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Analysis Of Migration Strategy And Maintenance Impact Of One-And-Half Breaker System At 150 Kv Substation: Case Study Of Gandul Substation

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Abstract

Gandul Substation (GI Gandul) serves as a critical nodal point within the 150 kV Java–Bali transmission network, playing a significant role in maintaining system stability and ensuring reliable electricity delivery. As electricity demand continues to increase, the conventional Double Busbar configuration has begun to face limitations in terms of operational flexibility, asset maintenance, and service continuity. This study aims to analyze the technical and operational impacts of migrating the existing substation arrangement to a One-and-Half Breaker (1.5 Breaker) configuration. The research employs a quantitative approach based on reliability index assessment and protection coordination review to evaluate the effectiveness of the proposed system upgrade. Key reliability indicators, particularly Expected Energy Not Served (EENS), are utilized to measure the potential improvement in system performance. The findings are expected to demonstrate that the inherent redundancy provided by the 1.5 Breaker arrangement significantly reduces EENS values, thereby enhancing overall system reliability and availability. Furthermore, the proposed configuration enables maintenance activities on circuit breakers without requiring complete outages of transmission bays or transformer bays, minimizing service interruptions and improving operational efficiency. The study also highlights the strategic advantages of the 1.5 Breaker scheme in substations with limited land availability while maintaining high reliability standards. The results provide valuable insights and practical guidance for Engineering, Procurement, and

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Construction (EPC) contractors, transmission planners, and system operators in designing and implementing future substation infrastructure upgrades to support growing power system demands.

Keywords: One-and-Half Breaker (1.5 Breaker); GI Gandul; Reliability; Expected Energy Not Served (EENS); Substation Maintenance.

INTRODUCTION

The improvement of transmission system reliability in highly populated and high-load regions such as Jakarta and its surrounding metropolitan areas has become a strategic priority for power utilities and transmission operators. Rapid urbanization, industrial expansion, and the increasing dependence of economic activities on uninterrupted electricity supply have significantly raised the demand for reliable power delivery systems. Consequently, transmission substations serving as major power transfer nodes are required to maintain high levels of availability and operational flexibility. Any disruption occurring within these substations may lead to widespread service interruptions, financial losses, and reduced system stability. Therefore, modern transmission infrastructure must be designed not only to accommodate growing demand but also to support continuous operation during maintenance activities and equipment outages (Ahmed et al., 2024).

Gandul 150 kV Substation (GI Gandul) represents one of the most important transmission hubs within the Java–Bali interconnected power system. As a backbone facility responsible for transferring electrical energy to major load centers, the substation plays a critical role in ensuring system security and maintaining voltage stability across the network. The strategic importance of GI Gandul has increased in recent years due to the rising load demand in the Greater Jakarta area. Consequently, transmission operators are required to continuously evaluate the effectiveness of existing substation configurations and identify opportunities for enhancing reliability, operational efficiency, and maintenance flexibility (Sani et al., 2023).

The existing Double Busbar configuration implemented in many transmission substations has long been recognized as a reliable arrangement because it provides redundancy through the use of two busbars. Under normal operating conditions, this configuration allows operators to transfer loads between busbars and perform limited maintenance activities without significantly affecting service continuity. However, as transmission networks become more complex and load levels continue to increase, several operational limitations of the Double Busbar arrangement

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have emerged. These limitations include intricate switching procedures, dependence on manual operational sequences, and increased vulnerability to operational mistakes during maintenance processes (Kumar & Singh, 2022).

One of the most critical challenges associated with the Double Busbar system is its dependence on a primary operational busbar during routine maintenance and switching operations. Maintenance activities involving circuit breakers (PMT) often require multiple switching maneuvers, increasing operational complexity and creating opportunities for human error. In high-load substations such as GI Gandul, an incorrect switching sequence may result in unnecessary outages, equipment stress, or even cascading failures affecting multiple transmission circuits. Consequently, utilities are increasingly seeking alternative substation configurations that can reduce operational risk while maintaining uninterrupted power delivery (Rahman & Choi, 2024).

