Review of ISO New England Measurement and Verification Equipment Requirements

FINAL REPORT

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Prepared for:
Northeast Energy Efficiency Partnerships' Evaluation and State Program Working Group

Comprised of the following sponsors:

Cape Light Compact
Connecticut Municipal Electric Energy Cooperative
Efficiency Vermont
National Grid USA
NSTAR Electric
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Table of Contents

Figures, Equations, and Tables

Northeast Energy Efficiency Partnerships
Review of ISO New England Measurement and Verification Equipment Requirements

Executive Summary

This document reports the research performed in 2007 and 2008 to interpret and assess the feasibility of compliance with the ISO New England Manual for *Measurement and Verification of Demand Reduction from Demand Resources (M-MVDR)*. Concerns from various parties that the M-MVDR may have implications on the qualification of Other Demand Resources (ODRs) participating in the Forward Capacity Market (FCM) spawned this effort. Accordingly, this report focused upon potential M-MVDR repercussions on the M&V typically performed in the evaluation of energy-efficiency program impacts.

Some issues herein are technical and complex, and few M-MVDR requirements lend themselves to concise expressions or clear recommendations for compliance. However, the following list highlights some of the key conclusions from this study:

1. Any direct measurement of electrical demand (kW) shall be true-RMS and accurate within ±2%;
2. Any computation of electrical demand using indirect measurement, assumptions, or proxy variables shall culminate in an overall kW accuracy within ±2%, although this poses considerable challenges as detailed later in this report;
3. The accuracy, error, or uncertainty contributions of all measurement equipment, instrumentation components, or data sources employed in these demand estimates shall be quantified and aggregated such that the overall kW accuracy does not exceed ±2%;
4. Equipment specifications shall be examined with great care because manufacturer accuracy ratings are not universally reliable or consistent;
5. One shall not employ assumptions regarding parameters such as power factor, harmonic distortion, or phase balance in the measurement or derivation of electrical demand;
6. Certification marks from Nationally Recognized Testing Laboratories such as UL, ETL, CSA, and TUV are authoritative indicators that M&V instruments and accessories such as probes, sensors, and clamps comply with ANSI safety standards;
7. Recorder time shall be NIST synchronized and accurate with ±2 minutes per month;
8. All instrumentation shall be calibrated traceable to NIST by no greater than third-order calibration equipment;

Detailed discussion of these and other important findings follow in the body of this report. In addition, this report highlights some potential repercussions of the M-MVDR requirements with the hope of stimulating discussion about reasonable means of compliance within available evaluation resources. Some readers may find particular interest in "Compliance of M&V Equipment" on page 38 of this report which lists some popular equipment that appears to comply with M-MVDR §10.2 requirements.

Finally, please recognize that this report reflects the research of several M&V experts. Some of this subject matter is complex, and valid objections to our observations may arise, but final judgment lies with ISO New England. M-MVDR §10.2 Requirement #16 does permit alternative demonstrations of satisfactory compliance with these standards.

Northeast Energy Efficiency Partnerships
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1. Introduction

In April 2007, the ISO New England published the Manual for *Measurement and Verification of Demand Reduction from Demand Resources (M-MVDR)* to specify the measurement and verification (M&V) requirements for Other Demand Resources (ODRs) participating in the Forward Capacity Market (FCM). Accordingly, current and prospective FCM participants, including this project's sponsors, must ensure and document compliance with the *M-MVDR*.

Section 10.2 of the *M-MVDR* addresses requirements related to "Measurement Equipment Specifications." Since *M-MVDR* publication, current and prospective FCM participants have strived to ascertain whether their M&V contractors, equipment, and methods comply with the requirements. Much discussion has ensued amongst prospective FCM participants and M&V contractors, including RLW Analytics, Inc. RLW has contributed technical insight on how to interpret and comply with these standards. RLW advised that this issue would benefit from a collaborative, regional effort that includes Program Administrators, M&V contractors, equipment manufacturers, and the ISO-New England. In response, NEEP and the Steering Committee of NEEP's Evaluation and State Program Working Group assumed a leadership position and requested a proposal from RLW to direct an effort to facilitate compliance with the M&V standards.

The Evaluation Steering Committee outlined the following objectives for this work:

- Search the standards developed by the standards-developing organizations referenced by the ISO-NE manual and list the specific ones that may be relevant.
- Collect information from M&V equipment manufacturers on specifications, their interpretation of applicable standards, and any declarations of compliance.
- Consult other M&V contractors on the equipment they use, their interpretation and/or concerns about compliance, and how they plan to meet M&V requirements.
- Develop a working list of equipment that complies with M&V requirements.
- Identify any aspects of the requirements that challenge or conflict with currently available equipment.
- Characterize how secondary variables such as temperature, pressure, status, etc. metered by an EMS may affect compliance.
- Build consensus on interpretation of the published M&V requirements and, if necessary, identify any areas where the published requirements would potentially benefit from clarification or possible revision.

ISO-NE M&V Requirements

The specific requirements published in Section 10.2 of the *M-MVDR* are as follows:

> *The Project Sponsor must describe in its Measurement and Verification Plan how it will satisfy each of the requirements listed below:*
>
> 1. *All solid-state measurement, monitoring and data recording equipment must meet or exceed the relevant standards set by the American National Standard Institute ("ANSI") or equivalent standard.*

2. *Measurement, monitoring and data recording equipment that is directly measuring watt-hour, volt-hour, volt-ampere-hours, reactive volt-ampere-hour, and the associated demand components should conform to ANSI or equivalent standards.*
3. *Instruments or transducers for the analog or digital measurement of volt, volts-squared, amperes, amperes-squared, phase angle, volt-amperes, watts, and reactive volt-amperes should conform to ANSI or equivalent standards.*
4. *Data recorders that are recording pulses from measurement and monitoring devices must utilize a pulse rate within the resolution capabilities of the recorder.*
5. *All measurement, monitoring and data recording equipment installed on electric circuits with significant harmonics must meet the relevant standards provided by the Institute of Electrical and Electronics Engineers ("IEEE").*
6. *Any measurement or monitoring equipment that directly measures electrical demand (kW) must be a true RMS measurement device with an accuracy of no less than ±2%.*
7. *Any measurement or monitoring equipment that directly measures electrical demand from three-phase devices must be installed such that measurements are taken on all three-phases to account for any phase imbalance or an equivalent method that can measure electrical demand using two phases.*
8. *Any measurement or monitoring equipment that directly measures electrical demand on circuits with significant harmonics must have a digital sampling rate of at least 2.6 kHz as defined in the relevant IEEE Standards.*
9. *Any measurement or monitoring equipment of proxy variables that do not directly measure electrical demand, including but not limited to voltage, current, temperature, flow rates and operating hours, must have an accuracy rating such that the overall accuracy of the calculated demand (kW) using the proxy variables is not less than ±2%.*
10. *Any measurement or monitoring equipment of current (amps) and nominal voltage used to calculate electrical demand must include the power factor of the end-uses in the demand (kW) calculations.*
11. *Data recorders must be synchronized in time, within an accuracy of ±2 minutes per month, with the National Institute of Standards and Technology ("NIST").*
12. *All measurement, monitoring and data recording equipment must be calibrated by the Project Sponsor or its independent calibration contractor in such a way to meet or exceed the Federal Energy Management Program ("FEMP") Measurement and Verification Guidelines, applicable American Society of Heating, Refrigeration and Air Conditioning Engineers ("ASHRAE") standards, NIST, or equivalent standard.*
13. *The Project Sponsor must ensure that all measurement, monitoring and data logging equipment shall be maintained in such a way as to meet or exceed industry and manufacturer standards.*
14. *The Project Sponsor must maintain documentation on all measurement, monitoring and data recording equipment maintenance and calibration activities. Documentation and records must be maintained as specified in Section 12 of this Manual.*
15. *The Project Sponsor shall provide to ISO, upon request, measurement equipment maintenance, calibration and testing records to demonstrate that the Project Sponsor's measurement equipment is calibrated and maintained in accordance the requirements described in this Manual.*
16. *The Project Sponsor may propose alternative methods to demonstrate the measurement, monitoring and data recording equipment used in the*

determination of Demand Reduction Value satisfies the accuracy, calibration and maintenance standards described in the Manual.

17. *Interval metering devices shall collect electricity usage data at a frequency of 15 minutes or less.*[i]

Of the seventeen aforementioned requirements, many entail the specifications and compliance of the measurement hardware itself. The remaining requirements affect the methods by which the equipment and resultant data are employed.

Some have cited technical complexity and/or insufficient specificity in the *M-MVDR* requirements as obstacles to clear declarations of compliance. Several requirements refer to "relevant standards" from authoritative institutes but cite no specific standards. The Institute of Electrical and Electronics Engineers (IEEE) alone maintains over 900 active standards. From one perspective, it may have been impractical for ISO-New England to declare all relevant standards in the M-MVDR and thus reasonable to shift responsibility for assessing "relevance" to FCM participants and M&V providers. However, these parties now struggle with interpreting and complying with the M-MVDR given some of its non-specific requirements.

Approach

It is useful to recognize that this issue involves four distinct parties, each with a certain responsibility in the process:

A. **ISO-New England**. The ISO-NE defines the FCM rules with which current and prospective participants in the FCM must comply.

B. **Project Sponsors**. In order to qualify for Forward Capacity payments, electric efficiency program administrators and others seeking to submit the peak demand reduction associated with their portfolio of energy efficiency projects as a Demand Resource in a Forward Capacity Auction must document compliance with the *M-MVDR*.

C. **M&V Contractors**. Companies that perform M&V and impact evaluation of these demand resources must select and employ measurement equipment, data collection, and analysis methods that comply with *M-MVDR* requirements.

D. **Equipment Manufacturers**. The measurement equipment used in the M&V process must meet or exceed numerous technical specifications and standards from institutions such as ANSI, IEEE, ASHRAE, and NIST.

RLW proposed combining a "top down" and "bottom up" approach. The first acknowledges that the ISO-New England defines this set of rules which cascade downward through the holder of the demand resource to the M&V methods and equipment. The "top down" approach is requirement-centric and would begin by thoroughly examining the ISO requirements and researching which standards they may consider relevant. The second approach presumes that equipment manufacturers are a sound resource for mandatory and voluntary standards which are relevant to their products. The "bottom up" approach is product-centric and focuses on the M&V equipment currently in use.

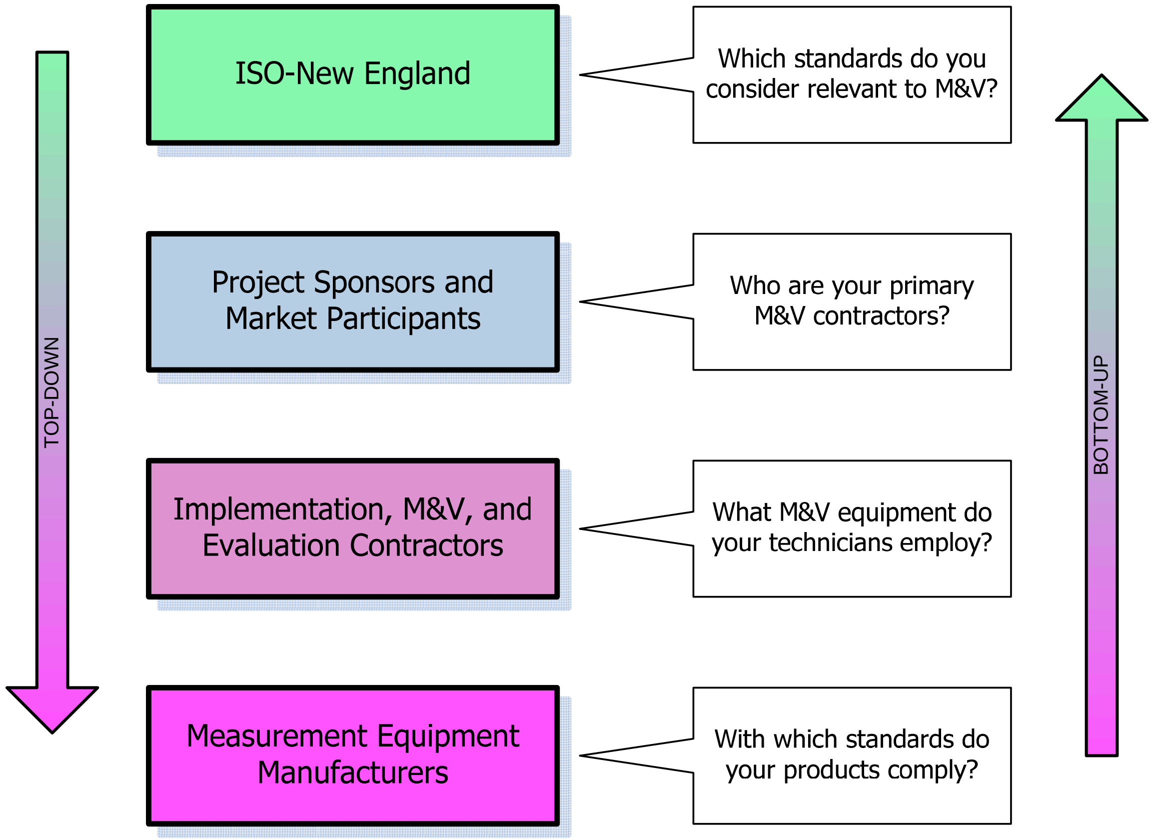

Figure 1 – Research Approach

The figure above outlines these two approaches and identifies key research questions for each involved party. RLW proposed that this research should consider all four research questions. For instance, Project Sponsors bidding efficiency program ODR must ensure that impact evaluations achieve ±10% precision at the 80% confidence interval as per *M-MVDR* §7.2. Attainment of said statistical precision depends not only on the M&V and sampling methods but also the accuracy of program tracking estimates. Several of the §10.2 *M-MVDR* requirements (e.g. #17 collection frequency) are process centric and necessitate research on how the M&V is performed, collected, and analyzed.

