IEEE SA
STANDARDS ASSOCIATION

IEEE Guide for the Functional Specification of Medium Voltage (1kV to 35kV) Electronic Shunt Devices for Dynamic Voltage Compensation

STANDARDS

IEEE Power and Energy Society

Developed by the
Substations Committee

IEEE Std 1623™-2020
(Revision of IEEE Std 1623-2004)

IEEE

IEEE Std 1623™-2020
(Revision of IEEE Std 1623-2004)

IEEE Guide for the Functional Specification of Medium Voltage (1kV to 35kV) Electronic Shunt Devices for Dynamic Voltage Compensation

Developed by the

Substations Committee
of the
IEEE Power and Energy Society

Approved 24 September 2020

IEEE SA Standards Board

Abstract: General guidelines on the preparation of a functional specification for a solid-state electronic shunt device used to compensate voltage fluctuation are provided in this guide. Devices rated medium voltage (1 kV to 35 kV) are covered in this guide. In general, these devices contain: an inverter, a rectifier or dc converter, an energy storage device, and a coupling transformer. The device is typically connected in parallel with the network using a coupling transformer.

Keywords: coupling transformer, energy storage, IEEE 1623™, inverter, parallel compensation, power electronics, power quality, sensitive loads, voltage control

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

PDF: ISBN 978-1-5044-7068-1 STD24414
Print: ISBN 978-1-5044-7069-8 STDPD24414

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (https://standards.ieee.org/ipr/disclaimers.html), appear in all standards and may be found under the heading "Important Notices and Disclaimers Concerning IEEE Standards Documents."

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE SA) Standards Board. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers are not necessarily members of IEEE or IEEE SA, and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE does not warrant or represent the accuracy or completeness of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to results and workmanlike effort. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. IEEE Standards documents are supplied "AS IS" and "WITH ALL FAULTS."

Use of an IEEE standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity, nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: THE NEED TO PROCURE SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE is the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that the presenter's views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, consulting information, or advice pertaining to IEEE Standards documents**.

Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its Societies and Standards Coordinating Committees are not able to provide an instant response to comments, or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in evaluating comments or in revisions to an IEEE standard is welcome to join the relevant IEEE working group. You can indicate interest in a working group using the Interests tab in the Manage Profile and Interests area of the IEEE SA myProject system. An IEEE Account is needed to access the application.

Comments on standards should be submitted using the Contact Us form.

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not constitute compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate licensing fees, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400; https://www.copyright.com/. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit IEEE Xplore or contact IEEE. For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE SA Website. Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in IEEE Xplore. Users are encouraged to periodically check for errata.

Patents

IEEE Standards are developed in compliance with the IEEE SA Patent Policy.

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at https://standards.ieee.org/about/sasb/patcom/patents.html. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

IMPORTANT NOTICE

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. IEEE Standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

Participants

At the time this draft guide was completed, the Power Electronics Equipment Working Group had the following membership:

Jeff McElray, *Chair*

Ram Adapa
Jim Campbell
Habeeb Ghossein
Syed Hussain
Jan Paramalingam
Robert Ramsey
Jorge Salinas
Cat Wong
Vahraz Zamani

The following members of the individual Standards Association balloting group voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

Saleman Alibhay
Christopher Belcher
Gustavo Brunello
Paul Cardinal
David Ezer
Jalal Gohari
Edwin Goodwin
Werner Hoelzl
Brian Johnson
Laszlo Kadar
John Kay
Tanuj Khandelwal
Yuri Khersonsky
James Kinney
Boris Kogan
Jim Kulchisky
Chung-Yiu Lam
Guo-ming Ma
Arturo Maldonado
James McConnach
Jeffrey McElray
Carl E. Miller
Dennis Neitzel
Arthur Neubauer
Joe Nims
Matthew Norwalk
Lorraine Padden
Jan Paramalingam
Bansi Patel
Howard Penrose
Branimir Petosic
Christopher Petrola
Charles Rogers
Surya Santoso
Bartien Sayogo
Kenneth Sedziol
Robert Seitz
P. Sivaraman
Gary Smullin
Wayne Stec
Andrew Steffen
David Tepen
Michael Thompson
Matthew Vacha
John Vergis
Kenneth White
Terry Woodyard
Nicholas Zagrodnik

When the IEEE SA Standards Board approved this guide on 24 September 2020, it had the following membership:

Gary Hoffman, *Chair*
Jon Walter Rosdahl, *Vice Chair*
John Kulick, *Past Chair*
Konstantinos Karachalios, *Secretary*

Ted Burse
Doug Edwards
J.Travis Griffith
Grace Gu
Guido R. Hiertz
Joseph L. Koepfinger*
David J. Law
Howard Li
Dong Liu
Kevin Lu
Paul Nikolich
Damir Novosel
Dorothy Stanley
Mehmet Ulema
Lei Wang
Sha Wei
Philip B. Winston
Daidi Zhong
Jingyi Zhou

*Member Emeritus

Introduction

> This introduction is not part of IEEE Std 1623, IEEE Guide for the Functional Specification of Medium Voltage (1 kV to 35 kV) Electronic Shunt Devices for Dynamic Voltage Compensation.

