure occurs due to insulation aging, overheating due to overexcitation, oil contamination, leakage, or reduced cooling. This type of failure jeopardizes this equipment, which is of vital importance for the EPS, so a timely response from the protection system is essential to minimize the impact of the damage [2].

For this reason, it is suggested the implementation of a suitable differential and overcurrent protection scheme that be reliable, safe, selective, fast, sensitive at detecting internal faults, and stable against external faults. An omission of operation or an unwanted electrical trip due to an external fault of this protection scheme can cause a huge impact on the SEP [3].

Traditionally, communications between IEDs have normally been carried out by using contact logic, that is, wiring the inputs and outputs of the different IEDs, and using serial type communications. The application of these old systems is not practical for new EPSs, since the lack of flexibility required for the amount of equipment that intervenes in the operation and performance of substations.

Nowadays, there is a great trend towards the automation of electrical substations. This tendency has led to the search for a communication architecture that allows interoperability between the different IEDs involved in the operations of control, measurement, and protection, of a substation. The use of the IEC 61850 standard in the development and implementation of protection schemes for distribution is analyzed from the point of view of improving selectivity performance and reducing total fault clearance time [4].

A study highlights the need for evolving protection strategies to ensure the reliability and resilience of modern energy systems, emphasizing the importance of adaptive settings and coordination among protection schemes, as well as accurate system modeling and fault detection techniques, especially in distribution grids with high Distributed Energy Resources [5]. Another research presents a decision model for fault localization and isolation in power grids, utilizing topology analysis to enhance grid efficiency and reliability. When integrated with the Supervisory Control and Data Acquisition system (SCADA), it enables real-time monitoring and control for effective grid management [6].

Different scenarios should be considered, as the integration of renewables with power electronics. Fault phase selection is critical in renewable scenarios, impacting functions like distance protection [7]. Digital substations offer enhanced control and protection opportunities. A multi-criteria fault phase selection algorithm for digital substations shows promising results in coordination between overcurrent IEDs and transformer differentials. Additionally, DC distribution systems, crucial for integrating renewables and loads, lack effective protection methods. This may be solved by taking into account event-based schemes using communication infrastructure and fault current derivatives [8]. It employs Intelligent Electronic Devices (IEDs) to transmit events to an Intelligent Protection Center (IPC) for fault identification. Simulation results demonstrate its efficacy in fault detection and isolation in challenging network conditions.

Line differential protection, though selective, faces limitations like line length and communication delays. The IEC 61850 standard enables digital substations, enhancing system reliability. Differential protection schemes using SV messages compliant with IEC 61850 have been used in Brazil, where the feasibility tests on 500 kV lines show promising results for real-world application [9]. Moreover, with numerous distribution substations and rising costs of busbar protection, Distribution System Operators seek cost-effective solutions. For this reason, there exist suggestions of distributed protection scheme using zero-sequence and negative-sequence components for fault detection [10]. Leveraging standard settings of overcurrent IEDs and IEC 61850 communication, the scheme distinguishes between busbar and feeder faults and identifies faulty sections during busbar coupler openings, enhancing reliability.

This work proposes a methodology to solve typical problems of unwanted tripping of protection systems, based on a reliable coordination of protections between the IEDs and a robust communication architecture that allows total selectivity in the system. Section 2 presents the most relevant foundations to become familiar with for the development of this research. It includes the most relevant concepts of the IEC 61850 standard, the system requirements, and the data mapping and control logic for the application of the protection scheme for a reliable coordination between overcurrent IEDs and transformer differential applying IEC 61850 standard for single bar type substations. Section 3 studies the conventional protection scheme versus the proposed one. It comprises comparison tests and outcome analysis. Finally, the conclusions are discussed in section 4.

II. METHODOLOGY

A. *The IEC 61850 standard*

The IEC 61850 standard, Communications networks in substations, was developed to meet the requirements of all the different functions and applications of substations, such as protection, control, automation, measurement, monitoring, information collection, and recording. This standardization focuses on the integration of equipment developed by different manufacturers, minimizing the need to use protocol converters and reducing engineering times [11].

Integrating this standard brings several benefits to the EPS, such the reduction of using of copper cabling for point-to-point communication, like in the conventional systems. A LAN network replaces the bulks of tangling wires, allowing to reach advantages, like improved data transmission speed, strong security, additional flexibility, and higher reliability [12].

Additionally, this standard is oriented to objects and functions, which allows dividing the substation into basic capabilities by introducing the concept of logical node, as shown in figure 1, and into simple units of information that greatly rationalize the database of the facilities, achieving a simple and manageable structure. The Substation Configuration Language (SCL) specifies a common file format to describe the capabilities of an IED, a system-specific schematic that can be viewed in terms of a single-line diagram, and a automation system description [13].

