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Effect of DC Load Currents on Solid State Residential Meters

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Technical Update, December 2011

EPRI Project Manager

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ABSTRACT

This report presents results of an extensive laboratory assessment of the impact of DC load currents (including half-wave rectified loads) on the metrological accuracy of residential solid state electricity meters. Sampled surveys were conducted to determine whether products producing DC currents are prevalent in residential premises. In addition, regulations and codes were studied to determine whether such products could naturally appear in the marketplace going forward.

Two each of six brands of socket-style (Form 2S) residential meters were included in the assessment. These meters used different kinds of internal current sensing technology, including current-transformer, Rogowski coil, and Hall cell. The testing included application of both flat DC current and half-wave rectified loads. A range of normal resistive loads were connected in parallel with DC loads during testing to understand the impact that a single DC load may have on a whole home's metering.

This project included follow-up with meter manufacturers and investigation into the ability to detect when DC loads are present and to pass this information to utility head-end systems to inform the utility of the condition. This research may be useful when considering future extensions to standard ANSI meter requirements.

Keywords
Solid-state
Meter
DC saturation
Half-wave rectified
Current sensor

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INTRODUCTION

Issue Description

This report presents the findings and recommendations resulting from an assessment of residential ANSI electricity meters and their ability to meter accurately in the presence of loads that create DC currents. The assessment focuses in particular on half-wave rectified loads and also looks into the possibility of a type of theft circuit that could create a DC offset of normal sinusoidal current consumption.

When commercial/industrial meters in the United States were being converted from electromechanical to solid state designs, there was much industry discussion regarding the current sensors to be used and their ability, or lack thereof, to tolerate DC bias in the measured current signal. Many manufacturers settled on designs that utilize Current Transformers (CTs). These sensors had known limits as to the amount and type of DC bias they could tolerate, and so the designs generally incorporated a DC-bias detection algorithm that detected and flagged abnormal conditions in order to guarantee revenue integrity.

In other parts of the world, similar discussions occurred, but with different decisions resulting. IEC standards were developed that required that meters have a high tolerance for DC bias and many European nations reference these standards. As a result, most meters in these markets use shunt resistors, Rogowski coils or other types of current sensors that are more tolerant or even immune to DC saturation.

About a decade later, residential meter designs in North America were also transitioned from electromechanical to solid state designs. However, only a limited level of industry discussion was given to the DC bias issue with this transition because the issues were considered to be better understood. Entering into this present research, the degree to which present ANSI residential products tolerate DC current bias was not clear, nor whether they could detect when it is present.

Many present-day residential meters include communication devices for Automated Meter Reading (AMR) or Advanced Metering Infrastructure (AMI). In many cases, these communication devices and associated networks are provided by separate companies, not related to the meter manufacturer. As a result, it was also not known whether DC saturation of current sensors can be readily reported to the utility, even if it is detected locally by the meter.

During unrelated testing in 2010, EPRI noted DC bias sensitivities in some types of meters that resulted in under-registration of consumption. At least two methods of creating the problem were identified and have been made the focus of this present research: half-wave rectified loads and true (flat) DC. In the context of this report, these two loads conditions are referred-to collectively as simply “DC loads”, as explained in more detail below. The concern with these observations includes the potential for both intentional and unintentional abuses.

Scope

Utilities are interested in fully understanding the capabilities and limitations of solid state electricity meters. To serve this interest, EPRI is performing ongoing testing and evaluation of these products in the Distribution Research Program, P180. Research in 2010 focused on over voltage conditions and involved exposing meters to a wide variety of voltage and load scenarios. In the course of that work, it was noted that there were energy registration issues when certain loads with DC content were presented. That observation led to discussion with the Program members and the EPRI metering interest group where this present 2011 research project was planned.

This research involved a comprehensive evaluation of ANSI solid-state meters and their characteristics in the presence of DC loads. Specifically, this project performed the following:

- Determine how meters respond when loads are partially half-wave rectified
- Assess the risk that meters will be exposed to such loads based on a sampled survey of product manufacturers
- Determine how meters respond when flat DC current is injected
- Assess the viability of devices that would intentionally inject DC current from the customer side of the meter
- Explore whether any codes or laws prohibit off-the-shelf products from drawing DC current.
- Assess the viability of intentional customer modification of products in order to steal energy
- Assess the ability of meters to detect the presence of saturating DC currents

This project evaluated only residential meters in ANSI form 2S, including the six major manufacturers currently providing such products in North America. Efforts to acquire European meter samples to include in this testing were not successful. The test loads that were used were purely resistive, including one bank directly presented as load and another bank half-wave rectified. This report presents the compiled results of this work.

2
IMPACT OF DC CURRENT ON SOLID STATE RESIDENTIAL METERS

Methods of Current Measurement in Meters

The solid state electricity meters involved in this testing employed one of three types of current measurement technology: current transformer (CT), Hall Effect, or Rogowski coil. Each technology has unique characteristics, advantages, and limitations. The following sections provide a high level overview of each type.

Current Transformers

Like any other transformer, a current transformer (CT) has a primary winding (usually a single turn conductor), a magnetic core, and a secondary winding. The alternating current flowing in the primary produces a time-varying magnetic flux in the core, which then induces a current in the secondary winding circuit. A primary objective of current transformer design is to ensure that the primary and secondary circuits are efficiently coupled, so that the secondary current bears an accurate relationship to the primary current. The primary circuit is largely unaffected by the insertion of the CT. Shapes and sizes vary depending on the application.

In the residential electricity meters involved in this testing, the CT's were toroidal, used a heavy gauge single turn primary, and a large number of secondary turns (see Figure 2-1). All were roughly 2" in outside diameter. The magnetic core materials were not known.

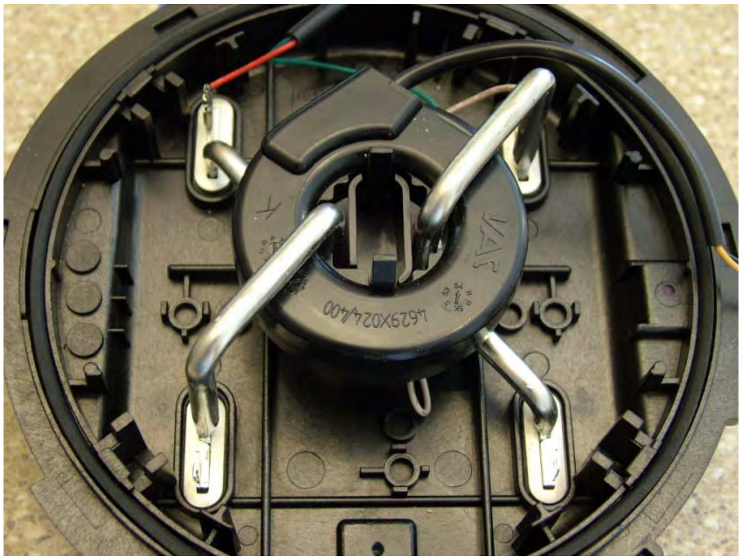

Figure 2-1
Example CT based Electricity Meter

Hall Effect Sensors

A Hall Effect sensor is based on a semiconductor transducer that varies its output in response to the magnetic field incident upon the Hall cell element. Hall sensors have a number of common uses such as proximity switching, positioning, speed detection, and, in the case of electric utility meters, current sensing. Current carried through a primary conductor produces a magnetic field that is focused by a magnetic core onto a Hall cell. Like other current measuring devices, a Hall sensor can be used to measure current without interrupting the circuit.

The tested implementation of a Hall Effect sensor for energy metering was an open-loop type. Although closed-loop Hall sensor designs exist, they are more complex and likely more costly. Hall Effect sensors typically have high frequency response and capability of measuring large currents. Traditional challenges in Hall sensor design include compensating for what is sometimes a large temperature drift and establishing a stable external source.

When the magnetic structures used to focus the current-induced magnetic field on the Hall sensor are air-gapped (i.e. the hall cell is positioned in a gap in the core), this technology can be relatively immune to DC saturation effects.

Rogowski Coils

A Rogowski coil is a secondary wire coil (generally many turns of fine wire) that is positioned such that the magnetic field produced by current in the primary conductor (generally a single heavy conductor) passes through the secondary coil. This is an air-coupled arrangement. The alternating magnetic field produced by the primary current induces a voltage in the coil which is proportional to the rate of change of current.

The direct output from the coil is given by Vout=M dI/dt Where M is the mutual inductance of the coils and dI/dt is the rate of change of current. To complete the transducer, the voltage is integrated (ideally creating a 90 degree phase shift) electronically so that the output from the integrator is a signal that accurately represents the measured current waveform.

In the example of Figure 2-2, the Rogowski secondary coil is built into the multilayer printed circuit board with the conductors carrying the primary current applied above and below by the “O” shaped bars. Note that the direction of the two primary conductors is reversed so that the field effects are additive.

Figure 2-2
Example Rogowski Coil Based Electricity Meter

One of the most important properties of a Rogowski coil measuring system is that it is inherently linear. The coils are air-linked, with no materials that can saturate, and the output increases linearly in proportion to current, up to the operating limit determined by other factors. The integrator is notionally designed to be linear up to the point where the electronics are limited. It is commonly held that their linearity makes Rogowski coils easy to calibrate because a transducer can be calibrated at any convenient current level. Rogowski coils are also generally considered to have wide dynamic range and good transient response.

A limitation is that Rogowski coils must be well shielded, especially at low currents when the primary is at line voltage. Faraday shields are sometimes used for this purpose.

Test Approach and Setup

The specific objective of this testing was to identify whether residential solid state meters exhibit a loss of kWh measurement accuracy when exposed to DC load currents, and to document the levels of the effects. The test plan was developed such that the tests would begin with minimal DC level, to verify the normal operation of the meter, and then increase the DC content in steps up to a reasonable limit. EPRI chose to limit testing to the level that could be created by half-wave rectification of the largest residential loads such as a water heaters, dryers, and HVAC resistive heating elements. While higher levels might result in the discovery of issues in more products, such levels were not considered to be a practical concern in the field.

The testing included two parts: half-wave rectified loads, and flat DC (offset). For measurement convenience, much of the flat DC part of the testing was conducted driving varying levels of flat DC current through one leg of the meter terminals (tying-in on the service side of the meter) while normal resistive non-rectified loads were varied.

The calibration rack and meters used during this testing are maintained and calibrated annually per the manufacturer's instructions. These calibration processes verify the accuracy of the test equipment relative to NIST-traceable standards. Regular calibration helps assure the scientific quality and repeatability of the testing and reporting performed by EPRI.

Meter Types Included in the Evaluation

Table 2-1 lists the six meter manufacturers and meter models that were included in the testing.

Table 2-1
Meter Models Tested

Manufacturer	Model	Serial Numbers	Number Tested
Echelon	ANSI 2S Meter	ELON027830, 8035	2
Elster	REX2	13103593, 4	2
GE	I210	46417375, 6	2
GE	I210+ (added)	50046236	1
Itron	Centron C1S	87083270, 1	2
Landis+Gyr	Focus	107454905, 20	2
Sensus	iCon A	28942681, 2	2

EPRI purchased two form 2S solid-state residential meters of each type. Each meter was generally subjected to four test steps: pre-test calibration check, half wave rectified power test, DC current test, and post-test calibration check. These steps are described in more detail in the following subsections.

Meter Calibration Checks

Initial calibration checks (full-load, light-load, power-factor) were conducted to confirm that the meters under test were in good condition before the tests were run. The post-testing calibration checks were conducted to confirm that the meters were not damaged during testing. Each meter was tested on a UTEC Model 5800 meter calibration system and the results were recorded to confirm the condition of the meter before and after the power tests were conducted. The summary results are presented in Table 2-2. No meter damage or calibration shift was observed, implying that the DC loads presented in the testing did not cause any permanent/lasting error.

Table 2-2
Summary Meter Calibration Results

Manufacturer	Serial Numbers	Pre Test Calibration Check FL/LL	Post Test Calibration Check FL / LL
Echelon ANSI 2S Meter	ELON027830	100.056/100.078	100.140/100.232
Echelon ANSI 2S Meter	ELON028035	100.003/100.057	100.220/100.215
Elster REX2	13103593	100.004/99.989	99.994/99.957
Elster REX2	13103594	99.444/99.981	99.839/99.908
GE I210	46417375	100.013/100.018	99.964/99.979
GE I210	46417376	100.047/100.037	100.010/99.997
GE I210+ (added)	50046236	Not tested	100.012 / 100.005
Itron Centron C1S	87083270	100.084/99.975	100.091/100.005
Itron Centron C1S	87083271	100.03/99.9	100.019/99.91
Landis+Gyr Focus	107454905	100.257/100.25	100.059/100.095
Landis+Gyr Focus	107454920	100.239/100.226	100.02/100.077
Sensus iCon A	28942681	99.941/99.994	100.006/100.005
Sensus iCon A	28942682	100.049/100.014	100.066/100.036

Half Wave Rectified Test Configuration

This test presented the devices-under-test with a combination of pure resistive loads in parallel with half-wave rectified loads. To facilitate this test, the arrangement illustrated in Figure 2-3 was constructed.

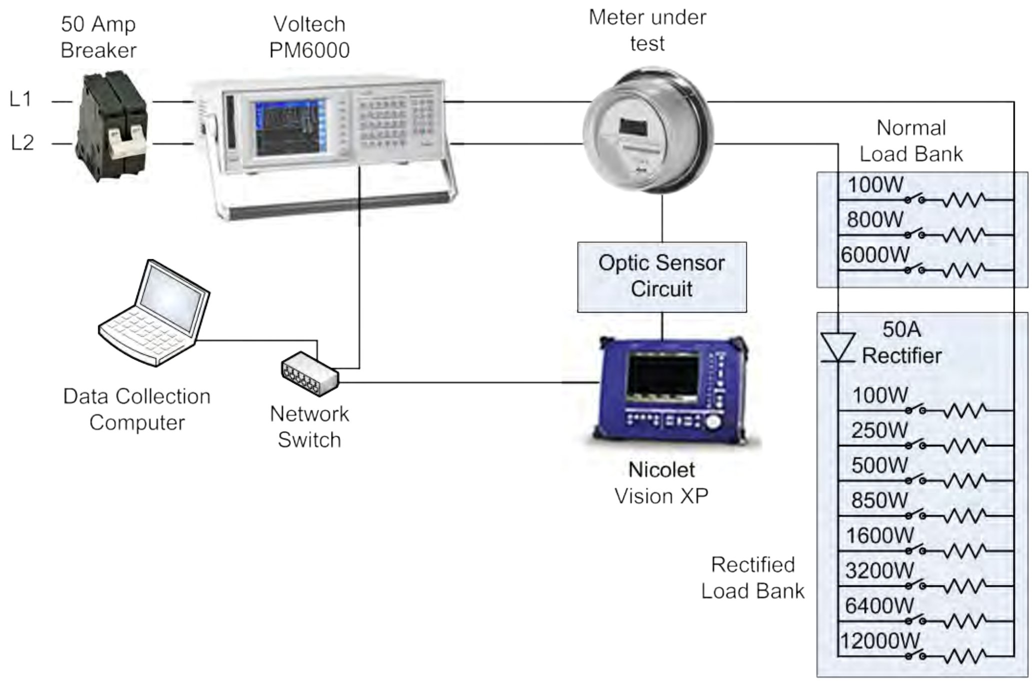

Figure 2-3
Half Wave Rectified Test Arrangement

All loads were pure resistive elements, with a simple diode used in series with some to create the half-wave rectification. The goal of this test was to measure the accuracy of the power measured by the meter when it is exposed to varying levels of both half-wave rectified and non-rectified loads. Non-rectified loads were included in this test in order to determine if any measurement inaccuracies that might exist relate to all loads applied to the meter or just the rectified portion. In other words, if a customer has only one appliance that is half-wave rectified, is the consumption of other appliances in the home measured accurately while the rectified product is operating?

The test configuration allowed a 240VAC source to drive multiple load combinations ranging from 100 to 12000 [Watts] non-rectified and 50 to 6000 [Watts] rectified. As illustrated in Figure 2-3 and depicted in Figure 2-4, the rectified portion was accomplished by mounting a switch bank on a load bank to control the number and size of the loads connected.

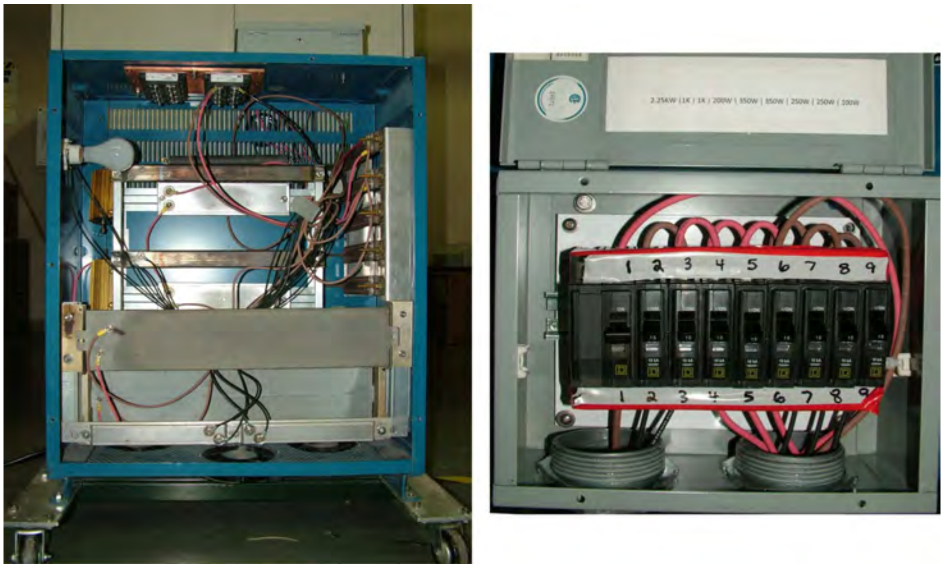

Figure 2-4
Rectified Load Box and Load Select Panel

The separate, non-rectified load bank, depicted in Figure 2-5, was connected in parallel with the rectified load.

