Residential Energy Meter Requirements

Rev 1.00

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Table of Contents

Revision History

Rev 0.00	Initial draft.	01-06-00
Rev 0.01	Updated based on fax from Kimbel Nap and conversations with Kevin Prudlow.	01-17-00
Rev 0.02	Added detail to the specifications.	01-19-00
Rev 1.00	First release. Added detail, incorporated comments from Chris Waters at Cadence, removed requirement for low-voltage access, removed low-power transmitter mode based on present NCI hardware design, updated NCI pin assignments.	01-20-00

Note to editors: Use these equation field codes: (1-1)

1 Introduction

This document defines the requirements for a residential energy meter. The product incorporates Innovatec's automated meter reading technology.

1.1 Reference Documents

- ANSI C12.16-1991 – *American National Standard for Solid-State Electricity Meters*, March 1991.
- IEC 1036 – *Alternating current static watthour meters for active energy (classes 1 and 2),* 1996.
- Title 47, Code of Federal Regulations (CFR) – *Telecommunications,* October 1, 1998.

1.2 Definitions

- *IMU* – Information Management Unit, typically a water or gas meter.

1.3 Background

This product serves as an electric energy meter within a wireless network. The meter exchanges messages with the utility's communication center via a local gateway node. The meter can also relay messages between a gateway node and a gas or water meter.

2 System Requirements

This section defines the overall performance and behavior of the meter.

The requirements below assume a Class-200, form-2S, residential meter for ANSI purposes. The nominal test current for a Class-200 meter is 30 amps.

Unless stated otherwise, each current circuit carries the entire load current; however, the currents through the two current circuits are 180 degrees out of phase with each other.

In some cases, the IEC-1036 serves as a basis for the specifications below when the ANSI requirements are either not clear or possibly insufficient. When applying IEC-1036 requirements, the basic current (I_b) is 50 amps and the maximum current (I_{max}) is 200 amps.

A bullet symbol precedes each specific requirement. Text without a bullet symbol is explanatory information or supporting material.

2.1 Reference Conditions

Many of the system requirements define the performance of the meter while changing one variable, such at temperature or load current. When testing the influence of one variable, the other variables are held at reference conditions as specified in the table below:

Table 1. Reference Conditions

Quantity	Reference Value	Tolerance
Ambient temperature	23 °C	±5 °C
Input Voltage	240 V_{RMS}	±3.0%
Frequency	60 Hz	±1 Hz
Waveform	Sinusoidal voltages and current.	< 3% distortion factor
Magnetic fields of external origin at the reference frequency.	0.0 mT	The external magnetic field may not induce an error greater than ±0.2% and shall always be less than 0.05 mT.

ANSI Section 10.1 defines these reference conditions. Test currents are within 3% of the desired value. IEC Section 5.6.1 includes a limit on external magnetic fields, which is included in the above table as a precaution against test errors.

2.2 Input Requirements

2.2.1 Operating Voltage Range

- The meter shall start and operate over a voltage range of 192 to 276 VAC.
  The extremes of voltage range may be reduced by 4 VAC for each Hertz that the line frequency deviates from reference conditions.

Justification: The ANSI C12.16-1991 standard does not appear to give limits for operating voltage range; however, the standard does maintain accuracy requirements over a ±10-percent range (ANSI Table 8), over which the meter must obviously operate. Because of the lack of guidance from ANSI, the requirement above is based upon the IEC requirements.

IEC Section 4.4.2.1 calls for specified operation within the range of 0.9 to 1.1 U_n. The value U_n is nominal line voltage. IEC also requires limits of operation — no damage to the meter — of 0.0 to 1.15 U_n, which is 276 VAC for high-line conditions. Table 15 in IEC Section 4.6.2 requires that the meter register energy down to at least 0.8 U_n, or 192 VAC.

The IEC voltage range encloses the ±10-percent ANSI range plus the ±3-percent test-source accuracy given in Table 1 of this document.

2.2.2 Operating Frequency Range

- The meter shall start and operate over a frequency range of 56 Hz to 64 Hz.

Justification: ANSI Table 9 includes accuracy requirements over a frequency range of ±5 percent or ±3 Hz. The requirement above adds ±1 Hz to allow for the accuracy of the test source given in Table 1.

2.2.3 Operating Current Range

- The meter shall operate with a continuous load current of up to 200 amps.

See Section 2.14.2 for temperature-rise limits at the maximum load current.

Justification: ANSI Section 10.1.9 and the meter class drive this requirement.

2.2.4 Demand-Reset Button

2.2.5 Display-Mode Button

2.3 Optional Input Requirements

2.3.1 Activation Button

2.4 Output Requirements

2.4.1 IR Calibration LED (Test Output)

- The meter shall generate infrared calibration pulses at a rate of one pulse per 5.0, 7.2, or 10.0 watthours. The width of each pulse shall be at least 30 ms.

The design need only implement one of the watthour constants above.

Justification: This satisfies the ANSI requirement for testing provisions of Section 4.11.

The 30-ms pulse width allows simple detection but remains less than one eighth of the fastest pulse period:

$$t_{\mathrm{PERIOD\_MIN}} = \frac{(5.0\ \text{watthours})(3600\ \text{seconds/hour})}{(240\ \text{volts})(200\ \text{amps})} = 375\ \text{ms}, \qquad (2\text{-}1)$$

This leads to a pulse width less than (375 ms)/8 or 47 ms, which the 30-ms requirement satisfies.

2.4.2 Display

- The meter shall contain an LCD that displays the quantities listed in the table below. Unless noted, the LCD need not show these values simultaneously.

