Ensuring Recloser Control Compliance With IEEE C37.60–2003 Testing

Matthew B. Watkins and Mark Zeller
Schweitzer Engineering Laboratories, Inc.

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Matthew B. Watkins and Mark Zeller, *Schweitzer Engineering Laboratories, Inc.*

***Abstract*—This paper examines the testing criteria and application of recloser control standards and also discusses the importance to the end user of testing to compliance standards.**

Recent changes to the *IEEE Standard C37.60, IEEE Standard Requirements for Overhead, Pad-Mounted, Dry Vault, and Submersible Automatic Circuit Reclosers and Fault Interrupters for Alternating Current Systems Up to 38 kV,* have improved the specifications and requirements for testing that are needed to ensure compliance. Standards created by organizations, such as IEEE, represent industry-wide efforts to ensure product robustness. Customers and suppliers use standards to establish baseline performance requirements. The *IEEE Standard C37.60–2003* allows modular testing of components and includes testing and acceptance criteria. Using IEEE standards and tests allows recloser control manufacturers and customers the security of compliance across recloser manufacturers and models.

I. Introduction

Volunteers, representing industry professionals with various interests, develop IEEE standards. The IEEE does not perform tests to verify accuracy of information within the documents nor does it perform tests on equipment indicating compliance to a standard. Use of these standards, by both equipment end users and manufacturers, is voluntary [1].

The *IEEE Standard C37.60* specifies in great detail both the design and production requirements for overhead switchgear mechanisms. Advancements in recloser technology drove the desire for the previously approved 1981 standard to be revised, which was approved in 2003. Informed customers recognize these changes do not address recloser control design and production testing. Although these standards provide an excellent resource for recloser testing, to ensure the recloser control design integrity, customers should consider other IEEE standards that are more relevant and strict in the design and production of protective controls.

II. IEEE Standard C37.60 Background

Electric utilities have used reclosers to improve reliability since the 1940s. Originally, reclosers were available only as single-phase devices, three-phase versions were offered in the 1950s. Technology limited the use of an electronic control to a mechanical-based hydraulic mechanism.

Control mechanisms are required to determine when the recloser should open or close its contacts. Hydraulic mechanisms required the use of a series trip coil, series trip solenoid, hydraulic pump, and lockout piston for control [2]. These components are integral to the recloser mechanism. Control technology changed in the 1960s to include external electromechanical controls, similar to electromechanical relays. Finally, microprocessors changed recloser technology in the 1980s and drastic improvements continued throughout the 1990s when recloser controls from several manufacturers became available.

Revision history of the *IEEE Standard C37.60–2003* includes the versions approved in 1981 and 1974. From 1974 to present, revisions focus on "significant improvements which reflect the present state of the art in recloser technology" [3].

III. IEEE Standard C37.60 Revision History

Recloser controls have made significant technological advancements in the 1980s and 1990s; however, these advancements have not been noted in revisions to *IEEE Standard C37.60–2003.* Revision history from *IEEE Standard C37.60–1974* includes items such as advancements in vacuum interrupting and submersible reclosers. Surge withstand capability testing was also included for recloser controls and partial discharge tests were "recognized" for some reclosers, however, not required [3]. Prior to 1981, only electromechanical type controls were available and the additional surge testing requirements were appropriate.

However, between 1981 and 2003, microprocessor-based recloser controls entered the industry and, since the late 1990s, electromechanical recloser controls have virtually become extinct. Surprisingly, though, of the 15 changes highlighted in the *IEEE Standard C37.60–2003* revision, one addressed recloser controls. This revision is presented only as an informative annex (Annex B), rather than a recloser control design or production test requirement. Other, more definite design and production test requirements listed in *IEEE Standard C37.60–2003* include gas-insulated reclosers, modification to voltage and interrupting ratings, and required partial discharge testing [1].