Figure 2-5
Non-Rectified Load Box

The power levels used in the testing are listed in the first two columns of Table 2-3. A total of 24 data points were taken for each meter tested. The percent registration is defined as the (meter power reading / actual power) * 100. The third column of Table 2-3 identifies the types of quantities that were recorded at each test point. The results are presented in graphical form in the next chapter of this report.

Table 2-3
Half Wave Rectified Meter Test Points

Non-Rectified Load	Half Wave Rectified Load	Results Recorded
100/800/6000 Watts	50 Watts	% Registration, Amperes, Voltage
100/800/6000 Watts	125 Watts	% Registration, Amperes, Voltage
100/800/6000 Watts	250 Watts	% Registration, Amperes, Voltage
100/800/6000 Watts	425 Watts	% Registration, Amperes, Voltage
100/800/6000 Watts	800 Watts	% Registration, Amperes, Voltage
100/800/6000 Watts	1600 Watts	% Registration, Amperes, Voltage
100/800/6000 Watts	3200 Watts	% Registration, Amperes, Voltage
100/800/6000 Watts	6000 Watts	% Registration, Amperes, Voltage

Flat DC Test Configuration, Simplified Method

As illustrated in Figure 2-6, this test used an arrangement similar to the previous test. The difference is that the half-wave rectified load bank was eliminated, and a DC current source was added.

The actual concern with flat DC injection was that it could be created by a circuit contained inside the customer’s home as evaluated in the next section. However, that method proved to be limited to lower current levels with the available equipment. For this reason, this “Simplified Method” was set-up to enable the assessment of higher levels of flat DC. A variable DC current source (built from DC batteries and a variable resistor) was connected directly across one leg of the meter, connecting from the load side to the line side. It is acknowledged that scenarios that connect to the line side are not an issue or concern in this context, because if such access were gained, one could simply steal electricity directly.

The DC current was increased in 12 Amp steps, and the meter was driving normal non-rectified loads rated at 100, 800, and 6000 Watts. The types of quantities recorded were the same as those from the previous test: % Registration, Amperes, and Voltage.

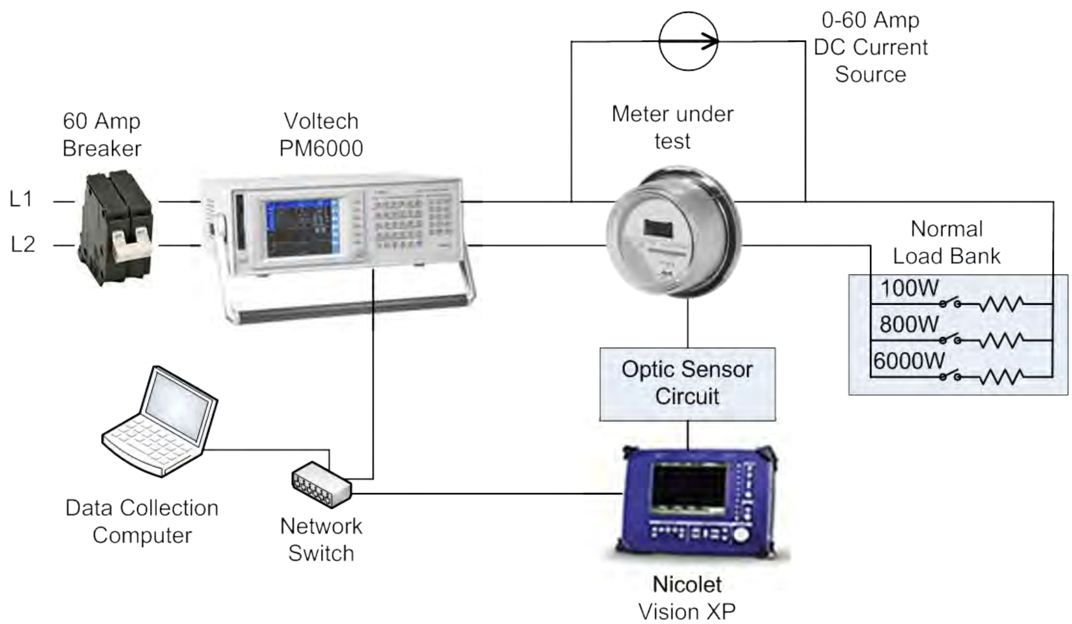

Figure 2-6
Flat DC Test Arrangement, Simplified Method

Residential Side Flat DC Current Injection

This test was conducted on a limited scale as an extension of the previous DC test. The purpose of this test was to validate the simplified method of DC current testing by evaluating the meters in the actual configuration that could exist in field installations. Limitations of the DC injection circuit used for this purpose limited the range of current that could be tested to 16A max.

This test was designed to inject DC current through the meter using the utility transformer as a return path so no connection to the utility side of the meter was required. An isolation transformer was used for this testing so no DC current was actually applied to the utility transformer. The current was injected at levels from 2 to 16Amperes in 2A steps across L1 and L2 on the residence side of the meter. For each DC current level, the load was varied in seven steps between 850 to 6000 Watts. The results recorded were % Registration, DC Amperes and Voltage. This test was performed using the test setup shown in Figure 2-7.

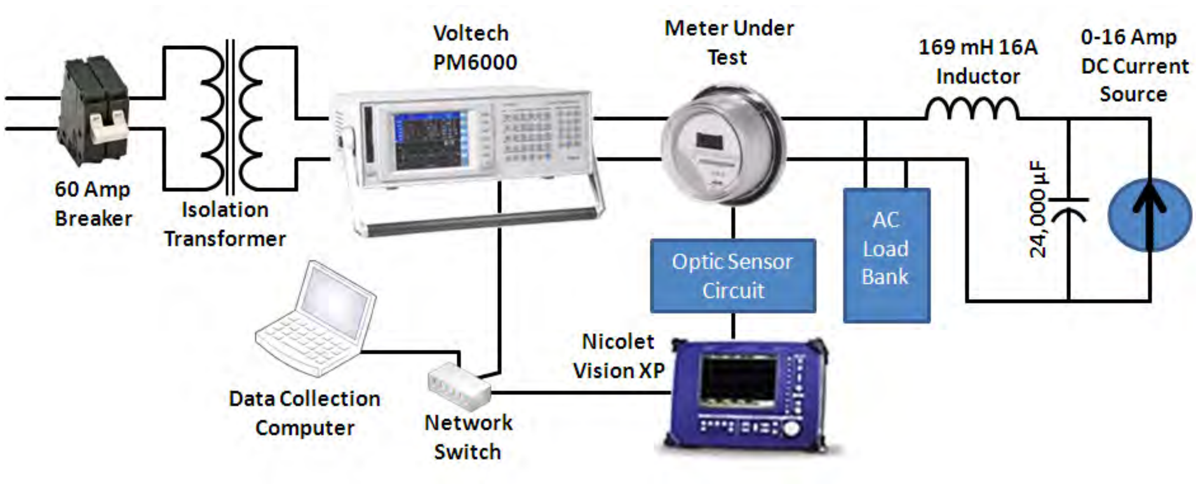

Figure 2-7
Simplified Residential Side DC Injection Schematic

General Test Equipment

Meter Base and Current Shunts

A form 2S meter base was mounted to a plate along with two current shunts, one for separately measuring the AC current entering the meter and the other used for measuring the DC current entering the system from the DC current source. Both shunts fed the Voltech PM6000. The DC current shunt was only used for the two Flat DC injection tests. The optic sensor circuit is just visible at the top of the picture, taped to the top of the meter. It was used to pick up the meter pulses and provide them to the Nicolet Vision XP used to capture the DUT meter power measurement.

The AC current shunt was rated at 50mV at 75 Amps and the DC shunt was rated 50mV at 100 Amps.

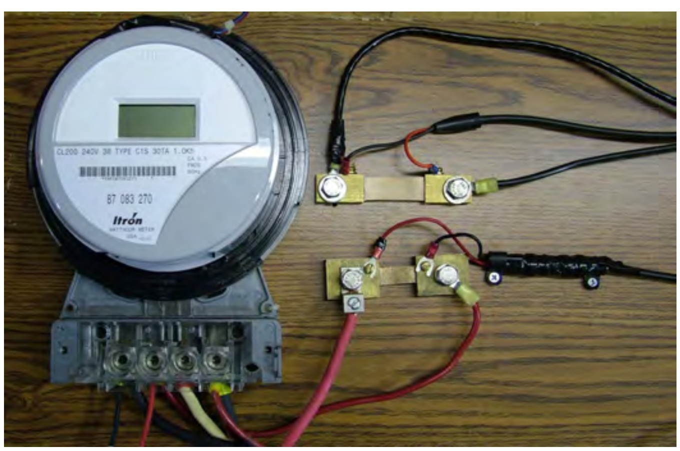

Figure 2-8
Meter Base and Current Shunts (Shown Uncovered)

Voltech PM6000

A Voltech PM6000 was used to record the reading for the power flowing through the meter. It was also used to record the DC current injected during the Flat DC Injection test.

Figure 2-9
PM6000 Universal Power Analyzer

Nicolet Vision XP

A Nicolet Vision XP was used to record the pulses returned from the utility meter under test. The time between pulses were measured during the same time that the power data was being recorded using the PM6000. The PM6000 data was averaged and recorded along with the average time between pulses for the same sample time.

Figure 2-10
Nicolet Vision XP

Test Results

The results provided in this section are organized by meter brand. The results from the half wave rectified testing are presented first, followed by the results from the flat DC current testing.

The surface plots provided below summarize the test results for each meter tested. Pulses received from the metrological LED of the meter were used to calculate meter power. The Z axis shows percent registration, determined by comparing the DUT power reading to the actual power reading from the Voltech PM6000. The Y axis is the non-rectified load (normal load) in Watts, and the X axis is the rectified load in Watts. While data presented in these plots uses approximated values for the rectified and normal loads, the exact values were measured with the Voltech PM6000.

Two meters of each type were tested to provide insight into the variation that might exist from one sample to another. As can be seen in the surface plots in this section, no significant variations were found. It should be noted that all the samples were purchased together, so variability that might have existed across multiple production lots was not captured.

Grid lines are shown for the different non-rectified loads tested, 100, 800 and 6000 Watts as well as the normal load at 100, 250, 500, 850, 1600, 3200, 6000, and 12,000 Watts.

Half-Wave Rectified Load Test Results

Summary

The detailed test results are presented in the following sections. Table 2-4 summarizes these results.

Table 2-4
Summary of Half-Wave Rectified Test Results

		Half-Wave Load Registration	**Other Coincident Load Registration**	**Comments**
Electromechanical	Baseline	No Issues Noted	No Issues Noted	Characteristic under-registration at light loads observed.
ECHELON	ANSI	No Issues Noted	No Issues Noted	CT based meter, physically large CT.
elster	REX2	Under Registration	No Issues Noted	CT based meter. REX1 was not tested.
GE Energy	I210	No Issues Noted	No Issues Noted	CT based meter.
	I210+	Under Registration	No Issues Noted	Dual CT based meter. I210+c was not tested.
Itron	Centron	No Issues Noted	No Issues Noted	Hall Cell based meter. Centron OpenWay not tested.
Landis+Gyr	Focus	Under Registration	No Issues Noted	CT based meter. FocusAX was not tested.
SENSUS METERING SYSTEMS	iCon A	No Issues Noted	No Issues Noted	Rogowski coil-based meter.

Electromechanical (Baseline)

As a point of reference, one electromechanical meter was also tested to determine its response. A standard Landis+Gyr Type MS meter was used for this purpose. As indicated in Figure 2-11, this meter performed well at high levels of normal and half-wave rectified load. The known reduction in registration of electromechanical meters at low load levels stands out when this data is considered relative to that of the solid-state meters included in this evaluation.

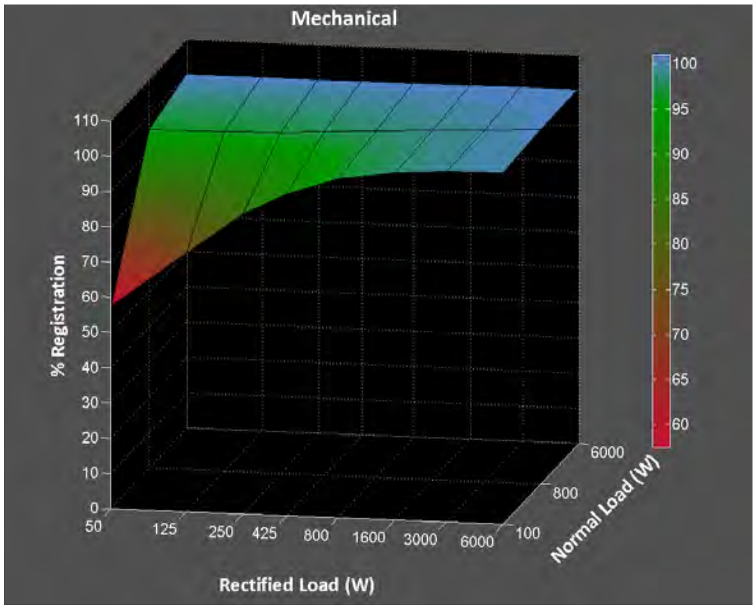

Figure 2-11
Electromechanical Baseline

Itron CIS Centron

The Itron Centron meter uses a Hall Effect sensor to read current. Half-wave rectified loads had no appreciable effect on the meter accuracy. Figure 2-12 and Figure 2-13 show the flat response surface with no visible error from the loading.

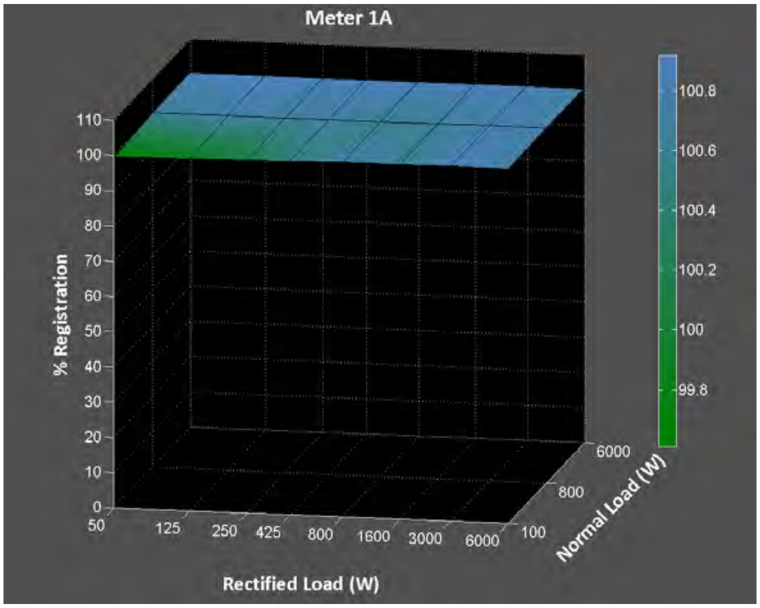

Figure 2-12
Itron Centron C1S Rectified Load Test

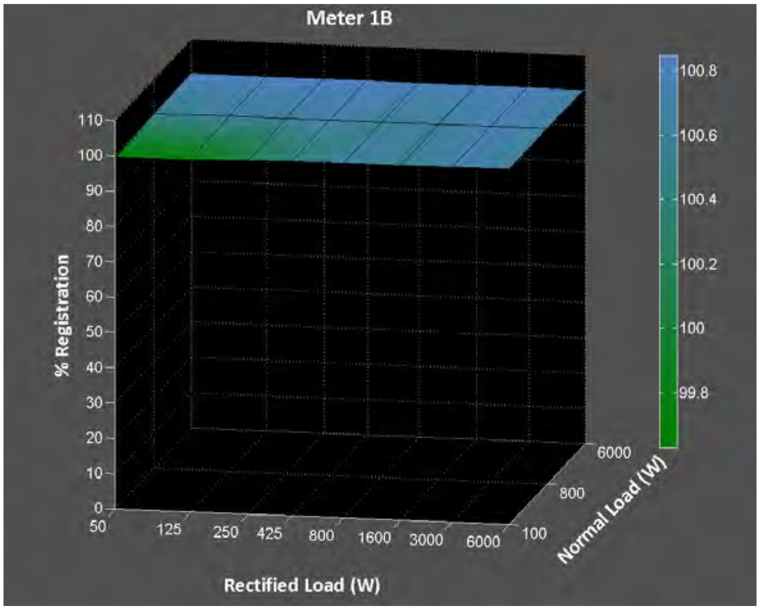

Figure 2-13
Itron Centron C1S Rectified Load Test

GE I210

The GE I210 meter uses a CT to measure current. As indicated by the test data in Figure 2-14 and Figure 2-15, both meters performed relatively well in the half-wave rectified test. In both cases, a slight increase in registration (about 1%) is observed as half-wave rectified levels reach 6000 Watts.

