



IEEE Recommended Practice for the Design and Application of Power Electronics in Electrical Power Systems

STANDARDS

IEEE Industry Applications Society
and the
IEEE Power Electronics Society

Developed by the
Petroleum and Chemical Industry Committee
and the
Standards Committee

IEEE Std 1662™-2023
(Revision of IEEE Std 1662-2016)



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Developed by the

**Petroleum and Chemical Industry Committee
of the
IEEE Industry Applications Society**

and the

**Standards Committee
of the
IEEE Power Electronics Society**

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IEEE SA Standards Board

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Abstract: Recommendations and requirements for the design and applications of power electronics in land-based (onshore) and marine (offshore) electrical power systems are provided in this standard. A wide range of power electronics equipment with aggregated power ratings at and above 100 kW with voltages equal to or less than 52 kV (ac) or (dc) is covered. Existing engineering practices, analytical methods, and performance characteristics are described. Applicable international and local standards are referenced with appropriate guidance to provide users of the standard with correct criteria for design, testing, and maintenance necessary for reliable operation of integrated power systems.

Keywords: IEEE 1662™, integrated power systems, PEBB, power electronic building blocks, power electronics

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Introduction

This introduction is not part of IEEE Std 1662-2023, IEEE Recommended Practice for the Design and Application of Power Electronics in Electrical Power Systems.

This revision of IEEE Std 1662-2016 provides recommendations and requirements for the design and applications of power electronics in land-based and marine electrical power systems. It covers a wide range of power electronics equipment with aggregated power ratings at and above 100 kW with voltages equal or less than 52 kV. It describes existing engineering practices, analytical methods, and performance characteristics. Applicable international and local standards are referenced with guidance to provide users of this standard with correct criteria for analysis, design, testing, and maintenance of power electronics and reliable integration of power electronics in electrical power systems. All recommendations in this standard are functional and do not specify any particular equipment or equipment type.

Acknowledgments

The working group especially acknowledges the contributions of the group member Dr. Michael (Mischa) Steurer from Florida State University Center for Advanced Power Systems, who passed away shortly before publication of this standard. This standard is dedicated to his memory.

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IEEE Recommended Practice for the Design and Application of Power Electronics in Electrical Power Systems

1. Overview

1.1 Scope

This document specifies ~~summarizes current electrical engineering methods and design practices for applying~~ power electronics (PE) ~~in electrical power distribution and conversion systems from a common frame of reference for reliable integrated electrical power systems. It recommends~~ equipment (PE) requirements, necessary power system analytical studies, ~~PE design analysis~~ and testing, ~~and~~ certification, and inspection procedures in land-based and marine electrical power systems. It covers a wide range of power electronics equipment with aggregated power ratings at and above 100 kW with voltages equal to or less than 52 kV (ac) or (dc). Applicable international and local standards are referenced with guidance to provide users of this standard with correct criteria for reliable integration of power electronics in electrical power systems.

1.2 Purpose

The purpose of this document is to specify requirements ~~recommend a methodology~~ for the design analysis and application ~~specifications parameters of PE equipment for electrical power systems. It analyzes the impact of power electronics in land-based building blocks (PEBBs) or integrated power systems (IPSs) on size, life cycle cost, weight, fuel efficiency, and~~ marine electrical power systems risk reduction of implementation.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{7,8}

⁷The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁸The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

1.4 Limitations

This standard is applicable to design and applications of PE equipment with aggregated power ratings at and above 100 kW in land-based and marine electrical power systems with voltages equal to or less than 52 kV (ac) or (dc).

1.5 Equipment covered by this standard

Some of the equipment is very specific to the power distribution system. Other equipment is the end-use equipment that uses electrical power to perform its function. Examples of equipment covered in this standard are as follows:

- Inverters
- Rectifiers
- Converters: dc to dc, dc to ac, frequency, cyclo-, and others
- Power factor and reactive power [static or dynamic volt-ampere reactive (VAR)] support
- Solid-state circuit breakers, solid-state transfer switches, and solid-state soft starters
- Current limiters
- Motor drives
- Active harmonic filters
- Uninterruptible power supply (UPS)
- Energy storage and pulse load systems

- Static VAR compensator ([SVC](#) ~~SVAR~~)
- ~~— Traction power diode rectifier (TPR)~~
- Energy storage and pulse load systems
- Other equipment with built-in PE that has a utility or microgrid service as the power source, such as auxiliary equipment, communication equipment, and radars

1.6 Guide for users

This standard is written to cover the needs of many different users of PE components, equipment, and systems. Examples of stakeholders include the following:

- Systems integrator
- System designer
- Equipment designer
- Component designer
- Equipment installer or repairman
- End user

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

[IEC 60146-1-1:2024, Semiconductor converters—General requirements and line commutated converters— Part 1–1: Specification of basic requirements.](#)⁹

[IEC TR 60146-1-2:2019, Semiconductor converters—General requirements and line commutated converters—Part 1–2: Application guidelines.](#)

⁹IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch>) and the American National Standards Institute (<https://www.ansi.org/>).