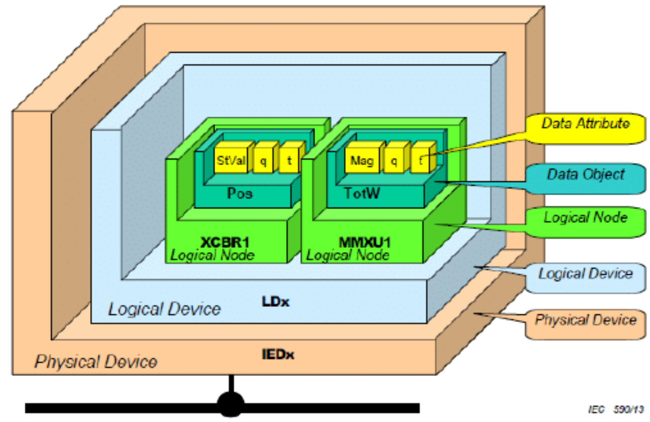

Fig. 1 IEC 61850 data model structure.

GOOSE (Generic Object Oriented Substation Event) messages are data packets that allow the transmission of events that appear as failures. They give the possibility of sending messages with a priority bit through the network to transmit information that requires high speed, as are the case of trips and the events required for interblocks in electrical systems [14]. By having a higher priority than common frames, the message is moved ahead the transmission queue, then sent to the network, guaranteeing short transmission times in cases of information saturation [15].

GOOSE service messages are multicast, that is, they are transmitted to several network devices, which are subscribed to receive this type of messages and subsequently process them. These messages have a fundamental period (To) if there is no change in their status. If there exists a change, GOOSE messages are sent spontaneously with a minimum period, this is kept until the fundamental period returns, as can be noted in figure 2. Cyclic transmission makes it possible to detect a transmission failure or that a communication channel is interrupted using logic blocks [16].

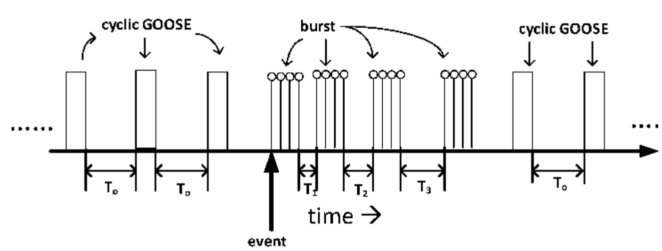

Fig. 1 GOOSE messaging transmission periods.

B. *Conventional protection scheme in single busbar substation*

In the typical protection scheme, all the circuits are connected to the single busbar by means of a switch. This configuration is mainly used in low and medium power installations, and when power cuts are admitted with a certain frequency [17]. Figure 3 shows the simple busbar configuration used, depicting the IEDs and measurement equipment to locate each protection zone.

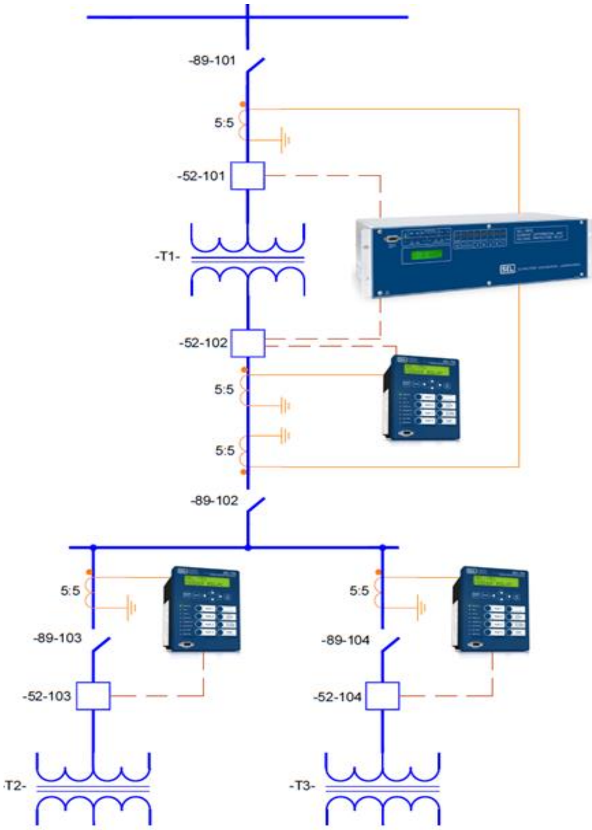

Fig. 3 Single-line diagram under study.