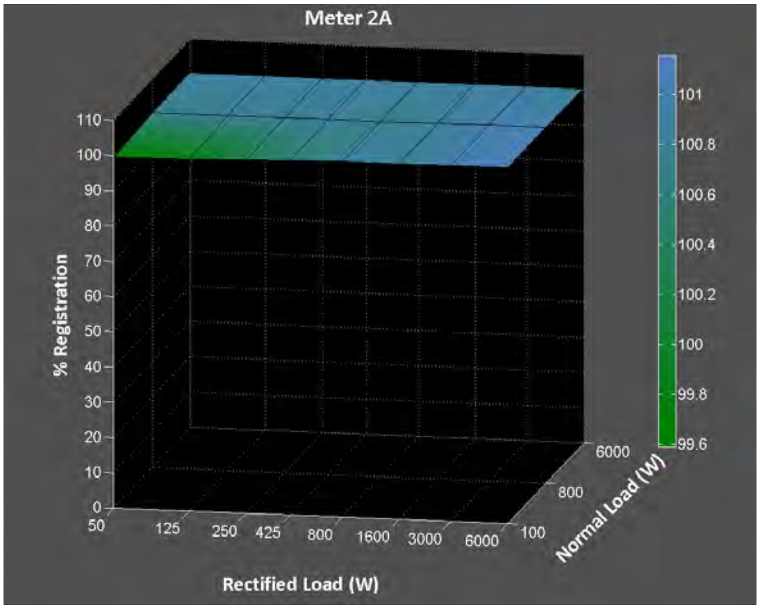

Figure 2-14
GE I210 Rectified Load Test

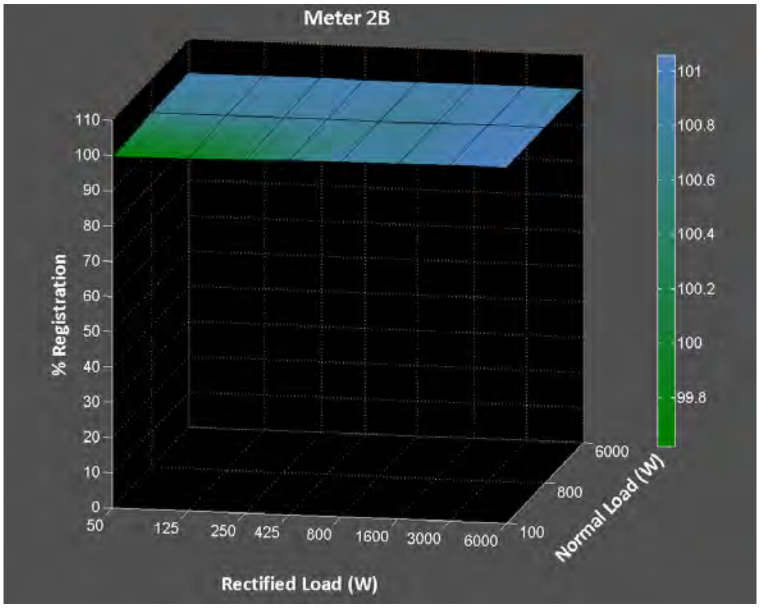

Figure 2-15
GE I210 Rectified Load Test

GE I210+

Late in this study, it was noted that the I210+ version of residential meter from General Electric used a current transformer type and arrangement different than the I210, so a unit was acquired and tested. As indicated in the photos of Figure 2-16, the previously tested I210 used a single large CT with both phase conductors passing through the core, while the I210+ used two smaller CTs, one on each phase.

Figure 2-16
Different CT Arrangements in GE Meters (I210 Left, I210+ Right)

The I210+ meter experienced registration inaccuracies when presented with the half-wave rectified test loads. As seen in the top view of Figure 2-17 the tested meter had a drop in % registration above the 425 Watt rectified load test point. The bottom view in Figure 2-17 shows the same data, but expressed in terms of Watt error rather than % registration. In this view, as it curves in only one direction, it is evident that the error in the reading is only related to the level of half-wave rectified load. In other words, the non-rectified portion of the load was metered correctly. More comments on this are provided in the next section.

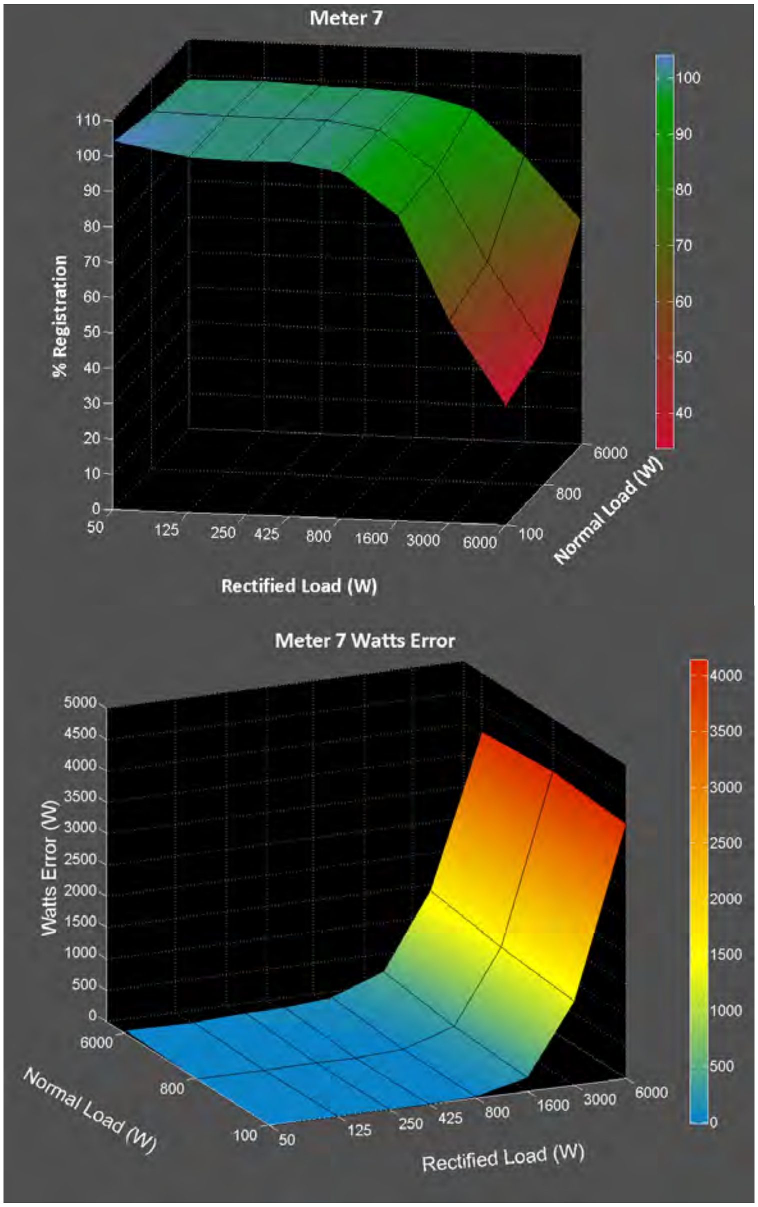

Figure 2-17
GE I210+, Rectified Load Test

Landis+Gyr Focus

The Landis+Gyr Focus meter experienced registration inaccuracies when presented with the half-wave rectified test loads. As seen in the top views of Figure 2-18 and Figure 2-19, both the meters that were tested reacted in a similar fashion having a drop in % registration above the 425 Watt rectified load test point. This meter uses a CT to measure current.

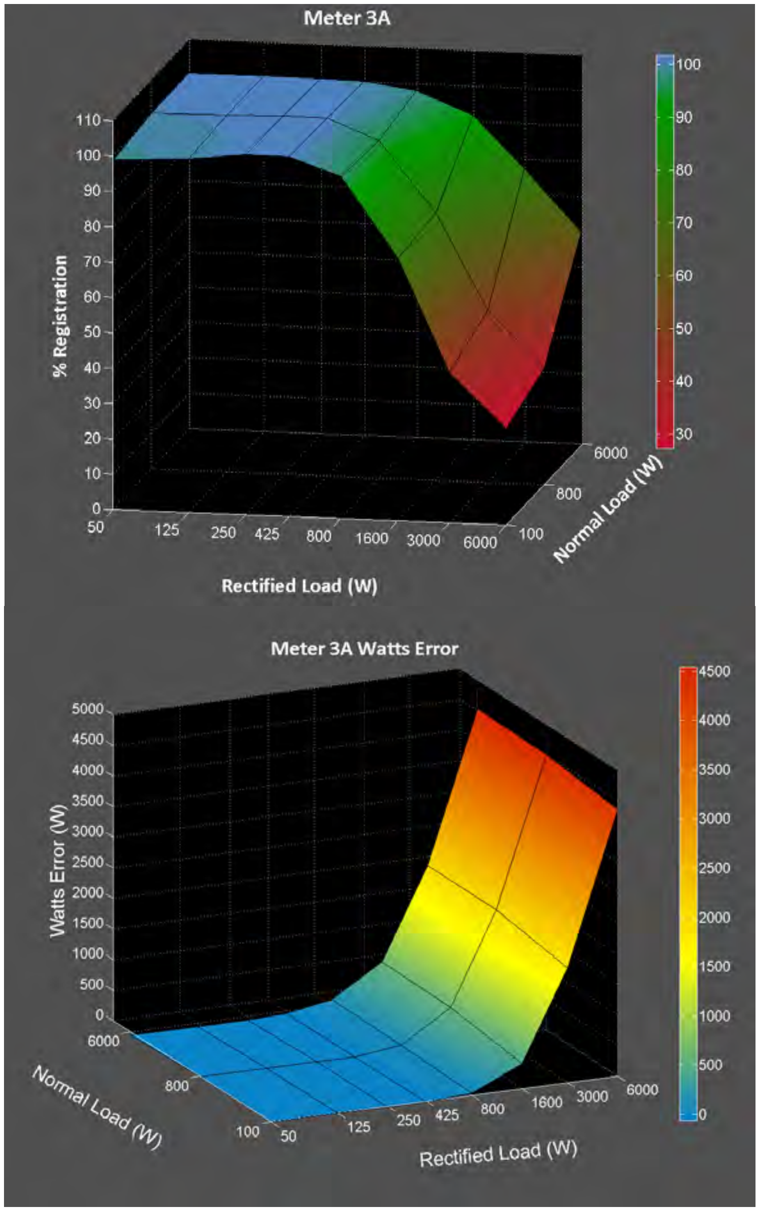

Figure 2-18
Landis+Gyr Focus, Rectified Load Test

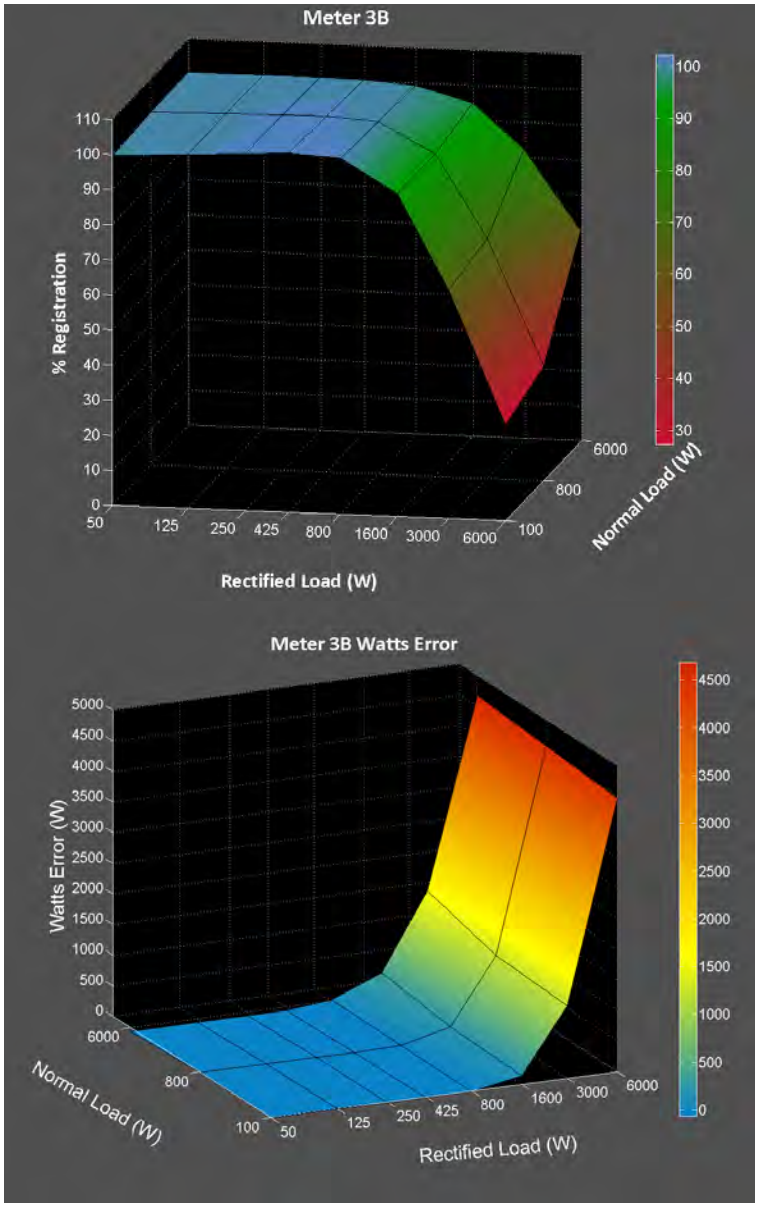

Figure 2-19
Landis+Gyr Focus, Rectified Load Test

Looking only at the percent registration surfaces at the top of each figure, it is not readily discernable whether the under-registration relates only to the half-wave rectified portion of the load, the non-rectified portion, or both. The bottom view in each figure presents the same data, but represented in terms of a pure Watt difference rather than a percentage of total load.

These views, tending to bend in only one direction, indicate that the error is changing only as the rectified load changes. In other words, as the normal load is increased from 100 to 800 to 6000 Watts, there is no additional loss of registration. This observation would seem to imply that if a single appliance in a residential home were half-wave rectified, it could be metered improperly, but other normal AC loads in the home that may be operating at the same time would be measured accurately.

This was a surprising observation. It was thought that if a single half-wave rectified load pushes the meter's CT into saturation, then all loads would be under-registered during that half cycle. Apparently, the symmetrical AC swing of the added loads has a self-compensating effect. This may or may not be the case with actual loads with non-unity power factors, and so further investigation is recommended.

Sensus iCon

The Sensus iCon A meter uses a Rogowski coil sensor to read current. Half-wave rectified loads had no appreciable effect on the meter accuracy. Figure 2-20 and Figure 2-21 show a flat response surface with no significant error from the loading.

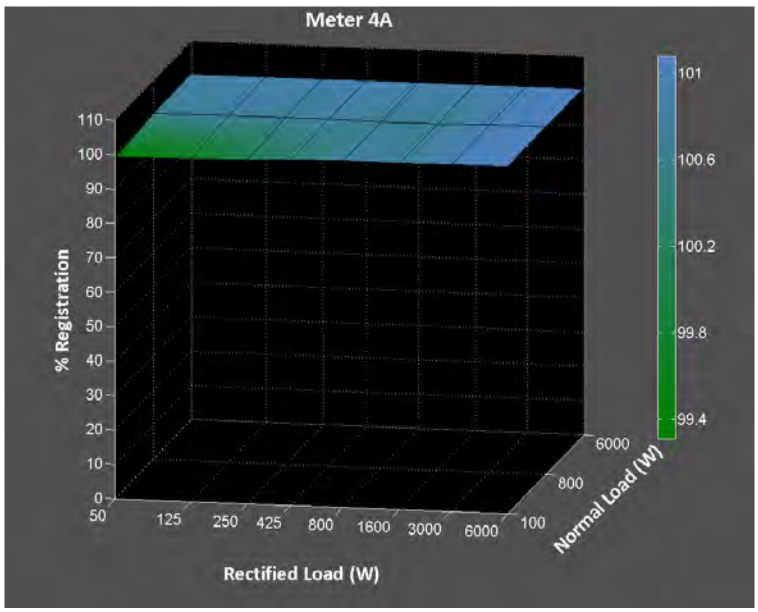

Figure 2-20
Sensus iCon A, Rectified Load Test

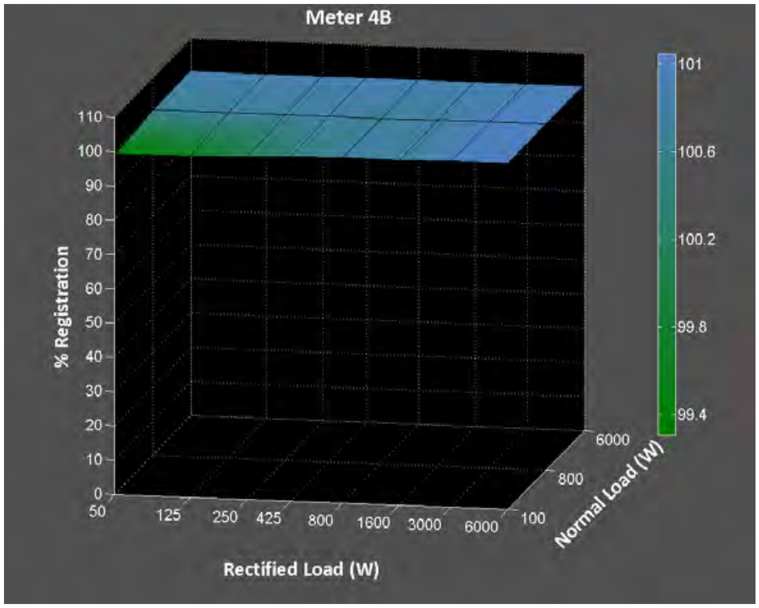

Figure 2-21
Sensus iCon A, Rectified Load Test

Echelon

The Echelon ANSI 2S meter uses dual CTs to read the current passing through the meter, cutting in half the current that each sensor must carry. As indicated by the test data in Figure 2-22 and Figure 2-23, both meters performed well in the half-wave rectified test. In both cases, a slight increase in registration (about 1%) was observed as half-wave rectified levels reach 6000 Watts.