Previous studies have highlighted the growing need to strengthen reliability assessments in GI Gandul as transmission network topology evolves. Research conducted by Sani et al. (2023) emphasized that the changing characteristics of power flows and network interconnections require more comprehensive reliability evaluations than those previously applied. Their findings suggest that conventional reliability approaches may no longer adequately represent the operational realities of modern transmission systems. As a result, transmission planners are encouraged to adopt advanced reliability evaluation techniques capable of capturing the interactions among equipment failures, maintenance schedules, and protection system performance.

Among the various alternative substation configurations available today, the One-and-Half Breaker (1.5 Breaker) scheme has attracted considerable attention due to its superior reliability characteristics. This configuration employs three circuit breakers for every two circuits, allowing each transmission line or transformer to remain connected through multiple protection paths. The redundancy inherent in this arrangement significantly reduces the probability of complete circuit disconnection following a single equipment failure. State-space reliability analyses conducted by several researchers have demonstrated that the 1.5 Breaker configuration exhibits a substantially lower failure probability compared with conventional Double Busbar systems (Li & Zhang, 2023).

The reliability advantages of the 1.5 Breaker arrangement have also been validated through empirical and simulation-based studies. Research by Yusuf et al. (2022) investigated the reliability performance of several substation configurations and concluded that the 1.5 Breaker

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arrangement achieved the lowest failure index among the evaluated alternatives. Their analysis revealed that the redundancy provided by the additional circuit breaker significantly improves system availability and minimizes the likelihood of service interruptions. These findings support the argument that the 1.5 Breaker scheme is particularly suitable for substations serving critical load centers where uninterrupted power supply is essential.

In addition to improving reliability, the 1.5 Breaker configuration offers substantial benefits in terms of protection system performance. Modern transmission systems require protection schemes capable of rapidly detecting and isolating faults while minimizing the impact on unaffected network components. Studies conducted by Palit et al. (2025) demonstrated that advanced protection coordination within a 1.5 Breaker arrangement enables selective fault isolation without interrupting power flow through adjacent feeders. Similarly, research by Wijaya (2022) showed that the protection architecture of this configuration effectively prevents widespread outages by limiting fault impacts to the affected section only. Such capabilities are particularly valuable in urban transmission networks where service continuity is a critical operational requirement.

Another important advantage of the 1.5 Breaker configuration relates to maintenance management. In conventional Double Busbar systems, maintenance on circuit breakers frequently necessitates temporary service interruptions or complicated switching arrangements. By contrast, the redundant structure of the 1.5 Breaker scheme allows maintenance personnel to isolate individual breakers while maintaining power transfer through alternative paths. This feature reduces maintenance-related outages, shortens work durations, and enhances overall operational flexibility. Furthermore, maintenance planning becomes more predictable because critical equipment can be serviced without significantly affecting transmission system availability (Garcia & Moreno, 2024; Khoiruman et al., 2026).

Despite the substantial body of literature addressing reliability improvement and protection coordination within 1.5 Breaker substations, an important research gap remains concerning the practical implications of transitioning from Double Busbar systems from the perspective of Engineering, Procurement, and Construction (EPC) contractors. Most previous studies have focused primarily on technical performance indicators, such as failure rates, reliability indices, and fault-clearing capabilities, while giving limited attention to implementation challenges, construction sequencing, maintenance management adaptation, and long-term operational efficiency following migration. Recent studies emphasize that successful infrastructure modernization requires integrating technical reliability objectives with practical

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project execution considerations (Tanaka et al., 2024; Rodriguez & Smith, 2023).

Therefore, this study seeks to address three critical issues associated with the migration of GI Gandul from a Double Busbar arrangement to a One-and-Half Breaker configuration. First, it evaluates the improvement of reliability indices following the implementation of the new configuration, with particular emphasis on system availability and Expected Energy Not Served (EENS). Second, it develops an adaptive protection scheme capable of accommodating the new breaker diameter arrangement while maintaining selective and dependable fault isolation. Third, it examines the efficiency of circuit breaker maintenance procedures under the proposed configuration from the perspective of EPC implementation and operational sustainability. Addressing these issues is essential to ensure that substantial investments in substation modernization generate measurable long-term benefits in reliability, operational flexibility, and maintenance effectiveness. The findings are expected to provide strategic guidance for utilities, transmission planners, EPC contractors, and system operators involved in the development of high-reliability substations operating under land constraints and increasing electricity demand (Morgan & Patel, 2025).

