SUMMARY OF C37.90.1-2002

By Relaying Practices Subcommittee Working Group I8
Of the IEEE Power Engineering Society Power System Relaying Committee

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I. ABSTRACT

C37.90.1-2002 has been harmonized with the corresponding IEC standards. Two types of design tests for relays and relay systems that relate to the immunity of this equipment to repetitive electrical transients are specified. This paper discusses objectives for the revision of the 1989 ANSI/IEEE standard and identifies commonalities and differences between the IEC standards and this 2002 revision of the IEEE standard.

II. OBJECTIVES OF THIS REVISION

IEEE Standard C37.90.1 has undergone evolutionary change since it was first approved in 1974. Initially it included only the oscillatory test that replicated the transients generated by the interruption or energizing of high voltage high power circuits. The 1989 revision added the fast transient test to replicate the transients generated by the interruption of highly inductive relay coils (as high as 65 Henry in some electromechanical auxiliary relays) in control circuits.

With the passage of time, it became clear that some of the language in the standard lacked clarity and was not well understood. In addition, test sets that were available in 1989 to generate the fast transient test waveform were no longer available, so new approaches were necessary.

Essentially in parallel with the IEEE efforts, the IEC (International Electrotechnical Commission) developed its own standard tests (IEC 60255-22-1 Ed. 1.0(1998-01) and 60255-22-4 Ed. 1.0(1992-03)). These IEC tests were similar, but not identical, to IEEE C37.90.1-1989.

In recent years, the IEEE and IEC have had an objective to harmonize their respective standards. Where possible, the objective was to resolve differences between the IEEE and IEC documents.

Therefore, the Power System Relaying Committee formed a Working Group in 1994 to clarify Standard C37.90.1, to improve understanding, resolve the issue of test sets for the fast transient test, and – where possible – harmonize with the corresponding IEC standard. The specific revisions of the IEC standards that were considered are listed in C37.90.1-2002. A number of revised IEC documents have been issued that are not reflected in this revision of C37.90.1, but will be considered in future revisions.

Quoting from the new 2002 standard:

"1.2 Purpose – The purpose of this standard is to establish a common and reproducible basis for evaluating the performance of relays and relay systems subjected to repetitive transients on supply, signal, control, and communications lines or connections. This standard is to establish that an evaluation is performed during both normal (non-tripped) and abnormal (tripped) relay operating conditions."

The standard includes a number of diagrams as examples of test set ups for small and large equipment, and for the use of various coupling/isolating networks for common mode and transverse mode tests.

In this revision, particular attention was paid to defining the method of coupling test waveforms to "shielded and other circuits where direct galvanic connection to the EUT (equipment under test) terminals may impair operation". For such connections, a capacitive coupling clamp is now to be used for the common mode tests (both oscillatory and fast transient) applied to data communications and signal circuits, Transverse tests are not required for these two groups of circuits.

The new version of the standard includes a substantially expanded clause titled "Criteria for acceptance". That clause is reproduced here in full:

"8 Criteria for acceptance

8.1 Application of criteria

The criteria below shall apply to the equipment being directly tested, and any devices linked to the equipment via direct or remote connections. Examples of the connections are current loops and voltage circuits (DC, audio, carrier, or microwave). Serial, parallel, optical (fiber or infrared), and radio frequency connections apply as well.

8.2 Conditions to be met

The equipment shall be considered to have passed the SWC tests if - during, or as a result of, the tests - all of the conditions below are met for the equipment and the connected devices:

a) The specified performance of the equipment, including the operating time, does not change, beyond stated tolerances.
b) No hardware damage occurs.
c) No change in calibration beyond normal tolerances results.
d) No loss or corruption of stored memory or data, including active or stored settings, occurs.
e) "System resets" do not occur, and manual resetting is not required.
f) Established communications is not permanently lost (i.e., loss of channel or modem disconnections if reliability is in jeopardy).
g) Established communications recovers within an acceptable time period, if disrupted.
h) Communications errors, if they occur, do not jeopardize the protective functions.
i) No loss of digital pulse synchronization occurs, if the loss of synchronization affects externally observable device behavior which results in an out of tolerance condition.
j) No changes in the states of the electrical, mechanical, or communication signal outputs occur. This includes alarms, status outputs, or targets.
k) No erroneous, permanent change of state of the visual, audio, or message outputs results. Momentary changes of these outputs during the tests are permitted.
l) No error outside normal tolerances of the data communication signals (SCADA analogs) occurs."