Overcurrent protection is used to protect all the input and output feeders of the substation. The differential protection seeks to protect the transformer of the substation. This differential protection can vary its scope depending on the protection zone assigned to the substation. This protection zone depends directly on where the current signals, needed by the IED numerical logic, are being taken. This expansion of the differential protection zone is not recommended as it reduces the efficiency of a conventional protection scheme, where all the elements of a power system must be correctly coordinated to guarantee that the IEDs only operate in the event of a fault.

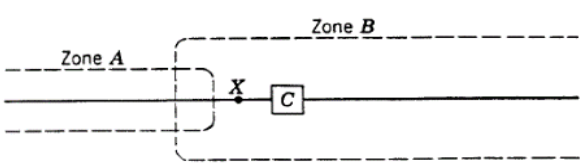

Fig. 4 Primary and backup protection zone.

IEDs are capable of detecting faults within a particular protection zone and outside of it, usually in adjacent zones, and can be used as a backup to primary protection as a second line of defense. It is essential to isolate any fault, even if the associated primary protection does not operate. Therefore, whenever possible, each element in the EPS should be protected by the primary and backup IEDs, as shown in figure 4.

This conventional protection scheme is not very useful when you have several adjacent protection zones. Protection coordination and protection zones tend to get mixed up, causing undesired operations in the substation. In this scenario, the proposed scheme will be implemented, guaranteeing a reliable coordination with the help of a control logic based on IEC 61850.

C. Proposed protection scheme implementing IEC 61850

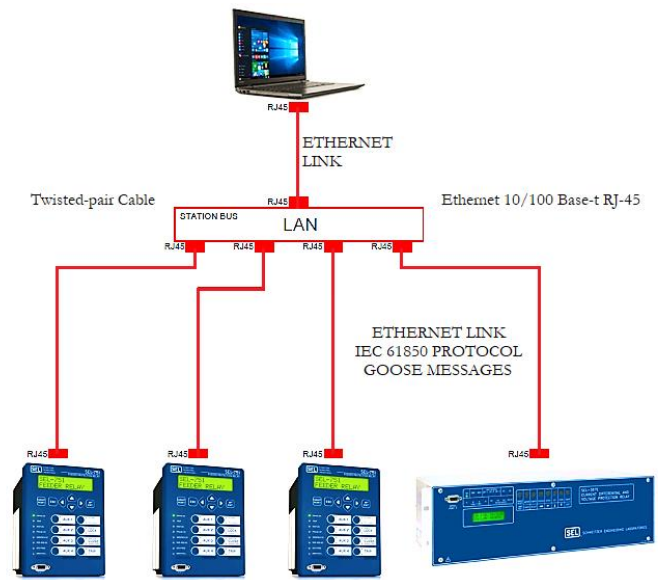

Fig. 5 - LAN network topology.

The scheme implements a LAN communication network with the IEC 61850 communication protocol to communicate the IEDs of the substation shown in figure 5. The IEC 61850 standard does not define any particular network topology; hence, the simple star topology is considered due to the physical limitations of the IEDs used for the tests. This topology is characterized by having a one-to-one physical link, generally used in small applications, and it does not have redundancy at the communication level, as in figure 5.

The development of the IEC 61850 standard was to meet the requirements of protection, control, automation, measurement and monitoring. In this scheme, GOOSE messages are used to share information on the protection functions status of an IED with the rest of the IEDs connected to the network [18]. With this, it is guaranteed that the information can be given the necessary priority to be used in the control logic, as permissive or blocked, to replace any conventional physical control wiring and avoid unwanted trips [19].

As for the IEDs, on the one hand, the main feeder, the output 1, and the output 2 use SEL 751, under protection function 50/51, protocol based on IEC 61850 standard, GOOSE messaging, and ethernet communication via RJ45. On the other hand, the transformer uses SEL 387E, under protection function 87-T, protocol based on IEC 61850 standard, GOOSE messaging, and ethernet communication via RJ45. Table 1 shows the setup communication information of each IED, including the switch to be controlled, and the IP address and the subnet mask assigned to form the LAN network.

TABLE I
IEDS COMMUNICATION SETUP

LOCATION	MAIN FEEDER
Control	52-102
IP address	192.168.1.10
Subnet mask	255.255.255.0
LOCATION	**OUTPUT 1**
Control	52-103
IP address	192.168.1.11
Subnet mask	255.255.255.0
LOCATION	**OUTPUT 2**
Control	52-104
IP address	192.168.1.12
Subnet mask	255.255.255.0
LOCATION	**TRANSFORMER**
Control	52-101 / 52-102
IP address	192.168.1.13
Subnet mask	255.255.255.0

D. *Data mapping*

TABLE II
SEL LOGICAL DEVICES

Logical Device	Description
ANN	Annunciator elements—alarms, status values
CFG	Configuration elements—datasets and report control blocks
CON	Control elements—Remote bits
MET	Metering or Measurement elements—currents, voltages, power, etc.
PRO	Protection elements—protection functions and breaker control

The IEDs used for testing, SEL 751 and SEL 387, have logical devices preconfigured, listed in Table 2. The PRO logical device is associated with the protection functions. PRO includes the logical nodes P1TPIOC1 "Instantaneous overcurrent" and P1TPTOC13 "Timed overcurrent". The data needed to monitor the status of IED protection functions are found in these logical nodes, listed in Table 3.

