White Paper **WP012001EN** Effective May 2013

High voltage circuit breaker standards—comparative guide

Stephen M. Cary
Principal Engineer
Eaton

Abstract

IEEE® C37 and IEC 62271 electrical standards govern the ratings, performance, features, and testing of circuit breakers and switchgear. The primary goal is to ensure that the circuit breakers serve the intended purpose of safely protecting the electrical distribution system. The secondary goal is to ensure that circuit breakers are electrically and mechanically interchangeable so that the electrical grid can be interconnected.

This paper will analyze and compare the similarities and differences among the requirements of these electrical circuit breaker standards.

Introduction

The International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE) were each founded around the end of the 19th century. The objective of the first meetings was to ensure the effective interconnection capabilities of the components in the alternating current power distribution system. Without electrical standards, the utility grids would be unreliable, costly to operate, and difficult to connect.

Low frequencies are most suitable for powering three-phase motors in most applications. Electric utilities desired higher frequencies for power generation to reduce capital costs. Depending on the distances from the power generation facility, it was economical to distribute power at several different voltages.

Over time, manufacturers and users began meeting to "standardize" these conflicting requirements by providing a preferred rating structure. The committees went beyond just choosing preferred ratings—they set specific criteria, like dimensions, for connections and other requirements that ensured safety.

As systems grew during the 1920s, users suffered some spectacular electrical failures. At that time, the standards organizations started to specify the minimum design and testing criteria to prove ratings assigned to power circuit breakers. In 1924, the Electric Power Club (NEMA®) issued a standard prohibiting "flame-throwing". In 1938, AIEE (now IEEE) issued standard 19 prohibiting the emission of any "appreciable quantity of oil".

To establish the capabilities of circuit breakers, manufacturers and third-party organizations built high power laboratories. During the tests, the circuit breakers must perform four basic functions: to open, to close, to remain open withstanding voltage, and remain closed conducting continuous and short-circuit currents.

This paper will address the requirements defined by the standards for voltage withstand, ratings, thermal load requirements, capacitor switching, and testing.

Insulation—voltage withstand

While closed or open, the circuit breaker must be capable of withstanding overvoltage without di-electric breakdown. **Table 1** provides criteria on power frequency withstand overvoltage and lighting impulse withstand overvoltages for each preferred operating voltage class.

Table 1. Insulation Power Frequency and Impulse Withstand Voltages

IEC 6227-100					IEEE C37				
Rated	PFWV U_d (kV)		LIWV (pk) U_p (kV)		Rated	PFWV (kV)		LIWV (pk) (kV)	
U_r (kV)	Com	Iso	Com	Iso	V (kV)	Com	Iso	Com	Iso
3.6	10	12	20 40	23 46	—	—	—	—	—
7.2	20	23	40 60	46 70	**4.76**	19	21	60	66
12	28	32	60 75	70 85	**8.25**	36	40	95	105
17.5	38	45	75 95	85 110	**15**	36	40	95	105
24	50	60	95 125	110 145	**27**	60	66	125	138
36	70	80	145 170	165 195	**38**	80	88	150	165

Note: IEC also lists the IEEE ratings.

PFWF = Power Frequency Withstand Voltage
LIWV = Lighting Impulse Withstand Voltage
Com = Common
Iso = Isolating Distance

Powering Business Worldwide

According to C37.09, after short-circuit testing, the circuit breaker must be able to withstand a one-minute power frequency voltage test at 80% of the original rated withstand voltage. Withstand voltage ratings is one area in which IEEE has more conservative requirements than IEC. The preferred power frequency withstand voltages (PFWV) is a factor of 3 times the respective IEEE rated maximum voltage and a factor of 2.3 times the IEC rated maximum voltage.

In addition to testing the circuit breaker at the power frequency, the circuit breaker must undergo a series of lightning impulse withstand voltage (LIWV) tests. The required wave-front rise-time requirement is 1.2 microseconds for both standards. In **Table 1**, IEEE LIWV ratings are more conservative than IEC ratings. IEEE lighting impulse voltage ratings are nearly 2 times the IEC rating for a given rated (maximum) voltage. The averaged summation of the IEEE lightning impulse ratings divided by the rated voltage yields 7.86 for IEEE versus 4.42 for IEC.