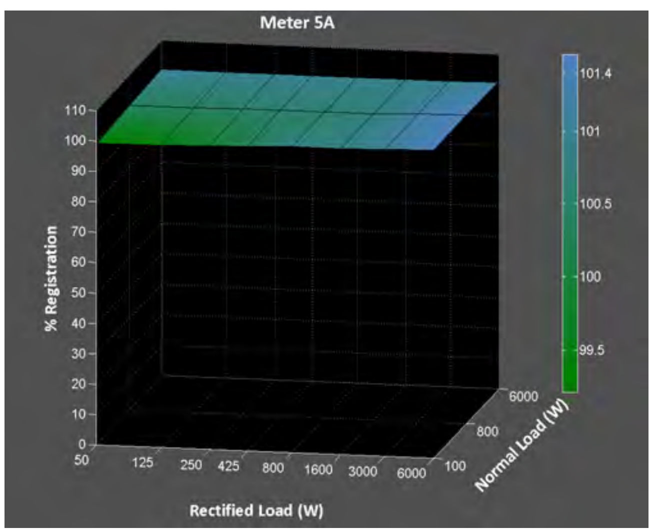

Figure 2-22
Echelon ANSI 2S, Rectified Load Test

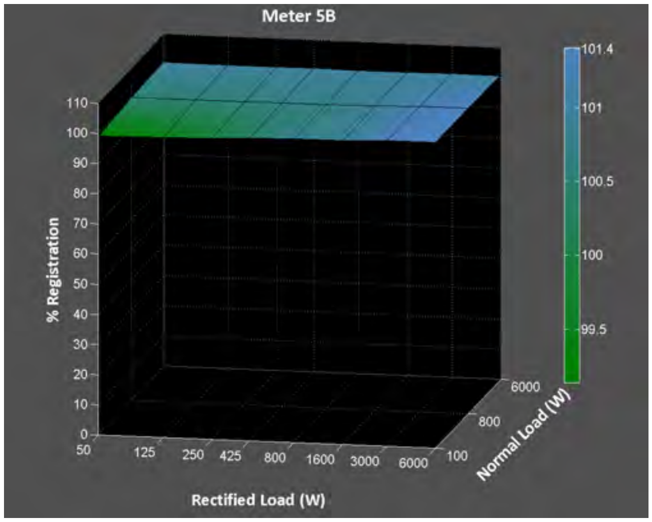

Figure 2-23
Echelon ANSI 2S, Rectified Load Test

Elster Rex2

The Elster REX2 meter experienced registration inaccuracies when presented with the half-wave rectified test loads. As seen in the top views of Figure 2-24 and Figure 2-25, both the meters that were tested reacted in a similar fashion; experiencing a drop in % registration above the 425 Watt rectified load test point. This meter uses a CT to measure current.

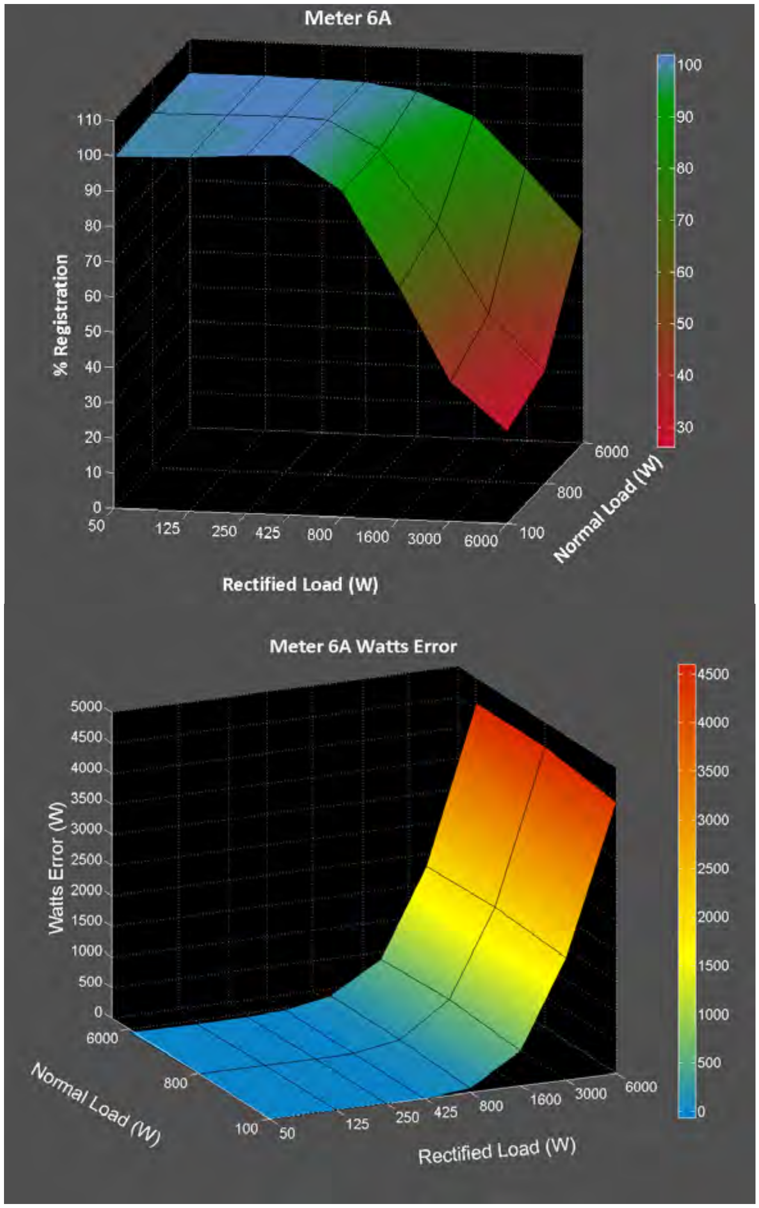

Figure 2-24
Elster REX2, Rectified Load Test

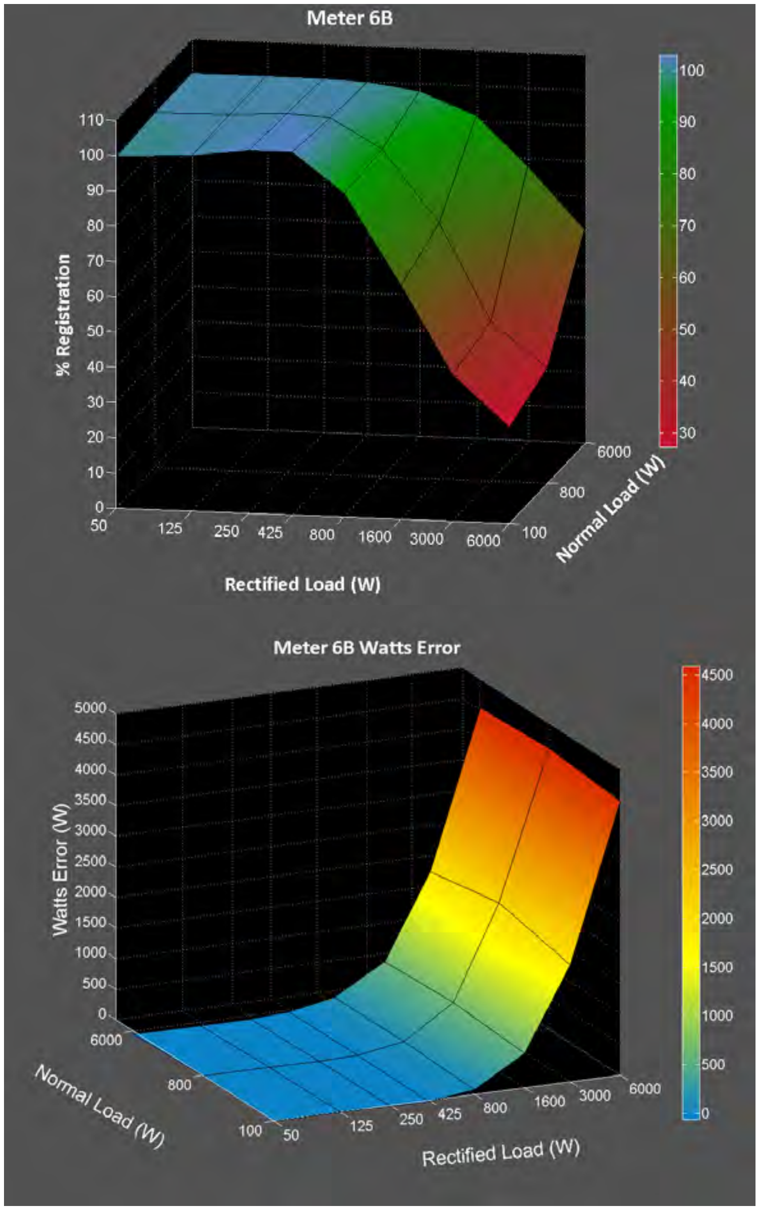

Figure 2-25
Elster REX2, Rectified Load Test

As with the similar results discussed previously, it is not readily discernable from the top surfaces in each figure whether the loss in registration is limited to the rectified portion. The surfaces shown at the bottom of each figure clarify the situation by expressing the error in terms of Watts. As was true in the case of the Landis+Gyr meter, it is evident that the error here is driven only by the rectified load. See further comments in the section above.

Flat DC Current Test Results

The test results presented in this section were measured according to the test description and arrangement described in the section entitled "Flat DC Test Configuration, Simplified Method" earlier in this Chapter. In this test, a flat DC current was injected through one leg of the meter as shown in Figure 2-26.

As indicated in these results, the same meter types that were affected by the half-wave rectified loads were also affected by flat DC current. Unlike the previous test where only the half-wave rectified portion of the load was found to be improperly metered, injection of flat DC current affected the accuracy of the meter for normal resistive loads.

Although the simplified method used for this test involved connecting one leg of the DC source to the utility side of the meter, matching results were obtained by generating DC current from the customer side, as described later in this report.

Summary

The detailed test results are presented in the following sections. Table 2-5 summarizes these results.

Table 2-5
Summary of Flat DC Test Results

		Coincident Load Registration in Presence of Flat DC	**Comments**
ECHELON	ANSI	No Significant Issues Noted	CT based meter, physically large CT.
elster	REX2	Under Registration	CT Based meter. REX1 was not tested.
GE Energy	I210	Over Registration	CT based meter. Over registration noted at light load and high flat DC current.
	I210+	Under Registration	Dual CT based meter. I210+c was not tested.
Itron	Centron	No Significant Issues Noted	Hall Cell based meter. Centron OpenWay not tested.
Landis+Gyr	Focus	Under Registration	CT Based meter. FocusAX was not tested.
SENSUS METERING SYSTEMS	iCon A	No Significant Issues Noted	Rogowski coil based meter.

Itron CIS Centron

The Itron Centron meter uses a Hall Effect sensor to read the current passing through the meter. Figure 2-26 and Figure 2-27 indicate the test results - a flat response surface with no significant error from the DC current.

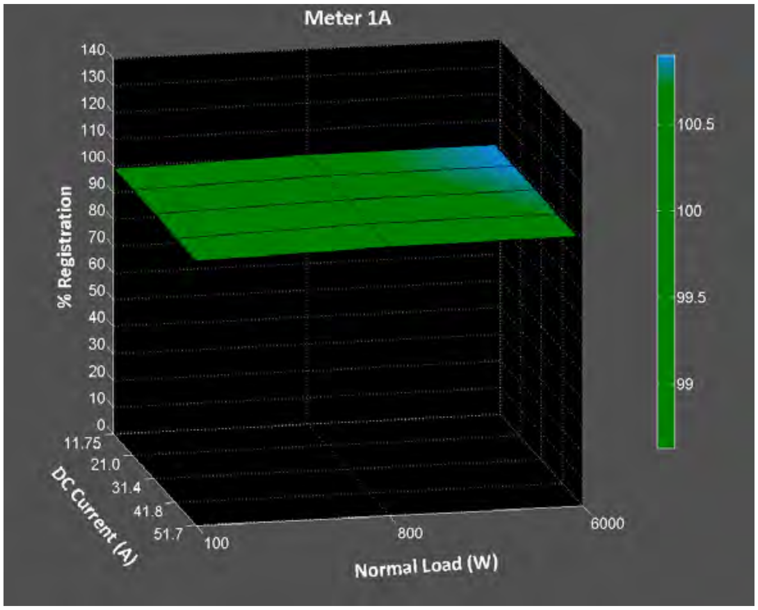

Figure 2-26
Itron Centron C1S, DC Current Test

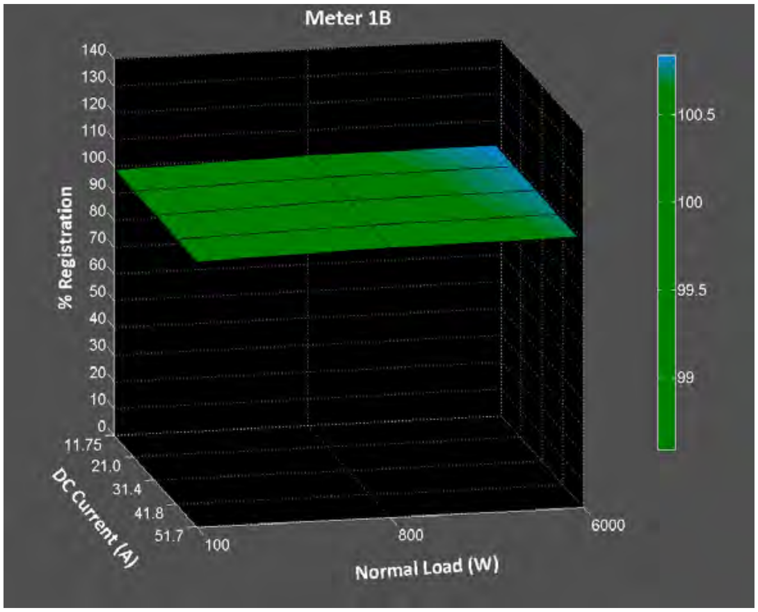

Figure 2-27
Itron Centron C1S, DC Current Test

GE I210

The GE I210 uses a CT to read the current passing through the meter. Figure 2-28 and Figure 2-29 indicate the test results – a surface that is generally flat across most of the test points. It is noted that at the lightest load (100W) and highest DC current level (50A), there was a sharp over-registration.