TABLE III
SEL 751 LOGICAL NODES

P1TPIOC1	Op.general	50P1T	Level 1 phase instantaneous overcurrent element trip
P1TPIOC1	Str.general	50P1P	Level 1 phase instantaneous overcurrent element pickup
P1TPIOC1	Str.dirGeneral	unknown	Direction undefined
P1TPTOC13	Op.general	51P1T	Level 1 maximum phase time-overcurrent element trip
P1TPTOC13	Str.general	51P1P	Level 1 maximum phase time-overcurrent element pickup
P1TPTOC13	Str.dirGeneral	unknown	Direction unknown due to settings

E. *Control logic*

GOOSE messages ensure that each IED has knowledge of the status of the protection functions of all the equipment connected to the LAN network in real-time, providing a desired level of reliability. After the DataSet is configured, the .CID files must be loaded in each IED to configure the control logic [20].

The main goal of the proposed design is the implementation of logical interblocks for each protection zone [21], it will confirm the appropriate operation of the protection scheme in the single busbar substation. Table 4 presents the typical-failure scenarios in a substation, which have been considered in this study. This is possible through the logical node P1TPIOC1, that refers to "Level 1 phase instantaneous overcurrent element trip", corresponding to the 50P1T protection function.

TABLE IV
FAILURE SCENARIOS

TYPE OF FAILURE	Transformer internal fault	Transformer external fault	Busbar fault	Output 1 fault	Output 2 fault
IED1 Main feeder	**1**	**1**	**1**	**1**	**1**
IED2 Output 1	**0**	**0**	**0**	**1**	**0**
IED3 Output 2	**0**	**0**	**0**	**0**	**1**
IED4 Transformer differential	**0**	**1**	**1**	**1**	**1**

GOOSE messages are used for the timed overcurrent faults corresponding to the 51P1P protection functions. Thus, the IEDs located on the low voltage side of the transformer inform IED1, via the logical node P1TPTOC13, using the Str.general data, which refers to "Level 1 maximum phase time-overcurrent element pickup". It is considered this information to turn the status LEDs on to provide visualization to the end user.

Additionally, for security reasons, the fast trip option is implemented in the event that the relay is working, but the protection equipment cannot dissipate the fault. In this case, the option for upstream protection to operate is activated; hence, the fault should be cleared.

III. RESULTS

A. *Conventional protection scheme for a single busbar substation*

Figure 6 shows a simulation using the PowerFactory software, by Digsilent. This tool allows to take into consideration various test scenarios for the single busbar substation scheme. For the conventional model, power flow and maximum short-circuit current were calculated. The resulting values for the power flow and maximum short-circuit current of the basic single busbar scheme are shown in figures 7 and 8, respectively.

