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IEEE Guide for the Functional Specification of Medium Voltage (1–35 kV) Electronic Series Devices for Compensation of Voltage Fluctuations

IEEE Power Engineering Society

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Substation Committee

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Abstract: An approach to prepare a specification for an electronic device connected in series to compensate voltage fluctuations is presented. This guide intends to provide a base specification to allow users to modify specific parts of the document to meet their practical needs.
Keywords: energy storage, injection transformer, inverter, power electronics, power quality, sensitive loads, series compensation, voltage control

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Introduction

(This introduction is not part of IEEE Std 1585-2002, IEEE Guide for the Functional Specification of Medium Voltage (1–35 kV) Electronic Series Devices for Compensation of Voltage Fluctuations.)

Several utilities are experimenting with 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 has to be collected and used for the specification of a new device.

The working group collected specifications from different manufacturers and utilities. These documents have been combined together to define a comprehensive method for the specification of future devices. This guide is not a tutorial. The application of its content to prepare a specification requires technical knowledge and understanding. Each user should 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.

Participants

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

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When the IEEE-SA Standards Board approved this standard on 12 September 2002, it had the following membership:

Contents

IEEE Guide for the Functional Specification of Medium Voltage (1–35 kV) Electronic Series Devices for Compensation of Voltage Fluctuations

1. Overview

1.1 Scope

This guide provides general guidelines for the preparation of a functional specification for solid-state electronic series devices used mainly for compensation of voltage fluctuation. The guide covers devices rated to medium voltage (1–35 kV). In general, these devices contain: an inverter, a rectifier or dc-to-dc converter, an energy storage device, injection transformers connected in series with the load, and a normally open by-pass switch.

In order to interface these devices with the load, additional equipment should be provided including current and potential transformers, bypass and isolation breakers, fast acting solid-state bypass switch, and three-phase low-voltage service for auxiliary power.

1.2 Purpose

This guide includes technical clauses describing the user's requirements, including operation methods and environmental conditions. It specifies basic requirements of solid-state electronic devices used for compensation of voltage fluctuations. In addition, the guide covers the required installation and start-up services.

1.3 Application

This guide should be considered as a general-purpose source and does not include all details needed for specific applications. Likewise, since the electronic device is typically designed to address a specific application, not every part of this guide may be applicable. The user of this guide should evaluate how, and to what extent, each clause applies to the development of a specific device specification.

2. References

This guide shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision shall apply. The solid-state electronic device components should comply with all applicable ANSI and IEEE standards for electrical equipment.

Accredited Standards Committee C2-2002, National Electrical Safety Code® (NESC®).[1]

ANSI C57.12.24-2000, American National Standard for Transformers: Underground-Type Three-Phase Distribution Transformers, 2500 kVA and Smaller; High Voltage, 34 500 GrdY/19 920 Volts and Below; Low Voltage, 480 Volts and Below—Requirements.[2]

ANSI C57.12.28-1999, American National Standard for Pad-Mounted Equipment—Enclosure Integrity.

ANSI C57.12.70-1978 (Reaff 1993), American National Standard for Terminal Markings and Connections for Distribution and Power Transformers.

IEEE Std 80™-2000, IEEE Guide for Safety in AC Substation Grounding.[3, 4]

IEEE Std 139™-1988 (Reaff 1999), IEEE Recommended Practice for the Measurement of Radio Frequency Emission from Industrial, Scientific, and Medical (ISM) Equipment Installed on User's Premises.

IEEE Std 519™-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.

IEEE Std 693™-1997, IEEE Recommended Practices for Seismic Design of Substations.

IEEE Std 1100™-1999 IEEE Recommended Practice for Powering and Grounding Electronic Equipment (IEEE Emerald Book™).

IEEE Std 1159™-1995, IEEE Recommended Practice for Monitoring Electric Power Quality.

IEEE Std 1250™-1995, IEEE Guide for Service to Equipment Sensitive to Momentary Voltage Disturbances.

IEEE Std C37.100™-1992 IEEE Standard Definitions for Power Switchgear.

IEEE Std C57.12.00-2000, IEEE Standard for General Requirements for liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.80-1978 (Reaff 1992), IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90-1999, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

[1]The NESC® is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[2]ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[3]The IEEE standards referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

SEMI F47-0200, Specification for Semiconductor Processing Equipment Voltage Sag Immunity.[5]

ITI (CBEMA) Curve, Revised 2000, Information Technology Industrial Council, Curve 2000.[6]

NEMA 250-1997, Enclosures for Electrical Equipment (1000 Volts Maximum).[7]

NFPA 70-1999, National Electrical Code® (NEC®).[8]

3. Definitions

For the purpose of this guide the following terms and definitions apply. IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms* and IEEE Std C37.100-1992[9] should be referenced for terms not defined in this clause.

