practice. The seismic qualification identification plate may state that these bushings are qualified to the current recommended practice.

D.5.5.4 Bushings previously qualified by time history shake-table test

Bushings that were required to be qualified by time history shake-table test under previous versions of this recommended practice shall be demonstrated to satisfy the following adequacy of input spectrum and conductor load effects requirements.

a) *Adequacy of input spectrum.* The previous shake-table test is demonstrated to be equivalent to or more severe than the provisions in the current recommended practice if the spectral acceleration of the old TRS at 0.95 to 1.05 times the stiff-mounted frequency of the bushing exceeds the value of the plateau of the required response spectrum specified in D.5.2.1.d).

b) *Capability to accommodate conductor load effects.* The bushing is demonstrated to have sufficient capacity to withstand conductor load effects of the current recommended practice by meeting one of the following conditions:

   1) If the bushing was over tested, that is, the spectral acceleration of the TRS at the stiff-mounted frequency exceeds the plateau of the required response spectrum, a margin in the equivalent dynamic cantilever load exists over the equivalent dynamic cantilever load at the plateau spectral acceleration. If this margin can accommodate the conductor load effects of either the MAF or ETF, the bushing is qualified.

   2) If the bushing was not over tested, or if requirements in 1) above are not satisfied, the bushing can be subjected to a cantilever pull test equal to or greater than the equivalent dynamic cantilever load plus the conductor load effect of either the MAF or ETF.

If a) and b) are satisfied, the seismic qualification identification plate can state that the bushing meets the requirements of the current recommended practice. A supplemental report shall be prepared that clearly explains and documents how these requirements have been satisfied.

The determination of the equivalent dynamic cantilever load shall be based on measurements from strain gauges on the bushing (A.2.4.5).

D.6 Qualification of surge arresters

Surge arresters of all voltage classes shall be qualified in accordance with the requirements of D.6.

Surge arresters are preferred to be mounted on dedicated supports, and not mounted on transformers in order to improve seismic performance of the surge arrester.

Surge arresters shall be independently qualified in accordance with the requirements of Annex K. If a surge arrester is mounted on a transformer, the transformer manufacturer shall provide bracing or other means of support for the arrester such that the base of the arrester will be sufficiently restrained to prevent movement relative to the transformer body in both horizontal and vertical directions during a seismic event. Bracing need not be applied for surge arresters with DCV < 90 kV. Arrester supports and their bracing shall not be attached to the transformer radiator or bushing turret.

Surge arresters mounted on transformers shall be qualified using an input motion that is amplified by a factor of 2.5 to account for flexibility of the transformer and arrester support.

D.7 Acceptance criteria

D.7.1 Transformers

The qualification will be considered acceptable if the requirements given in this annex, the applicable clauses, and the requirements given in D.7.1 are met.

a) *General criteria.* The stresses in parts, members, tank components, appendages, including connection elements such as welds and bolts, shall meet the requirements of A.2.1.

b) *Requirements for radiators.* For radiators of transformers and liquid-filled reactors having a high side of 115 kV and above, horizontal and vertical seismic bracing for the radiator shall be connected directly to the body of the transformer. Bending, shear, and axial loads across the gasket connection of the radiators or radiator manifolds to the main body of the transformer shall be limited by assuring that stiffness of the radiator bracing system is much larger than that of the gasket connection. Radiator piping shall not be counted upon to provide structural support of the radiator unless the piping, flanged joints, welds, and other connections are subjected to structural evaluation. As an alternative, the radiator can be supported independent of the transformer and connected to the transformer by flexible connections. Support of the radiator by both the transformer and an independent support to the foundation is not permitted, unless the following conditions are met:

   1) The radiator is supported on the same continuous pad as the tank.

   2) The horizontal seismic bracing for the radiator is connected directly to the body of the transformer. Vertical dead weight and seismic loads only may be transmitted directly to the foundation from the radiator.

   3) Bending, shear, and axial loads across the gasket connection of the radiators or radiator manifolds to the main body of the transformer shall be limited by assuring that stiffness of the radiator bracing system is much larger than that of the gasket connection.