IV. IEEE Standard C37.60 Analysis

IEEE Standard C37.60–2003 is divided into several major sections including: definitions, ratings, design tests (type tests), production tests (routine tests), and construction requirements. Recloser control customers should evaluate the importance of informative Annex B and be aware of the problems it addresses that can lead to improper control operation. For many of the sections in Annex B, other IEEE standards must be reviewed for a complete understanding of the product requirements.

A. Definitions

Unit operation in reference to a recloser is the only term defined in *IEEE Standard C37.60–2003 (see Fig. 1)*; however, the standard does describe the following three tests.

“1. ***Control Electronic Elements Surge Withstand Capability (SWC) Tests****. The control must withstand, without damage, voltage surges originating in the low-voltage energy source, in either or both of the current and voltage transformers connected to the control elements, or in the control leads connecting the recloser and control elements.*

2. ***Mechanical Duty Test****. 2000 close-open operations performed by the recloser without maintenance.*

3. ***Switching Tests****. Tests performed to demonstrate the capability of the recloser to interrupt all load currents up to and including the assigned rated continuous current.”*

For additional term definitions, *IEEE Standard C37.60* references *IEEE Standard C37.100–1992*. Specific to the discussion in this paper, the following terms are defined in *IEEE Standard C37.100–1992* [4]:

“1. ***Automatic Circuit Recloser****. A self-controlled device for automatically interrupting and reclosing an alternating-current circuit, with a predetermined sequence of opening and reclosing followed by resetting, hold-closed, or lockout operation.*

Note*: when applicable, it includes an assembly of control elements required to detect overcurrents and control the recloser operation.*

2. ***Calibration****. The adjustment of a device to have the designed operating characteristics, and the subsequent marking of the positions of the adjusting means, or the making of adjustments necessary to bring operating characteristics into substantial agreement with standardized scales or markings.*

3. ***Design Tests****. Those tests made to determine the adequacy of a particular type, style, or model of equipment with its component parts to meet is assigned ratings and to operate satisfactorily under normal service conditions or under special conditions if specified.*

Note*: design tests are made only on representative apparatus to substantiate the ratings assigned to all other apparatus of basically the same design. These tests are not intended to be used as a part of normal production. The applicable portion of these design tests may also be used to evaluate modification of a previous design and to assure that performance has not been adversely affected. Test data from previous similar designs may be used for current designs, where appropriate.*

4. ***Dielectric Withstand-Voltage Tests****. Tests made to determine the ability of insulating materials and spacing to withstand specified overvoltages for a specified time without flashover or puncture.*

5. ***Interrupting Tests****. Tests that are made to determine or check the interrupting performance of a switching device.*

6. ***Making Current Capability****. The value of the available current at the time the device closes.*

7. ***Partial Discharge****. A localized electric discharge resulting from ionization in an insulation system when the voltage stress exceeds the critical value. This discharge partially bridges the insulation between electrodes.*

8. ***Production Tests (for switchgear)****. Those tests made to check the quality and uniformity of the workmanship and materials used in the manufacture of switchgear or its components.*

9. ***Radio-Influence Tests****. Tests that consist of the application of voltage and the measurement of the corresponding radio-influence voltage produced by the device being tested.*

10. ***Temperature-Rise Tests****. Tests to determine the temperature rise, above ambient of various parts of the tested device when subjected to specified test quantities.*

11. ***Trip or Tripping (adj) Used in Reference to Minimum Tripping Current****. Pertaining to a release that initiates an opening operation only.”*

B. Ratings

Section 5 of the *IEEE Standard C37.60–2003* specifies the rating that must be defined for a recloser. These ratings include: rated maximum voltage, rated power frequency, rated continuous current, rated minimum tripping current (series-trip reclosers only), rated symmetrical interrupting current, rated symmetrical making current, rated lightning impulse with-stand voltage, and rated control voltage. Only one of these ratings refers to recloser controls.

