

Standards-Based Design Of 50/60 Hz Shore Power Converter

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Abstract— Shore power systems allow berthed ships to switch off their auxiliary engines and reduce emissions, noise, and fuel consumption. However, frequency differences between a 50 Hz shore grid and 60 Hz shipboard systems can limit shore power services for international vessels. This study aims to develop a standards-based design approach for sizing and integrating a 50/60 Hz frequency converter into a low-voltage shore connection system. A case study was conducted at an anonymized terminal in Surabaya, Indonesia, which operates a 400 V, 50 Hz shore power system with five berth panels. A conservative load current of 250 A per panel was used as the design basis. The converter capacity was calculated using the three-phase power equation. Three converter integration architectures were evaluated, while the adequacy of the protection devices and conductor ampacity was assessed using a 125% design margin and the IEC/IEEE 80005-3 framework. The results show that each berth panel requires 147.05 kW, resulting in a total demand of 735.25 kW. A distributed architecture using one 200 kW converter for each berth panel provides approximately 73.5% utilization per unit. Five converter units are required, consisting of three units for the domestic terminal and two units for the international terminal. The assessment also shows that MCCB GU III should be increased from 800 A to 1250 A. In addition, the ACB-transformer feeder requires an ampacity upgrade. These findings provide a practical design approach for reliable 50/60 Hz shore power interoperability.

Keywords— Shore power; frequency converter; low-voltage shore connection; IEC 80005-3; overcurrent protection; conductor ampacity.

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I. INTRODUCTION

Shore power also known as shore connection/shore-to-ship power is increasingly adopted in modern ports to allow berthed ships to switch off their auxiliary diesel generators while maintaining onboard electrical supply[1]. Using shore power instead of auxiliary engines can reduce ship emissions at berth by up to ~98% when electricity comes from a low carbon grid[2]. This practice directly addresses two practical port-side challenges: (i) the need to ensure continuous electrical power for hotel loads and cargo-handling support systems when a ship is alongside, and (ii) the need to reduce local emissions and noise caused by running auxiliary engines during berthing operations[3]. In the Indonesian context where maritime connectivity is strategically important and ship calls are expected to increase ports require reliable and standardized electrical infrastructure to support safer and cleaner operations[4].

The anonymized Surabaya terminal provides a relevant case because it already operates a shore connection service with a total capacity of 1000 kVA, nominal voltage 400 V, frequency 50 Hz, and five connection boxes distributed at the berth[5]. Greenport practices improve port image and user satisfaction[6].

Operational records show that, over the reported

period up to early June 2021, the facility was used 17 times at the domestic terminal, with an average consumption of 187.76 kWh and an average connection duration of 22.51 hours per use.

These figures indicate that shore power is not merely a conceptual option but an actively used service that must be engineered for robust, repeatable performance under real operating conditions. repeated trips and protection operations during normal use, confirming that shore power must be engineered for robust, repeatable performance under real operating conditions[7].

However, practical deployment is not only a matter of providing a connection point; it must also satisfy electrical safety and design requirements[8]. The technical evaluation of the anonymized Surabaya terminal case indicates that parts of the installed electrical system require reassessment particularly the current-carrying capacity of conductors (KHA/ampacity) and the coordination and adequacy of overcurrent protection devices (GPAL) to ensure compliance with national electrical installation requirements when the system is assessed at a full-load current of 250 A[9]. Protection settings and coordination must be revisited whenever fault levels, load levels, or network configuration change; otherwise main/backup selectivity and timing margins can be lost[10]. In other words, as shore power utilization grows and ships demand higher at-berth loads, the feeder sizing and protective scheme must be verified to prevent thermal overstress, nuisance tripping, or more critically protection failure during abnormal conditions.

A second and equally important motivation is international interoperability. While the onshore utility supply in Indonesia is typically 50 Hz, some international vessels are designed for 60 Hz onboard systems[11]. In such cases, a shore power service without frequency adaptation may be unable to supply

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compatible power to visiting ships[12]. The Teluk Lamong analysis therefore recommends the inclusion of a frequency converter to enable service to international shipping using 60 Hz, aligning the design approach with the LV shore connection standard family (IEC 80005 series), particularly IEC 80005-3 for low-voltage shore connection systems[13].

IEC 80005-3 is relevant because it defines general requirements for low-voltage shore connection (LVSC) systems on both the ship and shore side, covering the design, installation, and testing of the complete interface including shore distribution, shore-to-ship connection equipment, transformers/reactors, frequency converters, and protection/control/monitoring functions[14]. It is intended for applications up to about 1 MVA while at berth and covers three-phase systems rated 250 A and above within the typical LV range (roughly 400–1000 V AC). This scope maps closely to the anonymized Surabaya terminal service rating and the 250 A loading basis used in the technical assessment.

