NEMA SM31000-7 Standard:
Electrical Submeter – Current Sensor Accuracy

Published by

National Electrical Manufacturers Association
1300 North 17th Street
Rosslyn, Virginia 22209
www.nema.org

NOTICE AND DISCLAIMER

The information in this publication was considered technically sound by the consensus of persons engaged in the development and approval of the document at the time it was developed. Consensus does not necessarily mean that there is unanimous agreement among every person participating in the development of this document.

The National Electrical Manufacturers Association (NEMA) Standards and guideline publications, of which the document contained herein is one, are developed through a voluntary consensus standards development process. This process brings together volunteers and/or seeks out the views of persons who have an interest in the topic covered by this publication. While NEMA administers the process and establishes rules to promote fairness in the development of consensus, it does not write the document and it does not independently test, evaluate, or verify the accuracy or completeness of any information or the soundness of any judgments contained in its Standards and guideline publications.

NEMA disclaims liability for any personal injury, property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, application, or reliance on this document. NEMA disclaims and makes no guaranty or warranty, expressed or implied, as to the accuracy or completeness of any information published herein, and disclaims and makes no warranty that the information in this document will fulfill any of your particular purposes or needs. NEMA does not undertake to guarantee the performance of any individual manufacturer or seller’s products or services by virtue of this Standard or guide.

In publishing and making this document available, NEMA is not undertaking to render professional or other services for or on behalf of any person or entity, nor is NEMA undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. Information and other standards on the topic covered by this publication may be available from other sources, which the user may wish to consult for additional views or information not covered by this publication.

NEMA has no power, nor does it undertake to police or enforce compliance with the contents of this document. NEMA does not certify, test, or inspect products, designs, or installations for safety or health purposes. Any certification or other statement of compliance with any health or safety–related information in this document shall not be attributable to NEMA and is solely the responsibility of the certifier or maker of the statement.

FOREWORD

In the preparation of this Standard, input from users and other interested parties has been sought and evaluated. Inquiries, comments, and proposed or recommended revisions should be submitted to the concerned NEMA product subdivision by contacting the:

NEMA Technical Operations Department
National Electrical Manufacturers Association
1300 North 17th Street, Suite 900
Rosslyn, Virginia 22209

This Standard was originally developed by the NEMA BS-SM SM31000 Working Group and announced to ANSI (PINS) under NEMA SM31000-7 designation. NEMA has changed its designation policy in 2021 and subsequently changed the designation of the entire SM31000 standards series to SM31000.

Main contributors were:

Daniel	**Aljadeff**	**Panoramic Power / Centrica**
Henry	**Alton**	**Metergy Solutions Inc. Triacta Power Solutions Division**
Dave	**Bovankovich**	**Quadlogic Controls Corporation**
Nathaniel	**Crutcher**	**Continental Control Systems, LLC**
Craig	**Denson**	**DENT Instruments, Inc.**
Don	**McComas**	**Eaton**
Aaron	**Parker**	**Schneider Electric**

CONTENTS

NOTICE AND DISCLAIMER 2
FOREWORD 3
CONTENTS 4
1 GENERAL 6
  1.1 Scope 6
  1.2 Normative References 6
  1.3 Informative References 6
  1.4 Definitions 7
2 GENERAL REQUIREMENTS 9
  2.1 Markings 9
    2.1.1 Recommended Secondary Outputs 9
  2.2 Documentation 9
3 PERFORMANCE REQUIREMENTS AND TEST PROCEDURES 10
  3.1 Accuracy Classes 10
  3.2 Current Sensor Types 10
  3.3 Current Sensor Output Loading 10
  3.4 Testing Overview 11
    3.4.1 Test Condition Tolerances 11
  3.5 Gain and Phase Tests 11
  3.6 Multiple Frequency Tests 13
  3.7 Effect of Variation of Output Loading 13
  3.8 Temperature Variation 13
    3.8.1 Allowable Error from Temperature Variation 13
  3.9 EMC Requirements and Tests 14
    3.9.1 Current Sensor Design Type EMC Immunity Tests 15
    3.9.2 Active Current Sensor Design Type EMC Immunity Tests 15
ANNEX A VOLTAGE OUTPUT CURRENT SENSORS (VCS) FOR PARALLEL APPLICATIONS 16~~17~~
  A.1 Foreword .... 16~~17~~
  A.2 VCS Parallel Function Explanation .... 16~~17~~
  A.3 VCS Parallel Applications .... 17~~18~~
  A.4 VCS Paralleling Rules .... 17~~18~~
ANNEX B WORKING GROUP DECISIONS AND RATIONALE (INFORMATIVE) .... 18~~19~~
  B.1 Open Tasks .... 18~~19~~
  B.2 Notes and Background .... 18~~19~~
  B.3 Should We Include Potential Transformers? .... 18~~19~~
  B.4 Units .... 18~~19~~
  B.5 Accuracy Limits, Parallelogram .... 18~~19~~
  B.6 Accuracy Classes .... 19~~20~~
  B.7 Current Sensor Output Loading .... 19~~20~~
  B.8 Different Sensor Output Types .... 19~~20~~
  B.9 Harmonics .... 20~~21~~
  B.10 EMC .... 20~~21~~
  B.11 Current Sensor Gain/Phase Limit Table Layout Options .... 21~~22~~
  B.12 Markings .... 21~~22~~
  B.13 Multiple Frequency Tests .... 22~~23~~
  B.14 Phase Angle of a Current Sensor .... 22~~23~~
  B.15 Documentation .... 22~~23~~
  B.16 Rationale for temperature coefficients on sensors .... 22~~23~~
  B.17 Rationale for Testing Overview .... 23~~24~~

B.18 Rationale for Testing Condition Tolerance .... 23~~24~~

1 General

1.1 Scope

SM31000-7 covers metrological requirements and associated testing for current sensors used with electrical energy submeters. The Standard applies to multiple sensor technologies with a variety of outputs. These sensors enable current measurement for AC and DC energy submetering.