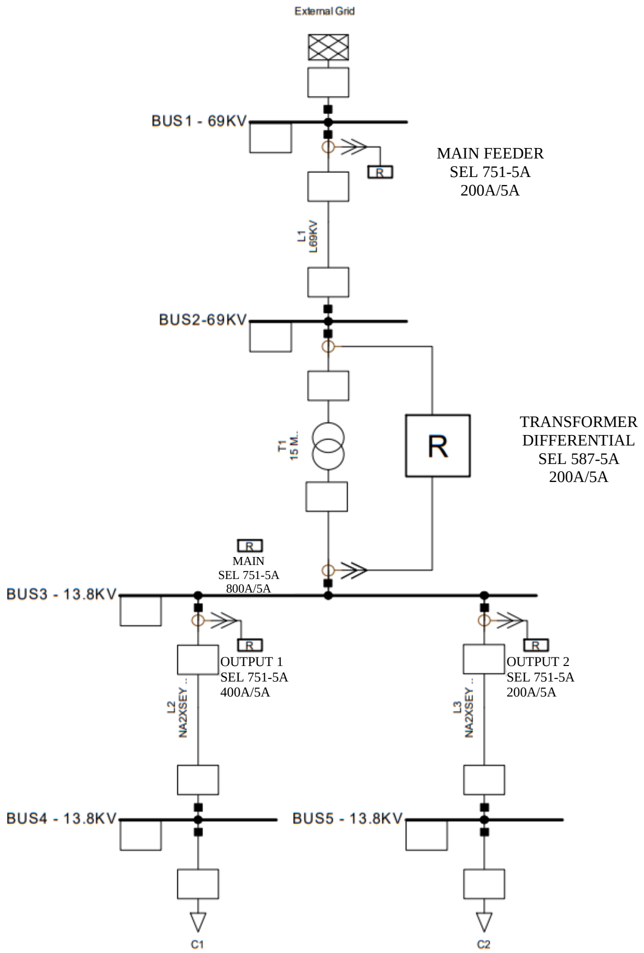

Fig. 6 Single busbar scheme designed using the Powerfactory software.

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-----------------------------------------------------------------------------------------
| Grid: Grid                     System Stage: Grid               | Study Case: Study Ca
-----------------------------------------------------------------------------------------
|            rated                                    Active Reactive Power                |
|           Voltage      Bus-voltage                  Power   Power   Factor Current Loading|
|             [kV]   [p.u.]    [kV]    [deg]        [MW]   [Mvar]    [-]    [kA]     [%]  |
-----------------------------------------------------------------------------------------
|BUS1 - 69KV                                                                              |
|            69.00    1.00   69.00    0.00                                                |
|   Cub_2  /Xnet      External Grid                9.20     5.79   0.85    0.09          |
|   Cub_1  /Lne       L1                           9.20     5.79   0.85    0.09     9.10 |
|                                                                                         |
|BUS2-69KV                                                                                |
|            69.00    1.00   69.00    0.00                                                |
|   Cub_2  /Lne       L1                          -9.20    -5.79  -0.85    0.09     9.10 |
|   Cub_1  /Tr2       T1                           9.20     5.79   0.85    0.09    72.49 |
|                                                                                         |
|BUS3 - 13.8KV                                                                            |
|            13.80    0.98   13.53  -32.71                                                |
|   Cub_1  /Lne       L2                           5.51     3.38   0.85    0.28    79.02 |
|   Cub_2  /Lne       L3                           3.64     1.72   0.90    0.17    49.41 |
|   Cub_3  /Tr2       T1                          -9.15    -5.10  -0.87    0.45    72.49 |
|                                                                                         |
|BUS4 - 13.8KV                                                                            |
|            13.80    0.97   13.36  -32.70                                                |
|   Cub_1  /Lod       C1                           5.44     3.37   0.85    0.28          |
|   Cub_2  /Lne       L2                          -5.44    -3.37  -0.85    0.28    79.02 |
|                                                                                         |
|BUS5 - 13.8KV                                                                            |
|            13.80    0.97   13.35  -32.77                                                |
|   Cub_1  /Lod       C2                           3.60     1.75   0.90    0.17          |
|   Cub_2  /Lne       L3                          -3.60    -1.75  -0.90    0.17    49.41 |
|                                                                                         |
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Fig. 7 Power flow of the basic scheme.

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---------------------------------------------------------------------------------------------
 Grid: Grid              System Stage: Grid          |                        | Annex:
---------------------------------------------------------------------------------------------
                      rtd.V.    Voltage    c-       Sk"            Ik"            ip      Ib     Sb
                      [kV]    [kV]  [deg] Factor  [MVA/MVA]    [kA/kA]  [deg]   [kA/kA]  [kA]   [MVA]
---------------------------------------------------------------------------------------------

BUS1 - 69KV           69.00    0.00   0.00  1.10   400.00 MVA   3.35 kA  -84.29   8.26 kA  3.35  400.00
    L1                BUS2-69KV                      0.00 MVA   0.00 kA    0.00   0.00 kA
    External Grid                                  400.00 MVA   3.35 kA  -84.29   8.26 kA

BUS2-69KV             69.00    0.00   0.00  1.10   400.00 MVA   3.35 kA  -84.29   8.26 kA  3.35  400.00
    L1                BUS1 - 69K                   400.00 MVA   3.35 kA   95.71   8.26 kA
    T1                BUS3 - 13.                     0.00 MVA   0.00 kA    0.00   0.00 kA

BUS3 - 13.8KV         13.80    0.00   0.00  1.10   136.35 MVA   5.70 kA  -85.61  14.51 kA  5.70  136.35
    L2                BUS4 - 13.                     0.00 MVA   0.00 kA    0.00   0.00 kA
    L3                BUS5 - 13.                     0.00 MVA   0.00 kA    0.00   0.00 kA
    T1                BUS2-69KV                    136.35 MVA   5.70 kA   94.39  14.51 kA