Quantity	Units	Resolution or Format	Notes
Time	24-hour time	*hh:mm:ss*	
Date		*mm-dd-yy*	
Total active (real) energy	kWh	*xxxxxx*	6 digits. [Do received and delivered energy require separate displays? This may be necessary when utilities have different buy-back rates for alternate-energy customers.]
Total reactive energy	kVARh	*xxxxxx*	6 digits.
Serial numbers	—	*xxxxxx*	[How many digits? Can a meter have more than one serial number?]
Last power failure	Date and time	*mm-dd hh:mm*	
Last power restoration	Date and time	*mm-dd hh:mm*	
Frequency, minimum and maximum	Hertz	*xx.x yy.y*	
Peak demand time stamp	Date and time	*mm-dd hh:mm*	Peak demand time is based upon peak active power.
Peak active demand	kW	*xxxxx.x*	
Peak reactive demand	kVA	*xxxxx.x*	Peak reactive demand is the reactive power associated with the instant of peak active demand. [Should peak reactive demand have its own time stamp?]
Voltage, minimum and maximum	V_{RMS}	*xxx yyy*	
Time of use			This display shows, at a minimum, the time-of-use period in effect and the amount of energy in that period. It may also allow scrolling through other time-of-use periods.
Load profile			Data for previous load-profile intervals are accessible at the meter.
Active power	kW	*xxxxx.x*	
Reactive power	kVA	*xxxxx.x*	
Frequency	Hertz	*xx.xx*	
Voltage	V_{RMS}	*xxx.x*	
Power usage indicator	—	—	Flashing icon indicates power usage. This indicator is always visible. The flash rate matches the pulse rate of the calibration LED described in Section 2.4.1; however, the flash has an approximate 50% duty cycle rather than a fixed pulse width.
Energy direction	—	—	Icon shows energy direction and is always visible. May be combined with usage indicator above.

2.4.3 Relay (Actuator) Outputs

- The meter shall contain two open-collector relay outputs controlled by the utility through the network. The outputs shall be capable of switching 30 VDC at 1 amp with a saturation voltage of less than [?] volts.

No short-circuit protection is currently defined.

Justification: These electrical requirements are from a June 21, 1999 conference call with John Lofgren. A more specific reference for these requirements is desirable. This requirement needs a defined limit on saturation voltage.

[Are these outputs appropriate? Would outputs that can interrupt the typical 24 VAC contactor circuit on an air-conditioner condensing unit be more practical?]

[Cadence/Diablo note: Should the meter contain load-control outputs? Since it is a wireless network, perhaps separate load-control boxes would make a better system solution.] [Also, bringing Class 2 (low-voltage, fire and electric-shock safe) circuits into the meter enclosure complicates the design.]

2.5 Optional Outputs

2.5.1 Disconnect Relay

- Versions of the meter that include the prepay feature shall include a 200-amp disconnect relay that can close or open the current circuit at a rate of up to once per minute.
- The meter shall allow verification of the relay action over the network.

Justification: Some versions of the meter may serve as a prepaid electricity meter.

2.6 Connector and Interfacing Requirements

Define connectors for external connections (load control, telephone, etc.) in this section as necessary.

2.6.1 Meter Base

- The meter shall have a base compatible with the standard ANSI meter socket (S-base).

2.7 System Accuracy Requirements

2.7.1 No Load

- With 276 VAC applied to the line terminals and with zero load current, the calibration LED (see Section 2.4.1) shall generate no more than one pulse during a 90-minute test interval.

The meter may use software techniques to stop the meter below the starting load current of Section 2.7.2.

Justification: IEC Sections 4.6.4.2 and 5.6.4 set this requirement. The test interval is calculated from the IEC-supplied equation with the following numbers:

$$\Delta t_{\mathrm{MIN}} = \frac{600 \times 10^6}{\left(\frac{1000\ \mathrm{Wh/kWh}}{7.2\ \mathrm{Wh/pulse}}\right)(1\ \mathrm{element})(240\ \mathrm{volts})(200\ \mathrm{amps})} = 90\ \mathrm{minutes} \qquad (2\text{-}2)$$

ANSI Section 10.1.1 also defines a no-load test. However, this test uses the kilowatthour display, which is much coarser than the pulse output used by the IEC test. In any case, given the small amount of energy represented by a test pulse, the 90-minute IEC test is more stringent than the 24-hour ANSI test.

2.7.2 Starting Load

- The meter shall start and operate continuously with a load current of 0.2 amps at unity power factor.

Justification: IEC Section 4.6.4.3 requires a starting current of 0.004 I_b, which equals 0.2 amps. ANSI Section 10.1.2 requires a starting current of 0.3 amps, which is also met by the above requirement.

2.7.3 Load Variation

- At reference conditions of temperature, voltage, and frequency, the meter shall have a registration error no greater than given by the table below:

Table 2. Error Limits over Load Variation

Load Current (amps)	Error Limits (± percent)
2	2.0
$2.5 \le I < 3.0$	1.5
$3.0 \le I \le 200$	1.0

Justification: The table above is an amalgamation of IEC and ANSI requirements.

IEC Section 4.6.1 specifies error limits of 1.5 and 1.0 percent for the current ranges of 0.05 I_b to 0.1 I_b (2.5 to 5.0 amps) and 0.1 I_b to I_{max} (5.0 to 200 amps) respectively.

ANSI Section 10.1.3 has error limits given by the table below.

Table 3. ANSI Accuracy over Load Variation (Reference Information)

Load Current (amps)	Maximum Deviation from Reference Performance (± percent)
2	2.0
3	1.0
6	1.0
20	1.0
30	Reference
60	1.0
100	1.5
150	2.0
180	2.0
200	2.0

The IEC and ANSI accuracy requirements are similar except at currents of 100 amps and above; at these higher load currents, the IEC requirements are more stringent.

2.7.4 Power-Factor Variation

- At power factor, the meter shall conform to the error limits in the table below.

Table 4. Error Limits at Power Factor

Load (amps)	Power Factor	Error Limits (± percent)
$5.0 \le I < 10.0$	0.5 inductive (60° lag) 0.8 capacitive (37° lead)	1.5 1.5
$10.0 \le I \le 200$	0.5 inductive (60° lag) 0.8 capacitive (37° lead)	1.0 1.0

These limits apply at reference conditions of temperature, voltage, and frequency.

Justification: The accuracy limits of IEC Section 4.6.1 at power factor are more stringent than the ANSI requirements. Therefore, the table above is simply the IEC requirements.