2. Scope and Report Organization

Based upon information provided by NEEP and National Grid, RLW proposed the following scope of work:

Research

1. Thoroughly examine the ISO-New England *M-MVDR* for specific references to technical standards. Also, review the *M-MVDR* for broad references to technical standards.
2. Consult each Project Sponsor and obtain a list of their consultants/contractors that perform M&V related to this issue. Inquire whether the Sponsor has any knowledge or insight regarding specific standards which may be relevant to FCM M&V. Probe the extent to which the Sponsor complies with applicable §10.2 requirements, such as maintaining documentation on maintenance and calibration activities (#14).
3. Consult each M&V contractor and obtain a list of the equipment they employ in the measurement and verification of demand resources. Inquire whether the contractor has any knowledge or insight regarding specific standards which may be relevant to their M&V equipment, methods, or analyses. Probe the extent to which their processes comply with applicable §10.2 requirements, such as time synchronization (#11) and three-phase measurements (#7). Investigate the incidence of 'proxy variable' measurement in the determination of electrical demand and the accuracy of said calculations.
4. Consult each equipment manufacturer and obtain a list of technical specifications and standards to which the equipment complies. Inquire whether the manufacturer knows of other specific standards which may be relevant to their equipment. Probe the extent to which the equipment complies with applicable §10.2 requirements, such as sampling rate (#8) and true-RMS accuracy (#6).
5. Perform a cursory review of ANSI, ASHRAE, NIST, and IEEE information resources for standards not yet identified but potentially relevant to §10.2 requirements.
6. For all relevant standards identified in the preceding tasks, acquire a copy of the standard publication and interpret the standard as it pertains to §10.2 and general M&V practices in New England.
7. Research and qualify propagation of error implications as they pertain to the 'proxy variable' findings from Task 4.

Deliverables

1. Produce a written document which summarizes the results of the research, including each relevant standard, its application and significance, and a clear set of criteria for complying with the standard.
2. Produce a working list of the M&V equipment currently in use that complies with all applicable standards. Produce another list of the M&V equipment currently in use that does not comply with all applicable standards.
3. List any aspects of the relevant standards that are particularly difficult, costly, impractical, or impossible to meet with currently available equipment.
4. Summarize relevant feedback regarding how the involved parties have achieved or intend to deal with compliance issues.

5. Identify any changes to the §10.2 requirements which may be warranted.
6. Characterize the incidence of 'proxy variable' metering and the implications on the statistical precision of the demand estimate due to error propagation in the calculations.

Organization of Report

In Section 3, "Development and Use of Standards in the U.S.," we provide a practical overview of American National Standards, the organizations which develop them, and the implications of normative references within standard publications.

Section 4, "Relevance and Compliance," establishes working definitions of the key terms *relevance* and *compliance* that proved fundamental to this review.

As no explicit ANSI references were found in the *M-MVDR*, Section 5, "Background on ISO-NE's Use of Standards," examines several references to specific ANSI standards in other highly relevant ISO New England documents.

The backbone of this report, Section 6, "Review of *M-MVDR* §10.2 Requirements," is a methodical review of each of the seventeen equipment requirements. This section strives to clarify the concise language of each requirement and provide a technical yet plain-English interpretation of its role in M&V equipment selection and usage. A key objective of this section is to associate specific documents with broad references such as "ANSI or equivalent standards."

Although indications emerged in the preceding section's research, the authors reserved final determination of relevance for Section 7, "Findings and Recommendations." Abandoning the sequential requirements list, this section is organized by topic and synthesizes the diverse research findings into several major issues. As applicable, each issue culminates in recommended paths to compliance with the *M-MVDR*.

Section 8, "Compliance of M&V Equipment," is the foundation of a working list of M&V equipment in popular use and its compliance with the ±2% kW accuracy requirement.

Section 9, "Commentary," contains additional comments on the requirements and related issues not contained elsewhere in this report.

3. Development and Use of Standards in the U.S.

Even before embarking on this project, it was apparent that most parties would benefit from a better understanding of our standards and conformity assessment system. For over 90 years, the American National Standards Institute (ANSI) has served as administrator and coordinator of the United States private sector voluntary standardization system. The primary goal of ANSI is "the enhancement of global competitiveness of U.S. business and the American quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems and promoting their integrity."

While ANSI standards are inherently voluntary, federal government agencies are required to use voluntary standards for regulatory and procurement purposes when appropriate, and state and local governments and agencies have formally adopted thousands of voluntary standards produced by ANSI. Globally, ANSI is the sole U.S. representative of the two major non-treaty international standards organizations: the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC).

ANSI does not develop American National Standards (ANS). Rather, ANSI accredits the procedures used by other standards developing organizations (SDOs). Conformity assessment or "demonstration that specified requirements relating to a product, process, system, person or body are fulfilled" is another high priority for the Institute.

Standards Developing Organizations

Today there are hundreds of standards developing organizations, but the twenty largest SDOs produce about 90% of the standards. The Institute of Electrical and Electronics Engineers (IEEE), the National Electrical Manufacturers Association (NEMA), and the Instrumentation, Systems, and Automation Society[1] (ISA) are the SDOs responsible for developing most of the standards relevant to our current M&V issue. Other SDOs that may also be relevant include: the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the National Fire Protection Association (NFPA), the National Institute of Standards and Technology (NIST), the North American Electric Reliability Council (NERC), and Underwriters Laboratories (UL).

For crosscutting technologies such as electrical metering products, relevant ANSI standards can span numerous SDOs. IEEE is one of the most published SDOs, with literally thousands of highly technical standards about transformers, harmonics, grounding, etc. NEMA standards encompass electricity revenue metering and other electrical equipment, while ISA - an organization not cited explicitly in the MVDR - maintains most handheld instrumentation standards. As shown in the following sections, "relevant ANSI standards" to our core M&V issue are likely to include publications by many distinct SDOs.

[1] Founded in 1945 as the Instrument Society of America, ISA changed its name in 2000 to reflect both international reach and growth beyond instruments.

Normative References in ANSI Standards

Most ANSI standards, but IEEE publications in particular, contain a "References" section which states: "This standard shall be used in conjunction with the following publications. When the following publications are superseded by an approved revision, the revision shall apply." This is termed a *normative reference* and is common practice amongst SDOs. A normative reference means that the referenced document is officially part of the referring document.

The 2007 revision of the *IEEE Standards Style Manual* clarifies this usage. IEEE standards now require an explicit "Normative references" section and the use of the following normative reference clause:

> *The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.* [ii]

The normative reference is a critical component of written standards. Without normative references, standards documents would become unwieldy volumes of redundant language. More importantly, normative references assure that dependent documents remain inherently current with latest revisions of referenced documents.

Normative references for standards cited herein are listed in Appendix A of this report.

4. Relevance and Compliance

A key objective of this project was to identify American National Standards that are most relevant to the *M-MVDR* Section 10.2 metering requirements. There are thousands of American National Standards, vast numbers of which relate to electricity, electrical metering, and instrumentation with varying degrees of significance. The authors sought a working definition of "relevant standards" to focus attention on those most pertinent to the current M&V issue.

To illustrate, consider ANSI C12.1-2001 *American National Standard for Electric Meters and Code for Electricity Metering*, one of the more obvious relevant standards. ANSI C12.1-2001 contains twenty-three normative references to standards and other non-standard publications (see Appendix A: "Normative References"). Yet many of these references have little bearing on the matter at hand, e.g. "Analog Indicating Instruments" (ANSI C39.1-1992), "High-Voltage Testing" (IEEE Std 4-1994), and "Salt-Spray (Fog) Testing Apparatus" (ASTM B117-97). Others are so generic that they offer little practical importance, e.g. "National Electrical Code" (NFPA 70-1999) and "Standard for Safety Enclosures" (UL 50-1995).

Relevant Standards

The following definitions of "relevant" from popular reference material offer a starting point:

1. Having a bearing on or connection with the matter at hand.[iii]
2. Having significant and demonstrable bearing on the matter at hand.[iv]
3. Capable of making a difference in decision making.[v]

The first definition seems too generic for our purpose, for it would include all normative references no matter how distant the relationship. The second definition is more focused, limiting relevance to matters of demonstrable significance. The last definition comes from business terminology and emphasizes significance in decision making. Since our "matter at hand" involves several key decisions – determining which ANSI standards are relevant and selecting M&V equipment that complies with *M-MVDR* requirements – it is logical that "relevance" should affect the outcome. We propose the following blended definition for this M&V context:

A "relevant standard" is one that has significant and demonstrable bearing on the selection and usage of measurement and verification equipment.

While interpretations of "significance" may ensue, this definition serves to focus attention on standards that contain demonstrable criteria that affect equipment selection and usage. This is a worthy distinction for our M&V issue. Some standards contain few concrete specifications and thus no practical significance. Other standards involve computational methods inexpressible by specifications, such that only most senior manufacturing designers are qualified to issue any demonstrable bearing on selection.

Compliant Equipment / Methods

Having established a working definition of relevance, researchers next considered how to apply such criteria to the process of selecting M&V equipment and methods that comply with the published ISO-NE requirements. Like "relevance", the term "compliance" may also be subject to interpretation.

The *M-MVDR* suggests two aspects of compliance in the context of M&V requirements. In general terms, compliance is defined by the lead-in sentence of Section 10.2:

> *The Project Sponsor must describe in its Measurement and Verification Plan how it will satisfy each of the requirements listed below:*

This language is clear but important enough to warrant emphasis. The Project Sponsor a) must satisfy each of the seventeen requirements and b) must describe how it will do so in its M&V Plan. Thus, the broad aspect of the compliance definition is that the Project Sponsor is responsible for satisfying all specified requirements and documenting proof.

The more specific aspect of compliance involves the a) interpretation of scope, b) measures taken to fulfill, and c) determination of satisfaction of each individual requirement. The Project Sponsor must "meet or exceed", "conform", or otherwise satisfy the specifications of each of the seventeen requirements. Much of this review document focuses upon the details and challenges associated with interpreting and satisfying these individual M&V requirements.

Finally, some basic assumptions were necessary to focus this review effort. Consistent with the principles of normative reference, researchers limited technical criteria to those defined in the most recently adopted standard and/or guideline documents, excluding superseded publications. A corollary to this assumption is that M&V equipment will be held to all standards in effect at the time the device is employed; meters in use today shall not be "grandfathered" by standards that were current at the time of purchase. Researchers also assumed that the applicable metering technologies would not include analog instrumentation.

5. Background on ISO-NE's Use of Standards

One of the principle challenges for Market Participants pursuing *M-MVDR* §10.2 compliance lies in the interpretation of broad references to American National Standards. Six of the seventeen specifications require Participants to "meet," "meet or exceed," or "conform" to "relevant standards," "or equivalent standards," or "industry and manufacturer standards." Accordingly, much of this research effort focused on identifying and reviewing these standards with due diligence.

While the *M-MVDR* itself contains no explicit references to ANSI standards, the ISO-NE does cite specific standards in Operating Procedure No. 18.

ISO-NE Operating Procedure No. 18

ISO-NE provides Operating Procedures to Market Participants which detail the Regional Transmission Organization (RTO) requirements. There are twenty-one ISO-NE Operating Procedures each directing a particular aspect of RTO operations. Operating Procedure No. 18 (OP18) is entitled "Metering and Telemetering Criteria" and establishes standards for metering and telemetering within its RTO market. While not uniformly applicable to the FCM, in general terms, OP18 is intended to ensure that Market Participants:

1. Report the necessary power system parameters,
2. Measure and transmit these data with appropriate accuracy and audit trail, and
3. Maintain equipment so that required accuracy levels persist.

In response to request for more specificity on standards they deem relevant, the ISO-NE identified Operating Procedure No. 18 as containing relevant ANSI citations, as seen in the following excerpt from that Procedure:

> *All metering devices used shall conform to applicable American National Standard Institute (ANSI) C-12 standards as amended from time to time.*
>
> 1. *Metering of watt-hour, volt-hour, volt-ampere-hours, reactive volt-ampere-hour, Q-hours and the associated demand components should conform to ANSI standard C12.*
> 2. *Instruments or transducers for the analog or digital measurement of volt, volts-squared, amperes, amperes-squared, phase angle, volt-amperes, watts, and reactive volt-amperes should conform to ANSI standards C39.1, C39.5 and C37.90.*
> 3. *Instrument transformers should conform to ANSI standard C57.13.*[vi]

In the preceding text, the ISO-NE cites five distinct ANSI standards. Each is discussed in turn below.

ANSI References in OP18

From this point forward, a star (★) is used to denote publications that the authors consider most relevant to the M&V issue. The standards listed but not annotated either qualify as part of the original citation (e.g. ANSI C12.x) or represent evolution of a standard since replaced (e.g. ANSI C39.5).

ANSI standard C12 is a broad reference to the accredited standards committee (ASC) C12 encompassing most aspects of electricity metering. The C12 standards group falls under NEMA's authority and is comprised of the following individual standards, only the first of which likely apply to modern M&V metering technologies:

★	ANSI C12.1-2001	*American National Standard for Electric Meters and Code for Electricity Metering*
	ANSI C12.4-2002	*Mechanical Demand Registers*
	ANSI C12.5-2002	*Thermal Demand Meters*
	ANSI C12.6-2002	*Marking and Arrangement of Terminals for Phase-Shifting Devices Used in Metering*
	ANSI C12.7-2005	*Requirements for Watthour Meter Sockets*
	ANSI C12.8-2002	*Watthour Meters, Test Blocks and Cabinets for Installation of Self-Contained "A" Base*
	ANSI C12.9-2005	*Test Switches for Transformer-Rated Meters*
	ANSI C12.10-2004	*Electromechanical Watthour Meters*
	ANSI C12.14-1993	*Magnetic Tape Pulse Recorders for Electricity Meters*
	ANSI C12.17-1991	*Cartridge-Type Solid-State Pulse Recorder for Electricity Metering*
	ANSI C12.18-2006	*Protocol Specification for ANSI Type 2 Optical Port*
	ANSI C12.19-1997	*Utility Industry End Device Data Tables*
	ANSI C12.20-2002	*Electricity Meters 0.2 and 0.5 Accuracy Classes*
	ANSI C12.21-2006	*Protocol Specification for Telephone Modem Communication*

The scope of the C12.1 Metering Code is highly relevant to the M&V issue:

> *This Code establishes acceptable performance criteria for new types of ac watthour meters, demand meters, demand registers, pulse devices, and auxiliary devices. It describes acceptable in-service performance levels for meters and devices used in revenue metering. It also includes information on related subjects, such as recommended measurement standards, installation requirements, test methods, and test schedules. This Code for Electricity Metering is designed as a reference for those concerned with the art of electricity metering, such as utilities, manufacturers, and regulatory bodies.* [vii]

ANSI standard C39.1 appears not to have been revised since 1992, perhaps because it applies solely to analog indicating instruments. As such, it is likely not to apply to modern M&V metering technologies.