Electric utilities are installing electronic devices to reduce voltage fluctuations. Industrial customers with sensitive loads are installing different electronic devices to mitigate voltage fluctuations. A significant number of these devices are installed every year. Most of these devices are bought using specifications provided by various manufacturers. Technical literature describes the operation of specific devices and provides results of computer simulations to prove the effectiveness of the devices. However, no document defines the technical data that may be collected and used for the specification of a new device.

This guide is not a tutorial. The application of its content to prepare a specification requires technical knowledge and understanding. Each user may modify the material to meet with user specific conditions. This guide does not include all topics necessary for every application and does not address the commercial aspect of the specifications.

This guide was prepared by Working Group I1, Power Electronic Equipment, of the FACTS and HVDC Stations Subcommittee for the IEEE PES Substations Committee.

Contents

1. Overview 10
   1.1 Scope 10
   1.2 Purpose 10
   1.3 Word usage 10

2. Normative references 11

3. Definitions, acronyms, and abbreviations 11
   3.1 Definitions 11
   3.2 Acronyms and abbreviations 12

4. System and project description 12
   4.1 System description 12
   4.2 Project description 13

5. Scope of supply, schedule, environmental, and power system data 15
   5.1 Scope of supply and warranty 15
   5.2 Equipment, material, and services furnished by the user or its agent 16
   5.3 Schedule 16
   5.4 User furnished site and environmental data 16
   5.5 Power system characteristics 17

6. Shunt compensation device characteristics 17
   6.1 Rating 17
   6.2 Losses 18
   6.3 Harmonic performance 18
   6.4 Audible noise 18
   6.5 Electromagnetic interference (telephone and radio) 18
   6.6 Cooling system 19
   6.6.1 Air cooling (if applicable) 19
   6.6.2 Liquid cooling (if applicable) 19
   6.6.3 Cooling system protection 20
   6.7 Enclosures 21
   6.8 Reliability, availability, and maintenance 21
   6.9 Control and diagnostics 22
   6.10 Protection 23
   6.11 Insulation and grounding 23
   6.12 Safety and signs 23
   6.13 Lead time 24
   6.14 Installation and spare parts 24
   6.15 Equipment testing and system commissioning 24
   6.16 Quality assurance 24
   6.17 Contractual generalities 25

Annex A (informative) Bibliography 26

IEEE Guide for the Functional Specification of Medium Voltage (1kV to 35kV) Electronic Shunt Devices for Dynamic Voltage Compensation

1. Overview

1.1 Scope

This document provides general guidelines on the preparation of a functional specification for a solid-state electronic shunt device used mainly to compensate for voltage fluctuation. The guide covers devices rated to medium voltage (1 kV to 35 kV). In general, these devices contain: a bidirectional converter, an energy storage device, and a coupling transformer connected in parallel. The guide also covers the following equipment to assure proper interface with the electric network including, but not limited to, voltage and current transformers, disconnect switches, circuit breakers, and three-phase low voltage service for auxiliary power.

Normally these devices are not designed for flicker compensation. If flicker compensation is needed, the specification may be modified and the manufacturer can design the device for flicker compensation.

1.2 Purpose

The purpose of the guide is to provide information to utilities and other users to prepare a specification when they intend to purchase a shunt device.

The guide includes technical clauses describing the user's requirements, including operation methods and environmental conditions. It specifies basic requirements of solid-state electronic shunt devices used for compensation of voltage fluctuations by injection of reactive power.

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*).[1,2]

[1]The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.
[2]The 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*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they may 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.

IEEE Std 139™, IEEE Recommended Practice for the Measurement of Radio Frequency Emission from Industrial, Scientific, and Medical (ISM) Equipment Installed on User's Premises.[3,4]

IEEE Std 141™, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*).

IEEE Std 519™, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.

IEEE Std C57.12.90™, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

ITI (CBEMA) Curve Application Note, 2000.[5]

NEMA 250, Enclosures for Electrical Equipment (1000 Volts Maximum).[6]

NFPA 70®, National Electrical Code® (NEC®).[7]

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary* may be consulted for terms not defined in this clause.[8]

four-quadrant control: An inverter control algorithm, which allows real and reactive power (watts and vars) to be independently delivered to or extracted from a load. A shunt device using this control generates or absorbs both real and reactive power.

[3]The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.
[4]IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (https://standards.ieee.org/).
[5]ITIC documents can be obtained from the Information Technology Industrial Council, http://www.itic.org.
[6]NEMA publications are available from Global Engineering Documents, http:// global.ihs.com/.
[7]NFPA publications are available from Publications Sales, National Fire Protection Association (http://www.nfpa.org/).
[8]*IEEE Standards Dictionary* 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.

two-quadrant control: An inverter control algorithm, which makes the inverter capable of accepting or delivering power between the dc bus and the line. A shunt device using this control absorbs or generates reactive power.

voltage flicker: A slow, low-frequency modulation of the sinusoidal voltage of the load or supply.

voltage sag: A short-duration decrease of the rms voltage value, at the power frequency. Typical values are between 0.1 per unit and 0.9 per unit, at the power frequency, for 0.5 cycles to 120 cycles in duration. (IEEE Std 1250™ [B8]).

NOTE—The International Electrotechnical Commission (IEC) terminology is "voltage dip." [9]

voltage swell: A short duration increase of the rms voltage value, at the power frequency, typical values are 1.1 per unit to 1.8 per unit, between 0.5 cycles to 120 cycles in duration. (IEEE Std 1250™ [B8]).