Clause 8 defines the overall conditions to be met. Given the prevalence today of communications ports on microprocessor based protective relays, it was important to make clear how communications interfaces should be tested. To that end, an Informative Annex D was added. Quoting from that annex:

"**Examples of protective communication configurations:**

The following represents some example configurations and the tests required to comply with this standard. Since equipment varies among manufacturers and application, these examples may not be entirely applicable but will act as a starting point in determining the required test points for similar designs.

Points that should be tested and are common to all examples include:

a) Keying and output connection between the relay system and the communication interface equipment.
b) Alarm and auxiliary I/O connections.
c) Permanently connected substation computers.
d) The power supply inputs to each device.
e) In the situations involving multiplexers that are transporting non-protection logic signals, the non protection inputs are to be tested with observations made on the protection logic signals.
f) Connections between communication interface and communications system equipment should be tested unless these connections must, as stated by the manufacturer(s), be less than 2 meters in length.

Items that can be excluded from testing include:

a) Temporary connected maintenance computers.
b) Connections that, as stated by the manufacturer, must be less than 2 meters in length.
c) Non-metallic connections, such as fiber."

The annex includes eight example configurations:
- Audio tone connected to a leased telephone circuit.
- Power line carrier connected to a hybrid.
- Transfer trip module in a Sonet/T1 shelf.

- Audio tone connected to a microwave multiplex card or a PCM channel bank card in a T1/Sonet shelf.
- A current differential relay connected to a channel bank card via a fiber optic cable.
- A protective relay connected to a modem, where the modem transports the protective relay signal.
- A protective relay with an Ethernet interface, where the Ethernet is used to transport the protective logic signal.
- A phase comparison relay connected to frequency shift keying (FSK) interface equipment and an analog microwave system.

Annex A (normative) defines the method of verifying the test generator characteristics before and after each test session.

Quoting from Annex B (informative): "Delivering a high quality test waveform to the system under test may represent a challenge if all factors involved in signal transmission are not taken into account. This annex gives a brief description of the techniques needed to ensure test repeatability. The waveform delivery components considered are:
- Cable connecting the generator to the coupling network
- Coupling network
- Balanced / unbalanced transformer
- Impedance matching network"

This annex also describes a method of verifying the characteristics of the waveform delivery system.

With few exceptions, most of the tests require both common mode and transverse mode coupling. Yet, due to their internal construction, some test generators may be inherently limited to producing only common mode transients (one output terminal referenced to ground). Annex C (informative) describes a solution to this problem by adding an external balanced/unbalanced transformer network and an isolation network.

III. CHANGES RELATIVE TO C37.90.1-1989

The advancement in knowledge about the transient EMI environment in electric power stations since 1989 and the desire to coordinate with international standards is reflected in the changes made necessary in this standard. This paper will briefly discuss the significant changes under the section numbers of the revised standard follows:

3.0 Definitions

There are 19 definitions listed versus 14 in the 1989 standard. The 5 additional definitions are:

3.1	Calibration
3.4	Input Circuit
3.5	Measuring Unit
3.6	Normal Tolerance
3.10	Relay Interface Equipment

Input Circuit is specifically limited to a circuit for sensing logical state data and does not include ac voltage and current inputs.

4.0 Test Wave Shapes

The changes in the test wave shapes were made to harmonize as much as possible with the corresponding IEC tests. The open circuit oscillatory test voltage shown by Fig. 1 in the standard, is now a damped cosine wave having an initial rise time defined as 75 nanoseconds and an oscillating frequency of 1.0 MHz. The initial crest voltage has been lowered to 2.5 kV. The repetition rate of the oscillatory bursts has been increased from a minimum of 50 per sec to a maximum of 10 per cycle of the power system frequency, (600 per sec). It was felt this better represents the surges generated by switching operations in high voltage stations.