Rated control voltage is defined in Section 5.9 of *IEEE Standard C37.60* and indicates the “preferred rated control voltages for the control power supply of the switching and interrupting devices.” Table 7 of *IEEE Standard C37.60 s*pecifies the preferred power supply ratings of the switching and interrupting device. Many reclosers require external ac or dc power sources for operation, such as the following:

1. Potential transformers
2. Substation battery supplies
3. Internal control battery power

When these power sources are operating with the maximum operating current flowing, the interrupting mechanism should operate over the ranges provided. Recloser control operating voltage range is not specified within Table 7.

C. Design Tests

Section 6 of *IEEE Standard C37.60* defines the design test requirements for reclosers and fault interrupters. The product is qualified using design tests to ensure compliance with the intent of the standard. Manufacturers must repeat design tests if product modifications include performance changes. Otherwise, these tests are only conducted once to confirm compliance to the standard.

According to the definitions listed in Section IV of this paper, manufacturers can perform the following design tests, in accordance with *IEEE Standard C37.60–2003,* without being connected to a recloser control [1]:

1. Insulation (dielectric) tests
2. Switching tests
3. Making current capability tests
4. Rated symmetrical interrupting current tests
5. Partial discharge (corona) tests

6. Radio influence voltage tests (RIV)
7. Surge current tests—series-trip reclosers/fault interrupters (FI)
8. Temperature rise test
9. Mechanical duty test

Recloser controls must meet the following tests [1]:

1. Minimum tripping current test
2. Time-current tests
3. Control electronic elements surge withstand capability (SWC) tests

1) Minimum Tripping Current Test

Reclosers must pass a minimum tripping current test. Current is applied at 80% of the minimum tripping current and slowly increased. At the time of the trip, the current must be ±10% of the expected trip. This test can be easily performed with any recloser control.

2) Time-Current Tests

Time-current tests are conducted at 25°C, ±2°C. Section 6.11.2.2 of *IEEE Standard C37.60–2003* identifies methods for performing contact parting time-current tests based on Fig. 1. As shown in Fig. 1, contact-parting time is the addition of the control's release delay (control response time) and the opening time of the recloser mechanism. With consistent recloser mechanism operation, the recloser control can be easily tested for proper response time for a specific overcurrent value.

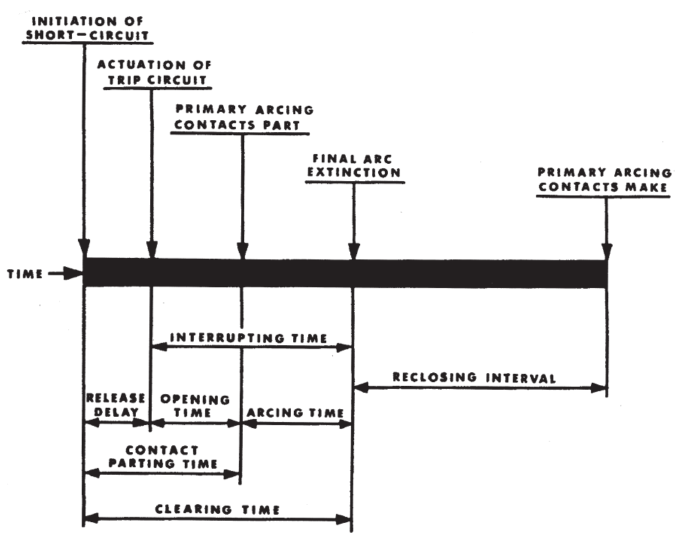

Fig. 1 Recloser Unit Operation [1]

3) Control Electronic Elements Surge Withstand Capability (SWC) Tests

The SWC tests must be performed on the recloser and control. This is the key test to establish recloser control compatibility. These tests are commonly performed using a third-party test lab. The recloser and control element is subjected to simulated fast lightning surges. Voltage changes are monitored based on the rate of current change and the impedance of the ground connection. Fig. 2 illustrates the test setup.