For reference, the requirements of ANSI Section 10.1.4.1 appear in the table below. Because each ANSI error limit is relative to a specific reference condition rather than an absolute error, the ANSI requirements are quite loose compared to the IEC limits.

Table 5. ANSI Error Limits over Power-Factor Variation (Reference Information)

Reference Condition		Test Condition		Maximum Deviation from Reference Performance (± percent)
Load (amps)	**Power Factor**	**Load (amps)**	**Power Factor**	
3.0	1.0	6.0	0.5 lag	2.0
100	1.0	100	0.5 lag	2.0
200	1.0	200	0.5 lag	2.0

2.7.5 Voltage Variation

- The additional registration error due to voltage variation beyond the load-variation error limits of Table 2 and Table 4 shall not exceed the limits in the table below.

Table 6. Voltage Influence Limits

Voltage Range (VAC)	Load Current (amps)	Power Factor	Error Limits beyond Table 2 and Table 4 (percent)
$0 \le V < 192$ (–100% to –20%)	$2.5 \le I \le 200$	1.0	–100 to +10
	$5.0 \le I \le 200$	0.5 lag	–100 to +10
$192 \le V < 216$ (–20% to –10%)	$2.5 \le I \le 200$	1.0	± 2.1
	$5.0 \le I \le 200$	0.5 lag	± 3.0
$216 \le V \le 264$ (±10%)	$2.5 \le I \le 200$	1.0	± 0.7
	$5.0 \le I \le 200$	0.5 lag	± 1.0
$264 < V \le 276$ (+10% to +15%)	$2.5 \le I \le 200$	1.0	± 2.1
	$5.0 \le I \le 200$	0.5 lag	± 3.0

Justification: IEC Section 4.6.2 drives the above table. ANSI Section 10.1.5 also limits the influence of voltage as shown in the table below; however, the IEC limits are more stringent and therefore prevail.

Table 7. ANSI Limits of Voltage Influence (Reference Information)

Reference Condition		Test Condition		Limits of Deviation from Reference Performance (± percent)
Load (amps)	**Percent of Rated Voltage**	**Load (amps)**	**Percent of Rated Voltage**	
3.0	100	3.0	90	1.0
3.0	100	3.0	110	1.0
30.0	100	30.0	90	1.0
30.0	100	30.0	110	1.0

2.7.6 Frequency Variation

- The meter shall maintain accuracy over frequency variation as the table below specifies.

Table 8. Frequency Influence Limits

Reference Condition	Test Condition	Limits of Deviation from Reference Performance (± percent)

Load (amps)	Frequency (Hz)	Load (amps)	Frequency (Hz)	
3.0	60	3.0	57	1.0
3.0	60	3.0	63	1.0
30.0	60	30.0	57	1.0
30.0	60	30.0	63	1.0

Justification: ANSI Section 10.1.6 sets these requirements. IEC Section 4.6.2 also dictates limits of frequency influence; however, the IEC numbers for frequency variation and error limits are both roughly half the ANSI numbers so the ANSI and IEC requirements are roughly equivalent.

2.7.7 Load-Current Imbalances

- The meter shall maintain accuracy, as shown by the table below, when load current flows through only one current circuit at a time.

Table 9. Error Limits with Load-Current Imbalances

Reference Condition		Test Condition		Limits of Deviation from Reference Performance (± percent)
Load (amps)	Current Circuits	Load (amps)	Current Circuit	
3.0	Both	6.0	A	1.0
3.0	Both	6.0	B	1.0
30.0	Both	60.0	A	1.0
30.0	Both	60.0	B	1.0

Justification: ANSI Section 10.1.7.1 sets these limits. Table 14 of IEC Section 4.6.1 has some similar limits, but the table applies primarily to current imbalances in polyphase meters — the table's application to load-current imbalances in single-phase meters is not clear, so the ANSI limits apply.

2.7.8 Internal Heating

- When subject to internal heating created by load current, the meter shall maintain accuracy according to the table below.

Table 10. Self-Heating Influence Limits

Load Current (amps)	Power Factor	Limits of Variation (±percent)
200	1.0	0.7
200	0.5 lag	1.0

The self-heating test method is as follows:

(1) Energize the voltage circuit for at least two hours with no load current.

(2) Apply the load current.

(3) Immediately measure the meter error after application of load current and then at intervals short enough to observe the registration error as a function of time.

(4) The test proceeds for at least one hour and then until the variation during a 20-minute period is less than 0.2 percent.

(5) The total variation with self-heating, relative to the first measurement, shall be less than the limits in the table above.

Justification: IEC Section 4.4.4 sets these limits; IEC Section 5.4.4 dictates the test method. ANSI Section 10.1.10 also includes self-heating error limits; however, the ANSI limits are looser by approximately a factor of two, so this document adopts the IEC limits.

2.7.9 Stability over Time

- The meters shall run continuously with a load current of 3 amps. Under these conditions, the percent registration shall be measured at the beginning of the test and at 10 successive intervals at least 24 hours apart within a two-week period. The registration at the beginning of the test shall not differ from the registration of any subsequent test by more than ±1 percent.

Justification: ANSI Section 10.1.11 drives this requirement. This test is a good check of stability. However, the test may have less importance (than in the ANSI specification) with the absolute error limits defined in Table 2 of this document — the *absolute* error limits of Table 2 necessitate some reasonable meter stability. The original ANSI accuracy limits over load variation are *relative* to a reference load current; therefore, the ANSI test method effectively removes much of the error caused by drift over time and necessitates a separate stability test.

2.7.10 Voltage Interruption

- With zero current applied to the current circuits, the internal energy register of the meter shall not change by more than 0.048 kWh during the following voltage interruptions. The meter shall function correctly after the interruptions.

Table 11. Voltage Interruptions

Voltage Dip (percent)	Interruption Time	Number of Interruptions	Restoration Time between Interruptions
100	1 second	3	50 ms
100	20 ms	1	—
50	1 minute	1	—
100	100 ms	6	1 second

Justification: IEC Sections 4.4.2.2 and 5.4.2.1 set these requirements. ANSI Section 10.2.2 sets the timing for the last sequence (six interruptions) but not the test limits.

