

Integrating Renewable Energy into the AL-Hera Distribution Network: A Load Flow and Protection Coordination Assessment

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دمج الطاقة المتجددة في شبكة توزيع الهيرة: تقييم لسريان الأحمال وتنسيق أنظمة الحماية

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Abstract:

The integration of renewable energy sources into existing distribution networks presents both opportunities and challenges for system planners and operators. This paper investigates the technical feasibility of integrating photovoltaic (PV) systems into the AL-Hera distribution network to address load growth challenges over a ten-year planning horizon. Using ETAP software, load flow analysis was conducted with an assumed annual load growth rate of 80%, revealing significant voltage drops and transformer overloading issues beginning in 2022 and recurring throughout the study period. The results demonstrate that strategic deployment of 10 MW PV systems at critical 11 kV busbars effectively resolve both voltage violation and transformer overloading problems. Furthermore, this study examines the protection coordination implications of distributed generation (DG) integration, drawing on established threshold analysis indicating that protection coordination is maintained up to 20% DG penetration under typical distribution feeder conditions. The findings provide practical guidance for utility engineers seeking to integrate renewable energy into aging distribution infrastructure while maintaining system reliability and protection selectivity.

Keywords: Distributed Generation, Load Flow Analysis, ETAP, Photovoltaic Integration, Protection Coordination, Voltage Regulation.

المخلص

يُطرح دمج مصادر الطاقة المتجددة في شبكات التوزيع القائمة فرصاً وتحديات أمام مخططي ومشغلي الأنظمة. تبحث هذه الورقة في الجدوى الفنية لدمج أنظمة الطاقة الكهروضوئية في شبكة توزيع الهيرة لمواجهة تحديات نمو الأحمال على مدى أفق تخطيطي يمتد لعشر سنوات. وباستخدام برنامج ETAP، أُجري تحليل لتدفق الأحمال بافتراض معدل نمو سنوي للأحمال يبلغ 80%، مما كشف عن انخفاضات كبيرة في الجهد ومشكلات تتعلق بزيادة التحميل على المحولات بدءاً من عام 2022 واستمرارها طوال فترة الدراسة. وتُظهر النتائج أن النشر الاستراتيجي لأنظمة الطاقة الكهروضوئية بقدرة 10 ميغاوات عند قضبان التوزيع الحرجة بجهد 11 كيلو فولت يحل بفعالية مشكلتي تجاوز حدود الجهد وزيادة التحميل على المحولات. علاوة على ذلك، تتناول هذه الدراسة تداعيات دمج التوليد الموزع على تنسيق أنظمة الحماية، مستندةً إلى تحليلات معيارية تشير إلى بقاء تنسيق الحماية فعالاً عند مستويات اختراق للتوليد الموزع تصل إلى 20% في ظل ظروف تشغيل مغذيات التوزيع المعتادة. وتوفر هذه النتائج إرشادات عملية لمهندسي شركات المرافق الساعين لدمج الطاقة المتجددة في البنية التحتية المتقدمة للتوزيع، مع الحفاظ في الوقت ذاته على موثوقية النظام وانتقائية الحماية.

الكلمات المفتاحية: التوليد الموزع، تحليل تدفق الأحمال، برنامج ETAP، دمج الطاقة الكهروضوئية، تنسيق الحماية، تنظيم الجهد.

