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PROTECTION COORDINATION OF 69/13.8 KV POWER DISTRIBUTION SUBSTATION IN VALENCIA - LOS RIOS, ECUADOR

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Abstract. This research project focuses on the coordination of electrical protections at the Valencia Distribution Substation, located in La Nueva Unión parish of the Valencia canton. The primary issue addressed is the high incidence of short circuits in the electrical distribution networks due to factors such as tree branches, atmospheric discharges, and vandalism, which can result in power outages and equipment damage. The objective is to achieve the selection, adjustment, and coordination of electrical protections to reduce the impacts of electrical faults. This will be accomplished through a short-circuit study, the selection of protection elements, the coordination of electrical devices, and the proposal of improvements to prevent improper general power cuts and damage to the substation. The project highlights the proper management of electrical protections through a detailed short-circuit study and the identification of suitable protection devices. Effective coordination between these devices is achieved to minimize undesired disconnections. Furthermore, there is an emphasis on the need to upgrade certain components due to the increased electrical demand in the area. The results demonstrate significant improvements in the substation's operational reliability, reducing the frequency and impact of power outages and equipment damage.

Keywords: Electrical protections, Electrical faults, Protection coordination, Distribution substation

INTRODUCTION

The reliable and continuous distribution of electrical power is a critical component for sustainable development and quality of life in modern societies. The Valencia Distribution Substation plays a vital role in ensuring a stable electricity supply to the Nueva Unión parish and surrounding areas. However, the substation is susceptible to various electrical faults, such as short circuits and overloads, which can lead to power interruptions, equipment damage, and potential safety hazards [1], [2], [3].

Proper coordination of electrical protections is essential to mitigate the adverse effects of electrical faults and ensure the safe and efficient operation of the substation [4], [5]. This study aims to address the critical issue of protection coordination at the Valencia Distribution Substation by conducting a comprehensive analysis and proposing optimized solutions.

The importance of electrical protection systems in distribution substations cannot be overstated. These systems are designed to detect and rapidly isolate faults, preventing further damage to equipment and ensuring the continuity of power supply [6], [7]. Inadequate protection coordination can lead to unnecessary power outages, equipment failures, and potential safety risks for personnel and the public [8], [9].

The coordination of protection devices involves meticulously adjusting their operating characteristics and time-current curves to ensure selective and rapid operation during fault conditions [10], [11]. This process aims to minimize unnecessary disconnections and equipment damage while maintaining the overall stability and reliability of the electrical system [12], [13].

This study employs a comprehensive methodology that includes a detailed short-circuit study to determine the maximum fault currents and identify critical scenarios within

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the substation [14], [15]. Additionally, an evaluation of the existing protection devices is conducted, and suitable components, such as relays and circuit breakers, are selected to effectively protect the substation against various electrical faults [16], [17].

Furthermore, the coordination of protection devices, including relays and circuit breakers, is meticulously carried out, ensuring selective and rapid operation during fault conditions. This coordination process involves adjusting the operating characteristics and time-current curves to minimize unnecessary disconnections and equipment damage.

Based on the analysis and findings, recommendations for system improvements are proposed to address any identified deficiencies in the current protection system. These recommendations aim to prevent unnecessary power outages and mitigate potential equipment damage within the substation, ultimately enhancing the overall reliability and safety of the electrical distribution system.

The study highlights the importance of effective protection coordination and the need to adapt to the increasing electrical demand in the area. By implementing the proposed solutions, the Valencia Distribution Substation can enhance its reliability, safety, and overall performance, ensuring a stable and continuous electricity supply to the surrounding communities.

METHODOLOGY

The methodology employed in this study involves a systematic approach to achieve the correct selection, adjustment, and coordination of electrical protections at the Valencia Distribution Substation. The following steps outline the methods used.

SHORT-CIRCUIT STUDY

A detailed short-circuit study was conducted to determine the maximum fault currents and identify critical scenarios within the substation. This analysis provided the necessary information for accurately adjusting the protection elements. The study considered various fault types, including three-phase, phase-to-phase, phase-to-phase-to-ground, and phase-to-ground faults. The short-circuit study is essential for understanding the fault levels and ensuring that the protection devices are set correctly to handle these faults [3], [18].

