VOL. 21, NO. 6, MARCH 2026 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MODELING AND PROTECTION PLAN ELABORATION FOR MEDIUM VOLTAGE ELECTRICAL NETWORK: APPLICATION TO BERECINGOU SUBSTATION

Patrice Koffi Chetangny[1], Victor Zogbochi[1], Mawuena Medewou[1], Mèhundo Walix Leslie D. E.[1], Gérald Barbier[2] and Didier Chamagne[3]
[1]Laboratoire d'Electrotechnique, de Télécommunication et d'Informatique Appliquée (LETIA) Ecole Polytechnique d'Abomey-calavi, Université d'Abomey-Calavi Cotonou, Bénin
[2]Laboratoire de Physique et Mécanique Textiles (LPMT), Université de Haute Alscase (UHA - ENSIA) Mulhouse, France
[3]Université Marie et Louis Pasteur, CNRS, Institut FEMTO-ST, F-90000 Belfort, France
E-Mail: chetangny@yahoo.com

ABSTRACT

The growing energy demand in Natitingou, Kouandé, Kérou, and Péhunco (2KP) necessitates the densification and extension of electrical networks, requiring a reassessment of protection relay settings. This study focuses on developing a comprehensive protection plan for the Bérécingou substation's Medium Voltage (MV) network and optimizing its relay settings. The methodology follows a structured approach: first, the Bérécingou network was modeled using the NEPLAN software, incorporating detailed parameters of the substation and feeders. Next, two-phase and three-phase short-circuit currents were computed analytically using the impedance method, following IEC 60909 standards. The results were validated through NEPLAN simulations, ensuring accuracy and reliability. A comparative analysis was then performed, contrasting the computed values with actual relay settings in the substation to identify discrepancies and areas for improvement. Based on these findings, new protection settings were proposed, emphasizing optimal coordination and selectivity to enhance network stability and fault response efficiency. The study's outcomes demonstrate the necessity of recalibrating the protection system to align with updated short-circuit characteristics. The proposed settings, validated through both analytical and simulation methods, improve fault isolation, minimize unnecessary power outages, and enhance the resilience of the substation's protection scheme. These findings provide a robust framework for designing and implementing efficient protection strategies in MV distribution networks.

Keywords: short-circuit, protection plan, relay setting, electrical network, NEPLAN simulation.

Manuscript Received 17 February 2026; Revised 25 March 2026; Published 20 May 2026

INTRODUCTION

Electrical energy is the backbone of modern industrial, economic, and social development. Its reliability and availability directly affect productivity, service quality, and the overall performance of critical infrastructures. However, as electrical networks grow in complexity and interconnection, they become increasingly susceptible to disturbances such as short-circuit faults, overcurrents, and protection malcoordination. These issues can severely compromise system stability, causing extensive outages, equipment damage, and financial losses [1].

In Benin, the expansion of the medium-voltage (MV) distribution network-particularly in the regions of Natitingou, Kouandé, Kérou, and Péhunco (collectively referred to as 2KP)-has led to an increase in power flows and fault levels. The Société Béninoise d'Énergie Électrique (SBEE), which operates the national distribution system, faces growing challenges in maintaining effective fault protection, especially as new substations and feeders are added to the network [2]. The evolution of network topology modifies line impedances, transformer configurations, and relay coordination conditions, often rendering previously adjusted protection settings obsolete. These changes underscore the need for a systematic and adaptive protection plan capable of evolving with the grid's operational realities.

Short-circuit analysis is a cornerstone of power system protection design. It enables the accurate determination of fault currents under different network configurations, providing essential data for the selection and calibration of protective devices. According to the IEC 60909 standard, short-circuit current calculations are essential for determining the maximum and minimum fault conditions within three-phase and two-phase configurations, ensuring the adequacy of circuit breakers, relays, and fuses [3]. In practical terms, the impedance method-which combines source and line impedances-is the most commonly adopted analytical approach for determining fault currents in MV systems, due to its accuracy and simplicity [4].

Beyond analytical methods, the advent of advanced simulation tools such as NEPLAN, DIgSILENT PowerFactory, and ETAP has revolutionized protection engineering by allowing detailed modeling of network components, fault scenarios, and relay dynamics. These platforms enable the validation of analytical calculations through quasi-dynamic simulations, ensuring that theoretical results align with practical conditions [5]. NEPLAN, in particular, offers integrated modules for short-circuit computation, relay coordination, and selectivity analysis, making it a widely adopted tool in modern protection studies [6].

One of the persistent challenges in medium-voltage distribution systems lies in relay coordination. Improper coordination between upstream and downstream protective devices can result in false tripping or excessive fault-clearing times, leading to prolonged outages or cascading failures. Studies such as Das (2020) and Singh et al. (2019) emphasize that precise time-current discrimination and adaptive setting adjustments are critical to achieving selectivity and operational security [7], [8]. The use of optimization algorithms-such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and hybrid PSO–GA approaches-has further improved coordination efficiency by automating the search for optimal relay settings in complex and dynamic networks [9].

Within this framework, the Bérécingou substation represents a crucial element of Benin's northern MV network. It interconnects multiple feeders that supply the 2KP region and adjacent localities, serving as both a distribution and protection hub. Given its strategic importance, an accurate assessment of its short-circuit characteristics and relay settings is essential to guarantee selective fault clearance and stable operation.