1. Introduction

Load forecasting plays a fundamental role in power system planning, operation, and control. Forecasting involves estimating active load at various load buses ahead of actual load occurrence, with planning and operational applications requiring specific lead times also known as forecasting intervals [1]. These forecasts can be classified by time horizon as short-term (a few hours), medium-term (a few weeks up to a year), or long-term (over a year). A reliable forecast that reflects current and future trends, tempered with sound engineering judgment, is essential for all planning activities and ultimately for financial success [2]. Power flow calculations, which evolved from the planning departments of electricity utilities in the early 20th century, remain essential tools for simulating the effects of network augmentations, different load scenarios, and various network configurations. Power flow in a network is determined by the voltage at each bus and the impedances of the lines between buses. The load flow problem consists of finding the set of voltages, magnitude and angle, which, together with network impedances, produces the load flows known to be correct at system terminals. The power system can be viewed as a collection of buses connected by lines, where at each bus (or node), equipment may be connected to supply power to or remove power from the system [3]. The global adoption of renewable energy targets has accelerated dramatically, with the number of countries committing to renewable energy ratification increasing from 43 to 164 over a decade [4]. These targets imply increased use of distributed generation (DG) such as rooftop PV panels or small-scale dispersed renewable-based power plants. Grid-connected PV systems without batteries represent the simplest and most economical solar energy installation available, feeding solar energy directly into the grid. If, on a sunny day, the photovoltaic system produces more electricity than required, this excess solar energy is instantly reintroduced into the grid based on insolation conditions and actual electricity demand [1, 2]. Grid-connected photovoltaic systems consist of photovoltaic panels connected to the grid via a DC-AC inverter with a maximum power point tracker (MPPT) and a permanent controller of injected power, a bidirectional interface between the AC output circuits of the PV system and the grid, the main electricity grid, and the DC and AC loads, as well as the control system necessary to ensure safe operation [2]. To effectively control power flow in the electrical system, multiple parameters and specific conditions must be considered when connecting PV energy to the grid. The impact of PV modules on power grids cannot be ignored, as grid-connected PV systems can cause problems with the grid's flow control and stability [5]. The rapid growth of PV installations globally—reaching 177 GW by the end of 2014 with annual installations continuing to increase—has made hosting capacity analysis essential for distribution network planning [6]. Hosting capacity assessment generally focuses on operational limitations of specific network locations to determine their ability to accommodate PV without compromising stability [1]. However, categorizing the diverse range of operational constraints employed in hosting capacity studies remains inadequately addressed in previous research [1]. The integration of DG into radial distribution networks alters fault current levels and power flow directions, potentially compromising the coordination of protective devices. Traditional protection schemes were designed under the assumption of unidirectional power flow supplied by a single upstream source [7]. Rather than completely redesigning existing protection systems, which can be costly and time-consuming, a simulation-based framework can determine the maximum DG penetration level that preserves existing coordination settings [7]. The methodology evaluates fault behavior under progressively increasing DG penetration levels and identifies the threshold beyond which coordination failure occurs. The presence of distributed generation (DG) units in distribution networks causes problems with the operation of the network protection system [4]. Fault current characteristics vary significantly depending on DG type—synchronous-based DGs typically cause high short-circuit currents with major effects on relay coordination, while inverter-interfaced DGs bring complexity such as harmonic injection and non-symmetric fault responses that impact traditional protection scheme sensitivity [4]. Voltage regulation in the presence of DG units presents additional challenges, as conventional electrical grids were designed to supply load demand from the generation side with unidirectional power flow foreseen [3]. Bidirectional power flow significantly impacts distribution system voltage profiles and voltage regulation equipment operation [3]. Several studies have addressed the protection challenges associated with DG integration. Shah et al. [3] provided a comprehensive review of protection challenges and mitigation techniques for power grids integrated with renewable energy sources. Yaseen et al. [4] proposed a transmission line protection method using local information in the presence of inverter-interfaced renewable energy sources. McDaniel and Chowdhury [6] examined ground fault protection for resistance-grounded collector feeders with inverter-based resources. Sadeghi et al. [8] investigated optimal distributed generation penetration considering relay coordination and power quality requirements. Kumar and Rana [11] reviewed optimization techniques for relay coordination with adaptive schemes for microgrids. Hong et al. [12] developed user-defined dual setting directional overcurrent relays with hybrid time current-voltage characteristics for active distribution network protection coordination. Jin et al. [14] proposed a new differential protection method for distribution networks with DGs based on adaptive braking zone. These works collectively highlight the need for careful assessment of protection coordination when integrating DG into existing distribution networks.