Taken together, these factors motivate a focused engineering study on capacity design and integration of a 50/60 Hz frequency converter within an LV shore power system, while simultaneously. Correct sizing of 50/60 Hz converter for 1 MVA LV system, realistic hotel loads, harmonics, and voltage drop; grid forming SFCs and motor drive based SFCs need droop control and transient studies[15]. Remain compliant with applicable requirements under realistic loading. In addition to safety and interoperability, the Teluk Lamong case also indicates that shore connection operation can be economically attractive compared with running ship auxiliary engines while berthed, providing a further operational incentive to strengthen the technical design so the service can be expanded with confidence. Terminal Teluk Lamong already operates a low-voltage shore power service rated at 1000 kVA, 400 V, 50 Hz, delivered through five shore connection boxes along the berth.

Operational records indicate that the service has been used repeatedly (e.g., 17 uses recorded up to early June 2021 at the domestic terminal, with average energy use 187.76 kWh and an average connection duration of 22.51 h). Despite this operational traction, the technical readiness of the installed electrical infrastructure must be ensured for safe and reliable expansion. The existing installation has been identified as requiring improvements in key electrical design elements especially conductor current-carrying capacity (KHA/ampacity) and overcurrent protection devices (GPAL) to satisfy PUIL 2011 requirements under the assessed loading condition (full-load basis reported at 250 A)[16].

A second challenge is interoperability for international calls. While the shore supply is typically 50 Hz, some international vessels operate onboard systems at 60 Hz, creating a compatibility barrier if no frequency adaptation is provided. The Teluk Lamong case explicitly motivates the adoption of a 50/60 Hz frequency converter referencing IEC 80005-3 to enable service for 60 Hz vessels.

From an engineering standpoint, this introduces

additional design questions: how to size converter capacity and decide its deployment scheme, and how to coordinate protection and conductor sizing around the converted supply so the overall system remains compliant and operationally robust.

Research objectives

This paper therefore aims to develop and demonstrate a standards-oriented design and integration approach for shore power systems that must serve both domestic (50 Hz) and international (60 Hz) vessels. Specifically, the objectives are to:

- a. Assess the adequacy of the existing shore power installation in terms of protection and conductor ampacity against the relevant PUIL 2011 criteria under the stated loading basis.
- b. Design the capacity (sizing) and integration strategy of a 50/60 Hz frequency converter for international-vessel service, using the case's converter specification basis (e.g., 200 kW unit parameters) as the starting point for configuration and deployment.
- c. Propose a protection and conductor redesign where required, following the case's demonstrated method of applying a safety margin (e.g., the 125% rule used for MCCB selection) and identifying feeders whose KHA is below the required margin.

Although shore power has been implemented in several ports, practical publications that translate standards requirements into a step-by-step engineering design workflow covering frequency-converter sizing for 50/60 Hz interoperability while simultaneously verifying conductor ampacity and protection adequacy under realistic berth loading remain limited, particularly for Indonesian port case studies. Using the Teluk Lamong shore connection system as a representative implementation, this paper fills that gap by presenting a reproducible, standards-oriented approach and reporting the resulting design recommendations. The remainder of the paper is organized as follows: Section II describes the case data, assumptions, and the sizing/compliance methods; Section III presents the converter sizing, protection, and ampacity verification results and discusses practical implications; and Section IV concludes the work and outlines directions for further validation and deployment.

Despite the availability of an existing low-voltage shore connection system, several technical problems may limit its capability to serve both domestic and international vessels. First, the 50 Hz shore supply is not directly compatible with vessels operating at 60 Hz, making frequency conversion necessary. Second, the installation of a frequency converter changes the loading and protection requirements of the shore-side electrical network. The converter capacity must therefore be coordinated with the berth load, upstream transformer capacity, circuit-breaker ratings, and conductor ampacity. Third, equipment that remains adequate under the current operating demand may become under-rated when several berth panels operate simultaneously at the conservative design current. Consequently, the engineering problem is not merely to select a frequency converter, but to determine an appropriate converter

capacity and integration architecture while ensuring that the associated protection devices and conductors remain adequate under peak loading conditions.

Previous studies have generally examined shore-power emission reduction, shore-to-ship interface safety, frequency-converter technology, power quality, or protection systems as separate research topics. However, limited studies have presented a reproducible engineering workflow that simultaneously combines frequency-converter sizing, converter deployment architecture, overcurrent protection adequacy, and conductor ampacity verification for a 50/60 Hz low-voltage shore connection system. This limitation is particularly evident in practical case studies of Indonesian ports. The novelty of this study is therefore an integrated standards-based design workflow that links the conservative berth-loading scenario with converter capacity calculation, comparison of centralized, terminal-group, and distributed integration architectures, and identification of the required protection and conductor upgrades. The proposed approach does not treat the frequency converter as an independent component but as part of the complete shore-side electrical system. It produces specific design recommendations, including the converter rating and allocation, the required uprating of the domestic feeder protection, and the reinforcement of the critical upstream conductor segment.