PROTECTION DEVICE SELECTION

An evaluation of the existing protection devices was conducted, and suitable components, such as relays and circuit breakers, were selected to effectively protect the substation against various electrical faults. The selection process involved the elements show in Fig. 1.

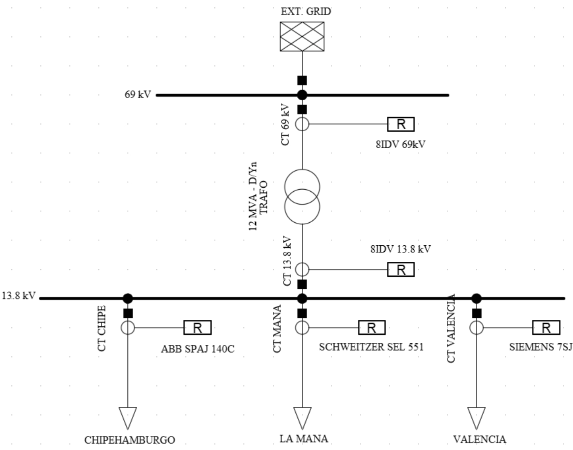

Fig. 1. Scheme of the protection devices of distribution substation in Valencia – Los Rios.

For the Differential Protection Relay (87T), the ZIV 8IDV relay was chosen for the power transformer to provide comprehensive protection against internal faults [19], [20].

The protection element for Chipe Hamburgo Feeder is the ABB SPAJ 140C relay, which was selected for overcurrent and ground fault protection [21], [22]. The

Valencia Feeder use the Siemens 7SJ80 relay was chosen for overcurrent protection [23], [24]. Finally, in La Mana Feeder, the SEL-551 relay was selected for overcurrent protection [25], [26].

PROTECTION COORDINATION

The coordination of protection devices, including relays and circuit breakers, was meticulously carried out. This involved adjusting the operating characteristics and time-current curves to ensure selective and rapid operation during fault conditions. The coordination process is shown in the Fig. 2:

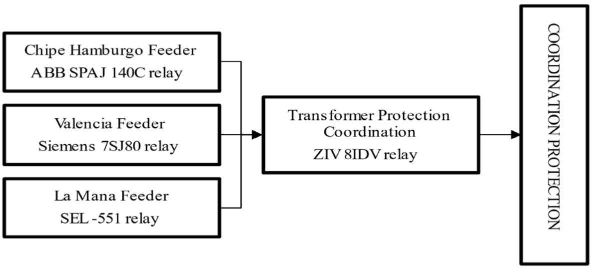

Fig. 2. Coordination of protection devices of distribution substation in Valencia – Los Rios.

The differential protection (87T) and overcurrent protection (51) elements of the ZIV 8IDV relay were coordinated to provide comprehensive protection for the power transformer [19], [20].

ABB SPAJ 140C relay (Chipe Hamburgo Feeder), Siemens 7SJ80 relay (Siemens 7SJ80 relay) and SEL-551 relay (La Mana Feeder) were coordinated in a separately way with the ZIV 8IDV relay (Power transformer) [21], [22].

SYSTEM IMPROVEMENT RECOMMENDATIONS

Based on the analysis and findings, recommendations for system improvements were proposed to address any identified deficiencies in the current protection system. These recommendations aimed to prevent unnecessary power outages and mitigate potential equipment damage within the substation. The recommendations included:

i. Due to the increasing electrical demand in the area, it is recommended to upgrade certain components, such as conductors and circuit breakers, to handle higher fault currents and ensure reliable operation [27], [28].

ii. The integration of advanced protection schemes, such as adaptive protection or communication-assisted protection, could enhance the system's reliability and selectivity [29], [30].

iii. Regular maintenance and testing of protection devices should be implemented to ensure their proper functioning and timely replacement when necessary [29], [31].

iv. Implementing a continuous monitoring and data analysis system can provide valuable insights into the system's performance, enabling proactive measures and optimizations to be made [32], [33].

DATA COLLECTION AND ANALYSIS

DATA COLLECTION

The data collection process involved gathering information from various sources, including:

i. Direct observation of the substation and its components to understand the current state and identify any issues [3], [18].

ii. Analysis of past records and events to understand the performance of the existing protection system [19], [20].

iii. Review of manuals, technical specifications, and diagrams of the protection devices and substation layout [21], [22].