BUS4 - 13.8KV         13.80    0.00   0.00  1.10   119.18 MVA   4.99 kA  -76.23  10.50 kA  4.99  119.18
    L2                BUS3 - 13.                   119.18 MVA   4.99 kA  103.77  10.50 kA

BUS5 - 13.8KV         13.80    0.00   0.00  1.10   108.75 MVA   4.55 kA  -71.25   8.84 kA  4.55  108.75
    L3                BUS3 - 13.                   108.75 MVA   4.55 kA  108.75   8.84 kA
---------------------------------------------------------------------------------------------
```

Fig. 8 Short-circuit of the basic scheme considering the IEC60909 standard.

Taking into account these results, the selection of the protection parameters for each IED on the 13.8 kV side of the single busbar substation was carried out. The summary is presented in Table 5.

TABLE V
IEDS PARAMETRIZATION

FEEDER		IED1 Main	IED2 Output 1	IED3 Output 2	IED4 Dif Transf 13.8KV
T. CURRENT		800:5	400:5	200:5	800:5
PICKUP	50P1P	20	35	40	25
T DIAL	50P1D	0.04	0.02	0.02	0.05
PICKUP	51P1P	2.85	3.5	4.3	3.15
CURVE	51P1C	U3	U3	U3	U3
T DIAL	51P1D	2.3	3	3	2.5

Once the adjustments were applied, the inverse time over current curves were obtained. These graphs confirm the coordination among the different IEDs connected to the single busbar substation, as it can be noticed in figure 9.

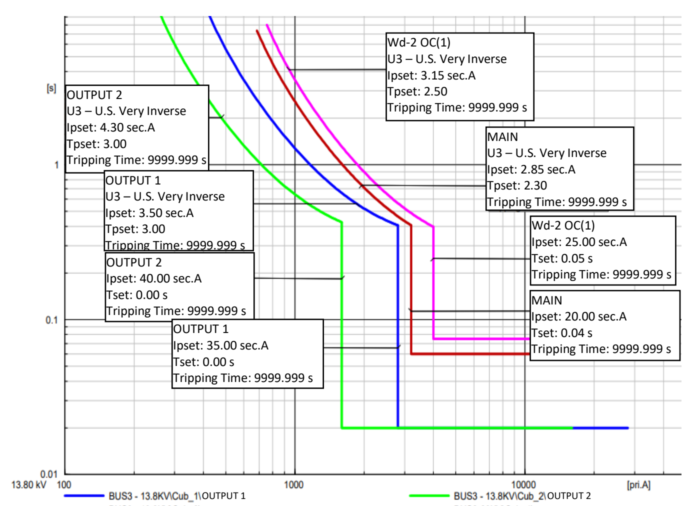

Fig. 9 Protection coordination curves.

As a case of analysis and validation of the fault clearance time between IEDs, the fault on busbar 4 (BUS4) is studied. The results shown in table 6 theoretically indicate that the fault clearing time is suitable since, for each protection zone, there is enough time between IEDs to be able to actuate without involving the backup relay.

TABLE VI
BUSBAR 4 FAULT CLEARING TIME

PARAMETERS	IED1 Main	IED2 Output 1	IED3 Output 2	IED4 Dif Transf 13.8 kV
Fault clearing time	0.060 s	0.020 s	NA	0.075 s
Fault current	4986.13 A	4986.13 A	4986.13 A	4986.13 A

In a practical way, it is not ideal because the time it takes to activate the protection equipment that clears the fault must also be considered. As shown in figure 10, not taking this parameter into account causes the effective fault clearing time to be higher, producing an unwanted trip if corrective actions are not taken or if the methodology based on the IEC 61850 standard proposed in this work is not applied.

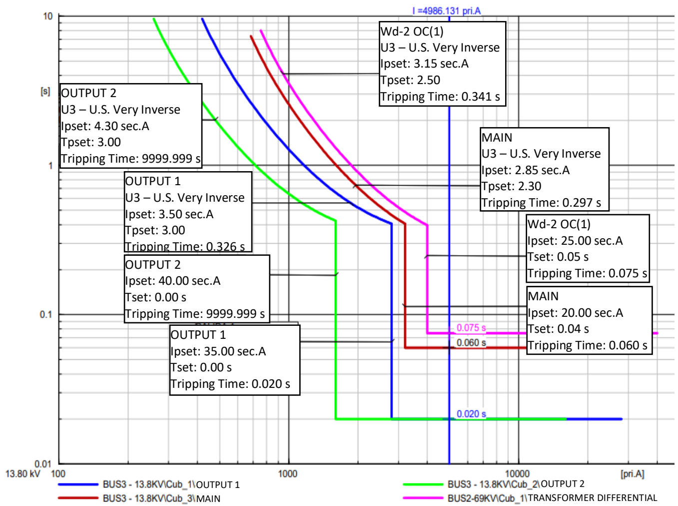

Fig. 10 Fault clearing time considering a fault in busbar 4.

B. *Proposed protection scheme implementing IEC 61850*

The acSELerator QuickSet SEL-5030 and Architect SEL-5032 software tools are used for the equipment parameterization and system implementation. Such tools allow engineers and technicians to quickly and easily configure, commission, and manage devices for protection, control, measurement and monitoring of the energy system [22].

TABLE VII
MARGIN OF ERROR BETWEEN SIMULATION AND INJECTION TEST

IED	Fault current	Fault clearing time (simulation)	Fault clearing time (test)	Error (%)
IED 1	4986.13A	0.060 s	0.0678 s	11.8 %
IED 2	4986.13A	0.020 s	0.0256 s	21.9 %
IED 3	4986.13A	NA	NA	NA
IED 4	4986.13A	0.075 s	0.0890 s	15.7 %