II. METHOD

A. Case study data and existing system description

This study adopts a single-case design using the operational shore power facility at Terminal Teluk Lamong (Surabaya) as the reference system. The case data were compiled from the port/operator technical records and the documented system inventory, covering (i) service rating and utilization history, (ii) distribution architecture at berth and at the main substation, (iii) installed protection devices, and (iv) power transformer nameplate specifications.

1. Shore power service rating and usage profile.

The shore connection service is rated at a total capacity of 1000 kVA, with a nominal output of 400 V, 50 Hz, delivered through five connection boxes along the berth. To describe how the system is actually used, the operational record (up to early June 2021) reports 17 usage events at the domestic terminal, with an average energy consumption of 187.76 kWh and an average connection duration of 22.51 hours per event.

2. Existing distribution layout (domestic vs. international terminals).

The system is organized into domestic and international berth groups. The domestic side is represented by three berth panels (Panel Dermaga I–III), while the international side is represented by two berth panels (Panel Dermaga IV–V). At the main substation (Gardu Utama), the distribution to these berth groups is handled through three MCCBs (GU I, GU II, GU III) and one upstream ACB acting as the main circuit protection. In the documented configuration, MCCB GU I and GU II

are allocated to serve the international terminal, while MCCB GU III serves the domestic terminal.

3. Installed protection devices (type, rating, quantity, and model).

Protection device inventory is summarized from the system specification table: the domestic berth panels use MCCB 400 A (3 units), the international berth panels use MCCB 800 A (2 units), and the main substation includes MCCB 800 A (3 units) plus an ACB 2000 A (1 unit). These devices define the baseline protection scheme that is later checked for adequacy and coordination against the loading assumptions and the applicable installation criteria.

4. Power transformer specification at the main substation.

The shore power distribution is fed through a transformer rated at 1250 kVA, with a 20 kV primary and 400 V secondary, operating at 50 Hz with a Delta–Star winding configuration. This transformer specification is used as the reference when discussing overall capacity utilization and constraints on shore-side supply.

5. Frequency converter baseline specification for 50/60 Hz interoperability (catalog-based).

To enable service compatibility for vessels requiring 60 Hz, a frequency-converter unit specification is taken from the documented equipment basis: series 134F0389, rated at 200 kW, with an input voltage range of 380–500 V, input frequency 50–60 Hz, and power factor 0.92. The case document also proposes an initial deployment quantity of 3 units for the domestic terminal and 2 units for the international terminal to support operational coverage.

B. Standards and design criteria (PUIL 2011 and IEC 80005-3)

This paper applies a standards-oriented approach combining (i) a PUIL 2011–based margin rule used in the case document for overcurrent protection (GPAL) and conductor ampacity (KHA), and (ii) IEC/IEEE 80005-3 as the system-level reference for low-voltage shore connection (LVSC) and frequency-converter integration for international-vessel interoperability[17].

1. Overcurrent protection criterion (PUIL 2011–based margin)

$$I_{nmin} = 125I_{max} \quad (1)$$

This criterion is used in the case to redesign GPAL capacity (e.g., total domestic load 750 A → minimum 937.5 A → MCCB selection 1250 A).

2. Conductor ampacity criterion (PUIL 2011–based margin)[18].

$$KHA_{min} = 125I_{max} \quad (2)$$

Conductor adequacy is verified by comparing KH_{Amin} against the installed cable's KHA; any feeder with installed KHA below KH_{Amin} is classified as non-compliant and subject to redesign[19].

3. IEC 80005-3 applicability and system-level criteria.
IEC 80005-3 specifies provisions for the design, installation, and testing of LVSC systems on both shore and ship sides and covers ships requiring up to 1 MVA while at berth, with three-phase shore connections rated 250 A and above and nominal voltage 400–1000 V AC.

In this study, IEC 80005-3 is used to justify and structure the 50/60 Hz frequency converter integration for servicing international vessels (60 Hz) from a 50 Hz shore supply, consistent with the case recommendation

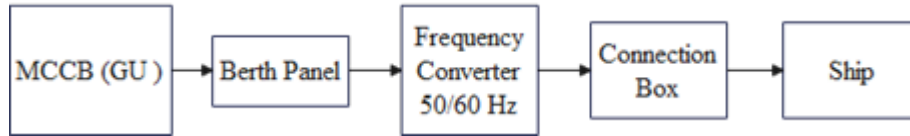


Figure. 2. The distributed converter reference

4. Sizing procedure and assum
The Teluk Lamong shore connection service is rated 1000 kVA, 400 V, 50 Hz, with five connection boxes. A conservative full-load evaluation is ported 250 A condition used in the case's technical assessment[20].

