COMPARISON OF ANSI/IEEE AND IEC REQUIREMENTS FOR LOW-VOLTAGE SWITCHGEAR

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Abstract – As economies become more global in scope, the ability to satisfy different markets with a single or basic product is attaining an increased focus. For electrical distribution and control products, this is made somewhat difficult due to the difference in standards and market expectations in different parts of the world. This paper discusses and compares some of the major conformance testing and constructional differences between metal-enclosed switchgear designed in accordance with ANSI/IEEE standards with similar switchgear and controlgear equipment designed in accordance with IEC standards. With the comparison of the constructional and conformance test procedures between the two standards, it becomes evident that the application of the products in an environment foreign to the standard to which it was designed requires careful consideration.

Index Terms – Low-voltage Switchgear, ANSI C37.20.1, IEC 60439-1

I. INTRODUCTION

The ANSI standards in combination with North American practices provide clear separation between low-voltage power distribution and control equipment. These categories include low-voltage metal-enclosed switchgear, low-voltage distribution switchboards, low-voltage distribution panelboards and low-voltage motor control assemblies. In the North American marketplace, independent ANSI or UL standards exist for each type of equipment. In the IEC marketplace, these types of equipment are consolidated into one assembly with one product standard enveloping the products sectionalized by ANSI and UL. This paper only discusses the major differences between ANSI low-voltage metal enclosed switchgear and the IEC low-voltage switchgear and controlgear standard.

There are several basic differences in power system designs for the two areas (ANSI and IEC). The most obvious differences are in operating voltage, current ratings, power system frequencies and earthing systems. These differences are reflected in the associated equipment designs along with many other constructional deviations that are precipitated by the requirements set forth by each standard regarding topics such as environmental protection and separation.

The North American market place is primarily influenced by two third party organizations, UL (Underwriters Laboratories) and CSA (Canadian Standards Association), which use ANSI C37.20.1 and ANSI C37.51 as the basis for low-voltage switchgear construction and conformance test procedures. The remainder of the world, with the exception of a few isolated locations, utilizes IEC 60439-1 as the basis for low-voltage switchgear construction and test procedures. As in North America, European countries construct and test low-voltage switchgear to individual country standards (Euronorms) which use IEC 60439-1 as the template.

II. SCOPE

A. Scope of Standards

The scope of ANSI C37.20.1 covers "metal-enclosed low-voltage power circuit-breaker switchgear assemblies containing but not limited to such devices as low-voltage power circuit breakers (fused or unfused), other interrupting devices, switches, control, instrumentation and metering, protective and regulating equipment". It is concerned "only with enclosed, rather than open, switchgear assemblies". Furthermore, it states that "it does not apply to equipment covered by industrial control standards, communication switchboards, communication switching equipment, switchboards for use on board ships, or deadfront distribution switchboards".

IEC 60439-1, on the other hand, is much broader in scope. "This standard applies to assemblies intended for use in connection with generation, transmission, distribution and conversion of electric energy and for the control of electric energy consuming equipment." "This standard also applies to stationary or movable assemblies with or without enclosure." Furthermore, it also applies to many special service conditions such as ships, rail vehicles, hoisting equipment, explosive atmospheres and for domestic (operated by unskilled persons) applications provided the "relevant specific requirements are complied with".

Although both standards address and incorporate dc equipment, the dc aspects are not within the scope of this paper.

B. Definition of Products Covered

ANSI defines "metal-enclosed low-voltage power circuit breaker switchgear" as an assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) containing the following equipment as required:

1. Low-voltage power circuit breakers (fused or unfused)

2. Bare bus and connections
3. Instrument and control power transformers
4. Instruments, meters, and relays
5. Control wiring and accessory devices

It also requires that the circuit breakers be contained in individual grounded metal compartments.

IEC 60439-1 defines low-voltage switchgear and controlgear assemblies as "a combination of one or more low-voltage switching devices together with associated control, measuring, signaling, protective, regulating equipment, etc." The compartmentalization of circuit breakers or "functional units" is contingent upon the form of separation declared by the manufacturer. IEC requires an enclosure to have a minimum of an IP2X rating that provides protection against ingress of a solid object no greater than 12.5 mm in diameter.

IEC 60439-1 defines "type tested assembly" (TTA) and "partially type tested assembly" (PTTA) nomenclature to describe the classification of testing to which the equipment conforms. IEC 60439-1 defines TTA as "a low-voltage switchgear and controlgear assembly conforming to an established type or system without deviations likely to significantly influence the performance, from the typical assembly verified to be in accordance with this standard (IEC 60439-1)". As can be seen from the definition of "TTA", the important factor is that the vital characteristics of the type tested assembly remain intact and no deviation exist that would adversely impact the performance of the equipment. Within the definition, there is introduced a degree of subjectivity pertaining to the phrase "without deviation likely to significantly influence the performance". IEC 60439-1 defines PTTA as "a low-voltage switchgear and controlgear assembly, containing both type-tested and non type-tested arrangements provided that the latter are derived (e.g. by calculation) from the type-tested arrangements which have complied with the relevant tests". The intent of the PTTA nomenclature is to address production type assemblies in which alterations are necessary, or for assemblies which have been individually customized to suit specific needs. ANSI defines no such classification for tested assemblies.