ANSI C39.1-1992	*American National Standard Requirements for Electrical Analog Indicating Instruments*

The evolution of ANSI standard C39.5 is complex. Originally developed in 1964, ANSI C39.5 was reaffirmed in 1969 and revised in 1974. In 1982, responsibility for C39.5 was transferred to the ISA and the document was renumbered ISA-S82.01. Under ISA, S82.01 evolved into various parts under ISA-S82.02 and ISA-S82.03 as it was rewritten to align with international IEC standard 61010. In 2004, Underwriters Laboratories published UL 61010-1 as an American National Standard; ISA co-published the standard. UL 61010-1 is aligned with international standard IEC 61010-1 except for some National differences. UL 61010-031 was finalized in 2007 as an ANS pertaining to hand-held probe assemblies, and UL 61010B-2-032 has yet to be ANSI approved but applies to hand-held *current clamps*.

	ANSI C39.5-1974	*Safety Requirements for Electrical and Electronic Instrumentation*
	ISA S82.01-1994	*Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment, General Requirements*
	ISA S82.02.01-1999	*General Requirements for Electric and Electronic Test, Measuring, Controlling, and Related Equipment*
	ISA S82.02.02-1996	*Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use (Hand-Held Probe Assemblies)*
	ISA S82.02.04-1996	*Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use (Hand-Held Current Clamps)*
	ISA S82.03-1988	*Safety Standard for Electrical and Electronic Test, Measuring, Controlling, and Related Equipment*
★	UL 61010-1-2005	*Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use – Part 1: General Requirements*
★	UL 61010-031-2007	*Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use – Part 031: Safety Requirements for hand-held probe assemblies for electrical measurement and test*
★	UL 61010B-2-032	*Standard for Electrical Equipment for Measurement, Control, and Laboratory Use – Part 2: Particular Requirements for Hand-Held Current Clamps for Electrical Measurement and Test*

ANSI standard C37.90 applies to relays and relay systems associated with electric power apparatus. Like S82.02 above, C37.90 has been reorganized into subparts to address more specific aspects of the standard. Relays do not pertain directly to M&V equipment in our context.

IEEE C37.90-2005	*IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus*
IEEE C37.90.1-2002	*IEEE Standard for Surge Withstand Capabilities (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus*
IEEE C37.90.3-2001	*IEEE Standard Electrostatic Discharge Tests for Protective Relays*

Finally, ANSI standard C57.13 establishes the standard requirements for instrument transformers. This is highly relevant to most M&V equipment.

★	IEEE C57.13-1993	*Standard Requirements for Instrument Transformers*
	IEEE C57.13.6-2005	IEEE Standard for High Accuracy Instrument Transformers

In summary, ISO-NE OP18 references five specific ANSI standards in the context of metering equipment. Two of the ANSI standards mentioned in OP18 (C39.1 and C37.90) are not particularly relevant to this review. As the "Code for Electricity Metering," ANSI C12 is extremely relevant to electrical M&V. ANSI C57.13 remains a key standard for instrument transformers, and UL 61010 safety standards apply to most M&V instrumentation. Armed with three highly relevant standards from ISO-NE OP18, researchers proceeded to examine each of the specific *M-MVDR* §10.2 requirements in turn.

6. Review of *M-MVDR* §10.2 Requirements

This section presents a detailed review of the metering equipment requirements specified in §10.2 of ISO-NE's *M-MVDR*. Table 1 below summarizes the application and type of requirement into one of four categories.

#	Application	Standard Conformance	Technical Specs	Usage/ Method	Calibration/ Maintenance
1	All solid-state measurement equipment	X			
2	Equipment directly measuring power or demand	X			
3	Instruments measuring volts, amps, and phase angle	X			
4	Data recorders that are recording pulses			X	
5	Equipment exposed to significant harmonics	X			
6	True RMS kW measurements and accuracy		X		
7	Measuring imbalanced three-phase loads			X	
8	Sampling rate on circuits with significant harmonics	X	X		
9	Accuracy of demand calculated with proxy variables		X	X	
10	Demand calculations to use power factor of the end-use			X	
11	Data recorders must be synchronized in time with NIST	X	X	X	
12	Equipment calibration to appropriate standards	X			X
13	Equipment maintenance to appropriate standards	X			X
14	Documentation of calibration and maintenance activities				X
15	Availability of calibration and maintenance records				X
16	Alternative accuracy, calibration, and maintenance standards				X
17	Interval data collection frequency		X	X	

Table 1 – §10.2 Requirements Matrix

The categories assigned above are neither exclusive nor definitive; they are presented simply as a means of illustrating the breadth and interrelation of the requirements. Eight requirements in the "Standard Conformance" category call for adherence to some set of standards, be they ANSI, IEEE, relevant, equivalent, or industry/manufacturer in nature. Five of the requirements indicate a technical specification that must be met. Six requirements involve the methods by which the equipment is installed or used. Finally, five requirements specifically target calibration and maintenance of M&V equipment.

Several of the *M-MVDR* §10.2 requirements call for adherence to relevant national standards. It is important to note that a reference to ANSI standards by definition includes other SDOs such as IEEE and NIST. With over 10,000 American National Standards and more emerging each year, our research cannot be conclusive with absolute certainty. However, having performed extensive, full-text searches of standards databases and publications from multiple sources, researchers consider it unlikely that an ANSI standard of significant relevance has been overlooked.

Each of the seventeen requirements is reviewed in sequence below. This section of the report interprets each requirement and, as applicable, cites standards or other publications related to the requirement. Any assessments of relevance or recommendations for compliance are reserved for Section 7: "Findings and Recommendations."

(1) All solid-state measurement, monitoring and data recording equipment must meet or exceed the relevant standards set by the American National Standard Institute ("ANSI") or equivalent standard.

Given the organization and context of all ANSI and IEEE references in *M-MVDR* §10.2, Requirement #1 clearly is the most generic. Having examined all seventeen requirements and performed extensive searches for relevant standards published by all SDOs, we deduce by process of elimination that **safety** is the issue most pertinent to Requirement #1. Requirements #2 and #3 contain specific language pertaining to electrical power measurements, whereby Requirement #1 has broad application to "all solid-state measurement, monitoring and data recording equipment."

The 1974 publication of ANSI C39.5 is the foundation for current safety standards relevant to electrical M&V test equipment. As stated in Section 5, the following original ANSI C39.5 or ISA S82 standards technically are outdated:

ANSI C39.5-1974	*Safety Requirements for Electrical and Electronic Instrumentation*
ISA S82.01-1994	*Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment, General Requirements*
ISA S82.02.01-1999	*General Requirements for Electric and Electronic Test, Measuring, Controlling, and Related Equipment*
ISA S82.02.02-1996	*Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use (Hand-Held Probe Assemblies)*
ISA S82.02.04-1996	*Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use (Hand-Held Current Clamps)*
ISA S82.03-1988	*Safety Standard for Electrical and Electronic Test, Measuring, Controlling, and Related Equipment*

Currently, UL and ISA are responsible for publishing ANSI safety standards that pertain to most electrical measurement and test equipment. These two SDOs coauthored the following American National Standard versions of modern IEC 61010 standards that build upon ANSI C39.5 and ISA S82. Researchers conclude that these three UL standards are highly relevant to M&V instrumentation and significant to this first *M-MVDR* equipment requirement:

★	UL 61010-1-2005	*Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use – Part 1: General Requirements*
★	UL 61010-031-2007	*Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use – Part 031: Safety Requirements for hand-held probe assemblies for electrical measurement and test*
★	UL 61010B-2-032 (in development)	*Standard for Electrical Equipment for Measurement, Control, and Laboratory Use – Part 2: Particular Requirements for Hand-Held Current Clamps for Electrical Measurement and Test*

Independent testing laboratories are most qualified to assess compliance with these UL safety standards. A listing or certification mark from a Nationally Recognized Testing Laboratory (NRTL) such as UL, ETL, or CSA offers assurance that the instrument bearing the mark complies with these and any other relevant U.S. safety standards (see Appendix B: "Independent Testing Laboratories").

(2) Measurement, monitoring and data recording equipment that is directly measuring watt-hour, volt-hour, volt-ampere-hours, reactive volt-ampere-hour, and the associated demand components should conform to ANSI or equivalent standards.

Unlike Requirement #1, this language clearly pertains to equipment that directly measures time-dependent electrical energy and underlying demand components. Traditionally, ANSI C12 has governed metering of electricity for utility revenue purposes. Today, the National Electrical Manufacturers Association publishes the ANSI standards that pertain specifically to electricity metering. Other standards in the C12 family remain relevant to revenue metering but have little bearing on our M&V context.

The two standards below are highly relevant to the measurement and verification of electrical impacts. IEEE Standard 120-1989 offers instructions on the measurement of electrical quantities and guides the selection of methods and instrumentation, while NEMA C12.1 focuses upon traditional utility/regulatory concerns such as performance criteria and testing of the metering equipment itself. These standards are lengthy and somewhat generic in content, yet extremely significant to electrical M&V:

★	ANSI C12.1-2001	*American National Standard for Electric Meters and Code for Electricity Metering*
★	IEEE Std 120-1989	*IEEE Master Test Guide for Electrical Measurements in Power Circuits*

(3) Instruments or transducers for the analog or digital measurement of volt, volts-squared, amperes, amperes-squared, phase angle, volt-amperes, watts, and reactive volt-amperes should conform to ANSI or equivalent standards.

Requirement #3 is unique from the previous because transducers and transformers do not measure electricity directly. The forward of ANSI/NEMA C12.1 clearly states its intention to "form the basic requirement document for all metering devices except instrument transformers." Accordingly, several national standards apply specifically to the instrument transformers and transducers that are fundamental to nearly all electrical measurement technologies. While all four of following standards possess relevance to this third requirement, the first standard is considered the most significant:

★	IEEE C57.13-1993	*Standard Requirements for Instrument Transformers*
	IEEE C57.13.3-2005	*IEEE Guide for Grounding of Instrument Transformer Secondary Circuits and Cases*
	IEEE C57.13.6-2005	*IEEE Standard for High Accuracy*[2] *Instrument Transformers*
	IEEE Std 1451.4-2004	*IEEE Standard for Analog Inputs to Protective Relays from Electronic Voltage and Current Transducers*

(4) Data recorders that are recording pulses from measurement and monitoring devices must utilize a pulse rate within the resolution capabilities of the recorder.

Some electric meters and watt-hour transducer systems output digital "pulses" in proportion to accumulated kWh, e.g. one pulse = X kWh of energy. A data recorder can count such pulses relative to a real-time clock to derive a profile of electrical demand over time. To translate the pulses into unitized values, the data recorder – or end user – requires the "pulse rate" employed at the metering source. In practice, electric meters are configured to generate pulses that are both a) fast enough to provide meaningful time-series resolution and b) slow enough to remain distinguishable by the pulse counter.

We interpret Requirement #4 to mean that the pulse counting equipment must be compatible with the source pulse signal. For example, one popular digital measurement module has a maximum input range of 20 pulses per second. A pulse source that exceeds 20 Hz would saturate the sensor and hence violate Requirement #4.

This is the first of several *M-MVDR* requirements concerned with accuracy and the appropriate selection and usage of measurement and data collection devices. Requirement #4 does not reference any ANSI standards. No M&V contractor has suggested any ambiguity about the intent or scope of Requirement #4.

(5) All measurement, monitoring and data recording equipment installed on electric circuits with significant harmonics must meet the relevant standards provided by the Institute of Electrical and Electronics Engineers ("IEEE").

Electrical waveforms throughout a given facility's distribution system can deviate greatly from the sinusoidal waves at the generation source. Non-linear loads such as variable-speed drives and switched-mode power supplies distort these waveforms and introduce harmonics on the fundamental 60 Hz frequency. As non-linear loads have grown more prevalent, harmonics have become a significant component of modern power systems. To be accurate, electrical power measurements must capture and account for these harmonic effects.

At first blush, Requirement #5 seems to beg a definition of "significant harmonics" perhaps in terms of total harmonic distortion (THD). But pragmatically speaking, an M&V contractor requires appropriate equipment nonetheless to either verify the absence of significant harmonics or otherwise measure their effects.

[2] This particular standard covers 0.2 and 0.5 accuracy class instrument transformers. More common in modern revenue meters, this level of accuracy is cost-prohibitive for most M&V work.

IEEE Standard 1159-1995 is a milestone publication on harmonics; its introduction offers an excellent overview:

> *This recommended practice was developed out of an increasing awareness of the difficulty in comparing results obtained by researchers using different instruments when seeking to characterize the quality of low voltage power systems. One of the initial goals was to promote more uniformity in the basic algorithms and data reduction methods applied by different instrument manufacturers. This proved difficult and was not achieved, given the free market principles under which manufacturers design and market their products. However, consensus was achieved on the contents of this recommended practice, which provides guidance to users of monitoring instruments so that some degree of comparisons might be possible.*[viii]

Both IEEE Standards 1159-1995 and 519-1992, the latter of which includes a chapter on electrical measurements, are considered relevant and significant to the M&V of demand resources:

- ★ IEEE Std 1159-1995 — *IEEE Recommended Practice for Monitoring Electric Power Quality*
- ★ IEEE Std 519-1992 — *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*

These standards offer few conclusive recommendations for measurement equipment specifications. IEEE Std 1159-1995 underscores the benefit of using true-RMS (root mean square) measurements based upon high-frequency digital samples and emphasizes the importance of CT response accuracy to the measurement.

(6) Any measurement or monitoring equipment that directly measures electrical demand (kW) must be a true RMS measurement device with an accuracy of no less than ±2%.

With so much emphasis on kW measurement accuracy, Requirement #6 warrants some background and discussion of specific terminology.

Terminology

Currently, the International Organization for Standardization (ISO) *Guide to the Expression of Uncertainty in Measurement (GUM)*[ix] is the internationally accepted rulebook for measurement uncertainty. The *International Vocabulary of Basic and General Terms in Metrology (VIM)*[x] is a companion document to the *GUM* which defines many important terms in the measurement field. The *GUM* and *VIM* approaches were adopted in the U.S. by NIST via *Technical Note 1297 (TN 1297)*,[xi] and more recently, the GUM was adopted as American National Standard ANSI/NCSL Z540-2-1997.[xii]

The aforementioned publications take great care to distinguish the following terms. Though often (and incorrectly) used interchangeably, these terms are not synonymous:

Accuracy is the closeness of the agreement between the result of a measurement and the "true" value of the particular quantity subject to measurement a.k.a. "measurand."

Error is the result of a measurement minus the value of the measurand.

Uncertainty is a parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand within a given statistical confidence.