Three-phase power relations (sizing)[21]

$$S = \sqrt{3} VLL I \quad (3)$$

For this case, VLL is taken as 400 V (shore LV service)

$$P = \sqrt{3} VLL IPF \quad (4)$$

Energy–time relation

The case document reports the following basic relationship for energy use:

$$W = VIt \quad (5)$$

and equivalently:

$$W = Pt \quad (6)$$

These equations are used as supporting relations when interpreting the logged energy and connection duration data.

C. Load/current basis and sizing approach

This section defines the design load basis and the step-by-step sizing approach used to evaluate (i) the shore connection load currents at different distribution levels (berth panels and main substation), and (ii) the required ratings for protection devices, conductor ampacity, and the 50/60 Hz frequency converter.

1. Design current basis (full-load scenario)

The maximum operating current used as the design basis was obtained from an interview record with the project supervisor, where the highest load current observed during shore connection service was 250 A. A conservative full-load assessment was then defined with the following assumptions: all berth panels (Panel Dermaga I–V) carry the maximum current, the maximum load current is fixed at 250 A, and the analysis is performed using manual engineering calculations.

a. Current aggregation across distribution levels

To translate the panel-level load into upstream currents, the shore power distribution is grouped into domestic panels (I–III) and international panels

(IV–V). Under the full-load assumption of 250 A per panel, the aggregate currents are:

$$I_{Dom} = \sum_{k=1}^3 I_{Panel-k} = 3 \times 250 = 750A \quad (7)$$

The case document explicitly reports that the domestic terminal current reaches 750 A under full-load conditions.

$$I_{Dom} = \sum_{k=4}^5 I_{Panel-k} = 2 \times 250 = 500A \quad (8)$$

These aggregated currents are then used to evaluate upstream protection at the main substation level, where protection adequacy is assessed at both panel and substation breakers as shown in the case's full-load GPAL table.

D. Frequency converter integration design

This subsection defines where the 50/60 Hz frequency converter is placed in the shore power chain, the single-line logic used for the case study, the shore–ship interface boundary, and the protection coordination principles at the converter input and output [22].

1. Integration architecture options

The Teluk Lamong LV shore power service is rated 1000 kVA, 400 V, 50 Hz, delivered via five connection boxes along the berth. The distribution is organized through a main substation (Gardu Utama) with an upstream ACB and three MCCBs, where MCCB GU I and GU II serve the international terminal, and MCCB GU III serves the domestic terminal. The case also recommends a frequency converter (IEC 80005-3 reference) to serve 60 Hz international vessels[23].

Based on this configuration, three practical integration options are considered:

- a. Option A-Centralized conversion (substation-level). A single, larger converter is installed at the substation, feeding all shore outlets downstream. This simplifies maintenance but creates a single point of failure and requires higher converter capacity for simultaneous users.
- b. Option B-Terminal-group conversion (domestic vs international feeders)[24]. Converters are installed on the feeder groups (e.g., downstream of MCCB GU III for domestic; downstream of MCCB GU I/GU II for international). This

improves redundancy versus Option A while keeping the number of converter locations limited.

- c. Option C- Distributed conversion (panel/connection-box level).
Each berth panel (or each connection box) is equipped with its own converter module. This matches the case recommendation of 3 units for the domestic side and 2 units for the international side, using the catalog-based 200 kW converter module.

2. Single-line diagram logic (textual)
The existing shore power supply chain is represented with the following simplified single-line logic Figure 1[25]. For the distributed converter reference (Option C), the converter is inserted at each berth branch Figure 2[26]. The converter module specification used as the equipment basis is 200 kW, input voltage 380–500 V, input frequency 50–60 Hz, PF 0.92.

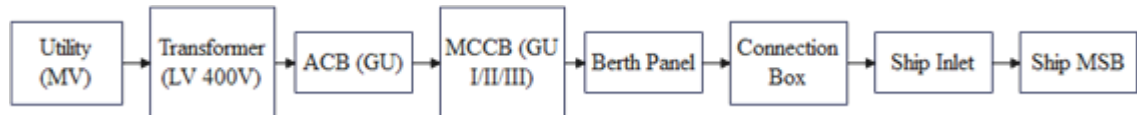


Figure. 1. The existing shore power supply chain

3. Shore-ship interface boundary (scope definition)
To keep responsibilities and measurements clear, the shore connection is partitioned into three domains:
 - a. Shore-side domain: from the transformer LV bus, ACB/MCCB at Gardu Utama, berth panels, converter (if installed), up to the connection box outlet.
 - b. Interface domain: the physical connection between shore and ship (connection box outlet, cable, ship inlet), where energization is allowed only after safety checks (pilot/interlock/earthing practices follow LVSC engineering conventions; the case motivates standard-based implementation).
 - c. Ship-side domain: from the ship inlet to the ship main switchboard (MSB) and onboard distribution.