The present study focuses on developing an optimized protection plan for the Bérécingou substation, integrating both analytical and simulation-based approaches. First, the network was modeled in NEPLAN, incorporating detailed line, transformer, and source parameters. Then, two-phase and three-phase short-circuit currents were computed analytically using the impedance method, following IEC 60909 procedures. The analytical results were validated through NEPLAN simulations to ensure precision. Finally, the study proposes new relay settings based on updated short-circuit levels, aiming to achieve faster fault isolation, improved selectivity, and enhanced overall reliability of the MV protection scheme.

This approach bridges the gap between classical analytical methods and modern digital simulation techniques. It also establishes a replicable methodological framework for other SBEE-operated substations, contributing to the modernization and standardization of MV protection systems in Benin and across the West African Power Pool (WAPP).

REVIEW OF THE LITERATURE

Medium-Voltage Protection Standards and Principles

Protection of medium-voltage (MV) electrical networks aims to ensure the rapid and selective isolation of faulty components while maintaining supply continuity to unaffected sections. International standards such as IEC 60909 (for short-circuit current calculations) and IEC 60255 (for relay functional requirements) serve as the fundamental technical references for the design, testing, and coordination of protection systems [10].

According to these standards, the selection and setting of protective relays must account for network topology, source impedance, and fault levels to guarantee both sensitivity and selectivity. Time-overcurrent relays (functions 50/51) are typically used for phase faults, whereas zero-sequence overcurrent relays (functions 50N/51N) provide ground fault protection [11]. Proper grading between primary and backup relays is achieved by defining time-current coordination curves that respect minimum discrimination intervals, usually between 0.3 s and 0.5 s [12].

The reliability of a protection plan depends not only on accurate short-circuit current determination but also on proper discrimination between protection zones. Mis-coordination, resulting from uncalibrated time delays or outdated settings, can lead to widespread outages and unnecessary tripping, which are particularly critical in interconnected MV systems with mixed radial and meshed configurations [13].

Relay Coordination and Optimization Approaches

Conventional relay coordination relies on graphical and analytical methods derived from manufacturer curves and field experience. However, with the increasing size and complexity of modern power systems, manual coordination has become inefficient and prone to errors. Recent developments have therefore focused on optimization-based approaches to determine the optimal relay settings that minimize fault-clearing time while maintaining selectivity and system stability [14].

Among the most prominent methods, Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Differential Evolution (DE) have been successfully implemented in complex distribution networks. These algorithms enable the automatic tuning of relay parameters-such as pickup currents and time dial settings-under multiple fault scenarios and system constraints [15]. Singh *et al*. (2019) and Ezzeddine *et al*. (2022) demonstrated that metaheuristic algorithms significantly reduce the total operation time of protection devices while maintaining discrimination under load fluctuations [16].
More recently, adaptive protection systems have been developed to respond to real-time network reconfigurations and distributed generation (DG) variability. Such adaptive or self-adjusting relay schemes can modify their settings dynamically based on grid measurements, thereby increasing fault-detection accuracy in active networks [17].

Simulation Tools and Modern Trends in Protection Studies

Advances in computational modeling have enabled the integration of analytical protection concepts within digital environments. Simulation platforms such as NEPLAN, DIgSILENT PowerFactory, ETAP, and PSCAD/EMTDC provide powerful capabilities for modeling MV networks, computing short-circuit levels,

VOL. 21, NO. 6, MARCH 2026 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

and visualizing relay coordination under steady-state and transient conditions [18].

Among these, NEPLAN is widely adopted by utilities and academic institutions due to its user-friendly interface, compliance with IEC standards, and comprehensive modules for relay setting analysis and selectivity studies. Its simulation environment allows engineers to validate analytical results through time-domain analyses, verify grading margins, and optimize coordination schemes based on real operating data.

Furthermore, recent studies have emphasized the importance of combining analytical IEC-based methods with simulation-based validation to enhance reliability in complex MV systems. This dual methodology ensures consistency between theoretical calculations and field performance, leading to robust and standardized protection strategies across large-scale electrical networks.

The reviewed literature highlights a clear evolution from conventional, manual coordination methods toward intelligent, optimization-assisted, and simulation-driven protection planning. While extensive research has been conducted globally on short-circuit analysis and relay coordination, few studies have addressed medium-voltage protection challenges in sub-Saharan African contexts, where grid expansion, limited redundancy, and outdated relay configurations remain major concerns.

This study contributes to bridging that gap by combining IEC 60909-compliant analytical methods with NEPLAN-based simulations for the Bérécingou substation. The proposed approach aims to establish a reliable and replicable framework for protection planning within Benin's electrical distribution networks, ensuring improved selectivity, coordination, and operational security.

Methodology for Elaborating a Protection Plan

A protection plan is a structured and coordinated set of measures designed to ensure the availability of electrical energy while safeguarding both personnel and equipment [19]. It plays a crucial role in minimizing network disturbances and ensuring the reliability of power distribution. An effective protection plan must achieve the following objectives [20]:

- Fault isolation: Detect and eliminate faults by disconnecting the faulty section using appropriate switching devices such as circuit breakers or fuses.
- Backup protection: Ensure fault clearance by upstream protection when a downstream device fails, integrating redundancy mechanisms to prevent cascading failures.
- Equipment protection: Safeguard critical components of the electrical network, including power transformers, protection links, medium-voltage (MV) switchboards, and capacitors.
- Operational flexibility: Allow temporary modifications of relay settings (e.g., sensitivity, response time) to accommodate specific operational needs such as live maintenance work or transformer paralleling.