3.2 Acronyms and abbreviations

BIL	basic insulation level
RTU	remote terminal unit
SCADA	supervisory control and data acquisition
SIL	switching impulse insulation level
SMES	superconducting magnetic energy storage
THD	total harmonic distortion
TIF	Telephone Influence Factor

4. System and project description

4.1 System description

The solid-state electronic shunt device is a power electronic primary power delivery (distribution) system element that is connected in parallel with a primary power delivery circuit typically via a coupling transformer. The device supplies reactive power to, as well as absorbs reactive power from, the power delivery system, either to regulate voltage to a set point value or inject reactive power as specified by the user. The most frequent function of the device is to dynamically regulate the load voltage of a sensitive load by rapid reactive power exchange.

Optionally, the device may be equipped with a four-quadrant control and energy storage subsystem to allow voltage control by both real and reactive power exchange with the system.

Figure 1 shows an example for the circuit diagram of a solid-state electronic shunt device used for compensating voltage fluctuations by reactive power injection or absorption. In case of a voltage disturbance on the utility feeder, the device injects an appropriate amount of reactive power to maintain the feeder voltage.

In Figure 1, a converter (dc to ac converter) generates ac voltage and injects or absorbs reactive or active power through a coupling transformer secondary connected in parallel with the feeder. A dc link provides the input voltage and stored energy to the inverter. The inverter uses the energy stored in a capacitor or other kinds of energy storage devices [such as batteries, a superconducting magnetic energy storage (SMES) device, or a flywheel through a suitable converter] or from an ac source (supply feeder) through a rectifier.

[9]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement this standard.

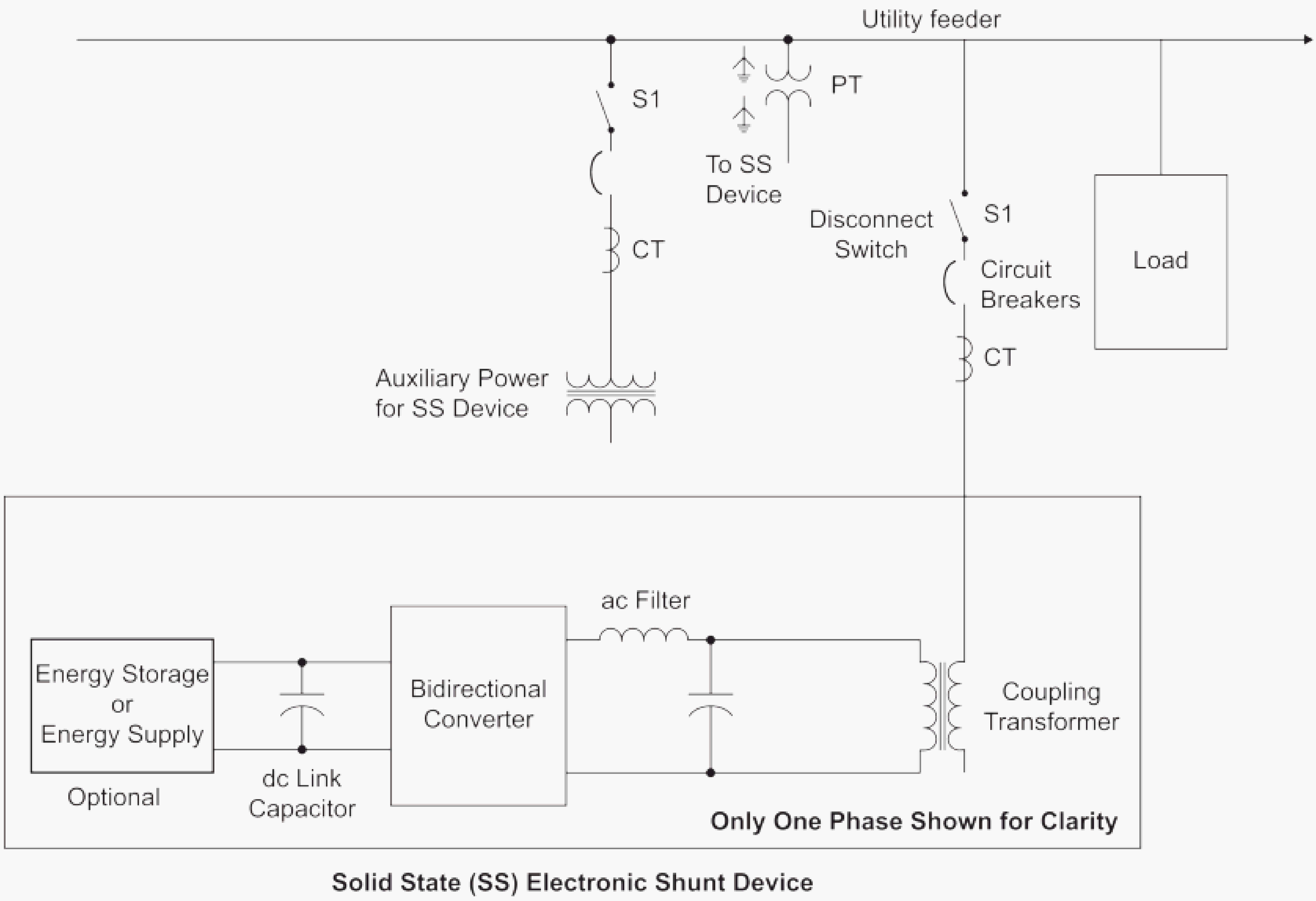

Figure 1—One-line diagram of a three-phase solid-state shunt electronic voltage compensation device

The device may or may not require dedicated energy storage, depending on the anticipated magnitude of sag or swell. The device controls can help minimize the need for energy storage during unbalanced fluctuation by charging the dc bus from the high (unaffected or swelled) voltage phase(s). Sufficient stored energy must be provided to allow the device to compensate fluctuation of maximum expected duration.