3.1 voltage sag: A short duration decrease of the rms voltage value, to between 0.1 and 0.9 pu, at the power frequency, for 0.5–120 cycles in duration. (IEEE Std 1250-1995)

NOTE—The IEC terminology is voltage dip.

3.2 voltage swell: A short duration increase of the rms voltage value, at the power frequency, for 0.5–120 cycles in duration.

NOTE—The voltage swell is likely to occur when

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 large load is switched off.
c) A large shunt capacitor bank is switched on.

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

4. System description

The solid-state electronic series device is used in a three-phase or single-phase distribution system (rated voltage is up to 35 kV) for dynamic compensation of voltage sag (dip) and swell. A step-up transformer may be required to connect to the utility voltage level.

Figure 1 shows an example of the circuit diagram of a solid-state electronic series device used for compensating voltage fluctuations. In case of a voltage disturbance on the utility distribution feeder, the device injects an appropriate compensation voltage in the line to maintain the voltage at the terminals of the customer's sensitive load.

[5]SEMI publications are available from the Semiconductor Equipment and Materials International, 1401 K. Street, NW, Suite 60, Washington, DC 20005, USA (http://www.semi.org/).

[6]The Information Technology Industrial Council's Curve 2000 is available at http://www.itic.org/technical/iticurv.pdf.

[7]NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

[8]The NEC® is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA (http://www.nfpa.org/). Copies are also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

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

An inverter generates the compensating voltage and injects it through a transformer whose secondary is connected in series with the sensitive load. The injection transformer may consist of three single-phase, single-core transformers or a three-phase, five-legged core unit.

A DC link provides the input voltage and energy to the inverter. The inverter uses the energy stored in a capacitor or other kinds of energy storage devices [e.g., such as batteries, super-conducting magnetic energy storage (SMES) devices, flywheels] through a dc-to-dc converter, or from an ac source (supply feeder) through a rectifier.

Under regular, undisturbed system voltage conditions, the device inverter modules can operate in a "standby" or short-circuit mode or be continuously "on line" (gating) to provide injected voltage to compensate for voltage drop through the series injection transformer. Upon detection of a line side sag or swell, the inverter compensates for it by injecting the appropriate voltage. Energy may be delivered or absorbed.

The device may or may not require dedicated energy storage, depending on the power factor of the load, the anticipated depth of sag, and the symmetry of the sag. The device controls should minimize the need for energy storage during unbalanced sags by charging the dc bus from the high (unaffected or swelled) voltage phase(s). Sufficient stored energy or power must be provided to allow the device to compensate sags of maximum expected duration.

In order to interface the device with the load, additional equipment should be provided, including current and potential transformers, surge arresters, bypass and isolation breakers, and three-phase low-voltage service for auxiliary power. Surge arresters are not required under all conditions.