ANSI Section 10.2.2 defines a less stringent requirement for voltage interruption; however, the ANSI requirement is based upon the meter display. Since the least significant meter digit is in units of kWh, the ANSI test has less resolution. Also, since the meter's internal energy register may be very close to a change of the display digit, some instances of the test may be *too* sensitive to voltage interruptions. For completeness, the table above includes the ANSI interruption timing but uses the IEC test limits.

2.7.11 External Magnetic Field

- At a load current of 50 amps, a DC electromagnet applied to any external surface of the meter shall not cause a registration change greater than ±2 percent. The magnet is energized at 1000 amp-turns.

Justification: Permanent magnets should not disrupt the meter; this helps reduce the likelihood of successful tampering. IEC Sections 4.6.2 and 5.6.2.3 drive this requirement. Annex D of the IEC specification shows the magnet construction details.

- At a load current of 50 amps, a 60-Hz magnetic field of 0.5 mT having the worst-case phase and direction shall not create a registration change greater than ±2 percent.

Justification: Nearby current-carrying conductors should not interfere with the meter. IEC Sections 4.6.2 and 5.6.2.4 drive this requirement. To generate the field, the meter sits at the center of a 1-meter-diameter loop carrying 400 amp-turns of current. [The ANSI-derived requirement below may be sufficient alone because both the load current and magnetic field are proportionally smaller.]

- At a load current of 3 amps, a 60-Hz magnetic field of 80 μT in phase with the load current shall create a metering error no greater than ±1.0 percent. This applies with the field aligned with any of the three axes of the meter. The field has a gradient of approximately 310 μT/m perpendicular to the field lines.

Justification: ANSI Section 10.2.4 includes the following test for external magnetic fields. A conductor carrying a 100-amp current in phase with the 3-amp test current generates the magnetic field. The meter shall have a registration change no greater than ±1.0 percent for three orientations of the conductor:

- In a horizontal orientation 10 inches behind the center of the meter.
- In a vertical orientation 10 inches behind the center of the meter.
- In a vertical orientation 10 inches right or left of the center of the meter.

The field-generating conductor is one side of a 6-foot, square loop. See the ANSI standard for further details.

This test setup creates a magnetic field of approximately

$$H_{\mathrm{TEST}} = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi \times 10^{-7}\ \mathrm{H/m}\right)\left(100\ \mathrm{amps}\right)}{2\pi\left(10\ \mathrm{inches}\right)\left(0.0254\ \mathrm{m/inch}\right)} = 79\ \mu\mathrm{T}. \qquad (2\text{-}3)$$

This magnetic field also has a gradient of

$$\frac{dH_{\mathrm{TEST}}}{dr} = -\frac{\mu_0 I}{2\pi r^2} = \frac{-\left(4\pi \times 10^{-7}\ \mathrm{H/m}\right)\left(100\ \mathrm{amps}\right)}{2\pi\left[\left(10\ \mathrm{inches}\right)\left(0.0254\ \mathrm{m/inch}\right)\right]^2} = -310\ \mu\mathrm{T/m}, \qquad (2\text{-}4)$$

which may be significant in designs that use cancellation techniques to reduce the effect of external magnetic fields.

2.7.12 Temperature Coefficient

- The meter shall meet the temperature-coefficient limits specified in the two tables below. The first table applies to unity power factor, and the second table applies to an inductive power factor of 0.5.

Table 12. Temperature-Coefficient Limits at Unity Power Factor

Load (amps)	**Temperature Coefficient Limits (±ppm/°C)**	
	–20 °C to +23 °C	**+23 °C to +50 °C**
3.0	700	740
5.0 ≤ I < 30	500	500
30 ≤ I ≤ 100	465	370
100 < I ≤ 200	500	500

Table 13. Temperature-Coefficient Limits at 0.5 Inductive Power Factor

Load (amps)	**Temperature Coefficient Limits (±ppm/°C)**

	–20 °C to +23 °C	+23 °C to +50 °C
6.0	940	1110
$10.0 \le I < 200$	700	700

Justification: The above tables are a combination of ANSI and IEC limits. IEC places a fixed limit on TC over a wide load range, while ANSI relaxes the limits at the extremes of load range. However, at loads of 30 to 100 amps at unity power factor, the ANSI limits are more strict than the IEC limits.

For background information, the table below summarizes the ANSI Section-10.2.5 limits for the effect of temperature. The reference performance is measured at +23 °C and at the same current and power factor as each temperature test point. All temperatures are controlled to ±5 °C, and the meter remains energized at each test temperature for at least 2 hours before performing measurements at that temperature.

Table 14. ANSI Limits of Effect of Ambient Temperature (Reference Information)

Temperature (°C)	Load (amps)	Power Factor	Maximum Deviation from Reference Performance at +23 °C (± percent)	Average TC (ppm/°C)
+50	3.0	1.0	2.0	740
+50	30.0	1.0	1.0	370
+50	100.0	1.0	1.0	370
+50	6.0	0.5 lag	3.0	1110
+50	30.0	0.5 lag	2.0	740
+50	100.0	0.5 lag	2.0	740
–20	3.0	1.0	3.0	700
–20	30.0	1.0	2.0	465
–20	100.0	1.0	2.0	465
–20	6.0	0.5 lag	4.0	930
–20	30.0	0.5 lag	3.0	700
–20	100.0	0.5 lag	3.0	700

IEC Section 4.6.3 specifies temperature variation directly as a temperature coefficient. The IEC test measures meter registration 10 °C above and 10 °C below the temperature of interest. The test procedure than calculates the average temperature coefficient over the resulting 20-°C interval. The IEC limits follow in the table below.

Table 15. IEC Limits of Temperature Coefficient (Reference Information)

Load	Power Factor	Limit of average temperature coefficient (ppm/°C)
$0.1\, I_b \le I \le I_{max}$	1.0	500
$0.2\, I_b \le I \le I_{max}$	0.5 inductive	700

2.7.13 Harmonic Power

- Under the following test conditions, the meter shall register the sum of fundamental energy and harmonic energy with an error of less than ±0.8 percent plus the error limits of Table 2. This gives a total allowable error of ±1.8 percent.

