BY KEVIN L. PETERSON,
PENIAMIN "BEN" CHAVDARIAN,
MOHAMMED ISLAM, &
CHRISTOPHER CAYANAN

Electrical power consumption at the shore side has rapidly grown for commercial ships. The environmental impact of the pollution created while at berth has many ports restricting the operation of on-board generators. Shutting off these on-board generators and supplying ship's power from the shore power system can reduce the air pollution emissions. With the development of medium-voltage power plugs and receptacle assemblies, cold ironing projects for larger ships are more prevalent. Various organizations are working on developing standards for implementing shore power. This article will highlight the efforts of the IEEE, the International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC) to develop

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TACKLING SHIP POLLUTION FROM THE SHORE

Development of shore power standards

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standards for medium-voltage on-shore power supply connections for serving commercial vessels.

Environmental Issues at Ports

California has a reputation for tackling environmental issues, and a target of the latest round of initiatives is pollution from ports, which includes emissions from ships while at berth. The California Air Resources Board [1] estimates that emissions can be reduced by 18 tons per day if every vessel calling three or more times per year to California's ports was able to connect to shore-side power. Two major ports in Southern California have implemented plans to supply power to vessels making frequent calls and are putting serious efforts into developing standards for these connections. These ports are located adjacent to each other on San Pedro Bay, about 20 mi south of downtown Los Angeles. Together, they form the third-largest port complex in the world.

Why are they serious about proving shore power? Hoteling emissions from ocean-going vessels account for about 20% of the total diesel particulate matter (PM) emissions from the ports in the Los Angeles area. These emissions are responsible for about 34% of the port emissions-related risk in the modeling receptor domain based on the population-weighted average risk. These emissions resulted in the largest area (2,036 acres) where the potential cancer risk levels were greater than 200 in a million in the nearby communities. The second highest category contributing to cancer risk levels above 200 in a million was cargo handling equipment, which impacted a residential area of 410 acres and is responsible for about 20% of the total risk in the modeling receptor domain based on the population-weighted average risk. Reducing emissions from these two categories will have the most dramatic effect on reducing the port emissions-related risks in nearby communities [2].

New standards development has been initiated to ensure that systems are compatible at ports around the world. The coordinated development of analytical techniques, port infrastructure, and shipboard electrical plants will facilitate the implementation of an any ship, any port concept.

Plugging into shore-side power, known as cold ironing, should make use of near-zero or zero emissions technology to provide cleaner power to docked ships. Shore-side power measures call for the following:

1) ports to require shore-side power as a condition of new terminal leases or renewals
2) ports to invest in infrastructure for electrical power
3) ports to redevelop shore-side power for providing power to ships
4) ports to negotiate opportunities to subsidize development of shore-side power for harbor craft
5) ship owners to fund the costs of retrofitting ships to accommodate shore-side power.

To provide shore power to the vessel, appropriate provisions and modifications are required on the shore and on the vessel. On the shore side, an appropriate special power system is required to hook up the power delivery cabling system via power receptacles and power plugs. Power may be delivered at 11 kV, 6.6 kV, or 440 V depending on the rating of the vessel's on-board normal power supply equipment. However, the 6.6-kV system appears to be the voltage that will apply in the majority of installations. Many ship operators and port authorities are struggling with the absence of appropriate standards and specifications for interconnecting the ship service loads to on-shore power distribution systems.

This article will review the current state of providing shore power for large commercial ships. It will describe the main features of a shore power system, with an emphasis on personnel and equipment protection and recommendations on the standardization of methods of analysis of interconnected shore power and vessel power systems. The article will also discuss fault current analysis (protection), power system stability, loading and unloading of vessel power systems to shore utility systems, methods of communication, and protective relaying.

Current State of Shore Power

Shore-side power for large ocean-going vessels has been a hot subject for the past few years in the port authority, environmental protection, and engineering circles. Many known implementations of shore-side power systems are presented in [3] and [4]. The viability of shore-side power applications and their ability to power ships at berth depend greatly on the infrastructure outlay. For this measure to be successful, sufficient power must be available for use at the wharves and on land for substation development, and cable-laying right of ways must be available close to the terminals. In addition, all ships must be modified to enable connection to shore power.