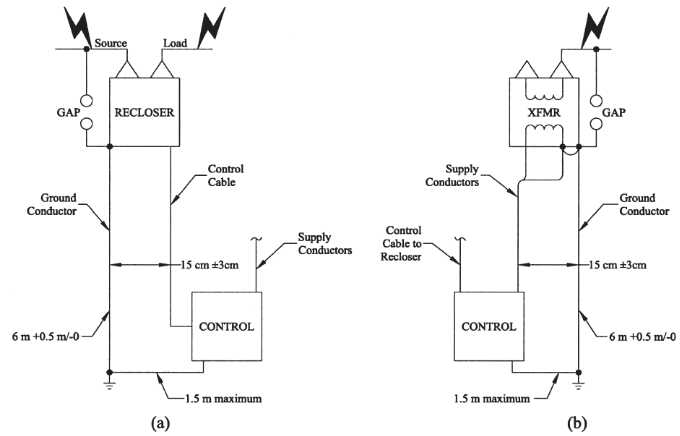

Fig. 2 Surge Withstand Test Circuit [1]

D. Production Tests

Section 7 of *IEEE Standard C37.60–2003* recommends manufacturers perform the following routine tests on all products prior to shipment [1].

1. Calibration.
2. Control, secondary wiring and accessory device test.
3. Dielectric withstand test, 1-minute dry power frequency.
4. Partial discharge test.
5. No-load mechanical operation test.
6. Water leak test, submersible reclosers/FI only.
7. Gas leak test (gas-filled reclosers/FI only).

Similar to the list of design tests, the majority of these tests apply to the recloser mechanism. Only the first two tests (calibration and control, secondary wiring, and accessory device tests) apply to recloser controls.

Calibration is defined in Section IV of this paper. Section 7.1 of *IEEE Standard C37.60* states, "Calibration may be performed on the individual control elements subassembly prior to final assembly on the recloser," and recommends calibrating the following items [1]:

1. Minimum tripping current test
2. Trip settings
3. Time current tests
4. Sequence tests
5. Remote features
6. Special features

Compliance with this standard requires manufacturers to, at a minimum, include calibration results of these items in their production test report.

IEEE Standard C37.60–2003 requires a control, secondary wiring, and accessory device test for the recloser control. This test can include a continuity check for circuits to verify operation. Accessory-specific tests should also be performed, however, the standard does not address all available accessories and tests specific to each accessory to ensure proper operation.

E. Construction Requirements

Section 9 of *IEEE Standard C37.60* describes the construction requirements for reclosers/FIs. Items include, tank construction, insulating medium indicators, oil sampling, manual operation, position indication, nameplate markings, stored energy mechanism charge indicator, enclosure integrity, counters, and conductor terminal sizes [1]. Besides the nameplate markings, these items are not specific to the recloser control.

F. Informative Annex B

IEEE C37.60–2003 Annex B provides additional information relating to simulated surge testing.

> *"Experience has shown that an electronic control built and tested to meet the preceding standards may often misoperate or be permanently damaged after exposure to lightning surges normally encountered on a distribution power system."*

Annex B also lists IEEE surge testing standards that were developed from EMC protection practices commonly used in substations. For example, electromagnetic compatibility can be successfully reduced in substation construction by using greater distances between switchgear and controls [1].

Testing beyond *IEEE Standard C37.60* is required to reduce the likelihood of misoperation due to electromagnetic interference. Electromagnetic disturbances in the recloser control can result in a variety of problems including CPU resets, display lockouts, and others. **Manufacturers must recognize the need for reliable products and be innovative in developing tests to ensure proper operation even in the harshest environments** [1].

V. Testing Beyond IEEE Standard C37.60–2003

The IEEE and IEC have long histories of providing useful standards to improve performance and reliability of electrical equipment. The *IEEE Standard C37.60–2003* references many other IEEE and IEC standards in Annex B. *IEEE Standard C37.90 for Relays and Relay Systems Associated with Electric Power Apparatus* [5] and *IEC 60255 for Protective Relays* [6] provide excellent specifications that should be evaluated for application to recloser controls. A useful analogy is the relationship of a circuit breaker and the corresponding microprocessor-based protective relay.