Test Parameter	Value	Units
Fundamental current (60 Hz).	100	amps
Fundamental voltage.	240	V_{RMS}
Fundamental power factor.	1	—

Test Parameter	Value	Units
Fifth-harmonic (300-Hz) voltage component.	24	V_{RMS}
Fifth-harmonic current component.	40	amps
Harmonic power factor.	1	—
Relative phase of fundamental and harmonic voltages.	Positive zero-crossings coincide.	—

The total power under these conditions is

$$P_{\text{TOTAL}} = P_{\text{FUNDAMENTAL}}\left[1.0+\left(\frac{40\text{ amps}}{100\text{ amps}}\right)\left(\frac{24\text{ volts}}{240\text{ volts}}\right)\right]=1.04P_{\text{FUNDAMENTAL}}. \quad (2\text{-}5)$$

Justification: IEC Sections 4.6.2 and 5.6.2.1 drive this requirement. ANSI does not appear to have clear requirements for harmonic response.

2.7.14 DC Load Current

- With a half-wave-rectified load current of 141 amps, the meter registration error shall be less than ±4 percent.

The 141-amp value applies before half-wave rectification, so the meter sees an rms current of 100 amps. The test setup allows the standard meter to see the full 141-amp current (without DC), so in the absence of error, the meter under test should register exactly half the energy of the standard meter.

Justification: This self-contained meter may be exposed to DC load current. IEC Sections 4.6.2 and B.1 drive this requirement and specify a test current of $I_{max}/\sqrt{2}$. With this DC load-current component, IEC allows an additional ±3 percent of error beyond the normal error limits for the 100-amp load current (see Table 2 of this document), which gives a total error limit of ±4 percent.

2.7.15 Temporary Overload

- With a temporary overload, the meter shall maintain accuracy as shown in the table below. To minimize residual magnetic effects, perform the test steps in the order shown by the table.

Table 16. Accuracy with Temporary Overload

Test Step		Load Current (amps)	Duration	Maximum Deviation from Reference Performance (± percent)
1	Reference	30	—	—
2	Reference	3.0	—	—
3	Overload	7000	6 cycles (100 ms)	—
4	Test	30	—	1.5
5	Test	3.0	—	1.5

Justification: ANSI Section 10.2.6 requires this test. The overload current also meets the requirements of IEC Section 4.4.3, which calls for a 6,000-amp, one-half-cycle overload. However, the IEC requirements allow the meter to cool for one hour after the overload and specify the accuracy test at I_b (50 amps).

2.8 Power-Consumption Requirements

2.8.1 Current-Circuit Loss

- The loss in each current circuit of the meter shall be less than 1.0 VA with a load current of 30 amps.

Justification: ANSI Section 10.1.8 calls for a maximum loss of 1.0 VA in each current circuit, presumably at the standard test current of 30 amps. IEC Section 4.4.1.2 allows a loss of up to 4.0 VA at the basic current of 50 amps, which, assuming a linear current-circuit impedance, is also met by the above requirement.

2.8.2 Voltage-Circuit Loss

- The loss in the meter's voltage circuit shall not exceed 2 watts and 10 VA.

This includes power used by the meter's control, display, and communication electronics. However, these are average values that may be momentarily exceeded — for example, a meter-reading transmission may require more than 2 watts, but the duty cycle of such transmissions are short.

Justification: ANSI Section 10.1.8 and IEC Section 4.4.1.1 both limit the voltage circuit to 10 VA. The IEC standard further limits the real power to 2 watts.

2.9 Other Functional System Requirements

2.9.1 Initial Start Up

- The meter shall be functional within 5 seconds after the application of rated voltage to the meter terminals.

Justification: IEC Section 4.6.4.1 places this requirement on the meter.

2.9.2 Registered Quantities

- The meter shall register kilowatthours (kWh) delivered.
- The meter shall register kilowatthours (kWh) received.
- The meter shall register kvar-hours (kVARh). [Should it separate received and delivered kvar-hours?]
- [Cadence/Diablo: Should the meter include a demand register for peak-demand billing?]
- The meter shall monitor rms line voltage as needed by the display, time-of-use, and load-profile functions set forth in this document.
- The meter shall monitor line frequency when needed by the frequency-display function of Section 2.4.2.

Justification: The functions required of the meter necessitate the above measurements. These are arguably derived requirements, but they appear here to clarify what the meter does and does not measure.

2.9.3 Time-of-Use Function

- The meter shall be capable of functioning in a time-of-use mode.
- The meter shall accept time-of-use reconfiguration messages over the network.

- The meter shall provide seven configurable time-of-use intervals per day. In billed meters, energy consumed during each time-of-use interval accumulates in one of seven corresponding bins. In prepay meters, each time-of-use interval shall have a configurable rate that deducts from the remaining prepay dollar balance.
- The meter shall internally store time-of-use information for the last 35 days. The stored information for each interval is kWh delivered, kWh received [are separate delivered/received records needed?], total kVARh, and rms voltage.

This corresponds to (7 intervals/day)(35 days) = 245 sets of records in addition to the accumulated totals for each time-of-use interval.

- The meter shall include configurable weekend and holiday rates. [This requirement needs more detail.]

Justification: Time-of-use function is a marketing requirement. Since rates and peak times may vary, the time-of-use function requires the capacity for reconfiguration over the network.

[Cadence/Diablo note: Are seven intervals best? A meter with 24 time-of-use bins, one for each hour of the day, may provide more flexibility. Also, if treated as a special case of load profile — that is, the load-profile interval equals one hour — the amount of history stored by the meter would allow head-end (central-office) processing of the data. This would reduce the amount of knowledge the meter requires about rate schedules, weekends, and holidays.]