The Standard applies to indoor and outdoor applications and covers temporary and permanently installed sensors for AC and DC applications.

The SM31000 Standard is broken into the following parts:

- SM31000-1 General Requirements
- SM31000-2 AC Active Energy Accuracy
- SM31000-4 Additional Measurements Accuracy
- SM31000-5 DC Energy Accuracy
- SM31000-6 Power Quality Measurements and Accuracy
- SM31000-7 Current Sensor Accuracy
- SM31000-8 Demand Metering
- SM31000-9 Field Testing
- SM31000-10: Voltage Sensor Accuracy

1.2 Normative References

In addition to the requirements of this part, products certified to this Standard shall also meet applicable requirements from the following other SM31000 parts.

- SM31000-1 General Requirements
- SM31000-2 AC Active Energy Accuracy

1.3 Informative References

- Canadian Electricity and Gas Inspection Act (R.S. 1985, c. E-4), subsection 9(4)
- Canadian Electricity and Gas Inspection Regulations (SOR/86-131), subsection 12(1)
- CAN/CSA/IEC-61869/C61869-1:14 Part 1 Instrument transformers – Part 1: General requirements
- CAN/CSA/IEC-61869/C61869-2:14 Instrument transformers – Part 2: Additional requirements for current transformers
- CAN/CSA/IEC-61869/C61869-4:14 Instrument transformers – Part 4: Additional requirements for combined transformers
- IEC 60044-8 2002-07: Instrument transformers – Part 8: Electronic current transformers
- IEEE Std C57.13-2008: IEEE Standard Requirements for Instruments Transformers.
- mA Current transformer references
    - Measurement Canada, LMB-EG-07: Specifications for the Approval of Type of Electricity Meters, Instrument Transformers, and Auxiliary Devices.
    - Measurement Canada, S-E-07: Specifications for the Approval of Measuring Instrument Transformers.

1.4 Definitions

See **SM31000-1** section **1.2 Definitions** for common definitions.

1.4.1 Burden

This Standard uses the term burden with current transformers with current output secondaries. Burden refers to either 1) the total impedance or resistance connected to the CT secondary or 2) the volt-amperes and power factor of the load seen by the CT secondary at the rated current and frequency. See also **1.4.7 Output Loading**.

1.4.2 Current Sensor

A device able to measure and output analog or digital representations of one or more currents. Examples of current sensors are current transformers, low-voltage current transducers, and Rogowski coils.

1.4.3 Current Transformer

Current transformers produce a secondary current output proportional to the current flowing through the primary winding. Also referred to as an instrument transformer.

1.4.4 Voltage Output Current Sensor

A current sensor with a low-voltage (generally less than 12 V) analog output signal representing the primary current. This is also called a low-voltage current transducer (LVCT), current transducer, low-voltage current sensor, a low-voltage current transformer, or a low-voltage instrument transformer. See **2.1.1 Recommended Secondary Outputs** below.

1.4.5 Marked Ratio

The ratio of the rated primary value to the rated secondary value.

1.4.6 Nominal Accuracy Percentage

The nominal accuracy percentage is the allowed gain error at 100% load for an accuracy class. The nominal accuracy percentage is multiplied by factors like 1.0, 2.0, etc. to determine the maximum gain error at different test loads. For example, a class 1.0 sensor would have an accuracy of ±1.0% at 100% load.

1.4.7 Output Loading

For analog current sensors, this is the load impedance, typically resistance, caused by the meter or other connected monitoring device. Output loading affects voltage output sensors, where a lower resistance or impedance would reduce the output signal. See also **1.4.1 Burden**.

1.4.8 Phase Angle of a Current Sensor

The phase displacement at the fundamental line frequency between the input (primary) current and the output (secondary) signal of a current sensor. A positive phase angle corresponds to the output signal leading the input current. The phase angle is not applicable for DC sensors.

1.4.9 Primary Operating Frequency

The frequency for which all the gain and other accuracy tests shall be performed). This may be DC for DC-only sensors.

1.4.10 Rated Input Current

The full-scale input or primary current selected for the basis of performance specifications.

1.4.11 Rated Output

The output signal of the current sensor at the rated input current.

1.4.12 Sensor Accuracy Class

The sensor accuracy class (C_S) is a nominal accuracy in percent from which particular test limits are derived. Some test limits may be higher or lower than the accuracy class. The accuracy class is written without the percent sign. The accuracy class designation may be followed by a single-letter suffix indicating the linearity factor, such as high, medium, or low linearity. When used in equations, use the value of C_S directly, not $C_S/100$. For example, for $C_S = 0.5$, use 0.5, not 0.5% or 0.005.

2 General Requirements

2.1 Markings

Current sensor markings shall include, as a minimum, where applicable, the following:

a) Manufacturer's or authorized reseller's name or trademark.
b) Model
c) Rated nominal frequencies (AC, DC, or AC/DC, as applicable)
d) Rated primary and secondary current(s) or voltage(s), if applicable
e) Rated line voltage of the primary conductor
f) Sensor polarity for the input (primary) current
g) Polarity or color-coded wires for the output (secondary) signal, if applicable

2.1.1 Recommended Secondary Outputs

The recommended rms or DC values of rated secondary voltage for voltage output current sensors at the rated primary current are:

22.5 mV – 150 mV – 200 mV – 225 mV – 333 mV – 1V

The recommended rms or DC values of rated secondary current for current transformers or current output current sensors at the rated primary current are:

80 mA – 100 mA – 1 A – 5 A

Other outputs are allowed, including but not limited to Rogowski coil signals and digital outputs.