III. RATINGS

A. Voltage

The voltage rating as defined by ANSI "is the highest rms voltage for which the equipment is designed, and is the upper limit for operation". This rating as defined by ANSI includes allowance for operating above nominal system voltage. IEC 60439-1 §4.1.1 indicates that the manufacturer shall state the limits of voltage necessary for correct functioning of the main and auxiliary circuits. These voltage levels for the assembly are dictated by the ratings of the associated devices contained therein. Thus, the assembly voltage rating is subject to the relevant IEC standard associated with the devices contained within the assembly. ANSI prescribes the switchgear assembly maximum primary voltage levels at 254, 508 and 635 VAC.

B. Current

1) Continuous Current: ANSI C37.20.1 refers to §4.4.2 for continuous current ratings of 600, 800, 1200, 1600, 2000, 3000, 3200, 4000 and 5000 amperes for Switchgear main bus. IEC 60439-1 states, "due to complex factors determining the rated currents, no standard values can be given".

2) Short-time Withstand Current: ANSI C37.20.1 §4.4.3 defines the rated short-time current as "the designated limit of available (prospective) current at which it shall be required to withstand its short-duty cycle (two periods of one-half second current flow, separated by a 15 second interval of zero current) at rated maximum voltage". IEC 60439-1 specifies the duration of current flow to be 1 second unless otherwise stated by the manufacturer. As indicated by Table 1, the power factor and peak values graduate with current while ANSI C37.20.1 specifies a maximum power factor of 15%, a peak current to be no less than 2.3 times the three phase rms symmetrical value and a minimum X/R ratio of 6.6.

TABLE I
IEC 60439-1 SHORT CIRCUIT TEST CONDITIONS

RMS Value of Short-Circuit Current	Power Factor	Multiplying factor for minimum value of peak current
I ≤ 5kA	70%	1.5
5 kA < I ≤ 10kA	50%	1.7
10kA < I ≤ 20kA	30%	2.0
20 kA < I ≤ 50kA	25%	2.1
50 kA < I	20%	2.2

Other subtle differences associated with test conditions include variations in test frequency (ANSI ±20%, IEC ±25%) and test voltage (ANSI – 254, 508 or 635 VAC, IEC – 1.05 times operating voltage).

3) Short Circuit Current Withstand: ANSI denotes this as a RMS current while IEC defines the rating as a peak current (peak withstand current). ANSI mandates minimum test duration of four cycles for the short-circuit current withstand test. IEC 60439-1 speaks of test arrangements with and without a short-circuit protective device incorporated into the incoming unit. For assemblies with incoming short-circuit protection, the current shall flow until broken by the protective device. The duration of the test current for assemblies without incoming short-circuit protection shall not be less than three cycles if the short-circuit current withstand and short-time current withstand tests are conducted separately.

Test conditions for both IEC and ANSI are identical to their respective short-time current withstand tests. For fused assemblies, ANSI increases the power factor to 20% with a X/R ratio of 5.0 being the lower limit. IEC 60439-1 makes no special considerations in test conditions for fused assemblies.

C. Frequency

ANSI indicates that the ratings for ac equipment are based on a frequency of 60 Hz. In the past, ANSI Switchgear has frequently been applied at 50Hz. IEC 60439-1 refers to the relevant IEC standards for the incorporated components and states that unless indicated by the manufacturer, the limits are assumed to be 98% and 102% of the rated frequency.

D. Control Voltage

ANSI C37.20.1 states that "voltage and current transformers shall be used for all instruments, meters and relays connected to circuits over 240 VAC so as to reduce the voltage on instrument wiring which must necessarily be closely grouped". IEC 60439-1 prescribes no limits but requires the manufacturer to state the limits of voltage for control circuits.

E. Current Transformer Ratings

ANSI C27.20.1 §4.6 covers current transformer mechanical ratings, thermal ratings and minimum accuracy requirements for current transformers. IEC 60439-1 refers to IEC 60185 for CT ratings.

F. Cumulative Circuit Breaker Load and Rated Diversity Factor

ANSI C37.20.1 submits preferred values for cumulative loading when multiple circuit breakers are housed in a single section. ANSI C37.20.1 conveys allowable cumulative load when all circuit breakers contained in the vertical section are of the same frame. The value of cumulative load can be based on equal loading (as a percentage of rating) of all cells or compartments within a vertical section or when equal loading is not practical, the load distribution should be such that the heavier loads are connected to the lowest mounted circuit breaker. For a vertical section with four cells, the following loading values are submitted.