DATA ANALYSIS

The collected data was analyzed using advanced software tools such as DIgSILENT PowerFactory and Microsoft Excel. The analysis included:

i. Determining the fault currents and critical scenarios [23], [24].

ii. Evaluating the power flow and demand in the substation and its feeders [25], [26].

iii. Adjusting the settings of protection devices to ensure selective and rapid operation during faults [27], [28].

RESULTS

SHORT-CIRCUIT STUDY

The short-circuit study conducted for the Valencia Distribution Substation provided critical insights into the fault currents and scenarios that could occur within the substation. The study considered various fault types, including three-phase, phase-to-phase, phase-to-phase-to-ground, and phase-to-ground faults.

For the maximum demand scenario, the short-circuit study is showed in the Table 1. In addition, it is important to mention that the maximum fault current is produced at the 13.8 kV bus when a phase-to-ground fault occurs.

Fault Type	69 kV Busbar, (kA)	13.8 kV Busbar, (kA)
Three-phase	3.67	4.47
Phase-to-phase	2.75	3.73
Phase-to-phase-to-ground	3.07	4.50
Phase-to-ground	2.04	4.74

Table 1. Short circuit study of Valencia Substation.

PROTECTION DEVICE SELECTION

Based on the short-circuit study findings and the substation's configuration, suitable protection devices were selected to safeguard the substation against electrical faults effectively.

Power Transformer Protection Unit Settings. The ZIV 8IDV relay was chosen for the power transformer to provide comprehensive protection against internal faults. The relay's differential and overcurrent protection characteristics were adjusted based on the short-circuit study results.

After the calculation of the nominal current of the transformer on the high side is 120.5 A and on the low side it is 602.5 A, considering the available CTs integrated in the transformer, a relationship is chosen. of 300:5 on the high side and 800:5 on the low side. In addition, the configuration must be star and delta respectively.

Restraint	Percentage
Mismatch	3.36%
Current transformer (CT) error	10.00%
Magnetization Current	5.00%
TAP exchanger	5.00%
Total percentage	23.36%

Table 2. Relay error percentage.

The current setting on the differential unit of the transformer relay is 2.01 A in the high side and 6.523 A in the low side. Additionally, Table 2 shows the error percentages associated with various restrictions in the power transformer relay. These constraints include mismatch error, current transformer error, magnetizing current, and TAP exchanger. Together, these errors add up to a total of 23.36% in the accuracy of the power transformer differential relay. Due to these considerations, an adjustment has been made to the differential relay, establishing a safety margin of 30% to ensure reliable operation in error situations.

Chipe Hamburgo Feeder. The ABB SPAJ 140C relay was selected for overcurrent and ground fault protection. The relay's settings were adjusted to handle the fault currents identified in the short-circuit study.

The Chipe Hamburgo feeder currently has a CT of 350:5. This CT is considered adequate to carry out long-term protection coordination, given that the maximum demand current recorded in the feeder has been 99.21 A. Furthermore, the overcurrent (51P), (50P) and ground fault (51G) protection is shown in the Table 3.

Valencia Feeder. The Siemens 7SJ80 relay was chosen for overcurrent protection. The relay's settings were adjusted to ensure proper coordination with the transformer protection.

The Valencia feeder currently has a CT with a nominal ratio of 200:5. However, a thorough analysis of the demand flow has revealed a constant increase in the feeder load. A maximum demand current of 182.54 A has been recorded, which is projected to exceed the nominal current of the relay connected to the secondary side of the CT in the coming months.

This situation poses a significant risk of the relay acting inappropriately due to the excessive current, which could result in an incorrect response from the protection system. Therefore, it is recommended to upgrade the CT of 200:5 to a 300:5 CT. This measure will ensure that the protection system has the necessary capacity to operate reliably and accurately under the current and future load conditions on the Valencia feeder.

Place, Feeder I pick-up A	Protection Elements		
	Overcurrent (51P) protection	Ground fault (51G) protection	Overcurrent (50P) protection
Chipe Hamburgo	1.70	0.14	84.46
Valencia	3.65	0.31	98.50
La Mana	3.74	0.31	98.52

Table 3. Setting current of protection elements in the study feeders.