Ratings

On the IEC rating tables, the standard provides a footnote "b," indicating the voltages used in North America. For all North American voltages, IEC has adopted the same TRV parameters for short-circuit capabilities.

A key difference between the standards is that IEEE specifies maximum rated voltages. IEC tolerances on operating voltages are ±5% while IEEE are ±10%. So in the case of a 3.6 kV circuit breaker, the typical operating voltage is 3.3 kV. The IEEE 4.76 kV circuit breaker, on the other hand, would be designed to operate at 4.16 kV. On many quantities, the IEC standards define explicit tolerances on measured test characteristics. No such equivalent tables exist in IEEE standards.

The standard rated short-circuit duration for the IEEE circuit breaker is 2 seconds. The ability of a breaker to withstand a high short-circuit current is an important factor in system coordination. Upstream circuit breakers must remain closed so that downstream circuit breakers can interrupt. The IEC circuit breaker must withstand the fault for only 1 second. IEC even has a preferred rating for 0.5 seconds. On this criterion, IEEE is more conservative.

The IEC standard has adopted the R10 series of numbers based on the tenth root of 10 for both short-circuit and continuous current ratings. The R10 series was created by Charles Renard and was adopted by ISO® in the 1950s as a standard for defining preferred numbers. The spacing between preferred numbers increases as the rating increases. IEC standards provide additional preferred ratings as shown in **Table 2**.

The rated operating sequence establishes the closing, opening, making, and breaking duty for which the breaker must be tested. IEEE requires a delay of 15 seconds after the first opening and the subsequent closings. This is more stringent than IEC, which allows for 3 minutes between openings and subsequent closings.

Table 2. Ratings

Rating	IEC 52271-100	IEEE C37
Voltage U_r (kV)	3.6, 4.76, 7.2, 8.25, 12, 15, 17.5, 24, 27, 36, 38	4.76, 8.25, 15, 27, 38
Frequency f_r (Hz)	16 2/3, 25, 50, 60	50, 60
Nominal current I_r (A)	630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000	1200, 2000, 3000 ①
Short-circuit current I_{sc} (kA)	10, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80	Same R10 Series as IEC
Short-time current I_k (kA)	$I_k = I_{sc}$	$I_k = I_{sc}$
Peak withstand current I_p (A)	2.5 x I_{sc} (50 Hz) 2.6 x I_{sc} (60 Hz)	2.5 x I_{sc} (50 Hz) 2.6 x I_{sc} (60 Hz)
Duration of short-circuit t_k	1s (option 0.5s and 2s)	2s
Operated sequence O = Open C = Close	O–3m–CO–3m–CO optional: O–0.3s–CO–3m–CO O–0.3s–CO–1m–CO O–0.3s–CO–15s–CO CO–15s–CO	O–15s–CO–3m–CO Option: O–0.3s–CO–3m–CO
Mechanical operation	M1 = 2000 Option M2 = 10,000	1500 to 10,000
Electrical operation	Option for E2—980% min.	800% I_t

① 4000A rating is available from most IEEE suppliers.

The development of sealed interrupters using vacuum as the dielectric medium has greatly improved both maintenance intervals and the life expectancy of circuit breakers over the last several decades. Contacts do not corrode, and arcing on some vacuum interruptions is no more than defuse blue plasma. Synthetic lubricants and precision computer designed parts allow manufacturers to design circuit breakers with capabilities well beyond the limits shown in **Table 2**.

Most manufacturers have the capabilities to run these no-load tests in house, but obtaining a third-party certificate is desirable to most users. Electrically, the IEEE breaker must sustain 800% I_t without maintenance. The IEC standard does not have an equivalent mandatory requirement unless the optional electrical duty Class E2 rating is specified by the purchaser.

Thermal load requirements

Rated current is the capability of the breaker to carry the rated load current when the breaker contacts are closed and conducting current continuously. The standards set different temperature limits for current carrying parts, connection points, and contacts. The allowed temperature rise for the insulating parts vary based on the insulating class used and the ambient temperature of the air surrounding the equipment.