~~CSA C22.1, Canadian Electrical Code.²~~

~~IACS UR E11, Unified requirements for systems with voltages above 1 kV up to 15 kV.~~

~~IEC 60068 2-2, Environmental Testing—Part 2-2: Dry Heat.³~~

~~IEC 60068 2-6, Environmental Testing—Part 2-6: Vibration (Sinusoidal).~~

~~IEC 60068 2-30, Environmental Testing—Part 2-30: Damp Heat.~~

IEC 60146-2:1999, Semiconductor converters—Part 2: Self-commutated semiconductor converters including direct d.c. converters.

IEC 61000-3:2024 SER Electromagnetic compatibility (EMC)—Part 3: Limit—ALL PARTS.

IEC 61850:2022, SER Communication networks and systems for power utility automation—ALL PARTS.

IEC 62271-1:2017+AMD1: 2021, High-voltage switchgear and controlgear—Part 1: Common specifications for alternating current switchgear and controlgear.

~~IEC 61439 (all parts), Low-voltage switchgear and controlgear assemblies.~~

IEC 62271-3:2015 ~~200~~, High-voltage switchgear and controlgear—Part 3: Digital interfaces based on IEC 61850 ~~200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV.~~

IEEE Std C37.240™, IEEE Standard Cybersecurity Requirements for Substation Automation, Protection, and Control Systems.^{10,11}

IEEE Std C57.18.10™, IEEE Standard for Practices and Requirements for Semiconductor Power Rectifier Transformers.

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³~~IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch/>). IEC publications are also available from the American National Standards Institute (<http://www.ansi.org/>).~~

IEEE Std 519™, IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.^{4,5}

IEEE Std 1012™, IEEE Standard for System, Software, and Hardware Verification and Validation.

IEEE Std 1100™, IEEE Recommended Practice for Powering and Grounding Electronic Equipment (*IEEE Emerald Book™*).

~~IEEE Std 1250™, IEEE Guide for Identifying and Improving Voltage Quality in Power Systems.~~

IEEE Std 1409™, IEEE Guide for Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV Through 38 kV.

IEEE Std 1547™, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

IEEE Std 1547.1™, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems and Associated Interfaces.

IEEE Std 1547.3™, IEEE Guide for Cybersecurity of Distributed Energy Resources Interconnected with Electrical Power Systems.

IEEE Std 1566™, IEEE Standard for Performance of Adjustable-Speed AC Drives Rated 375 kW and Larger.

IEEE Std 1676™, IEEE Guide for Control Architecture for High Power Electronics (1 MW and Greater) Used in Electric Power Transmission and Distribution Systems.

~~IEEE Std 1676™-2010, IEEE Guide for Control Architecture for High Power Electronics (1 MW and Greater) Used in Electric Power Transmission and Distribution Systems (Figure 1).~~

IEEE Std 1688™, IEEE Standard Requirements for the Control of Electromagnetic Interference Characteristics of Replaceable Electronic Modules.

IEEE Std 2030™-2011, IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads.

⁵IEEE publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

[IEEE Std 2030.7™-2017, IEEE Standard for the Specification of Microgrid Controllers.](#)

[IEEE Std 2030.8™-2018, IEEE Standard for the Testing of Microgrid Controllers.](#)

[IEEE Std 2800™-2022, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources \(IBRs\) Interconnecting with Associated Transmission Electric Power Systems.](#)

IEEE Std 3003.2™, IEEE Recommended Practice for Equipment Grounding and Bonding in Industrial and Commercial Power Systems.

IEEE Std 3007.2™-2010, IEEE Recommended Practice for the Maintenance of Industrial and Commercial Power Systems.

~~IEEE Std C37.20.1™, IEEE Standard for Metal Enclosed Low Voltage (1000 Vac and below, 3200 Vdc and below) Power Circuit Breaker Switchgear.~~

~~IEEE Std C37.20.7™, IEEE Guide for Testing Switchgear Rated up to 38kV for Internal Arcing Faults.~~

~~IEEE Std C37.90.1™, IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.~~

~~IEEE Std C57.18.10™, IEEE Standard for Practices and Requirements for Semiconductor Power Rectifier Transformers.~~

~~IEEE Std C62.92.1™, IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems—Part 1: Introduction.~~

ISO 9001, Quality management systems: Requirements.^{[12](#)⁶}

NEMA ICS 1.1, Safety Guidelines for the Application, Installation, and Maintenance of Solid State Control.^{[13](#)⁷}

NEMA ICS 10, AC Transfer Equipment, Part 2: Static AC Transfer Equipment.

^{[12](#)⁶} ISO publications are available from the International Organization for Standardization (<http://www.iso.org/>). ISO publications are also available from the American National Standards Institute (<http://www.ansi.org/>).

^{[13](#)⁷} NEMA publications are available from the National Electrical Manufacturers Association (<http://www.nema.org/>).