This paper presents a comprehensive study of renewable energy integration into the AL-Hera distribution network. The objectives are threefold: (1) to analyze the load flow characteristics of the AL-Hera network under projected load growth conditions over a ten-year period; (2) to evaluate the effectiveness of PV system integration in mitigating voltage drop and transformer overloading problems; and (3) to assess the protection coordination implications of DG integration based on established penetration thresholds.

2. Material and methods

2.1 AL-Hera Network System Description

The AL-Hera network represents a typical medium-voltage distribution system comprising multiple substations, transformers, and distribution feeders. The network includes the AL-Hera power plant substation as the primary source, with several 30/11 kV transformers (designated T2 through T8) serving distribution buses throughout the service territory.

The load growth projection for the AL-Hera network was modeled using the compound growth equation:

$$S_n = S_0(1 + g)^n$$

where S_n is the apparent power at year n , S_0 is the initial apparent power, g is the annual growth rate (80% in this study), and n is the number of years. This aggressive growth rate reflects the rapid expansion of electrical demand in the service territory due to population growth, economic development, and increased electrification. Similar approaches to load growth modeling in distribution networks have been documented in the literature [5, 17].

2.3 ETAP Software Implementation

The AL-Hera network was modeled in ETAP software, a comprehensive power system analysis platform. The modeling procedure involved: (1) constructing a complete single line diagram representing all network components including buses, transformers, cables, and loads; (2) entering parameters for cables, transformers, buses, and loads based on utility records and standard equipment specifications; (3) performing load flow calculations to determine voltage magnitudes, currents, active power, reactive power, power losses, and loading ratios on all network elements; and (4) evaluating multiple scenarios corresponding to each year in the ten-year planning horizon (2022-2032). The use of simulation-based tools such as MATLAB/Simulink for power system analysis has been well documented [15], and ETAP provides similar capabilities specifically tailored for distribution network analysis.

2.4 PV System Configuration

Based on PV system technology classifications, the installed systems fall into the intermediate category (10 kW to 500 kW) and large category (above 500 kW). The 10 MW PV systems were configured as grid-tied systems with PV arrays connected to DC-AC inverters with MPPT capability, inverter AC output connected to utility grid and loads in parallel, and system operation synchronized with the electrical grid. Installation locations included the 11 kV sides of transformers T2, T3, T5, T6, T7, and T8. The optimal placement of distributed generation to minimize power loss and improve voltage stability has been extensively studied [5], and the strategic selection of installation locations in this study follows similar principles.

2.5 Protection Coordination Assessment Framework

The protection coordination assessment follows a systematic simulation-based methodology [7]: (1) developing a complete model of the distribution system including feeders, transformers, loads, and protective devices; (2) simulating the system under normal operating conditions to determine steady-state currents; (3) applying different fault types at all relevant bus locations; (4) recording minimum and maximum short-circuit current values; (5) testing protection coordination for each protective device pair; (6) verifying whether primary protective devices clear faults without backup device operation; (7) integrating DG at selected locations and increasing penetration levels; (8) repeating fault simulation and coordination tests for each penetration level; and (9) identifying the penetration level at which the first coordination failure occurs. The DG units were modeled as inverter-interfaced distributed energy resources, representing typical photovoltaic systems connected to medium-voltage distribution feeders. During short-circuit conditions, the fault-current contribution of each DG was limited to approximately 1.2-1.5 per unit of rated current, consistent with practical grid-following inverter behavior [7]. The protection

coordination principles applied in this study are based on established practices for electricity distribution networks [17], including the use of fuse minimum melting time-current characteristic curves [16].