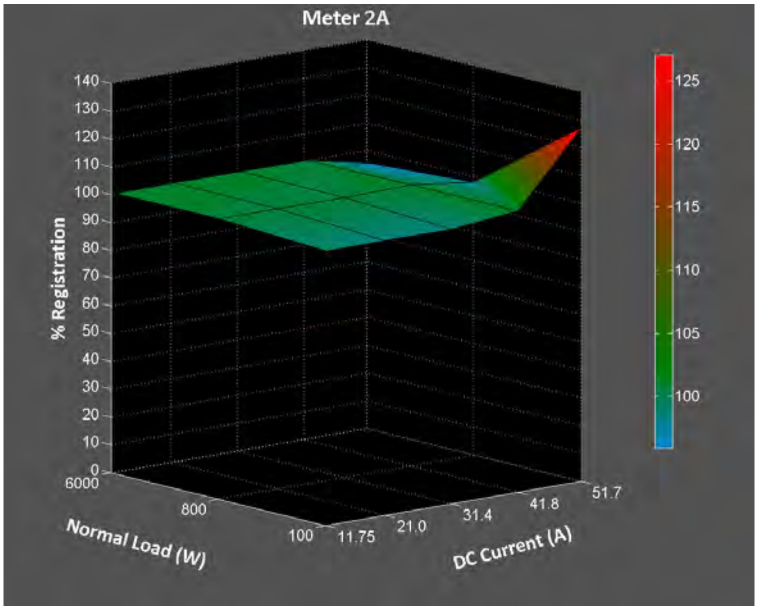

Figure 2-28
GE I210, DC Current Test

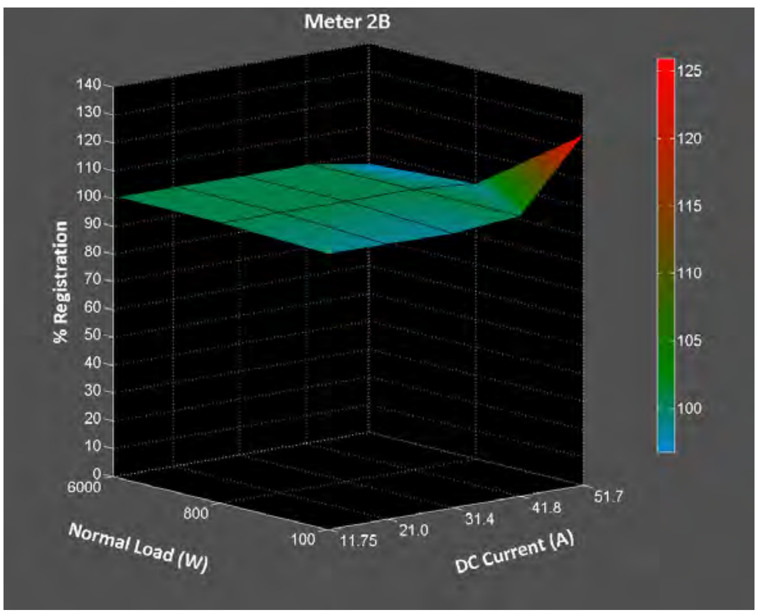

Figure 2-29
GE I210, DC Current Test

As indicated previously, a GE I210+ was added to this test after it was recognized that the current sensing technology was different than that of the regular I210. The GE I210+ experienced metrological inaccuracy when presented with injected flat DC current. As indicated in Figure 2-30, the meter reported approximately 80% registration at the starting DC current level used in this test and dropped further in % registration at higher DC currents. It is noted that because this test was conducted using the simplified method (driving DC current through only one leg of the meter) and this meter had separate CTs on each side, the % registration did not drop below 50%.

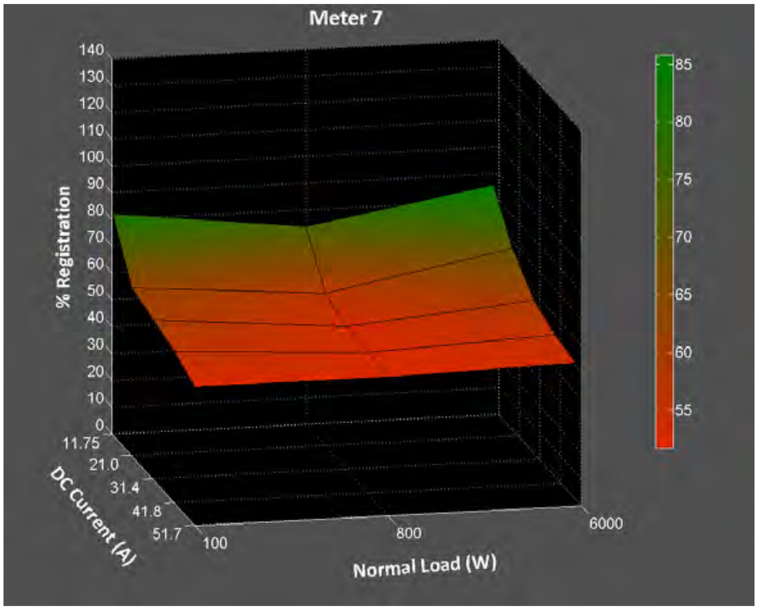

Figure 2-30
GE I210+, DC Current Test

Landis+Gyr Focus CL200

The Landis+Gyr meter experienced metrological inaccuracy when presented with injected flat DC current. As indicated in Figure 2-31 and Figure 2-32, both tested meters reacted in a similar fashion, reporting approximately 40% over registration at low DC current and low load conditions and dropping in % registration at high DC currents.

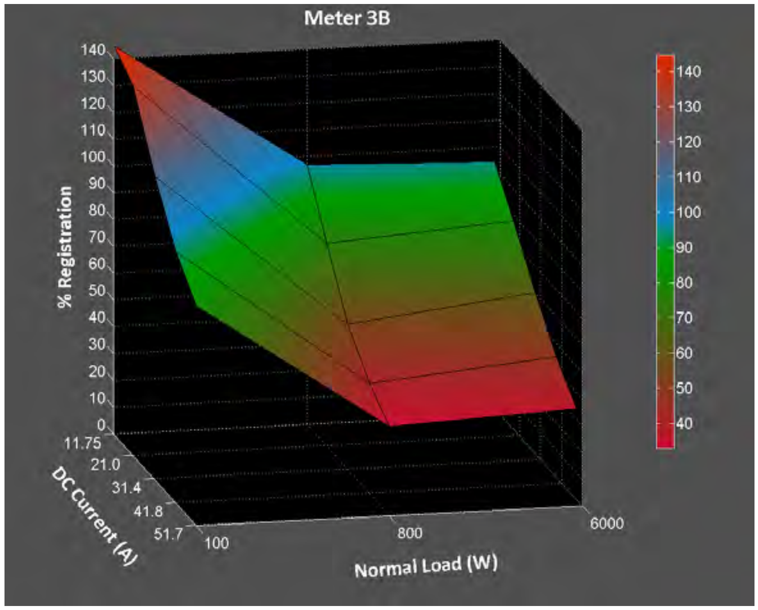

Figure 2-31
Landis+Gyr Focus, DC Current Test

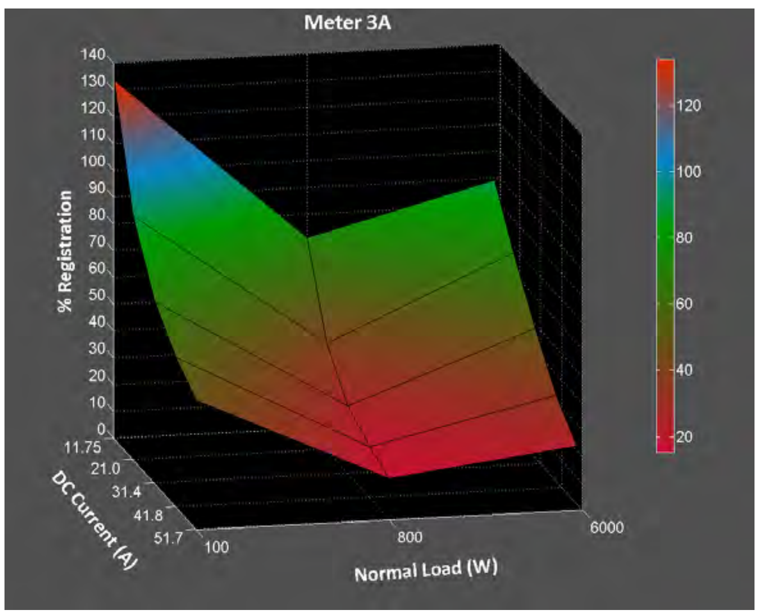

Figure 2-32
Landis+Gyr Focus, DC Current Test

Sensus

The Sensus iCon A meter uses a Rogowski coil sensor to measure current. Figure 2-33 and Figure 2-34 indicate the test results - a flat response surface with no significant error from the injected DC current.

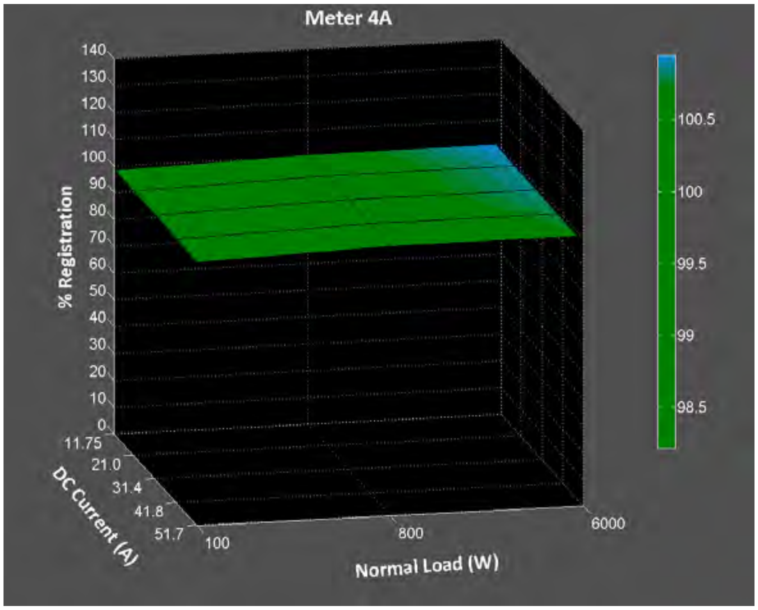

Figure 2-33
Sensus iCon A, DC Current Test

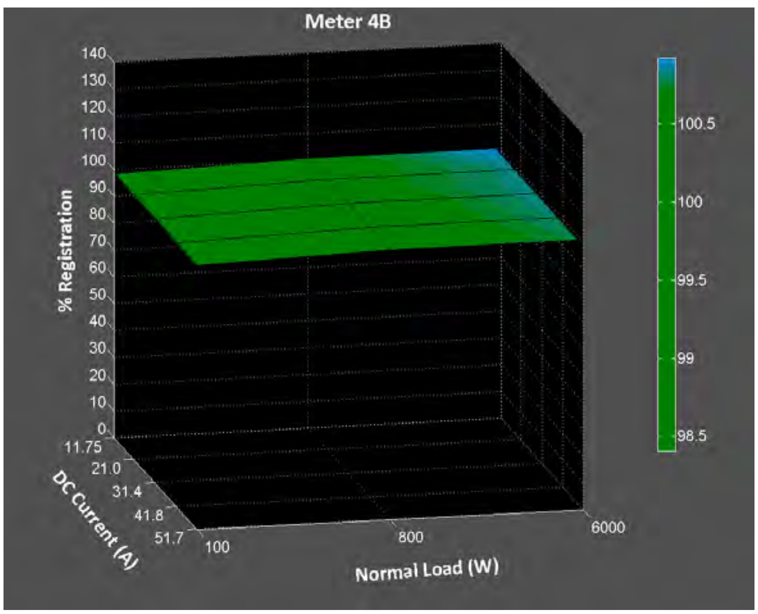

Figure 2-34
Sensus iCon A, DC Current Test

Echelon 83021-2IAA

The Echelon ANSI 2S meter uses dual CTs to read the current passing through the meter. Figure 2-35 and Figure 2-36 indicate the test results – a flat response surface with no significant error from the injected DC current.

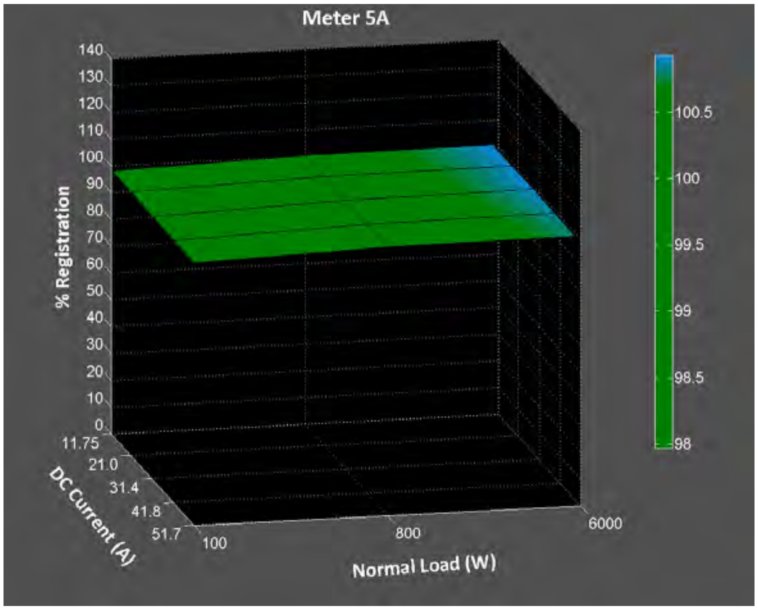

Figure 2-35
Echelon ANSI 2S, DC Current Test

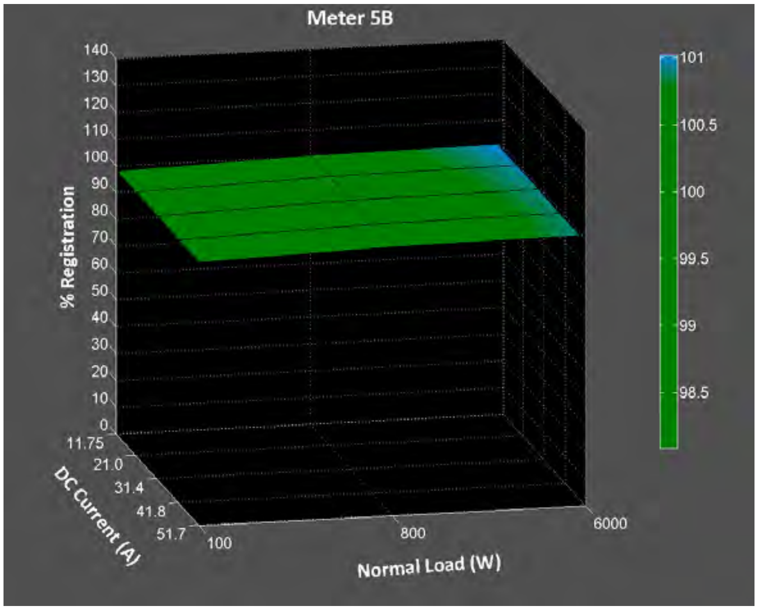

Figure 2-36
Echelon ANSI 2S, DC Current Test

Elster REX2

The Elster REX2 meter experienced metrological inaccuracy when presented with injected flat DC current. As indicated in Figure 2-37 and Figure 2-38, both meters reacted in a similar fashion, dropping in % registration as the DC current increased.

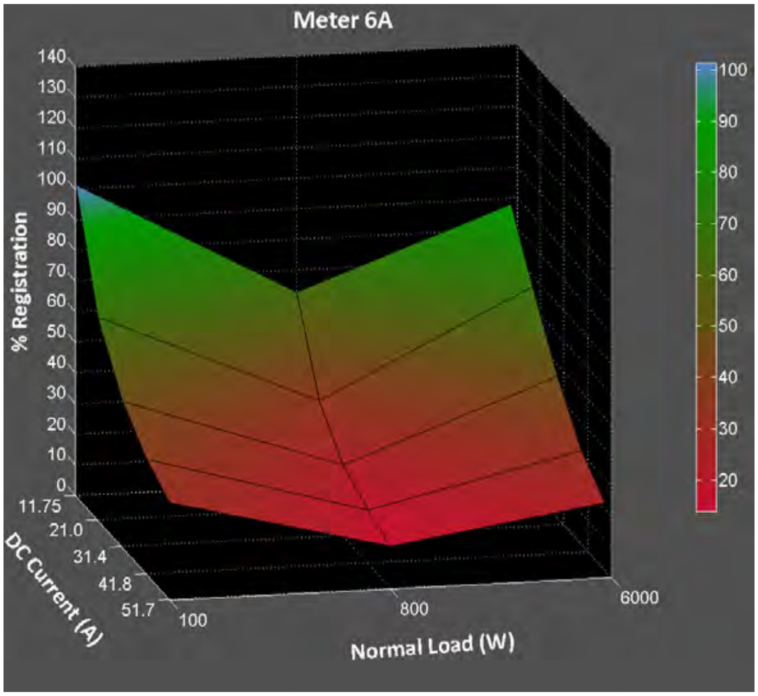

Figure 2-37
Elster REX2, DC Current Test

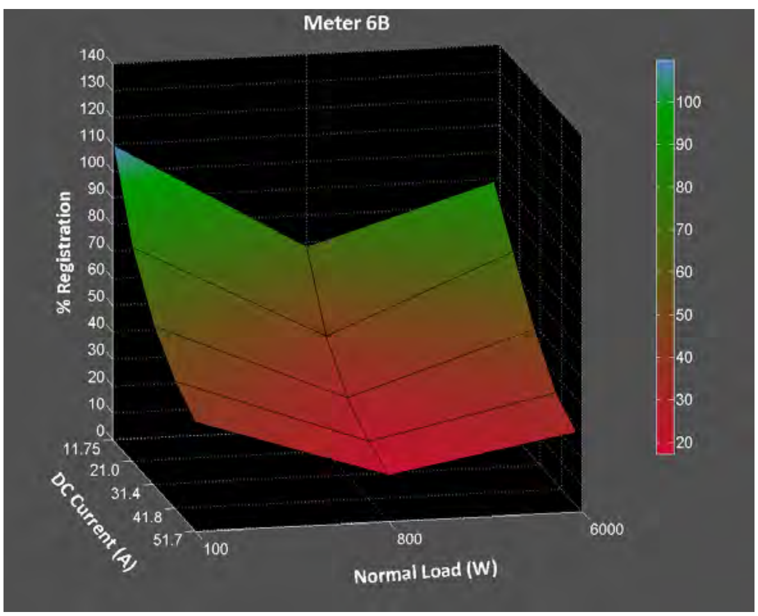

Figure 2-38
Elster REX2, DC Current Test

Flat DC Current Test Results, Secondary Injection

The test results presented in this section were measured according to the test description and arrangement described in the section entitled “Residential Side Flat DC Current Injection” earlier in this Chapter. In this test, a flat DC current was injected from the customer side of the meter as shown in Figure 2-7.