NFPA 70®, National Electrical Code® (NEC®).^{14,15 8,9}

UL 347A, Medium Voltage Power Conversion Equipment.^{16 10}

UL 508C-2008, ~~Standard for~~ Power Conversion Equipment.

UL 1008S, ~~Standard for~~ Solid-State Transfer Switches.

UL 1741, Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources.

~~UL 1066, Standard for Low Voltage AC and DC Power Circuit Breakers Used in Enclosures.~~

UL61800-5-2, ~~Standard for~~ Adjustable Speed Electrical Power Drive Systems—Part 5–2: Safety Requirements—Functional.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.^{17 11}

active filtering: Controlling power quality with power electronic equipment without impacting primary control of system voltage.

energy storage system (ESS): System that is capable of absorbing energy, storing it, and dispatching the energy back into the power system.

fault: An abnormal condition where voltages and or currents exceed ~~exceeding~~ designated limits, and which warrants immediate shutdown of the affected section of the ~~entire~~ system. Faults often lead to cascading systems failure if not addressed correctly.

^{14 8} NFPA publications are available from the National Fire Protection Association (<http://www.nfpa.org/>).

^{15 9} National Electrical Code, NEC, and NFPA 70 are registered trademarks in the U.S. Patent & Trademark Office, owned by the National Fire Protection Association.

^{16 10} UL publications are available from UL publications are available from Underwriters Laboratories (<http://www.ul.com/>).

^{17 11} *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org/>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

integrated power system (IPS): A power system where all prime movers are used to produce electrical power that is shared among propulsion, mission, microgrids, or service loads. Discriminating attributes of IPSs are flexibility of arrangements, mechanical decoupling between prime movers and propulsors, an increased level of energy conversion and transmission redundancy, and flexibility of redistributing available electrical power for future electrical loads.

integrated power and energy system (IPES): An IPS that also features a distributed energy storage system (ESS).

interoperability: The capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely and effectively.

land-based (onshore offshore) power systems: Power systems installed on the land as distinguished from being in deep or open waters.

~~**line-replaceable unit (LRU):** A modular component designed to be replaced quickly at location.~~

low voltage: Rated 1000 V (ac) or 1500 V (dc) and below.

marine (offshore) power systems: Power systems with multiple power sources installed on ships, boats, mobile, and fixed offshore units.

medium voltage (MV): Rated above 1000 V (ac) or 1500 V (dc) and less than or equal to 52 kV.

~~**per unit (PU):** The reference unit, established as a calculating convenience, for expressing all power system electrical parameters on a common reference base. One PU is 100% of the base chosen.~~

power electronic building block (PEBB): A generic building-block concept for power electronics that incorporates standard modules that can be quickly configured to meet the specific hardware and software needs of particular applications.

power electronics (PE): Single device or system utilizing power semiconductors for conversion, switching, protection, and distribution of electrical power.

protecting: Mitigating measures to manage ~~effects from~~ fault currents, overvoltages, or loss of power source.

pulse load: Variable level non-continuous load

resistance grounded: Grounded through impedance, the principal element of which is resistance, to limit current to the ground.

solidly grounded: Connected directly to ground through an adequate ground connection in which no impedance has been inserted intentionally.

sourcing: Converting power from one or more voltage or frequency levels while being in control of the output voltage or current (or phase angle in the case of alternating current) at its electrical output terminals.

ungrounded: A system, circuit, or apparatus without an intentional connection to ground, except through voltage-indicating or measuring devices, or other very high impedance devices.

zonal distribution: Electrical power architecture structured by zones where a zone is a logical and physical grouping of generation, storage, or consumption assets arranged in a common neighborhood. Zones with generation or storage may be operated for periods of time independently from the power system. A zone is the smallest logical and physical grouping of assets.

3.2 Acronyms and abbreviations

2-D	two-dimensional
3-D	three-dimensional
~~ac~~	~~alternating current~~
AFE	active front end
<u>ASD</u>	<u>adjustable speed drive</u>
BSES	backup stored energy system
<u>CSI</u>	<u>current source inverter</u>
~~dc~~	~~direct current~~
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EMP	electromagnetic pulse

ESS	energy storage system
HMI	human machine interface
HRG	high resistance grounding
HSSB	hybrid solid-state breaker
IGBT	insulated gate bipolar transistor
IPS	integrated power system
LAN	local area network
LRU	line replaceable unit
MTBF	mean time between failures
MTTR	mean time to repair
MV	medium voltage
MVDC	medium voltage direct current
~~NEC~~	~~National Electric Code® (NEC®) (NFPA 70)~~
PE	power electronics
PEBB	power electronic building block
~~PU~~	~~power unit~~
PWM	pulse width modulation
QOS	quality of service
SCR	silicon-controlled rectifier, thyristor
SMES	superconducting magnetic energy storage
SSCB	solid-state circuit breaker
SSSS	solid-state soft starter
STS	solid-state transfer switch
~~SVC~~ ~~SVARC~~	static VAR compensator