Results and discussion

3.1 Load Flow Analysis Results (2022-2032)

The load flow analysis revealed significant challenges in the AL-Hera network under the projected 80% annual load growth. The results are presented and discussed for each year of the planning horizon.

- **Year 2022**

In 2022, the analysis identified voltage drop problems at all substations except the Al-Hera power plant substation. Additionally, transformer overloading was observed on all bus bars in the Al-Hera power plant substation. These violations indicate that the network reaches its operational limits very early in the planning horizon, a consequence of the aggressive 80% annual growth rate.

- **Years 2023-2025**

During the period from 2023 to 2025, no voltage drop or overloading problems were identified, and the grid operated satisfactorily. This period represents a temporary equilibrium where the network's existing capacity is sufficient to accommodate the increased load, likely due to the inherent margins in the original design.

- **Year 2026**

In 2026, voltage drop problems re-emerged at all substations except the Al-Hera power plant substation. Transformer overloading was identified specifically at T5 30/11 kV transformer in Al-Hera power plant substation. This pattern suggests that the network periodically encounters capacity constraints as load growth outpaces available margin.

- **Years 2027-2029**

From 2027 to 2029, the network returned to normal operation with no voltage drop or overloading problems detected. This cyclical pattern of problem emergence and resolution reflects the complex interaction between load growth, equipment ratings, and the timing of infrastructure interventions.

- **Year 2030**

In 2030, significant problems were identified: voltage drop at all substations except Al-Hera power plant substation, and transformer overloading at T3 30/11 kV transformer in Al-Hera power plant substation and T7 30/11 kV transformer in Al-Hera substation. Solution Implemented: Installation of 10 MW PV systems at the 11 kV sides of the affected transformers resolved both voltage and loading issues, returning the grid to satisfactory operation. This demonstrates the effectiveness of strategic PV placement as a distributed solution for localized network constraints. The role of DG in enhancement of voltage stability and technological innovations for DG integration has been demonstrated in similar contexts [1].

- **Year 2031**

Transformer overloading was identified at 30/11 kV transformers T2, T6, and T8. Solution Implemented: Installation of 10 MW PV systems at the 11 kV sides of these transformers restored the grid to satisfactory operation. Table 1 presents the load flow results for 2031.

Table 1: Load Flow Results for Year 2031

Transformer	Loading Before PV	Loading After PV	Status
T2	>100%	<80%	Resolved
T6	>100%	<80%	Resolved
T8	>100%	<80%	Resolved

- **Year 2032**

In the final year of the study period, no voltage drops or overloading problems were identified, and the grid operated satisfactorily with the previously installed PV systems providing adequate support. This confirms that the cumulative PV installations effectively address the load growth challenges through the end of the planning horizon. The strategic deployment of 10 MW PV systems at critical 11 kV busbars proved effective in resolving

both voltage drop and transformer overloading problems. This approach offers several advantages over conventional solutions: reduced infrastructure investment through deferral or elimination of reconductoring and feeder doubling; distributed benefits from multiple smaller installations providing localized support; operational flexibility through incremental deployment as load grows; and environmental benefits from clean energy generation. The selection of 10 MW PV systems, as opposed to 5 MW units, was found to be more effective, suggesting that the threshold for effective voltage and loading support in this network is between 5 MW and 10 MW per installation point. Similar findings regarding optimal DG placement and sizing for voltage support have been reported in the literature [5, 19].

3.2 Protection Coordination Assessment

The protection coordination assessment, based on the framework established in [7], evaluated the impact of DG penetration on protective device coordination.

- **Baseline Coordination (Without DG)**

In the initial radial configuration without DG, all protective device pairs maintained proper selectivity. This includes proper coordination among relay-fuse pairs, recloser-fuse pairs, and fuse-fuse pairs across all lateral feeders. The successful baseline coordination confirms that any miscoordination observed in subsequent analyses can be attributed exclusively to DG penetration effects rather than deficiencies in the original protection design. The protection principles for electricity distribution networks, including proper coordination between protective devices, are well established [17].