In order to interface the device with the power delivery network, additional equipment should be provided, including current and potential transformers, surge arresters, isolation breakers, disconnect switches, and three-phase low-voltage service for auxiliary power. Surge arresters may not be required for all installations.

Figure 1 is a representative example for the dynamic compensation device. However, other system configurations are available. Clause 4 may not be included in the specification issued by the purchaser.

4.2 Project description

This specification defines the project performance and scope to furnish, install, test, commission, operate, warrant, train user personnel, and place into commercial operation an electronic device for compensation of voltage fluctuations at <(general location)>

The purpose of the device is to correct the voltage of <(feeder name)>, connected to <(location)> point.

The device should dynamically maintain voltage at acceptable levels to the above feeder during momentarily voltage fluctuations (both balanced and unbalanced) that occur on the feeder, assuming that the voltage deviation is within the device ratings. As an additional feature, the device may be used for steady-state voltage regulation of a load and phase balancing of line voltages.

The nominal injection current is _______ A at nominal voltage and frequency.

The nominal feeder current is _________ A at nominal voltage and frequency.

The maximum injection current is ______ A at nominal voltage and frequency.

The system short circuit level is _____ MVA at nominal voltage and frequency.

The system impedance times the injection current determines the voltage that compensates the dip or swell. The nominal kilovolt ampere rating of the device converter and associated power electronics is specified as the maximum voltage times the injected current.

The power delivery system voltage is ____ kV, and the acceptable load voltage variation is ± ____% of nominal voltage.

For systems with energy storage device and capability to inject real power the nominal energy rating of the device should be at least _________ Joules.

NOTE 1—The nominal energy rating or usable stored energy is defined as nominal feeder voltage times the maximum desired injection current during balanced sag times the maximum duration of the sag.

The maximum sag/swell to be compensated is for:

Three-phase disturbance ________ V
Single-phase disturbance ________ V
Line-to-line disturbance ________ V

The maximum duration of the sag/swell is for:

Three-phase disturbance ________ s
Single-phase disturbance ________ s
Line-to-line disturbance ________ s

NOTE 2—Typically, the voltage sag or swell is caused when the following occurs:

a) A single-line-to-ground fault on the system causes a temporary voltage rise on the un-faulted phases and a voltage sag on the faulted phase
b) A line-to-line fault occurs
c) A large load is switched off
d) A large shunt capacitor bank is switched on or off
e) A transmission line feeding the bus is switched off

However, the duration of the last two events tends to be longer.

The maximum acceptable sag magnitude and duration is _________V for ________s.

NOTE 3—Several existing power quality standards, like the IEEE Std 493™ (*IEEE Gold Book*) [B3][10], ITI (CBEMA) Curve 2000, or SEMI F47 criteria [B16], address maximum acceptable sag magnitude versus sag duration ratio, but the user is cautioned that such standards may not fit the specific application. Therefore, the user is urged to evaluate the specific requirement before specifying the device.

[10] The numbers in brackets correspond to those of the bibliography in Annex A.

NOTE 4—Many drive systems restrict voltage change to 10%. This may be relative to the pre-disturbance voltage and not 10% of nominal.

The regional and local site location is shown in Figure ________. The proposed one-line diagram of the facility after installation of the device is shown on drawing ________. The area of the device facility is shown on drawing ________.

The manufacturer should agree to provide device dimensions, weight, center of gravity, and auxiliary power requirements ________ days after the signature of the contract.

The point of electric interconnections of the supplier-furnished electronic device and the user-furnished facilities are shown in the following drawings:

Drawing No:	Description
__________	Single-line diagram
__________	Auxiliary power single-line diagram
__________	Grounding plan and details
__________	Control and protection
__________	Location layout, general arrangement, elevation drawings, road access
__________	Site sub-surface and geo-technical data
__________	Foundation and civil drawings including grading and drainage
__________	Others (conduits, cable summary etc.)
__________	Communications interface (telecom, SCADA, Ethernet, etc.)
__________	External control interface

5. Scope of supply, schedule, environmental, and power system data

5.1 Scope of supply and warranty

The equipment, materials, and services to be furnished by the supplier include, but are not limited to the following:

a) DC to ac converter
b) Coupling transformer or reactor as appropriate
c) AC filter as appropriate
d) Isolation circuit breaker(s) and disconnect switch
e) MOV surge arresters if necessary
f) Current and voltage transformers (optional)
g) Energy storage device, including charging unit or transformer and rectifier to supply the dc link (optional)
h) Control, protection, alarm, and monitoring system for the device
i) On-line monitoring and annunciation system via common IT systems (modem, Internet)
j) Special maintenance equipment and tools
k) Training program for operation and maintenance personnel
l) Spare parts

m) Testing and commissioning service

n) Documentation including as built drawings and diagrams, instruction manuals, software description and licenses, etc.