This circuit and test set-up was used on one of the meters previously seen to have loss of registration in the presence of Flat DC current. As indicated in Figure 2-39, this test was run in 2A steps from 2A up to the setup limit of 16A.

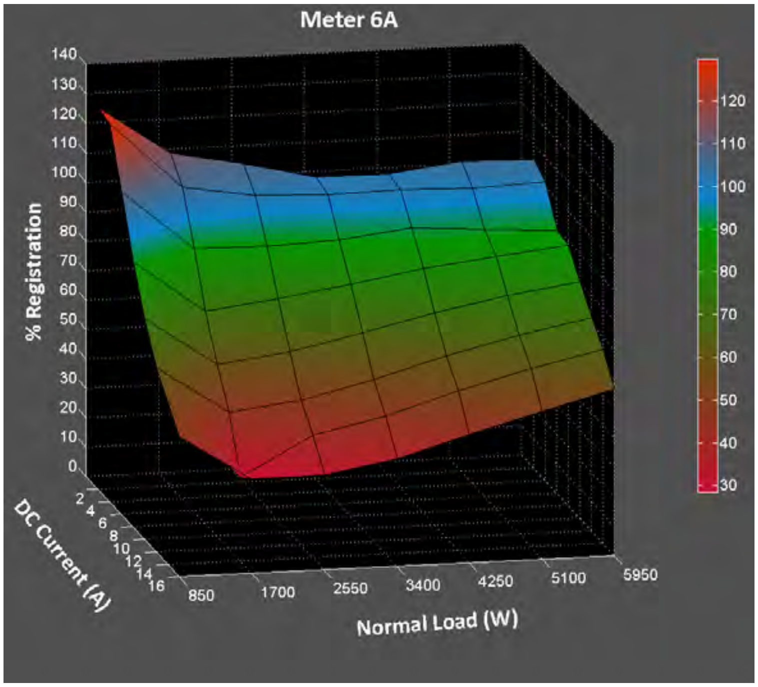

Figure 2-39
Meter Registration Reduction from DC Induced on the Customer Side

Although the test ranges differed, this data aligned with that measured previously using the "Simplified Method" – indicating that the effect on the meter was the same. Because the DC resistance in the path (see red arrows in Figure 3-4) was very low in this setup, induced DC voltages were also very low. Whether or not a circuit such as this would cause damage to regular household equipment remains unknown. This testing was conducted on a dedicated service in EPRI's laboratory with no other residential equipment connected.

3
RISK ASSESSMENT: POTENTIAL PRESENCE OF DC LOADS

The level of concern associated with meter tolerance of DC loads depends on the likelihood that such loads may be encountered in the field. This study looked specifically at the possibility of two types of DC load – half-wave rectified and flat DC, as described in the following subsections.

Half-Wave Rectified Current

A straightforward way to generate a DC load is by half-wave rectifying a normal AC load – in simple terms, by the placement of a diode in series with the load, as illustrated in Figure 3-1.

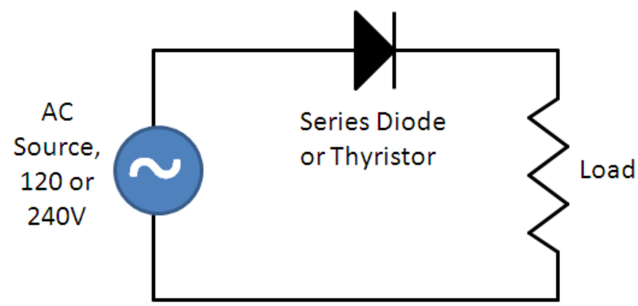

Figure 3-1
Simple Half-Wave Rectified Load Circuit

A configuration of this kind could hypothetically appear in customer systems in one of two ways:

1. Naturally - being part of a product manufacturer's original design. This would assume that:
   a. There is a use or value in such a design, with the half-wave rectification or thyristor serving some meaningful purpose.
   b. There are no laws, codes, or regulations prohibiting such configurations.
2. By customer modification – the result of an intentional change made to cheat on electricity bills.

Modification of products to convert to half-wave rectified load was found to be a simple process in many cases. This was particularly true for the most likely candidate devices – those with relatively large power consumption and a thermal nature that could tend to make reduction to half of normal power tolerable to a consumer. For example, a modified water heater would only have half of its normal heating wattage, but its control circuitry would still bring the water to the same set-point. The negative impact to the consumer would be only that the recovery time would be twice as long. Another example is that of a thermostat-controlled resistive heating system. As long as the normal (pre-modification) duty cycle of the heater was less than 50%, the system would likely still be able to maintain the desired temperature set-point with a diode in series with the heating element. Figure 3-2 and Figure 3-3 illustrate how simple instructions could be created to show consumers how to modify their products.

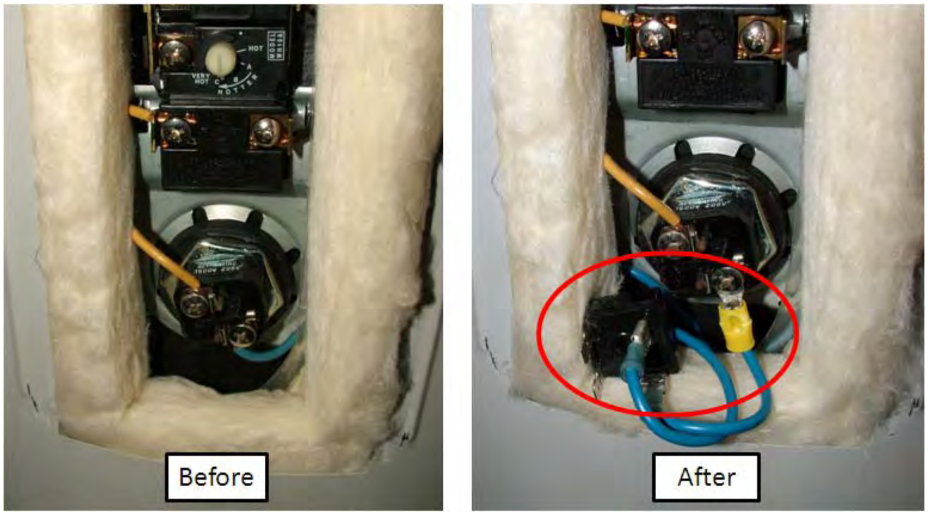

Figure 3-2
Water Heater Modification for Half-Wave Rectification

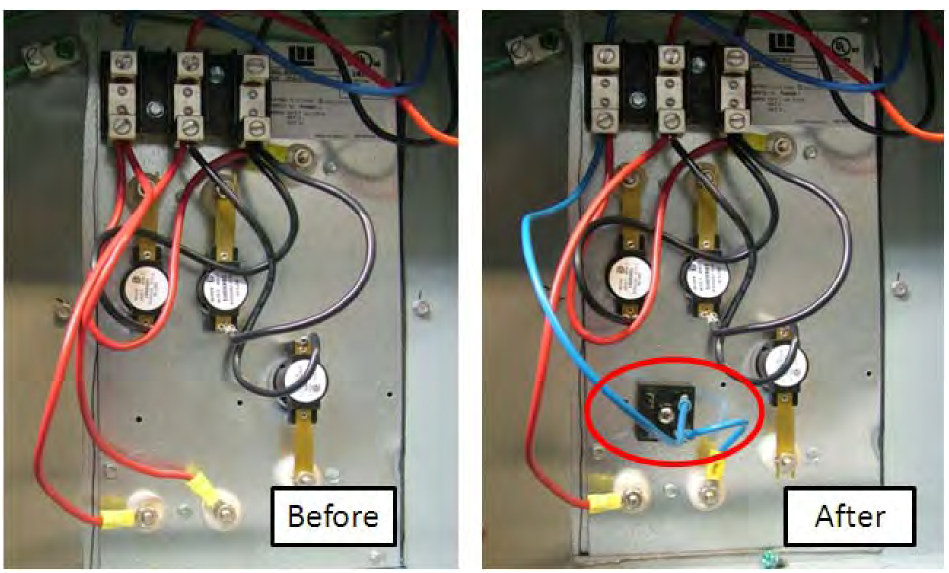

Figure 3-3
Electric Heater Modification for Half-Wave Rectification

Circuit to Generate Flat DC Current

Another possibility considered in this research was that a specialized electronic circuit could intentionally create a flat DC current that would result in a DC shift of the normal sinusoidal load current, as illustrated in Figure 3-4.

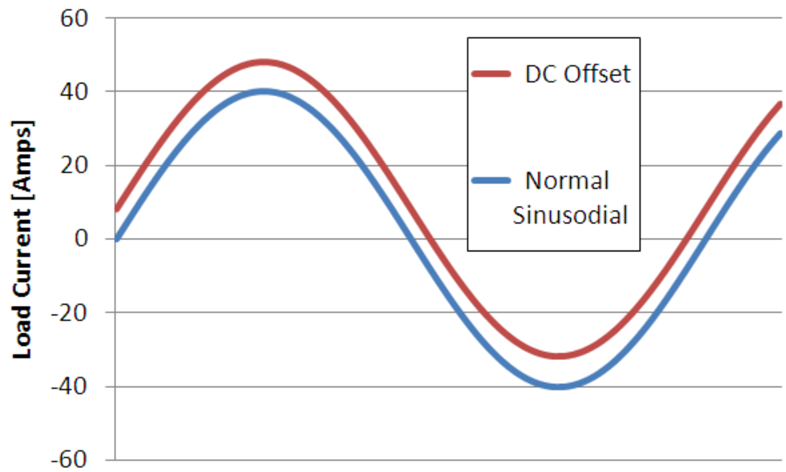

Figure 3-4
Flat DC Offset

It is suggested that such an offset current is not likely to occur naturally, but could be created by a circuit intentionally designed for this effect, as illustrated in Figure 3-5.

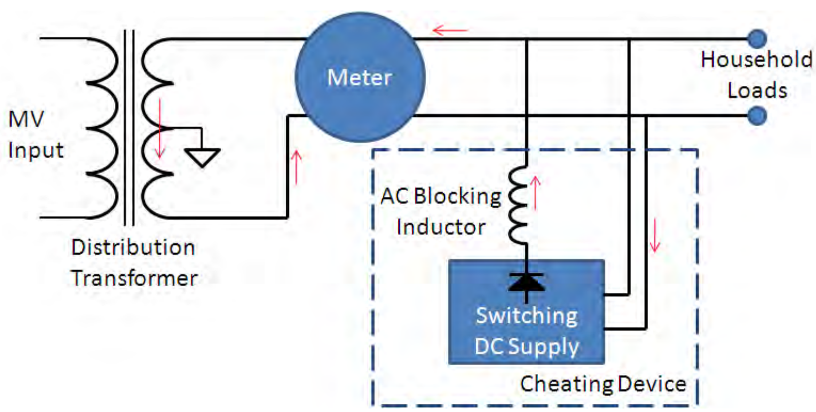

Figure 3-5
Conceptual DC-Current Generating Circuit

EPRI's primary concern with this possibility was based on the potential that a device might be promoted as a "green" energy efficiency device. It was thought that this could be a simple box, plugged into any outlet, and employed by those not aware of the nature of the device and not intending to cheat.

While EPRI did construct a working model of such a circuit, it was found not to be practical due to the size and cost of the AC blocking inductor required. The size of this component is driven by the requirement that it maintain sufficient inductance (blocking impedance at 60Hz), while carrying a DC current of 16 Amps or more. Figure 3-6 shows the bulk of the components used in the EPRI circuit.

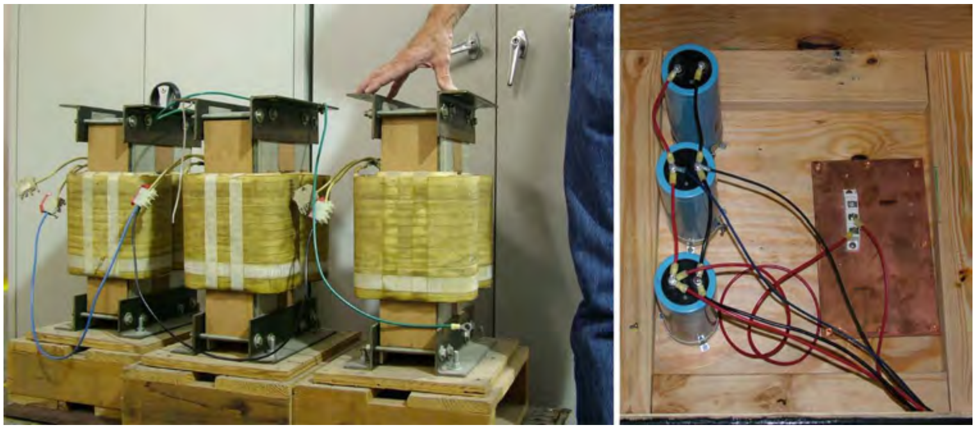

Figure 3-6
Large Inductors and Capacitors for Concept DC Circuit

Other circuit concepts were considered for generating flat DC current from the customer side of the meter, including those that did not require a large inductor. These included a number of high-frequency switching topologies and switched-capacitor techniques. None of these ideas led to a working circuit. It is, however, quite possible that such a design exists. If or when found, this concern should be given more consideration.

Search for Products with DC Load Characteristics

Although there is significant lore regarding residential products that draw half-wave rectified current, EPRI research was unable to identify any specific product make and model. The investigation included those outlined below, focusing on products likely to draw power at the levels required to cause errors in meter accuracy or damage to residential transformers. The following common device types were investigated on a sample-basis.

Electric Water Heaters

Three leading manufacturers of electric water heaters were contacted, including General Electric, Whirlpool, and Rheem. Each was asked if their present or legacy product lines produced DC current draw for even a few cycles. All confirmed that some form of relay was used to turn on and off power to the heating elements, resulting in a balanced draw from both sides of the AC wave form. Although temperature control mechanisms varied slightly, none drew DC current for either control or heating.

As indicated in Figure 3-2, it was found to be relatively easy to modify these products to draw half-wave rectified current.

Inline Electric Water Heaters

Three leading manufacturers of inline (on-demand) electric water heaters were contacted, including Eemax, Chronomite and Stiebel-Eltron. Each was asked if their product lines produced DC current draw under any circumstances. All of these vendors used Triac control circuitry that switched both sides of the wave, producing no DC offset to the current draw.

Another manufacturer of inline water heaters, Seisco, was previously the subject of an EPRI report[1]. This product did present a half-rectified load that might be sufficient to cause meter errors but this only occurred during abnormally low water flow conditions. During normal flow, this product exhibited a normal balanced AC load but during low flow conditions the load appeared half wave rectified to prevent water from overheating. While this condition may cause electric meters to record incorrect data, this is not a primary concern because it is not how the device is typically used. If a sink is being filled with hot water, the flow rate is typically high, eliminating the problem. The times that a low flow rate is used are likely to be rare and short in duration.

It would not be a simple task to convert one of these units to a half wave rectified DC source since this would reduce the effective heating by 50%. Unlike tank water heaters, inline units do not have the time to make up for the loss of heating, requiring the flow rate to be reduced by 50% also to maintain effective heating. This would be unacceptable to most consumers.

Heat Pump Electric Heating Strips

Three top suppliers of residential HVAC systems were contacted to determine if their units drew any significant DC current. All responded and confirmed that their devices did not have this characteristic. All were controlled using relays or triacs that drew evenly from both sides of the wave form. Their control temperature control systems did not produce a DC current draw even for a few cycles at a time.

Because these are resistive heating systems, they can be modified to produce a half wave rectified DC load. This would require disassembly of some components, requiring knowledge of how the system works. As with any resistive heating system, this will reduce the wattage supplied for heating by half, doubling the duty cycle required to maintain temperature control.

Resistive Floor Heaters

Market share of the various manufacturers proved difficult to ascertain in this industry. As a result, multiple vendors were contacted that were readily accessible to customers and used as a representative sample. Despite anecdotal reports of commercial resistive floor heating systems that used SCR systems for power control, all of the residential resistive floor heating manufacturers contacted by EPRI reported using relay control systems that switch the AC load on or off without using anything that would provide a DC component. None of the manufacturers were aware of any company that uses, or has used, a different approach.

Because these are resistive heating systems, they can be easily modified to produce a half wave rectified DC load (See Figure 3-3). As with any resistive heating system, this will reduce the wattage supplied for heating by half, doubling the duty cycle required to maintain temperature control or possibly failing to reach the desired temperature set-point.

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[1] *Electric Tankless Water Heater (TWH) Performance Evaluation and System Compatibility Report.* EPRI, Palo Alto, CA: 2005. 1011850

Clothes Dryers

Prominent makers of household white-goods, and electric clothes dryers in particular, include Bosch, General Electric, Samsung, and Whirlpool.