RESEARCH METHODOLOGY

This study adopts a quantitative engineering approach combined with technical simulation methods to evaluate the effectiveness of migrating the existing Double Busbar configuration at Gandul 150 kV Substation (GI Gandul) to a One-and-Half Breaker (1.5 Breaker) arrangement. The 1.5 Breaker configuration is widely recognized for its ability to provide superior operational flexibility and reliability by utilizing three circuit breakers to serve two transmission bays. This arrangement creates a highly redundant network structure in which the middle circuit breaker, commonly referred to as the tie breaker, can maintain power flow continuity when one of the adjacent breakers is unavailable due to faults, maintenance activities, or operational constraints. Such redundancy significantly reduces the probability of service interruptions and enhances system resilience under contingency conditions (Yusuf et al., 2022). Therefore, the study focuses on assessing the technical and operational impacts of implementing this configuration within the real operating environment of GI Gandul.

The research utilizes both primary and secondary data sources to ensure comprehensive analysis and reliable results. Primary data are obtained from the actual technical specifications of equipment installed at GI Gandul, including circuit breakers, disconnect switches, current transformers, voltage transformers, busbars, and protection relays. These data provide the

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foundation for developing an accurate representation of the substation's operational characteristics. Secondary data consist of historical equipment failure rates, maintenance records, outage statistics, and reliability parameters obtained from PLN operational reports, IEEE reliability standards, and relevant technical literature. The integration of these data sources enables the development of realistic simulation models that accurately reflect operational conditions and equipment performance throughout the system lifecycle (Billinton & Allan, 1996).

The first analytical instrument employed in this study is Reliability Block Diagram (RBD) analysis. This method is used to quantify system availability and evaluate the reliability performance of both the existing Double Busbar configuration and the proposed 1.5 Breaker arrangement. The RBD approach models the interrelationships among critical substation components and determines the overall system reliability based on individual component failure rates and repair times. Reliability indicators such as system availability, forced outage rates, and Expected Energy Not Served (EENS) are calculated to measure the effectiveness of the proposed migration. The methodology follows the reliability assessment framework developed by Wijaya et al. (2025), which has been widely applied in transmission system studies to predict power availability and identify critical reliability bottlenecks. Through this analysis, the study aims to determine whether the additional redundancy provided by the 1.5 Breaker configuration can significantly improve service continuity and reduce operational risks (Wijaya et al., 2025; Li & Zhang, 2023).

The second and third analytical instruments focus on protection system evaluation and operational impact assessment. Protection analysis is conducted through relay coordination simulations to examine the performance of protection schemes under the new breaker diameter arrangement. The migration to a 1.5 Breaker configuration requires comprehensive relay setting adjustments to ensure proper fault detection, selective isolation, and prevention of unnecessary breaker tripping. Simulation scenarios include line faults, busbar faults, transformer faults, and circuit breaker failures to verify system protection effectiveness under various operating conditions (Palit et al., 2025). Furthermore, operational impact analysis is performed by reviewing maintenance-related Standard Operating Procedures (SOPs) before and after migration. This assessment evaluates how the new configuration influences maintenance flexibility, switching complexity, outage duration, and human error exposure during field operations. By combining reliability evaluation, protection coordination simulation, and operational procedure analysis, the study provides a comprehensive framework for assessing the technical feasibility and long-term operational benefits of implementing a 1.5 Breaker system at GI Gandul (Garcia & Moreno, 2024).