5.2 Equipment, material, and services furnished by the user or its agent

The following equipment, materials, and services to be furnished by others include, but are not limited to, the following:

a) Site suitable for the device available ________ days after contract start.

b) Existing facilities and equipment.

c) Station service during construction (auxiliary power) for the device at ________ V, ________ A available ________ days after contract start (if needed).

d) Station service (permanent auxiliary power) for the device at ________ V, ________ A available ________ days after contract start.

e) The foundations and buildings for the device will be available ________ days after the contract start.

f) Interconnections and all ancillary service will be available ________ days after the contract start.

5.3 Schedule

Project completion is ________ calendar days after contract start.

The supplier project schedule is due ________ days after contract start and should include, but not be limited to, the dates for commencement and completion of the work of several controlling features of the project, dates for user furnished services, dates on which supplier-furnished drawings will be provided and the required approval dates, and the dates and length of time of any required power outages.

Review meetings should be held between the user and supplier to review and discuss progress of the supply of the device. The first review should be held within ________ days after contract start.

5.4 User furnished site and environmental data

The device should be designed to meet all ratings and performance requirements specified herein while operating in the following site and environmental conditions. Usual design values are given in parenthesis.

Site elevation above sea level	________
Maximum ambient air temperature (50 °C rated load)	________
Minimum ambient air temperature (−40 °C may use supplementary heating)	________
Maximum relative humidity	________
Solar radiation (Peak, Daily maximum watt-hours/m^2, Annual watt-hours/m^2)	________
Seismic zone and withstand data	________
Isokeraunic level	________
Contamination (dust, chemicals, etc.)	________
Wind velocity (maximum sustained and maximum gusts, if applicable)	________
Ice loading (maximum, if applicable)	________
Availability of cooling media (water flow rate, pressure, cleanliness level, maximum ambient water temperature, etc.)	________

5.5 Power system characteristics

The ac power system characteristics at the point of connection prior to device installation are listed below. Typical design values are given in parenthesis.

a) Nominal ac system frequency (50 Hz or 60 Hz) ________

b) Frequency variation (0.5 Hz from nominal, 1 Hz from nominal for 1 min maximum, 1.5 Hz from nominal for 30 s maximum, 2.5 Hz for 10 s maximum, 4.0 Hz for 0.35 s maximum) ________

c) Maximum rate of change of frequency (10 Hz/s) ________

d) Maximum continuous ac system voltage, line-to-line (V or %) ________

e) Minimum continuous ac system voltage, line-to-line (V or %) ________

f) Maximum load current ________

g) Maximum short-term ac system voltage, line-to-line (110% of the ITIC high voltage) ________

h) Voltage Total Harmonic Distortion (THD) ________

i) Voltage Single Harmonic Distortion ________

j) Current THD ________

k) Current Single Harmonic Distortion ________

l) Minimum short-term ac system voltage, line-to-line (70%, 0.5 s) ________

m) Continuous negative sequence voltage component (4%) ________

n) Continuous zero sequence voltage component ________

o) Basic Impulse Insulation Level (BIL), if applicable ________

p) Switching Impulse Insulation level (SIL) ________

q) Three-phase fault current ________

r) Maximum single-phase fault current ________

s) Harmonic impedance sectors ________

t) Background harmonic voltage or current spectrum ________

6. Shunt compensation device characteristics

6.1 Rating

The device may inject single-phase current or three-phase balanced or unbalanced current, as required, into the feeder.

The functional application of the device is to dynamically maintain line-to-line or line-to-neutral voltage as measured prior to an event (fault) and in accordance with IEEE Std 141™[11], IEEE Std 519™ or ITI (CBEMA) Curve 2000, to three-phase or single-phase loads during large voltage fluctuations (i.e., balanced or unbalanced sags or swells) that occur on the feeder. The voltage must be self-adjustable to the pre-event voltage between the specified upper and lower voltage limits.

NOTE—For the short duration of a voltage sag, harmonics may be of a lesser issue than speed of response.

The response of the device should be such that the device may inject full current from a state of zero injected current within time periods that maintain load voltage. The load voltage should be maintained within the ITIC Curve 2000, IEEE Std 141 limits, or otherwise specified voltage profile.

The device should be capable of attaining 90% of nominal rated output prior to the event (sag or swell) with detection in ________ half cycles or less. A typical response time is ________ half cycles.

[11]Information on references can be found in Clause 2.

Energy storage elements, if used, should be in sizes compatible with customer voltage restoration requirements. Energy storage elements should have a ________ kVA short term rating and ________ Wh capacity. The system should be designed to recharge the energy storage either through the main converter or through a dedicated charging unit.

The device can be built with smaller modules connected in parallel or series. The manufacturer should specify the module size, the number of modules, the module configuration and the number of modules that can fail without having to shut down the system.

If the system contains several modules connected in parallel, equal current sharing among the modules should be achieved by suitable circuits, which are incorporated in the converter modules. The current sharing should be better than 95% among the in-service modules.

If the system contains several modules connected in series, equal voltage sharing among the modules should be achieved by suitable circuits, which are incorporated in the converter modules. The voltage sharing should be better than 95% among the in-service modules.

6.2 Losses

The supplier should specify the total system losses in idle mode, including transformer losses, in kW and in percentage of the device rating. In addition, the losses should include all auxiliary loads including cooling fans and pumps, battery chargers, UPS systems, controls, and other auxiliary loads and losses.