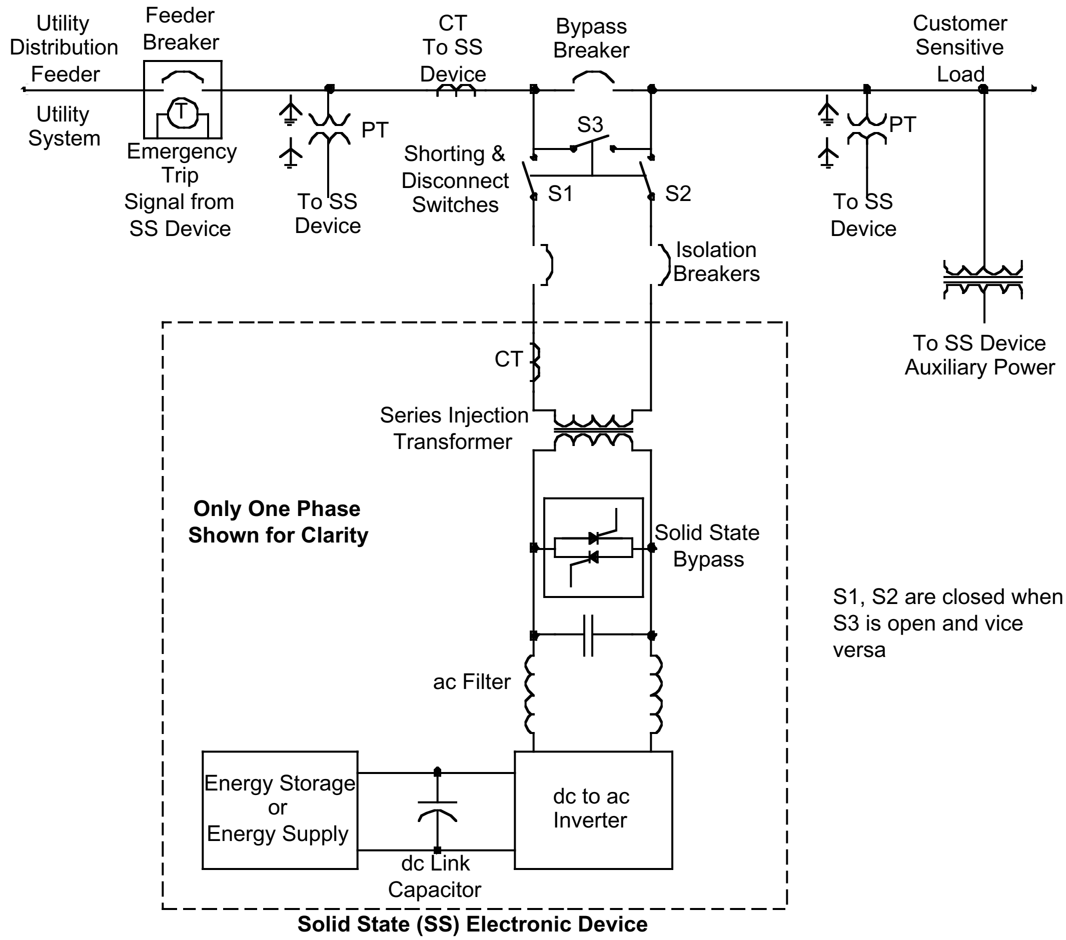

Figure 1—Example of a three-phase solid-state series electronic voltage compensation device circuit diagram

5. Project description

This specification defines the project scope to furnish, install, test, commission, warrant, train user personnel, and place into commercial operation an electronic device for compensation of voltage fluctuations at __________.

The purpose of the device is to correct the voltage of __________, which is a sensitive load, connected to __________ point. The device should temporarily and dynamically maintain voltage at acceptable levels to the above three-phase or single-phase loads during voltage sags and swells (both balanced and unbalanced) that occur on the source side, 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 load is __________ kVA at nominal voltage and frequency.

The nominal load current is __________ A at nominal voltage and frequency.

The maximum load is __________ kVA.

The maximum current is __________ A.

The nominal kVA rating of the device inverter and associated power electronics is specified as the desired maximum voltage injection times the nominal load current.

The system voltage is __________ kV, acceptable load voltage variation is ±__________% of nominal voltage.

The nominal energy rating or usable stored energy is defined as nominal load current times the desired voltage injection during balanced sag times the maximum duration of the sag. Typical value of the maximum sag duration is 300–500 ms. The manufacturer should describe the idle mode of operation of the device when the device is not correcting sag or swell. The user should specify the maximum load, maximum voltage sag, and its duration, for both three-phase and single-phase disturbances.

The user should specify the maximum acceptable sag magnitude versus sag duration ratio, for the specific industrial process to be protected. In addition, the user should specify the maximum acceptable response time for the device to act upon detection of voltage sag. There are several existing power quality standards that address this issue, such as the ITI, Curve 2000 or SEMI F47 criteria, but the user is cautioned that such standards may not fit his or her application. Therefore, the user is urged to evaluate his or her specific requirement before specifying the device.

NOTE—Many drive systems restrict voltage change to 10%. This will 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 point of electric interconnections of the supplier-furnished solid-state electronic device and the user-furnished facilities are shown in the following drawings:

Drawing No:	Description
__________	Main single line diagram
__________	Auxiliary power single line diagram
__________	Grounding plan and details
__________	Control and protection
__________	Location layout, general arrangement, elevation drawings
__________	Site sub-surface and geo-technical data in case of outdoor installation
__________	Foundation and civil drawings
__________	Others