This paper's sizing and protection assessment focuses on the shore-side and interface domains, consistent with the case's emphasis on conductor ampacity, protection devices, and converter provisioning.

4. Converter input/output protection and coordination (design rules)

The converter introduces a new "electrical node" that must be protected on both its input and output. Coordination is described using a selective-tripping principle: downstream protective devices should operate before upstream devices for faults local to a branch.

- a. Input-side protection (shore → converter)

Input protection is placed upstream of the converter to isolate converter internal faults and to coordinate with upstream substation breakers (ACB/MCCB at GU). The minimum nominal current is evaluated using the same PUIL-based 125% margin approach used throughout the case analysis:

$$I_{n,min}^{in} = 1.25 I_{max}^{in} \quad (9)$$

A practical estimate of the maximum converter input current can be expressed as:

$$I_{max}^{in} = \frac{P_{load}}{\sqrt{3} V_{LL} PF \eta} \quad (10)$$

5. Output-side protection (converter → ship)
Output protection is located downstream of the converter and upstream of the shore outlet/connection box. Its functions are to:
 - a. Isolate shore-to-ship faults (e.g., cable faults, ship-side faults reflected to shore),
 - b. Coordinate with input protection (output should clear first for downstream faults),
 - c. enforce safe energization (interlocked switching).

The design current basis used in this study for full-load evaluation is 250 A, as stated in the case's technical assessment.

6. Coordination checkpoints

Selectivity: set time-current characteristics so that the closest downstream device trips first (ship/outlet → converter output → converter input → GU MCCB → GU ACB). The existing GU allocation (GU I/II international, GU III domestic) provides the feeder structure for coordination. Thermal margin: verify that conductor ampacity (KHA) meets the 125% margin along the feeder path (the case identifies the ACB-to-transformer segment as needing improvement). Operational redundancy: distributed conversion (3 domestic + 2 international) limits service disruption if one converter is out of service.

E. Protection and conductor redesign workflow (Steps 1–6)

Step 1 — Define operating scenarios and select design currents

Two current bases are used to guide redesign decisions: (i) the current-use (as-operated) condition derived from recorded ship load calculations (maximum observed about 116.77 A), and (ii) a conservative full-load evaluation adopted in the technical assessment at 250 A. These currents are mapped to each protection/conductor segment (panel level and upstream feeders) using the distribution hierarchy in the existing system.

Step 2 — Compute required overcurrent protection ratings (GPAL) using the 125% margin.

For each protection level, the minimum nominal rating is calculated as formula (1).

Step 3 — Verify protection adequacy and select the nearest higher commercial rating.

Protection adequacy is checked by:

$$\text{Adequate if } I_n \geq I_{n,\min} \quad (11)$$

If inadequate, the redesign selects the next higher standard device rating available in the market. In the case study, the calculated requirement of 937.5 A led to selecting a 1250 A MCCB (Schneider NS1250N).

Step 4 — Compute minimum conductor ampacity (KHA) requirement using the same margin rule

For every feeder segment associated with the protection levels above, the minimum required ampacity is calculated as formula (2).

Step 5 — Identify non-compliant feeders and redesign conductor configuration

Conductor compliance is evaluated using:

$$\Delta KHA = KHA_{\text{installed}} - KHA_{\text{min}} \quad (12)$$

Under the full-load evaluation, the case identifies the ACB GU–Transformer feeder as non-compliant because

the required ampacity is 1562.5 A while the installed value is 1356 A, prompting replacement/upgrade. Redesign actions may include increasing the conductor cross-section, increasing the number of parallel runs, or both while keeping voltage level and installation constraints consistent with the existing shore LV network.

Step 6 — Integrate frequency converter sizing outputs into protection and conductor redesign

To enable service to 60 Hz international vessels, frequency conversion is included as recommended by the case. The converter module basis is taken from the documented specification (200 kW, 380–500 V input, 50–60 Hz input, PF 0.92) and the proposed deployment (3 units domestic, 2 units international). Converter integration affects both (i) branch currents and (ii) fault-clearing coordination; therefore, the final redesign checks that the converter input and output protection meet the Step-2 criterion for their respective $I_{\max}$, and the upstream feeder cables remain compliant with Step-4 after converter placement and load allocation are finalized.

TABLE 1.
OBSERVED SHIP DEMAND STATISTICS FROM SERVICE RECORDS.