Bosch reported that their clothes dryers, including both vented and condensate models, do not draw current on the half-cycle, and that both the motors and the heaters are always in the full-wave mode.

Whirlpool reported that, for dryer heater elements, there is not and has never been, DC / half-wave consumption. Whirlpool has always used timer switches and/or relays to connect the heater to the power mains, resulting in AC resistive loading. It was noted that some older electronic control boards could have drawn half wave current, however, these controls use only a couple of Watts and are not a concern in this regard.

Samsung reported that their clothes dryers presently do not, and historically have not, used half-wave rectified power for the heating elements or other high power elements.

Because dryer heating element connections are internal and more difficult to access than those on a water heater, clothes dryers are viewed as being less likely to be intentionally modified. Halving the drying wattage may cause longer drying times, a user inconvenience.

Electric Vehicles and Chargers

Although Electric Vehicles (EVs) and the associated Electric Vehicle Service Equipment (EVSE's) are just emerging, it is appropriate to consider their potential impact because they are sizeable loads and are likely to operate over several hours.

At the time of this report, DC vehicle charging equipment (using a power supply in the EVSE) are not yet present in the U.S. Instead, EVSE's are simply switch mechanisms that pass the AC voltage to a charging circuit that is built into the vehicle.

Ford reported that none of their on board chargers are half-wave rectified. In fact, Ford chargers are quite sophisticated and have power-factor-correcting front ends that step up to an intermediate high (DC) voltage, followed by a forward converter to the correct battery voltage.

Nissan reported that the LEAF on board charger does not draw half-wave current. It has an advanced multi-stage charger that includes full-wave rectification and a power factor correcting stage.

Other Examples

Other example product categories were identified but less concern. For example, older hair-dryers used a diode in series with the fan and heater element in order produce a "low" setting, then bypassed the diode to produce a "high" setting. Another example is that of the light bulb socket inserts for saving energy that were marketed in the past. These disc-shaped devices were essentially diodes that halved the Wattage delivered to the bulb.

Search for Prohibitive Standards, Codes, or Laws

Another factor in determining the level of risk that might be posed by DC loads is whether or not any standards, codes, or laws prohibit such products. Per the analysis in the preceding section, the present marketplace does not appear to have significant quantities of products that present DC loads. But without laws prohibiting such products, there is some risk that a new type of product could emerge that has these undesirable characteristics. Both EV chargers and on-demand water heaters are examples of high-power products that are relatively new in the marketplace.

EPRI contacted the agencies identified in Table 3-1 to determine if any standards, codes, laws, or guidelines exist to prevent vendors from producing, or to prohibit customers from using, DC loads.

Table 3-1
Table of Standards and Codes

Organization	Prohibitions Found?	Comments
AHAM – Association of Home Appliance Manufacturers	N	AHAM is not aware of any standards with maximum limits on DC current draw on appliances. All of our electrical products operate within the sphere of Underwriters Laboratories Standards (there are about 30 covering home appliances) and most are very similar in this regard.
AHRI – Air-Conditioning, Heating, and Refrigeration Institute	N	AHRI could not identify any rules restricting DC content or any characteristic that it would cause in the levels required to cause errors in meter reporting.
ANSI – American National Standards Institute	N	ANSI could not identify any rules restricting DC content or any characteristic that it would cause in the levels required to cause errors in meter reporting.
ASHRAE	N	ASHRAE was not aware of any standards that would restrict or limit DC consumption. ASHRAE suggested that the NEC (new section 705) might have some bearing. ASHRAE also suggested contacting the NFPA.
IEC	Y	Although not broadly applied in the U.S., IEC 62053-21 establishes half-rectified and DC tolerance for electricity meters.
IEEE 519	Possible	Section 10.4, Current Distortion Limits, of IEEE 519 states that "Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed." While this appears to block the use of devices drawing DC current from the utility connection, it is typically only applied to commercial and industrial customers and products. It may need to be specified in the customer service agreement to be applied in a residential situation.
NEC – National Electric Code	N	Nothing found relating to residential products and DC current consumption.
NFPA – National Fire Protection	N	The NFPA could not identify any rules restricting DC content or any characteristic that it would cause in the levels required to cause errors in meter

Organization	Prohibitions Found?	Comments
Association		reporting.
NEMA	N	NEMA has not been able to identify any codes or regulations addressing DC loads, other than the generic requirement that the circuits and connected devices must be suitable for the loads controlled.
UL	N	UL could not identify any rules restricting DC content or any characteristic that it would cause the kind of levels required to cause errors in meter reporting.
Utility Commission Statements / Customer Service Contracts	Partial Coverage	Although not uniform nationally, some utility commission statements and/or customer service contracts include language to the effect that “customers are not allowed to connect any devices that are harmful to the utility owned equipment.” For example, a section of National Grids’ tariffs state: 5. DISTURBANCES: 5.1 Company's service may be refused or withdrawn when Customer's wiring or equipment is so designed or operated as to disturb Company's service to other Customers. If what the individual does, impacts revenue, then it is indirectly impacting (or disturbing) the service to others, i.e., the cost of providing service to the other customers will change.

In summary, there was no solid code found that would provide assurance that products with DC load characteristics have not, or will not, appear in the U.S. marketplace. The limitation created by the IEEE 519 current distortion limits is not typically found to be applied in residential settings. Local utility commission statements or customer service contracts appear more likely to provide the rules, but their local nature raises the question of visibility to vendors and demotes the issue to a utility/customer confrontation rather than maintaining it where it should be: as a marketplace/codes issue.

4 IMPACT ON DISTRIBUTION TRANSFORMERS

In the course of this evaluation, it was noted that DC load currents that might impact meters may also have an adverse effect on distribution transformers. Specifically, DC current on the secondary side of the transformer could hypothetically cause core saturation, reducing the primary magnetization inductance, resulting in high primary currents and overheating.

This effect was observed during one attempted laboratory setup that utilized a small isolation transformer. This transformer was inserted to prevent other laboratory equipment that shared the same service connection from being exposed to the DC currents and voltages resulting from this testing. As the DC load current was increased, the isolation transformer core saturated, its primary current increased, and a breaker supplying the transformer tripped. For this laboratory transformer, it was found that 7.5 amperes of DC current through the secondary caused the primary inductance to drop by a factor of 10. This observation, together with vendor feedback, prompted EPRI to expand the scope of this study to examine distribution transformers.

This chapter provides the results of testing conducted on two residential transformers:

- General Electric Prolec 15KVA GE K 280 55B
- General Electric Prolec 25KVA GE K 280 55B

In addition, testing was done using a 50KVA pad-mount transformer that is part of EPRIs regular Knoxville, TN power service from the local power distributor. Although it was not possible to make primary-side measurements when using this transformer, it was noted that the secondary voltage remained well regulated throughout the testing and the transformer did not exhibit any observable noise or heating.

To be consistent with the test modes used on the meters previously, this transformer testing was conducted using both half-wave rectified loads and a flat DC current injection into the secondary. The results are presented in the following subsections.

Distribution Transformer Test: Half Wave Rectified

This test was conducted using the arrangement illustrated in Figure 4-1. The first step was to close the switch around the rectifier and collect base line data for the transformer operating normally. The resistive load bank was then incremented from 1 kW to 12 kW in 1 kW steps with primary and secondary data collected at each step. The test was then repeated with the rectifier bypass switch open.

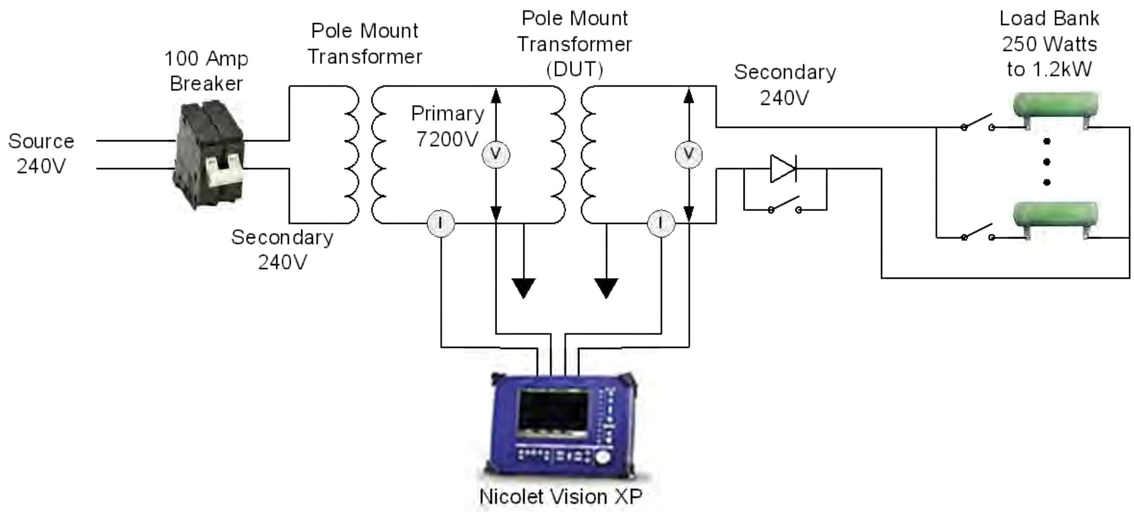

Figure 4-1
Transformer Rectified Load Test

As indicated, the testing was accomplished by using two utility transformers, each with 7.2kV primary voltage ratings. One transformer was back-fed to produce the medium voltage input to the DUT.

High resolution sampled data was captured and analyzed. Figure 4-2 and Figure 4-3 present the real power loss in the transformer as a function of power to the load for the 15kVA and 25kVA transformers, respectfully.

For the same power level, the half-wave rectified loads resulted in transformer losses approximately 70% higher than those resulting from normal resistive loads. Over the load range of 0 to 6000W, the half-wave rectified losses can be seen to increase relatively linearly, not tending to curve substantially upward with increasing load.

Figure 4-4 illustrates the typical primary voltage and current waveforms observed during this test. The current waveform (red) exhibits an asymmetrical shape with a high peak as a result of the half-wave rectified load.

The performance of both tested units was similar. As expected, the 25kVA transformer's no-load losses were slightly higher than those of the 15kVA transformer, but the load-related losses were approximately 25% lower.

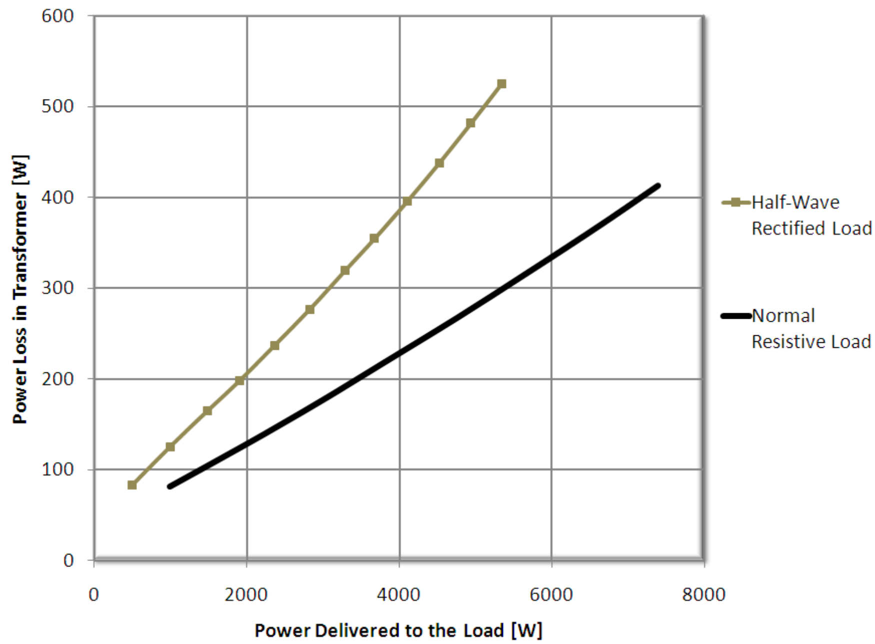

Figure 4-2
15kVA Transformer, Half-Wave Rectified Test Results

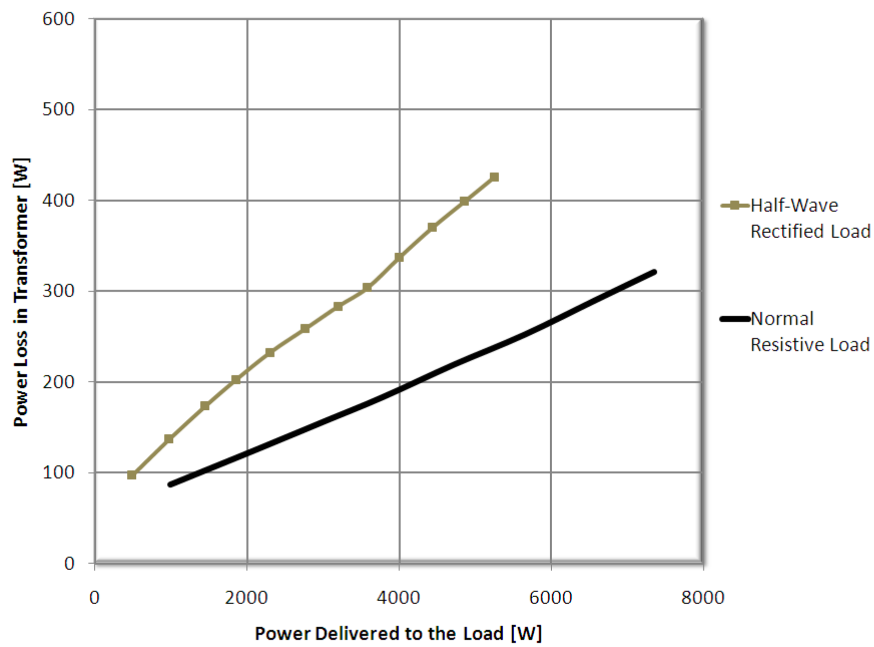

Figure 4-3
25kVA Transformer, Half-Wave Rectified Test Results

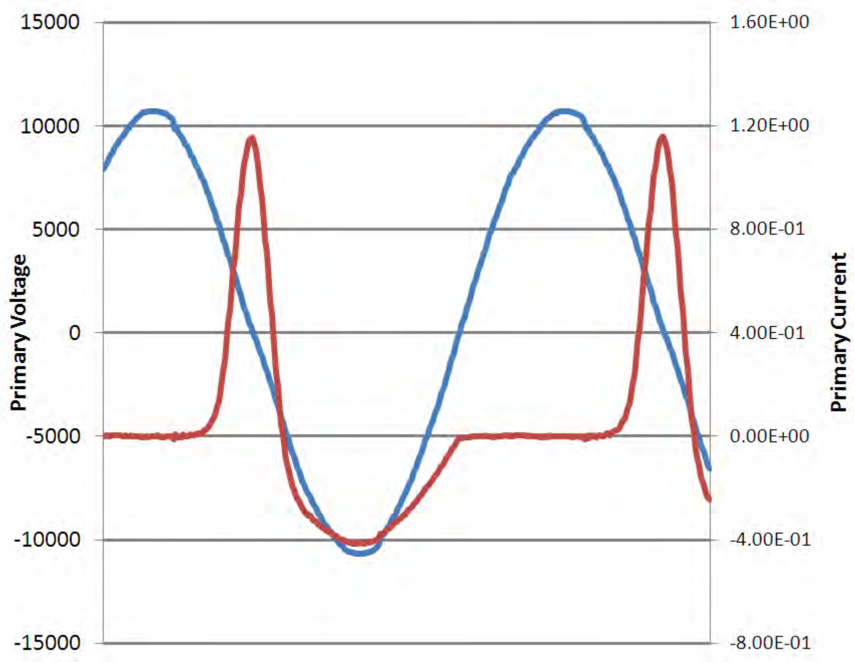

Figure 4-4
Typical Half-Wave Rectified Transformer Test Waveforms

Distribution Transformer Test: Flat DC

DC current was injected into the transformer secondary in 2 Amp steps, from 2 Amps to 12 Amps. At each DC current level, the load bank was incremented from 1 kW to 7 kW in 1 kW steps. Data was collected at each step.

