Future Architecture of the Network
TE WHATUNGA HIKO

Case-Study:

Short-Circuit Analysis of a Multi-Source Multi-Terminal DC System

Methodological Implementation and Comparison of IEC 61660-1

Author

Saad Ahmed Khan
University of Auckland

Reviewers

Prof. Abhisek Ukil
University of Auckland

Dr. Gabriel Ooi Heo Peng
American Bureau of Shipping

June 24, 2026

Collaborating Partners

Academic Partner
The University of Auckland

Waipapa Taumata Rau University of Auckland

Industry Partner
American Bureau of Shipping

ABS

1 Introduction

1.1 Overview

The augmentation of renewable-generation capacity, increased electrification, and rising efficiency requirements are accelerating the development of more complex multi-terminal DC power system architectures. Future DC networks are expected to connect multiple sources and loads through shared transmission infrastructure using power-electronic converters. In this context, New Zealand's electricity system is also evolving toward greater electrification, renewable integration, and battery-supported operation, laying the foundation for future DC grid deployment.

While these technologies support decarbonisation and improved system efficiency, they also introduce new challenges for safety, reliability, protection design, and equipment rating [1, 2, 3]. In multi-source multi-terminal DC (MTDC) systems, short-circuit current may be supplied simultaneously by converter terminals, DC-link capacitors, and other distributed sources. The resulting fault current depends not only on the capacity of each source, but also on its location, the electrical path to the fault, shared network branches, and the stored capacitive energy within the system [4, 5].

The research applies IEC 61660-1 to a multi-source MTDC system for short-circuit current calculation. This challenge is relevant to both future land-based DC grids and shipboard power systems, which require reliable fault-current calculation, equipment rating, and protection design despite differing operating environments and capacities. This shared need has created mutual benefit for all collaborators: the Future Architecture of the Network (FAN) has provided the future-network context [6], the University of Auckland has contributed research expertise, and the American Bureau of Shipping (ABS) has provided industry relevance in safety, classification, certification, marine, and offshore applications [7]. The collaboration has already produced a journal-paper manuscript [4] as a tangible research contribution and continues to strengthen New Zealand's capability in safe, reliable, and standards-based DC grid development while generating knowledge applicable across several sectors.

1.2 Background

Short-circuit current calculation is a fundamental requirement for safe and reliable power-system design. It supports equipment rating, protection selection, fault clearing, and system reliability. While conventional AC systems benefit from mature protection practices, DC systems pose greater challenges because the lack of a natural zero-crossing in DC complicates fault interruption [8]. In addition, fault currents rise quickly and impose severe stress on power-electronic converter components, especially freewheeling diodes [9]. This challenge is even more critical in converter-dominated DC grids.

These challenges are amplified in future MTDC systems, where multiple converter terminals, DC-link capacitors, and distributed sources may contribute to the same fault through different electrical paths [4, 10]. The stored energy in DC-link capacitors can discharge quickly and strongly influence the initial fault-current peak [11]. Therefore, protection design and equipment rating require more than the total short-circuit current; they also require an understanding of the peak current, time to peak, dominant source contribution, and the influence of source location and shared network branches.

IEC 61660-1 provides an established standards-based method for calculating short-circuit currents in DC installations [1]. However, applying this standard to a converter-dominated multi-source MTDC system is not direct, because several sources may contribute through topology-dependent paths and shared branches [4]. This research addresses that gap by applying IEC 61660-1 source-wise, using topology-specific correction factors, and superimposing the corrected current contributions. This provides the basis for the journal-paper manuscript presented in this report and leads directly to the research contribution described in the following section.

2 Research Contribution and Benefits

2.1 Research Contribution

The main research contribution is the application of IEC 61660-1 to short-circuit current calculation in a converter-dominated multi-source MTDC system. The studied system represents a future MTDC network in which several sources, including converter terminals and distributed DC-link capacitors, may simultaneously contribute to the same fault. This reflects the practical complexity of emerging MTDC architectures, where fault behaviour is shaped not only by individual source capacity but also by network topology, source and fault locations.

The research applies an IEC 61660-1 source-wise calculation approach in which each fault-current contribution is evaluated separately and then corrected for its electrical path and shared network branches. These topology-specific correction factors enable combining the corrected source currents to estimate the total short-circuit current for each fault location. This method provides a transparent means of identifying the peak current, time to peak, dominant source contribution, and the most critical source or location for protection and equipment-rating decisions.

The IEC-based analytical results are compared with simulation-based results, demonstrating that the approach provides practical and reliable short-circuit current estimates for the studied MTDC system. The work has matured into a journal-paper manuscript, making it a tangible research output of the collaboration rather than just a concept. Overall, the contribution provides a standards-based calculation pathway that can support future DC network planning, protection design, equipment rating, and cross-sector applications in land-based and offshore power systems.

2.2 International Standards and Benefits for New Zealand

International standards provide a common technical language for calculation, design, comparison, review, and industry adoption. They help ensure that engineering decisions are transparent, repeatable, and aligned with recognised practice. IEC 61660-1 provides a structured basis for calculating short-circuit currents in DC installations [1, 2]. Therefore, applying this standard provides the research with a recognised engineering foundation rather than relying solely on isolated simulation-based studies.

This is particularly important for future MTDC systems, which are expected to be converter-dominated, multi-source, and strongly influenced by network topology. By applying IEC 61660-1 to such systems, the research extends standards-based thinking into emerging MTDC architectures and provides a practical analytical pathway for understanding short-circuit current behaviour. This pathway can complement simulation studies while supporting engineering judgement, design review, and technical communication across academic, industry, and future regulatory contexts.