The selection and coordination of protection systems represent a fundamental aspect of power system design, ensuring compliance with technical and safety standards [21]. By implementing an optimized protection strategy, it is possible to enhance fault detection, relay coordination, and overall network stability.

The protection architecture for distribution networks is depicted in Figure-1, illustrating the hierarchical organization of protective devices and their role in maintaining network integrity.

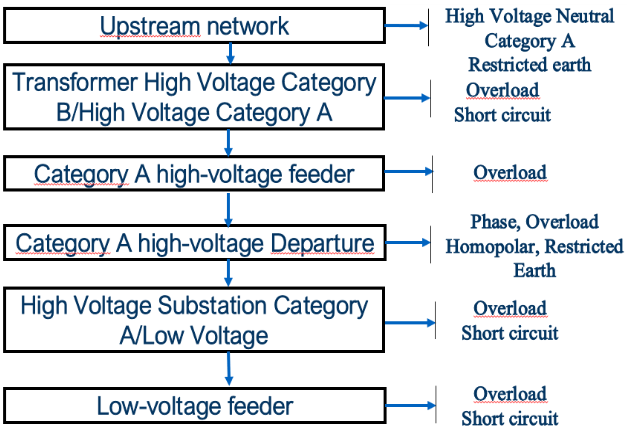

Figure-1. Organization of the protection chain.

Methodology for Calculating Short-Circuit Currents

To ensure effective protection of an electrical installation, it is essential to evaluate short-circuit currents at different points within the network. These calculations play a crucial role in selecting appropriate switching devices for fault interruption and defining protection settings to enhance network reliability. According to the IEC 60909 standard, the determination of minimum two-phase short-circuit currents for each feeder is necessary [2]. These values are fundamental for:

- Defining the tripping characteristics of switching devices, ensuring accurate fault clearance within an optimal time frame.
- Setting protection thresholds for overcurrent protection devices, facilitating proper coordination and selectivity between protection elements.

The impedance method is the most widely used analytical approach for short-circuit current evaluation. This technique determines the fault current at any given point by summing the resistances and reactances of the fault loop, from the power source to the fault location, and computing the equivalent impedance [22]. Using Ohm's law, the short-circuit current is then derived, providing a precise basis for configuring the protection system.

VOL. 21, NO. 6, MARCH 2026 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

$$I_{cc3} = \frac{c \cdot U_{ref}}{\sqrt{3} \cdot Z_{cc}} . \quad (1)$$

$$I_{cc2} = \frac{\sqrt{3}}{2} I_{cc3} . \quad (2)$$

Uref: Voltage between phases at the point under consideration
Zcc: Impedance of the circuit upstream of the fault
$Icc2$: Two-phase short-circuit current
$Icc3$: Three-phase short-circuit current

In an analytical short-circuit calculation, the fault condition that results in the maximum short-circuit current is typically a three-phase fault, which is generally assumed to occur at the feeder head. This assumption aligns with industrial network protection strategies, such as those outlined in Schneider's technical guide [23]. Conversely, the minimum short-circuit current is associated with a two-phase fault, which is commonly considered to take place at the end of the line, where the fault impedance is highest.

The electrical network's response to a short circuit can be represented using an equivalent circuit model, consisting of a voltage source positioned before the fault and the corresponding network impedance components, including positive-sequence (direct), negative-sequence (reverse), and zero-sequence impedances at the fault location [24].

To accurately determine short-circuit current values, NEPLAN software was employed to simulate and compute:

- Minimum short-circuit currents (two-phase faults) occurring at the farthest points of the network.
- Maximum short-circuit currents (three-phase faults) occurring at the feeder head.

This approach ensures a precise assessment of fault current magnitudes, facilitating the optimal configuration of protection settings for enhanced system reliability.

MODELING THE BERECINGOU NETWORK

Presentation of the Network Studied

The Bérécingou substation is supplied by two main sources: the 161 kV Djougou substation operated by the Compagnie Énergie du Bénin (CEB) and a thermal power plant. The 161 kV voltage from CEB reaches the 161 kV busbar at the substation, where it is stepped down to 33 kV through a 161/33 kV transformer before being distributed via the SBEE's busbar.

The distribution network consists of multiple feeders:

- A 33 kV feeder supplying the 2KP region.
- A 33 kV underground feeder extending 12 km across Natitingou, reaching a mini-distribution substation that supplies the Kouarfa, Boukoumbé, and Tanguiéta feeders.
- Another 33 kV feeder connects to a 33/11 kV transformer, where voltage is stepped down to 11 kV for further distribution.

The Bérécingou thermal power plant, with an installed capacity of 12 MW, comprises six generator sets, each rated at 2 MW and 11 kV. Historically, this plant served as the primary power source for the entire region. However, it is now designated as a backup generation facility, activated in case of unavailability of the main CEB source. Currently, only five out of six units are operational. To integrate the thermal generation into the network, a 12 MVA, 11 kV/15 kV transformer is used to raise the voltage before supplying the Natitingou and Park Autobus feeders. Electrical power is transported through aluminum conductors of varying cross-sections, installed on both sides of the network. To ensure proper voltage levels at end-users, distribution transformers step down the transmission voltage to 400 V, the standard operating voltage.