1. Bottom compartment – 100% of compartment rating
2. Second Compartment – 75% of compartment rating
3. Third Compartment – 60% of compartment rating
4. Top Compartment – 50% of compartment rating

IEC 60439-1 refers to a rated diversity factor that is the ratio of the maximum sum of the assumed currents of the main circuits (main breakers or incoming units and branch circuits or outgoing units) to the sum of the rated currents of the main circuits. Thus, the methodology for deriving this factor is somewhat different for the two standards. ANSI de-rates based upon the number of circuits and cell location in a given vertical section versus a quantity only basis by IEC. According to IEC 60439-1, this diversity factor can be expressed for an assembly or, like ANSI, part of an assembly (vertical sections with individual mounting compartments). ANSI does not address cumulative circuit breaker load on an assembly basis. IEC diversity factors are as follows:

TABLE II
IEC DIVERSITY FACTORS

Number of Main Circuits	Diversity Factor
2 and 3	0.9
4 and 5	0.8
6 to 9 inclusive	0.7
10 and above	0.6

IEC 60439-1 permits the use of these diversity factors when conducting continuous current tests.

IV. DESIGN TESTS

A. Dielectric Tests

IEC 60439-1 states that the verification of dielectric properties is performed by impulse withstand testing if the manufacturer declares a value. Otherwise, conventional (hypot) dielectric testing validates the dielectric integrity of main and control circuits. Only dielectric testing of main and control circuits is required by ANSI.

1) *Main Circuits (When no Impulse Rating is Declared for IEC Equipment):* The dielectric test value for ANSI assembly voltage ratings is 2200 VAC for one minute regardless of system voltage levels (254, 508, 635 VAC). If no impulse withstand voltage ratings are declared by the manufacturer, IEC 60439-1 varies the dielectric test voltage according to rated operational voltage of the equipment. ANSI specifies a range for the dielectric test voltage frequency of ±20% while IEC dictates a range of 45 to 62Hz. ANSI C27.20.1 reduces the test voltage level from neutral to ground to 1800V with IEC 60439-1 making no exception. Insulation and dielectric test voltages for IEC 60439-1 is tabulated below.

TABLE III
IEC 60439-1 INSULATION AND DIELECTRIC TEST VOLTAGES

Rated Insulation Voltage (U_I)	Dielectric Test Voltage (AC rms)
$U_I \leq 60$	1000
$60<U_I \leq 300$	2000
$300<U_I \leq 690$	2500
$690<U_I \leq 800$	3000
$800<U_I \leq 1000$	3500

2) Auxiliary and Control Circuits (when no impulse rating is declared for IEC equipment): ANSI C37.20.1 does not require dielectric testing of control circuits as a design test but is required on production assemblies. IEC 60439-1 requires testing to voltage levels in accordance with Table III.

3) Impulse Withstand: Although not required, IEC 60439-1 references specified impulse withstand values to verify clearance and creepage distances in the event an impulse withstand voltage is declared by the manufacturer for main and control circuits. Additionally, impulse withstand values are detailed in IEC 60439-1 for withdrawable devices in the isolated (disconnect) position. ANSI references no such tests for low-voltage switchgear. Preferred impulse withstand ratings are given in IEC 60439-1, Annex G, Table G.1 and G.2 and offer a correlation between system operating voltage and impulse withstand voltage.

B. Continuous Current

A comparison of ANSI C37.20.1 and IEC 60439-1 temperature rise limits is given in Appendix A.

ANSI C37.20.1 submits several arrangements to be used for various continuous current ratings. Each of these arrangements includes one circuit breaker in the uppermost cell intended for mounting. In each case, the circuit breaker is loaded to the frame value. IEC does not submit arrangements for type testing. ANSI C37.20.1 dictates the measurement of ambient temperatures be taken 12.00 inches from the enclosure at the following locations: (1) One level with the top of the structure (2) One 12 inches above the bottom of the structure and (3) One midway between the two positions indicated by (1) and (2). IEC 60439-1 requires the ambient measurements be made 1 meter from the enclosure at approximately half its height. Both standards dictate the limits for ambient temperature during testing must be between +10° C and +40° C for a valid test.

C. Short-time Current Withstand

Both IEC and ANSI require short-time current withstand testing. However, ANSI C37.20.1 specifies no device for detecting fault current between the enclosure and ground. In past ANSI qualification testing, a #10 AWG wire or 30 ampere fuse has been utilized for this purpose as a carryover from ANSI C37.50 (LV Power Circuit Breaker Conformance Testing Standards). IEC 60439-1 requires the use of a 0.8mm diameter wire not less than 50 mm in length for detection of fault current.

The criteria for acceptable performance differ slightly. ANSI states that “the test arrangement shall be considered as having passed the test if there is no breakage of the bus supports and the equipment can withstand the dielectric requirements of ANSI C37.51 §4.4”. IEC 60439-1 states that the clearances and creepage distances specified in §7.1.2 must be complied with by manufacturers. Furthermore, it states that the essential characteristics of the conductor insulation shall not degrade the mechanical and dielectric properties of the equipment. Although both standards require post withstand dielectric testing, the IEC 60439-1 requirements appear to be more stringent with regard to clearances and creepage distances along with post-test insulation integrity.