Temperature is a function of the resistance of the conductor and the square of the current flowing through that conductor. The expected life of the insulation is an inverse power function of the temperature of the conductors where they contact the surface of the insulation. The rule of thumb is that if the temperature increases by 10 degrees, the insulating life is reduced by one half.

When comparing thermal capabilities of circuit breakers, the IEEE standard is more conservative as outlined by **Table 3**.

Table 3. Temperature Limits

	Temperature Limits °C Above a 40°C Ambient			
	IEC 62271		IEEE C37	
Description	Air	SF_6	Air	SF_6
Bare-copper contacts	75	105	70	90
Silver-coated contacts	105	105	105	105
Bare-copper connections	90	115	70	100
Silver-plated connections	115	115	105	115
Tin-plated connections	105	105	105	105
Bare-copper to silver-plate	115	—	70	—
Normally touched parts	70	—	50	—
Not normally touched parts	80	—	70	—

Note: From Table J.1 of C37.100.1 (most stringent listed).

For the temperature rise test, the temperatures of conductors are measured by thermocouples placed on the part. For measuring the ambient temperature, oil-filled containers are used to reduce temperature variations. Three measuring points are specified at 3 feet from the circuit breaker. One measurement is at the top, one at the bottom, and one in the middle.

The standards have set no limit for the contact temperatures of a vacuum breaker. The unspecified limit is attributed to the endurance capacity of the vacuum interrupter relative to air, oil, and gas circuit breakers.

Capacitor switching

Capacitors are often applied to the electrical grid to stabilize voltages following power distributions and to improve power quality. The preferred circuit breaker for capacitor switching is one that has a low probability of restrike. If the circuit breaker is unable to successfully interrupt, the transient voltage can escalate on successive re-strikes. Therefore, the standards have set series of test procedures and ratings to help establish the circuit breakers capacitor switching capabilities. **Table 4** outlines the optional tests that can be conducted on breakers intended for use on capacitor circuits.

Table 4. Capacitor Switching

Description	IEC 62271-100	IEEE C37
Capacitor switching classes	C1 = low probability of restrike C2 = very low probability of restrike	C0 = 1 restrike/operation OK C1 same as IEC C2 same as IEC
Cable charging breaking current I_c	10, 25, 31.5A optional	10, 25, 31.5A mandatory
Single capacitor bank breaking current	400A	250, 400, 630, 1000, 1600A
Back-to-back capacitor bank breaking current	400A	400, 630, 1000, 1600A
Inrush making current	20 kA	15, 20, and 25 kA
Frequency of inrush current	4.25 kHz	1.3, 2, and 4.3 kHz

If a capacitor exists on both the line and load side, it is referred to as a back-to-back capacitor bank. IEEE has three ratings—C0, C1, and C2—with C1 and C2 being equivalent to the defined IEC ratings. A significant difference between the standards is that IEEE requires the manufacturer to conduct cable capacitance switching while IEC does not.

Testing

The prototype breaker used for the design must be tested in accordance with the standards. **Table 5** outlines some of the key test requirements. IEEE C37.06 requires the breaker to switch currents in the range of 3% to 7% and 95% to 100%. IEEE breakers must also undergo single-phase asymmetrical testing. The IEEE circuit breaker that meets C37.54 criteria must successfully clear a series of fault interruptions that accumulate to 800% of the rated short-circuit capacity of the breaker.

Table 5. Testing ①

Description	IEC 62271-100	IEEE C37
Circuit time constant for asymmetry (%DC)	45 ms; options 50, 75, 120 ms	45 ms ②
Outdoor breakers TRV	Same as indoor	More severe
Peak value	$U_c = 1.715 \times U_r$	$U_c = 1.15 \times U_r$
RRRV—Class S1	Harmonized	Harmonized
RRRV—Class S2	—	Time to peak ~ 50% faster
Max. interrupting time	No limit ③	50 ms and 83 ms
Single-phase short circuit	O is optional	O and O
Single-phase asymmetrical	Not required	O and O
Double-line-to-earth fault breaking current test	$0.87 \times I_{sc}$ @ U_r is optional	Not required
Short-circuit endurance tests	Optional E2	800% x I_t asymmetrical
Load current breaking		
3% to 7% of I_r	Not mandatory	(3) C-O
95% to 100% of I_r	Not mandatory	(3) C-O
Out-of-phase switching	Not mandatory	Not mandatory

① Table is for breakers less than 40 kV.