D.7.2 Bushings

D.7.2.1 General

The qualification will be considered acceptable if the requirements given in this annex, the applicable clauses, and the requirements given in D.7.2 are met.

a) *General criteria.* For components that are shake-table tested, there shall be no evidence of damage, such as broken, shifted, or dislodged insulators; or broken support flanges.

b) *Time history shake-table test.* Bushings subjected to Performance Level time history test (D.5.2.1) shall satisfy the acceptance criteria of A.2.2.

c) *Leakage criteria for bushings.* Bushings shall not leak, and porcelain bushings shall not slip at the porcelain-flange interface.

d) *Static pull test*. Bushings qualified by the static pull test shall meet the requirements of A.2.3. Items a) and b) of D.7.2.1 do not apply to bushings qualified by static pull test.

D.7.2.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.4.2.

After shake-table testing of bushings, they shall be subjected to and pass all routine tests as specified in the latest revision of IEEE Std C57.19.00.

D.7.3 Surge arresters

The qualification will be considered acceptable if the requirements given in K.5, and the applicable clauses are met.

Surge arresters qualified by the time history shake-table test shall be subjected to and pass all standard production electrical and mechanical tests as defined by IEEE Std C62.11 following the time history test.

D.8 Design requirements

D.8.1 Design and construction

The transformer or liquid-filled reactor tank shall be fabricated from steel. The transformer or liquid-filled reactor and supports for appendages shall be designed in accordance with A.4.

D.8.2 Anchorage

Transformers and liquid-filled reactors may be designed to be field welded to embedded plates or beams. The manufacturer shall indicate, on the seismic outline drawing, locations, size, and length of field welds, and if applicable, locations where welding is not allowed.

If the equipment is designed for anchorage with anchor rods, the manufacturer shall provide brackets or fittings of sufficient stiffness and strength to transfer the required forces, including prying effects. The manufacturer shall indicate on the seismic outline drawing, locations, and sizes of the required anchors.

The user shall be responsible for adequacy of anchorage elements embedded in concrete.

D.9 Report

Portions of the transformer or liquid-filled reactor are qualified by analysis, whereas other portions are qualified by testing (bushing and surge arresters).

For portions qualified by analysis, an analysis report shall be prepared and supplied in accordance with A.6.

For components qualified by testing, a test report shall be prepared and supplied in accordance with A.5. The report for center-clamped bushings that are tested shall document the proper pre-load in the core and the pre-load used for qualification testing.

D.10 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.7.

Annex E

(normative)

Disconnect and grounding switches

E.1 General

E.1.1 Voltage classes and other characteristics

The voltage/voltage class, kV, as used in this annex, is the rated maximum voltage as defined in IEEE Std C37.30.1.

All qualifications of disconnect and grounding switches shall include the operating mechanism and other associated equipment required for a field installation.

E.1.2 High seismic qualification level

The requirements of E.1, with the exception of E.1.3 and E.1.4, are applicable to all disconnect and grounding switches, for qualification to the high seismic level.

E.1.3 Moderate seismic qualification level

The requirements of E.1, with the exception of E.1.2 and E.1.4, are applicable to all disconnect and grounding switches for qualification to the moderate seismic level.

E.1.4 Low seismic qualification level

The requirements of A.1.1.9 are applicable to all disconnect and grounding switches for qualification to the low seismic level.

E.2 Operational requirements

The disconnect switches, grounding switches, and support structures shall be designed to meet the seismic qualification objectives described in 5.2. The operational state shall remain correct during the seismic event.

E.3 Seismic qualification methods

Seismic withstand capability shall be demonstrated as follows:

170 kV and above	By performance level time history shake-table testing	E.4.1
123 kV to < 170 kV	By dynamic analysis	E.4.2
38 kV to < 123 kV	By static coefficient analysis	E.4.3
Less than 38 kV	By inherently acceptable	E.4.4

E.4 Qualification procedures

E.4.1 Performance level time history shake-table testing

E.4.1.1 General

The qualification procedures shall be according to the requirements of A.1.