TCR	thyristor-controlled rectifier
TPDR	traction power diode rectifier
TRD	total rated-current distortion
UPS	uninterruptible power supply
~~VAR~~	~~volt-amp reactive~~
VFD	variable frequency drive
VSC	voltage source converter
VSI	voltage source inverter

4. Power electronics (PE) equipment applications

4.1 Types of system-level functions

Four types of system-level functions may be assumed by any given PE equipment or subsystem. They are listed as follows:

a) Power conversion

- 1) Sourcing: The PE could be viewed as a source at one or more of its terminals. As such, it converts power from one or more voltage or frequency levels while being in control of the output voltage or current [or phase angle in the case of alternating current (ac)] at its electrical output terminals. The PE may include substantial energy storage capacity. Examples for this application are active inverter connected to a high-~~inertia~~ ~~speed~~ generator, direct current (dc)/dc converter feeding a zone in a dc zonal distribution system, and dynamic voltage restorer.

- 2) Loading: The PE may be viewed as a load at one or more of its terminals. As such, it is passive with respect to fundamental voltage or current control. Although normally it will be demanding power from the portion of the power system upstream of its terminals, it may also temporarily provide power. The PE may provide substantial energy storage capability. Examples for this application are a diode rectifier of a propulsion drive and a dc/dc converter fed from the dc lateral bus in a dc zonal distribution system.

b) Power conditioning

- 1) Protecting: The PE should protect equipment, conductive path, and continuity of power. As such, it does not convert power between voltage or frequency levels, nor does it include any substantial energy storage capacity. Examples for this application are transfer switch, fault current limiting circuit breaker, and crowbar switches.
- 2) Active filtering (shunt connected): The PE may actively control the power quality of the system voltage or current. It is passive with respect to fundamental [frequency](#) voltage control, but will actively control non fundamental components of the system voltage or current, and it may control reactive power in ac systems.

The purpose of distinguishing these functions is to segregate specific PE applications, converter functions, and converter topologies as discussed [in Clause 7](#) ~~later~~ from their respective system-level functions.

The reason for defining the two basic functions “sourcing” and “loading” for power conversion is to acknowledge the importance of voltage control in converter fed systems. Although a converter that assumes the function of *sourcing* performs primary voltage control, the one that is *loading* behaves passively with respect to voltage control. Many converters can assume either function solely by applying different control algorithms. These two basic functions have nothing to do with the actual flow of power. In many applications, only one converter will assume the function of *sourcing* in order to maintain system stability. However, it is conceivable that in special cases, more than one converter can assume *sourcing* simultaneously. Three examples that illustrate the different combinations of power flow and function are as follows:

- The active front end of a variable speed motor drive may regenerate power into the system to which it is connected without participating in system voltage control. Therefore, even during the regeneration phase, this front end converter still assumes the function of *loading*.
- The machine inverter of a flywheel energy storage system (ESS) connected to a dc distribution system. During the charging of the flywheel, the inverter assumes the function of *loading* with respect to the dc system. However, if the upstream converter feeding the dc system shuts down and the dc system should be powered from the flywheel ESS, its machine inverter will change its function to *sourcing* because it then controls the voltage in the dc system.
- Bi-directional rectifier connected to an ac distribution system and powering a dc system assumes the function *sourcing* on the dc side regardless of the actual power flow. Therefore, even if power flows from the dc system into the ac system, the rectifier is *sourcing* the dc system.

PE that converts power between different frequencies or voltages may also participate in system-level protection functions, whereas certain PE only assumes the function of “protecting.” It specifically does not convert power between different frequencies or voltages, and behaves passively ~~passive~~ with respect to voltage control. Therefore, this protective function is specifically called out in this recommended practice ~~guide~~. Examples include static transfer switches, solid-state fault current limiters, and solid-state crowbar switches.

A fourth system level function exists called “active filtering.” This function only affects the quality of the voltage or current waveforms, although it does not actively control the magnitude of the fundamental waveform component. Only a static VAR compensator (SVC) ~~an SVAR~~, which is also considered to assume the function of *active filtering*, affects the fundamental current waveform component in voltage-controlled systems. However, while performing the function of *active filtering*, it does not provide primary voltage control, and hence, does not assume the function of *sourcing*.

4.2 Recommended PEBB architecture for PE applications

The PEBB concept includes power processor blocks (single phases or multiple phases), gate drives and sensor blocks, analog-to-digital converter blocks for sensor signals, switching or gate drive control blocks, and blocks for communication with higher level controllers. The exact requirements for the system protection depend on its mission and configuration of the system. Each PEBB includes built-in self-protection against voltage surges, overvoltage and undervoltage, fault currents, ground currents, internal faults, overloads, and over temperature. Recommended PEBB architecture for PE applications is shown in Figure 1 from IEEE Std 1676TM-2010,^{18 42}

4.3 ~~Typical applications~~

~~Examples of typical and future applications of PE in electrical power systems described by Wheeler and Bozhko [B53], Nii and Makato [B48], Dragicevic et al. [B2], and Khersonsky [B34] are shown in Figure 2.~~

^{18 42} Information on references can be found in Clause 2.