In both standards, short-time current withstand testing is not required for the neutral conductor. However, ANSI C37.20.1 requires the ground bus be capable of carrying the rated short-time current of the LV Switchgear for 0.5 second. IEC does not reference a short-time current test for the ground (protective conductor) bus.

D. Short Circuit Current Withstand

Both IEC and ANSI require short-circuit current withstand testing. Differences in fault detection and acceptable performance results are identical to those stated above in the “Short-time Current Withstand” section above.

For short-circuit withstand testing associated with a neutral conductor, IEC 60439-1 states that the “value of the test current in the neutral bar shall be 60% of the phase current during the three-phase test”. ANSI does not address the current value associated with neutral testing and is assumed to be the same value as tested during three phase testing.

Both standards require short-circuit withstand tests for the ground bus (protective conductor) at line to line voltage. As with the phase bus testing, ANSI mandates a 4-cycle duration while IEC 60439-1 permits the duration to be determined by the protective device.

E. Mechanical Endurance

ANSI C37.20.1 and C37.51 require 100 mechanical operations for each frame of draw-out circuit breakers. During the course of these tests, the proper operation of the following elements is required:

1. Separable primary contacts
2. Separable control contacts
3. Circuit breaker removable element position interlocks
4. Stored-energy mechanism interlocks
5. Housing mounted breaker position switches (cell switch).

IEC 60439-1 does not require mechanical endurance tests if devices have already been type tested according to their relevant specifications. In the event type testing has not been completed, operation of mechanical interlocks shall be verified after installation in the assembly by 50 mechanical operations.

F. Paint Qualification

ANSI C37.20.1 §5.2.8 requires a paint qualification test of 200 hours salt-spray. IEC 60439-1 makes no mention of paint qualification for low-voltage switchgear equipment.

G. Verification of Clearances and Creepage Distances

IEC 60439-1 requires the verification of clearances and creepage distances by measurement. If impulse voltage withstand tests are performed, the minimum clearance dimensions in air are given in Appendix B.

As indicated by the data, the minimum values are dependent upon the pollution degree and field conditions. ANSI C37.20.1 references no such rating scale for the environmental conditions in which the equipment operates. Furthermore, ANSI C37.20.1 does not dictate the through air or creepage distances. Historically, these numbers have been 1.00 inch (25.4 mm) through air and 2.00 inches (50.8 mm) over surface for 600V class Switchgear. These values are mandated by the UL 1558 standard.

The IEC 60439-1 guidelines for creepage distances are given in Appendix C. Since pollution degrees 1 and 2 are not recommended for industrial applications, only pollution degrees 3 and 4 are presented in Appendix C.

Like the through air clearances, the minimum creepage distances specified by IEC 60439-1 are significantly lower than the generally accepted values corresponding to ANSI type equipment.

H. Rain Test for Outdoor LV Switchgear

ANSI C37.20.1 details the testing requirements for outdoor Switchgear enclosures. IEC 60439-1 does not address test requirements for outdoor equipment but refers to IEC 529 (“Degrees of Protection Provided by Enclosures”) for ingress protection ratings and states the second numeral to be at least three.

V. PRODUCTION (ROUTINE) TESTS

A. Dielectric Withstand Tests (Main Circuits)

ANSI C37.20.1 requires low frequency withstand tests (2200V, 1 minute) on each production assembly. IEC requires similar tests per the guidelines discussed in section IV.A.1 either by impulse withstand (if manufacturer declares rating) or dielectric testing. However, for IEC production or routine tests, the dielectric test voltage is only required for 1 second.

B. Mechanical Operations

ANSI specifies tests shall be performed to ensure the proper functioning of mechanical interlocks and interchangeability of removable elements designed to be interchangeable. IEC requires similar mechanical operation testing but does not address devices that are mechanically interchangeable.

C. Electrical Operation and Control Wiring Tests

1) Control Wiring Continuity: ANSI requires the correctness of control wiring be verified by either actual electrical operation of the devices or by conducting individual circuit continuity checks. IEC states "the conformity of the assembly to the circuit and wiring diagrams, technical data, etc. provided by the manufacturer shall be checked".

2) Control Wiring Dielectric Test: Both standards require control wiring dielectric testing on production assemblies. ANSI requirements include a test voltage of 1500V for one minute or 1800V for one second. IEC test values are based upon the rated insulation voltage as given in IV.A.2. For production tests, the voltage is to be applied for one second. Recall for design tests, the voltage is applied for one minute.

3) Polarity Verification: ANSI C37.20.1 requires testing to verify "that connections between instrument transformers and meters or relays are correctly connected with proper polarities in accordance with circuit diagrams". IEC 60439-1 makes no direct reference to verifying polarities of instrument transformers and meters or relays. Rather, correctness of polarities is implied under control wiring continuity verification.

4) Sequence Tests: Testing for proper sequencing of devices is required by ANSI while IEC states that depending upon the complexity of the assembly, sequence tests may need to be conducted to ensure proper operation.