One port in Southern California has fitted two terminals with shore power, and plans are being developed for seven other terminals. Figure 1 illustrates an installation in Los Angeles. Another port in Southern California has two shore power projects under construction and three others in the design stage. Both ports have committed to provide shore power to vessels while at berth. These ports have planned and selected a 6.6-kV supply voltage infrastructure with power delivery up to 7.5 MVA per berth. Figures 2 and 3 illustrate a method for accommodating the ship-to-shore cables. Specific shore side power supply system grounding requirements are still under discussion with various ship authorities. Initial discussions with a few ship authorities indicated shore side power supply system grounding to be high-resistance grounding to ungrounded system.

Other U.S. ports investigating the possibility of cold ironing projects are Houston, Texas; Richmond and Norfolk, Virginia; Seattle and Tacoma, Washington; and Oakland and San Francisco, California. International activity includes the

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A 6.6-kV connection box on the wharf.

Hanseatic Ports (Baltic Sea), which have shore-side power as part of their environmental program, and Lubeck Port, which implemented a trial shore connection in August 2005.

The existing installations of shore power are specific to the vessel class. These installations can be grouped into the following categories: container ships, tanker vessels, ferries or barges, bulk carrier ships, and passenger ships. Each category has requirements specific to its vessel type.

Shore Power System Features

Shore power connections for commercial ships typically range from 2 MVA to more than 10 MVA in capacity. Figure 3 shows the shore-side system for connecting container vessels.

Shore Power Supply

The shore power supply typically requires interface with the serving utility. Container and bulk carrier ships are typically fed with 6.6 kV, whereas passenger ships connect at 6.6 and 11 kV. All recent installations have been at 60 Hz. ISO and IEC standardization efforts thus far support only 60 Hz as the standard for future installations. Low-resistance grounding is typically specified for safety reasons.

Cable reel on ship for shore-side connection.

Cable extended from ship for shore-side connection.

An earth grounding switch is provided to discharge the induced voltage of the shore power feeder before being disconnected from the shore power outlets. The grounding switch has a mechanical interlocking scheme between the shore power circuit breakers and shore power outlets to prevent the mating or unmating of a plug and receptacle while the shore power feeder is energized [5].

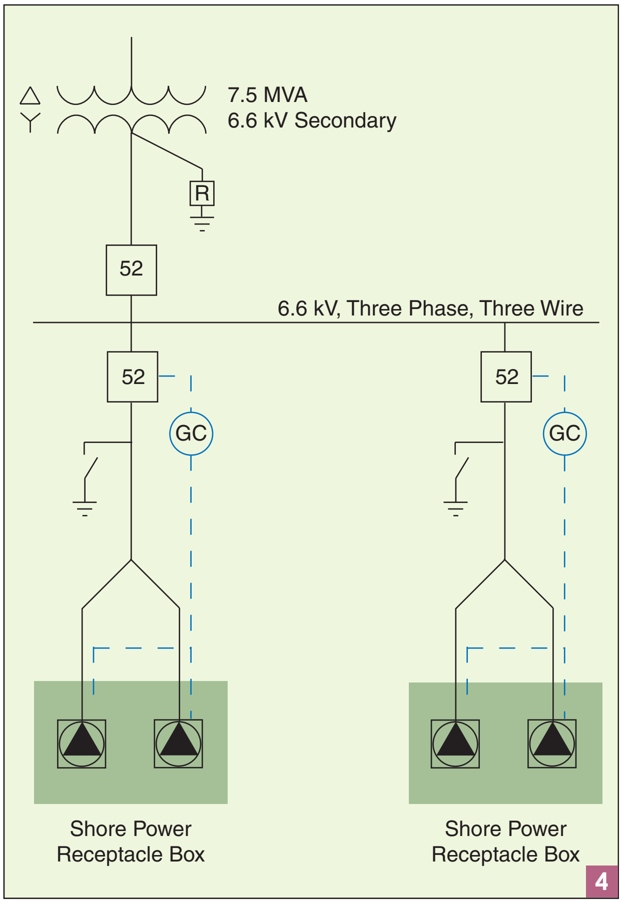
Shore Power Receptacle Boxes: Pier Side

The shore connection enclosure houses power and control receptacles for connecting the ship to shore. The shore power receptacle box shown in Figure 4 contains two 7.2-kV, three-phase, 350-A receptacles.

Shore-side connections need to be located away from cranes at the edge of the wharf at locations flexible enough to accommodate different ships at berth.