For network flexibility and maintenance purposes, manually operated overhead switches are strategically deployed, allowing for sectionalization, fault isolation, and servicing without major disruptions to the power supply.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

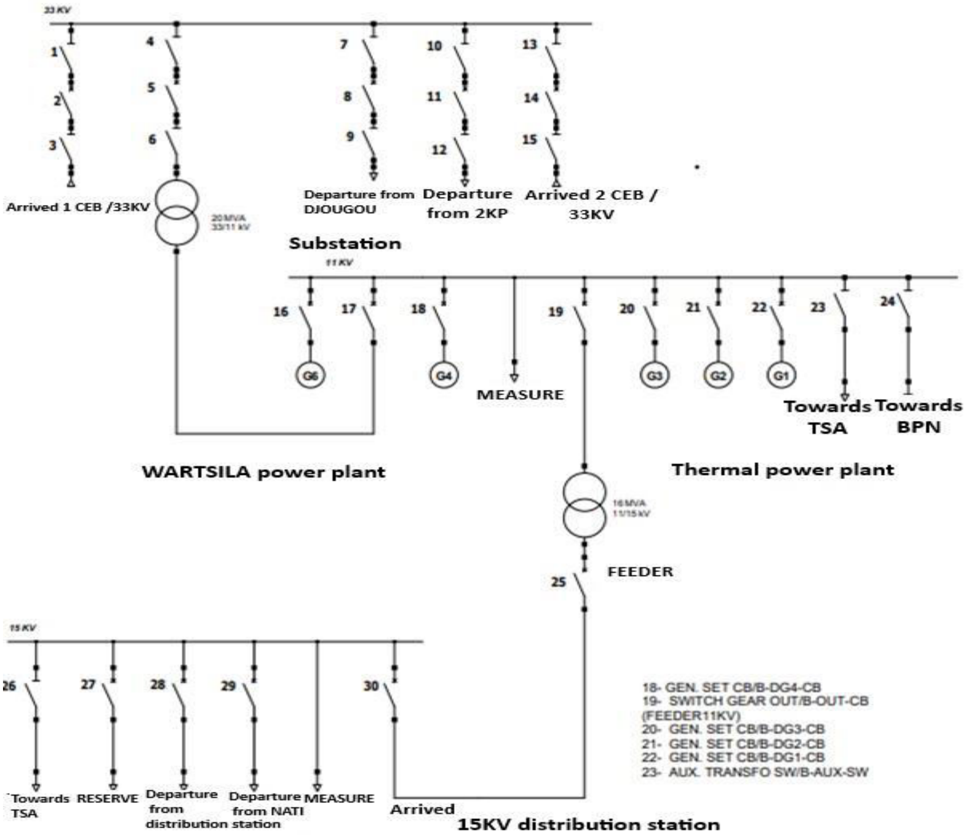

Figure-2. Single-line diagram of the Bérécingou substation [25].

Representation of the Bérécingou Substation network Using Neplan Software

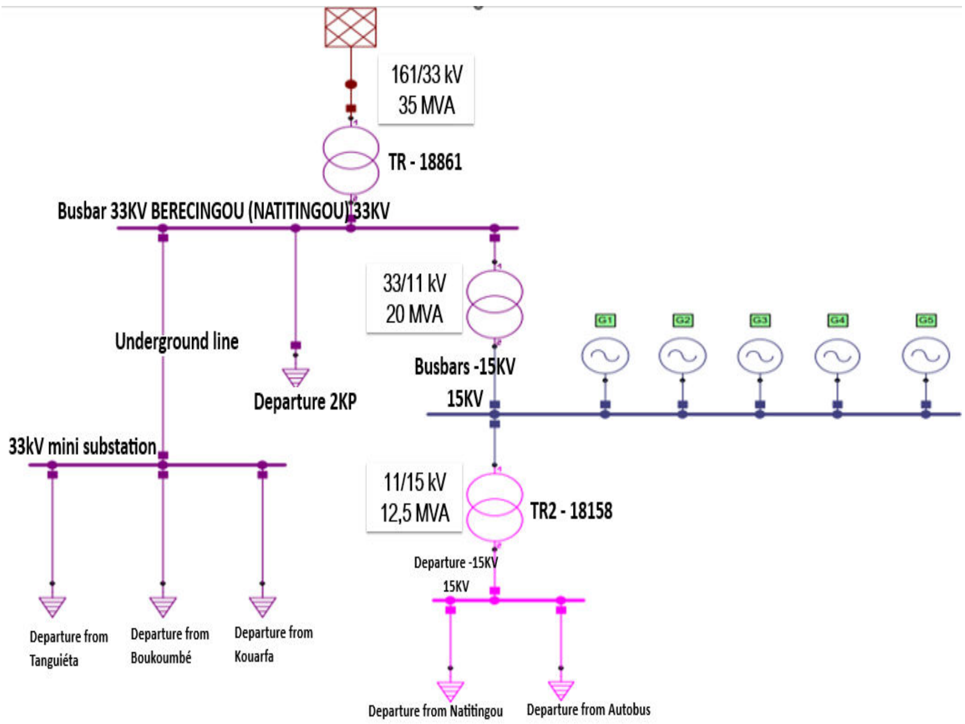

Figure-3. Bérécingou substation.