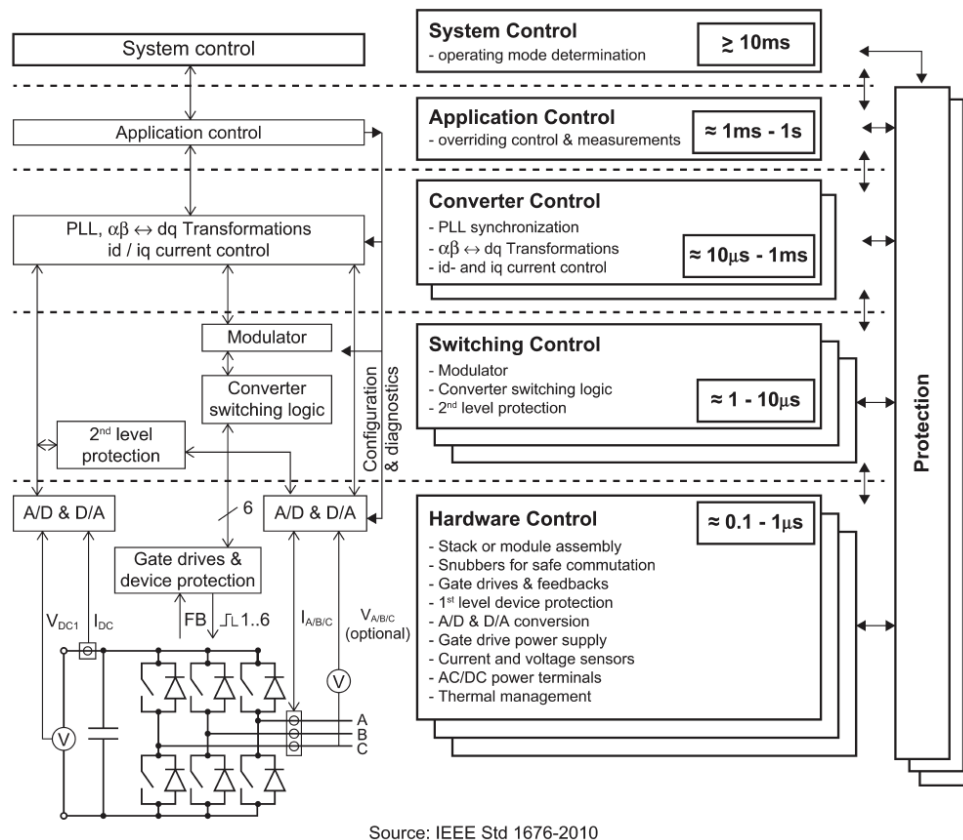


Figure 1—Recommended architecture for PE applications

Power electronics (PE) in marine power systems

4.3 Land-based (onshore) and marine (offshore) power systems differences

Equipment designers and system designers should consider that marine electric power systems are significantly different than onshore land-based electric power systems. Therefore, equipment designers and system designers should take into account the following aspects:

- Generating capacity and rotational inertia are relatively small compared with a number of single loads. Therefore, the concept of an “infinite bus” or “slack bus,” often applied for design and analysis of land-based electric power systems, is not applicable for microgrids or shipboard electric power systems.

- Shipboard electric power system prime movers for generators are smaller than their land-based counterparts. The smaller prime movers have time constants much closer to the generators' electrical time constants. Therefore, the separation of mechanical and electrical time scales for system analysis, a method yielding acceptable results for land-based systems, is often not applicable for shipboard electric power systems. In fact, mechanical and electrical dynamics are very strongly coupled.
- Connections between equipment (i.e., cable runs) are electrically very short compared ~~to~~ ~~with~~ land based systems, with the exception being fixed offshore systems like offshore wind turbines. Therefore, transmission line dynamics typically do not play a significant role.

The small size, lack of inertia, tight coupling, and “close” electrical proximity of microgrids and shipboard electric power systems require fast frequency and voltage controls. During parallel operation of generation equipment (both rotating machinery and PE based), control information may have to be provided to all the equipment very rapidly in order to enable appropriate load sharing between the units to help prevent power interruptions.

PE equipment is the enabler for the highly dynamic and rapid allocation of resources through fast control of the load flow throughout the electrical power system. Therefore, the normal line impedance-based load flow formulations may not apply. For the dynamic analyses, it may be inappropriate to assume constant voltage and frequency conditions and the concept of constant power injection. Furthermore, advanced control methods such as control agent technologies may be applied to microgrids and shipboard electric power systems.