5) Checking of Protective Measures and of the Electrical Continuity of the Protective Circuits: IEC 60439-1 requires that protective circuits be checked by inspection to ensure their continuity by effective interconnections either directly or by means of conductors. These measures are detailed in IEC 60439-1 §7.4.3.1.5 and should include random inspection of screw type terminals.

VI. CONSTRUCTION FEATURES

A. Nameplates

Both standards require equipment nameplates. ANSI C37.20.1 requires the following minimum information on nameplates:

1. Manufacturer's name and address
2. Manufacturer's type designation (optional)
3. Manufacturer's identification reference
4. Rated maximum voltage
5. Rated frequency

IEC 60439-1 requires the manufacturer's name or trademark and type designation or identification number to appear on the equipment nameplate. A host of other information including additional ratings and equipment description must appear either on the nameplate or in technical documentation if applicable. A description of this information is given in §5.1 of IEC 60439-1.

B. Internal Barriers and Forms of Separation

ANSI requires circuit breakers to be mounted in separate metal-enclosed compartments. The metal barriers between compartments are required to be a minimum of MSG No. 11 (nominal thickness of 0.1196 in. or 3 mm) material. Ventilation openings are permitted provided that the gases produced by circuit breaker interruption shall not impair the operation of adjacent compartments. Additionally, when bus sectionalizing breakers are utilized (main or tie breakers), barriers are required in the bus compartment to segregate the separate bus sections from each other. For branch circuits, no barriers in the bus compartment are required.

IEC addresses internal barriers to varying degrees. The following are typical forms of separation by barriers.

1. Form 1 – No separation
2. Form 2 – Separation of bus bars from the functional units.
3. Form 3a – Separation of bus bars from the functional units and separation of all functional units but not of their terminals for external conductors, from one another. The terminals for external conductors need not be separated from the bus bars.
4. Form 3b – Separation of bus bars from the functional units and separation of all functional units from one another. Separation of the terminals for external conductors from the functional units, but not from each other.
5. Form 4 – Separation of bus bars from the functional units and separation of all functional units from one another, including the terminals for external conductors which are an integral part of the functional unit.

The barriers defined by the "Forms of Separation" can be either metallic or non-metallic in construction. IEC does not specify thickness of material for these barriers. In order to effectively comprehend the requirements of separation, it is important to understand the term "functional unit". IEC defines this as "a part of an assembly comprising all the electrical and mechanical elements that contribute to the fulfillment of the same function". Thus, one could deduce that the device, along with its associated accessories and conductors, are meant as the intent of the definition.

Much commentary has been written regarding IEC forms of separation. This element represents one of the major differences between ANSI and IEC construction. Since ANSI offers no such varying degrees of separation, the level of separation as defined by IEC for ANSI type equipment is difficult to apply. For 3-wire applications, one could argue that the standard ANSI construction coupled with additional insulation for circuit breaker connectors meets the requirements of "Form 3b" given by the written definition and the typical arrangements given in IEC 60439-1, Annex D. However, since 4-pole devices are not frequently used in ANSI type distribution Switchgear, the conductors associated with "functional" units for 3 phase 4 wire applications are not packaged in close proximity due to the remotely mounted neutral conductors. Hence, the isolation of "functional units" becomes much more difficult due to the differences in construction. Therefore, the level of separation would have to be reduced to "Form 2" or possibly "Form 1" depending upon construction techniques.

C. Interchangeability of Removable Elements

ANSI requires those removable elements of the same type and rating for a given assembly to be physically interchangeable. However, it is not mandated that secondary control circuits for these devices are electrically interchangeable. IEC does not address interchangeability.

D. Size of Neutral Conductor

IEC 60439-1 states that unless agreed upon by the manufacturer and user, the neutral conductor shall have half the current carrying capacity of the phase conductor with a minimum of 10 mm^2 if the phase conductor exceeds 10 mm^2. If the phase conductor is less than 10 mm^2, the neutral shall have equivalent capacity. ANSI C37.20.1 does not address the capacity of neutral conductors.

IEC 60439-1 refers to IEC 60364-4-41 for earthing systems and requires that suitable earthing systems be indicated on the product labeling. Four earthing systems are defined in IEC 60364-4-41, TN-C as used in the USA and TN-S, TT and IT systems. In TN-C systems, the neutral and ground are combined and the neutral does not need to be considered as a live bar. In the other three systems, the neutral has to be considered to be live and must be treated as a phase conductor. It has to be separated to the level required by the Form designation and have some means of isolation that often results in the use of 4-pole breakers, particularly for bus-tie breakers.

E. Ground Bus (Protective Conductor)

IEC 60439-1 specifies the cross sectional area of protective conductors according to the following table.

TABLE IV
IEC 60439-1 GROUND CONDUCTOR SIZE

Cross Sectional Area of Phase Conductors S Mm^2 (in^2)	Minimum Cross-sectional area of the Corresponding Protective Conductor S_P mm^2 (in^2)
S≤16 (.025)	S
16 (.025)<S≤35 (.054)	16 (.025)
35 (.054)<S≤400 (.62)	S/2
400 (.62)<S≤800 (1.24)	200 (.31)
S>800 (1.24)	S/4

ANSI does not specify the cross sectional area of ground conductors. However, the ground bus in ANSI low voltage Switchgear is sized to the NEC requirement of 12.5% of phase conductor cross section. In comparing typical ampere ratings, the IEC requirements are much more demanding with regard to conductor size.