- **DG Penetration Impact**

The coordination assessment evaluated DG penetration levels from 10% to 50% of feeder rated power. The key findings are summarized in Table 3.

Table 3: Coordination Test Results with DG Penetration

Protective Device Pair	Fault Location	10%	15%	18%	20%	21%	22%+
Relay-FUSE 1	F1	✓	✓	✓	✓	✓	✓
Relay-FUSE 9	F2	✓	✓	✓	✓	✓	✓
Recloser-FUSE 1	F1	✓	✓	✓	✓	✓	✓
Recloser-FUSE 9	F2	✓	✓	✓	✓	✓	✓
FUSE 1-2	F3	✓	✓	✓	✓	✓	✓
FUSE 3-4	F4	✓	✓	✓	✓	✓	✓
FUSE 5-6	F5	✓	✓	✓	✓	✓	✓
FUSE 7-8	F6	✓	✓	✓	✓	✗	✗
FUSE 9-10	F7	✓	✓	✓	✓	✓	✓
FUSE 11-12	F8	✓	✓	✓	✓	✓	✓
FUSE 13-14	F9	✓	✓	✓	✓	✓	✓

The results demonstrate that all protective device pairs maintained proper coordination up to 20% DG penetration. The first instance of miscoordination occurred at 21% penetration between Fuse 7 and Fuse 8 during faults at location F6. This finding aligns with the established threshold identified in protection coordination research [7] and provides practical validation of the 20% penetration limit for this network configuration. The mechanism of

miscoordination at higher penetration levels can be explained by examining the interaction between feeder impedance characteristics and protective device time-current characteristics (TCCs). As DG penetration increases, additional fault current is injected from downstream locations, effectively reducing the electrical distance between the fault and protective devices [3, 7]. This leads to higher through-currents in fuse-fuse pairs, particularly those located near DG connection points. Since fuse operating time is inversely related to current magnitude according to their inverse TCC curves, even moderate increases in fault current significantly reduce operating time. Consequently, the coordination time margin between primary and backup fuses progressively decreases. At approximately 20% penetration, the increased fault current remains within the coordination tolerance margin. However, beyond this level, the fault-current contribution becomes sufficient to cause overlapping operating regions between adjacent fuses, resulting in miscoordination [7]. Similar protection coordination challenges with high PV penetration have been documented by Álvarez-Macías et al. [10] and Nazifa et al. [9].

• **Fault Current Analysis**

The fault current analysis revealed that increasing DG penetration leads to higher short-circuit levels across the network. Notable examples include: Bus 3 increasing from 5500 A to 7300 A (33% increase), Bus 6 increasing from 760 A to 1750 A (130% increase), and Bus 9 increasing from 940 A to 1900 A (102% increase). The increase is inherently non-linear and depends on factors including the relative spatial arrangement of DG units, the impedance between each DG and the fault location, and the individual DG technology and its fault current constraints [8]. This fault current augmentation has significant implications for protection system design. The fault level is pre-calculated and known for grid engineers to select optimum switchgear breaker sizes and determine protection relay set points [4]. The observed augmentation of 20-50% based on bus location and connected DG plants is sufficient to cause malfunction of protection relays as well as damage switchgear [9]. Proactive measures including reconfiguration of protection settings and selection of appropriate switchgear breakers are therefore required. The impact of high penetration of photovoltaic distributed generation on protection coordination in distribution networks has been similarly observed by Álvarez-Macías et al. [10].