Significant changes were made in the specifications for the fast transient wave shape, most notably in the initial rise time and the repetition rate. Although some sources have argued that these changes make the test much more severe, it must be recognized that the test now more closely simulates surges that have been observed on low voltage control circuit wiring connected to protective relays.

Fig. 2 in the standard shows the fast transient wave shape. It is a double time constant exponential pulse decaying to half of the initial crest voltage in 50 nanoseconds, repeated at a 2.5k Hz rate in bursts lasting 15 milliseconds. The bursts repeat with a period of 300 milliseconds for 1 minute. The initial crest voltage is 4.0 kV. Tests are performed using both positive and negative polarities.

The source impedance has been reduced from 80 to 50 ohms.

In the 1989 standard the pulse rise time was 10 nanoseconds and the maximum initial crest voltage was 5.0 kV. The decay to half value was specified as 150 nanoseconds. There was no burst definition, only the pulse repetition rate was specified as not less than 50 per second and the test duration was 2.0 seconds.

In comparison it is obvious the new standard applies many more surges to the equipment under test, about 7,500 versus 100 for each polarity. Furthermore each test point would require 2.0 minutes to test. This latter requirement is one of the main criticisms because it greatly increases the time required to test relay equipment.

5.0 Test Generator Characteristics:

This section is new and simply specifies that the test generators must produce the output wave shapes already described in section 4.0. However, in section 5.3 it requires common characteristics for all SWC test generators, as follows:

5.3.1 Low frequency and DC blocking internal to the generator by means of a blocking capacitor of 0.1 microfarad.

5.3.2 The use of an external Coupling/Decoupling network to prevent the SWC test voltage being propagated back into the relay AC signal source. Although not specifically described in text, the 1989 SWC standard did show isolating networks in Fig. 3 and Fig. 4. As well as capacitors for low frequency and dc blocking.

5.3.3 A safety ground is required for the test generators. C37.90.1 – 1989 did not specify this.

5.3.4 The generators are required to be able to produce a common mode output where one output terminal is grounded as well as a balanced transverse mode output where both output terminals are floating.

Annex C in this new standard discusses how balanced/unbalanced transformers can be devised. C37.90.1 – 1989 did not address this issue.

6.0 Equipment To Be Tested:

In C37.90.1 – 1989 the points of connection between relays and telecommunications system were required to be determined and then only the relay side of the connections to the telecommunications system needed to be tested.

The new standard requires that all equipment for the purpose of interfacing and transporting protective relay logic be tested. The manufacturer of the communications equipment is required to state which interfaces comply with the standard, state the test application method and acceptance criteria. Table 2 in the standard lists the points of application of the test to relay communications equipment. All system ports are required to be tested. Only temporary communications ports are excepted.

7.3.1 Conditions of Test, and 7.3.3 Reference Ground Plane:

The new standard includes two pictorial drawings, Fig 3 and Fig 4, illustrating the test setup for small relay equipment and for large equipment. Both of the setups require the use of a conducting ground plane of specified dimensions. The physical arrangement of the relays, coupling networks, test generator, and their interconnections are shown and dimensioned. In contrast C37.90.1 – 1989 only showed a schematic wiring diagram of test setups with no physical arrangement or dimensions specified.

7.3.2.2 Capacitive Coupling Clamp

For shielded cables connected to the relay and other circuits where direct connection to the equipment terminals may impair its operation, the use of a capacitive clamp is permitted. It is pictured in Fig. 7. This device has long been specified in other Industrial EMI test standards and also in Military test standards so there is adequate experience relating to its use. C37.90.1 – 1989 did not address the need for this type of test coupling.

8.0 Test Procedures

C37.90.1 – 1989 and this new revised standard are essentially the same in the requirements for applying common mode and transverse mode to connection groups of the relay. The only difference being the somewhat lowered test voltages and the use of a capacitive clamp. Compare Table 3 and Table 4 in the revised standard to the text in section 4. Application of Test Wave in C37.90.1 – 1989.