The traditional terms **accuracy** and **error** are unquantifiable ideals based upon the unknowable true value of the measurand. On the contrary, **uncertainty** acknowledges the lack of exact knowledge of the value of the measurand and may always be evaluated using accepted or well-defined reference standards. For this reason, the term **accuracy** effectively has been superseded by **uncertainty** in metrology:

> *NIST policy on expressing the uncertainty of measurement results normally requires the use of the terms standard uncertainty, combined standard uncertainty, expanded uncertainty, or their "relative" forms, and the listing of all components of standard uncertainty. Hence the use of terms such as accuracy, precision, and bias should normally be as adjuncts to the required terms and their relationship to the required terms should be made clear.*[xiii]

In response to pressure from the international standards community over the past two decades, reputable instrumentation manufacturers have issued technical application notes on accuracy vs. uncertainty. Despite official abandonment of the former, the terms accuracy and uncertainty continue to be used interchangeably, and manufacturers have yet to embrace the term uncertainty in published specifications. Some instrument manufacturers knowingly publish **uncertainty** yet *label* it as **accuracy**; the latter is clearly a far better marketing word.

> ***It may benefit ISO New England to abandon the contentious term "accuracy" in favor of the international standard expression of "uncertainty" at a specified "confidence level."***

Since the terms are currently (but incorrectly) used synonymously, the kW±2% specification would not change substantively. However, the *M-MVDR* and those it serves would benefit from:

1. Universally quantifiable measurement standards;
2. Reduced interpretation bias due to vague specifications;
3. Preemptive abandonment of nearly obsolete terminology; and
4. Harmonization with *M-MVDR* statistical requirements.

The authors will continue to use the term **accuracy** in this report in the context of M-MVDR language and manufacturer specifications. **Uncertainty** will be used in most other contexts in the interest of correctness.

Specifications

Requirement #6 is similar to Requirement #4 in that it governs the appropriate selection of measurement equipment without referencing any specific ANSI standards. While the term "accuracy" is flawed, its intent is clear, as are the published accuracy specifications of most equipment that measures electrical demand. While perhaps some M&V contractors utilize equipment beyond this kW±2% accuracy range, compliance with this direct measurement Requirement #6 simply involves use of equipment that meet this specification.

A few technical details warrant mention. First, "true RMS" is itself a specific requirement, and this exact phrase ought to be labeled on the meter. Instruments described as "average responding RMS indicating" or "RMS calibrated" or simply "RMS" – frankly anything but the literal words "true RMS" – presume sinusoidal behavior and are not appropriate for distorted (real world) electrical waveforms. Requirements #5 and #8 address this issue further. Also, there is no loophole pertaining to the "directly measures" language: this clause requires ±2% for direct kW measurement while Requirement #9 covers the specification of ±2% for calculated kW from indirect or "proxy" measurement.

(7) Any measurement or monitoring equipment that directly measures electrical demand from three-phase devices must be installed such that measurements are taken on all three-phases to account for any phase imbalance or an equivalent method that can measure electrical demand using two phases.

Like Requirements #4 and #6, Requirement #7 does not reference any specific ANSI standards. It is methodological in nature, defining an explicit means by which three-phase power measurements shall be installed and performed. Acceptable methods for three-phase power measurement are prescribed in both ANSI C12.1 and IEEE 120-1989.

Blondel's theorem states that (n – 1) watt meters are required to measure the true power of a system of n conductors. A good analogy is the Side-Angle-Side postulate of geometry in which a triangle can be fully described by the length of any two sides and the angle between them. ANSI C12.1-2001 states that "under certain circumstances, for economic reasons, slight departure from Blondel's theorem are permissible, depending upon the degree of unbalance between two or more of the voltages in a polyphase circuit."[xiv] Continuing the analogy, this last statement suggests that in the special circumstance of a balanced circuit (equilateral triangle) one may measure the power in just one phase (side of the triangle) and presume the other two are equal.

But consistently balanced three-phase power is a rare circumstance on modern electrical distribution systems, and the phase-balance assumption itself may introduce several percentage points of error. Accordingly, *M-MVDR* Requirement #7 forbids any shortcuts in power measurement that presume three-phase circuits are balanced. The language is clear and reasonable; all M&V demand measurements must be performed as if phase imbalance exists. ANSI C12.1-2001 details three distinct methods for measuring three-phase power (ANSI C12.1-2001, p. 61), only two of which comply with Requirement #7:

> *A.1.6.1 Three-wattmeter method* [Compliant with Requirement #7]
>
> *If the three loads are accessible as single-phase two-wire loads, the total power may be measured as the sum of the readings of the three wattmeters, each connected to one of the three loads as described in A.1.4.1. This method is correct for all conditions of loading. This method is also correct for three-phase four-wire circuits, except that the voltage coil of each wattmeter is connected between the line conductor in which its current coil is connected and the common conductor, or the neutral.*

A.1.6.2 Two-wattmeter method [Compliant with Requirement #7]

The total power in a three-phase three-wire circuit may be measured by means of two wattmeters, having the current coils connected one in each of two line conductors and the voltage coils connected between the line conductor in which its current coil is connected and the third line conductor. The algebraic sum of the readings of the two wattmeters indicates the total power supplied to any type of loading on the three conductors. This method is correct for any balanced or unbalanced load and for any power factor, but does not apply to three-phase four-wire circuits.

A.1.6.3 Balanced three-phase circuits [NOT Compliant with Rqmt. #7]

The power in a balanced three-phase three- or four-wire wye circuit may be measured by one wattmeter by connecting its current coil in one phase conductor and its voltage coil between that conductor and neutral, real or artificial, and multiplying its readings by three.

Some question whether Requirement #7 explicitly forbids short-term metering of one phase of a three-phase circuit if it can be demonstrated that the three phases are indeed consistently balanced. And while Requirement #7 literally applies to "equipment that directly measures electrical demand," its applicability to current measurements as permitted by Requirements #9 and #10 remains unclear. In the interest of maximizing the value of limited M&V equipment and budget resources, some impact evaluators derive three-phase demand from single phase current monitoring "calibrated" to spot three-phase measurements. M&V contractors and Project Sponsors both have expressed concern that Requirement #7 may prohibit such common evaluation methods.

Some handheld true-RMS power meters like the Yokogawa 2433 have a feature for computing power in a balanced three-phase system from one reading with *three* voltage probes and *one* current clamp. Other meters such as the Extech 382075 have a "3ϕ" setting which computes three-phase power from one reading with *two* voltage probes and *one* current clamp. In these particular modes, both meters presume the three-phase circuit is balanced and violate Requirement #7. Yet both of these meters comply with Requirement #7 since they may be used in a traditional manner to derive three-phase power from multiple measurements in strict adherence to Blondel's theorem. In this regard, Requirement #7 pertains more to the manner in which an instrument is used than to the instrument itself.

(8) Any measurement or monitoring equipment that directly measures electrical demand on circuits with significant harmonics must have a digital sampling rate of at least 2.6 kHz as defined in the relevant IEEE Standards.

Another reference to "significant harmonics," Requirement #8 underscores the effect of harmonics on power measurement in modern electrical systems. The same IEEE standards cited in Requirement #5 apply. In order to measure the effect of harmonics above the fundamental 60 Hz frequency, an instrument must sample the waveform digitally in accordance with the Nyquist Criterion:

> *Also known as the Sampling Theorem, the Nyquist Criterion states that in order to reproduce a time-varying signal without distortion caused by aliasing,*[3] *the signal must be bandwidth-limited, and the sample rate must be at least twice the frequency of bandwidth limitation, f_c.*[xv]

By establishing a minimum sampling rate of 2.6 kHz, Requirement #8 ensures accurate power measurement up to the 20th harmonic.

(9) Any measurement or monitoring equipment of proxy variables that do not directly measure electrical demand, including but not limited to voltage, current, temperature, flow rates and operating hours, must have an accuracy rating such that the overall accuracy of the calculated demand (kW) using the proxy variables is not less than ±2%.

One may approach Requirement #9 from various perspectives. In the most basic context, it requires an engineer to "propagate" the uncertainty of *component* measurements throughout a calculation of *overall* demand. Requirement #9 is clear that uncertainty propagation ought not to be limited to electrical quantities but applies to *all* variables which contribute to the calculated demand estimate.

Propagation of Uncertainty

By differentiating "directly measured" demand from "calculated" demand, Requirement #9 suggests that the accuracy of calculated demand estimates should incorporate the uncertainty of its component terms, e.g. separate voltage and current measurements. When component uncertainty terms are random[4] and statistically independent, uncertainty of a product propagates according to the root-sum-square (RSS) method, i.e. the square-root of the sum of the squares of the component uncertainties.

Mathematically, for a given function $y = f(x_1, x_2, \ldots, x_N)$, the RSS uncertainty is:

Equation 1 – The Law of Propagation of Uncertainty

$$\Delta u_{RSS} = \sqrt{\left(\frac{\partial f}{\partial x_1}\Delta x_1\right)^2 + \left(\frac{\partial f}{\partial x_2}\Delta x_2\right)^2 + \ldots + \left(\frac{\partial f}{\partial x_N}\Delta x_N\right)^2}$$

where the uncertainty of each variable x_N is expressed as $\pm\Delta x_N$.

Consider the instance of a handheld true-RMS clamp meter that computes real power (kW) by sampling the voltage and current inputs at a high rate and averaging the instantaneous products.[5] Manufacturers normally publish explicit kW accuracy ratings for such meters, but if not, kW uncertainty is represented by the RSS of the voltage and

[3] Aliasing is an effect that causes different continuous signals to become indistinguishable when sampled. See http://en.wikipedia.org/wiki/Aliasing#Sampling_sinusoidal_functions.

[4] In *Measurement Uncertainty, An Approach via the Mathematical Theory of Evidence* (Springer Science+Business Media, 2007), Simona Salicone suggests that it might not be acceptable to assume that measurement uncertainty is purely random, i.e. without any systematic contributions. This advanced text resolves the limitations of the standard probabilistic approach by performing mathematical operations on data containing systematic uncertainty using random-fuzzy variables (RFVs).

[5] This 'instantaneous product' method occurs within a true-RMS power meter and must not be confused with kW calculation using separate measurements of true-RMS voltage, true-RMS current, and power factor (see Requirement #10).

current uncertainties.[6] For example, if Δu_{Volts} is ±1.5% and Δu_{Amps} is ±1.5%, then the overall kW uncertainty will be:

$$\Delta u_{kW} = \sqrt{(\Delta u_{Volts})^2 + (\Delta u_{Amps})^2}$$
$$= \sqrt{(0.015)^2 + (0.015)^2} = \sqrt{0.00045} \approx 2.1\%$$

The previous example represents a handheld meter with an integrated current clamp, but some power measurement equipment employ external current transformers. The kW accuracies of such meters that utilize third-party components usually are published as *exclusive of sensor error*. In order to express the overall uncertainty, one must include the uncertainty of the current transformer (CT) in addition to the voltage and current input uncertainty of the recorder itself. In this example, if Δu_{Volts} is ±1.0%, Δu_{Amps} is ±1.0%, and Δu_{CT} is ±1.0%, then the overall kW uncertainty will be:

$$\Delta u_{kW} = \sqrt{(\Delta u_{Volts})^2 + (\Delta u_{Amps})^2 + (\Delta u_{CT})^2}$$
$$= \sqrt{(0.01)^2 + (0.01)^2 + (0.01)^2} = \sqrt{0.0003} \approx 1.7\%$$

Uncertainty propagation with non-electrical proxy variables follows the same RSS procedure, but one must take care to include <u>all</u> contributions of uncertainty. Consider a constant-speed pump, fan, or compressor. At minimum, the theoretical energy usage of most mechanical equipment is a function of the temperature, pressure, and flow rate of the fluid (liquid or gas) operated upon. But robust computations require additional physical properties of the fluid such as enthalpy, specific heat, or density which also vary with temperature and pressure conditions. Together, these parameters may characterize thermodynamic *output*, but electrical *input* – our primary concern – also is a function of mechanical, thermal, and electrical efficiency, none of which are constant; all vary according to load and/or ambient conditions. Finally, adding a variable speed drive (VSD) to this system adds not only rotational speed to the mix but also the accuracy, resolution, and sensitivity of the digital VSD controls and algorithms themselves.

The aforementioned electrical and thermodynamic computations are common in energy M&V. It has been shown how rigorous handing of measurement uncertainty compounds: the largest term dominates, and it takes only four equivalent 1% uncertainty terms in RSS to hit the maximum allowable 2% uncertainty. The engineering discipline often takes it for granted that measurements, set points, and even physical constants are not 100% certain. Requirement #9 obliges engineers to consider, quantify, and propagate all measurement error contributions appropriately in demand computations.

Clearly, it is impossible to achieve ±2% overall uncertainty via RSS unless <u>all</u> component specifications are better than ±2%. In practice, *M-MVDR* professionals should target ±1% accuracy for all component measurements to ensure the overall accuracy of the

[6] Assuming voltage and current are statistically independent and without systematic uncertainty. Such assumptions should be a last resort. One should contact the instrument manufacturer for detailed, authoritative statements of measurement accuracy, or specifically **uncertainty** with a **confidence level**.

calculated demand remains within ±2%. But measurement with ±1% accuracy can be impractical, prohibitively expensive, or unreasonably burdensome to customers.

Other Implications

Requirement #9 extends beyond error *handling* and assigns responsibility for quantifying the uncertainty of the data source itself. In the case of direct kW measurement (Requirement #6), the M&V technician is responsible for selecting a compliant power meter. But due to a variety of practical constraints, M&V contractors perform a limited amount of direct electrical measurement ("primary data collection") and leverage all available "secondary" data, particularly electronic trending from energy management systems (EMS). Since these secondary data sources are likely unknown or >2% accuracy, Requirement #9 may have tremendous cost and accuracy implications for Other Demand Resources.

Other influences on overall accuracy of the calculated demand include:

- The uncertainty introduced when less than 100% of the equipment is actually measured within a sample point or site;
- The accuracy of computational methods (e.g. linear regression); and
- The manner in which computational methods are applied (e.g. averaging and extrapolation).

While well established in academia, national laboratories, and highly technical fields, these issues are largely unexplored in the M&V and impact evaluation community. Whereby calibration (Requirements #11 through #16) has received much attention, the implications of this Requirement #9 are proving most contentious amongst utilities and M&V contractors. RLW foresees need for a technical publication and/or training seminar on its implications.

(10) Any measurement or monitoring equipment of current (amps) and nominal voltage used to calculate electrical demand must include the power factor of the end-uses in the demand (kW) calculations.

Literally, Requirement #10 allows for the calculation of kW using "end-use" power factor, "nominal" voltage, and measured current. However, the accuracy implications of the first two terms are nearly assured to violate ±2% kW accuracy Requirement #9. RLW advises Project Sponsors to consult the ISO New England and verify this interpretation. If Requirement #10 is intended as an exception or alternative route to compliance, this should be confirmed and stated clearly.