6. Scope of supply and schedule

6.1 Scope of supply

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

a) DC to AC inverter
b) Solid-state bypass switch
c) Injection transformer
d) Bypass (circuit breaker, and/or solid-state switch)
e) Shorting and disconnect switches
f) Isolation circuit breaker(s) (optional)
g) MOV surge arresters if necessary
h) Current and voltage transformers (optional)
i) Energy storage device including charging unit or transformer and rectifier to supply the dc link
j) Control, protection, alarm, and monitoring system for the device
k) On-line monitoring and annunciation system via common IT systems (modem, Internet)
l) Special maintenance equipment and tools
m) Training program for operation and maintenance personnel
n) Spare parts
o) Testing and commissioning service
p) Documentation including instruction manuals
q) Device dimensions, weight, and center of gravity

6.2 Equipment, material, and services furnished by the user

The user shall furnish the following equipment, materials, and services:

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) Project completion is __________ calendar days after contract start. The supplier project schedule is due __________ days after contract start and should include, but not 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.

7. 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.

a) Site elevation above sea level__________
b) Maximum ambient air temperature, (50 ˚C at rated load)__________
c) Minimum ambient air temperature, (–40 ˚C may use supplementary heating)__________
d) Maximum relative humidity
e) Solar radiation (Peak, Daily maximum Watt-hours/m^2, Annual total Watt-hours/ m^2)__________
f) Seismic zone and withstand data__________
g) Isokeraunic level__________
h) Contamination (dust, chemicals, etc.)__________
i) Availability of cooling media (water flow rate, pressure, cleanliness level, etc.)__________

8. Power system characteristics

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

a) Nominal ac system frequency (50 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 ac system voltage, line-to-line (V or %)__________
e) Maximum duration of the maximum system voltage__________
f) Minimum ac system voltage, line-to-line (V or %)__________
g) Maximum duration of minimum ac system voltage__________
h) Maximum load current__________
i) Maximum short-term ac system voltage, line-to-line (110% of the ITIC high voltage)__________
j) Voltage Total Harmonic Distortion (THD) (5% THD and 3% for any single harmonic)__________
k) Current THD (5% THD and 3% for any single harmonic)__________
l) Minimum short term ac system voltage, line-to-line__________
m) Continuous negative sequence voltage component (4%)__________
n) Continuous negative sequence current component (50% of through flow current, when a phase is open) __________
o) Continuous zero sequence voltage component __________
p) Low side and high side Basic Impulse Insulation Level (BIL), if applicable__________
q) Switching Impulse Insulation level (SIL)__________
r) Three-phase fault current__________
s) Maximum single-phase fault current__________

t) Harmonic impedance sectors__________

u) Transient over-current (110% rated current for <1 min)__________

v) Background harmonic voltage or current spectrum__________

9. Series compensation device characteristics

9.1 Rating

The device should insert positive sequence, negative and zero sequence voltage, if required, into the line.

The functional application of the device is to dynamically maintain line-to-line or line-neutral voltage as measured prior to an event (fault) and in accordance to IEEE Std 519-1992 or ITIC levels, to three-phase or single-phase loads during large voltage fluctuations (i.e., balanced or unbalanced sags or swells) that occur on the source side of the device. The voltage must be self-adjustable to the pre-event voltage between the specified upper and lower voltage limits.

NOTE—For the short duration upon 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 should insert full inverter voltage from a state of zero inserted voltage within time periods that maintain load voltage. The load voltage should be maintained within the ITIC curve 2000, or IEEE Std 519-1992 limits, or otherwise specified harmonic and unbalanced voltage.

The device should be capable of attaining 90% of nominal line to neutral voltage from event (sag or swell) detection in __________ cycles or less. Energy storage elements should be in sizes compatible with customer voltage restoration requirements. Energy storage converters should have a __________ kVA short term rating. (Typically the energy storage converter rating should be at least as large as the rating of the main inverter assembly.) The nominal interconnection voltage should be attained by the use of a series insertion transformer or through direct connection of the inverter if suitable. The system should be designed to recharge the energy storage either through the main inverter or through a dedicated charging unit.

The device can be built with smaller modules connected in parallel. The manufacturer should specify the module size and the number of modules.

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

9.2 Losses

a) The supplier should specify the total system losses in idle mode, including transformer losses, in kW and in percentage of the maximum load. In addition, the losses should include all parasitic loads, including cooling fans and pumps, buttery chargers, UPS systems, controls, and other auxiliary loads and losses.

b) Losses evaluation should calculate the __________ $/kW and __________ $/kWh values.

c) The supplier should present alternative methods to reduce losses.