Losses evaluation should be performed using ________ $/kW and ________ $/kWh values.

The supplier should present alternative methods to reduce losses.

6.3 Harmonic performance

Total voltage and current harmonic distortion should be calculated under worst-case system conditions in accordance with the procedure outlined in IEEE Std 519. These calculations should be done based on the kilovolt ampere capacity and harmonic impedance of the supplying source.

The harmonic distortion should be verified through tests. The test results should be made available to the customer. The manufacturer should propose a standardized or industry-accepted test method to verify harmonic performance.

The device should be configured to avoid resonance with common power system components, including shunt capacitors.

6.4 Audible noise

Noise generated by the device in idle and full load operation should not exceed ________ dBA and ________ dBA respectively. The noise is measured at 3 m from the nearest surface of the device enclosure. The suppliers should establish existing audible noise level prior to installation of the device. A report should record the audible noise levels prior to and after the installation of the device. The selection of the noise level should comply with IEEE Std C57.12.90™.

6.5 Electromagnetic interference (telephone and radio)

Radiated and conducted EMI generated within the device should be suppressed to help prevent excessive interference with nearby electronic equipment. The I·T product should be less than ________, where I·T is defined as the square root of the sum of the squares of the weighted harmonic current; the corresponding weights are the Telephone Influence Factor (TIF) weighting factors established in 1960 (IEEE Std 519).

The V·T product should be less than ________, where V·T is defined as the square root of the sum of the squares of the weighted harmonic voltage; the corresponding weights are the TIF weighting factors established in 1960 (IEEE Std 519).

The device should not be susceptible to misoperation due to EMI generated by a hand-held general mobile radio service transmitter from a distance of 6.1 cm (2.4 in) in front of the device with the doors closed. Specific frequencies for testing may be supplied by the user.

Higher frequency electromagnetic emissions can be limited to avoid interference with any properly licensed radio, TV, microwave or other equipment in service. The radio frequency emission produced by the device may be less than ________ mV over a range of 0.15 MHz to 1 MHz, when measured 500 m from the building. The measurement should be made in accordance with IEEE Std 139™, using a quasi-peak detector reading.

6.6 Cooling system

The cooling system should be able to maintain full capacity at maximum ambient temperature and maximum device losses.

The cooling system should be able to operate at the lowest ambient temperature and minimum device losses, and the supplier should describe how this is done.

Replacement of selected critical cooling equipment if defective should be possible while the cooling system still operates. However, the user may determine whether this redundancy is required.

The supplier should describe the necessary maintenance actions and their frequency.

6.6.1 Air cooling (if applicable)

Cooling for semiconductors should be by natural convection or forced air.

An air-cooling system should provide full heat rejection with redundancy in blowers, filtering, monitoring, and heat exchangers (if required).

The supplier should describe the air filtering system and details of monitoring of the status of blowers, filters, and other components.

If filters are used, all air inlets should have exchangeable filters. Filters should be provided with pressure differential alarms.

6.6.2 Liquid cooling (if applicable)

A closed loop re-circulating system should provide full heat rejection capacity with redundancy for pumps, heat exchangers, and fans, appropriate to the device availability requirements.

The cooling system should be able to maintain full capacity at maximum ambient temperature and maximum device power output.

The cooling system should be able to operate at the lowest ambient temperature and zero output and the supplier should describe how this is done.

If high resistivity is required, purifying loop to maintain liquid resistivity should be provided. The supplier should state the design value of liquid resistivity and describe methods of detecting and responding to abnormal conditions.

If high resistivity is required, the quantity of de-ionizing material should be sufficient to operate correctly for a period 1.5 times longer than the specified maintenance interval operation without replacement. De-ionizing materials should be replaceable without cooling system shut down. Instructions for frequency of inspection and change can be given.

The supplier should describe the necessary maintenance actions and their frequency.

Maintenance of closed loop systems and make up for loss of liquid should be required more than once a year.

6.6.3 Cooling system protection

The cooling system should monitor its own operation and the condition of the cooling medium. In a redundant cooling system, the component failure should activate alarms first. If the cooling system has no remaining redundancy, the component failure should shut down the system. The warning and shutdown alarms should be modified according the cooling system configuration.

a) For air-cooled systems, the protection system should include as a minimum the following warning alarm:
   1) Blower transfer, if applicable
   2) High exhaust air temperature or high heat sink temperature
   3) High differential pressure across the filter, if applicable
   4) Low air flow, if applicable
b) For air-cooled systems, the protection system should include as a minimum the following shutdown alarm:
   1) Excessive exhaust air temperature or high heat sink temperature
   2) Loss of air flow
c) For liquid-cooled systems, the protection system should include as a minimum the following warning alarm:
   1) Depleted de-mineralized (de-ionizing) cell, if high resistivity is required
   2) Low water resistivity, if high resistivity is required
   3) Low coolant level
   4) Primary pump stopped
   5) Primary fan stopped
   6) High coolant temperature
   7) Failure of pump cycling scheme
   8) Leak detected
d) For liquid-cooled systems, the protection system should include as a minimum the following shutdown alarm:
   1) Extra high temperature
   2) Extra low coolant level
   3) Both pumps stopped or blocked flow

6.7 Enclosures

The device system shall be housed in enclosures appropriate to the application.

For outdoor pad-mounted installations, all device system components should be enclosed in an electrically grounded weatherproof enclosure with provisions for securely anchoring the enclosure to the foundation.