La Mana Feeder. The SEL-551 relay was selected for overcurrent protection. The relay's settings were adjusted to ensure proper coordination with the transformer protection.

La Mana feeder is currently equipped with a current transformer (CT) with a ratio of 200:5. However, after a thorough study of the demand flow, a constant increase in the load of this feeder has been evidenced. The maximum demand current recorded on the feeder has reached 187.06 A.

This increase in load has raised concerns regarding the existing CT's ability to maintain effective protection coordination. Therefore, it is recommended to upgrade the CT to one with a ratio of 300:5.

The overcurrent (51P), (50P) and ground fault (51G) protection is shown in the Table 3.

PROTECTION COORDINATION

The coordination of protection devices was a critical aspect of this study. The time-current characteristics of the selected relays and circuit breakers were meticulously adjusted to ensure selective and rapid operation during fault conditions.

Transformer Protection Coordination. The differential protection (87T) and overcurrent protection (51) elements of the ZIV 8IDV relay were coordinated to provide comprehensive protection for the power transformer. The coordination ensured that the relay operated correctly during internal faults while avoiding unnecessary trips during external faults.

Chipe Hamburgo Feeder. The overcurrent (51P) and ground fault (51G) protection elements of the ABB SPAJ 140C relay were coordinated with the transformer protection. The coordination ensured that the relay operated correctly during faults on the feeder while avoiding unnecessary trips during faults on other feeders.

Curves of the different inverse time overcurrent relays (51-P) and definite time overcurrent relays (50P) that protect from the Chipe Hamburgo feeder to the power transformer of the substation are shown in Fig. 3.

For the ABB SPAJ 140C protection relay of the Chipe Hamburgo feeder, a secondary setting current of 1.7 A, a primary current of 119 A, a time dial (TD) of 0.2, and a very inverse curve type are used. Additionally, the definite time current is set to 40 A on the secondary side, 2800 A on the primary side, with a time setting of 0.15 seconds.

When the maximum system fault occurs on the 13.8 kV bus, there is a protection coordination that allows a time delay of 0.219 seconds between the ABB SPAJ 140C protection relay connected to the feeder and the 8IDV relay connected on the low side of the power transformer.

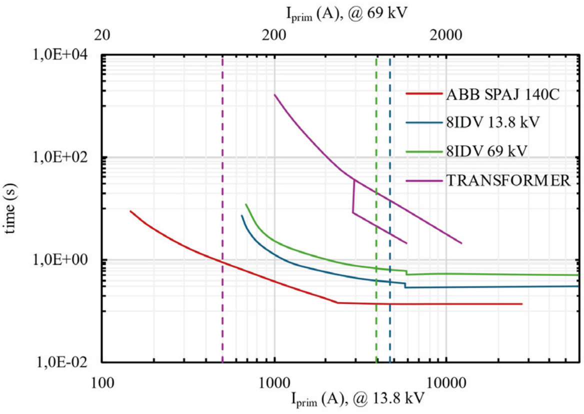

Fig. 3. Coordination of the overcurrent relays of the Chipe Hamburgo Feeder.

Valencia Feeder. The overcurrent protection elements of the Siemens 7SJ80 relay were coordinated with the transformer protection. The coordination ensured that the relay operated correctly during faults on the feeder while avoiding unnecessary trips during faults on other feeders.

Fig. 4 shows the curves of the different inverse time overcurrent relays (51-P) and definite time overcurrent relays (50P) that protect from the Valencia feeder to the power transformer of the substation.

For the SIEMENS 7SJ80 protection relay of the Valencia feeder, a secondary setting current of 3.65 A, a primary current of 219 A, a time dial (TD) of 0.5, and an ANSI/IEEE inverse curve type are used. Additionally, the definite time current is set to 98.5 A on the secondary side, 5910 A on the primary side, with a time setting of 0.025 seconds.

When the maximum system fault occurs on the 13.8 kV bus, there is a protection coordination that allows a time delay of 0.263 seconds between the SIEMENS 7SJ80 relay connected to the feeder and the 8IDV relay connected on the low side of the power transformer.