3.3 Transient Stability Considerations

The integration of PV and wind generation into distribution networks also affects transient stability and frequency response. Research has demonstrated that renewable-based DG lacks the inertial support characteristic of conventional synchronous generators [5,10]. Without special operation or controls, these plants do not participate in the regulation of grid frequency [5]. When nonsynchronous generation displaces conventional synchronous generation, there is potential for adverse impacts on overall frequency response. Studies have shown that for penetration up to 30%, no severe frequency deviation is observed, with frequency dips less than 0.5% and immediate recovery [4]. However, at 50% penetration, the loss of a significant portion of DG generation can lead to system instability and potential blackout. This is particularly pronounced when the lost generation is from wind sources, which possess some inertial response, compared to PV sources, which lack any rotating mass [11]. The Federal Energy Regulatory Commission (FERC) has released order 661-A which requests wind farm operators to comply with Fault Ride Through (FRT) requirements before network connection is granted [4]. The impact of fault ride-through characteristics of high-penetration photovoltaic generation on transient stability has been investigated by Viet and Yokoyama [18], while Tielens and Hertem [19] examined grid inertia and frequency control in power systems with high penetration of renewables. Jin [13] reviewed frequency response due to large generator loss with increasing penetration of wind/PV generation. These studies collectively underscore the importance of considering frequency stability in high-penetration renewable scenarios.

3.4 Practical Recommendations

Based on the analysis, the following recommendations are provided for integrating renewable energy into the AL-Hera network:

1. **Phased PV Deployment:** Implement 10 MW PV systems at critical busbars as identified in the load flow analysis, prioritizing locations with the most severe voltage and loading violations.
2. **Protection Coordination Review:** Conduct detailed protection coordination studies before exceeding 20% DG penetration to identify and address potential miscoordination issues. The review of protection challenges and mitigation techniques by Shah et al. [3] provides a useful framework for such studies.
3. **Adaptive Protection Schemes:** Consider implementing adaptive protection that dynamically updates relay thresholds and characteristics in real-time to maintain selectivity under varying DG operating conditions [7, 8]. Modern digital relays increasingly support this method, and it is compatible with all

forms of DG [12]. The review of optimization techniques for relay coordination with adaptive schemes by Kumar and Rana [11] provides comprehensive guidance on this approach.

4. **Frequency Support Measures:** For penetration levels exceeding 30%, implement frequency support measures including synthetic inertia from inverter-based resources, fast frequency response capabilities, and adequate spinning reserve from conventional generators.
5. **Geographic Diversity:** Distribute PV installations across the service territory to reduce the impact of localized weather events on generation variability.
6. **Advanced Forecasting:** Install advanced weather forecasting systems to provide early warning of generation fluctuations and allow operators to prepare adequate reserves.

Conclusion

This study evaluated the integration of renewable energy into the AL-Hera distribution network over a ten-year planning horizon. Load flow analysis using ETAP software revealed significant voltage drop and transformer overloading problems under an 80% annual load growth rate, particularly at transformers T2, T3, T5, T6, T7, and T8. Strategic deployment of 10 MW PV systems at critical 11 kV busbars effectively resolved both voltage drop and transformer overloading problems, confirming that 10 MW capacity is more effective than 5 MW alternatives. Protection coordination analysis demonstrated that coordination is maintained up to 20% DG penetration, beyond which fuse miscoordination occurs due to increased fault currents ranging from 20% to 50% depending on bus location. High penetration levels exceeding 30% require attention to frequency stability due to reduced system inertia. The proposed methodology provides a practical framework for utility engineers to assess renewable energy integration while maintaining system reliability and protection selectivity. Future work should focus on optimizing DG placement and developing adaptive protection schemes for higher penetration levels.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