VOL. 21, NO. 6, MARCH 2026 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

The Bérécingou substation (Figure-3) is a critical node in the regional medium-voltage (MV) and low-voltage (LV) power distribution network. It consists of the following key infrastructure components:

- One 161/33 kV source substation, responsible for stepping down the high-voltage transmission power for distribution.
- Two distribution substations operating at 33/11 kV and 11/15 kV, facilitating voltage conversion for local distribution.
- A total of 198 HTA/LV distribution substations, categorized as:
-
- 181 H61 substations, ensuring power distribution across various regions.
- 17 H59 substations, serving specific load requirements.

The Bérécingou substation supplies electricity through six primary feeders, each covering distinct geographical zones:

- 2KP feeder
- Natitingou feeder
- Autobus feeder
- Kouarfa feeder
- Tanguiéta feeder
- Boukoumbé feeder

This infrastructure plays a vital role in ensuring efficient power distribution, fault management, and network stability within the serviced regions.

RESULTS AND DISCUSSIONS

For various substation configurations, we performed calculations to determine:

- The maximum short-circuit currents, which occur at the feeder head and represent the most severe fault conditions.
- The minimum short-circuit currents are observed when a fault is located at the end of the line, where impedance is highest.

The obtained results exhibit high reliability and provide a valuable reference for optimizing the protection settings of the Bérécingou network. These values can be effectively utilized by SBEE to refine relay coordination, enhance fault isolation, and improve overall system stability.

Table-1. Theoretical results of two-phase short-circuit current calculations.

	Length considered [m]	**Line impedance [Ω]**	**Transformer impedance [Ω]**	**Upstream network impedance [Ω]**	**Short-circuit impedance [Ω]**	**Short-circuit current [A]**
2KP 33kV	223000	75.11	13.29	3.17	76.27	274.75
KOUARFA 33kV	27024	8.38	13.29	3.17	15.71	1333.68
BOUKOUMBE 33kV	98077	42.48	13,.30	3.17	44.51	470.76
TANGUIETA 33kV	275203	62.81	13.30	3.17	62.25	336.65
NATITINGOU 15kV	75000	1.65	15.38	3.17	31.86	657.76
AUTOBUS 15kV	3369	27.90	15.38	3.17	11.73	1782.87

VOL. 21, NO. 6, MARCH 2026 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-2. Numerical results of the calculation of polyphase short-circuit currents.

Network point	Nominal voltage (kV)	Voltage factor c	Two-phase short-circuit current in (A)	Three-phase short-circuit current in (A)
2KP	33	1.1	275	318
Underground feeder 33 kV	33	1.1	275	318
KOUARFA feeder	33	1.1	1334	1807
BOUKOUMBE feeder	33	1.1	471	567
TANGUIETA feeder	33	1.1	337	389
NATITINGOU	15	1.1	658	759
AUTOBUS	15	1.1	1786	2062

Table-3. Comparative study of calculated theoretical values and simulation values.

Start	Theoretical calculation	Simulation	Relative difference (%)
2KP	274.753	275	0.2457
KOUARFA	1333.688	1334	0.312
BOUKOUMBE	470.761	471	0.24
TANGUIETA	336.650	337	0.35
NATITINGOU	657.761	658	0.239
AUTOBUS	1785.872	1786	0.128

The relative error analysis of the computed short-circuit currents indicates a maximum deviation of 1.5%, confirming the high accuracy of the applied calculation method. This level of precision validates the reliability of the analytical and simulation results, ensuring their applicability in practical network settings. Consequently, these verified values can be effectively utilized to determine and optimize the protection settings for the various feeders and circuit breakers within the Bérécingou substation.

Classic Method for Calculating Protection Thresholds

The theoretical calculation is carried out on transformer output points, as well as on SBEE HTA feeders.

The phase overcurrent protection devices installed at the Bérécingou substation are activated to detect overloads and overcurrents. Two thresholds are set for this purpose.

The first threshold is for overload detection, and the method for calculating this threshold is as follows: (3)
This threshold is followed by a time delay.

The second threshold for detecting overcurrents, especially a polyphase fault or short-circuit, is determined by:

$$I >> 0.8 \cdot I_{ccb} . \quad (3)$$

This threshold is instantaneous and follows no time delay.

Overcurrent protection is also activated on protection devices to detect earth fault currents.
In this case, two thresholds are also set:

The first threshold for detection against a fugitive earth fault, but this threshold is followed by a time delay:

$$I_0 >> 0.06 \cdot I_n(TC) . \quad (4)$$

The second threshold can also be used to detect a single-phase fault or short-circuit. Unlike the first threshold, it is not time-delayed and can be set by pressing a key:

$$I_0 >> 0.12 \cdot I_n(TC) . \quad (5)$$

Protection Settings on Each Feeder of the Bérécingou Substation

VOL. 21, NO. 6, MARCH 2026 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

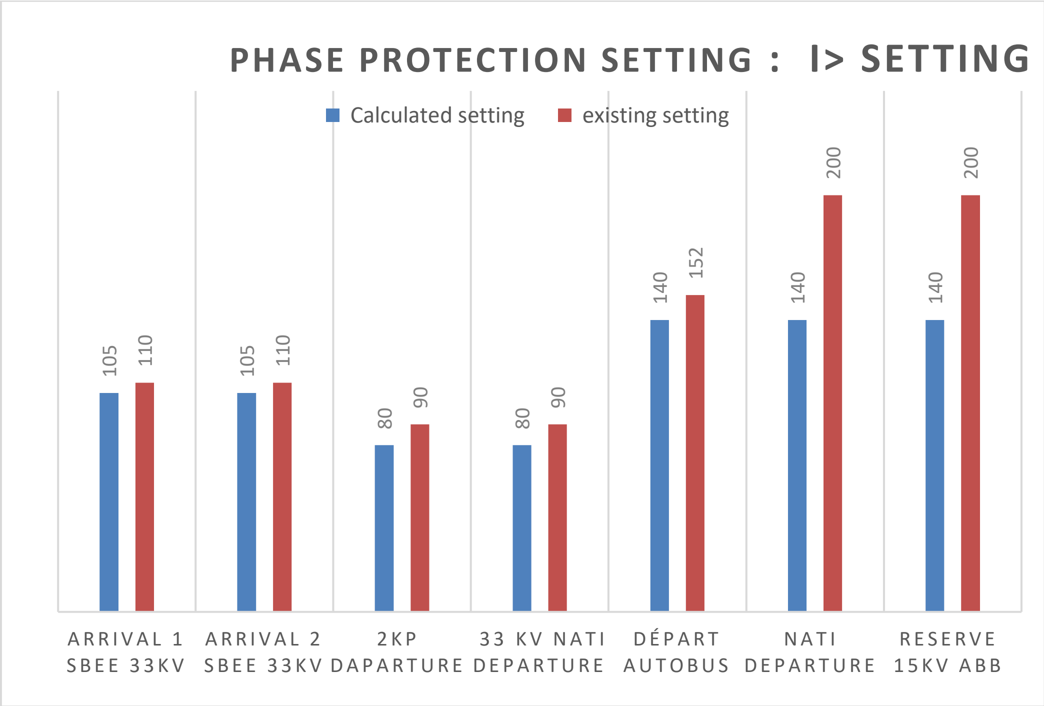

Figure-4. Phase protection setting: function 51 I>.

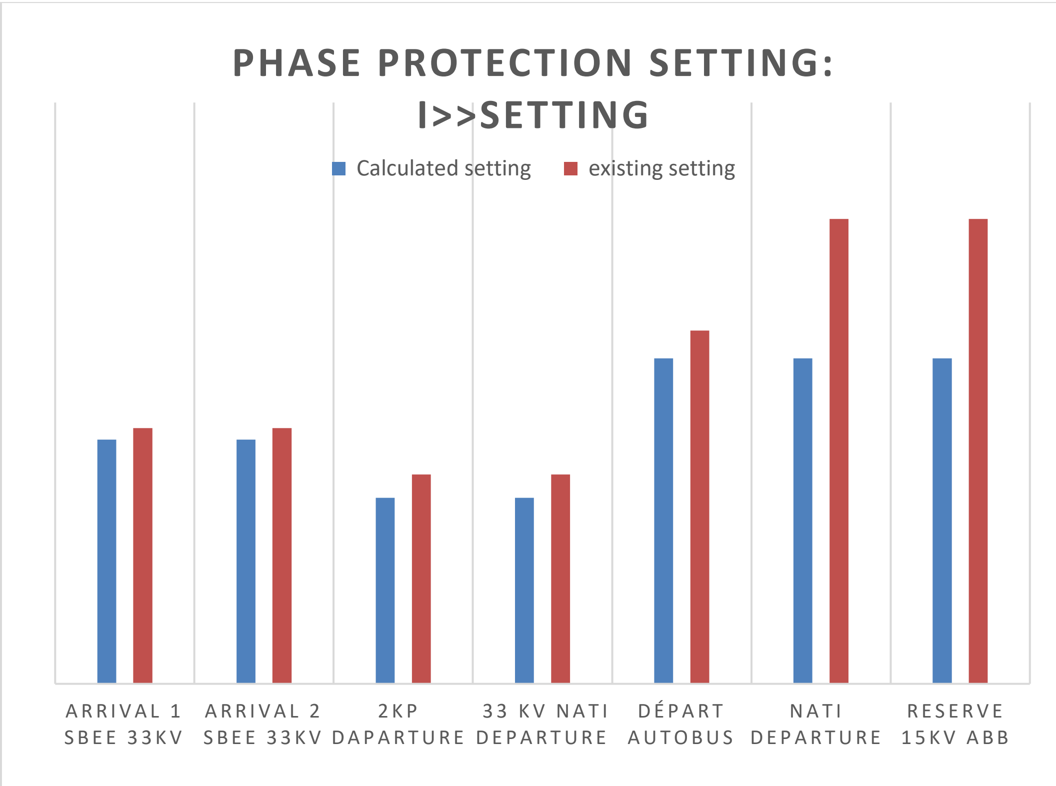

Figure-5. Phase protection setting: function 50 I>>.