9.3 Harmonic performance

a) Total voltage and current harmonic distortion should be calculated under worst-case conditions in accordance with the procedure outlined in IEEE Std 519-1992. These calculations should be done based on the KVA capacity and harmonic impedance of the supplying source, the latter including the impedance of the transformer supplying the device. The customer should supply this information to the device supplier.

b) The harmonic distortion should be verified through tests. The test results should be made available to the customer.

c) The device should be configured to avoid resonance with common power system components, including shunt capacitors of rating 10 MVAR or less, which may be located at either terminal of the series insertion transformer.

d) If the device is a "standby design," the evaluation of harmonics should consider that, most of the time, the device operates in a transient/sub-transient mode, for a few hundred ms only. The harmonics distortion may be less important under these circumstances.

9.4 Audible noise

Noise generated by the device in idle operation should not exceed __________ dBA measured at 3 m from the nearest surface of the cabinet. 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 ANSI C57.12.24-2000.

9.5 Telephone and radio interference

a) Radiated and conducted EMI generated within the device should be suppressed to 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 519-1992.)

b) 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 Telephone Influence Factor (TIF) weighting factors established in 1960. (IEEE Std 519-1992.)

c) 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 61 cm in front of the device with the doors closed.

d) Higher frequency electromagnetic emissions should 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 should be less than __________ mV over a range of 0.15–1 MHz, when measured 500 m from the building. The measurement should be made in accordance with IEEE Std 139-1988, using a quasi-peak detector reading.

9.6 Cooling and ventilation

9.6.1 Air cooling (if applicable)

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

b) An air-cooling system should provide full heat rejection with redundancy in blowers, filtering, monitoring, and heat exchangers (if required). The cooling system should permit work on a defective unit without shutting down the system.

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

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

9.6.2 Liquid cooling (if applicable)

a) A closed loop re-circulating system should provide full heat rejection capacity with redundancy for pumps, heat exchangers, and fans that are 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.

b) If defective, replacement of certain cooling equipment (pumps, fans, cooler unit) should be possible while the cooling system still operates.

c) 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.

d) If high resistivity is required, the quantity of deionizing material should be sufficient to operate safely for a period 1 1/2 times longer than the specified maintenance interval operation without replacement. Deionizing materials should be replaceable without cooling system shutdown. Instructions for frequency of inspection and change should be given.

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

f) Maintenance of closed loop systems and make up for loss of liquid should not be required more than once a year.

NOTE—The evaluation of the cooling system should consider that the devices operates only few ms. Due to the short duration of operation, most of the heat will be stored in the semiconductor and in the heat sink.

9.6.3 Cooling system protection

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

a) For liquid-cooled systems, the protection system should include, as a minimum, the following warning alarms:
   1) Depleted demineralized (deionizing) 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

b) For liquid-cooled systems, the protection system should include, as a minimum, the following shutdown alarms:
   1) Extra high temperature
   2) Extra low coolant level
   3) Both pumps stopped or blocked flow

c) For air-cooled systems, the protection system should include, as a minimum, the following warning alarms:
   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

d) For air-cooled systems, the protection system should include, as a minimum, the following shutdown alarms:
   1) Excessive exhaust air temperature or high-heat sink temperature
   2) Loss of air flow

9.7 Enclosures

a) The device system shall be housed in enclosures appropriate to the application.
b) For outdoor ground-mounted installations, all device system components should be enclosed in a electrically-grounded weatherproof enclosure with provisions for securely anchoring the enclosure to the foundation.
c) For outdoor overhead installation, all device system components shall be housed in electrically grounded rain-tight (NEMA 250-1997) enclosures designed for ease of installation and maintenance access from standard utility overhead line service equipment.
d) For indoor installation, all device system components shall be housed in electrically-grounded metal enclosures designed to ensure that the opening of a door exposes no live parts. NEMA 250-1997 (dust proof) enclosure is recommended for indoor installation.
e) Energy storage in excess of 500 kJ usable capacitive energy storage, or rectifier, if appropriate, should be located in a suitable separate enclosure with mechanical and electrical interlocks provided to maintain a proper and safe operating sequence.
f) If transportable device modules are mounted on a trailer. The trailer dimension should not exceed 2.6 m in width, 14.6 m in length, and 4.5 m in height; otherwise special oversize load permits may be required for transporting the unit.[10]
g) Supplier should furnish shipping weights and dimensions of each individual separately shipped module.
h) Supplier should furnish detailed foundation drawings showing all tie-down points, pier foundation location and load-bearing requirements, and ground pads.

10. Performance and availability

a) Design availability of an individual module should exceed 95% for forced outages and should exceed 99.5% for scheduled outages, after the commissioning period.