IEEE Standard C37.90 defines a relay as follows:

> *"an electric device designed to respond to input conditions in a prescribed manner and, after specified conditions are met, to cause contact operation or similar abrupt change in associated electric control circuits. A relay may consist of several relay units, each responsive to a specified input, with the combination of units providing the desired overall performance characteristic of the relay. Inputs are usually electrical but may be mechanical, thermal, or other quantities, or a combination of quantities. Limit switches and similar simple devices are not relays.*
>
> *Relay terminology covers a wide area from the detailed relay structural principles through complex power system relay applications. The following basic areas of power system relay applications provide a convenient method of classification by function:*
>
> 1. *Protective*
> 2. *Monitoring*
> 3. *Regulating*
> 4. *Auxiliary*
> 5. *Reclosing*
> 6. *Synchronism check"*

Clearly this definition of a relay can be applied to modern microprocessor-based recloser controls. Using the circuit breaker/microprocessor-based relay analogy and applying the IEEE standards normally applied to protective relays, users should investigate the advantages of increased testing requirements for recloser controls. Standards typically applied to protective relays include:

1. Dielectric Strength
2. Operating Temperature
3. Environmental Tests
4. Radio Frequency Interference
5. Surge Immunity
6. Impulse Tests
7. Vibration and Shock Tests
8. Electrostatic Discharge Tests

While there continues to be value in type testing the recloser with the associated recloser control, testing of the control can be expanded to include type testing used for other protective relays. A typical specification for applying relay specifications to recloser controls is outlined below.

A. Dielectric Strength

Dielectric strength requirements in *IEEE Standard C37.60* Section 6.2 are mainly directed at the recloser mechanism. Improper dielectric strength can result in a false trip, failure to trip, destruction of the relay, and risk to the operator. Dielectric strength testing from *IEEE Standard C37.90* and *IEC 60255* can be applied to a recloser control [7] [8]. These tests apply 2000 volts ac on all analog inputs and contact inputs and outputs (I/O), 2500 volts ac on the ac current inputs, and 2830 volts ac on the power supply and analog outputs. The system under test should hold these voltages without breakdown to ground.

B. Operating Temperature

Recloser controls are subject to temperature gradients of the area of installation. In addition, the temperature of the control inside an enclosure is higher than the ambient air temperature. This increased temperature is due to both direct solar heating and heat generated by the recloser control. Depending on the manufacturer, this increase can approach 20°C. Life expectancy of electrical equipment has a direct correlation to the rated operating temperature. Proper specification of the equipment will result in longer, more reliable service. *IEC 60068-2-1* and *-2-2* provide environmental testing procedures applicable to recloser controls [9] [10]. The manufacturer typically specifies the testing temperature range. A wider operating temperature range is a key indicator of life expectancy and reliability. Make sure the rated operating temperature range is compatible with the expected installation conditions, and make sure the heat buildup inside any enclosure is accounted for when evaluating the proper operating temperature range.

C. Environmental Tests

Recloser controls are typically field-mounted devices subject to temperature variations and weather extremes. Additional type testing of the recloser controls to withstand these variations will result in better product reliability. The customer should evaluate the recloser control and the enclosure as noted in the following paragraph from *IEC 60068-2-30* [11].

> *"IEC 60068 determines the suitability of components, equipment or other articles for use, transportation and storage under conditions of high humidity—combined with cyclic temperature changes and, in general, producing condensation on the surface of the specimen. This testing simulates extreme environmental conditions assuring proper operation in all types of weather conditions."*

The *IEC 60529* standard describes a system for classifying the degrees of protection provided by the enclosures of electrical equipment [12]. Users should properly select the level of enclosure needed for the environment in which the recloser will be installed.