2.9.4 Load Profile

- The meter shall store load profiles with a configurable load-profile interval of 1 to 60 minutes.
- The meter shall internally store data records for the last 3360 load-profile intervals. Each data record shall include kWh delivered, kWh received [are separate delivered/received records needed?], total kVARh, and rms voltage. The time and date of each record shall be available even if the load-profile interval changes during the last 3360 records.

Justification: Load-profile operation is a marketing requirement. The 3360 load-profile records provide 35 days of 15-minute load-profile intervals.

2.9.5 Non-Volatile Memory

- The meter shall retain data during a power failure according to the following table.

Data	Retention Time Without Power
Calibration factors	10 years
Serial number, network address	10 years
Total kWh and kVARh	1 year
Prepay balance	1 year
Time-of-use totals	3 months
Time-of-use history	3 days
Load-profile history	3 days

Justification: The meter may be exposed to power losses and must retain billing and other critical information during the power loss.

2.9.6 Factory Set up and Calibration

- The meter shall only accept calibration and initialization messages through the PCCI adapter card. [Is the practical in the manufacturing environment? — may want to allow calibration with the meter cover installed. The PCCI adapter card is unique to the original Innovatec meter prototypes. For a product based on an existing meter design, the meter manufacturer may define the calibration and set-up procedure.]

Justification: This feature reduces the likelihood of meter tampering via the RF link.

- The meter shall not require programming of the EEPROM before installation on the circuit board.

Justification: Programming the EEPROM before placement would complicate the manufacturing process.

2.10 Network Communication Requirements

2.10.1 Innovatec Network Compatibility

- The meter shall function within Innovatec's automated meter-reading network and conform to Revision 2 of the communication protocol.
- [Channel or frequency assignment?]

2.10.2 Relay Node

- The meter shall function as a relay node for reading up to sixteen water and gas meters (also called IMUs – information management units) conforming to Innovatec's network protocol.

The particular sixteen or fewer IMUs for which the meter relays messages are stored in a configurable IMU list.

- The meter shall have a configurable retry scheme for communicating with IMUs.
- The meter shall store the last time and date of communication with each IMU.

2.10.3 Power-Fail Transmission

- The meter shall transmit a power-fail message to the gateway node upon an impending power failure. The meter need not verify receipt of the transmission.
- The meter shall not transmit a power-fail message unless power has been good for at least 5 minutes.

Justification: This feature allows utilities to monitor failures with the power distribution system. The power-good time requirement prevents brownout conditions and faulty power supplies from generating excessive power-fail messages.

[A power-restoration message may also be useful, but again, must have some limits on the number of transmissions to prevent excessive transmissions during brown-out conditions.]

2.10.4 Prepay Alarms Messages

- In meters configured for prepay operation, the meter shall allow up to three configurable thresholds for alarms. The alarm is a message sent through the network to the utility.

Justification: The utility likely requires notification of a meter's prepaid amount running low or running below zero.

2.10.5 Prepay Display Unit Messages

- Meters configured for prepay operation shall periodically transmit updates for the remote prepay display unit.
- Meters configured for prepay operation shall employ techniques to prevent transmission collisions with the prepay-display transmission of nearby meters.

Justification: Prepay customers will likely have a display unit that is located within the dwelling unit. This display unit requires periodic updates of dollar balance and current usage, for example, from the meter.

2.10.6 Antenna Pattern

- The meter's transmitter and receiver shall use vertical polarization.
- To the extent possible given the metallic meter box, the receiver and transmitter radiation patterns shall be uniform in and shall not have nodes in the horizontal plane.

Justification: Vertical polarization is used by all components of the Innovatec LAN. Because the directions of the gateway node and IMUs relative to the meter are not controlled, the radiation pattern should be omnidirectional in the horizontal plane.

2.10.7 Transmitter Power

- The meter shall transmit with an effective radiated power of +28 to +30 dBm.

Justification: Section 15.247 of CFR Title 47 limits spread-spectrum transmissions in the 902- to 928-MHz band to 1 watt with an antenna gain of up to +6 dBi. This permits an ERP of up to +36 dBm. The specification above is a reasonable target that could increase slightly in the future.

2.10.8 Receiver Sensitivity and Rejection

- At the peak of the antenna's radiation pattern, the meter shall have a receiver sensitivity better than *x* [?] dBμV/m at a packet failure rate of 10 percent.

Justification:

2.10.9 Receiver Interference Rejection

- At a signal level of +95 dBμV/m, the meter shall tolerate broadband Gaussian noise of x [?] dBμV/m/√Hz with a packet failure rate less than 10 percent.
- At a signal level of +95 dBμV/m, the meter shall tolerate narrowband interference, both CW and on-off-keyed with a 1-kHz square wave, at the following signal-to-noise ratios with a packet failure rate less than 10 percent. For the on-off-keyed interference, the SNR applies to the "on" level of the signal, not the average power.

Frequency Range	SNR (dB)	Notes
10 kHz – 806 MHz	–60	This covers the broadcast bands and most unintentional radiation of nearby devices.
806 – 902 MHz		Primarily cell-phone interference.
902 – 928 MHz		Other users of the ISM band may interfere. Narrowband rejection limited by process gain.
928 MHz – 3 GHz		

Verification protocols for the interference requirements above may directly drive the antenna terminals using estimates for the antenna gain at the test frequencies.

Justification: The meter-reading network must operate in the presence of various sources of electromagnetic interference. The signal field strength of +95 dBμV/m for these requirements corresponds to a 1-watt gateway node at 100 meters. Some interference sources to consider are broadcast transmitters (UHF television with an ERP of 5 MW at approximately 1 km), cell phones (1 watt intermittently at perhaps at a 10-meter distance), and other users of the ISM band such as cordless phones.

2.10.10 Receiver Saturation

- At the peak of the antenna's radiation pattern, the receiver shall decode in input signal of +126 dBμV/m with a packet failure rate less than 1 percent.

Justification: This allows for reception of a 1-watt gateway node at a minimum (worst-case) distance of 3 meters.

2.11 Electromagnetic-Immunity and Electrical-Stress Requirements

The electrical stress requirements below affect primarily the power supply and metering circuitry.