The tests shall be performed with the disconnect switch open and closed. If a ground switch is included, the tests shall be performed with the disconnect switch open and the ground switch closed, with the disconnect switch open and the ground switch open, and with the disconnect switch closed and the ground switch open.

The switch, structure, operating mechanism, and other associated equipment shall be set up (on the shake table) and adjusted. Correct operating (full opening and full closing) is to be verified before any testing. After the equipment is set up and adjusted, the testing is to proceed as follows:

The equipment and structure shall be tested according to the requirements of A.1.2.

A resonant frequency search shall be performed according to the requirements of A.1.2.5.

E.4.1.2 Monitoring requirements

Critical locations on the disconnect switch and grounding switch shall be monitored for maximum displacements, maximum accelerations, and maximum loading on insulators. Monitoring requirements shall be in accordance with A.2.4.5 and the following:

a) Maximum displacement at the top of the insulator.

b) Maximum accelerations, vertically and horizontally, at the top of the insulator, the end of the blade, and the top of the shake table.

c) Maximum stresses at the base of the porcelain insulator.

d) Any electrical equipment, such as a motor operator, shall be energized during testing and monitored to detect relay bounce and the potential for misoperation.

All data shall be time dependent, so values can be compared.

E.4.2 Dynamic analysis

The qualification procedures shall be according to the requirements of A.1.

The analysis shall be performed with the disconnect switch open and closed. If a ground switch is included, the analysis shall be performed with the disconnect switch open and the ground switch closed, with the disconnect switch open and the ground switch open, and with the disconnect switch closed and the ground switch open.

The qualification procedure shall be according to the requirements of A.1.4.7.

E.4.3 Static coefficient analysis

The qualification procedures shall be according to the requirements of A.1.

The analysis shall be performed with the disconnect switch open and closed. If a ground switch is included, the analysis shall be performed with the disconnect switch open and the ground switch closed, with the disconnect switch open and the ground switch open, and with the disconnect switch closed and the ground switch open.

The qualification procedure shall be according to the requirements of A.1.4.6. A static coefficient of 1.0 may be used.

E.4.4 Inherently acceptable

The qualification procedure shall be according to the requirements of A.1.5.

E.5 Acceptance criteria

E.5.1 General

The qualification will be considered acceptable if the requirements given in this annex, the applicable clauses, and the requirements given in E.5.1 and E.5.2 are met. The general requirements are as follows:

a) The criteria of A.2.1 for design level qualifications and A.2.2 for performance level qualifications.

b) During the testing, the disconnect switch and grounding switch shall maintain the correct operational state. When tested in the “closed position,” it shall stay closed throughout the duration of testing, and when tested in the “open position,” it shall stay open throughout the duration of testing.

c) For the performance level time history test, the requirements of A.2.2.

d) For the dynamic and static coefficient analysis, the requirements of A.2.1.

E.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.4.2.

The shake-table tested switch shall pass the following tests to ensure its functionality:

a) *Millivolt drop test*. Circuit resistance shall be tested before and after the shake-table test as specified in IEC 62271-102.

b) *Continuity*. Electrical continuity shall be monitored across the main disconnect switch or ground circuit when the switch or ground is closed during shake-table testing.

c) *Mechanical operating test*. The disconnect switch and the ground switch, if applicable, shall be operated (closed to opened, and opened to closed). Correct operation, full opening, and full closing shall be verified. The correct operation and function of all associated equipment shall be verified. Insulator support plates, shafts, and mechanical linkage should be evaluated or monitored for deformation or failure.

The post shake-table millivolt drop test and the mechanical operating test shall be performed while the disconnect switch is on the shake table.

E.6 Design requirements

The equipment and support shall be designed according to A.4.

All linkage connections that operate the main and grounding blades shall have positive mechanical connections such that resistance is not dependent solely on friction.

E.7 Report

E.7.1 Report for shake-table test

The report shall be prepared in accordance with A.5.

The values of critical variables shall be tabulated for the blade open and blade closed switch configurations.

E.7.2 Report for dynamic or static coefficient analysis

The report shall be prepared in accordance with A.6.

E.8 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.7.