D. Radio Frequency Interference and Interference Tests

Section 6.8 of *IEEE Standard C37.60–2003* requires testing of the recloser for radiated emissions. This test measures the radio interference emitting from the recloser. Radio Frequency Interference (RFI) is also a concern for the recloser control. Excessive RFI can cause misoperation of the control. High resistance to RFI enables the control to properly operate during fault and transient conditions. Additionally, many modern reclosers include radio communications or another communications interface. Special care should be given to ensure the radio transmission or other communication does not interfere with the operation of the recloser control. Applying *IEEE Standard C37.90* to the recloser control can protect against possible RFI misoperation. *IEEE Standard C37.90* and *IEC 60255* provide excellent testing criteria [13–16]. Immunity tests are typically performed both at 10 volts/meter and 35 volts per meter. Fast transient, burst immunity include 4000 volts at 2.5 kHz, 2000 volts at 5.0 kHz, 2500 volts oscillatory, and 4000 volts fast transient.

E. Surge Immunity

In addition to the complete system test in *IEEE C37.60* performed on the recloser and control, individual testing from *IEC 60255*, *IEC 61000*, and *IEEE C37.90* for surge immunity and surge withstand can be applied to the recloser control [17]–[21]. Surge immunity tests are 2000 volts line-to-line and 4000 volts line-to-earth.

F. Surge Withstand Tests

Field mounting of reclosers and recloser controls subjects them to severe electrical impulses and downed conductors. Section 6.13 of *IEEE Standard C37.60* specifies impulse tests for the recloser and the recloser control as a system. *IEEE C37.90* also provides testing standards for surge withstand testing that should be applied to the recloser control separately [22].

IEC 60255-5 lays down general requirements for the insulation coordination of measuring relays and protection equipment. It gives guidance for the selection of clearances and creepage distances and other aspects related to the insulation of measuring relays and protection equipment; and it also specifies requirements for voltage tests and insulation resistance measurement [23]. This testing includes 2500 volts common-mode, 2500 volts differential mode, and 1000 volts common-mode on communications ports.

G. Vibration and Shock Test

Recloser controls are typically mounted on the poles supporting the recloser. This mounting subjects the control to vibration, jostling, and sometimes sudden bumps. Standardized testing for vibration and shock has been ongoing for protective relays for many years. *IEC 60255* provides clear requirements that can be applied to recloser controls [24]–[27]. Mechanical vibration and shock testing can include bumps up to 10 G and frequencies up to 300 Hz.

H. Electrostatic Discharge Test

Electrostatic discharges are a common problem facing electronics today. Charges can be transferred through connection cables or even human contact. Circuitry in today's microprocessor-based relays can withstand electrostatic discharges. Proper design and construction can provide significant immunity to all parts of the protective relay including the communications ports, case, and pushbutton interface. *IEC 60255* provides standards for testing the protective relay [28]. Electrostatic discharge immunity severity level 4 includes testing levels of 8000 volts contact discharge, and 15,000 volts air discharge.

VI. Summary

IEEE Standard C37.60–2003 provides standards and testing criteria for reclosers and recloser controls. These standards do not specify the interface or connection requirements. Each manufacturer is free to design and construct the recloser and control with a great deal of latitude. Testing to the *IEEE Standard C37.60–2003* ensures the performance of the recloser and control under a variety of circumstances. *IEEE Standard C37.60–2003* is mainly focused on the performance of the recloser mechanism. Some of the testing does include the recloser control. The standard allows for production testing the recloser separate from the recloser control. This allows purchasers the flexibility to connect *IEEE Standard C37.60–2003*-tested equipment together and still meet the requirements of the standard. Compatibility between reclosers and recloser controls is a requirement of the individual manufacturer and is not stipulated by *IEEE Standard C37.60–2003*.

Specifying compliance with *IEEE Standard C37.60–2003* is a good start to ensuring the performance of a recloser. Additional testing to existing IEEE and IEC standards for protective relays can be a valuable addition to the specifications of a recloser and control system.

VII. Recommendations

When specifying a recloser and recloser control, add testing requirements that will increase the reliability and robustness of the system. IEEE and IEC provide excellent standards for protective relays that have been proven effective for equipment in the power industry.

