# Postprint: Research on Seamless Grid-Connected Switching Technology for Multi-Unit Parallel Ship Shore Power Supply

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## Abstract

Conventional frequency conversion power supplies can achieve standalone power supply functionality, but cannot satisfy the requirements for seamless grid-connected power supply. Before a frequency conversion power supply can provide power to a vessel, the vessel' s main generator set must first be shut down. Conversely, the frequency conversion power supply system must be shut down before the ship' s generator set can be brought back online. This paper focuses on the multi-unit parallel technology of shore power systems, employing micro-grid application technology to design a frequency conversion shore power supply system that emulates the operating principle of ship generators. Through power detection sensors that continuously monitor the voltage and frequency of the ship' s power grid, the system adjusts its output voltage and frequency in real time to achieve synchronization between the two, thereby realizing the seamless grid-connected power supply function of the frequency conversion shore power supply system.

## Full Text

### Research on Grid-Connected Seamless Switching Technology for Multi-Unit Parallel Operation of Ship Shore Power Supply

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**Abstract**

Conventional frequency conversion power supplies can achieve independent power supply functionality but cannot meet the requirements for seamless grid-connected power supply. Before a frequency conversion power supply can provide power to a vessel, the ship' s main generator set must first be stopped. Conversely, the frequency conversion power supply system must be stopped before the ship's generator set can be restored. This paper focuses on multi-unit parallel technology for shore power systems, employing microgrid application technology to design a variable-frequency shore power supply system that simulates the working principle of ship generators. Through power detection sensors that monitor the voltage and frequency of the ship' s power grid in real time, the system adjusts its output voltage and frequency accordingly to achieve synchronization, thereby realizing seamless grid-connected power supply functionality for the variable-frequency shore power system.

**Keywords:** Ship shore power, Multi-unit parallel operation, Grid connection, Seamless switching

## 1 Introduction

Vessels equipped with special equipment often connect to shore-based power supplies while docked to obtain electricity for water pumps, lighting, ventilation, and other needs. During this time, ships shut down their diesel generators, which not only eliminates noise from onboard equipment operation but also reduces exhaust emissions to some extent—an important contribution to both sustainable port development and energy conservation. Furthermore, using shore-based power while berthed offers significant economic benefits by substantially reducing the operation and maintenance costs of the ship' s power supply system and greatly improving energy utilization efficiency.

However, conventional frequency conversion power supplies, while capable of independent power supply, cannot achieve seamless grid-connected power supply. Before a frequency conversion power supply can energize a ship, the vessel's main generator set must first be stopped. Similarly, the shore power system must be deactivated before the ship' s generators can be restored. In summary, research on a seamless switching technology suitable for multi-unit parallel operation of ship shore power systems is essential.

In terrestrial power grids, microgrid approaches have gained considerable acceptance for addressing large-scale integration of distributed generation, with related projects being implemented worldwide. Microgrids represent an effective pathway for sustainable development of the power industry. Meanwhile, shipboard power systems are characterized as strongly nonlinear, tightly coupled, and compact systems, featuring distinct differences from terrestrial power systems in terms of overall grid structure design, installation techniques, system stability theory, protection and reconfiguration technology, and operational modes. Therefore, this paper focuses on multi-unit parallel technology for shore power systems, applying microgrid technology to design a variable-frequency shore power supply system that simulates ship generator operation principles, aiming to achieve seamless grid-connected power supply functionality.

## 2 Seamless Grid-Connected/Islanded Switching Control Based on Microgrid Principles

### 2.1 Two Operational Modes

The frequency conversion power supply is a key core component of the entire shore power system. With the construction of ultra-large-capacity shore power systems, multi-unit parallel technology has attracted attention. Parallel operation technology not only expands power capacity but also offers advantages such as operational flexibility and mutual redundancy, including fault redundancy and shore power microgrid capabilities.

As shown in [Figure 1: see original paper], three frequency conversion power supply systems operate in parallel. The three units can function as an integrated whole, or one or two units can be selected for operation based on the type of docked vessel and its power consumption. Redundancy means that if a single frequency conversion system fails during operation, it can be automatically disconnected from the system. Provided capacity requirements are met, this does not affect overall system operation. The redundancy function ensures uninterrupted power supply on the ship side and improves system reliability.

In addition to the above operational scheme, the configuration shown in [Figure 2: see original paper] can also be adopted. Besides combined usage, individual units can operate independently. This approach features networked control of the entire port' s shore power, forming a shore power microgrid concept. The frequency converter' s operation mode simulates generator parallel operation characteristics, enabling flexible networking. Individual frequency conversion power supplies can be used separately or in combination. During combined grid connection, the subsequently connected units collect voltage information from the shore power output bus, adjust their output voltage, lock frequency and phase, and automatically switch upon successful phase locking, forming a shore power microgrid state. This microgrid operational mode for ship shore power will become a future trend for port power systems—large capacity and networked operation—which forms the basis of this research on seamless switching control technology.