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RESULTS AND FINDINGS

A. Results

1. Secondary Data Recapitulation of Equipment Failure Rates

The reliability assessment of the 150 kV Gandul Substation was initiated by collecting and evaluating secondary reliability data from the major components involved in power transmission operations. The reliability parameters utilized in this study consisted of the failure rate (λ), expressed in failures per year, and the mean repair time (r), expressed in hours per failure. These parameters were obtained from historical operational records of PLN and standardized reliability references based on IEEE Std 493-2007 (Gold Book). The use of standardized reliability data ensures consistency and comparability in evaluating the performance of existing and proposed substation configurations.

The collected data indicate that the circuit breaker (CB) is one of the most critical components within the substation reliability structure. The circuit breaker exhibits a failure rate of 0.0056 failures per year and requires an average repair time of 24 hours per failure. Although the probability of failure is relatively low, the lengthy repair duration significantly contributes to overall system unavailability. Since circuit breakers are responsible for fault interruption and switching operations, their reliability directly influences the operational continuity of the transmission network.

The disconnecting switch (DS) demonstrates a lower failure rate of 0.0021 failures per year and an average repair duration of 8.5 hours. While disconnecting switches are not designed to interrupt fault currents, they play a crucial role in maintenance procedures and equipment isolation. Failures in these devices may delay maintenance activities and increase operational complexity during system reconfiguration processes.

The reliability analysis further reveals that the 150 kV busbar possesses one of the lowest failure rates among all major components, with a value of 0.0015 failures per year and a repair time of approximately 14 hours. Similarly, differential protection relays exhibit excellent reliability characteristics, with a failure rate of only 0.0010 failures per year and an average repair duration of four hours. Current transformers (CTs), which are essential for measurement and protection functions, display a failure rate of 0.0032 failures per year and require approximately 12 hours for restoration.

Overall, the collected reliability parameters indicate that the existing substation configuration is highly dependent on the operational availability of circuit breakers and busbar systems. Consequently, any modification capable of introducing additional redundancy into these

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components is expected to provide significant improvements in system reliability and operational flexibility.

2. Evaluation of System Reliability Indices

Following the collection of reliability parameters, a Reliability Block Diagram (RBD) model was developed to evaluate the reliability performance of both the existing Double Busbar configuration and the proposed One-and-Half Breaker (1.5 Breaker) configuration. The RBD model was designed to represent the actual operational topology of GI Gandul and to quantify the probability of system availability under various operational scenarios.

The simulation results reveal substantial differences in reliability performance between the two configurations. Under the existing Double Busbar arrangement, the calculated Expected Energy Not Served (EENS) reaches 138.4 MWh per year. This value indicates a relatively high risk of energy interruption resulting from maintenance-related outages, equipment failures, and operational switching activities. The majority of the energy losses originate from planned maintenance procedures involving transmission bay circuit breakers, where partial service interruptions are often unavoidable.

A more detailed examination of the existing configuration demonstrates that maintenance activities on a single circuit breaker frequently require temporary isolation of associated transmission elements. As a result, power transfer capability becomes restricted, reducing system flexibility and increasing the likelihood of service interruptions during maintenance windows. This operational limitation is particularly significant in heavily loaded transmission substations such as GI Gandul, where maintaining uninterrupted power delivery is essential.

In contrast, the proposed 1.5 Breaker configuration achieves a remarkable reduction in EENS, decreasing from 138.4 MWh/year to only 15.2 MWh/year. This represents an improvement of approximately 89%, indicating a substantial enhancement in overall system reliability. The significant reduction in EENS is primarily attributed to the availability of the tie-breaker arrangement, which enables continuous power flow even when one of the primary circuit breakers is removed from service.

The reliability improvement observed in the simulation confirms that the additional redundancy introduced by the 1.5 Breaker topology effectively minimizes the impact of both planned and unplanned outages. The results demonstrate that the proposed configuration can significantly improve power supply continuity, reduce customer interruption risks, and increase transmission system resilience under both normal and contingency operating conditions.

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3. Protection Coordination Simulation Based on the New Configuration

To evaluate the protection performance of the proposed configuration, power flow and short-circuit simulations were conducted using ETAP software. The simulation model incorporated actual equipment parameters, fault current limits, relay settings, and network topology data obtained from GI Gandul. Particular attention was given to the performance of differential busbar protection and overcurrent protection schemes under various fault scenarios.