Application of these standards will help ensure that the recloser and recloser control installation will provide reliable, robust service in all conditions. Compatibility and reliability are performance guaranties by the manufacturers. Choose equipment that meets or exceeds IEEE and IEC standards for protective relays as well as the IEEE standards for reclosers.

The IEEE standards committees are constantly reviewing and recommending changes to the standards. User participation in this review is encouraged. This participation will have far reaching positive effects on the recloser and recloser control testing and certification.

VIII. References

[1] *IEEE Standard C37.60–2003, IEEE Standard Requirements for Overhead, Pad-Mounted, Dry Valt, and Submersible Automatic Circuit Reclosers and Fault Interrupters for Alternating Current Systems up to 38 kV*, 2003, IEEE.

[2] Cooper Power Systems, *Electrical Apparatus 280-10 Reclosers*, June 1999.

[3] *IEEE Standard C37.60–1981, IEEE Standard Requirements for Overhead, Pad-Mounted, Dry Valt, and Submersible Automatic Circuit Reclosers and Fault Interrupters for Alternating Current Systems up to 38 kV*, 1981, IEEE.

[4] *IEEE Standard C37.100–1992, IEEE Standard Definitions for Power Switchgear*, 1992, IEEE.

[5] *IEEE Standard C37.90, IEEE Standard for Relays and Relay Systems Associated With Electric Power Apparatus*, IEEE.

[6] *IEC 60255 for Protective Relays.*

[7] *IEEE C37.90–1989, IEEE Standard for Relays and Relay Systems Associated With Electrical Power Apparatus*, Section 8: Dielectric tests, Severity Level: 2500 Vac on contact inputs, contact outputs, and analog inputs. 3100 Vdc on power supply. Type tested for 1 minute. 1989, IEEE.

[8] *IEC 60255-5–2000, Dielectric Tests, Electrical Relays*, Part 5: Insulation tests for electrical relays, Dielectric tests, Severity Level: 2500 Vac on contact inputs, contact outputs, and analog inputs. 3100 Vdc on power supply. Type tested for 1 minute.

[9] *IEC 60068-2-1–1990, 1993, 1994, Environmental Testing Procedures*, Part 2: Tests—Test Ad: Cold (type test).

[10] *IEC 60068-2-2–1974, 1993, 1994, Environmental Testing Procedures*, Part 2: Tests—Test Bd: Dry Heat (type test).

[11] *IEC 60068-2-30–1980, 1985, Basic Environmental Testing Procedures,* Part 2: Tests—Test Db and Guidance: Damp Heat, Cyclic (12 + 12-hour cycle), Severity Level: 25^{o} to 55^{o}C, 6 cycles, Relative Humidity: 95%.

[12] *IEC 60529–2001, 1992, Degrees of Protection Provided by Enclosures (IP code): Object Penetration and Dust Ingress.*

[13] *IEEE C37.90.2–1995, 2004, IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference From Transceivers*, Severity Level 35 V/m (type test).

[14] *IEC 60255-22-1–2005, Electrical Disturbance Tests for Measuring Relays and Protection Equipment*, Part 1: 1 MHz Burst Disturbance Tests, Severity Level 3: 2.5 kV peak common mode, 2.5 kV peak differential (type test).

[15] *IEC 60255-22-3–2000, Electrical Relays, Section 3: Radiated Electromagnetic Field Disturbance Tests*, Severity Level 3 (10 V/m) (type test).

[16] *IEC 60255-22-4–2002, Electrical Disturbance Tests for Measuring Relays and Protection Equipment*, Section 4: Fast Transient Disturbance Test, Severity Level 4 kV at 2.5 kHz and 5 kHz (type test).

[17] *IEC 60255-22-5–2002, Electrical Relays*, Part 22-5: Electrical Disturbance Tests for Measuring Relays and Protection Equipment, Surge Test, Severity Level: 1 kV Line to Line, 2 kV Line to Earth.