The tests were carried out with the help of a secondary current injection suitcase that simulates the fault in busbar 4. It helps check the relays' setting and the fault clearing times specified in the simulation. The results shown in Table 7 let observe a deviation of the fault clearing time. This is mainly due to the time that must be added because of the activation of the actuator that clears the fault away.

A new test with the IEC 61850 protocol activated was carried out. For this, each IED was set up through the communication port. It generates new DataSet values considering the new data of the protection logical node as indicated in Table 8 for SEL 751 (Main feeder, Output 1 and Output 2) and SEL 387E (Transformer differential).

TABLE VIII
DATASET FOR IEDS BASED ON SEL 751 AND SEL 387

SEL 751	PRO	Protection	Logical node
Data	50P1T	Trip	PRO.P1TPIOC1.Op.general
	50P1P	Pickup	PRO.P1TPIOC1.Str.general
	51P1T	Trip	PRO.P1TPIOC13.Op.general
	51P1P	Pickup	PRO.P1TPIOC13.Str.general
SEL 387E	**PRO**	**Protection**	**Logical node**
Data	51P1T	Pickup - W1	PRO.P1PTOC1.Op.general
	51P1	Trip - W1	PRO.P1PTOC1.Str.general
	50P11T	Pickup - W1	PRO.P11PTOC2.Op.general
	50P11	Trip - W1	PRO.P11PTOC2.Str.general
	51P2T	Pickup - W2	PRO.P1PTOC1.Op.general
	51P2	Trip - W2	PRO.P1PTOC1.Str.general
	50P21T	Pickup - W2	PRO.P11PTOC2.Op.general
	50P21	Trip - W2	PRO.P11PTOC2.Str.general

Once the DataSets have been configured and the .CID files loaded, it is possible to set each IED up, considering its respective control logic, via virtual bits and GOOSE receive messages. This new control logic allows to obtain the results for the fault test in busbar 4 listed in table 9.

TABLE IX
INJECTION TEST RESULT WITH GOOSE MESSAGES

IED	FAULT CURRENT	TEST TIME	STATUS
IED 1	4986.13 A	N.A.	Blocked
IED 2	4986.13 A	0.0261 s	Fault cleared
IED 3	4986.13 A	N.A.	No data
IED 4	4986.13 A	N.A.	Blocked

In this case, IED1 (Busbar 3), IED2 (Busbar 4) and IED4 (Transformer differential, side of 13.8 kV) will detect the fault current P1TPIOC1 that is generated in busbar 4. Oppositely, the IED3 (Busbar 5) will not sense it. The device responsible for isolating the fault is IED2. It is in charge of communicating and blocking the rest of the IED equipment, allowing only the respective bus 4 protection to operate. Figure 11 depicts this configuration.

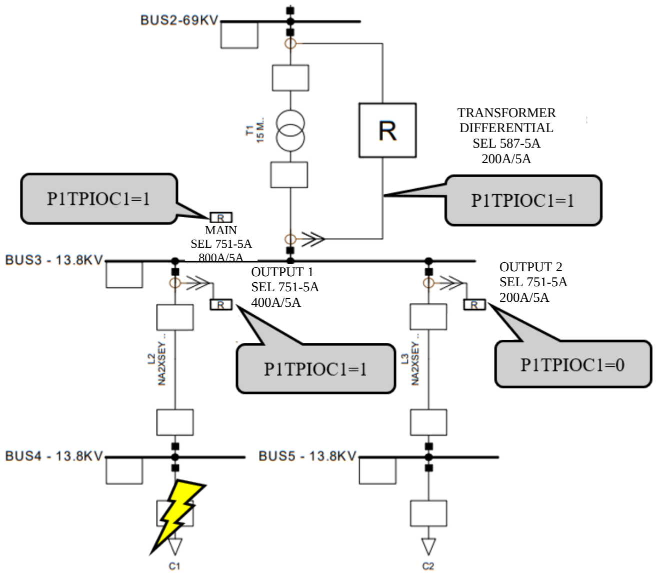

Fig. 11 GOOSE messages for fault in busbar 4.

For the case of a fault in the zone of the transformer differential, if the same protection function (P1TPIOC1) is taken into consideration, the fault current is only sensed by IED4 on the 69 kV side. This device acts by comparing the status of the other IEDs to command its protection system to open immediately. Additionally, it sends a signal via GOOSE so the protections of all output branches also act, leaving the protection zone completely isolated as shown in figure 12.

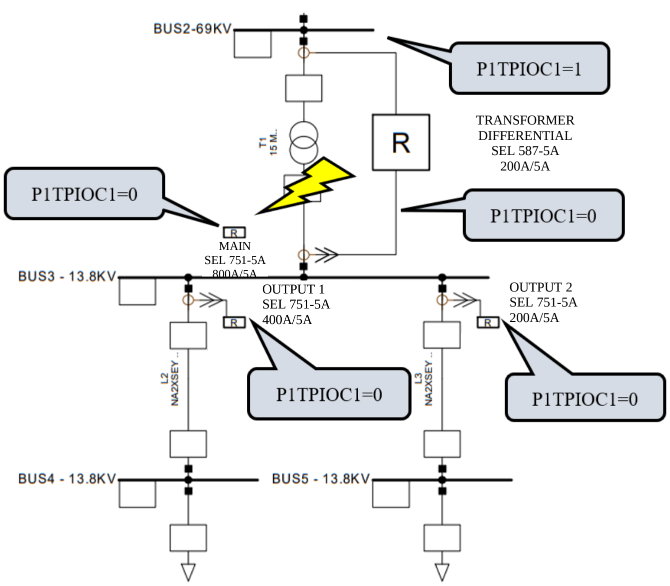

Fig. 12 GOOSE messages for transformer differential fault.

C. Comparison of conventional and proposed protection schemes