For outdoor overhead installation, all device system components shall be housed in electrically grounded rain-tight enclosures (NEMA 3R) designed for ease of installation and maintenance access from standard utility overhead line service equipment.

For indoor installation, all device system components shall be housed in electrically grounded metal enclosures designed to help ensure that the opening of a door exposes no live parts. A dust proof enclosure (NEMA 12) is recommended for indoor installation.

Energy storage in excess of 139 Wh usable capacitive energy storage, or rectifier connected to ac supply, if appropriate, should be in a suitable separate enclosure with mechanical and electrical interlocks provided to maintain a proper and safe operating sequence.

If transportable device modules are mounted on a trailer, the trailer dimension should not exceed in most cases 2.6 m (8.5 ft) in width, 14.6 m (48 ft) in length, and 4.5 m (14.8 ft) in height. Otherwise, special oversize load permits may be required for transporting the unit.

The supplier should furnish shipping weights and dimensions of each individual separately shipped module.

The supplier should furnish detailed foundation requirements (drawings) showing all tie down points, pier foundation location and load bearing requirements, and ground pads.

6.8 Reliability, availability, and maintenance

Design availability of an individual module should exceed 98% for forced outages and should exceed 99.5% for scheduled outages, after the commissioning period.

Design availability factor for forced outages of devices consisting of multiple modules (including provisions for de-rating) should exceed 95% after the commissioning period.

Scheduled maintenance that requires that the unit be taken out of service should not exceed 8 h per year, on average, for a 20-year minimum design lifetime.

Replacement of any power electronics assembly should be capable of being accomplished in 2 h or less, with parts available on site.

The device should be able to withstand the loss of one cooling fan or pump with no degradation in nominal output capability.

The device should be capable of operation in high isokeraunic areas (80 or more thunderstorm days per year). The device should be capable of restoring voltage for multiple (not less than five) sequential maximum duration, maximum depth sags at 5 s intervals if required by the user.

The supplier should provide a recommended list of spare parts consistent with desired reliability performance.

6.9 Control and diagnostics

The device control should achieve the functional objectives outlined in Clause 4. The accuracy of the voltage should be within 2% of the reference voltage. The response of the control to a disturbance should be faster than 2 ms.

Control interface should provide access to the adjustment of control parameters both locally and remotely, via a modem or by an Internet/LAN connection. The control interface should allow the setting of the following parameters both locally and remotely:

- Start and stop of operation
- Change of reference voltage
- Alarm acceptance and, if appropriate, reset

The automatic functions include pre-start verification of the control and protective functions, synchronization of the control to the bus voltage, and closing of the isolation switches. None of these operations should produce a transient in the load voltage, which exceeds 3% for two cycles or more.

The device should be able to be shut down from a remote command or from an internal diagnostic or protective command. The automatic functions include shutdown of the converter, discharge of the dc bus and energy storage, and release of protective interlocking for the equipment. None of these operations should produce a transient in the load voltage, which exceeds 3% for two cycles or more.

The device should be able to accommodate momentary outages of source power. When the condition has passed, the device should automatically restart and resume normal operation. This operation cannot have critical time constraints, and outages lasting several minutes will be acceptable.

Sufficient diagnostics should be made available so that the source of a failure of a major electronic component or sub-assembly can be accurately and quickly identified by maintenance personnel. The diagnostic data available from a modem or other communication device may include, but not be limited to, the following:

a) Three-line voltages (magnitude and phase)
b) Three-line currents (magnitude and phase)
c) Three converter voltage magnitudes and phase, if applicable
d) Three converter current magnitudes and phase, if applicable
e) Ambient temperature
f) DC bus voltage
g) Converter valve status for all valves
h) Semiconductor element status
i) Cooling system status
j) Breaker status
k) UPS/battery status, if required
l) Energy storage status (level stored, if applicable)
m) On-board Power Quality Monitor for voltages and currents

As an option, a remote terminal unit (RTU) for connection to a Supervisory Control and Data Acquisition (SCADA) System should be made available at additional cost to the customer.

6.10 Protection

The control of the device should monitor its operation and the operation of various components. Two levels of protection should provide warning and shutdown where appropriate. A warning indicates a developing problem that exists but the equipment or its proper operation is not in immediate danger. A shutdown indicates a fault that prevents operation or that may cause damage if left uncorrected.

The device protection should be properly coordinated to help prevent incorrect operation. Fail-safe principles should be applied. The protection system should be equipped with voltage and current transformers, which are either part of the device package or supplied by the user. Redundant protective functions should be demonstrated and recorded.

The device should withstand an external phase-phase or phase-ground fault cleared by backup protection without the failure of a major sub-assembly.

The device should withstand internal fault on the ac side of the converter bridges cleared by backup protection from the distribution system without failure of the converter components and without damage to the dc bus or energy storage system.

The protection should remove the device from the service with appropriate diagnostic message in case of:

a) High impedance faults
b) Short circuit as specified previously

The device should detect over-voltage and over-current conditions within the converter circuits, the dc bus circuit, and the energy storage circuits. It should initiate a shutdown rapidly enough to help prevent consequential failure of components. It shall provide diagnostic information that shows the reason for each shutdown.