VOL. 21, NO. 6, MARCH 2026 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

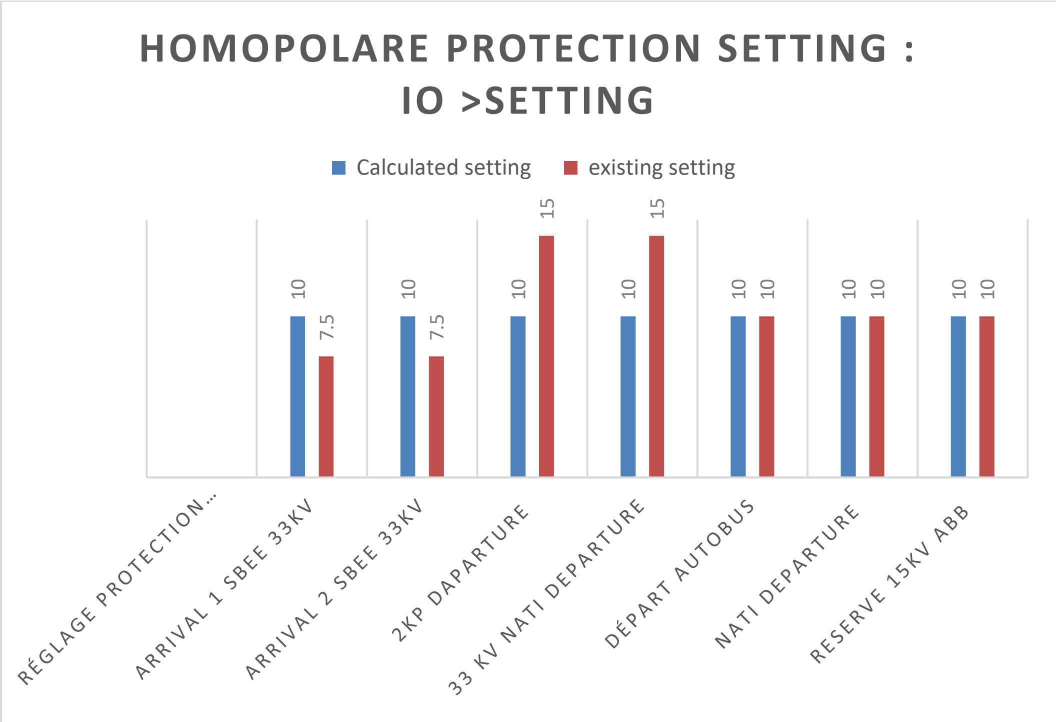

Figure-6. Zero-sequence protection setting: function: 51N Io>.

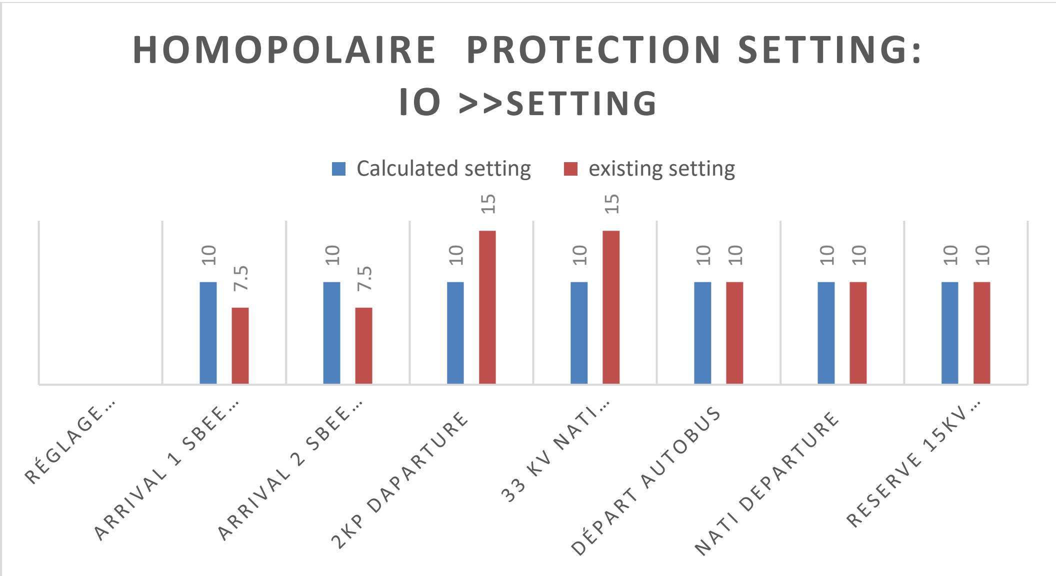

Figure-7. Zero sequence protection setting: function 50N Io>>.

The analysis of the histograms highlights a significant discrepancy between the calculated protection settings and those currently implemented in the system. This divergence arises due to non-compliance with the recommended calculation methodology when configuring the protection relays during fault conditions.
Such inconsistencies in relay settings have two major consequences:

- Prolonged power outages, which negatively impact the network's operational reliability.
- Accelerated degradation of protection devices, leading to premature failures and increased maintenance costs.

From the comparative analysis of the tables and histograms, it is evident that the calculated relay settings offer a more optimized configuration, enhancing both fault response efficiency and network stability. By implementing these revised settings, the Bérécingou substation can achieve better selectivity, reduce unnecessary power interruptions, and improve overall energy availability across the distribution network.