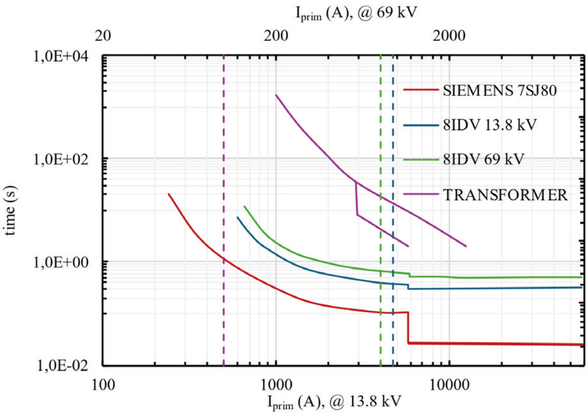

Fig. 4. Coordination of the overcurrent relays of Valencia Feeder.

La Mana Feeder. The overcurrent protection elements of the SEL-551 relay were coordinated with the transformer protection. The coordination ensured that the relay operated correctly during faults on the feeder while avoiding unnecessary trips during faults on other feeders.

Fig. 5 shows the curves of the different inverse time overcurrent relays (51-P) and definite time overcurrent relays (50P) that protect from the Valencia feeder to the power transformer of the substation.

For the SCHWEITZER SEL 551 protection relay of La Maná feeder, a secondary setting current of 3.7 A, a primary current of 222 A, a time dial (TD) of 1, and a U.S. very inverse curve type are used. Additionally, the definite time current is set to 80 A on the secondary side, 4800 A on the primary side, with a current setting of 0.01 seconds inherent to the relay.

When the maximum system fault occurs on the 13.8 kV bus, there is a protection coordination that allows a time delay of 0.256 seconds between the SCHWEITZER SEL 551 protection relay connected to the feeder and the 8IDV relay connected on the low side of the power transformer.

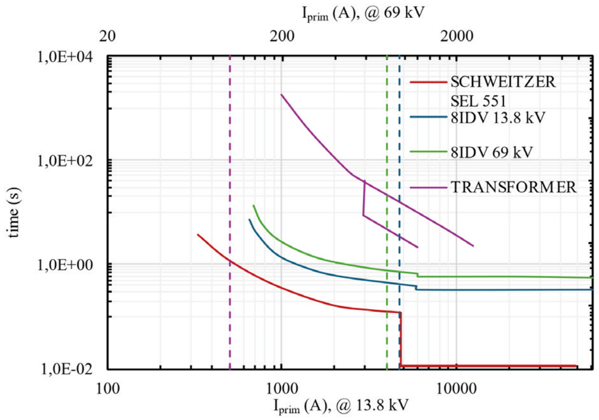

Fig. 5. Coordination of the overcurrent relays of La Maná Feeder.

CONCLUSION

This study has comprehensively addressed the correct selection, adjustment, and coordination of electrical protections in the Valencia distribution substation. Through a detailed evaluation of the short-circuit study, the selection of protection elements, and the coordination of devices, an adequate management of electrical protections has been achieved to ensure a safe and reliable power supply.

The short-circuit study conducted at the Valencia distribution substation has been an essential component for achieving effective protection coordination. By analyzing various short-circuit scenarios, it was determined that the maximum fault current is 4.73 kA when a two-line-to-ground fault occurs on the 13.8 kV bus.

A field review of the substation components enabled the identification and specification of appropriate protection devices essential for preserving the integrity and operational continuity of the substation in the face of potential electrical contingencies.

Through an analysis of the configuration and parameters of the protection devices, as well as their interaction, an effective coordination system has been established. This system minimizes unwanted disconnection times and ensures a precise and timely response to electrical fault events. Effective coordination has been achieved between the feeder relays and the power transformer relay.

While the current electrical protection system of the Valencia substation operates adequately, areas for future improvement have been identified due to the progressive increase in electrical demand in the serviced areas. It is necessary to plan the upgrade of the Current Transformers (CTs) for the La Mana feeders within 2 years and the Valencia feeders within 5 years. These will be replaced by CTs of 300:5, as both currently have CTs of 200:5, which could exceed the nominal value of the relays.

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