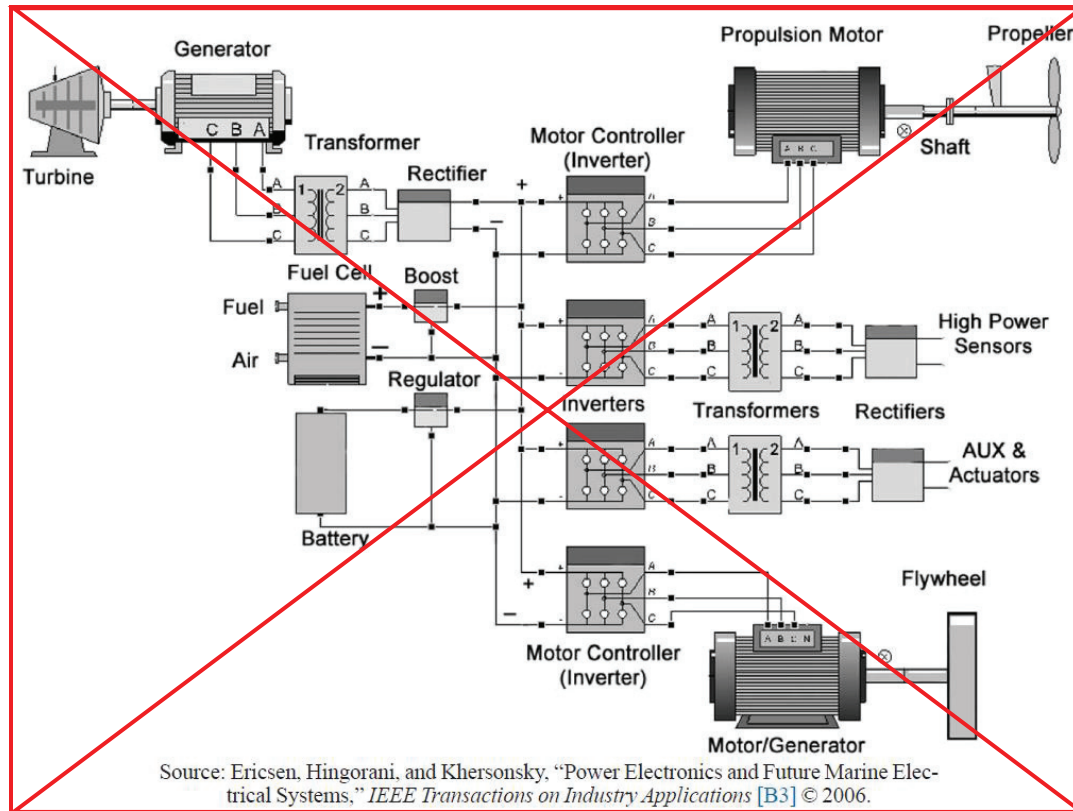
ISO/IEC/IEEE 80005-1:2012(E) [B34 B31] should be applied for ship-to-shore (Black Start) ship power system to utility connections.¹⁹

Despite fast controls, the lack of substantial inertia, and the specific characteristics of prime movers may result in large excursions of voltages and frequencies under normal and contingency operations of the system. For land-based systems, the allowable ranges of such excursions are restricted by standards and guidelines to protect the proper functioning of the wide variety of possible loads customers may connect to the power system. However, the concept of separating “utility provider” and “power customer” is, to a large extent, meaningless onboard a ship or for a microgrid.

¹⁹[The numbers in brackets correspond to those of the bibliography in Annex A.](#)

It can be expected that future [smart](#) microgrids and marine power designs may require that the PE equipment perform and function, possibly at reduced power, under more severe excursions of system voltages and frequencies than currently stated in the standards governing power quality.

~~Figure B.1 from Ericsen et al. [B3] shows marine electrical power system totally protected by PE with circuit breakers used only for no load visible disconnect. Figure B.2 from Kim et al. [B37] shows an IPS with conventional circuit breakers.~~



~~(Deleted)~~

~~**Figure B.1—Advanced marine electrical power system**~~

5. General requirements

5.1 Introduction

PE should comply with the IEEE, IEC, and UL standards applicable to the specific type of PE equipment, [and](#) standards listed ~~as normative~~ in Clause 2, [IEEE Std 2030.7™](#), [IEEE Std 2030.8™](#), and [IEEE Std 3003.2™](#), as well as with all requirements in this standard.

5.2 Power rating

The PE power rating can be impacted by environmentally specific requirements, overload conditions, and protection equipment. The nominal power rating of PE equipment is the rated load at which the equipment can continuously operate without exceeding the steady-state temperature rise as specified by the manufacturer. The nominal rating should be stated on the nameplate.

Power converters often have constant power load [behavior](#) and ~~also~~ are subject to voltage and current limits; therefore, ~~the power ratings are often functions of the source and load conditions. For example, high and low line voltage conditions often result in different power capabilities from those of the nominal conditions, and therefore, the requirements specified should consider these conditions.~~ dynamic operating conditions such as start-up inrush, ride through, switching transients, and faults can ~~also~~ impact the converter power rating characteristics.

These operating conditions require system-level analysis. In addition, efficiency and power factor are two important converter parameters. Note that the displacement factor is often used in place of power factor, although strictly speaking, the displacement factor only refers to the fundamental frequency, voltage, and current relationship.