[18] *IEC 61000-4-5–1995 + A1:2001, 1996, Electromagnetic Compatibility (EMC)*, Part 4: Testing and Measurement Techniques, Section 5: Surge Immunity Test, Severity Level: 1 kV Line to Line, 2 kV Line to Earth.

[19] *IEC 60255-22-1–2005, Electrical Relays—Electrical Disturbance Tests for Measuring Relays and Protection Equipment*, Part 22-1: 1 MHz Burst Disturbance tests, Severity Level: 2.5 kV peak common mode, 1.0 kV peak differential mode.

[20] *IEEE C37.90.1–2002, Surge Withstand Capability (SWC), Tests for Protective Relays and Relay Systems Associated With Electric Power Apparatus*, Severity Level: 2.5 kV oscillatory, 4 kV fast transient waveform.

[21] *IEC 61000-4-12–2001, 1996 + A1:2001, Electromagnetic Compatibility (EMC)*, Part 4-12: Testing and Measurement Techniques—Oscillatory Waves Immunity Test, Severity Level: Ring Wave: 2 kV peak common and 1.0 kV peak differential; Oscillatory: 2.5 kV common and 1.0 kV differential.

[22] *IEEE C37.90.1–1989, IEEE SWC Tests for Protective Relays and Relay Systems,* Severity Level: 4 kV at 2.5 kHz oscillatory, 5 kV fast transient (type test).

[23] *IEC 60255-5–2000, Electrical Relays*, Part 5: Insulation Tests for Electrical Relays, Section 6: Dielectric Tests, Series C (2500 Vac on analog inputs; 3000 Vdc on power supply, contact inputs, and contact outputs) and Section 8: Impulse Voltage Tests, 0.5 Joule 5 kV (type test).

[24] *IEC 60255-21-1–1988, 1996 + A1:1996, Electrical Relays*, Part 21-1: Vibration, Shock, Bump and Seismic Tests on Measuring Relays and Protection Equipment, Section 1: Vibration Tests (sinusoidal), Severity Level: Class 1 Endurance, Class 2 Response.

[25] *IEC 60255-21-1–1988, Electrical Relays*, Part 21: Vibration, Shock, Bump, and Seismic Tests on Measuring Relays and Protection Equipment, Section 1: Vibration Tests (sinusoidal), Class 1 (type test).

[26] *IEC 60255-21-2–1988, Electrical Relays*, Part 21: Vibration, Shock, Bump, and Seismic Tests on Measuring Relays and Protection Equipment, Section 2: Shock and Bump Tests, Class 1 (type test).

[27] *IEC 60255-21-3–1993, Electrical Relays*, Part 21: Vibration, Shock, Bump, and Seismic Tests on Measuring Relays and Protection Equipment, Section 3: Seismic Tests, Class 2 (type test).

[28] *IEC 60255-22-2–1996, Electrical Disturbance Tests for Measuring Relays and Protection Equipment*, Section 2: Electrostatic Discharge Tests, Severity Level 4 (Equipment is tested at both polarities at levels 1, 2, 3, 4) (type test).

IX. Biographies

Matthew B. Watkins received his BS, Summa Cum Laude from Michigan Technological University in 1996 and an MBA from Cardinal Stritch University in 2003. Prior to joining Schweitzer Engineering Laboratories in 2005, he worked for five years as a distribution protection engineer, responsible for the applications of reclosers throughout the distribution system. Presently he is a product manager for distribution products, including protective relays and recloser controls.

Mark Zeller received his BS, from the University of Idaho in 1985. He has broad experience in industrial power system maintenance, operations and protection. Upon graduating, he worked over 15 years in the pulp and paper industry, where he worked in engineering and maintenance with responsibility for power system protection and engineering. Prior to joining Schweitzer Engineering Laboratories in 2003, he was employed by Fluor to provide engineering and consulting services for Alcoa. He has been a member of IEEE since 1985.

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