When there exists an instantaneous overcurrent fault in one of the feeders, the methodology that implements GOOSE messaging would have the highest level of selectivity since a control logic can be anticipated based on the overcurrent status (P1TPIOC1). This will help block the backup protection operation, only leaving the corresponding fault protection operation enabled. This maneuver does not happen in a conventional protection scheme since it depends on the curves and the adjustments made. Likewise, when a differential fault occurs in the transformer protection zone, it can be guaranteed that the fault zone will be correctly isolated through the control logic.

Regarding timing, the results for the injection test with GOOSE messaging, shown in Table 9, make it clear that there is no significant time advantage compared to the results of simulations and injection test without GOOSE messaging, shown in Table 7. The competitive advantage lies in blocking the operation of the rest of the equipment in order to guarantee correct selectivity. The results of an Indonesian research [23] show similar outcomes to what was obtained in this paper.

IV. CONCLUSION

This work improves the reliability of the entire system, since it guarantees the correct operation of the overcurrent protections and the transformer differential through GOOSE-based logical interblocking that works on the substation information network. The main advantage of this methodology is its applicability to any substation working with IEC 61850 compatible IEDs, and the implementation of LAN networks.

The implementation of IEDs that follow the IEC 61850 standard constitutes a profitable and long-lasting investment thanks to the easiness and flexibility to expand the system and its multiple functionalities. It provides support to any physical architecture, regardless of the equipment manufacturer. This proposal leaves aside the physical copper wiring for signaling that is sometimes still used to perform additional block controls.

The findings of this study significantly contribute to the energy sector by enhancing the reliability and operability of single busbar substations. By implementing a coordinated approach between overcurrent IEDs and transformer differentials based on the IEC 61850 standard, we ensure the correct operation of protection mechanisms crucial for safeguarding substation assets.

Using GOOSE-based logical interblocking over the substation information network offers a versatile and scalable solution applicable to any substation equipped with IEC 61850-compatible IEDs and LAN networks. This not only improves system reliability but also represents a shift towards modernizing substations by minimizing reliance on physical copper wiring for signaling, thereby reducing maintenance costs, and enhancing system flexibility.

Furthermore, the ease of expanding the system and the compatibility with various equipment manufacturers make this approach a profitable and sustainable investment for the future of substation protection and control systems. Finally, it is important to highlight that the proposed methodology marks a significant step towards advancing the efficiency, reliability, and adaptability of power distribution infrastructure in the evolving energy landscape.

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