2.11.1 Fault Current

- The meter shall withstand a 12,000-amp-rms, 60-Hz, symmetrical fault current for 4 cycles without damage to the mechanical structure or a reduction in insulation level.

Justification: ANSI Section 10.2.6.2 drives this requirement.

2.11.2 High-Voltage Line Surges

- After the application of single 6-kV, 1.2x50-μs surges in both the line-to-line and line-to-ground configuration, the internal energy registers shall change no more than ±0.1 kWh or ±0.1 kVARh. The meter shall operate properly after the test.

Justification: ANSI Section 10.2.3 requires this surge test. ANSI uses the displayed value for the test, but reading the internal energy registers allows greater resolution and repeatability. [Although implied, an accuracy-drift requirement may be useful.]

2.11.3 Current Surge in Ground Conductor

- A 20,000-amp, 20x50-μs surge current through a vertical conductor 1.5 inches behind the flat portion of the meter's base shall not cause a registration change greater than ±1 percent. The load current for the accuracy test is 30 amps.

Justification: ANSI Section 10.2.7 sets this requirement.

2.11.4 Oscillatory Surge

2.11.5 Superimposed Signals

2.11.6 Radio-Frequency Immunity

2.11.7 ESD Immunity

2.11.8 Electrical Fast Transient (EFT)

2.12 Environmental

2.12.1 Operating Temperature Range

- The meter shall start and operate correctly over an ambient temperature range of –40 °C to +70 °C.

Because of internal meter heating, the internal meter components should allow for an ambient temperature of up to +85 °C.

<u>Justification</u>: ANSI Section 10.2.5 implies an operating temperature range of –20 °C to +50 °C. IEC Section 4.3.1 requires –25 °C to +60 °C for an outdoor meter, which is more extreme.

Cadence/Diablo recommended a –40 °C to +85 °C range. However, the reduction of the high end to +70 °C meets the IEC and ANSI requirements while allowing for internal heating. Internal heating in conjunction with a +85 °C requirement could push many of the components beyond the industrial temperature range. Still, accelerated life testing at +85 °C or higher could disclose weaknesses in the design.

2.12.2 Humidity

- Under the following humidity conditions, the meter shall operate properly and shall meet the isolation-voltage requirements.

Table 17. Relative Humidity

Conditions	Relative Humidity (percent)
Annual mean.	≤ 75
For 30 days spread in a natural manner over one year.	95
Occasionally on other days.	85

<u>Justification</u>: IEC Section 4.3.2 sets these requirements. For a possible verification protocol, see IEC Section 5.3.3.

2.12.3 Shock

- After application of the shock described in the table below, the meter shall show no damage and shall operate in accordance with the requirements of this document.

Table 18. Mechanical Shock

Description	Value
Meter condition.	Non-operating, without the packing.

Description	Value
Shock waveform.	Half-sine pulse.
Peak acceleration.	30 G (300 m/s^2)
Duration of pulse.	18 ms

Justification: IEC Section 5.2.2 drives this requirement.

2.12.4 Vibration

- After application of the vibration described in the table below, the meter shall show no damage and shall operate in accordance with the requirements of this document.

Table 19. Vibration

Description	Value
Meter condition.	Non-operating, without the packing.
Frequency range.	10 Hz to 150 Hz
Transition frequency.	60 Hz
Displacement amplitude (applies below 60 Hz).	0.075 mm peak-to-peak
Acceleration (applies above 60 Hz).	9.8 m/s^2 rms (1 G)
Number of sweeps per axis.	10
Sweep time.	7.5 minutes

See IEC 68-2-6 for details of test procedure A.

Justification: IEC Section 5.2.3 drives this vibration requirement.

2.12.5 Spring Hammer Test

2.12.6 Storage

2.13 EMC

- The meter shall conform to FCC Class-B limits for both radiated and conducted emissions.

Justification: The meter is targeted for residential (FCC Class-B) use.

2.14 Safety

2.14.1 Isolation Voltage

- With the meter voltage and current circuits de-energized, the insulation between separate current-carrying circuits and between current-carrying circuits and other metallic parts shall withstand 2500 VAC at 60 Hz for 1 minute.

Justification: ANSI Section 10.2.1.

2.14.2 Temperature Rise

- No current-carrying part [of the current circuit?] shall exceed 55 °C.

Justification: ANSI Section 10.1.9 drives this requirement. A higher temperature may be acceptable if the conductor uses a suitable insulating material.

2.14.3 Leakage Current

2.14.4 Creepage and Clearance

2.14.5 Component Faults

2.15 Other

2.15.1 Product Life

- The meter shall have a life of 20 years. [Define failure rate over this period.]

<u>Justification</u>: This is a marketing requirement from an earlier specification. [Recheck this requirement.]

3 Subsystem and Subsystem Interface Requirements

This section places requirements on particular subsystems. User needs or environmental requirements do not directly drive these requirements; instead, the particular architecture of the meter drives these subsystem requirements.

3.1 LAN Radio PCB (NCI) Interface

This section describes the interface and space allowances for the NCI card within the meter.

3.1.1 NCI Physical Volume

- The meter's mechanical design shall provide a physical space of 4.15 x 2.30 x *t* inches plus any necessary clearance, for the attachment of an NCI radio card.

The figure below shows a reference drawing of the PCB footprint. Refer to the latest revision of drawing #IN960-00017 for details. [Is the connector on the component or solder side of the board?]