Power factor is the ratio of real power (kW) to apparent power (kVA). It is comprised of two component effects: *displacement* power factor, stemming from the phase-shift between current and voltage waveforms, and *distortion* power factor from harmonics that disrupt the fundamental sine wave. Not that long ago, engineers neglected distortion and presumed generic displacement power factors for a given industry or facility. But modern facilities are fraught with non-linear loads such as electronic ballasts, variable speed drives, and switched-mode power supplies, so harmonic distortion now is highly significant.

Requirement #10 acknowledges that power factor is a key component of basic demand calculations, but "end-use" - be it the type (e.g. lighting), purpose (e.g. manufacturing), location (e.g. electrical circuit), or specific equipment itself - is a meaningless differentiation. Power factor varies with time, for each load, and throughout a facility depending upon proximity to sources of both phase displacement and harmonic distortion. In practice, M&V contractors should either: a) spot measure the power factor as close as possible to the demand reduction and include its error in the calculation or b) avoid these "calculated demand" issues and measure kW "directly."

As discussed in the preceding Requirement #9, one also must consider the error associated with the power factor measurement on overall kW accuracy. Electrical demand (kW) is the product of true-RMS voltage, true-RMS current, and power factor. In order to express the overall accuracy of this scenario, one must include the uncertainty of all three terms in RSS. For example, if Δu_{Volts} is ±1.0%, Δu_{Amps} is ±1.0%, and Δu_{PF} is ±1.0%, then the overall kW accuracy will be:

$$\Delta u_{kW} = \sqrt{(\Delta u_{Volts})^2 + (\Delta u_{Amps})^2 + (\Delta u_{PF})^2}$$

$$= \sqrt{(0.01)^2 + (0.01)^2 + (0.01)^2} = \sqrt{0.0003} \approx 1.7\%$$

It is critical to understand that instruments which display power factor do so in one of two ways. A true-RMS power meter typically will derive power factor from the ratio of measured kW to kVA and hence captures both displacement and distortion effects. But a true-RMS voltage/current meter – a.k.a. digital multi-meter or 'DMM' – may only present the displacement power factor as derived from the difference in the voltage and current phase angles. The latter instruments which specify power factor accuracy in ±degrees of phase angle are <u>not</u> true power factor measurements.

Requirement #10 specifies that one may use the power factor of the "end-uses" in a kW calculation. Since Requirements #5 and 8 call for rigorous treatment of harmonics, then verbally-reported, rule-of-thumb, nameplate, or displacement-only values for power factor ought not to be acceptable. Though not specified in the actual requirement, it follows that M&V methods pertaining to Requirement #10 should use power factor measurements that are inclusive of both displacement and distortion effects.

Thus, it is our interpretation that Requirement #10 does <u>not</u> provide an alternative for estimating kW without any means of true-RMS power (and hence displacement and distortion power factor) measurement. The irony for M&V technicians is that meters capable of 'real' power factor measurement are inherently capable of direct kW measurement. In effect, in order to compute kW, one must measure kW.

Finally, it is perplexing that *M-MVDR* Requirement #10 permits "nominal" voltage values in kW calculations. Since ANSI C84.1–1989 *Voltage Ratings for Electrical Power Systems and Equipment* specifies allowable limits of ±5% of nominal voltage (120V, 240V, 480V) for electrical power distribution, calculations using nominal voltage *which may be ±5%* are unlikely to be compatible with ±2% kW accuracy standards expressed elsewhere in the *M-MVDR*.

(11) Data recorders must be synchronized in time, within an accuracy of ±2 minutes per month, with the National Institute of Standards and Technology ("NIST").

The National Institute of Standards and Technology (NIST) is responsible for providing the ultimate measurement reference for all physical quantities - including time and frequency - in the United States. Requirement #11 establishes both the allowable time drift of the meter's clock (±2 minutes/month) and the reference to which these clocks are set. Many companies - RLW included - maintain official time on our computers via regular synchronization with NIST over the Network Time Protocol (NTP). Compliance with Requirement #11 is achieved by a) choosing equipment with a compliant real-time clock crystal (±2 min/mo ≈ 46 ppm[7]) and b) deploying said equipment with computers that are regularly synchronized with a NIST time source.

(12) All measurement, monitoring and data recording equipment must be calibrated by the Project Sponsor or its independent calibration contractor in such a way to meet or exceed the Federal Energy Management Program ("FEMP") Measurement and Verification Guidelines, applicable American Society of Heating, Refrigeration and Air Conditioning Engineers ("ASHRAE") standards, NIST, or equivalent standard.

M-MVDR §10.2 Requirements #12 through 16 deal with calibration and maintenance issues. Two obvious references in Requirement #12 are FEMP M&V Guidelines: Measurement and Verification for Federal Energy Projects, Version 2.2 and ASHRAE Guideline 14-2002, Measurement of Energy and Demand Savings. Both are worthy M&V resources; however as "guideline" publications neither is particularly authoritative or specific about calibration.

As the "ultimate measurement reference," NIST maintains U.S. standards for measurements such as the watt, volt, amp, etc. Thus, NIST is inherently linked to all matters of measurement calibration; calibration and testing laboratories in the United States are often required to show traceability to NIST standards. It might appear that Requirement #12 contains some flexibility with phrase "or equivalent standard," but both the FEMP and ASHRAE guidelines imply NIST authority on this issue.

Calibration References

FEMP M&V Guidelines: Measurement and Verification for Federal Energy Projects

> *§4.2 Metering. Calibration of sensors and meters to known standards (i.e., National Institute of Standards and Technology (NIST) standards) is required to ensure that data collected are valid. Project information and metered data must be maintained in usable formats. Both "raw" and "adjusted" data should be submitted to the federal agency with post-installation and regular interval reports.*
>
> *§4.2.2 Sensor and Meter Calibration. Sensors and meters used to collect M&V data should be calibrated to known standards (such as NIST). Forms indicating that calibration has been conducted are a required part of the M&V reports.*

[7] Clock performance typically is expressed in non-dimensional terms of "parts per million" (ppm). A 46 ppm real-time clock crystal will drift 46 minutes over a 1,000,000 minute period. Since one million minutes is about 23 months, this clock drifts 46 minutes in 23 months, or 2 minutes per month.

ASHRAE Guideline 14-2002: Measurement of Energy and Demand Savings

> *§5.5.1 Hardware. Equipment must be recalibrated as defined by the manufacturer. Clause 7 contains guidelines in these matters.*
>
> *§7.5.1 Recommendations. It is highly recommended that instrumentation used in measuring the information required to evaluate energy and demand savings be calibrated with procedures developed by the Nation Institute of Standards and Technology (NIST). Primary standards and no less than third order NIST-traceable calibration equipment[8] should be utilized wherever possible.*
>
> *§7.5.2 Calibration Requirement Classifications. The level of calibration required will be dependent upon the rigor of the test plan. Listed below are suggested requirements for minimum, optimal, and advanced or very rigorous test plans. It is highly recommended that any equipment that is used for calibration and verification be appropriately calibrated.*
>
> *§7.5.2 Recalibration of Instrumentation. The period of recalibration should be provided in the measurement procedure. If data validity is in doubt, recalibrate. Recalibration should focus on the most critical measurement points.*
>
> *§7.8.1.2 When to Recalibrate. For critical measurement points, which are a part of a long-term testing project, a six-month to yearly calibration interval is highly recommended. Long-term tests should also be subject to a post-test calibration. All spot measurement or temporary instrumentation should have had an appropriate calibration within the past six months.*

Some manufacturers of electrical metering equipment perform quality control "bench testing" of each instrument before shipment. When performed against NIST-traceable calibration equipment, this factory testing may qualify as sufficient initial calibration.

The ASHRAE recommendation of "six month to yearly recalibration" is fairly clear and applicable to the *M-MVDR* context. Instrument manufacturers have been extremely coy on this issue, unwilling to state whether bench testing is "calibration" or specify any recommended calibration interval.

ISO New England, Operating Procedure No. 18

The ISO New England's OP18 manual contains similarly rigorous criteria for watthour meters:

> *IX. Testing, Calibration and Maintenance Standards. Section D.4. In-service testing of watthour meters shall be tested at a frequency in accordance with the local state utility control and distribution utility requirements for retail loads such as Asset Related Demands. All other assets shall be tested at the frequency specified as follows: Solid-state*

[8] In this context, "order" refers to the degrees of separation in an "unbroken chain of comparisons." Third order NIST-traceable calibration equipment has been certified against a second order reference. A second order reference has been calibrated to a first order reference which, by definition, has been certified by NIST itself.

> *meters, the operation of which is monitored daily, must be tested at least once every two calendar years. All other meters must be tested at least once a calendar year.*

Edison Electric Institute, Handbook for Electricity Metering, 10th Edition

In contrast, the Edison Electric Institute (EEI) suggests a more lenient protocol in consideration of the stability of modern electronic meters:

> *Long-Term Drift and Calibration Requirements, p. 396. Carefully designed and manufactured electronic meters can provide reliable metering operation over more than 20 years of service. Usually, however, meter accuracy is verified on a routine basis every 1 to 16 years, depending on location, accuracy class, and revenue flow through the meter. Government certification requirements can play a major role in defining the time period between verifications.*

> *Electronic Meter Testing, p. 506. Electronic or solid-state meters require testing to confirm their accuracy but do not normally have calibration adjustments. These meters are calibrated in the factory by running a succession of tests and finding an internal register constant that produces 100% registration. This constant is then burned into the meter to prevent it from accidentally being changed. This is a calibration process that is best left to the manufacturer.*

This last paragraph is consistent with the "self-calibration circuitry" described in the Dent Instruments "Calibration Stability & Traceability Statement" (see Appendix C) for their ELITEpro™ power recorders.

Commentary

Selecting a calibration interval is a complex task which involves interval analysis of measurement data with a goal of identifying the optimal interval that balances acceptable uncertainty against the practical cost of achieving it. The National Conference of Standards Laboratories (NCSLI) has published a Recommended Practice (RP-1) entitled Establishment & Adjustment of Calibration Intervals. This 132-page document examines the issue using a variety of engineering and statistical methods, both predictive and reactive, including maximum likelihood estimation (MLE), interval analysis, and ten distinct measurement reliability models. The manual does not conclude actual calibration intervals but offers guidelines for those "assigned the responsibility of designing and developing a calibration interval analysis system."[xvi]

Of potential interest is Chapter 8 of NCSLI's RP-1 manual which lists several conditions under which "No periodic calibration required (NCPR)" may be justified, including situations where the instrument is "a component of a calibrated system or function" or "makes measurements … which are monitored by a calibrated device, meter, or gage during use."[xvii] This seems to support the assertion that "self-calibrating" devices such as Dent Instruments' ELITEpro™ recorders require little to no periodic calibration.

Given that FEMP and ASHRAE imply NIST authority on calibrations, it is logical that a NIST-traceable calibration would comply with Requirement #12. If one adheres to the

ASHRAE guideline, M&V instrumentation should to be calibrated to "no less[9] than third order NIST-traceable calibration equipment." This indicates that the calibration of the M&V instrument itself should be *at worst* fourth-order NIST-traceable.

Unfortunately, this review is inconclusive with regard to calibration intervals. The various authorities referenced by Requirement #12 have published either unclear or inconsistent specifications for calibration interval. It is the author's opinion that the six-to-twelve month interval stated in ASHRAE Guideline 14-2002 §7.8.1.2 is unreasonable for our M&V context. The language in §5.5.1 of the same document "Equipment must be recalibrated as defined by the manufacturer" seems much more reasonable.

Adherence to ASHRAE §5.5.1 would establish a minimum calibration interval of three years for the ELITEpro™ as per Dent Instruments' statement in Appendix C of this report.

(13) The Project Sponsor must ensure that all measurement, monitoring and data logging equipment shall be maintained in such a way as to meet or exceed industry and manufacturer standards.

Requirement #13 deals strictly with equipment maintenance. At minimum, contractors should adhere to all manufacturer-specified maintenance instructions. M&V contractors also should observe applicable ANSI safety standards and follow industry "standard practice" when using this equipment. As with all of these requirements, this is directed at the Project Sponsor, and assigns them responsibility for ensuring that the requirement is met.

Although slanted toward the public utility meter lab, the EEI Handbook for Electricity Metering offers some additional guidelines for maintenance of instruments:

Edison Electric Institute, Handbook for Electricity Metering, 10th Edition

> *Maintenance of Instruments, p. 125. Most public utilities maintain a laboratory for calibration and minor repairs of instruments. Good practice directs that all instruments be returned to the laboratory for recalibration on a routinely scheduled basis. The length of time between laboratory inspections and calibrations generally depends on the accuracy class and the use of the instrument. When an instrument has been subjected to any accidental electrical or mechanical shock, even though no apparent damage may have resulted, return it to the laboratory for recalibration. Whenever there is any doubt concerning the accuracy of an instrument's indications, return it to the laboratory for testing.*

In absence of other "industry standards" for M&V equipment maintenance, Requirement #13 effectively instructs one to maintain equipment in accordance with manufacturer recommendations. If the manufacturer does not publish maintenance specifications, then one can either 1) inquire with the manufacturer directly, or 2) use reasonable judgment. Surely, M&V contractors have a vested interest in protecting their investment in costly M&V equipment via appropriate use and care.

[9] This is poor language choice on ASHRAE's part, for the word "less" is used here qualitatively not quantitatively. Clearly, first and second order NIST-traceable calibration equipment is acceptable.

(14) The Project Sponsor must maintain documentation on all measurement, monitoring and data recording equipment maintenance and calibration activities. Documentation and records must be maintained as specified in Section 12 of this Manual.

Administrative in nature, Requirement #14 outlines the responsibilities of the Project Sponsor pertaining to documentation of maintenance and calibration activities.

(15) The Project Sponsor shall provide to ISO, upon request, measurement equipment maintenance, calibration and testing records to demonstrate that the Project Sponsor's measurement equipment is calibrated and maintained in accordance the requirements described in this Manual.

Likewise, Requirement #15 states that Project Sponsors are responsible for providing all aforementioned documentation to the ISO upon request.

(16) The Project Sponsor may propose alternative methods to demonstrate the measurement, monitoring and data recording equipment used in the determination of Demand Reduction Value satisfies the accuracy, calibration and maintenance standards described in the Manual.