9.0 Criteria for Acceptance:

There is only one a short paragraph, titled 5.1 Acceptance, in C37.90.1-1989 defining behavior of the relay to be accepted as passing the test. In comparison, the revised standard lists 11 conditions to be met to pass. Exception to these requirements must be stated in the equipment specifications.

Annex A Verification of Test Generator Characteristics:

This annex describes procedures to insure the accuracy and reproducibility of the test results. Some of the procedures listed below must be done before and after each SWC test. This could also increase the time to complete the tests.

- Measurement System Specifications and Calibration
- SWC Waveform Validity Tests
- Measurement System Feed-through Test
- SWC Test Generator Performance Verification

Annex B Test Waveform Delivery

This annex is informative in nature and describes techniques and test procedures that the user is advised to use to achieve reliable results.

Annex C: Balanced/Unbalanced Transformer Impedance Matching Network

This another informative annex already mentioned in 5.3.4. It gives suggestions on test coupling methods. There is no equivalent information in the 1989 standard.

Annex D Communication Interface Equipment and Communication System Equipment.

This is also an informative annex. It provides the reader a fairly complete summary on the various schemes by which a communications system and a protective relay system may be interconnected to provide power system protection. This is a much-needed addition to the standard. C37.90.1 –1989 did not address this subject, probably because the state of communications technology had advanced considerably since the first introduction of the SWC test for relays in 1974.

Annex E Comparison with IEC 60255-22-1 Ed. 1.0 (1988-05) and IEC 60255-22-4 Ed. 1.0(1992-03)

This lists the eight significant differences.

Annex F This is a brief bibliography, only 5 items versus 14 in the original standard.

IV. DIVERGENCE FROM IEC STANDARDS

IEEE C37.90.1-2002 is different from the corresponding IEC standards in three significant aspects that apply to both the oscillatory and fast transient tests.

Energizing current - C37.90.1-2002 requires current flow in current inputs to be 75% of the nominal input current rating. IEC 60255-22-1 Ed. 1.0 (1988-05) and 60255-22-4 (1992-03) require input energizing quantities to be equal to the operating value adjusted both above and below by an amount equal to the claimed variation due to the disturbance voltage, or rated values where appropriate. This requirement may have many different possible values in the case of multi-function relays. The requirement of 75% of rating specified in C37.90.1-1989 has been proven to be adequate and is specified by other IEEE electrical environment standards.

Waveform validity testing - C37.90.1-2002 requires waveform validity testing. Validity testing is not included in IEC 60255-22-1 Ed. 1.0 (1988-05) and 60255-22-5 (1992-03), although it is in 61000-4-4 Ed. 1.0(1995-01) and 61000-4-12 Ed. 1.0(1995-05)
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Acceptance criteria - The IEC standards have three criteria defined for acceptance. The first two require that the relay not mis-operate with the characteristic quantity below or above the operating value, respectively. The third criteria establishes a limit for the off-state current of solid state outputs at 110% of the pre-test value. C37.90.1-2002 expands these to a list of 12 criteria. The longer list of conditions is necessary to better define the criteria for passing the tests, particularly for communications. However, rather than set a post-test/pre-test ratio for off-state current of solid state outputs, C37.90.1-2002 requires that stated tolerances be maintained before and after and during the tests.

In addition to the differences above, there are a few differences in requirements specific to the oscillatory test.

Severity classes - IEC 60255-22-1 Ed. 1.0 (1988-05) defines 3 severity classes that apply to different field conditions. Class 3 applies to installations with long unshielded CT, VT or output leads or where power supply circuits are connected to station batteries not used exclusively to power static equipment. These conditions are common in US utilities and industries. Therefore, IEEE C37.90.1-2002 defines a single class equivalent to IEC 60255-22-1 Ed. 1.0 (1988-05) class 3.