### 2.2 Seamless Grid-Connected/Islanded Switching Control

The AC bus of the ship shore power microgrid connects to the public grid through a Point of Common Coupling (PCC) switch PCC-S0 controlled by the microgrid control system, as shown in [Figure 3: see original paper]. To achieve seamless switching between grid-connected and islanded states, the shore power microgrid control system must coordinate and control multiple parallel microgrid converters and schedule energy within the system.

Using voltage sensors, the microgrid control system can simultaneously detect public grid voltages UUV, UVW and microgrid AC bus voltages UAB, UBC. Through Phase-Locked Loop (PLL) calculation, it obtains the public grid voltage angular frequency  n and phase angle  n, as well as the ship shore power microgrid AC bus voltage angular frequency  m and phase angle  m, ultimately calculating the public grid voltage Un and microgrid AC bus voltage Um.

When the shore power microgrid control system detects a public grid fault, such as power loss or undervoltage, it controls the PCC-S0 switch to disconnect, completing the transition from grid-connected to islanded state. During switching, because the microgrid converters have voltage source output characteristics, they can provide stable frequency and voltage support for internal microgrid loads. Therefore, within capacity limits, the converters can support seamless switching from grid-connected to islanded state and, in islanded mode, automatically distribute loads through primary frequency and voltage regulation to ensure stable parallel operation of multiple units.

When the microgrid control system detects grid fault recovery, the microgrid must resume grid-connected operation. To achieve seamless switching from islanded to grid-connected state and suppress inrush current during PCC-S0 closure, the microgrid AC bus voltage must first achieve secondary synchronization with the public grid voltage—i.e., achieve identical frequency, phase, and amplitude. To accomplish this, the microgrid control system uses communication to implement secondary voltage and frequency regulation control of the microgrid converters (see [Figure 3: see original paper]). The shore power microgrid control system performs secondary voltage and frequency regulation by controlling the no-load frequency  0 and no-load voltage U0 in the converter droop characteristic curves.

When the shore power microgrid system requires voltage or frequency adjustment, it can achieve this by controlling only a few main voltage or frequency regulation power sources, greatly simplifying system control.

While performing the aforementioned secondary voltage and frequency regulation control of microgrid converters, the shore power microgrid control system continuously monitors the synchronization status between microgrid voltage and grid voltage: (1) The microgrid system voltage frequency has entered a new steady state and matches the grid frequency; (2) The microgrid system voltage amplitude has entered a new steady state and matches the grid voltage amplitude; (3) The microgrid system voltage phase matches the grid voltage phase.

When the microgrid system voltage simultaneously satisfies all three conditions—identical frequency, phase, and amplitude with the grid voltage—the microgrid control system controls the PCC-S0 switch to reclose, completing the transition from islanded to grid-connected state. Since the shore power microgrid system voltage is synchronized with the grid voltage before switch closure, the voltage difference across the switch is zero. Consequently, no excessive inrush current occurs at the PCC during the islanded-to-grid-connected transition, enabling seamless switching.

## 3 Practical Engineering Verification

Unlike motor loads for frequency converters, ship loads include single-phase equipment that makes absolute three-phase load balance impossible, potentially causing different voltage drops between phases. The frequency conversion power supply designed based on this approach features independent three-phase output control technology with closed-loop voltage control. Even with 25% three-phase load imbalance, it maintains symmetrical three-phase line voltage output. Field test waveforms are recorded in [Figure 4: see original paper] and [Figure 5: see original paper]. During startup, the three-phase load is unbalanced with significant current differences between phases, yet the voltage waveforms remain stable and symmetrical.

Using data from a COSCO Africa vessel connection as an engineering verification case, the distribution panel supports both manual and automatic grid-connection modes. Both modes were tested on-site, with grid-connection instantaneous waveforms shown in [Figure 4: see original paper]. The waveform channels are: 1) Frequency conversion power supply U-phase output current; 2) W-phase output current; 3) Isolation transformer U-phase output voltage; 4) V-phase output voltage; 5) W-phase output voltage.

[Figure 4: see original paper] shows that the isolation transformer output current peak is 320A at the grid-connection instant, while the frequency conversion power supply output current peak is 377A, with an on-site overcurrent point of 160% (peak 852A).

[Figure 5: see original paper] shows the three-phase output voltage and two-phase output current waveforms during the first manual grid connection. After grid connection, the three-phase output current waveforms exhibit significant distortion for a period (approximately 500ms), yet the frequency conversion power supply' s three-phase output voltage remains symmetrical. These experimental results demonstrate that the proposed design can achieve seamless switching from islanded to grid-connected state for vessels.

## 4 Conclusion

This paper proposes a control method for ship shore power microgrid converters that enables voltage source output characteristics rather than the current source characteristics of traditional grid-connected converters. This voltage source characteristic allows converters to provide stable voltage and frequency support for microgrid loads during islanded operation and completes seamless switching from grid-connected to islanded state without shutdown. Data from the COSCO Africa vessel connection verified its effectiveness.

By applying microgrid technology to simulate ship generator operation principles, this approach uses power detection sensors to monitor ship grid voltage and frequency in real time, adjusting system output voltage and frequency accordingly to achieve seamless grid-connected power supply functionality for variable-frequency shore power systems. This provides valuable reference for practical engineering applications.

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*Note: Figure translations are in progress. See original paper for figures.*