PE should be designed for continuous operation at 110% of rated power (IEEE Std 1566TM) within the maximum ambient and cooling water or air temperature (if water or air cooled) without reduction of the equipment's performance. The number and type of PE equipment and the capacity for a specific application should be determined ~~as follows: The selection of capacity for PE equipment supplying groups of loads should be based~~ on the normal operating load under the specified operating conditions as determined by the load analysis. The reserve capacity to support the microgrid or ship service load and future growth should be provided as specified in the acquisition specification. The selection of capacity for PE equipment supplying individual loads should be based on normal connected load unless otherwise specified.

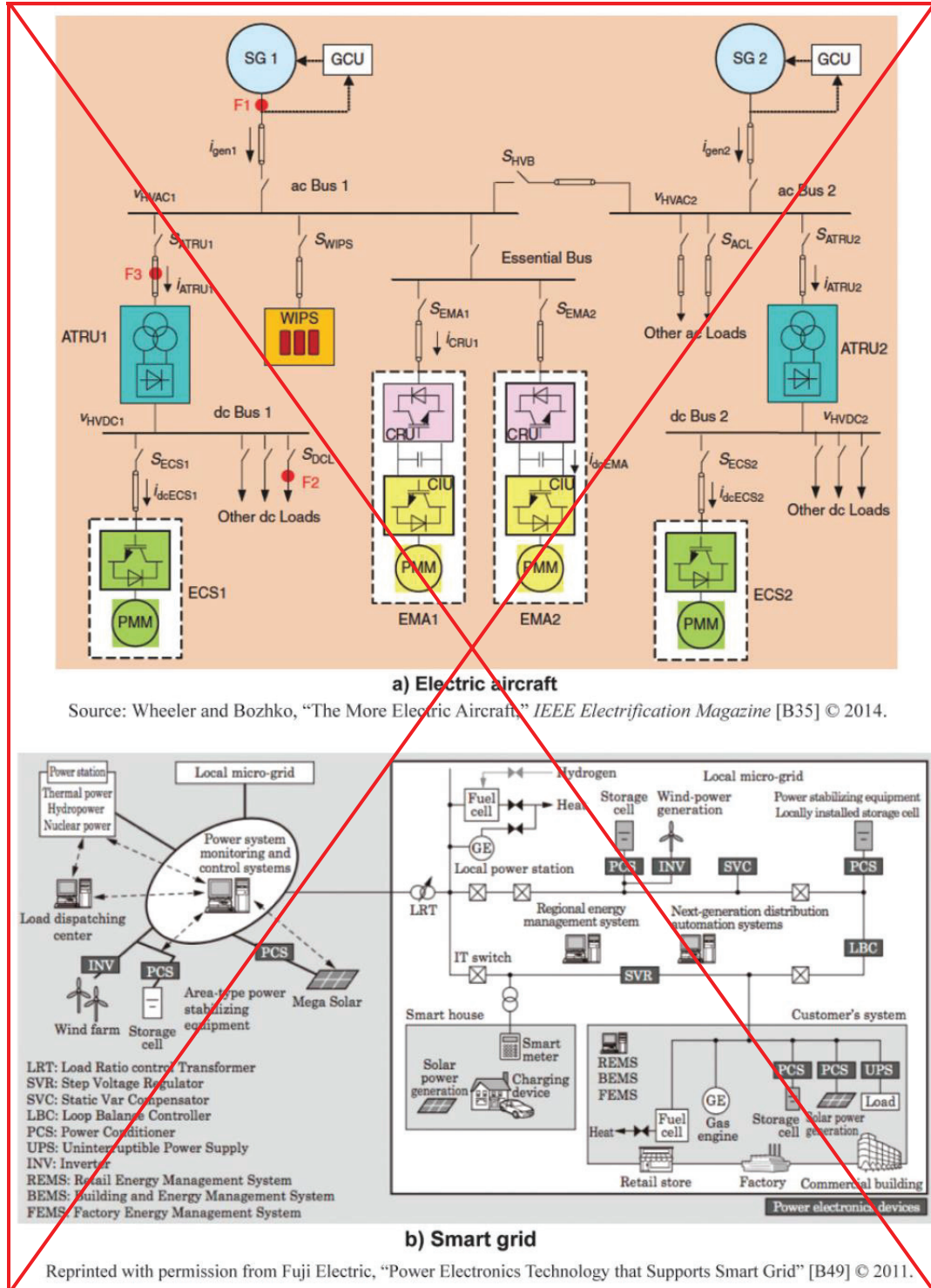


Figure 2—PE applications in power systems

5.3 Voltage requirements

5.2.1 Rated voltages

The system voltage selection should be performed by a system designer and is driven by the power level, with consideration of cable size and protection devices limitations. Nominal voltages for ac systems are defined in IEEE Std C37.20TM and the IEEE C37.100TM series of standards for switchgear assemblies. Nominal voltages for medium-voltage direct current (MVDC) in IEEE Std 1709TM [B24 B22] could be applied.