For New Zealand, this capability supports planning for renewable integration, battery storage, EV charging, shore and offshore power, DC distribution, and hybrid AC/DC systems across land-based, marine, and offshore sectors. It enables safer equipment rating, stronger protection design, improved fault preparedness, and more resilient electricity infrastructure. Notably, the research also helps New Zealand build capability not only as a user of international standards, but as a contributor to future knowledge on converter-dominated DC and MTDC power systems.

3 Industry Collaboration and Strategic Impact

3.1 FAN, University of Auckland, and ABS Partnership

This research is positioned within the Future Architecture of the Network (FAN) programme, supported by the University of Auckland and linked with the American Bureau of Shipping (ABS) as an international industry collaborator. FAN provides the future-network context for New

Zealand, including the need to prepare electricity infrastructure for renewable integration, electrification, resilience, and emerging AC/DC architectures. The University of Auckland contributes academic research capability through technical modelling, standards interpretation, analytical development, and validation of the IEC-based MTDC short-circuit current calculation method. ABS contributes industry relevance through safety, classification, certification, verification, and practical engineering perspectives related to shipboard and offshore power systems.

The partnership is valuable because multi-source DC fault-current behaviour is common to future land-based DC grids and shipboard or maritime DC power systems. Although these systems differ in scale and operating environment, they share the need for reliable fault-current calculation, equipment rating, and protection design. The resulting journal-paper manuscript demonstrates a concrete research outcome and strengthens New Zealand's capability through work that is academically rigorous, industry-relevant, and aligned with international standards.

3.2 Strategic Impact and Future Opportunities

This research strengthens New Zealand's capability in DC fault analysis, protection design, equipment rating, and standards-based engineering practice. Its methods extend beyond a single MTDC case study to support renewable-rich networks, battery systems, EV charging, shore and offshore power, DC distribution, and hybrid AC/DC systems.

The work is transferable across land-based, marine, shipboard, and offshore sectors, supporting safer decarbonisation and more resilient infrastructure. The journal-paper manuscript provides a solid foundation for future work, including protection coordination, practical tools, hardware validation, and contributions to standards development.

4 Conclusion

Future power systems are increasingly shaped by renewable integration, electrification, battery-supported operation, power-electronic conversion, and emerging DC or hybrid AC/DC infrastructure. In this context, multi-source MTDC systems introduce complex short-circuit behaviour, where converter terminals, DC-link capacitors, and distributed sources may feed the same fault through topology-dependent paths. The rapid rise of DC fault current, stress on converter components, and absence of natural zero-crossing make reliable calculation essential for protection design and equipment rating.

This research applies IEC 61660-1 source-wise to a converter-dominated multi-source MTDC system using topology-specific correction and corrected-current superposition. The collaboration has produced a journal-paper manuscript as a concrete standards-based research contribution. With FAN providing future-network context, the University of Auckland contributing research capability, and ABS adding industry relevance, the work strengthens New Zealand's readiness for safe, reliable, resilient, and standards-aligned DC power-system development across land-based, marine, shipboard, and offshore sectors.

5 References

[1] International Electrotechnical Commission, *IEC 61660-1:1997, Short-circuit currents in d.c. auxiliary installations in power plants and substations – Part 1: Calculation of short-circuit currents*. International Electrotechnical Commission, Geneva, Switzerland, 1997.

[2] British Standards Institution, *BS EN 61660-1:1997, Short-circuit currents in d.c. auxiliary installations in power plants and substations – Part 1: Calculation of short-circuit currents*. British Standards Institution, London, United Kingdom, 1997.

[3] International Electrotechnical Commission, *IEC TR 61660-3:2000, Short-circuit currents in d.c. auxiliary installations in power plants and substations – Part 3: Examples of calculations*. International Electrotechnical Commission, Geneva, Switzerland, 2000.

[4] S. A. Khan, G. Ooi Heo Peng, and A. Ukil, "Short-circuit current calculation using IEC 61660-1 in a multi-source MTDC system." Electric Power Systems Research, Manuscript under review, 2026.

[5] S. A. Khan, "IEC 61660-1 implementation report for multi-source MTDC short-circuit current calculation," 2026. Technical implementation report.

[6] Future Architecture of the Network, "Future Architecture of the Network official website." `https://www.fan.ac.nz/`, 2026. Accessed: 22 June 2026.

[7] American Bureau of Shipping, "American Bureau of Shipping official website." `https://ww2.eagle.org/en.html`, 2026. Accessed: 22 June 2026.

[8] A. Ukil, Y. M. Yeap, and K. Satpathi, *Fault Analysis and Protection System Design for DC Grids*. Singapore: Springer, 2020.

[9] S. Ahmed Khan, A. Ukil, and N.-K. C. Nair, "DC fault detection and classification using time-derivative of Butterworth highpass filtered currents without threshold," *Electric Power Systems Research*, vol. 255, p. 112830, 2026.

[10] S. A. Khan, A. Ukil, and N.-K. C. Nair, "Design and Simulation of Radial Multi-Terminal DC system with Zonal DC Protection," in *2025 IEEE PES 17th Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, pp. 1–6, Dec 2025.

[11] S. A. Khan, A. Ukil, and N.-K. C. Nair, "DC Fault Detection Using Time Derivative of High-Pass Filter Response in MTDC Systems," in *IECON 2024 – 50th Annual Conference of the IEEE Industrial Electronics Society*, pp. 1–6, 2024.