The "alternative methods" wording in Requirement #16 likely affords Project Sponsors an opportunity to declare compliance in good faith. The ELITEpro™ recording poly-phase power meter by Dent Instruments is the predominant M&V logger today. Dent Instruments calibrates each logger against a NIST certified reference during manufacturing, but this does not mean that the loggers themselves are NIST calibrated. Dent includes a "Logger Calibration Data Sheet" with every ELITEpro logger, and the authors have never seen a measurement error as high as even ±0.10% (for amps or volts) on these sheets. As stated in Appendix C, ELITEpro™ loggers are "self-calibrating" in that they contain a chip which delivers a highly-accurate, constant voltage reference to compensate for drift. The logger firmware monitors and compensates against the embedded reference to maintain the original voltage calibration. The highly accurate results on calibration reports of new ELITEpro™ loggers, the NIST traceability of the Dent calibration reference, and the ELITEpro™ self-calibration circuitry collectively make a compelling demonstration for a compliant "alternative method."

Another "alternative method" to NIST-calibration of each individual M&V instrument might be in-house calibration against a single NIST-traceable reference. A contractor with a significant inventory of M&V instruments, or a Sponsor reporting significant Other Demand Resources, could easily justify investment in a calibration reference and maintenance program.

(17) Interval metering devices shall collect electricity usage data at a frequency of 15 minutes or less.

Requirement #17 does not reference any ANSI standards, but it may be interpreted as ambiguous for failing to differentiate between sampled and integrated values. The likely intention was to double the Nyquist frequency thus mitigating data aliasing in equipment that duty cycles such as air conditioning and water heaters.

Many interval metering devices employed by M&V contractors sample data *continuously*, *integrating* and storing data at a programmable interval. For data of this nature, rigorous computation of coincident peak demand impacts requires no more resolution than hourly data.

For some data collection, Requirement #17 may pose a cost or technical challenge if M&V contractors are expected to monitor data across an extended duration (e.g. June, July, and August). Compact data loggers such as those used for temperature contain a finite amount of memory for recording data. One could argue that temperature data has a slow dynamic response that is unsusceptible to aliasing.

This concludes the detailed review of Section 6: "Review of *M-MVDR* §10.2 Requirements." In the following section, we summarize these findings by topic, not Requirement number, and develop some conclusions and recommendations for compliance.

7. Findings and Recommendations

A key objective of this project was to establish some basis for assessing compliance of popular M&V equipment with relevant ANSI standards. This goal has proved particularly challenging. Initially, researchers hoped that manufacturers of M&V equipment would already have published statements of compliance pertaining to relevant ANSI standards. With the exception of high-end instruments and safety compliance inferred by a UL listing, such declarations have not been forthcoming.

Researchers have concluded that ANSI standards, as voluntary consensus publications, tend not to facilitate clear compliance verdicts. These standards often are impressive statements of guidelines and recommended practice; few standards may be boiled down to an unambiguous list of requirements. The practical threshold for due diligence review of "relevant standards" is unclear in this regard.

Researchers expended considerable effort compiling and examining standards, assessing their relevance, and culminating in a concise list of the most pertinent ANS documents. The scope, relevance, and – as practical – route to compliance for each is summarized below.

Relevant Safety Standards

As stated earlier in Section 6, researchers conclude that safety is likely the principle issue associated with *M-MVDR* §10.2 Requirement **#1**. To a lesser extent, maintenance Requirement **#13** also suggests a safety relationship. As it pertains to ISO New England objectives for the *M-MVDR* requirements, surely safety is not paramount to accuracy; but safety is of vital concern to the M&V contractor, and safe equipment and practices are fundamental to the attainment of quality, reliable, and accurate results.

<u>UL 61010-1-2005 — Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use – Part 1: General Requirements</u>

Scope: This standard specifies general safety requirements for electrical equipment intended for professional, industrial process, and educational use, which may incorporate computing devices: electrical test and measurement equipment; electrical control equipment; electrical laboratory equipment; or accessories intended for use with them, used under specified environmental conditions.

<u>UL 61010-031-2007 — Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use – Part 031: Safety Requirements for hand-held probe assemblies for electrical measurement and test</u>

Scope: This standard applies to hand-held and hand-manipulated PROBE ASSEMBLIES of the types described below, and related accessories. These PROBE ASSEMBLIES are for use in the interface between an electrical phenomenon and a measuring or test instrument. They may be stand-alone PROBE ASSEMBLIES which are themselves within the scope of UL 61010-1-2005, or accessories to other equipment within the scope of UL 61010-1-2005.

<u>UL 61010B-2-032 (Ed. 1) — Standard for Electrical Equipment for Measurement, Control, and Laboratory Use; Part 2: Particular Requirements for Hand-Held Current Clamps for Electrical Measurement and Test</u>

Scope: This standard applies to hand-held and hand-manipulated CURRENT CLAMPS. These CURRENT CLAMPS are for use in the measurement of current without interruption of the current path of the circuit in which it is measured. They may be stand-alone CURRENT CLAMPS which are themselves within the scope of UL 61010-1-2005, or accessories to other equipment within the scope of UL 61010-1-2005. This standard does not apply to current transformers or current transducers intended for fixed installations.

Relevance: UL standards are extremely expensive, and unlike other standards deemed relevant, researchers did acquire copies for further examination. The UL standards are also very lengthy and, as they are concerned with safety, not accuracy, may not be as high a priority as other ANSI publications. Nonetheless, in the context of safety, these standards are highly relevant publications for most electrical test and measurement equipment. Literal compliance with all relevant standards, reserving any presumption or inference, must include seemingly tangential concerns such as safety. Thus, this interpretation concludes that Project Sponsors must ensure that equipment employed for demand resource M&V complies with UL 61010 safety standards. [10]

Compliance: Either a) Utilize UL-listed instrumentation and make sure that the measurement equipment is rated for and used in the conditions for which it was designed or b) Obtain and review these UL standards to make an independent determination of whether non UL-listed equipment complies.

Relevant Metering Standards

M-MVDR §10.2 Requirements **#2, 3, 5, and 8** all defer to relevant ANSI/IEEE standards in the context of electrical measurement. The following four standards all pertain very specifically to electrical metering and/or devices employed in typical M&V activities.

ANSI/NEMA C12.1-2001 — American National Standard for Electric Meters and Code for Electricity Metering

Scope: This standard establishes acceptable performance criteria for new types of ac watthour meters, demand meters, demand registers, pulse devices, and auxiliary devices. It describes acceptable in-service performance levels for meters and devices used in revenue metering. It also includes information on related subjects, such as recommended measurement standards, installation requirements, test methods, and test schedules. This Code for Electricity Metering is designed as a reference for those concerned with the art of electricity metering, such as utilities, manufacturers, and regulatory bodies.

Relevance: As portrayed in the above scope, this standard pertains mostly to utility revenue metering and the testing standards and methods employed by the meter shop. Nearly all references to portable equipment in C12.1 are in the context of "portable standard watthour meters" which are NIST-traceable and used for field calibrating utility revenue meters. The only clear applicability of C12.1 to the portable, short-term M&V

[10] It remains unclear, but research has not identified any basis for excluding equipment produced *before* a given safety publication, e.g. recent UL 61010 standards, from compliance criteria.

typically performed to validate ODR lies not in the standard itself, but in an "informative appendix"[11] to the C12.1 standard.

Compliance: Engineers and technicians performing M&V ought to be trained and experienced in the basic measurement methods outlined in ANSI C12.1-2001 Appendix A. Unbeknownst to many, there is remarkable potential for methodological error in electrical power measurement. While there are just several 'standard' electrical service configurations, unconventional and non-conforming variants abound on customer premises that stymie even veteran electricians. Common amateur mistakes include confusing three-phase delta and wye services, improper phase reference, violation of Blondel's theorem, neglecting ground loops, etc.

To avoid such errors, Project Sponsors might consider developing specific qualification criteria for companies and personnel who perform electrical measurement and verification. The myth that an electrical license qualifies someone to perform M&V must be dispelled. Electrician training is indeed arduous, but the trade is overwhelmingly founded in electrical installations and renovations. While electricians are authorities in building codes, electrical safety, and wiring methods, few electricians possess the highly specialized skills to be competent M&V contractors.

<u>ANSI/IEEE Std 120-1989 — IEEE Master Test Guide for Electrical Measurements in Power Circuits</u>

Scope: It is the purpose of this guide to give instructions for those measurements of electrical quantities that are commonly needed in determining the performance characteristics of electric machinery and equipment. The methods given here relate to measurements, as made with either analog or digital indicating or integrating instruments, of power, energy, voltage, and current, in dc or ac rotating machines, transformers, induction apparatus, arc and resistance heating equipment, mercury arc, thermionic, or solid-state rectifiers and inverters. Measurements made with supplementary instruments and devices are also included.

Relevance: This guideline document is one of the best available information resources on electrical measurement. It offers some fundamental electrical theory, provides instructions for performing measurements, and proposes a variety of methods. But as a guideline publication, it rarely prescribes requirements and more often presents generalized commentary or suggestions on measurement techniques and technologies. It is worth noting that the document has not been revised since 1989 when watthour meters used for M&V were not so portable or capable.

Compliance: Literal interpretation of these guidelines would formalize procedures such as a) the use of meters rated to "operate at loads well removed from the light-load part of the load curve" and b) meter installations "in the circuit sufficiently long before readings are taken to ensure uniform and constant temperature throughout."

A qualified M&V technician possesses the theoretical and practical knowledge of electrical systems and instrumentation which is vital to performing accurate power measurements with confidence. Six *M-MVDR* §10.2 requirements fall under the "Usage/Methods" heading back in Table 1: **#4, 7, 9, 10, 11 and 17**. The average

[11] An "informative appendix" provides additional information that complements the standard but is not required for compliance with the standard itself.

technician performing M&V likely falters unknowingly on one or more of these requirements, whereas a trained competent M&V professional already follows these procedures because they are fundamental to proper electrical measurements.

ANSI/IEEE Std C57.13-1993 — IEEE Standard Requirements for Instrument Transformers

Scope: Electrical, dimensional, and mechanical characteristics are covered, taking into consideration certain safety features, for current and inductively coupled voltage transformers of types generally used in the measurement of electricity and the control of equipment associated with the generation, transmission, and distribution of alternating current. The aim is to provide a basis for performance, interchangeability, and safety of equipment covered and to assist in the proper selection of such equipment. Accuracy classes for metering service are provided. The test code covers measurement and calculation of radio and phase angle, demagnetization, impedance and excitation measurements, polarity determination, resistance measurements, short-time characteristics, temperature rise tests, dielectric tests, and measurement of open-circuit voltage of current transformers.

Relevance: According to this standard, an "instrument transformer" is "one that is intended to reproduce in its secondary circuit, in a definite and known proportion, the current or voltage of its primary circuit with the phase relations substantially preserved." A current transformer (CT) is an obvious component of most electrical measurement instruments; just as some devices measure voltage directly, while others also employ a voltage transformer (VT) or potential transformer (PT). Some of the most pertinent issues involve arranging instrumentation to minimize spurious magnetic coupling and maximize the accuracy of the instrument transformer. For CTs in particular, accuracy may be influenced by location, orientation, percent full load rating, heating, and even magnetization.

Compliance: The manufacturer of current transformers used for most M&V work does not specify compliance with this standard nor could they comment on its applicability to their products. M&V contractors should recognize that operating range, ambient conditions, and location/orientation can have a tremendous effect on the accuracy of current transformers.

ANSI/IEEE Std 1159-1995 — IEEE Recommended Practice for Monitoring Electric Power Quality

Scope: This guide applies to the monitoring of electric power quality of single-phase and poly-phase AC power systems, definitions of power quality terminology, impact of poor power quality on utility and customer equipment and the measurement of electromagnetic phenomena are covered in this IEEE standard.

Relevance: This standard is relevant insofar as the *M-MVDR* makes multiple references to power quality issues such as harmonics and power factor, and this IEEE recommended practice is perhaps the preeminent ANSI publication on power quality today. Electrical measurements with imperfect power quality pervade modern systems and should be performed and analyzed with great care. Electrical data containing power quality anomalies is easily misinterpreted, distorting the resultant impacts and precision.

Compliance: One could argue that measurement for the purpose of savings and/or ODR verification does not qualify as a "monitoring power quality" issue. But *M-MVDR* Requirements **#5, 8, and 10** suggest the ISO-NE considers it relevant. At minimum, M&V contractors ought familiarize themselves with IEEE 1159-1995 and choose equipment with clear specifications with regard to harmonics and distortion. Occasionally, specifications for a true-RMS power recorder with harmonics capabilities cite this ANSI/IEEE Standard 1159-1995.

Calibration Guidelines

M-MVDR §10.2 Requirements **#12, 14, 15, and 16** all involve the calibration of M&V equipment. While most requirements do not reference specific publications, Requirement **#12** explicitly cites FEMP M&V Guidelines in the context of meter calibration.

The FEMP M&V Guidelines were first published in 1996 and represented the first major guide for performance contracts in U.S. federal facilities. The International Performance Measurement and Verification Protocol (IPMVP) is similar, albeit with broader scope, and dates back to 1995. Along with ASHRAE's 2002 publication of Guideline 14, these three documents represent valuable resources for most M&V activities. While they are not American National Standard publications, *M-MVDR* §10.2 Requirement #12 indicates that the FEMP document, at minimum, is a path to compliance.

Oddly absent from the *M-MVDR*, the IPMVP is the most current, widely-accepted publication on M&V methods. Like the FEMP guidelines, it was originally published in the mid 1990's with many of the same authors and contributors. ASHRAE's Guideline 14 provides complementary detail to the IPMVP and shared many of the same original authors as IPMVP. The FEMP M&V Guidelines are generally consistent with the IPMVP framework, except in some requirements for site measurement of energy use.

<u>The International Performance Measurement and Verification Protocol (IPMVP) — Concepts and Options for Determining Energy and Water Savings, Volume I (2007)</u>

Scope: The International Performance Measurement and Verification Protocol (IPMVP) Volume I is a guidance document describing common practice in measuring, computing and reporting savings achieved by energy or water efficiency projects at end user facilities. The IPMVP presents a framework and four measurement and verification (M&V) Options for transparently, reliably and consistently reporting a project's saving. M&V activities include site surveys, metering of energy or water flow(s), monitoring of independent variable(s), calculation, and reporting. When adhering to IPMVP's recommendations, these M&V activities can produce verifiable savings reports. The IPMVP is intended to be used by professionals as a basis for preparing savings reports.

Relevance: The IPMVP makes extensive mention of calibration in the context of energy usage and savings modeling but relatively little of the calibration of actual meters. However, IPMVP section 4.8.3.2 asserts the following regarding meter calibration:

> *Meters should be calibrated as recommended by the equipment manufacturer, and following procedures of recognized measurement authorities. Primary standards and no less than third-order standard traceable calibration equipment should be utilized wherever possible. Sensors and metering equipment should be selected based in part on the*

> *ease of calibration and the ability to hold calibration. An attractive solution is the selection of equipment that is self-calibrating.* [xviii]

Compliance: As discussed earlier in Section 6, this passage echoes ASHRAE Guideline 14-2002 requirements that call for no less than third order traceable calibration equipment. The explicit reference to 'self-calibrating' equipment appears to support the Dent Instruments ELITEpro™ power recorder – the M&V workhorse of energy efficiency program evaluation – as intrinsically compliant with *M-MVDR* calibration requirements.