The simulation process involved multiple fault conditions, including three-phase short circuits, line-to-ground faults, and busbar faults. Among these scenarios, a 12 kA short-circuit fault was intentionally applied to Bus A to evaluate the response characteristics of the protection system under severe operating conditions. The simulation results demonstrated that the differential protection relay successfully detected the fault and initiated tripping commands within 0.15 seconds.

The relay coordination analysis showed that the faulted section was isolated by opening the associated Bus A circuit breaker and the corresponding tie-breaker. This rapid response effectively prevented fault propagation to adjacent sections of the substation. More importantly, the circuit breakers connected to Bus B remained in service and continued supplying power to healthy transmission feeders without interruption.

The absence of mal-trip events during all simulated fault scenarios represents one of the most significant findings of this study. Selective isolation was achieved with high precision, ensuring that only the faulted section was disconnected while unaffected circuits remained operational. This outcome confirms that the protection coordination strategy designed for the 1.5 Breaker configuration satisfies the fundamental requirements of selectivity, sensitivity, speed, and reliability.

Furthermore, the simulation results indicate that the proposed protection arrangement provides enhanced operational security compared to the existing Double Busbar configuration. The additional flexibility offered by the tie-breaker enables more effective fault isolation while simultaneously reducing the risk of widespread service interruptions. Consequently, the new protection scheme contributes directly to improving both system reliability and operational continuity.

4. Operational Maintenance Impact Analysis

One of the most important objectives of this study was to evaluate how the migration to a 1.5 Breaker configuration affects maintenance efficiency and operational procedures. To achieve

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this objective, field observations and maintenance Standard Operating Procedures (SOPs) were analyzed and compared between the existing and proposed configurations.

Under the existing Double Busbar arrangement, maintenance activities involving circuit breakers require extensive switching operations before equipment can be safely isolated. Operators must transfer loads between busbars through disconnecting switches, verify system conditions, and implement multiple safety procedures before maintenance can commence. Based on operational records, this isolation process requires an average of approximately 110 minutes for each maintenance activity.

The complexity of these switching operations not only increases maintenance duration but also introduces additional operational risks. Every switching action creates opportunities for human error, equipment misoperation, or unexpected network conditions. In highly loaded substations, such risks may lead to service interruptions or compromise system stability during maintenance periods.

Following the implementation of the 1.5 Breaker configuration, maintenance procedures become substantially simpler due to the availability of alternative current paths through the tie-breaker. Equipment isolation can be performed without extensive bus transfer operations because power flow continuity is maintained through the redundant breaker arrangement. As a result, the average isolation time is reduced to approximately 40 minutes.

This reduction corresponds to a maintenance efficiency improvement of 63.6%. Beyond the reduction in maintenance duration, the simplified operational procedure also decreases operator workload, minimizes switching complexity, and reduces exposure to human error. The findings indicate that the 1.5 Breaker configuration provides not only technical reliability benefits but also significant operational advantages that enhance the overall effectiveness of asset management programs.

From an Engineering, Procurement, and Construction (EPC) perspective, these results demonstrate that investments in advanced substation configurations generate measurable long-term benefits through improved reliability, reduced maintenance costs, enhanced operational flexibility, and increased availability of transmission assets. Therefore, the migration toward a 1.5 Breaker configuration can be considered a strategically justified solution for high-load substations that require both reliability enhancement and maintenance optimization.

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DISCUSSION

1. Reliability Characteristics of Major Substation Components

The reliability assessment of the Gandul 150 kV Substation was initiated by analyzing the historical failure characteristics of the major components operating within the transmission network. The analysis utilized standardized reliability parameters consisting of failure rate (λ), expressed in failures per year, and mean repair time (r), expressed in hours per failure. These parameters were derived from a combination of IEEE Std 493 recommendations and historical operational records collected from PLN transmission assets. The selected components included circuit breakers, disconnecting switches, busbars, differential protection relays, and current transformers, all of which are considered critical elements affecting overall substation availability (Ahmed et al., 2024).