PE supplied from the electrical distribution systems should be capable of being operated satisfactorily under occurring variations in voltage, frequency, and power quality conditions, as stated herein. The electrical equipment supplied from the main or emergency systems are to be capable of being operated satisfactorily under occurring variations in voltage and frequency. Unless otherwise specified in national or international standards, the variations in Table 1, Table 2,⁴³ and Table 3 apply.²⁰

Table 1— Voltage and frequency variations for ac distribution systems

Quantity in operation	Permanent variation	Transient variation (recovery time)
Frequency	± 5%	± 10% (5 s)
Voltage	+6%, -10%	± 20% (1.5 s)

Table 2— Voltage variations for dc distribution systems

Parameters	Variations
Voltage tolerance (continuous)	± 10%
Voltage cyclic variation deviation	5%
Voltage ripple (ac root-mean-square over steady dc voltage)	10%

NOTE—IEEE Std C37.20.1TM specifies upper voltage limitation for dc systems used for control power or auxiliary functions as +12%.

²⁰ ⁴³ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

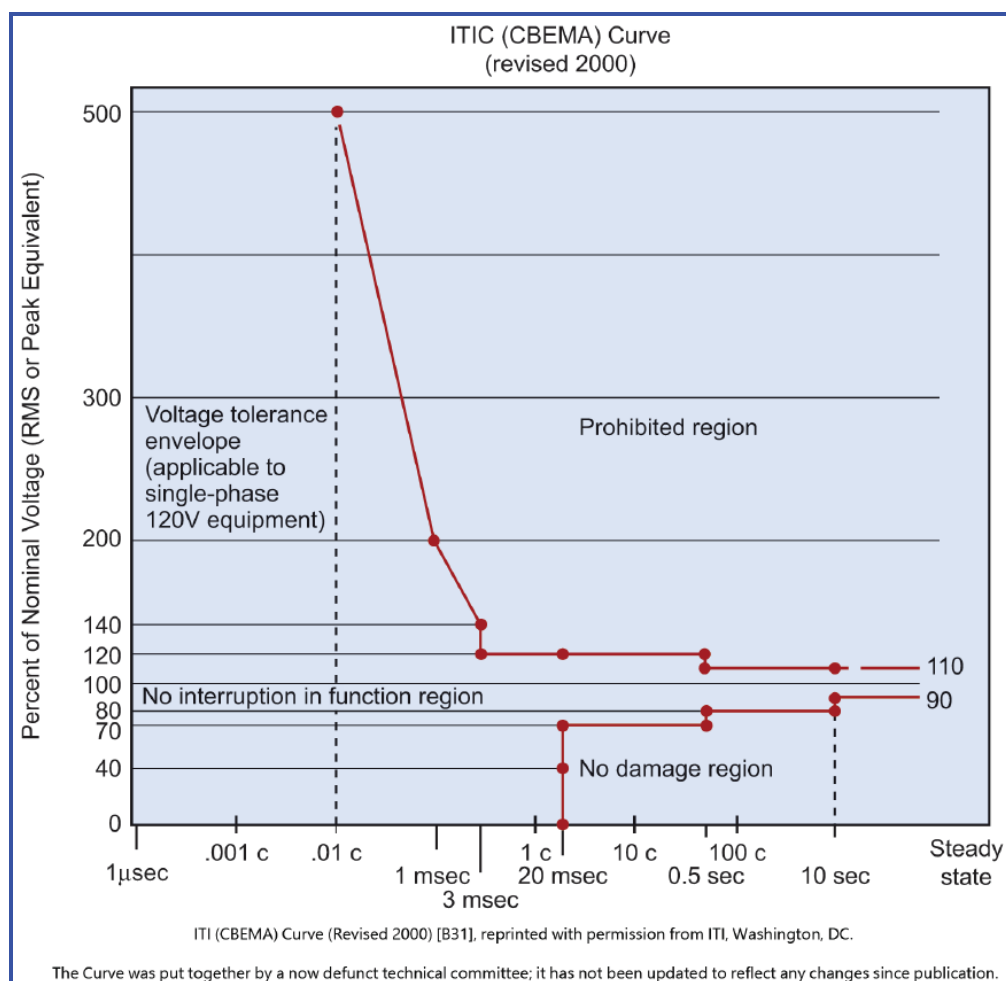
Table 3— Voltage variations for battery systems

Type of system	Variations
Components connected to the battery during charging	+30%, -25%
Components not connected to the battery during charging	+20%, -25%

Any special system, such as electronic circuits, whose function cannot operate satisfactorily within the limits shown in [tables Table 3, Table 4, and Table 5](#), should be supplied directly by a stabilized supply.

5.2.2 Voltage tolerance

If equipment users do not specify it, at any voltages, PE should tolerate without damage ITI (CBEMA) Curve voltage tolerance envelope (shown in Figure 2.3) as the design goal. ÷



(New)