2.2 Documentation

The product documentation shall specify the following:

1) The manufacturer's or authorized reseller's name or trademark.
2) The applicable models
3) The current sensor type, such as current transformer, low-voltage current sensor, Rogowski coil, etc.
4) The rated nominal frequencies (AC, DC, or AC/DC, as applicable)
5) The rated primary and secondary current(s) or voltage(s)
6) The accuracy class (C_S) and linearity factor (LF)
7) The specified current sensor output loading
8) The specified temperature range (see **SM31000-1, section 1.2 Definitions**)
9) Installation instructions to achieve specified performance
10) Documentation of the sensor polarity marking system
11) Guidelines on positioning the conductor in the sensor opening or documentation that the sensor will meet its rated accuracy regardless of the conductor position
12) Guidelines on positioning the sensor near sharp angles in the primary conductor or documentation that the sensor will meet its rated accuracy regardless of the primary conductor geometry
13) Guidelines on positioning the sensor near external conductors or documentation that the sensor will meet its rated accuracy regardless of the position of external conductors

3 Performance Requirements and Test Procedures

3.1 Accuracy Classes

This Standard allows the use of any accuracy classes for sensors but recommends the following nominal accuracy percentages:

0.1 0.15 0.2 0.3 0.5 0.6 1.0 1.2

The accuracy class (C_S) contains a suffix that denotes the linearity factor. See **Table 2** and **Table 3** below for details.

- H = High Linearity
- M = Medium Linearity
- L = Low Linearity

The combination of the nominal accuracy percentage and the linearity factor defines the accuracy class. For example: 0.5H = 0.5% nominal accuracy, high linearity; 1.0L = 1.0% nominal accuracy, low linearity.

Based on the test results, it is permissible to assign a current sensor multiple accuracy classes. The most common reason might be when a sensor meets one class as high linearity and a better class as medium linearity. For example, the same sensor might meet 0.5H and 0.2M.

An accuracy class is considered equivalent to or better than a second accuracy class if both of the following are true:

- The nominal accuracy percentage is the same or lower than the nominal accuracy percentage of the second accuracy class.
- The linearity is the same or better than (high is better than medium and medium is better than low) the linearity of the second accuracy class.

3.2 Current Sensor Types

This Standard is intended for use with any type of current sensor, including but not limited to the types listed below.

- Current transformer
- Voltage output current sensor
- Rogowski coil current sensor
- Shunt current sensor
- Hall effect sensor

3.3 Current Sensor Output Loading

Different types of current sensors may be impacted differently by the output loading. For example, current transformers perform best when the burden is near a short-circuit. Voltage output current sensors perform best when the output loading is high impedance.

To ensure current sensors meet the limits of the Standard, manufacturers shall specify, in the current sensor documentation, the allowable burden or output loading for all current sensors with an analog output. Depending on the current sensor type, this may be specified as one or more of the following:

- an allowable range of burden resistance or impedance
- an allowable range of burden volt-ampere load, optionally with the power factor specified
- an allowable range of output loading
- a sensor-specific output specification

It is permissible to document different accuracy classes based on the output loading. For example, a current sensor might achieve accuracy class 0.2 under ideal loading and accuracy class 0.3 under more severe loading.

3.4 Testing Overview

Phase tests shall only be performed for current sensors that measure AC or AC/DC.

The tests may be performed in any order, except for the temperature test that shall be performed after the gain and phase tests in section **3.5 Gain and Phase Tests**.

Sensors may be tested with multiple primary turns to achieve the required test currents.

Multiple sensors with the same or different current ratings may be tested simultaneously with a single current generator. Different numbers of primary turns may be used on the different sensors if the sensors support multiple turns. Any data collected for a sensor that is not in accordance with the required load shall not be part of the test results for that sensor. The configuration of the primary turns shall be under the direction of the manufacturer.

The manufacturer shall specify the primary operating frequency (AC or DC) and each additional nominal operating frequency.

3.4.1 Test Condition Tolerances

The test condition tolerances set the limits on the accuracy of the test sources used to generate the test signals and conditions. See **SM31000-1** for information on the required accuracy of test equipment used to measure signals. See **3.3 Current Sensor Output Loading** for more information.

Table 1: Test Condition Tolerances

Condition	Tolerance
Currents below 10% Load	±5.0%
Currents from 10% to 100% Load	±3.0%
AC frequency	±0.2%
AC voltage and current waveform distortion (THD)	±2.0%
Temperature	±3°C
Output loading or burden (≥1Ω)	±1.0%
Output loading or burden (<1Ω)	Not spec.

3.5 Gain and Phase Tests

The accuracy classes for current sensors are based on the requirement that the sensor is within specified limits for the following conditions:

a) The output loading is within manufacturer specified limits.
b) Normal operating conditions. See **SM31000-1, Section 2.3.2, Test Condition Tolerances**.

The following tables identify AC and DC tests and accuracy limits.

Table 2: AC Accuracy Class (C_S) Limits and Test Levels

	H = High Linearity		**M = Medium Linearity**		**L = Low Linearity**	
Linearity Factor	1.0		1.5		3.0	
Test % of Rated Amps	**Max. Gain Error**	**Max. Phase Error**	**Max. Gain Error**	**Max. Phase Error**	**Max. Gain Error**	**Max. Phase Error**
Load 1%	2.0·C_S	n/s	3.0·C_S	n/s	4.0·C_S	n/s
Load 5%	1.0·C_S	50·C_S	1.5·C_S	75·C_S	3.0·C_S	100·C_S
Load 10%	1.0·C_S	50·C_S	1.33·C_S	67·C_S	2.0·C_S	75·C_S
Load 30%	1.0·C_S	50·C_S	1.0·C_S	50·C_S	1.0·C_S	50·C_S
Load 100%	1.0·C_S	50·C_S	1.0·C_S	50·C_S	1.0·C_S	50·C_S

Table 3: DC Accuracy Class (C_S) Limits and Test Levels

	H = High Linearity	**M = Medium Linearity**	**L = Low Linearity**
Linearity Factor	1.0	1.5	3.0
Test % of Rated Amps	**Max. Gain Error**	**Max. Gain Error**	**Max. Gain Error**
Load 1%	2.0·C_S	3.0·C_S	4.0·C_S
Load 5%	1.0·C_S	1.5·C_S	3.0·C_S
Load 10%	1.0·C_S	1.33·C_S	2.0·C_S
Load 30%	1.0·C_S	1.0·C_S	1.0·C_S
Load 100%	1.0·C_S	1.0·C_S	1.0·C_S

Note: The limits for a particular percentage of rated amps apply from that percentage up to the next higher percentage. There are no specified limits below 1% or above 100%.