F. Enclosures

1) Environmental Classification: ANSI indicates that Low Voltage Switchgear shall be ventilated enclosures (NEMA Type 1) intended to provide a degree of protection against contact with the enclosed equipment.

IEC 60439-1 submits guidelines for degrees of environmental conditions. IEC indicates that unless otherwise stated, assemblies for indoor, industrial applications are generally for use in a pollution degree 3 environment while outdoor, industrial applications are for use in a pollution degree 4 environment. The following definitions exist for degrees of pollution.

a) *Degree 1:* No pollution or only dry, non-conductive pollution occurs.
b) *Degree 2:* Normally, only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation may be expected.
c) *Degree 3:* Conductive pollution occurs, or dry, non-conductive pollution occurs which becomes conductive due to condensation.
d) *Degree 4:* The pollution generates persistent conductivity caused, for instance, by conductive dust by rain or snow.

2) Degrees of Protection: The ANSI requirements are that the enclosure design shall provide a degree of protection against limited amounts of falling dirt but will not prevent the entry of dust or liquids. Furthermore, a rod entry test is required to prevent the insertion of a rod of diameter 0.50 inch (12.7 mm) into an external opening unless the distance between the opening and the nearest live part is greater than 4 inches (101.6 mm). In this case, a rod of diameter greater than 0.75 inch (19 mm) shall not be permitted to enter the opening.

IEC has extensive commentary regarding degrees of protection (references IEC 60529) and uses an "IP" (ingress protection) rating to classify the degrees. The elements of the IP code are presented in Appendix D.

The letter "X" indicates that the characteristic need not be specified. IEC 60439-1 submits a set of preferred IP numbers where some protection against ingress of water is not required and mandates that the enclosure degree of protection of an enclosed assembly for indoor use to be at least IP2X and that the minimum IP between compartments be IP2X. An IP2X rating provides protection against the ingress of a solid object no greater than 12.5 mm in diameter. Test specifications and pass/fail criteria for each numeral or letter are given in IEC 60529. It should also be noted that if the degree of protection of part of the assembly, for example, on the operating face differs from that of the main portion, the manufacturer shall indicate the degree of protection of that part separately.

For comparison sake, the IP code for the standard ANSI construction would be IP10.

G. Doors and Covers

IEC 60439-1 states that if it is necessary to make provision for removal of barriers, opening of enclosures or withdrawal of parts of enclosures, one of the following protective measures must be used to guard against direct contact with live parts.

1. Removal, opening or withdrawal must necessitate the use of a key or tool.
2. All live parts that can unintentionally be touched after the door has been opened shall be disconnected before the door can be opened.
3. An internal obstacle or shutter shielding all live parts shall exist which provides protection against unintentional contact when the door is open.

ANSI does not address the issue of incidental contact when doors or covers are removed. It does limit the size of removable covers for inspection and maintenance purposes to 12 ft^2 or 60 pounds unless equipped with lifting means or hinges.

H. Interlocks

Although required by the ANSI power circuit breaker standard, C37.20.1 restates the requirement for several interlocks. They include:

1. Prevention from moving the circuit breaker to or from the connected position when the circuit breaker is in the closed position.
2. Prevention from closing the circuit breaker unless the primary disconnecting devices are in full contact or are separated by a safe distance.
3. For circuit breakers with stored energy mechanisms, the release of energy shall not be permitted unless the mechanism is fully charged.
4. Operators shall be protected from the accidental discharge of the stored energy mechanism.

Additionally, ANSI requires door interlocks on compartments in which current-limiting fuses are mounted in separate removable elements. This interlock prevents door opening unless the associated breaker or switch is in the open position.

IEC 60439-1 does not address interlocks specifically, but does require that "withdrawable parts shall be fitted with a device which ensures that the apparatus can only be withdrawn after its main circuit has been interrupted".

I. Control and Secondary Wiring

1) Wire Type: ANSI C37.20.1 §6.1.3 requires the use of type TBS or SIS wire for use between component devices or parts of Switchgear assemblies. In addition, it requires the wire to be a minimum of 14 AWG stranded with an insulation rating of 600V. IEC 60439-1 §7.8.3.1 states that the wiring shall be rated for at least the rated insulation voltage of the circuit concerned. This implies the usage of different insulation ratings is permissible in control circuits. IEC 60439-1 does not address wire size or type.

2) Terminal Blocks: ANSI C37.20.1 dictates that external connections be suitable to accept AWG #10 and be of the solderless variety. IEC 60439-1 permits the use of soldered connections provided where provision is made for these type connections on the apparatus. For applications with vibrations, supplementary means for securing should be provided.