Metric	Active power, P (kW)	Voltage, V (V)	Power factor, $\cos\phi$	Current, I (A)
Maximum	68,69	400	0,85	8,84
Average	22,50	400	0,85	8,84
Minimum	05,02	400	0,85	8,84

III. RESULTS AND DISCUSSION

A. Case operational baseline and design basis

The anonymized Surabaya terminal operates an LV shore connection service rated at 1000 kVA, 400 V, 50 Hz, with five connection boxes distributed along the berth. Operational logs report 17 shore-connection uses up to early June 2021, with an average energy use of 187.76 kWh and an average connection duration of 22.51 h. To assess “full-load readiness” and to design for future international-vessel compatibility, the analysis adopts a conservative design case where the maximum recorded shore-connection current is assumed to be 250 A, and all berth panels (Panel Dermaga I–V) are simultaneously loaded at this maximum level.

This full-load basis is explicitly used to evaluate the adequacy of (i) overcurrent protection devices (GPAL) and (ii) conductor ampacity (KHA), and to support the sizing and placement of a 50/60 Hz frequency converter for ships requiring 60 Hz supply.

1. Observed ship-side demand under current operation (as-operated)

Although the full-load basis (250 A per berth panel) is intentionally conservative for design verification, the service history indicates that the shore connection is typically operated at substantially lower demand. From the calculated ship load records (400 V, power factor

0.85), the maximum observed ship demand reached 68.69 kW (≈ 116.77 A), while the average demand was 22.50 kW (≈ 38.26 A) and the minimum demand was 5.20 kW (≈ 8.84 A).

These statistics provide a practical baseline for interpreting why the installed protections are currently adequate in routine service, while also highlighting the gap between present utilization and the worst-case scenario required for future readiness. In particular, the full-load design current of 250 A per panel is more than twice the maximum observed current in the current-use dataset, implying that equipment that appears sufficient in present operation may become limiting when multiple berths operate simultaneously or when future loads grow.

Consistent with this observation, the current-use protection check (based on the highest panel current around 116.83 A) indicates that the installed domestic panel MCCBs (400 A) and the upstream devices at the main substation remain compliant under present loading. However, because future interoperability for international vessels requires frequency conversion and because the design target explicitly considers full utilization of berth capacity, the paper proceeds with a full-load verification that is aligned with standards-driven margin criteria and intended to prevent hidden bottlenecks under peak demand.

B. Overcurrent protection adequacy (GPAL) and recommended uprating

Table 2 summarizes the GPAL adequacy check under the full-load basis. Using the 125% margin rule (minimum nominal rating equals $1.25 \times$ load current), all berth-level protections remain adequate; however, one upstream device—MCCB GU III—becomes the limiting

element because it carries the aggregated domestic load. Table 2 evaluates the adequacy of GPAL ratings using the full-load assumption 250 A per berth panel and the 125% margin rule (PUIL-based), then compares the calculated minimum ratings to the installed protection.

TABLE 2.
GPAL ADEQUACY UNDER FULL-LOAD OPERATION (I_{LOAD} = 250 A PER BERTH PANEL).

Protection location	I _{load} (A)	I _{n,min}	Inst I _n (A)	Status	Recom I _n (A)
Dom berth panel I	250	312,50	400	Adeq	400
Dom berth panel II	250	312,50	400	Adeq	400
Dom berth panel III	250	312,50	400	Adeq	400
Inter berth panel IV	250	312,50	800	Adeq	800
Inter berth panel V	250	312,50	800	Adeq	800
MCCB GU I (Inter)	250	312,50	800	Adeq	800
MCCB GU II (Inter)	250	312,50	800	Adeq	800
MCCB GU III (Dom group)	750	937,50	800	Not Adequate	1250
ACB GU (Main)	1250	1562,50	2000	Adeq	2000

Key interpretation. All panel-level devices are compliant (400 A on domestic panels; 800 A on international panels) because they exceed the minimum 312.5 A requirement at 250 A load.

The only non-compliance appears at MCCB GU III (domestic feeder): the domestic terminal totals 750 A at full load, requiring 937.5 A, but the installed device is 800 A.

Design recommendation. The redesign selects the nearest higher commercial rating, namely 1250 A (Schneider NS1250N), which resolves the compliance gap while providing headroom for transient loading. Conductor ampacity verification (KHA) and required cable upgrade

Table 3 summarizes the conductor ampacity (KHA) verification under full-load operation. Compliance is assessed by comparing the installed ampacity against the

minimum required ampacity ($KHA_{min} = 1.25 \times I_{load}$). The results indicate that most feeder segments meet the minimum requirement; however, the ACB GU–Transformer feeder is identified as non-compliant and should be upgraded. Table 3 checks whether each key feeder segment meets the minimum conductor ampacity requirement under the 125% margin rule, then flags segments that are thermally under-rated. Most feeder segments remain adequate; however, the ACB–Transformer segment is explicitly flagged in the full-load analysis and discussed as the only cable that does not satisfy the minimum requirement. Design recommendation. The narrative states the required ampacity for this segment is 1562.5 A, while the installed ampacity is 1356 A, so the feeder should be replaced/upgraded (e.g., higher cross-section and/or additional parallel runs until total ampacity ≥ 1562.5 A).