6.11 Insulation and grounding

The device system should be equipped with switches (circuit breakers or disconnect switches as appropriate) to permit isolation from the primary system voltage. The transformer basic insulation level (BIL) may be in accordance with appropriate ANSI/IEEE standards. The insulation level of the converter side of the transformer should be coordinated with that of the converter. Surge protective equipment should be used as required.

The switches and links should be adequately sized to carry the maximum steady state and transient fault currents.

Grounding switches or equipment and grounding points should be provided for maintenance and repair.

The device enclosure shall be grounded to the facility ground grid in at least two points.

6.12 Safety and signs

Equipment should be furnished with permanent conspicuous signs stating “Danger—High Voltage—Keep Out” in accordance with National Electrical Code® (NEC®) (NFPA 70®) and customers should be apprised of the need to provide clear working space during maintenance in accordance with Table 110-34(A) of NFPA 70-2020.

Suitable interlocks should be placed in service to help ensure that the equipment cannot be energized with personnel inside a converter or energy storage module.

6.13 Lead time

Delivery to the installation site should be within ________ months. Typical delivery time is 9 months after the contract award.

The installation time is ________ months, and the commissioning requires ________ months.

6.14 Installation and spare parts

The user provided wiring installation and handling should be in accordance with manufacturer's recommendations.

The user should provide adequate storage space for the equipment supplied by the device manufacturer. Prior to installation and during construction at the job site, the device should be protected against damage. The device should be stored in a clean, dry environment with temperature and humidity within the range as specified by the device manufacturer. Space heaters should be energized during storage, as recommended by the manufacturer.

The manufacturer should provide a list of necessary spare parts for the first year of operation and a spare parts list that assures trouble free operation.

The manufacturer should also provide a maintenance recommendation, which includes the description of the maintenance procedures and schedules.

Any special tools required for routine maintenance should be provided.

6.15 Equipment testing and system commissioning

The device should be fully tested at the manufacturing location. The supplier must provide a test program ________ weeks prior to the start of the tests. Owner may witness owner specified tests as required. The tests may include:

- Type test performed on selected components. The manufacturer should maintain a certified copy of the test reports.
- Production tests performed on the components/assemblies manufactured for this installation. The manufacturer should maintain a certified copy of the test reports. The owner may send a representative to witness the tests.
- The manufacturer and the owner should perform joint checkout and start-up test of the solid-state electronic device equipment under the technical direction of the manufacturer's service engineer.
- The manufacturer and the owner should perform joint functional test to prove the overall integrated system performance and design.
- The manufacturers should provide training to the owner's operation and maintenance personnel.

A copy of all tests and checks performed in the field, complete with meter readings and recordings, where applicable, should be submitted to the owner for its record.

6.16 Quality assurance

The manufacturer should demonstrate that an established quality assurance program may be used during the manufacturing of the device. This program must be agreeable for both parties.

6.17 Contractual generalities

The manufacturer should provide to the owner a startup service for the device provided.

This service should include:

a) Inspection, final adjustments, operational checks of the provided device
b) Functional checks of spare parts
c) Final report for record purposes

The manufacturer should include _________ parts and labor warranty from date of completion of commissioning for the device provided.

System will not be accepted by owner until satisfactory completion of the commissioning of the unit.

The manufacturer should provide a training course for the owner's personnel. It can be completed within one week after the completed installation. Representatives of the manufacturer should present the course at the job site or other location selected by the owner.

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] Accredited Standards Committee C2, National Electrical Safety Code® (NESC®).[12]

[B2] IEEE Std 80™, IEEE Guide for Safety in AC Substation Grounding.

[B3] IEEE Std 493™ IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (*IEEE Gold Book*).

[B4] IEEE Std 693™, IEEE Recommended Practice for Seismic Design of Substations.

[B5] IEEE Std 1031™, IEEE Guide for the Functional Specification of Transmission Static Var Compensators.

[B6] IEEE Std 1100™, IEEE Recommended Practice for Powering and Grounding Electronic Equipment (*IEEE Emerald Book*).

[B7] IEEE Std 1159™, IEEE Recommended Practice for Monitoring Electric Power Quality.

[B8] IEEE Std 1250™, IEEE Guide for Identifying and Improving Voltage Quality in Power Systems.

[B9] IEEE Std C37.06™, IEEE Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities for Voltages Above 1000 V.

[B10] IEEE Std C37.30.1™, IEEE Standard Requirements for AC High-Voltage Air Switches Rated Above 1000 V.

[B11] IEEE Std C37.90.1™, IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.

[B12] IEEE Std C37.100™, IEEE Standard Definitions for Power Switchgear.

[B13] IEEE Std C57.12.00™, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

[B14] IEEE Std 1409™, IEEE Guide for Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV Through 38 kV.

[B15] NEMA ICS 1, Industrial Control Systems: General Requirements.

[B16] SEMI F47, Specification for Semiconductor Processing Equipment Voltage Sag Immunity.[13]

---

[12] The NESC is available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[13] SEMI publications are available from SEMI, https://store-us.semi.org/collections/standards

IEEE SA
STANDARDS
ASSOCIATION

RAISING THE WORLD'S STANDARDS

Connect with us on:

Twitter: twitter.com/ieeesa

Facebook: facebook.com/ieeesa

LinkedIn: linkedin.com/groups/1791118

Beyond Standards blog: beyondstandards.ieee.org

YouTube: youtube.com/ieeesa

standards.ieee.org
Phone: +1 732 981 0060

IEEE