Accuracy and Uncertainty

M-MVDR §10.2 Requirements **#6 and 9** are very clear on the specification of ±2% accuracy for kW measurements and/or computations. Yet sometimes it can be very unclear how to characterize the effective or overall accuracy[12] of a given meter – or combined set of instrumentation – from manufacturer claims, specification sheets, or marketing materials.

One challenge is the disparity in how manufacturers publish specifications for electrical measurement equipment. Lack of adoption of the proper expression **uncertainty** and popular misinterpretation of the terminology **accuracy**, **resolution**, and **sensitivity** further confound the issue. Fortunately, the *M-MVDR* specification is literally for accuracy, and nearly all meters are accompanied by accuracy specifications.

However, some higher-end meters specify accuracy with both "gain" or percent reading (±X%) and "offset" terms in least significant digits ("dgt") or count ("cnt"). For example, one Fluke power meter reports kW measurement accuracy of ±1.5% of reading ±5 digits. There is little consistency amongst manufacturers; some report both the "gain" and "offset" terms while others roll all contributions to measurement uncertainty into a single 'worst case' accuracy specification.

Since 1) there is no valid means to combine the gain and offset terms into one quantity, and 2) the offset term is only significant at the extreme low end of an instrument's measurement range, the authors have decided to neglect "offset" while assessing compliance with the M-MVDR kW±2% accuracy requirement. However, contractors must recognize the *potential* significance of the term and accept responsibility for meter selection and usage in consideration of accuracy offset effects.

Given such inconsistencies in **accuracy** specifications and the lack of proper expressions of measurement **uncertainty** and **confidence level**, it is often necessary to contact the manufacturer to make a correct interpretation and objective assessment of published accuracy ratings.

Measurement Intervals

A language revision may be warranted in Requirement **#17** to distinguish between 'sampled' and 'integrated' data measurements. Fifteen minute resolution is appropriate for sampled data to improve confidence of the hourly estimate. However, resolution greater than hourly is unnecessary and potentially cost-prohibitive for integrated data measurements.

[12] As discussed in Section 6 under Requirement #6, **accuracy** is an unquantifiable ideal; **uncertainty** is the proper expression, although these terms are incorrectly used interchangeably.

8. Compliance of M&V Equipment

One objective of this project was to "develop a working list of equipment that complies with M&V requirements." This section presents these findings, first for two popular short-term monitoring devices, and then for a variety of handheld power meters.

Dent Instruments' ELITEpro™ Energy Logger

The ELITEpro™ energy logger by Dent Instruments is one of the most popular devices for short-term M&V of electrical performance. The ELITEpro™ complies with Requirement #11 real-time clock accuracy specifications of ±2 minutes per month. Unfortunately, the published electrical accuracy requirements for the ELITEpro™ are somewhat unclear and subject to interpretation.[13] The manufacturer has been advised but has yet to publish revised specifications, so the authors have proceeded with the most conservative interpretation: Voltage±1.0%, Current±1.0%, and kW±1.4% (via RSS – see page).

To measure current and hence power, the ELITEpro™ requires external current sensors, and Dent Instruments sells a variety of current transformers for the device. Dent and Magnelab make split-core CTs in a wide array of physical and amperage rating sizes with ±1.0% accuracy from 10% to 130% of the rated current. Using RSS, the combined (net) kW accuracy of the ELITEpro™ with any of the ±1.0% split-core CTs is ±1.7% as seen in the first row of Table 2.

ELITEpro™ with Current Transformer	**Accuracy**			
	Voltage	**Current**	**Sensor**	**Net kW**
Split-Core (10-130% of rating)	1.0%	1.0%	1.0%	1.7%
150A Clamp (2-80A)	1.0%	1.0%	1.0%	1.7%
150A Clamp (80-150A)	1.0%	1.0%	1.5%	2.1%
500A Clamp (<25A)	1.0%	1.0%	5.0%	5.2%
500A Clamp (25-100A)	1.0%	1.0%	2.0%	2.4%
500A Clamp (100-250A)	1.0%	1.0%	1.0%	1.7%
500A Clamp (250-500A)	1.0%	1.0%	1.0%	1.7%
1000A Clamp (<10A)	1.0%	1.0%	3.0%	3.3%
1000A Clamp (10-50A)	1.0%	1.0%	1.5%	2.1%
1000A Clamp (50-200A)	1.0%	1.0%	0.8%	1.6%
1000A Clamp (200-1200A)	1.0%	1.0%	0.5%	1.5%
3000A Flexible	1.0%	1.0%	1.0%	1.7%

Table 2 – ELITEpro™ Accuracy with Various Sensor Combinations

Dent offers three clamp-on CTs of 150A, 500A[14], and 1000A nominal rating, however the accuracy specifications for these sensors varies with the magnitude of current being measured. The 3000A flexible CT or "Rogowski Coil" is ±1.0% accurate when the conductor is centered and orthogonal to the coil, but a Dent Application Note indicates that the accuracy can degrade as poorly as -3.80% with improper position. All

[13] The published accuracy specification for the ELITEpro™ reads "Better Than 1% (<0.5% typical) for V, A, kW, kVAR, kVA, PF exclusive of sensor error." The specification is unclear because current, voltage, and kW accuracy cannot be identical in a digital true-RMS power meter.
[14] The Dent specifications for the 500A clamp-on CT read ±2.5%, but this appears to be a simplification of the accuracies obtained from the OEM reflected in Table 2.

accuracies in Table 2 presume usage within operating limits and installation in accordance with manufacturer guidelines.

Table 2 concludes that all ELITEpro™ configurations with ±1.0% split-core and flexible CTs comply with Requirement #6 with a kW accuracy of ±1.7%. Within the three clamp-on CT configurations, the measurement system is compliant for five of the ten operating ranges. While clamp-on CTs are convenient, they require careful consideration of the operating range in order to ensure compliance. Similarly, flexible CTs facilitate monitoring in situations where other CTs may not fit, but they too require careful consideration of conductor position and coil orientation to ensure compliance.

Architectural Energy Corporation's MicroDataLogger®

The MicroDataLogger® (MDL) by Architectural Energy Corporation (AEC) is another popular device for short-term M&V of electrical performance. The MDL complies with Requirement #11 real-time clock accuracy specifications of ±2 minutes per month. The MDL is a modular data logger with highly accurate ±0.1% analog inputs. True-RMS power measurement is accomplished on the MDL via use of watt transducers such as the Hawkeye™ H8040 and the WattNode™ Transducer with split-core CTs.

AEC MicroDataLogger w/Hawkeye™ H8040 Transducer (kW±1.0%)
AEC MicroDataLogger w/WattNode™ Transducer and Magnelab CTs (kW±1.0%)

Both configurations comply with Requirement #6 with a kW accuracy of ±1.0%. Though less common, clamp-on and flexible CTs may be used with the MDL as well. As with the Dent ELITEpro™ above, M&V contractors should select these sensors carefully with regard to accuracy specifications in all operating ranges.

Compliant Portable/Handheld Meters

The following power meters are true-RMS measurement devices with kW accuracy ratings of ±2.0% or better for kW. The accuracies in the list below may differ from published specifications. If published specifications did not list kW accuracy or excluded sensor error, researchers developed overall kW accuracy using RSS of the component errors.

AEMC F05 Clamp-On Meter (kW±1.8%)
Extech 382065 Clamp Power Datalogger (kW±1.6%)
Fluke 1735 Three-Phase Power Logger w/0.5% Clamp CTs (kW±1.2%)
Fluke 345 Power Quality Clamp Meter (kW±1.8%)
Yokogawa 2433 Clamp Meter (kW±1.4%)

Non-Compliant Meters

To eliminate duplicate effort moving forward, researchers also compiled a list of meters and kW accuracies that were deemed non-compliant. The following power meters do not meet the overall accuracy ratings of ±2.0% or better for kW. For some items, the published specifications may suggest compliance, but consideration of all applicable root-sum-square (RSS) errors yields a higher overall accuracy rating.

Extech 380940 Watt Clamp Meter (kW±2.1%)
Extech 380975 Power Clamp Meter (kW±2.2%)
Extech 382075 Clamp-On Power Analyzer (kW±2.8%)
Extech 382090 Power Analyzer/Datalogger (kW±2.1%)

Fluke 1735 Three-Phase Power Logger w/Flexi-Set CTs (kW±2.3%)
Fluke LH1050/1060 Power Clamp Meters (kW±2.1%)

The following meters measure neither kW directly nor power factor; these instruments meter only volts and amps and thus are incapable of direct kW measurement as per Requirement #6. Even in tandem with a capable power factor meter, given the manner in which uncertainty propagates, it is unlikely that these meters will yield compliant results of kW±2.0% in accordance with Requirements #9 and #10.

AEMC 500 Clamp-On Meter (VA±2.2%)
AEMC 501 Clamp-On Meter (VA±2.1%)
AEMC 502 Clamp-On Meter (VA±2.4%)
AEMC 503 Clamp-On Meter (VA±1.7%)
AEMC 701 & 703 Clamp-On Multimeter (VA±2.2%)
AEMC F0 Series Clamp-On Meter (VA±1.8%)
Fluke 320 Series Clamp Meters (VA±2.2%)
Fluke 330 Series Clamp Meters (VA±2.5%)
Fluke 902 True-RMS HVAC Clamp Meter (VA±2.2%)

9. Commentary

Accuracy Requirements

Measuring kW with an accuracy of ±2% in adherence to Requirements #6 and #9 appears to pose the greatest challenge to M-MVDR compliance. Allowable ±2% error is the "acceptable performance" requirement specified in ANSI C12.1-2001 section 5.1.2.2. The principle of holding ODR assets to the same measurement standards as traditional revenue-metered DR assets is logical. But in practice, many portable measurement instruments – particularly those that are appropriate and practical for efficiency program evaluations – have difficulty achieving this accuracy level.

There is disturbing inconsistency in the published accuracy specifications for a number of measurement devices. With higher electricity prices and heightened efficiency awareness, the number of true-RMS power meters and recorders on the market has grown substantially in recent years. Like any 'hot' market, competition in electrical instrumentation can drive reputable manufacturers to develop low-end products. Some of the more dubious specifications are for meters manufactured by the company 'LEM' that are branded as Fluke, AEMC, and Extech.

The ELITEpro™ logger by Dent Instruments is the workhorse of energy efficiency program evaluation. Product specs indicate that the meter achieves kW±2% accuracy with standard split-core CTs, properly installed flexible CTs, and certain clamp-on CTs in specific operating ranges. The MicroDataLogger® by Architectural Energy Corporation is another popular instrument for short-term monitoring in energy program evaluation, and it too is kW±2% compliant for most popular configurations.

These observations apply to mainstream instrumentation products. High accuracy, portable kW instruments certainly exist for meter shop, laboratory, and utility field calibrations, but these instruments are extremely expensive, sensitive, and vulnerable in customer-side installations.

When uncertainty propagation is considered with rigor, about half of popular handheld kW meters exceed the *M-MVDR* kW±2% accuracy requirement. Replacement may necessitate significant investment on the part of M&V contractors and Project Sponsors.

Other Loggers

Much of this review has focused upon power measurement instrumentation, but other M&V equipment is subject to several M-MVDR §10.2 requirements. Relevant requirements for time-of-use loggers such as Dent Instruments SMART*logger* TOU product line are limited to Requirement #1 (General Safety), Requirement #11 (Time Accuracy), and Requirement #13 (Maintenance). The same requirements apply to the extensive HOBO line of temperature, humidity, light, etc. loggers by Onset Computer Corporation. Most of these devices comply with Requirement #11 for time accuracy no worse than ±2 minutes per month. As discussed earlier in Section 6 "Review of *M-MVDR* §10.2 Requirements," a key implication of Requirement #11 is that loggers must be synchronized in time with NIST which may require additional effort and procedural changes amongst M&V contractors.

Proxy Variables

There has been much reaction to Requirement #9 in the evaluation community. Whereas Requirement #6 requires ±2% accuracy for a literal measurement device, the language of Requirement #9 ("overall accuracy of the calculated demand") extends the same ±2% accuracy requirement past the measuring device, throughout any calculations, and – seemingly – to the final Demand Reduction Value (DRV) for the "site" or sampling unit of the impact evaluation. Some of these metering equipment compliance issues also may intersect with the acceptable DRV calculation methods specified in Chapter 5 of the M-MVDR.

Most parties recognize that a key intention of M-MVDR §10.2 is to hold all Demand Resources – including Other Demand Resources from energy efficiency – accountable to the same metering standards. Since a) the DRV for energy efficiency ODR is that of the FCM participant's submitted portfolio/program and b) the acceptable precision for said DRV under a statistical sampling framework is defined in M-MVDR §7, then it is logical to presume that the M-MVDR §10.2 accuracy requirement applies to the bottom-line DRV of the sample point.

This is the prevailing interpretation of Requirement #9, and it requires explicit clarification from ISO New England. Likewise, Requirement #7 may also conflict with common impact evaluation methods as expressed in Section 6 of this report. Depending upon final interpretation of these and other requirements, M-MVDR compliance may be prohibitively costly, overly burdensome on customers, and/or impossible to substantiate.

Even if Requirement #9 does not extend fully to the site-specific DRV, some M&V contractors still contend that it imposes much burden on impact evaluation, especially in the following two situations:

Amperage Measurement: Some contractors frequently use a combination of one-time kW readings with time-series amp data to generate a kW time-series. While admittedly inferior to dedicated kW metering given the voltage and power factor assumptions, inexpensive current loggers provide a means to cost-effectively "cover" an entire project.

EMS Data: M&V contractors often leverage trend data available from energy management systems (EMS) to obtain vast amounts of information that are completely impractical to measure under the cost constraints of evaluation budgets. Indeed, such data often contain higher uncertainty given that control sensors are generally much less accurate than the "research-grade" instrumentation. But prohibiting use of such EMS data would be a tremendous loss for evaluation rigor, requiring much added cost to replace the informational value.

Statistical Results with Measurement Uncertainty

Most efficiency programs and evaluation consultants carefully consider *statistical* uncertainty and quantify it with appropriate rigor. But in practice, evaluation engineers do not report the uncertainty of individual results, and statisticians do not explicitly model or account for it. Historically, statisticians have asserted that the effect of measurement error is negligible to these applications.