TABLE 3.
CONDUCTOR AMPACITY (KHA) ADEQUACY UNDER FULL-LOAD OPERATION.

Feeder seg	I _{load} (A)	KHA _{min}	Inst cable arrang	Inst KHA (A)	Status	Recomm
Ship → Dom berth panel	250	312,5	3× (1C×120 mm ²)	374	Adeq	No change
Ship → Inter berth panel	250	312,5	3× (1C×120 mm ²)	374	Adeq	No change
Dom panel → MCCB GU III	250	312,5	3× (1C×300 mm ²)	544	Adeq	No change
Inter panel → MCCB GU I/II	250	312,5	3× (1C×300 mm ²)	544	Adeq	No change
MCCB GU → ACB	1250	1562,5	3× (2C×500 mm ²)	1800	Adeq	No change
ACB → Transformer	1250	1562,5	4× (2×1C×300 mm ²)	1356	Not adeq	Upgrade conductor capacity
Transformer → Cubicle	25	312,5	1× (3C×50 mm ²)	173	Adeq	No change

C. Frequency converter capacity design and integration for 50/60 Hz operation

IEC 80005-3 is used in this case study to motivate the requirement that the ship-side and shore-side operating frequencies must match; therefore, a frequency converter is required to serve international vessels operating at 60 Hz from a 50 Hz shore supply. Converter capacity is determined by computing the active power demand per berth panel under the full-load current basis using:

$$P = \sqrt{3} VI \cos \varphi$$

which yields 147.05 kW per panel for $V = 400$ V, $I = 250$ A, and $\cos \varphi = 0.85$. The integration choice is one converter per berth panel, explicitly selected to keep local power supply and synchronization “optimal” at each berth branch. Table 3 computes the active power demand per berth panel under the full-load current basis (250 A), using the three-phase relation

$P = \sqrt{3} VI \cos \varphi$ with $V=400$ and $\cos \varphi=0.85$, giving 147.05 kW per panel and 735.25 kW total for Panels I–V. Key interpretation. The case design assigns one frequency converter to one berth panel, specifically to keep supply and synchronization “optimal” at each berth (distributed architecture). A 200kW converter module (Series 134F0389) is then selected, which comfortably exceeds the 147.05 kW panel demand, leaving operational headroom. Unit allocation recommendation. With five berth panels, this logic implies five converter units in total, distributed as 4 units for the domestic terminal and 2 units for the international terminal to keep the overall service coverage optima.

TABLE 4.
FREQUENCY CONVERTER SIZING AND UNIT ALLOCATION (DISTRIBUTED, ONE UNIT PER PANEL).

Berth panel	I_load (A)	V (V)	P_req (kW)	Select conv rat (kW)	Select conv rat (%)	Units
Panel I (Domestic)	250	400	147,05	200	73,5	1
Panel II (Domestic)	250	400	147,05	200	73,5	1
Panel III (Domestic)	250	400	147,05	200	73,5	1
Panel IV (International)	250	400	147,05	200	73,5	1
Panel V (International)	250	400	147,05	200	73,5	1
Total			735,25			5

1. Upstream capacity check against shore service and transformer rating

After selecting a distributed 50/60 Hz converter architecture, it is necessary to confirm that the upstream supply chain can support the expected apparent power demand at berth. The shore connection service is rated at 1000 kVA, 400 V, 50 Hz, with five connection boxes. The installed transformer at the main substation is rated at 1250 kVA, with a secondary voltage of 400 V and a delta–star winding configuration.

The case study also notes that transformer selection should consider maximum efficiency around 80% loading, and therefore estimates the minimum transformer capacity by dividing the load apparent power by 0.8. Using the full-load scenario adopted in this paper (five panels $\times$ 250 A), the total apparent power at 400 V

is $S=3VIS$, which yields approximately 866 kVA for $I = 1250$ A. This value remains within the 1000 kVA shore service rating, leaving headroom for conversion losses and reactive/harmonic components associated with power-electronic interfaces. From the transformer-efficiency perspective used in the case study, the minimum transformer capacity corresponding to this full-load apparent power is $S/0.8 \approx 1083S/0.8 \approx 1083S/0.8 \approx 1083$ kVA, which is still below the installed 1250 kVA transformer rating.

Consequently, the converter integration and full-load design remain compatible with both the shore service rating and the installed transformer nameplate capacity, provided that final commissioning includes verification of power quality and protective coordination at the converter interfaces.

TABLE 5.
SHORE SERVICE AND TRANSFORMER CAPACITY CHECK (CURRENT OPERATION VS FULL-LOAD DESIGN).