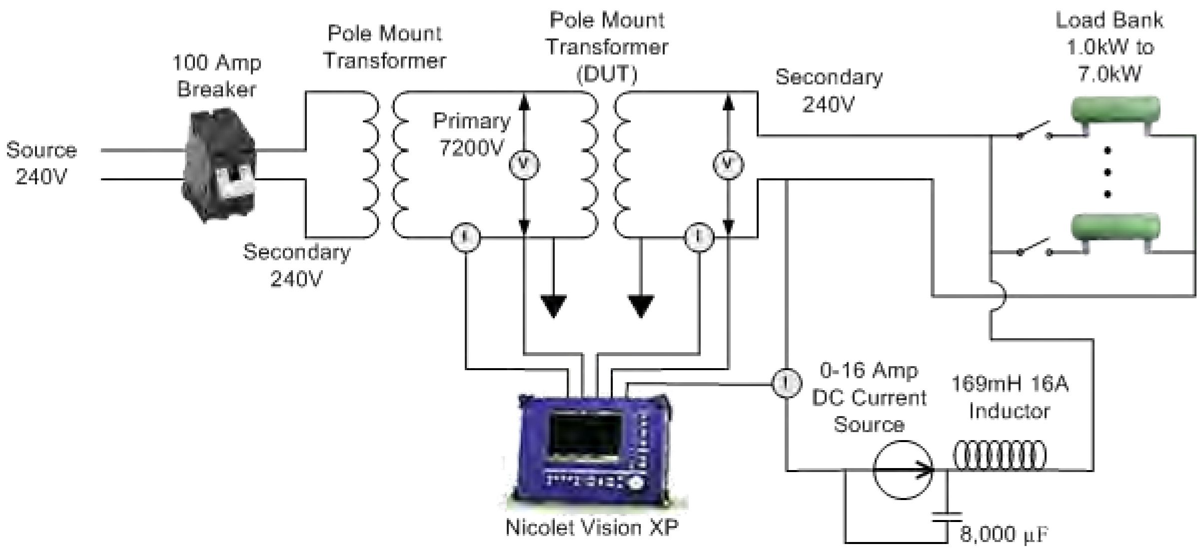

Figure 4-5
Transformer Injected DC Current Test

The DC current source was constructed from a bank of DC batteries, in series with a variable resistor. The same large AC blocking inductor that was used during meter testing was used to couple the DC current into this circuit.

Figure 4-6 and Figure 4-7 present the measured real power loss in the transformer as a function of power to the load for the 15kVA and 25kVA transformers, respectfully. In each chart, the losses with no DC current (normal resistive load only) are shown for reference.

Losses increased as DC current increased. The variation of loss as the AC resistive load increased remained relatively linear for all tested current levels, closely following the slope of the baseline data. The increase of losses as DC current increased was relatively constant (the vertical separation between the parallel lines), with no indication of a breaking point or sudden increase in losses seen in this test range.

At the highest DC current levels used (~12A), the transformer losses were approximately 50 to 70% higher for the same load level.

As with the half-rectified testing, the data in this test was similar between the 15 and 25kVA transformers, with the larger transformer having slightly higher no-load losses but less load-induced additional loss. Neither the 15kVA or 25kVA transformers exhibited easily discernable signs of stress.

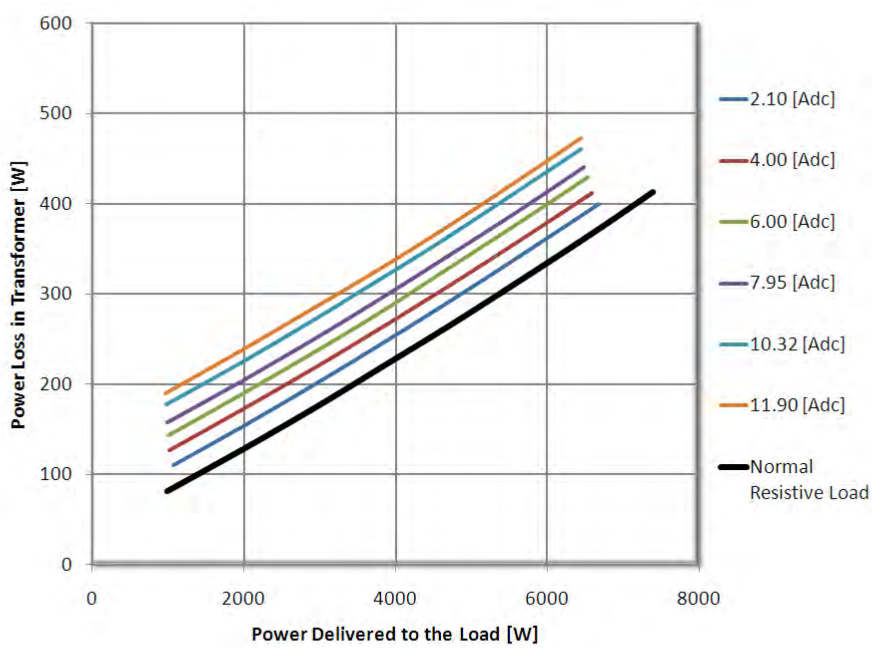

Figure 4-6
15kVA Transformer, Flat DC Current Test Results

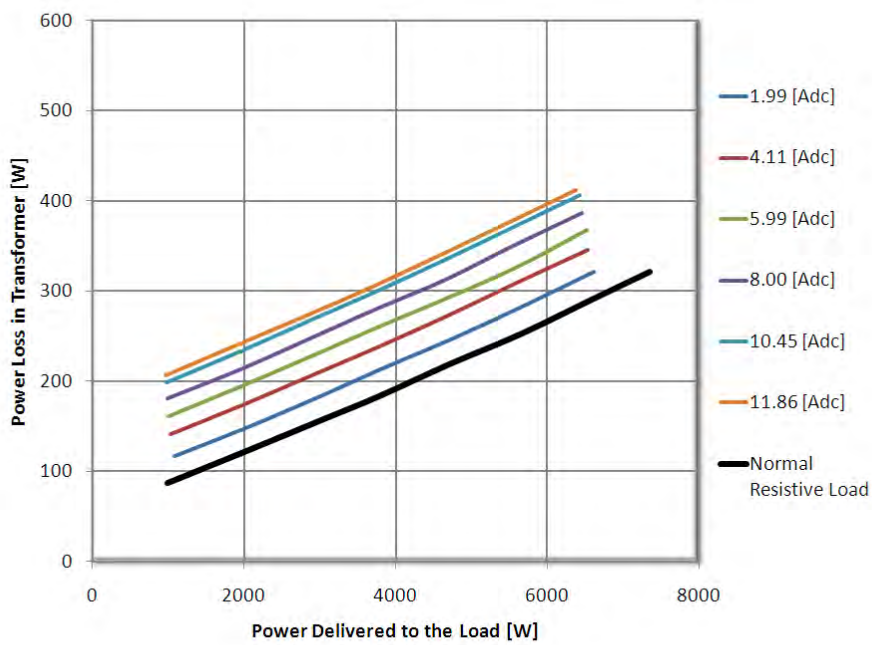

Figure 4-7
25kVA Transformer, Flat DC Current Test Results

Figure 4-8 illustrates the typical primary voltage and current waveforms observed during this test. The current waveform (red) can be seen to be shifted downward and exhibits an asymmetrical peak as a result of the DC magnetic bias on the core caused by the injected DC current on the secondary side.

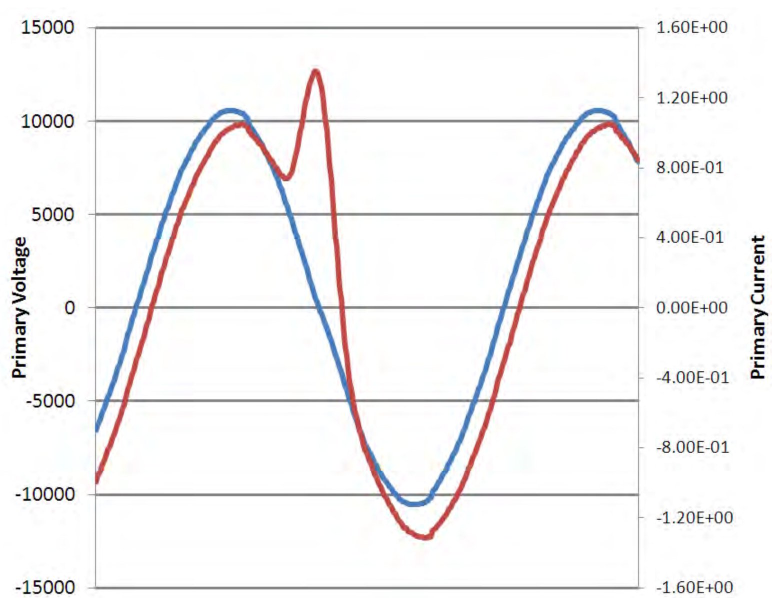

Figure 4-8
Typical Flat DC Current Transformer Test Waveforms

5
DETECTION AND REPORTING OF DC CURRENTS

This research raised the question of whether or not meters are able to detect and report when DC currents are present that could cause errors. This has been shown to be useful for two reasons:

1. Some meters have been shown to have measurement accuracy problems when presented with DC loads. However, it appears that such exposure is not likely to be widespread. If meters that are exposed to DC load currents could detect and report an error prior to reaching a level that caused metrological errors, then the utility's revenue is more protected – for all meters.
2. Distribution transformers, while generally appearing to tolerate more DC load current than meters, also have limits as to how much can be tolerated. If meters could detect and report the presence of DC load currents, it would aid utilities in the protection of their assets and in helping to assure maintenance of system efficiency.

It appears beneficial to recommend that all meters (independent of their own DC tolerance) be capable of detecting and reporting DC loads prior to reaching levels that could saturate or stress distribution transformers. Effective end-to-end support of DC flags requires several steps, potentially involving products from multiple companies. These are identified in the following subsections.

DC Load Detection (Sensing) Potential

The current sensors used in the meter must be capable of sensing the DC load through some mechanism. Certain sensors, such as current shunts and hall cells, may be able to directly measure DC – both in the form of flat DC and half-wave rectified loads. Others, such as Rogowski coils and current transformers may not directly measure DC, but may be able to detect the harmonic content associated with half-wave rectified loads or the distortion induced when current transformers begin to saturate. Current sensors cannot generally be replaced on products already deployed, so having the fundamental ability to sense DC content is an important consideration.

The signals from these sensors must then be processed in a way that intentionally identifies the presence of DC content. The algorithms for this processing are likely to be entirely in addition to the normal AC metering algorithms, where DC offsets could even be zeroed-out and removed as part of the normal processing. If the metrology portions of meters are firmware upgradeable, it may be possible to add the processing for DC detection, even after deployment.

The meter manufacturers represented in this project were contacted regarding their product's ability to detect saturating DC currents.

Table 5-1
Meter Ability to Detect Saturating DC Currents

	Present Product Detects Saturating DC Current	Ability to Upgrade Products Already in the Field	Future Production Could be Made to Detect DC	Comments
Echelon ANSI (3.1)	No	Possibly	✓	Meter can detect current THD and may be able to flag half-rectified load from this. To be determined. Consult with manufacturer.
Elster REX2	No	Possibly	✓	Mechanisms exist that could support upgradeability. Consult with manufacturer.
GE I210	No	No	✓	The I210 has high DC immunity. It lacks the computational means to detect DC and cannot be upgraded
GE I210+	No	Yes	✓	Since April 2011
GE I210+c	No	No	✓	Only the register is field upgradeable
Itron Centron	No	No		Changes to add support for DC detection are more likely to be made in the OpenWay platform.
Itron Centron OpenWay	No	No	✓	
Landis+Gyr Focus	No	No	✓	
Focus AX	No	Yes	✓	Support is part of a planned upgrade, expected to roll out in Q2 2012
Sensus iCon A	No	Yes, vast majority	✓	Some early fielded meters lacked this ability

DC Load Flagging

Once the presence of DC load is sensed and processed, meters must capture this in the form of a measurement or a flag that is set when a particular threshold is exceeded. This kind of function generally falls in the "register" portion of the meter and is typically more flexible in terms of configurability. Register electronics are more likely to be firmware upgradeable to add new functions and features.

EPRI contacted the ANSI group that manages the C12 communication standards and found that there is not presently any standard way for DC detection, or (sensor saturation) to be represented. Meters typically use the ANSI C12.19 Tables for representing data and there is no standard event of this type yet defined. The possibility of adding such a field, as well as other DC tolerance requirements is possible going forward.

AMI Reporting (Communication to the Utility)

Flags and/or measured data must ultimately be reported to the utility in order to be of benefit. This requires that AMI systems support the collection of this data from each meter at some interval, or a report-by-exception mechanism. Although some meter manufacturers are also AMI providers, these are often separate companies, and the DC load error data must be reliably passed from the electronics of the meter to those of the AMI system (sometimes present in the form of a separate communication card in the meter). Utilities interested in DC detection must take care in discussions with vendors to assure that both the meter sensing and the AMI reporting are supported.

Once DC detection information has been collected to the utility, a mechanism must exist for the flags to be called to the attention of Operations staff. This might be in the form of a daily report, a work-order, or other record. This reporting could be a function of the AMI headend, or an MDMS or other ancillary AMI data software.

6 SUMMARY

This evaluation of residential meters was conducted on twelve meters representing six models/brands. These meters utilized CTs, Rogowski coils, and Hall cells for sensing current. The results indicated that two of the six models have measurement inaccuracy when presented with load currents with significant DC components.

Overall Risk Perspective

In view of the findings of this research, EPRI suggests that the risk of residential loads with problematic DC characteristics is low. This does not mean that there is no risk, but that the factors identified have limited the risk to a fraction of what might have been found. This perspective is based on the following summary findings:

1. Although national rules do not prohibit residential devices with DC characteristics, they have not been found in the marketplace. This indicates that, thus far, there has been no natural motivation or benefit to designing a product that would draw power asymmetrically (on the half-cycle).
2. Local utility rules do exist in some locations that can be used to manage issues on a case-by-case basis, broadly prohibiting the connection of any equipment that would harm or disrupt the power system.
3. A gadget that would produce flat DC and possibly be marketed as an honest energy saving device does not appear to be practical – being both large and expensive in its simplest form.

The greatest risk appears to be that of intentional theft through consumer modification of products, typically in the form of adding a diode in series with a heating element. While the prevalence of such actions is no doubt limited by the electrical nature of the modifications, it is recognized that the Internet has provided a mechanism through which instructions may be broadly distributed.

Potential New Codes for Residential Electric Equipment

No national codes or laws were found that would be clearly applicable and provide assurance that DC loads will not appear in the future. Some utilities, however, already have individual rules that prohibit the connection of such products. Because the prospect of utility/customer conflict (regarding devices that were legally manufactured and legally purchased) is undesirable and should be unnecessary, consideration of additional codes that would formally prohibit DC loads is of interest.

This research would suggest that new codes would only need to apply to a small number of residential product types: those consuming approximately 200W or more. It would also indicate that the market impact of such new codes would be small because the sampled-survey of manufacturers of such products indicated that half-wave rectification is not presently used.

Intentional Theft

The greatest risk appears to be that of the intentional modification of products to steal energy. Typically, this modification would require only the addition of a diode in series with the load, and has been shown to be a simple modification – easily documented and replicated with the aid of an Internet instruction or video.

It should be noted that if multiple devices in a single home are half-wave rectified, the effects will cancel if the diodes are placed in opposing polarities. A sophisticated degree of understanding of power systems may be required in order to align multiple modified products to achieve an additive effect.

DC Detection and Reporting

Meter manufacturers and AMI providers were found to generally be capable of detecting the presence of DC loads (using a variety of mechanisms) and reporting to the utility. Although this capability is common among commercial / industrial meters, these residential meters did not tend to have such detection and reporting by default. Fortunately, the ability to add such features in future products or in existing products (via remote firmware upgrade) was indicated for most.

Current Transformer Considerations

Five of the seven meter types involved in this testing used CTs, and the three types that demonstrated registration errors were CT based. This should not, however, be interpreted to imply that CTs should not be used to sense current in meters, for several reasons:

1. Current transformers are the most commonly used and well understood current sensing technology in the utility industry. Their characteristics are well known and both their potential for accuracy and stability are well documented.
1. Two of the five CT-based meters tested showed no signs of error, or saturation, up to the levels used in the testing. These maximum levels were considered practical upper limits.
2. The DC load testing comprising this test is just one of a broad array of environmental tests to which meters could be subjected. Under other test conditions, it is possible that CT based meters could perform best. For example, toroidal CTs are known to have excellent self-shielding, and are resistant to externally applied 60[Hz] fields.
3. Along with other sensor types, CT type sensors were found to support the detection of DC loads causing saturation, based on waveform distortion and other characteristics.

It is interesting to note that in 2003, General Electric studied this issue and, as described in a public application note[2] converted the poly-phase GE kV2c from a DC-immune active CT (null flux) to a traditional CT with DC sensitivity, but the ability to detect the presence of DC. This

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[2] http://www.geindustrial.com/publibrary/checkout/kV2cCT?TNR=White%20Papers|kV2cCT|PDF

indicates that the metering industry is generally aware of the potential impacts of DC loads; that some are actively studying these impacts; and that current sensor selections, some including CTs, are being made accordingly.

Recommendations

Present ANSI standards for electricity meters do not require that any particular level of DC current be tolerated or that DC detection and flagging are supported. Based on the results of this evaluation, changes in both areas would be beneficial.

This research indicates that a new ANSI test for meters that requires a certain metrological accuracy, up to a level of half-wave rectified load in the 400 Watt range would:

1. Align with the observation that higher-power residential appliances do not use half-wave rectification
2. Align with levels that are presently supported by primary ANSI meter brands.

This research further indicates that a new ANSI requirement for meters that requires detection and flagging of saturating DC loads would be beneficial. For example, meters could be required to detect and flag half-wave rectified DC loads before meter registration errs by 3%, or by the time the half-rectified load level reaches 1000 Watts, whichever is lowest. This would help to ensure the utility's ability to protect distribution transformers from damage and/or sustained inefficient operation.

To support the reporting of these DC flags in a standard way, an addition to the ANSI C12.19 tables is suggested.

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