Note: Some limits are not specified (n/s) because SM31000-2 does not test the power factor below 5% of rated amps; therefore, it is not necessary to test the phase angle performance of current sensors below 5% of rated amps.

Max. Gain Error—This column specifies the required maximum allowable error where C_S is the nominal accuracy percentage. The accuracy classes and maximum errors indicate the allowable errors as percentages of reading. For example, $C_S = 0.5$ means 0.5%, and an error limit of 2.0·C_S would result in an error limit of ±1.0% of reading. **SM31000-1, section 2.3.1, Performance of the Test Equipment** allows an additional uncertainty allowance for the accuracy error limits.

Max. Phase Error—This column specifies the maximum allowable phase error in minutes, where C_S is the nominal accuracy percentage. For example, if $C_S = 0.5$, then an error limit of 50·C_S would result in a phase error limit of ±25 minutes.

Load %—This column specifies the load current as a percentage of the current sensor rated current.

Example: An AC current sensor with accuracy class 0.5M (medium linearity) will have the following limits:

Table 4: Example of Accuracy Class Limits

Test % of Rated Amps	Gain Limit	Phase Limit
Load 1%	$3.0 \cdot C_S = \pm 1.50\%$	n/s
Load 5%	$1.5 \cdot C_S = \pm 0.75\%$	$75 \cdot C_S = \pm 37.5$ minutes
Load 10%	$1.33 \cdot C_S = \pm 0.665\%$	$67 \cdot C_S = \pm 33.5$ minutes
Load 30%	$1.0 \cdot C_S = \pm 0.50\%$	$50 \cdot C_S = \pm 25.0$ minutes
Load 100%	$1.0 \cdot C_S = \pm 0.50\%$	$50 \cdot C_S = \pm 25.0$ minutes

3.6 Multiple Frequency Tests

If the sensor accuracy is specified for more than one nominal operating frequency, for each nominal frequency other than the primary operating frequency, repeat the tests at 5% and 100% of rated amps from **Table 2**.

3.7 Effect of Variation of Output Loading

For current sensors with an analog output, the current sensor shall meet the accuracy gain limit of $1.0 \cdot C_S$ and the phase limit of $50 \cdot C_S$ (phase minutes multiplied by the current sensor accuracy class) at 100% of rated amps at both the highest and the lowest output loading. See **3.3 Current Sensor Output Loading**.

If the **Table 2** or **Table 3** tests were performed at either the highest or the lowest output loading, then only the alternate loading shall be tested for this section.

3.8 Temperature Variation

See **SM31000-1, section 2.5 Temperature Variation** for requirements on testing and specified temperature ranges. The test for temperature variation shall be performed at the lower and upper temperature limits for the specified temperature range for the sensor.

In addition to the specified temperature ranges in SM31000-1, this Standard recommends the following range for current sensors:

Current Sensor Recommended: −20°C to 70°C

The temperature variation test is not required for sensors with accuracy class $C_S > 1$.

For sensors with accuracy class $C_S \leq 1$, test sensitivity to temperature variation at Load 5% and Load 100%. The Load 5% test shall be performed before the Load 100% test.

3.8.1 Allowable Error from Temperature Variation

This Standard limits the maximum temperature coefficient (TC) of the sensor, measured as the TCs from nominal ambient temperature to the lower temperature limit and from nominal ambient temperature to the upper temperature limit.

a. T_T : The temperature at which the test is being performed: the lower temperature limit or the upper temperature limit.
b. $\Delta T = T_N - T_T$: The difference in temperature between the nominal ambient temperature and the test temperature.
c. C_S : The nominal accuracy class of the sensor as a percentage. E.g. $C_S = 0.5$ means the nominal accuracy percentage is ±0.5%.
d. ΔG : The change in measured sensor gain between the test results at nominal ambient temperature and the test temperature.

e. ΔP : The change in measured sensor phase between the test results at nominal ambient temperature and the test temperature (for AC sensors).

f. E_G : The maximum gain error from **Table 2** or **Table 3** for the active load percentage, linearity factor, and Cs value.

g. E_P : The maximum phase error from **Table 2** for the active load percentage, linearity factor, and Cs value (for AC sensors).

h. Temperature coefficient multipliers in units of percentage per degree Celsius (%/°C)
    1. Gain TC multiplier: K_G = 0.06% / °C
    2. Phase TC multiplier: K_P = 2.0% / °C

The formula for the additional maximum gain change as a function of the temperature difference follows. ΔG is in units of percentage.

$$\Delta G = \Delta T \cdot K_G \cdot E_G \qquad \textit{Eq. 1}$$

For AC sensors, the formula for the additional maximum phase change as a function of the temperature difference follows. ΔP is in units of minutes.

$$\Delta P = \Delta T \cdot K_P \cdot E_P \qquad \textit{Eq. 2}$$

Where E_P = The maximum phase error from **Table 2** for the active load percentage, linearity factor, and Cs value.

AC Sensor Example:

- Tested sensor accuracy class (Cs): 0.5M
- Measured gain error at 23°C @5% load: +0.41%
- Measured gain error at 23°C @30% load: +0.23%
- Measured phase error at 23°C @5% load: -25 minutes
- Measured phase error at 23°C @30% load: -18 minutes
- Testing temperature: −20°C
- Temperature difference (ΔT): 23°C – (−20°C) = 43°C

Using the gain and phase TC's, we calculate the allowable errors for each load. The additional maximum allowable errors are calculated using equations 1 and 2.