Dr. Roger L. Wright has examined this issue further. If measurements errors are unbiased and mutually independent across the population of N projects, and a sample is randomly drawn independent of the measurement errors, then the overall relative precision is the square root of the sum of the squares of the sampling relative precision and the relative precision of the measurement errors, or what Cochran terms the "response relative precision."

Ultimately, the aforementioned "negligible" assertion stands: the response, i.e. the kW measurement, relative precision has little effect on the combined relative precision as long as it is somewhat smaller than the sampling relative precision. Thus, even if the response relative precision is ±5% (considerably higher than the ±2% targeted in the M-MVDR), then the overall relative precision is about ±11%, just slightly larger than the sampling relative precision of ±10%.

Measurement error does affect the sample design and the sampling relative precision since it increases the population variability of the measured savings. When the population is heterogeneous, i.e., dominated by a relatively small number of large sites, it becomes important to reduce the measurement error among the large sites. The sampling plan cannot reduce the response relative precision – the only way to reduce this is to reduce the site-specific measurement error, especially in the largest projects.

Despite the presence of measurement error, standard finite-population sampling techniques are fully applicable to the development of the sample design and the analysis, including the use of the finite population correction factor, since the analysis focuses on the estimation of the population mean of the measured savings.

Dr. Wright would be pleased to expand upon this summary in the form of a publication or workshop to the M&V community in New England.

Expanding the Research Scope

NEEP sponsored this research effort to help clarify and address concerns about requirements for measurement equipment specifications expressed in §10.2 of the ISO New England M-MVDR. In the process of performing this work, it became evident that measurement equipment specifications indeed interact with other areas of the M-MVDR such as statistical significance, baselines, and calculation methods.

Of particular concern is Requirement #9 because it restricts the "overall accuracy of the calculated demand." In the discussion of this requirement in Section 6 of this report, the authors contend that literal interpretation of Requirement #9 necessitates full expression of uncertainty for not only measurement but also for sub-sampling and computational methods such as regression.

Clarification of Requirement #9 is needed, for the potential implications are vast if this interpretation stands. At minimum, it will force retirement of the term **accuracy** from the M-MVDR and shift authority to ANSI/NCSL Z540-2-1997 (R2002), *U.S. Guide to the Expression Of Uncertainty in Measurement*. This would expand the relevant research scope to the multi-stage statistical sampling and evaluation of expanded uncertainty.

Appendix A: Normative References

This report concluded that the following publications are particularly relevant to matters of compliance with certain ISO-NE M&V requirements:

ANSI C12.1-2001
IEEE C57.13-1993
IEEE Std 120-1989
IEEE Std 1159-1995
IEEE Std 519-1992

Most ANSI standards, but IEEE publications in particular, contain a References section which states: "This standard shall be used in conjunction with the following publications. When the following publications are superseded by an approved revision, the revision shall apply." These aforementioned standards make normative reference to – and thereby include – the following publications:

ANSI C12.1-2001

ANSI C39.1-1992	*American National Standard Requirements for Electrical Analog Indicating Instruments*
EEI Handbook	*Chapter 13 in the Handbook for Electricity Metering, 9th Edition, Washington, D.C.: Edison Electric Institute, 1992*
IEEE C57.13-1993	*Standard Requirements for Instrument Transformers*
ASQ Z1.9-1993	*Sampling Procedures and Tables for Inspection by Variables for Percent Nonconforming*
ASQ Z1.4-1993	*Sampling Procedures and Tables for Inspection by Attributes*
IEEE Std 4-1994	*IEEE Standard Techniques for High-Voltage Testing*
IEEE Std 100-1996	*IEEE Standard Dictionary of Electrical and Electronics Terms*
ISA S82.01-1994	*Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment, General Requirements*
NEMA 250-1997	*Enclosures for Electrical Equipment (1000 Volts Maximum)*
NFPA 70-1999	*National Electrical Code*
UL 50-1995	*UL Standard for Safety Enclosures for Electrical Equipment, 11th Edition*
ASTM B117-97	*Standard Practice for Operating Salt-Spray (Fog) Testing Apparatus*
IEEE Std 1-1986	*IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation. (Reaffirmed 1992)*
IEEE C37.90.1-1989	*Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems (Reaffirmed 1991)*
IEEE C62.41-1991	*IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits*
IEC 61000 part 4-4	*Electromagnetic Compatibility for Industrial - Process Measurement and Control Equipment, Part 4: Electrical Fast Transient/Burst Requirements*
IEC 60068 part 2-6	*Basic Environmental Testing Procedures, Part 2: Tests, Test Fc and Guidance: Vibration (Sinusoidal)*
IEEE C63.4-1992	*Methods of Measurement of Radio-Noise Emissions From Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz*
CFR 47, Part 15	*Code of Federal Regulations (Telecommunication) CFR 47, Part 15—*

	Radio Frequency Devices, Subparts A—General and B—Unintentional Radiators
IEC 61000 part 4-2	*Electromagnetic Compatibility for Industrial - Process Measurement and Control Equipment, Part 2: Electrostatic Discharge Requirements*
ISTA TP 1A	*Test Procedure 1A, Performance Test for Individual Packaged-Products Weighing 150 lb. (68 kg) or Less, (revision date: July 2000), Vibration and Shock*
IEC 60068 part 2-27	*Basic Environmental Testing Procedures, Part 2: Tests, Test Ea and Guidance: Shock*
ASTM G155 1998	*Standard Practice for Operating Xenon Arc Light Apparatus for Exposure to Non-Metallic Materials*

IEEE C57.13-1993

ANSI C37.06-1987	*Preferred Ratings and Related Required Capabilities for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*
IEEE C37.04-1988	*IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis (ANSI)*
IEEE C37.09-1988	*IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis (ANSI)*
IEEE C57.12.00-1993	*IEEE General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers*
IEEE C57.12.90-1993	*IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers*
IEEE Std 4-1978	*IEEE Standard Techniques for High Voltage Testing (ANSI)*
IEEE Std 21-1976	*General Requirements and Test Procedures for Outdoor Apparatus Bushings*
IEEE Std 100-1992	*The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI)*
NEMA SG 4-1980	*Alternating-Current High-Voltage Circuit Breakers*

IEEE Std 120-1989

N/A

IEEE Std 1159-1995

IEC 1000-2-1 (1990)	*Electromagnetic Compatibility (EMC) - Part 2 Environment. Section 1: Description of the environment - electromagnetic environment for low-frequency conducted disturbances and signaling in public power supply systems*
IEC 50(161)(1990)	*International Electrotechnical Vocabulary - Chapter 161: Electromagnetic Compatibility*
IEEE Std 100-1992	*IEEE Standard Dictionary of Electrical and Electronic Terms (ANSI)*
IEEE Std 1100-1992	*IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (Emerald Book) (ANSI)*

IEEE Std 519-1992

ANSI C34.2-1968 (Withdrawn)	*American National Standard Recommended Practices and Requirements for Semiconductor Power Rectifiers*
IEEE C57.12.00-1987	*IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers (ANSI)*
IEEE C57.110-1986	*IEEE Recommended Practice for Establishing Transformer Capability*

	When Supplying Nonsinusoidal Load Currents (ANSI)
IEEE Std 18-1992	*IEEE Standard for Shunt Power Capacitors*
IEEE Std 59-1962 (Withdrawn)	*IEEE Standard for Semiconductor Rectifier components*
IEEE Std 100-1992	*The New IEEE Standard Dictionary of Electrical and Electronics Terms*
IEEE Std 223-1966 (Withdrawn)	*IEEE Standard Definitions of Terms for Thyristors*
IEEE Std 368-1977 (Withdrawn)	*IEEE Recommended Practice for Measurement of Electrical Noise and Harmonic Filter Performance of High-Voltage Direct-Current systems*
IEEE Std 444-1973	*IEEE Recommended Practices and Requirements for Thyristor Converters and Motor Drives: Part I -Converters for DC Motor Armature Supplies*
IEEE Std 469-1988	*IEEE Recommended Practice for Voice-Frequency Electrical-Noise Tests of Distribution Transformers (ANSI)*

Appendix B: Independent Testing Laboratories

Currently, the Occupational Safety and Health Administration (OSHA) recognizes the following sixteen (16) organizations as Nationally Recognized Testing Laboratories (NRTLs):

Canadian Standards Association (CSA) - also known as CSA International
Communication Certification Laboratory, Inc. (CCL)
Curtis-Straus LLC (CSL)
Electrical Reliability Services, Inc. (ERS) - also known as eti Conformity Services and formerly Electro-Test, Inc. (ETI)
FM Approvals LLC (FM) - formerly Factory Mutual Research Corporation
Intertek Testing Services NA, Inc. (ITSNA) - formerly ETL
MET Laboratories, Inc. (MET)
NSF International (NSF)
National Technical Systems, Inc. (NTS)
SGS U.S. Testing Company, Inc. (SGSUS) - formerly UST-CA
Southwest Research Institute (SWRI)
TUV America, Inc. (TUVAM)
TUV Product Services GmbH (TUVPSG)
TUV Rheinland of North America, Inc. (TUV)
Underwriters Laboratories Inc. (UL)
Wyle Laboratories, Inc. (WL)

The Occupational Safety & Health Administration (OSHA) maintains a list of the organizations currently recognized as NRTLs at http://www.osha.gov/dts/otpca/nrtl/. There is a common misconception that manufacturers are required to use UL for compliance testing against UL safety standards. This is incorrect; any NRTL is a qualified testing organization within its scope of recognition. For a variety of reasons, more manufacturers are turning to "alternative" testing labs such as ETL, CSA, and TUV for certification of electrical instrumentation.

NRTLs				NOT NRTL
UL	ETL	CSA	TUV	CE

Figure 2 – Some Popular Product Markings

Figure 2 displays some popular product markings. The first four marks are the NRTLs found most prominently on U.S. electrical instrumentation: UL, ETL, CSA, and TUV. There are graphical variants for some of these marks depending upon the specific application or jurisdiction of the compliance testing.

The CE mark is not NRTL approved. CE is a mandatory conformity mark for certain product groups to indicate conformity with the essential health and safety requirements set out in European Directives. Unlike the NRTL marks, the CE mark does not indicate the product has passed any third-party compliance testing. Many electrical instruments bear the CE mark in order to be sold in the European market; however, this mark has no bearing whatsoever on compliance with U.S. safety standards.

Nearly 700 test standards are recognized under the NRTL program; however *each* NRTL has its own scope of recognition, i.e. list of specific standards and programs that OSHA has recognized for the NRTL. Table 3 summarizes the recognized testing scope for standards relevant to M&V for the four NRTLs most prominent or widely accepted in U.S. electrical instrumentation.

Standard	Description	UL	ETL	CSA	TUV
ANSI C12.1	*American National Standard for Electric Meters and Code for Electricity Metering*	✓			✓
ANSI/IEEE C37.90	*IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus*	✓	✓		
ANSI/IEEE C57.13	*Standard Requirements for Instrument Transformers*	✓	✓	✓	
ANSI S82.02.01	*Electrical and Electronic Test, Measuring, Control and Related Equipment: General Requirements*		✓	✓	
ANSI S82.02.02	*Electrical Equipment for Measurement, Control, and Laboratory Use*		✓		
UL 61010A-1	*Electrical Equipment For Laboratory Use; Part 1: General Requirements*	✓	✓	✓	✓
UL 61010B-1	*Electrical Measuring and Test Equipment; Part 1: General Requirements*	✓	✓	✓	✓
UL 61010B-2-031	*Electrical Equipment for Measurement, Control, and Laboratory Use; Part 2: Particular Requirements for Hand-Held Probe Assemblies for Electrical Measurement and Test*	✓		✓	

Table 3 – Tested Relevant Product Standards by NRTL[15]

As seen in the table, there is some variation amongst NRTLs with regard to the standards to which they test. Indeed, the UL mark is the most encompassing (remember, the ANSI S82.02 standards have been superseded by UL 61010), but the ETL, CSA, and TUV marks span most relevant safety standards for M&V equipment. With UL marks being the most expensive and difficult to obtain, some equipment manufacturers are turning to the others marks for their products. These marks are useful indicators for M&V contractors in the process of selecting suitably compliant instrumentation.

[15] According to NRTL-specific product standards published on the NRTL website (March 27, 2008).

Appendix C: ELITEpro™ Calibration Statement

DENT
INSTRUMENTS

ELITE*pro*™

Calibration Stability & Traceability Statement
February, 2006

The **ELITE*pro™*** design includes an internal reference voltage source and self-calibration circuitry. The firmware program in the **ELITE*pro™*** instructs the instrument to recalibrate itself twice per day, at 12:00 noon and again at 12:00 midnight. The combination of a robust, inherently stable electrical design and its self-calibration feature make the **ELITE*pro™*** highly resistant to aging and drift phenomena that cause calibration errors. Our experience with this device indicates that the calibration of the **ELITE*pro*** remains within the manufacturer's specifications for a minimum of three years, and in most cases factory recalibration is never required.

The calibration of each **ELITE*pro™*** is traceable to the National Institute of Standards and Technology (NIST) using these reference instruments.

- Hewlett Packard 34401A Multimeter, Serial #s US36014292, US36082468
- Hewlett Packard 6253A Dual Power Supply, Serial # 241A-07086

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[vi] ISO New England, *Operating Procedure No. 18, Metering and Telemetering Criteria*, Revision No. 7, October 1, 2006, p. 12.
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[viii] Institute of Electrical and Electronics Engineers, IEEE Std 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality, p. iii.
[ix] International Organization for Standardization, Guide to the Expression of Uncertainty in Measurement, Geneva, Switzerland, 1993, revised 1995.
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[xiii] National Institute of Standards and Technology, Technical Note 1297, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, 1994, p. 14.
[xiv] National Electrical Manufacturers Association, *ANSI C12.1-2001, American National Standard for Electric Meters and Code for Electricity Metering*, §A.2.1.2 Application of Blondel's theorem, p. 62.
[xv] Institute of Electrical and Electronics Engineers, *IEEE Std 120-1989, IEEE Master Test Guide for Electrical Measurements in Power Circuits*, §8.1.2.2 Nyquist Criterion, p. 87.
[xvi] National Conference of Standards Laboratories, Establishment and Adjustment of Calibration Intervals, Recommended Practice RP-1, January 1996, p. 1.
[xvii] National Conference of Standards Laboratories, Establishment and Adjustment of Calibration Intervals, Recommended Practice RP-1, January 1996, p. 71.
[xviii] Efficiency Valuation Organization, International Performance Measurement and Verification Protocol, Concepts and Options for Determining Energy and Water Savings, Volume I, April 2007, p. 29.