② Generator breakers have different parameters.

③ Interrupting time to be measured and reported.

Conclusion

The requirements of IEEE, for the most part, equal or exceed IEC requirements. The reason for this is user participation at IEEE meetings. Standard voting is based on individual for IEEE and by country for IEC. **Table 6** provides a current summary of some of the key differences between the standards.

Table 6. Summary

Description	IEC	C37
Maximum interrupting time	Not required	50 and 83 ms
Short time duration	1 second	2 seconds
Operating duty (basic)	O-3m-CO-3m-CO	O-15s-CO-3m-CO
Electrical endurance	Short circuit only	800% of I_t
Normally touched parts	70°C	50°C
Abnormally touched parts	80°C	70°C
Copper contacts	80°C	75°C
Bare-copper connections	90°C	70°C
Silver connections	115°C	105°C
Silver to bare copper	115°C	70°C
PFWV/rated voltage ①	2.3	3.0
LIWV/rated voltage ①	4.4	7.9
Continuous current ratings	R10 series	Three listed ratings
Voltages specifically listed	World	North America
Single-phase asymmetrical test	Not required	Required
Cable capacitance switching	Not required	Required
Number of capacitor switch ratings	1	5
Load switching	Not required	Required
Double earth fault	Option	Not addressed
RRRV on outdoor breakers	Same as indoor	50% higher
Mechanical endurance	2000	1500 to 10,000

① PFWV and LIWV is the average of all ratings from 3.3 to 38 kV.

Note: C37.20.2–IEC 62271-1, 100, and 200 comparison.
C37.100.1 bare copper connections are 20°C higher than C37.20.2.

The test laboratories, at great expense, design circuits to simulate the system characteristics required and defined by the standard. It is expected of the manufacturer to meet all the minimum requirements of the standard. The loss of just one breaker could result in an entire plant shutdown. It is important that the user and the manufacturer check for compliance to the standards.

Author

Stephen M. Cary is a principal engineer at Eaton in Pittsburgh, PA, and is responsible for medium voltage codes and standards. Steve has more than 20 years of application engineering experience and has authored a number of IEEE technical papers. He has a mechanical engineering degree from Michigan State University and an MBA from the University of Pittsburgh. Currently, he is secretary of the IEEE C37.04 working group.

References

[1] C37.04-1999 IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers, and Addendums a (2003) and b (2008), Institute of Electrical and Electronics Engineers, 3 Park Avenue, New York, NY 10016-5997.

[2] C37.06-2009 IEEE Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Capabilities for Voltages Above 1000V, Institute of Electrical and Electronics Engineers, 3 Park Avenue, New York, NY 10016-5997.

[3] C37.09-1999 IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, and Addendums a (2005) and b (2010), Institute of Electrical and Electronics Engineers, 3 Park Avenue, New York, NY 10016-5997.

[4] C37.54-2002 American National Standard for Indoor Alternating Current High-Voltage Circuit Breakers Applied as Removable Elements in Metal-Enclosed Switchgear—Conformance Test Procedures—National Electrical Manufacturers Association, 1300 North 17th Street, Rosslyn, VA 22209

[5] IEC 62271-100 Ed. 2.2 High-voltage switchgear and controlgear Part 100 High-voltage alternating-current circuit-breakers International Electrotechnical Commission 3, rue de Varembe, Geneva 20, Switzerland.

[6] IEC 62271-200 High-voltage switchgear and controlgear Part 200, AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV International Electrotechnical Commission 3, rue de Varembe, Geneva 20, Switzerland.

Eaton
1000 Eaton Boulevard
Cleveland, OH 44122
United States
Eaton.com

Printed in USA
Publication No. WP012001EN / Z13645
May 2013