Table 5: Example Error Limits for Class 0.5M

Error type	**Load**	**Current Sensor Limits from Table 2**	**Additional Allowable Error ΔG, ΔP**	**Measured Error at 23°C**	**Actual Error Limits Allowed at -20°C**	
					Lower Limit	**Upper Limit**
Gain error (%)	5%	1.5·Cs	±1.94%	0.41%	-1.53%	2.35%
	30%	1.0·Cs	±1.29%	0.23%	-1.06%	1.52%
Phase error (minutes)	5%	75·Cs	±32.25	-25	-57.25	7.25
	30%	50·Cs	±21.50	-18	-39.5	3.5

3.9 EMC Requirements and Tests

The electromagnetic compatibility (EMC) of current sensors is not tested in isolation, but as part of a metering system. See **SM31000-2, section 2.5, ALTERNATE CURRENT SENSOR TESTS** for details.

For the following EMC tests, the output loading (See **3.3 Current Sensor Output Loading**) of the current sensor shall be within the manufacturer's specified limits.

3.9.1 Current Sensor Design Type EMC Immunity Tests

There are no EMC immunity tests required for passive current sensors.

3.9.2 Active Current Sensor Design Type EMC Immunity Tests

The following EMC tests shall be performed once for each active current sensor design type (see definition of **sensor design type** and **sensor, active** in **SM31000-1**). Follow the procedures and use the performance criteria from **SM31000-1, section 2.6, ELECTROMAGNETIC COMPATIBILITY (EMC) TESTS** to perform the EMC tests. Additionally validate the immunity using **3.9.2.1 Change of Energy Acceptance Criterion** and **3.9.2.2 Accuracy Verification Acceptance Criteria**. The sensor shall be connected to an electric watt-hour meter that complies with the manufacturer specified output loading (see **3.3 Current Sensor Output Loading**) and that can monitor for accumulated energy during the EMC tests. Any meter test voltage may be used that is within the meter's normal range. When an AC test signal needs to be applied, it shall be applied at the primary operating frequency (see **3.4 Testing Overview**).

Table 6: Active Current Sensor Design Type EMC Immunity Tests

Immunity Test Name	Load %
Radiated, Radio-Frequency (RF), Electromagnetic Field Immunity	0%
Electrical Fast Transient (EFT)/Burst Immunity (1)	0%
Ring Wave Immunity (1)	0%
Immunity to Conducted RF (3)	0%
Voltage Dips and Interruptions Immunity	0%

(1) These tests are not required for current sensors powered from a CAT II overvoltage protection level source.

(2) Load 0% can be generated with a disconnected primary conductor.

(3) The conducted RF shall be applied to the primary conductor, to any sensor power supply connections, and to the sensor output leads.

3.9.2.1 Change of Energy Acceptance Criterion

The Change of Energy Acceptance Criterion is applied for each test in **3.9.2** Active Current Sensor Design Type EMC Immunity Tests. The stored or indicated meter energy from the start to the end of each test shall not have changed by more than the following amount. This measurement shall be made using a single meter element. This shall be verified after each EMC test.

$$E_{MAX} = 0.5\% \cdot V_T \cdot I_R \cdot t_{HR} \qquad \textit{Eq. 3}$$

Where:

E_{MAX} : The maximum allowed change of energy in units of watt-hours
V_T : The test voltage
I_R : The rated amps of the current sensor
t_{HR} : The test duration in hours

3.9.2.2 Accuracy Verification Acceptance Criteria

The accuracy verification is performed after the **3.9.2 Active Current Sensor Design Type EMC Immunity Tests**. Test the accuracy by repeating the Load 30% test. The accuracy shall meet the acceptance criterion for this test as listed in **Table 2** or **Table 3** above. The verification test shall be performed either after each EMC test, at the end of all EMC tests, or after any grouping of tests.

Annex A Voltage Output Current Sensors (VCS) for Parallel Applications

A.1 Foreword

Voltage output current sensors (VCS) have a unique advantage that can be utilized in submetering applications. Because they are designed with an internal resistance burden, that converts the internal current loop to a voltage output, they can be used in parallel load applications that provide the submeter with an aggregate reading of those loads.

Note: this analysis may not apply to VCS with active circuitry. Check with the manufacturer of your sensors to confirm applicability.

It is important that strict rules be applied when using this type of application to provide an accurate metering installation.

A.2 VCS Parallel Function Explanation

The following explanation shows how a pair of VCS devices -- that are designed for a 2-volt output when used on a 200-amp circuit — can be effectively paralleled on individual 200 amp loads to create an aggregate 400-amp VCS.

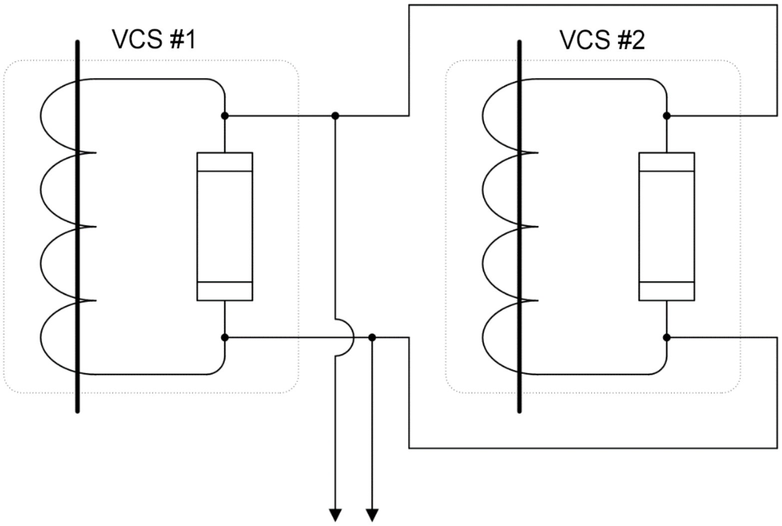

Figure 1: Paralleling of Voltage Output Current Sensors

To understand the nature of paralleling VCSs, it is important to understand how they function internally.