The collected data revealed that circuit breakers exhibited the highest operational significance due to their relatively higher failure rate of 0.0056 failures per year and a repair duration averaging 24 hours per event. Although the occurrence frequency is relatively low, the operational consequences of a circuit breaker outage are substantial because these devices directly control power flow continuity within transmission bays. In comparison, disconnecting switches demonstrated a lower failure rate of 0.0021 failures per year and shorter repair durations, indicating lower operational risk. Busbars and differential relays showed the lowest failure frequencies, reflecting the high reliability typically associated with static substation infrastructure and modern digital protection systems (Rahman & Choi, 2024).

Furthermore, the analysis indicated that current transformers (CTs) remain important contributors to system reliability because their failure may affect measurement accuracy, relay operation, and fault detection capability. Although their failure rate was measured at only 0.0032 failures per year, repair activities often require partial operational restrictions within the affected bay. These findings confirm previous studies suggesting that reliability improvement efforts should focus not only on reducing equipment failures but also on minimizing repair durations and maintenance-related outages (Kumar & Singh, 2022).

2. Evaluation of Reliability Indices Using Reliability Block Diagram (RBD)

The Reliability Block Diagram (RBD) model was developed to evaluate the overall availability of both the existing Double Busbar configuration and the proposed One-and-Half Breaker arrangement. The model incorporated all major substation components, their corresponding failure rates, and repair durations. The purpose of this analysis was to determine

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how the addition of a tie-breaker circuit breaker influences system reliability and service continuity under normal operating and maintenance conditions. Similar RBD approaches have been successfully applied in modern transmission reliability studies due to their capability to represent complex redundancy relationships among interconnected components (Wijaya et al., 2025).

The simulation results demonstrated a substantial improvement in system reliability after implementing the One-and-Half Breaker configuration. Under the existing Double Busbar arrangement, the calculated Expected Energy Not Served (EENS) reached approximately 138.4 MWh per year. This relatively high value was primarily attributed to maintenance-related outages involving transmission bay circuit breakers, which frequently require partial service interruptions and complex switching operations. During these maintenance activities, certain transmission paths become temporarily unavailable, increasing the probability of energy not supplied to downstream loads (Li & Zhang, 2023).

Following migration to the One-and-Half Breaker configuration, the EENS value decreased dramatically to only 15.2 MWh per year. This represents an overall reduction of approximately 89%, indicating a significant enhancement in supply continuity and system availability. The availability of the tie-breaker allows power transfer to continue through alternative paths even when one circuit breaker is removed from service. As a result, maintenance activities no longer necessitate widespread service interruptions, thereby reducing operational risk and improving network resilience. Similar improvements have been reported in transmission substations adopting redundant breaker arrangements for critical load centers (Yusuf et al., 2022).

3. Protection Coordination Performance Under the One-and-Half Breaker Configuration

Protection system performance was evaluated through comprehensive power flow and short-circuit simulations using ETAP software. The simulation model incorporated actual network parameters, fault current levels, and relay settings derived from the Gandul Substation operating environment. Particular attention was given to the coordination of differential busbar protection and overcurrent protection because these systems play a critical role in maintaining selectivity and preventing unnecessary outages during fault conditions (Palit et al., 2025).

A three-phase short-circuit fault scenario with a fault current magnitude of 12 kA was applied at Bus A to evaluate the effectiveness of the proposed protection scheme. The simulation results showed that the differential protection relay successfully detected the fault and initiated breaker tripping within approximately 0.15 seconds. The affected Bus A circuit breaker and the

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associated tie-breaker were isolated immediately, effectively removing the faulted section from the network while maintaining service continuity on adjacent circuits.

One of the most important findings was the absence of mal-trip incidents on Bus B and its associated feeders. Despite the severe fault conditions, the protection system maintained selective operation and prevented unnecessary disconnection of healthy transmission elements. This result demonstrates that the relay coordination strategy developed for the One-and-Half Breaker arrangement achieved excellent selectivity, sensitivity, and operational dependability. Such performance is particularly important in metropolitan transmission networks where widespread outages can have significant economic and social consequences (Zhang & Wu, 2024).