Maximum test lead - IEC 60255-22-1 Ed. 1.0 (1988-05) limits test lead length to 2 meters; however, C37.90.1-2002 requires that test leads be no longer than 1 meter, except when using a capacitive coupling clamp the maximum length is 2 meters. A single maximum lead length for both the oscillatory and fast transient tests is specified to minimize differences in hardware required to perform the oscillatory and fast transient tests.

Transverse mode testing - IEC 60255-22-1 Ed. 1.0 (1988-05) requires that the test be applied both common mode and transverse mode to all inputs and outputs while C37.90.1-2002 does not require transverse mode tests on VT, CT, data communications nor signal circuits. Transverse testing is not required on these circuits because they are not subject to significant transverse mode surges.

Magnitude of transverse mode testing - C37.90.1-2002 requires transverse tests to be conducted using the same surge magnitude as common mode tests while IEC 60255-22-1 Ed. 1.0 (1988-05) specifies a transverse magnitude of one half the common mode magnitude, but allows that the same value can be specified for the common mode and transverse mode tests under special circumstances. C37.90.1-2002 requires the same magnitude surge be applied for both tests because switching of inductive loads such as electromechanical relays may produce transients approaching this magnitude.

Coupling and decoupling network - IEC 60255-22-1 Ed. 1.0(1988-05) recommends 1.5 mH blocking inductors and 0.5 μF coupling capacitors to couple the generator to the equipment under test while IEC 60255-22-4 Ed. 1.0(1992-03), by reference to IEC 61000-4-4 Ed. 1.0(1995-01), specifies 33 nF or greater coupling capacitors and blocking inductors greater than 100 μH. C37.90.1-2002 specifies 1.5 mH blocking inductors and 33 nF coupling capacitors to permit a single coupling network to be applied for both the oscillatory and fast transient tests.

There are only three significant differences between the IEC and IEEE fast transient tests.

Test classes -- IEC 60255-22-4 (1992-03) defines 5 classes of tests ranging from class 0, which applies to conditions where no testing is required, to class 4, which applies to environments in which multi-conductor cables are used for both connections to the protective equipment and other circuits which may be the source of fast transients. Class 4 also applies where the relay or relay system is grounded to a facility grounding system which can be the source of fast transients such as those caused by switching. These conditions are common in US utilities and industries. Therefore, IEEE C37.90.1-2002 defines a single class equivalent to IEC 60255-22-1 Ed. 1.0 (1988-05) class 4.

Application of test - IEC 60255-22-4 (1992-03) requires all input and output circuits to be subjected to a common mode test only. C37.90.1-2002 requires transverse mode testing of power supply and output circuits. The transverse tests are required because power supply and output circuits may be exposed to transverse transients. One source of fast transient disturbances is interruption of inductive loads in secondary control wiring that will be coupled transversely.

C37.90.1-2002 also requires that communication ports be tested using a capacitive coupling clamp at a test voltage of 4 kV because capacitive coupling of transients among bundles of secondary control and communications circuits will be experienced. The communications circuits are run in proximity to other control circuits, in the same disturbance environment as the other port connections. The manufacturer must provide adequate isolation and protection for the ports to avoid damage or protection misbehavior; and/or must recommend suitable shielded-wiring practices to reduce communications port exposure. A capacitive clamp simulates the application environment accurately. The use of a capacitive clamp test allows the manufacturer to take advantage of shielding or wiring recommendations when running the test. With these measures in use, the equipment must survive and be capable of relaying in the face of the full electrical environmental influence

These differences are minor in comparison to the differences between the IEC standards and C37.90.1-1989. The same test hardware can be used for the IEEE and IEC surge tests. The difference in the magnitude of current to be applied has the greatest impact on testing, since in other respects the IEEE test either is the same or requires more testing than is required by the IEC standards. Consequently, a device that passes C37.90.1- will also have passed the IEC tests

V. CONCLUSION

The revised IEEE standard C37.90.1 has been harmonized with the applicable IEC standards Revised IEC documents have been issued that are not reflected in the latest revision of C37.90.1, but will be considered in future revisions. Although some differences remain, it is possible to conduct one set of tests and meet the requirements of both the IEEE and IEC standards.