VII. APPLICATION CONDITIONS

A. Temperature and Humidity

The range of ambient operating temperatures as declared by ANSI for indoor low-voltage Switchgear is -30°C to +40°C. IEC indicates the limits of temperature range to be -5°C to +40°C with the average over a period of 24 hours not exceeding +35°C. Lower minimums of -25°C and -50°C are given for equipment designed for artic conditions.

In addition to the ambient temperature conditions, IEC prescribes limits for the relative humidity. It states that the "relative humidity does not exceed 50% at a maximum temperature of +40°C". Higher relative humidities may be permitted at lower temperatures, for example 90% at +20°C.

B. Unusual Service Conditions

ANSI C37.20.1 §7 provides the application guide for low-voltage Switchgear. Unusual conditions such as exposure to hot and humid climates, abnormal vibration, shocks, tilting, excessive dust, damaging fumes, salt air, oil vapors, seismic shock, applications at high altitude and overload capabilities are addressed. IEC 60439-1 §6.2 states that "where special service conditions exists, the applicable particular requirements shall be complied with or special agreements shall be made between the user and manufacturer". Special service conditions are not addressed specifically by IEC 60439-1.

VIII. CONCLUSIONS

There are substantial differences in the testing procedures and construction techniques between ANSI and IEC low-voltage switchgear. In addition, there are many minor differences that were not discussed in this paper and it cannot be assumed that the two standards are in total agreement regarding these issues. These differences along with the associated power system designs of each market, require that special consideration must be given when applying ANSI or IEC equipment in an application differing from the design standard to which the equipment conforms. Unifying the two standards would be difficult based upon the vast differences in product scope and market expectations throughout the world.

IX. APPENDIX

APPENDIX A

COMPARISON OF TEMPERATURE RISE LIMITS, TABLE A-1

Description	**ANSI C37.20.1** **Rise (ºC) unless otherwise noted**	**IEC 60439-1** **Rise (ºC)**
Components		
Built-in Components	Subject to relevant standard for component	Subject to relevant standard for component
Bus		
Bare Copper Bus Connection	30	(1,2)
Plated Bus Connection	65	(1,2)
Connection to insulated cables, un-plated copper	30	70
Connection to insulated cable silver surfaced, tin surfaced or equivalent	45	70
Air Temperatures		
Surrounding Cables	65 (3,5)	(4)
Other parts or enclosure		
Metal parts subject to contact by operating personnel	50 (3)	15
Insulating parts subject to contact by operating personnel	50 (3)	25
External metal surfaces accessible to an operator in the normal course of duties	70 (3)	30
External insulating surfaces accessible to an operator in the normal course of duties	70 (3)	40
External metal surfaces not accessible to an operator in the normal course of duties	110 (3)	40
External insulating surfaces not accessible to an operator in the normal course of duties	Subject to temperature limits of insulating material	50

(1) IEC 60439-1 does not specify values specifically for buses but offers the following as guidelines for determining the upper limit:
- Mechanical strength of conducting material
- Possible effect on adjacent equipment
- Permissible temperature limit of the insulating materials in contact with the conductor
- The effect of the temperature of the conductor on the apparatus connected to it
- For plug-in contacts, nature and surface treatment of the contact material

(2) IEC 60439-1 offers no differentiation between plated and bare conductors.
(3) Total allowable temperature.
(4) Not addressed by IEC 60439-1.
(5) Temperature limitation is based on use of 90° C cable in a 40° C ambient.

APPENDIX B

IEC 60439-1 MINIMUM CLEARANCES, TABLE A-II

Rated Impulse Withstand Voltage (kV)	Minimum Clearances (mm)							
	Case A				Case B			
	Pollution Degree				Pollution Degree			
	1	2	3	4	1	2	3	4
0.33	0.01				0.01			
0.50	0.04	0.20			0.04	0.20		
0.80	0.10		0.80		0.10		0.80	1.60
1.50	0.50	0.50		1.60	0.30	0.30		
2.50	1.50	1.50	1.50		0.60	0.60		
4.00	3.00	3.00	3.00	3.00	1.20	1.20	1.20	
6.00	5.50	5.50	5.50	5.50	2.00	2.00	2.00	2.00
8.00	8.00	8.00	8.00	8.00	3.00	3.00	3.00	3.00
12.00	14.00	14.00	14.00	14.00	4.50	4.50	4.50	4.50

Note: Case A clearances are required for Pollution Degrees 3 and 4.