Annex F

(normative)

Instrument transformers

F.1 General

F.1.1 Voltage classes and other characteristics

The requirements of F.1 are applicable to all instrument transformers (IT), including the following:

a) Capacitor voltage transformers (CVTs)

b) Coupling capacitor voltage transformers (CCVTs)

c) Voltage transformers (VTs)

d) Current transformers (CTs)

e) Station service voltage transformers (SSVTs)

The voltage/voltage class, kV, as used in this annex, is the nominal system voltage (kV) per IEEE Std C57.13 for CT, VT, and SSVT, and per ANSI C93.1 for CVT and CCVT.

F.1.2 High seismic qualification level

The requirements of F.1, with the exception of F.1.3 and F.1.4 are applicable to all instrument transformers for qualification to the high seismic level.

F.1.3 Moderate seismic qualification level

The requirements of F.1, with the exception of F.1.2 and F.1.4 are applicable to all instrument transformers for qualification to the moderate seismic level.

F.1.4 Low seismic qualification level

The requirements of A.1.1.9 are applicable to all instrument transformers for qualification to the low seismic level.

F.2 Operational requirements

The equipment and supporting structure shall be designed to meet the seismic qualification objectives described in 5.2. In addition, equipment shall maintain the correct operational state during the seismic event.

F.3 Seismic qualification methods

Seismic withstand capability of the equipment shall be demonstrated by:

230 kV and greater, or having a total equipment height equal to or greater than 6.1 m (20 ft)	By performance level time history shake-table testing	F.4.1
69 kV to < 230 kV	By dynamic analysis	F.4.2
35 kV to < 69 kV	By static coefficient analysis	F.4.3
Less than 35 kV	By inherently acceptable	F.4.4

F.4 Qualification procedures

F.4.1 Performance level time history shake-table testing

F.4.1.1 General

The qualification procedures shall be according to the requirements of A.1.

The equipment to be shake-table tested shall be tested according to the requirements of A.1.2. Devices that are pressurized should be shake-table tested in a pressurized condition.

A resonant frequency search shall be performed according to the requirements of A.1.2.5.

F.4.1.2 Monitoring requirements

Critical locations on the equipment shall be monitored for maximum displacement, maximum accelerations, and maximum loading on insulating components. Monitoring requirements shall be in accordance with A.2.4.5 and the following:

a) Maximum displacement: Top of equipment

b) Maximum accelerations (vertical and horizontal): Top of equipment

F.4.1.3 Post-shake-table testing

The equipment shall undergo routine production electrical and mechanical tests after the completion of the shake-table tests. In addition, devices that are pressurized or sealed against atmospheric contamination shall be tested to ensure seal integrity. Oil-filled units shall be checked for leaks.

F.4.2 Dynamic analysis

The qualification procedures shall be according to the requirements of A.1. The equipment shall be dynamically analyzed according to the requirements of A.1.4.7.

F.4.3 Static coefficient analysis

The qualification procedures shall be according to the requirements of A.1. The equipment shall be analyzed according to the requirements of A.1.4.6. The static coefficient may be taken as 1.0.

F.4.4 Inherently acceptable

The qualification procedure shall be according to the requirements of A.1.5.

F.5 Acceptance criteria

F.5.1 General

The qualification will be considered acceptable if the requirements given in this annex, the applicable clauses, and the requirements given in F.5.1 and F.5.2 are met. The general requirements are as follows:

a) The general criteria of A.2.1 for design level qualifications and A.2.2 for performance level qualifications.

b) For the performance level time history shake-table test, the requirements of A.2.2.

c) For dynamic and static coefficient analysis, the acceptance requirements of A.2.1.3.

F.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.4.2.

Functional requirements for post-shake-table testing include passage of routine production electrical and mechanical tests. In addition, devices that are pressurized and sealed against atmospheric contamination shall be tested to ensure seal integrity. Oil-filled units shall not leak.

F.6 Design requirements

The equipment and support shall be designed according to A.4.

F.7 Report

F.7.1 Report for shake-table test

The report shall be in accordance with A.5.

F.7.2 Report for dynamic or static coefficient analysis

The report shall be in accordance with A.6.

F.8 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.7.