CONCLUSIONS

This study developed an optimized protection plan for the Bérécingou substation, focusing on enhancing fault detection, relay coordination, and network stability. The methodology combined analytical short-circuit calculations with NEPLAN software simulations, allowing for a detailed comparative analysis of existing and proposed relay settings. The results highlighted significant discrepancies in current protection configurations, demonstrating the need for recalibration to improve selectivity, fault isolation, and response times. A maximum relative error of 1.5% between analytical and simulated values confirmed the accuracy and reliability of the adopted approach. While NEPLAN software was used as the primary tool for network modeling and short-circuits analysis, it is important to note that alternative simulation tools such as ETAP, DigSILENT Power Factory, and PSCAD also exist. However, NEPLAN was selected for this study due to its user-friendly interface, compliance with IEC 60909 standards, and extensive functionality for relay coordination analysis, making it the most suitable choice for this particular research. The findings of this research contribute to the enhancement of MV network protection systems, ensuring greater power system reliability. Future research could focus on (1) the integration of adaptive protection schemes that dynamically adjust relay settings based on real-time grid conditions, (2) the implementation of AI-based fault prediction models to enhance proactive maintenance strategies, and (3) experimental validation of the proposed protection settings through hardware-in-the-loop (HIL) testing for real-world application assessment. These perspectives will further strengthen the resilience and operational efficiency of power distribution networks.

REFERENCES

[1] A. Oloulade. 2019. Contribution to the multi-criteria optimization of the operation of an electrical distribution network through the optimal placement of FACTS devices and the reconfiguration of its topology. Ph.D. Thesis, Université d'Abomey-Calavi, Bénin.

[2] M. A. Hounsou. 2011. Contribution to the improvement of the voltage level at the 63-15 kV SBEE-Akpakpa substation. Master's Thesis, Université d'Abomey-Calavi, Bénin.

[3] 2016. IEC 60909-0, Short-Circuit Currents in Three-Phase A.C. Systems - Part 0: Calculation of Currents, International Electrotechnical Commission, Geneva.

[4] P. Blackburn and T. Domin. 2021. Protective Relaying: Principles and Applications, 5th ed., CRC Press, Boca Raton, FL.

[5] S. R. Kamel and M. R. Zahran. 2022. Short-circuit analysis and relay coordination in distribution systems using NEPLAN. International Journal of Electrical Power & Energy Systems. 142: 108280.

[6] A. Raza, A. Baig and M. Jamil. 2022. Performance evaluation of IEC-based short-circuit calculations using simulation tools. Energy Reports. 8: 5734-5744.

[7] D. Das. 2020. Coordination of directional overcurrent relays in distribution systems: A review. Electric Power Systems Research. 189: 107984.

[8] S. Singh, B. Panigrahi and S. Sinha. 2019. Optimal overcurrent relay coordination using evolutionary algorithms. IEEE Transactions on Power Delivery. 34(3): 1234-1242.

[9] M. Ezzeddine, H. Chaoui and A. Chandra. 2022. A hybrid PSO-GA-based coordination for overcurrent relays in active distribution networks. Energies. 15(8): 2931.

[10] 2019. IEC 60255-151, Measuring Relays and Protection Equipment - Part 151: Functional Requirements for Overcurrent Relays, International Electrotechnical Commission, Geneva.

[11] P. M. Anderson and S. A. Fouad. 2020. Power System Protection and Switchgear, 2nd ed., CRC Press.

[12] P. Blackburn and T. J. Domin. 2021. Protective Relaying: Principles and Applications, 5th ed., CRC Press, Boca Raton.

[13] D. Das. 2020. Coordination of directional overcurrent relays in distribution systems: A review. Electric Power Systems Research. Vol. 189, 107984.

[14] A. Saeed and A. El-Fergany. 2023.Optimal relay coordination using an improved differential evolution algorithm. IEEE Access. 11: 20110-20124.

[15] S. Singh, B. Panigrahi and S. Sinha. 2019. Optimal overcurrent relay coordination using evolutionary algorithms. IEEE Transactions on Power Delivery. 34(3): 1234-1242.

[16] M. Ezzeddine, H. Chaoui and A. Chandra. 2022. A hybrid PSO-GA-based coordination for overcurrent

relays in active distribution networks. Energies. 15(8): 2931.

[17] C. Y. Zhang and M. Keerthi. 2024. Adaptive overcurrent relay coordination for modern power networks. IEEE Transactions on Industry Applications. 60(1): 57-69.

[18] S. R. Kamel and M. R. Zahran. 2022. Short-circuit analysis and relay coordination in distribution systems using NEPLAN. International Journal of Electrical Power & Energy Systems. 142: 108280.

[19] Technical Directorate of Distribution. 2016. Protection plan for electrical distribution networks. 2016. Accessed: 2023.

[20] H. Ouanter and Y. Nifaoui. 2023. Improvements in the protection of HTA/HTB source substations. 2015. Accessed: Oct. 5.

[21] A. Hammani, A. Bahri, B. Serouti and M. T. Hammani. 2023. Protection of a 30 kV medium voltage line. University of Echahid Hamma Lakhdar El-Oued, 2014. Accessed:

[22] S. Kheloufi and M. Hocine. 2022. Study of the protection of an HTA feeder. Master’s thesis in Electrical Engineering, 2018/2019. Accessed:

[23] R. Jeannot and C. Preve. 2022. Network Architecture: Guide to the Design of Industrial Electrical Networks, Schneider Electric, No. 6883 427-A, p. 51. Accessed:

[24] S. Houndedako. Optimal method for calculating short-circuit currents in a power distribution network.

[25] SBEE. 2022. Incident analysis report on the HTA network of Bérécingou. Period.