The VCS is designed with a precision resistor element that converts the internal loop current (amps) into a voltage output signal. The output signal is directly proportional to the loop current, which in turn is proportional to the primary current.

For example, if we designed a VCS with a turn ratio of 1000:1, a primary current of 200 amps would create an internal loop current of 0.2 amps (200 ma). By adding a 10-ohm resistor in series with the secondary winding, a voltage drop of 2 volts would occur at full load. Using Ohm’s law; 0.2 amps X 10 ohms = 2 volts. This VCS would now output 2 volts.

If we paralleled two of these VCSs, the effective resistance in the equivalent circuit would now be 5 ohms.

$$R_T = \frac{R_1 R_2}{R_1 + R_2} = \frac{10 \cdot 10}{10 + 10} = \frac{100}{20} = 5.0\Omega$$

Now, if we combine the two internal currents into this circuit, we will still have 2 volts at full load. Again, using Ohm's law; 0.4 amps X 5 ohms = 2 volts. So, we now see that with paralleled 200-amp VCSs that at 400 amps combined load the output is the same as if a 400A:2V were used. Therefore, we can use this combination as if we had a 400-amp meter.

So, what happens if there are unbalanced loads on the two circuits being monitored? Let's assume that one circuit is at 100 amps and the other at 50 amps. The internal currents in this case are 0.1 amps and 0.05 amps. When you look at the equivalent circuit you can readily see that they combine, creating a flow of 0.15 amps through a 5-ohm resistor. Again, doing the math with Ohm's law; 0.15 X 5 = 0.75 volts.

By understanding the internal circuitry and Ohm's law, the functionality of paralleled VCSs is made clear. In this example, we can see that a 0.75 volt output from a 400 amp VCS with a 2 volt secondary is the equivalent of 150 amps (0.75/2 X 400 = 150), making this combination both functional and accurate.

A.3 VCS Parallel Applications

Paralleling of voltage output current sensors can be either additive or subtractive. This capability gives the user added flexibility when utilizing paralleling in submeter installations.

- Examples of subtractive installations:
  - Installing VCS parallel units on common area load(s) fed from customer's distribution panel.
  - Installing VCS parallel units on an *industrial* load that does not produce a tangible personal property in order to account for sales tax exemption allowed on the production of these goods. (In states where this exemption is available)
- Examples of additive installations:
  - Installing VCS parallel units on an additional panel to account for both loads as an aggregate.
  - Installing VCS parallel units on the same types of loads in customer's distribution panel to segregate them by type.
  - Installing VCS parallel units on parallel load conductors when they are spread too far apart to be accommodated by a single VCS.

A.4 VCS Paralleling Rules

To provide a successful parallel installation, there are some rules that shall be followed. If they are not adhered to, the installation will not provide accurate meter data to the user.

1. The sensors shall be of the same internal design (turns and burden).
2. The sensors shall be the same primary amp to voltage output rating.
3. The meter reading shall be multiplied by the number of sets of sensors being paralleled. *As an example, a 200-amp meter with a second set of 200-amp sensors will have a multiplier of X2.*
4. The paralleled sensors shall be associated with the same phase (A + A, B + B, etc.). This relationship remains true even in a subtractive installation.
5. The subtractive sensors shall be installed in the reverse direction of the primary set.
6. The loads being monitored shall be from the same service. Loads from different transformers and voltages cannot be accurately monitored.
7. The sensor secondary leads shall be of the same polarity when connected to the meter current inputs.

Annex B Working Group Decisions and Rationale (Informative)

This section will be removed before the Standard is published. While work is proceeding on this Standard, we will record working group decisions and the rationale so that we can refer to these decisions later.

B.1 Open Tasks

B.1.1 Determine the Effect of Sensor Accuracy on the System Accuracy

How do we combine CT and meter accuracies to get a system error? Cannot just add gain errors. Maybe develop an equation based on gain and phase.

Dave Bovankovich, Nat Crutcher, and Daniel Aljadeff submitted documents.

B.1.2 Figure Out How to Handle Meters that Can Correct for Known Phase Shifts, Known Calibration Errors, Non-Integrated Rogowski Coil Outputs, and Other Non-Standard Situations

- Both Henry Alton and Don McComas pointed out that such CT/Meter combinations might have to be tested as a system, at least initially.
- Aaron: the manufacturer could specify two accuracies: base and corrected.

B.2 Notes and Background

- Aaron: have CTs that store correction tables in the sensors. TEDS (transducer electronic data sheet)

B.3 Should We Include Potential Transformers?

2019-09-17: Group decision: Yes, but as a lower priority and perhaps in a separate SM31000 section, such as SM31000-10.

B.4 Units

2019-09-05: Group decisions:

- Show errors as %
- Show phase as minutes and degrees

B.5 Accuracy Limits, Parallelogram

2019-09-05 and 2019-09-17: Group: Only one member had lukewarm support for the accuracy parallelogram used by C57.13 and Measurement Canada. The consensus was to use absolute (rectangular) limits like IEC 61869. There were a few reasons provided:

- The parallelogram is confusing.
- The parallelogram limits are appropriate for lagging power factor loads, but could allow unexpectedly large errors for leading power factor loads.
- In the groups' experience, few, if any, CTs exhibit a parallelogram shaped relationship between gain and phase accuracy, so the parallelogram probably would not make it easier for CT manufacturers.
- Most CT vendors will want to meet IEC 61869, which will require them to meet rectangular accuracy limits.
- Henry is planning to ask MC about parallelograms.

2019-09-17: Nat: Should our limits form a stairstep or a smooth ramp?

- Aaron and Nat like the straight lines connecting the points. This makes a nice graph and better fits the behavior of a real CT.
- Craig is concerned that we should add more test points if we want to imply accuracy in-between points.
- Don has seen step functions for meters; the step doesn't get tighter until the next higher point, so it is easiest possible for the manufacturer.