[10]In English units, trailer dimension should not exceed 8.5 ft in width, 48 ft in length, and 14.5 ft in height.

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

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

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

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

f) 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.

11. Control and diagnostics

a) The device control should achieve the functional objectives outlined in Clause 9. 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.

b) 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 or remotely:
   1) Start and stop of operation
   2) Change of reference voltage
   3) Alarm acceptance and if appropriate reset

c) The automatic functions include pre-start verification of the control and protective functions, synchronization of the control to the bus voltage, closing of the insolation switches, transfer of line current from the bypass breaker to the inverter, and opening of the bypass breaker. None of these operations should produce a discernible transient in the load voltage.

d) 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 transfer of line current to the bypass breaker, shutdown of the inverter, 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 that exceeds 3% for 2 cycles or more.

e) The device should be able to accommodate momentary outages of source power as well as overcurrent conditions due to faults by closing the bypass switch and removing the device from service temporarily. When the condition has passed, the device should automatically restart and resume normal operation. This operation will not have critical time constraints and outages lasting several minutes will be acceptable. The bypass system should not operate in case of normal inrush current of the motors starting at the load side. This may require special sensing and protection circuits.

f) Sufficient diagnostics should be made available so that the source of a failure of a major electronic component or subassembly can be accurately and quickly identified by maintenance personnel. The diagnostic data available from the modem or other communication device should include, but is not limited to, the following:
   1) Three line voltages at both source and line side (magnitude and phase)
   2) Three line currents (magnitude and phase)
   3) Three inverter voltage magnitudes and phase, if applicable
   4) Three inverter current magnitudes and phase, if applicable
   5) Ambient temperature
   6) DC bus voltage

7) Inverter valve status for all valves
8) Semiconductor element status
9) Cooling system status
10) Breaker status
11) UPS/battery status, if required
12) Energy storage status (level sored, if applicable)
13) 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.

12. Protection

a) 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 fault that prevents operation or that may cause damage if left uncorrected.

b) The device protection should be properly coordinated to 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.

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

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

e) The protection should remove the device from the service with appropriate diagnostic message in case of:
    1) High impedance faults
    2) Faults that short the secondary winding of the series insertion transformer

f) The device should detect overvoltage and overcurrent conditions within the inverter circuits, the dc bus circuit, and the energy storage circuits, and initiate a shutdown rapidly enough to prevent consequential failure of components. It shall provide diagnostic information that shows the reason for each shutdown.

13. Insulation and grounding

a) Switches should be provided to bypass the device series transformer leads both at the source and load sides.

b) 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 impulse insulation level (BIL) should be in accordance with appropriate IEEE standards. The insulation level of the inverter side of the transformer should be coordinated with that of the inverter. Surge protective equipment should be used as required.

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

d) Grounding switches or equipment should be provided for maintenance and repair.

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

14. Safety and signs

a) Equipment should be furnished with permanent conspicuous signs stating "Danger—High Voltage —Keep Out" in accordance with the National Electrical Code® (NEC®) (NFPA 70-1999), and customers should be apprised of the need to provide clear working space during maintenance in accordance with Table 110-34(a) of the National Electrical Code® (NEC®) (NFPA 70-1999).

b) Suitable interlocks should be placed in service to insure that the equipment cannot be operated with personnel inside an inverter or energy storage module.

15. Lead time

a) Delivery to the installation site should be within __________ months [typical delivery time is nine (9) months] after the contract award.

b) The installation time is __________ months and the commissioning requires __________ months.

16. Installation and spare parts

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

b) 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 at all times. 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.

c) The manufacturer should provide the necessary spare parts for the first year of operation. The manufacturer should prepare a spare part list that assures trouble-free operation.

d) The manufacturer should provide a maintenance recommendation that includes the description of the maintenance procedures and schedules.

17. Testing and check-out

The device should be fully tested at the manufacturing location. The tests should include the following:

a) Type test performed on selected components. The manufacturer should maintain a certified copy of the test reports.

b) 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.

c) 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.

d) The manufacturer and the owner should perform joint functional test to prove the overall integrated system performance and design.

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 his or her record.

18. Contractual generalities

a) The manufacturer should provide to the owner a start-up service for the device provided. This service should include the following:
   1) Inspection, final adjustments, operational checks of the provided device
   2) Functional checks of spare parts
   3) Final report for record purposes
b) The manufacturer should include __________ parts warranty from date of completion of commissioning for the device provided.
c) The manufacturer should provide a training course for the owner's personnel. It should 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.