Shore Connection Boxes: Ship Side

Most container ships are wired to accept either 6.6-kV or 480-V services from shore. To a much lesser degree, other voltage systems and even different frequencies do also exist. However, regardless of this fact, the owners of new container ships are informed by the ports in the Los Angeles area that 6.6 kV, 60 Hz will be the only voltage provided on shore. Conversions to other voltages, if needed by a particular ship, will be the responsibility of the ship owner to provide on the ship itself.



Typical shore-side power system. Although more than one shore power receptacle box may be installed on the secondary side of the transformer, only one shore power receptacle box will supply power to a ship at any one time.

Ship builders, ship owners, ports, and terminal operators are presently pursuing this thought as a standard that is forthcoming. If a particular installation is different than described here, it is because the port, the terminal operators, and ship owners have special circumstances and have agreed to cooperate with each other to encourage the implementation of cold ironing sooner than later. This is true for container ships only, and to some degree, this requirement will apply to other ships also, such as cruise ships, tanker vessels, and liquefied natural gas (LNG) carriers (Figure 5).

Cable Connections: Ship to Shore

For container ships, cables used for connecting the ship to the shore connection box are fed from cable reels on the ship. Cables for connecting other vessel types may be from the shore or ship.

Cable handling must accommodate tide changes and vessel movement. Cables need to be flexible and suitable for the marine environment. Cables are also subject to tension at times. Commercial ships can be fitted with cable managers to reel down cable to wharf connection points. The cable managers can be fitted with tension sensors to trip the circuit when allowable tensions are exceeded.

Ship Incoming Panel

Existing ships require retrofits to accept medium-voltage shore power connections. Many new ships are being built with the equipment necessary to make shore power connections.

Power Transfer

Vessels with critical loads may require parallel operation prior to deenergizing onboard generation. Both ship and shore electrical distribution systems including shore-to-ship power outlets will need to be rated for the increased fault levels. Most existing vessels are not equipped for parallel operation and will require modifications to permit paralleling the two sources.

Standards Activities

The IEEE, the ISO, and the IEC have taken steps to develop standards for connecting large commercial ships.

IEEE P1713 Electrical Shore-to-Ship Connections

The marine subcommittee under the Petroleum and Chemical Industry Committee of the IEEE Industry Applications Society (IAS) formed a working group in September 2006 to work on development of cold-ironing standards. The working group's project authorization request IEEE-P1713 was approved by IEEE-SA in December 2006. The scope of the project covers system components necessary for connecting large commercial ships including the shore power supply, shore connection boxes, cable connections, ship incoming shore power panel, and control system. The standard also addresses safety considerations, maintenance, and inspection.

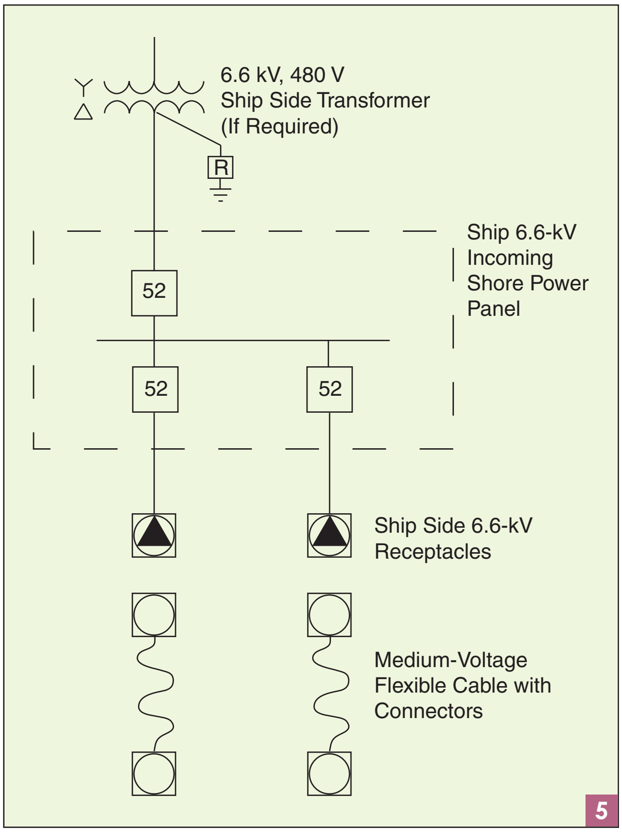
The standard will address various categories of ships for shore power connections: container ships, tanker vessels, ferries or barges, bulk carrier ships, and passenger ships. The areas to be covered include the following:

- general
  - system description
  - installation
  - industry sectors
  - system characteristics
  - system boundaries
- interface requirements
  - conductor interface
  - pilot wire interface
  - fiber optic communications interface
  - communications protocol
  - automated system operation and control
- utility technical requirements
- system transformer
- power system grounding
- medium-voltage switchgear
  - switchgear
  - earthing switch
  - shore power system protection
- shore-side plugs and receptacles
- shore-to-ship connection enclosure
- shore-to-ship cable
- power system testing, inspection, and maintenance
  - inspection, testing, and commissioning program
  - commissioning at first call of a vessel
  - system maintenance tests.