2020-01-20:

- The group agreed to match up the current sensor accuracy test points with the SM31000-2 points: 100%, 30%, 10%, 3% (or 6%), 1% (or 2%). We may or may not want a 75% test point: the limits would match the 100% and 30% limits.
- The group agreed to: "The limits for a particular percentage of rated amps apply from that percentage up to the next higher percentage."
- The group agreed to drop the 120% test point since we do not test meters at 120%. We also agreed that we might later add a test for higher percentages or crest factor handling, but not yet.

2020-02-03:

- Group tentatively decided to replace 3% and 6% limits in SM31000-2 and SM31000-7 with a single 5% limit.
- Group tentatively decided that we do not need 1% or 2% limits for CTs, since the meter power factor tests only go down to 5% (or perhaps 3%). This significantly improves the system accuracy of sensor and meter combination.

2020-02-27

- Group decided to remove the 75% limit and test as redundant.

2020-05-21

- Group decided to use the new low, medium, and high linearity limits proposed by Nat and implemented by Dani. These have the following benefits:
    - They reward more linear sensors with better system accuracy
    - They allow the use of lower linearity sensors
    - The new system for computing system accuracy is simple and flexible
- Group decided to add a 0.1 class, since some sensors are appearing with the accuracy level

B.6 Accuracy Classes

2019-09-05: Henry would like to see both IEC and C57 classes: 0.2, 0.3, 0.5, 0.6.

- Dani suggested we should not have strict limits below 10%. Nat argues for strict enough limits for the low end that we preserve SM31000-2 accuracy limits. Aaron agreed with Nat.
- A comment was made that we should design SM31000-7 to handle both monitoring and revenue.

2020-07-28: Group agreed to change the suffixes to H, M, and L to avoid conflict with B for burden and S for IEC 61869.

B.7 Current Sensor Output Loading

2020-04-27 WG reviewed and approved new language. The group agreed to remove the burden tables from this document.

B.8 Different Sensor Output Types

This includes 5A output, milliamp output, voltage output, Rogowski output, digital outputs, etc.

2019-09-17: Don: prefers that we use accuracy tables without specifying the output. This Standard should work with pretty much any output. The group seemed to agree.

2019-09-07: Don: for non-integrated Rogowski outputs, we may want to require system testing. Aaron thinks that we should be able to test Rogowski outputs separate from the meter. Don is concerned that this is harder and we might want to put it off for later. Henry advocates for putting some content in, but it might get shelved.

2019-09-07: Aaron: we may need to adjust how to specify Rogowski coils, which may be different from other technologies

B.9 Harmonics

2019-09-17: Don and Aaron: should we consider harmonics or CT bandwidth? The group seemed to think that we probably should. No details yet.

B.10 EMC

2019-09-05: Dani proposes that we use the SM31000-2 EMC requirements in 1-7.

New Comments for Dec 2/19 Review

Is the power metering section still relevant?

A test section will be added for the next review of this document. There was a comment that we only needed to discuss traceability. Does this mean that we will reference another document for testing such as “Energy Aware” for example? (There can be test certification for components as well.)

Some additional Details required for other technologies. Some input from other for this.

- Wireless technology
- Rogowski Coil

Add language that other technologies need to handle the limits after whatever corrections. This would cover the above technologies as an example.

Sensor markings from Craig Denson – for accuracy do we really need to have marking requirements. Proposal to not have any marking requirements for meter or sensor. For the revenue side we would bring these in.

Test content for this Standard. Might be helpful but could be an Annex. Could do this for both meters and sensors. Perhaps tests for corrections against different technologies.

Rationales and notes: 2020-08-21

- Magnetic Field: Craig and Nat think the meter should not matter, so this could be tested once with any meter.
- Other tests: Craig thinks the meter technology could matter much more
- Henry: has concerns about mix-and-match, but MC does allow this for 5A output CTs. Maybe we could figure something out by technology type.
- Group consensus that SM31000-2 is ok.
- Nat proposed we start with SM31000-2 and consider allowing mix-and-match more selectively.
- Craig: the EMC tests could be in both places.

2020-11-30: Rationale for dips and interrupts: the sensor might contain non-volatile memory. The power supply or microcontroller might get into a bad state due to brownout.

June 2021: Testing indicates that power frequency magnetic fields do not measurably interfere with passive current sensors, so the group eliminated testing requirements for this.

2021-04-29. Include conducted RF since it could be applied both to the primary conductor and to any power supply connections to the sensor.

B.11 Current Sensor Gain/Phase Limit Table Layout Options

These are some different layouts we considered. Option 2 is the one being used above. The group agreed on option 2 in our 2020-01-20 meeting.

Option 1

Henry’s Notes:

- Given in degrees.
- 120% of rated AMPs where SM31000-2 stops at 100%. Keep it in because ANSI tests over the limit. Doesn’t ANSI require 15% above full scale? The meter should match.
- The sensor has to do this too. SM31000-xx is currently at 100% and not over. Protection devices. Go for 100% only.

Current Sensor Accuracy Limits by Class

Accuracy Class	**0.15**		**0.2**		**0.3**		**0.5**		**0.6**		**1.0**		**1.2**	
% of Rated Amps	**Gain**	**Phase**	**Gain**	**Phase**	**Gain**	**Phase**	**Gain**	**Phase**	**Gain**	**Phase**	**Gain**	**Phase**	**Gain**	**Phase**
120%	0.15%	0.125	0.20%	0.167	0.30%	0.250	0.50%	0.417	0.60%	0.500	1.00%	0.833	1.20%	1.000
100%	0.15%	0.125	0.20%	0.167	0.30%	0.250	0.50%	0.417	0.60%	0.500	1.00%	0.833	1.20%	1.000
20%	0.15%	0.125	0.20%	0.167	0.30%	0.250	0.50%	0.417	0.60%	0.500	1.00%	0.833	1.20%	1.000
5%	0.26%	0.188	0.35%	0.250	0.45%	0.375	0.75%	0.625	0.90%	0.750	1.50%	1.250	1.80%	1.500
2%	0.41%	0.188	0.55%	0.250	0.68%	0.375	1.13%	0.625	1.35%	0.750	2.25%	1.250	2.70%	1.500
1%	0.56%	0.250	0.75%	0.333	0.90%	0.500	1.50%	0.833	1.80%	1.000	3.00%	1.667	3.60%	2.000