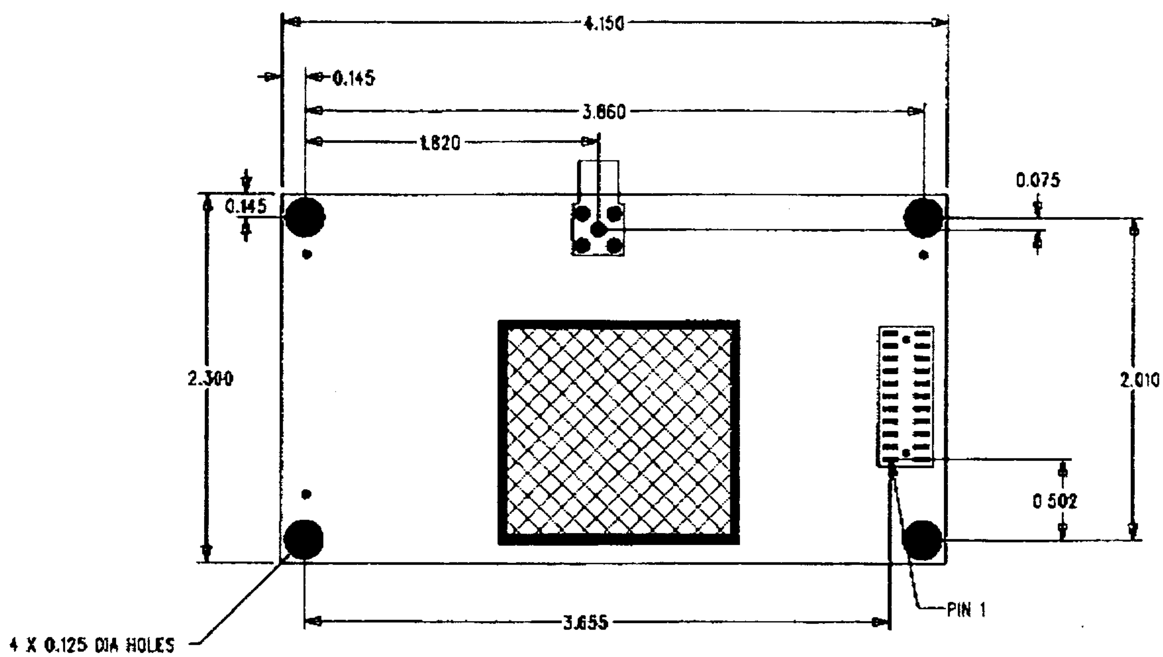

Figure 1. NCI Card Footprint (Reference Only)

3.1.2 NCI Electrical Interface

- One of the meter's PCBs shall provide a connector for the attachment of an NCI radio card. The connector is a 22-pin [P/N?] with a pin assignment as shown in the table below.

Table 20. NCI Connector Pin Assignment

Pin	Symbol	Signal Type (Meter's point of view)	Function
1, 2	GND	Ground	Signal and power supply common.
3	NC	—	No internal connection to NCI.
4	TEST0	?	NCI: Test-mode jumper. CPU: Short to GND for test mode. Otherwise, internally pulled up for normal mode.
5	NC	—	
6	CS/PULSE	Input, 3.6-volt	NCI: [high/low?] Indicates NCI is about to send. CPU: Interrupt from NCI indication SPI data transfer.
7	TEST1	?	NCI: Test-mode jumper. CPU: Short to GND for test mode. Otherwise, internally pulled up for normal mode.
8	RTS/TAMPER	Output, 3.6-volt	NCI: Signals NCI to request data. CPU: Pull [high/low] to send data to NCI's SPI master.
9	SYNC	Output, 3.6-volt	NCI: Enables synchronous serial operation. CPU: Set high or low for synchronous or asynchronous serial connection respectively.
10	SPICLK	Input, 3.6-volt	SPI port clock.
11	NC	—	
12	SPIIN	Input, 3.6-volt	NCI: SPI output. CPU: SPI port input.
13	NC	—	
14	SPIO	Output, 3.6-volt	NCI: SPI input. CPU: SPI output.
15, 16	+5.0V	Power output	Power for NCI transmitter.
17,18	+3.6V	Power output	Power for NCI logic and small-signal RF circuitry.
19	?		
20	P0.7	I/O, 3.6-volt	NCI: Not presently used. [Is it connected?] CPU: General purpose I/O port connection from NCI.
21, 22	GND	Ground	Signal and power supply common.

Justification: Cadence/Diablo supplied these pin assignments on January 19, 2000. [May want to supply the board with the L1GOOD signal so that the NCI board may autonomously transmit a power-fail message in future product versions.]

[May want to define timing details and the SPI bit rate.]

3.1.3 NCI Power Requirements

- The meter shall supply both 3.6 VDC and 5.0 VDC to the NCI board at the current levels specified by Table 21 below.
- Each supply voltage shall attain and maintain a tolerance of ±5 percent within 2 seconds after the application of nominal line voltage.
- The 3.6- and 5.0-volt power supplies for the NCI board shall have ripple voltages of less than 10 mV_{PP} and 50 mV_{PP} respectively.

Table 21. NCI Card Power Requirements

Mode	3.6-Volt Supply (mA)	5.0-Volt Supply (mA)	Duty Cycle Limits
Receive	95	0	State of the NCI card when not transmitting.
Transmit	130	1000	The maximum transmitter duration is 2.5 seconds. The maximum transmit-mode duty cycle averaged over any 15-second period is 20 percent.

Justification: Cadence/Diablo provided the supply-current values in the table above on January 19, 2000.

The 2-second startup time allows 3 seconds for MPU initialization to meet the 5-second system startup time of Section 2.9.1.

The ripple voltages are inherited from an earlier specification and require evaluation against the present NCI design — the limits may be too stringent and may unnecessarily increase the cost of the power supply.

The transmitter duty-cycle limit eases the thermal demands placed upon the power-supply components. This value may change in the future based upon the power supply design and upon the needs of the communication protocol.

3.1.4 NCI Hold-Up Times

- After deassertion of the L1GOOD (or equivalent) signal, the power supply shall maintain the NCI's power supplies for 40 ms. The 40-ms period after the deassertion of L1GOOD includes a 10-ms transmission.

The NCI board continues to draw the receive-mode load current until the 3.6-volt rail drops. The system load budget must account for this draw beyond 40 ms if other parts of the meter require longer hold-up times.

Justification: The meter must transmit a power-fail message at the beginning of a power failure; see Section 2.10.3.

3.1.5 NCI Logical Interface

- The meter's main board shall transfer data to and from the NCI card via the SPI lines using the formats and protocols set forth in firmware specification [?].

Justification: The NCI card must reliably communicate with the meter's MPU.