4. Operational and Maintenance Impact Analysis

The final stage of the study evaluated the operational implications of migrating from the Double Busbar configuration to the One-and-Half Breaker arrangement. This analysis focused on maintenance procedures, switching operations, equipment isolation requirements, and overall workforce efficiency. Observations of existing Standard Operating Procedures (SOPs) were combined with reliability data to assess how the new topology affects field maintenance activities. Recent studies emphasize that maintenance flexibility is one of the primary advantages of advanced substation configurations because it directly influences operational costs and equipment availability (Garcia & Moreno, 2024).

Under the existing Double Busbar configuration, preventive maintenance on a single circuit breaker required extensive switching operations involving multiple disconnecting switches. The average time required to complete load transfer and equipment isolation procedures was approximately 110 minutes. In addition to increasing labor requirements, these complex switching sequences elevated the risk of operator error and prolonged exposure to operational hazards. Maintenance planning therefore became more difficult, especially during periods of high system loading (Tanaka et al., 2024).

Following implementation of the One-and-Half Breaker configuration, maintenance procedures became significantly simpler. The redundancy provided by the tie-breaker enabled circuit breakers to be isolated without disrupting power transfer through adjacent bays. Consequently, the average maintenance preparation time decreased to approximately 40 minutes. This represents a maintenance efficiency improvement of 63.6%. The reduction in switching complexity also lowers human-error exposure and improves worker safety. These findings align with recent EPC-oriented studies indicating that highly redundant substation

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configurations provide substantial long-term operational benefits beyond traditional reliability improvements (Morgan & Patel, 2025).

The results clearly demonstrate that migrating GI Gandul from a conventional Double Busbar configuration to a One-and-Half Breaker arrangement provides substantial technical and operational benefits. The proposed configuration significantly improves reliability performance through an 89% reduction in EENS, enhances protection system selectivity during fault conditions, and simplifies maintenance procedures by reducing isolation time by more than 60%. Collectively, these improvements contribute to higher system availability, improved operational resilience, and greater maintenance flexibility. Therefore, the One-and-Half Breaker configuration can be considered a highly effective solution for critical transmission substations operating under high-load conditions and demanding reliability requirements.

CONCLUSION

The results of this study demonstrate that the migration of the Gandul 150 kV Substation from a conventional Double Busbar configuration to a One-and-Half Breaker arrangement significantly enhances both technical reliability and operational performance. The additional redundancy provided by the 1.5 Breaker topology substantially reduces the probability of service interruptions, as evidenced by an 89% decrease in the Expected Energy Not Served (EENS) index. Furthermore, the proposed configuration improves system availability by maintaining power continuity during circuit breaker maintenance and contingency conditions. From an operational perspective, the new arrangement offers greater flexibility for maintenance personnel, reducing switching complexity and shortening maintenance maneuver time by 63.6%. The protection coordination simulations also confirmed that the adapted relay settings provide effective fault isolation while preventing unnecessary breaker operations, thereby ensuring a high level of system selectivity, security, and dependability.

RECOMMENDATIONS

Based on these findings, Engineering, Procurement, and Construction (EPC) contractors, transmission planners, and utility operators are encouraged to prioritize the implementation of the One-and-Half Breaker configuration in strategically important transmission substations where reliability and operational continuity are critical requirements. Although the initial investment cost of this configuration is generally higher than that of conventional Double Busbar systems, the long-term benefits in terms of reliability improvement, maintenance efficiency, and reduced

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outage risk may justify the additional expenditure. Future research is recommended to conduct a comprehensive Life Cycle Cost (LCC) analysis comparing the refurbishment costs of existing Double Busbar substations with the capital and operational expenditures associated with the implementation of One-and-Half Breaker systems. Such studies would provide a more complete techno-economic basis for infrastructure investment decisions and support the development of sustainable transmission network modernization strategies.

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