Option 3

% of Rated Amps	120%		100%		20%		5%		2%		1%	
Accuracy Class	**Gain**	**Phase**	**Gain**	**Phase**	**Gain**	**Phase**	**Gain**	**Phase**	**Gain**	**Phase**	**Gain**	**Phase**
0.15	0.15%	0.125	0.15%	0.125	0.15%	0.125	0.26%	0.188	0.41%	0.188	0.56%	0.250
0.2	0.20%	0.167	0.20%	0.167	0.20%	0.167	0.35%	0.250	0.55%	0.250	0.75%	0.333
0.3	0.30%	0.250	0.30%	0.250	0.30%	0.250	0.45%	0.375	0.68%	0.375	0.90%	0.500
0.5	0.50%	0.417	0.50%	0.417	0.50%	0.417	0.75%	0.625	1.13%	0.625	1.50%	0.833
0.6	0.60%	0.500	0.60%	0.500	0.60%	0.500	0.90%	0.750	1.35%	0.750	1.80%	1.000
1.0	1.00%	0.833	1.00%	0.833	1.00%	0.833	1.50%	1.250	2.25%	1.250	3.00%	1.667
1.2	1.20%	1.000	1.20%	1.000	1.20%	1.000	1.80%	1.500	2.70%	1.500	3.60%	2.000

B.12 Markings

2020-01-12: Henry:

- “Department Approval number” We may need to visit some specific approval organization centric titles to see if they are necessary. This is with respect to commercial transaction meters vs. non-commercial transaction meters. Removed this one as it is Industry Canada centric.
- “May not be applicable but some like polarity are relevant. Leave this wide open: wire colors, labels or other markings. If auto detection not required. CT strips etc. may not use conventional. Pointer to load marking is common. CTs in a box optional.”
  - Terminals. The terminals markings shall identify:
    - the primary and secondary windings,
    - the winding sections, if any,
    - the relative polarities of windings and winding sections,
    - the intermediate tappings, if any.
    - Terminal markings shall be as set out in clause 3.10 of CSA Standard C13-82.

- "a) Manufacturer's or authorized reseller's name or trademark." Rationale: Allow resellers to brand products without requiring retesting. Group approved 2020-07-28.

2021-02-10: Allow for digital outputs and permanently tethered sensors by making "rated primary and secondary current(s) or voltage(s)" optional.

B.13 Multiple Frequency Tests

The group agreed to repeat the 5% and 100% tests on 2020-09-30. They felt this would be sufficient

We might make a similar change to SM31000-2, but Dani proposed keeping SM31000-2 unchanged.

B.14 Phase Angle of a Current Sensor

2020-09-20: The polarity of the phase angle was defined as "A positive phase angle corresponds to the output signal leading the input current."

From IEC 61869-1:2007

> **phase displacement (Δφ)**
>
> Difference in phase between the primary voltage or current and the secondary voltage or current phasors, the direction of the phasors being so chosen that the angle is zero for an ideal transformer.
>
> The phase displacement is said to be positive when the secondary voltage or current phasors leads the primary voltage or current phasors. It is usually expressed in minutes or centiradians.

IEEE C57.13 agrees.

B.15 Documentation

2021-02-10: Require documentation of primary conductor positioning, primary conductor geometry, and external conductors because the sensor may not achieve the specified accuracy if not installed according to documented guidelines.

B.16 Rationale for temperature coefficients on sensors

See spreadsheet analysis: **SM31000-7 CT Meter Accuracy vs. temperature_04.xlsx**

ESM1-7 CT Meter
Accuracy vs. tempera

2020-10-14 Rationale: C12 and SM31000-2 require system accuracy over temperature, so SM31000-7 will require specified current sensor accuracy over temperature. The group agrees with allowing some derating (reduced accuracy) as the temperature varies from nominal.

The rationale of using TCs when testing a sensor accuracy over temperature changes is as follows:

- Both the sensor gain and phase shift variations over temperature can be approximated with two linear segments with a different slope, typically intercepted close to 23°C. The negative temperature variation segment (i.e., temperatures ≤ 23°C) has typically a steeper slope.
- To simplify the testing, a single TC was defined approximated to the steeper slope.
- Using a TC allows quantifying the allowable error at any given temperature and this provides much more flexibility to both manufacturers and testing labs.

The rationale of using two different temperature coefficients for the gain and phase errors due to temperature is as follows:

- Phase and gain errors of sensors **are tested separately since we cannot combine the errors as we do with full meters** (i.e., in full meters, we test the influence of the temperature on the measured power or energy, at different power factors which combines the gain and phase errors).

- The influence of the gain error and the phase error to the measured power or energy (when the sensor is connected to a meter) is essentially different:
    - The gain error directly and linearly affects the measured power or energy
    - The phase error influence depends on the V/I phase. If the V/I is zero or close to zero, the phase error will have little influence. However, the V/I phase is large (45° or 60°), the influence is much more significant.

Rationale for TC's value selection

- The value of the gain TC was selected to be the same as defined in SM31000-2 (K_G = 0.06% / °C) for full meters (with an integrated sensor).
- The value of the phase TC was selected to ensure a power or energy error, similar or smaller to the error of a meter under the same test conditions. When PF<1, a meter is allowed to have an additional error in accordance with a TC of 0.1% / °C.
- The total allowable error calculation due to temperature variations, was also adapted to the sensor linearity factor.

B.17 Rationale for Testing Overview

Perform room temperature gain and phase tests before the temperature test because the temperature test needs the room temperature data.

B.18 Rationale for Testing Condition Tolerance

The tolerance for output loading or burden resistors at Measurement Canada labs is typically 0.1%. But the group determined that a 1% change in loading would have an insignificant effect on the accuracy and would be less costly.