Scenario	Basis current (A)	App pow, (kVA)	Min tran (kVA)	Inst tran (kVA)	Shore serv rat (kVA)	Cap status
Current oper (reported)	350,49	242,54	291,50	1250	1000	Adeq
Full-load design (this paper)	1250	≈ 866	≈ 1083	1250	1000	Adeq

D. Discussion

The only non-compliant protection element identified in the full-load assessment is MCCB GU III, because the domestic terminal comprises three berth panels whose currents aggregate to 750 A, thereby requiring a minimum nominal rating of 937.50 A under the 125% design rule. Accordingly, the recommended redesign is to select the next higher commercially available breaker

rating; in this case, the proposed Schneider NS1250N (1250 A) restores the required protection margin and improves operational robustness when the domestic terminal operates at maximum demand. After protection adequacy is ensured, the analysis highlights that the dominant thermal constraint shifts to the upstream conductor system, where the ACB GU–Transformer feeder becomes the limiting segment: the minimum

required ampacity under the full-load basis is 1562.50 A, while the installed capacity is insufficient. Therefore, a cable replacement or capacity upgrade is required to satisfy the same margin principle and to prevent the feeder from becoming a bottleneck during sustained high loading. Importantly, concentrating the conductor redesign on this single upstream segment is advantageous because it directly removes the principal thermal limitation while minimizing interventions in downstream berth circuits, reducing retrofit complexity and disruption. With the protection and conductor constraints addressed, the shore power system is technically positioned to support frequency interoperability for international vessels: a 200kW frequency converter module (Series 134F0389) comfortably exceeds the calculated 147.05 kW per-panel demand, yielding an estimated utilization of approximately 73.5% per unit and providing headroom for transient load variations and future growth. Finally, from an operational deployment perspective, distributing the converters as three units for the domestic terminal and two units for the international terminal aligns with the three-versus-two berth grouping and improves service availability by keeping each terminal segment independently supportable during maintenance or partial outages.

E. Overall design implication

Taken together, the case study demonstrates that achieving an IEC 80005-3-aligned shore power interface for international vessels is not only a matter of adding frequency conversion, but also requires verifying that the upstream electrical infrastructure remains compliant under conservative loading. Under the adopted full-load basis (250 A per berth panel), the protection assessment identifies a single critical uprating need MCCB GU III must be increased from 800 A to 1250 A to satisfy the minimum margin for the aggregated domestic feeder current (750 A $\rightarrow$ 937.5 A minimum) thereby improving selectivity and operational robustness at peak demand. In parallel, the conductor verification reveals that the dominant thermal constraint lies at the ACB GU–Transformer feeder, where the installed ampacity is insufficient relative to the 1562.5 A minimum requirement, motivating a focused cable-capacity upgrade at this upstream segment.

Finally, the capacity design and integration of the 50/60 Hz frequency converter is justified by the computed panel demand (147.05 kW per panel) and implemented through a distributed, one-converter-per-panel architecture using 200 kW modules, providing ~73.5% nominal utilization and enabling 60 Hz service without coupling disturbances across berths.

Overall, the results provide a practical, standards-oriented pathway for Indonesian ports to integrate frequency conversion for international calls while maintaining protection and ampacity adequacy in the shore-side LV distribution network.

IV. CONCLUSION

This study developed a standards-based approach for sizing and integrating a 50/60 Hz frequency converter

into an existing low-voltage shore connection system. The approach combined three-phase load calculation, converter architecture evaluation, overcurrent protection assessment, and conductor ampacity verification under a conservative design current of 250 A per berth panel. The analysis showed that each berth panel requires 147.05 kW, resulting in a total active-power demand of 735.25 kW for five berth panels. A distributed architecture using one 200 kW converter per berth panel was selected because it provides approximately 73.5% nominal utilization, operational independence, and reduced disturbance coupling between berths. Accordingly, five converter units are required, consisting of three units for the domestic terminal and two units for the international terminal.

The infrastructure assessment also demonstrated that frequency-converter installation must be accompanied by verification of the existing shore-side electrical network. Under the full-load scenario, MCCB GU III is under-rated for the aggregated domestic current and should be increased from 800 A to 1250 A. The ACB–transformer feeder was also identified as the main thermal bottleneck because its installed ampacity is lower than the minimum required value of 1562.5 A; therefore, its conductor capacity should be upgraded. These results confirm that reliable 50/60 Hz shore power interoperability depends on the coordinated design of converter capacity, deployment architecture, protection ratings, and conductor ampacity. The proposed workflow can support preliminary shore power retrofit planning in ports with similar low-voltage systems. Future studies should validate the proposed design through harmonic analysis, voltage-drop assessment, short-circuit calculations, protection-selectivity analysis, converter efficiency evaluation, and on-site commissioning tests.

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