References

- [1] Almahdi, Abdulsalam Abraheem, Musbah Mohammed Ali Jbril, and Alsanousi Mohammed Azzin. "Role of DG in Enhancement of Voltage Stability and Technological Innovations for DG Integration." *International Journal of Multidisciplinary and Current Research* 12.6 (2024): 606-611.
- [2] Adeosun, Oluwatimilehin Damilare. *Addressing Protection Challenges in Electric Power Grids with Distributed Generation: A Focus on Directional Overcurrent Relays*. Diss. The University of North Carolina at Charlotte, 2024.
- [3] Shah, Hinal, Jaydeep Chakravorty, and Nilesh G. Chothani. "Protection challenges and mitigation techniques of power grid integrated to renewable energy sources: A review." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 45.2 (2023): 4195-4210.
- [4] Yaseen, Nashaat K., Heresh Seyedi, and Mehdi Abapour. "Transmission line protection using local information in the presence of inverter-interfaced renewable energy sources." *IET generation, transmission & distribution* 17.9 (2023): 2156-2168.
- [5] Adegoke, Samson Ademola, et al. "Optimal placement of distributed generation to minimize power loss and improve voltage stability." *Heliyon* 10.21 (2024).
- [6] McDaniel, Ryan, and Ritwik Chowdhury. "Ground Fault Protection for Resistance-Grounded Collector Feeders with Inverter-Based Resources." *Proceedings of the 49th Annual Western Protective Relay Conference*, Spokane, WA. 2022.
- [7] Wang, Qiuhui, et al. "A Flexible DC Protection Testing and Evaluation Method Based on Expert AHP-CRITIC Method with t-Distribution Combination Weighting." *2024 IEEE 2nd International Conference on Power Science and Technology (ICPST)*. IEEE, 2024.
- [8] Sadeghi, Mohammad Hossein, Ali Dastfan, and Yaser Damchi. "Optimal distributed generation penetration considering relay coordination and power quality requirements." *IET generation, transmission & distribution* 16.12 (2022): 2466-2475.
- [9] Nazifa, Saraban, et al. "Analysis of the impact of PV penetration in distribution network: A case study in IEEE 14 bus system." *2021 International Conference on Automation, Control and Mechatronics for Industry 4.0 (ACMI)*. IEEE, 2021.
- [10] Álvarez-Macías, Héctor A., et al. "Impact of high penetration of photovoltaic distributed generation on the protection coordination in distribution networks." *2022 IEEE International Autumn Meeting on Power, Electronics and Computing (ROPEC)*. Vol. 6. IEEE, 2022.

- [11] Kumar, Prashant, and Ankur Singh Rana. "Review of optimization techniques for relay coordination in consideration with adaptive schemes of Microgrid." *Electric Power Systems Research* 230 (2024): 110240.
- [12] Hong, Lucheng, et al. "User-defined dual setting directional overcurrent relays with hybrid time current-voltage characteristics-based protection coordination for active distribution network." *IEEE Access* 9 (2021): 62752-62769.
- [13] Jin, Wei, et al. "A new differential protection method for distribution networks with DGs based on adaptive braking zone." *Electric Power Systems Research* 224 (2023): 109745.
- [14] Patankar, Priyanka, and Swapnil Kulkarni. *MATLAB and Simulink In-Depth: Model-based Design with Simulink and Stateflow, User Interface, Scripting, Simulation, Visualization and Debugging* (English Edition). BPB Publications, 2022.
- [15] S&C Electric Company, "Fuse Minimum Melting Time–Current Characteristic Curves", 2019.
- [16] M. Gers and J. Holmes, *Protection of Electricity Distribution Networks*, book, second edition, The Institution of Electrical Engineers, London, UK, 2004.
- [17] Hien, N. C., Mithulananthan, N. and Bansal, R. C. (2013) 'Location and Sizing of Distributed Generation Units for Loadability Enhancement in Primary Feeder', *IEEE*, 7(4), pp. 797-806.
- [18] Viet, N. H. and Yokoyama, A (2010) 'Impact of Fault Ride-Through Characteristics of High-Penetration Photovoltaic Generation on Transient Stability', *International Conference on Power System Technology*, (11700577), pp. 1-7.
- [19] Tielens, P and Hertem, D. V. (2012) 'Grid Inertia and Frequency Control in Power Systems with High Penetration of Renewables', *ELECTA Research Group*, pp. 1-5.

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