APPENDIX C

IEC 60439-1 CREEPAGE DISTANCES FOR EQUIPMENT, TABLE A-III

Rated Insulation Voltage	Pollution Degree				Pollution Degree			
	Material Group				Material Group			
	I	II	IIIa	IIIb	I	II	IIIa	IIIb
	mm (in.)				mm (in.)			
250	3.2 (.13)	3.6 (.14)	4.0 (.16)	4.0 (.16)	4.0 (.16)	5.6 (.22)	6.3 (.25)	6.3 (.25)
400	5.0 (.20)	5.6 (.22)	6.3 (.25)	6.3 (.25)	8.0 (.31)	10.0 (.39)	12.5 (.49)	12.5 (.49)
500	6.3 (.25)	7.1 (.28)	8.0 (.31)	8.0 (.31)	10.0 (.39)	12.5 (.49)	16.0 (.63)	16.0 (.63)
630	8.0 (.31)	9.0 (.35)	10.0 (.39)	10.0 (.39)	12.5 (.49)	16.0 (.63)	20.0 (.79)	20.0 (.79)

APPENDIX D

ELEMENTS OF THE IP CODE, IEC 60439-1, TABLE A-IV

<table>
<tr><th>Element</th><th>Numerals or Letters</th><th>Meaning for the Protection of Equipment</th><th>Meaning for the Protection of Persons</th></tr>
<tr><td>Code Letters</td><td>IP</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Against ingress of solid foreign objects</td><td>Against access to hazardous parts with</td></tr>
<tr><td rowspan="7">First Characteristic Numeral</td><td>0</td><td>Non-protected</td><td>Non-protected</td></tr>
<tr><td>1</td><td>≥50 mm diameter</td><td>Back of hand</td></tr>
<tr><td>2</td><td>≥ 12.5 mm diameter</td><td>Finger</td></tr>
<tr><td>3</td><td>≥ 2.5 mm diameter</td><td>Tool</td></tr>
<tr><td>4</td><td>≥ 1.0 mm diameter</td><td>Wire</td></tr>
<tr><td>5</td><td>Dust protected</td><td>Wire</td></tr>
<tr><td>6</td><td>Dust-tight</td><td>Wire</td></tr>
<tr><td></td><td></td><td>Against ingress of water with harmful effects</td><td>-</td></tr>
<tr><td rowspan="9">Second Characteristic Numeral</td><td>0</td><td>Non-protected</td><td>N/A</td></tr>
<tr><td>1</td><td>Vertically dripping</td><td>N/A</td></tr>
<tr><td>2</td><td>Dripping (15 degree tilted)</td><td>N/A</td></tr>
<tr><td>3</td><td>Spraying</td><td>N/A</td></tr>
<tr><td>4</td><td>Splashing</td><td>N/A</td></tr>
<tr><td>5</td><td>Jetting</td><td>N/A</td></tr>
<tr><td>6</td><td>Powerful jetting</td><td>N/A</td></tr>
<tr><td>7</td><td>Temporary immersion</td><td>N/A</td></tr>
<tr><td>8</td><td>Continuous immersion</td><td>N/A</td></tr>
<tr><td></td><td></td><td>Against access of solid foreign objects</td><td>Against access to hazardous parts with</td></tr>
<tr><td rowspan="4">Additional Letter (Optional)</td><td>A</td><td>The access probe, sphere of 50 mm diameter, shall have clearance from hazardous parts.</td><td>Back of hand</td></tr>
<tr><td>B</td><td>A jointed test finger of 12 mm diameter and 80 mm in length, shall have adequate clearance from hazardous parts.</td><td>Finger</td></tr>
<tr><td>C</td><td>An access probe of 2.5 mm diameter and 100 mm in length, shall have adequate clearance from hazardous parts.</td><td>Tool</td></tr>
<tr><td>D</td><td>An access probe of 1.0 mm diameter and 100 mm in length, shall have adequate clearance from hazardous parts.</td><td>Wire</td></tr>
<tr><td></td><td></td><td>Supplementary information specific to:</td><td>-</td></tr>
<tr><td rowspan="4">Supplementary Letter (Optional)</td><td>H</td><td>High-voltage apparatus</td><td>N/A</td></tr>
<tr><td>M</td><td>Moving parts in motion during water test</td><td>N/A</td></tr>
<tr><td>S</td><td>Moving parts stationary during water test</td><td>N/A</td></tr>
<tr><td>W</td><td>Weather conditions</td><td>N/A</td></tr>
</table>

X. ACKNOWLEDGEMENTS

The author gratefully acknowledges the contributions of Bob Yanniello and Richard Trussler who reviewed the paper several times during the course of its development.

XI. REFERENCES

[1] ANSI/IEEE C37.20.1-1993, *IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear*, New York, NY: IEEE.

[2] ANSI/IEEE C37.51-1989, *IEEE Standard for Metal-Enclosed AC Power Circuit Breaker Conformance Test Procedures*, New York, NY: IEEE.

[3] IEC 60439-1 (1999-09), *Low-Voltage Switchgear and Controlgear Assemblies*, Geneva, Switzerland: IEC.

[4] IEC 60947-1 (2001-12), *Low-Voltage Switchgear and Controlgear – Part1: General Rules*, Geneva, Switzerland: IEC.

[5] IEC 60529 (2001-02), *Degrees of Protection Provided by Enclosures (IP Code)*, Geneva, Switzerland: IEC.

XII. VITA

Eddie Wilkie graduated from North Carolina State University in 1990 with a BSME. He has been a design engineer and product development manager for Low-voltage Switchgear assemblies. He is currently the engineering manager for Low-voltage switching devices. He has been employed by Cutler-Hammer since 1990.