The marine industry subcommittee is responsible for the development of shipboard electrical standards, IEEE Standard 45 [6], IEEE Standard 1580 [7], IEEE Standard 1662 [8], IEEE-P1709 [9], and IEEE-P1713. IEEE-P1713 will make appropriate reference to these standards for maintaining shipboard electrical system integrity and safety.

ISO TC8/SC 3 N440: Ships and Marine Technology, Environmental Protection, and Cold Ironing

The first meeting of the working group was held in September 2006 in Washington, DC [10]. Recognizing the



Typical shipboard 6.6-kV shore power system.

obligation of port states and port authorities to ensure clean air for port communities and the reality that cold ironing is one of the options they are using to meet this requirement, the working group agreed to develop an ISO standard for onshore power supply. This standard will also consider the operational needs of ship owners, operators, facilities, and other affected parties in the marine industry. The working group agreed that drafting the standard would be best accomplished if it were divided among five drafting groups according to vessel type, tankers/LNG, bulkers, containerships and ro/ro, cruise ships, and ferries, with issues important to vessel types being discussed wholly within that drafting group and subissues important all groups being discussed by all groups, but concentration of ownership being assigned to one group, to ensure commonality is achieved where practically possible. The scope to be discussed by all groups was to cover at a minimum the following issues:

- power demand (for 20 years to come)
- voltage (440 V, 6.6 kV, 11 kV)
- frequency (50 or 60 Hz)
- power quality
- reliability and fault tolerance
- power transfer
  - phase rotation
  - voltage matching
  - synchronization
  - time to transfer
  - load tapchanging (LTC) transformer
- grounding
- code and standards coordination
- equipment location
  - transformer
  - frequency converter
  - shore connection point
  - wharf outlets (position and number)
  - cable management system (position and number of cables)
- communication, control, and protocol
- testing and responsibilities
- procedures.

IEC 60092-201 Clause 14: Shore Connections

IEC Technical Committee 18 circulated a draft copy for comment in October 2006 and intends to include the standard in a revision to the consolidated edition of the IEC 60092 series, Part 1: Design, Equipment, Installation, Verification, and Testing. The maintenance team (MT 26) in charge of IEC 60092-201 expects to release a publicly available specification (PAS) in 2009. The scope covers the following:

- general requirements
- shore requirements
  - high-voltage shore supply system
  - installation
- ship-to-shore connection and interface equipment
  - plug and socket outlets
  - ship-to-shore connection cable
  - control and monitoring cable
  - storage
- ship requirements
  - installation
  - ship electrical distribution testing
  - connection switchboard
  - on-board transformer
  - receiving switchboard connection point
  - emergency stop switches and shutdown conditions
  - high-voltage system control and monitoring (HVSC)
- verification and testing
  - initial tests
  - periodic tests and maintenance
  - documentation.

Conclusions

New standards development has been initiated to ensure shore power systems for connecting ships are compatible at ports around the world. Coordinated development of analytical techniques, port infrastructure, and shipboard electrical plants will facilitate the implementation of an any ship, any port concept.

When these standards are published, more ports will embrace shore power to reduce the environmental impact of pollution created while vessels are at berth.

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Kevin L. Peterson (k.l.peterson@ieee.org) is with P2S Engineering, Inc., in Long Beach, California. Peniamin "Ben" Chavdarian is with the Port of Long Beach, California. Mohammed Islam is with Northrup Grumman Ship Systems in Avondale, Louisiana. Christopher Cayanan is with Valero Energy Corporation in Wilmington, California. Peterson and Chavdarian are Senior Members of the IEEE. Islam and Cayanan are Members of the IEEE. This article first appeared as "State of Shore Power Standards for Ships" at the 2007 Petroleum and Chemical Industry Conference.