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# Accuracy of Digital Electricity Meters

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***An EPRI White Paper***

## Background

The meter is a critical part of the electric utility infrastructure. It doesn't provide a control function for the power system, but it is one of the most important elements from a monitoring and accounting point of view. Meters keep track of the amount of electricity transferred at a specific location in the power system, most often at the point of service to a customer. Like the cash-register in a store, these customer meters are the place where the transaction occurs, where the consumer takes possession of the commodity, and where the basis for the bill is determined. Unlike a cash-register, however, the meter sits unguarded at the consumer's home and must be trusted, by both the utility and the home owner, to accurately and reliably measure and record the energy transaction.

Electricity is not like other commodities because it is consumed in real-time. There is nothing to compare or measure later, nothing to return, nothing tangible to show what was purchased. This makes the meter all the more critical for both the utility and the homeowner. For this reason, meters and the sockets into which they are installed are designed to standards and codes that discourage tampering and provide means of detecting when it is attempted. Intentional abuses aside, the electricity meter itself must be both accurate and dependable, maintaining its performance in spite of environmental and electrical stresses.

In general, electricity meters have been able to achieve these goals and in so doing to earn the trust of utilities and homeowners alike. The average person may have experienced a broken-down car, a worn-out appliance, or a piece of electrical equipment that died in a lightening storm, but most don't likely recall their electricity meter ever failing. Such is the reliable legacy of the electromechanical meter.

## Historical Perspective – The Electromechanical Meter

By anyone's assessment, traditional electromechanical meters are an amazing piece of engineering work. Refined over a hundred years, the design of a standard residential electricity meter became an impressive combination of economy, accuracy, durability, and simplicity. For this reason, electricity meters have been late in converting to solid state electronics, compared to other common devices.

Three phase commercial and industrial meters, being inherently more complex, were first to make the transition to solid state, beginning in the 1980s, and becoming the norm in the 1990s. As recently as the year 2000, however, some still questioned if and when the simpler residential meter would be replaced by a solid state version, and whether they could attain the same balance of economy and durability.

Now just a decade later, it is clear that this conversion has taken place. Over the last decade, major electricity meter manufacturers have introduced solid state models and discontinued electromechanical production as indicated in Figure 1. This transition diminished the value of both the facilities and the art of traditional meter making and opened the doors of the meter business to new companies.

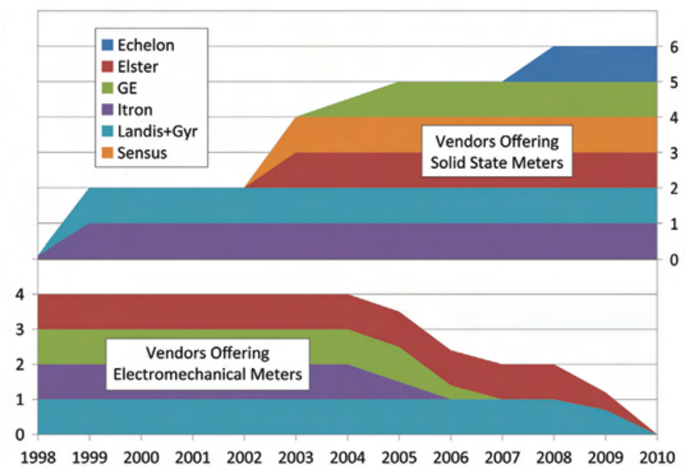


*Figure 1 – Replacement of Electromechanical Meter Production with Solid State Versions*

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*This white paper was prepared by Brian Seal and Mark McGranaghan of Electric Power Research Institute.*

## Functionality, the Driving Factor for Change

The impetus that finally drove the transition to solid state metering was not cost reduction, nor improvements in service life or reliability, but the need for more advanced functionality. Electromechanical meters, with that familiar spinning disk, did a fine job of measuring total energy consumption, but became extremely complex if required to do anything more. Versions that captured peak demand and versions that measured consumption in multiple time-of-use (TOU) registers have existed, but were not economical for residential purposes.

Today, residential meters are expected to provide a range of measurements, with some including demand, TOU, or even continuous interval data. Some may also be required to keep a record of additional quantities like system voltage – helping utilities maintain quality of service in a world that includes fast-charging electric vehicles and solar generation. In many cases, these solid state meters also include communication electronics that allow the data they measure to be provided to the utility and to the home owner without requiring a meter reader to visit the site.

## The Solid State Electricity Meter

Manufacturers who designed the first solid state residential meters understood the challenge they faced. The electromechanical devices they intended to replace held the trust of both utilities and the general public. Because dependable power delivery is critical for the economy, public safety and national security, utilities and regulators have been appropriately cautious in undertaking change. Manufacturers had to not only design a suitable replacement, but also to prove that the new meters could perform and be trusted.

From a utility perspective, several meter performance factors are of concern, including robustness, longevity, cost, and accuracy. But from the homeowner's perspective, the dominant concern is accuracy. If a meter breaks, the utility will fix it. If it becomes obsolete, it is the utility's problem to deal with. If however, a meter is inaccurate in the measurement of energy use, there is a potential that customers could be charged for more energy than they actually used. If the effect were only slight, then it could go undetected. For this reason, accuracy and dependability remain a common concern and a continued focus of dialogue regarding solid state meters.

Keeping in-step with the technology improvements associated with solid state metering, the American National Standards Institute (ANSI) developed new standards with more stringent accuracy requirements during the late 1990s. ANSI C12.20[1] established Accuracy Classes 0.2 and 0.5, with the Class numbers representing the maximum percent metering error at normal loads. Typical residential solid state electricity meters are of Class 0.5, whereas electromechanical meters were typically built to the less stringent ANSI C12.1 standards, as illustrated in Figure 2.[2] In addition, C12.20 compliant meters are required to continue to meter down to 0.1A (24 Watts), whereas C12.1 allowed metering to stop below 0.3A (72 Watts). While metering of such low loads is not likely significant on a residential bill, it is an accuracy improvement nonetheless.

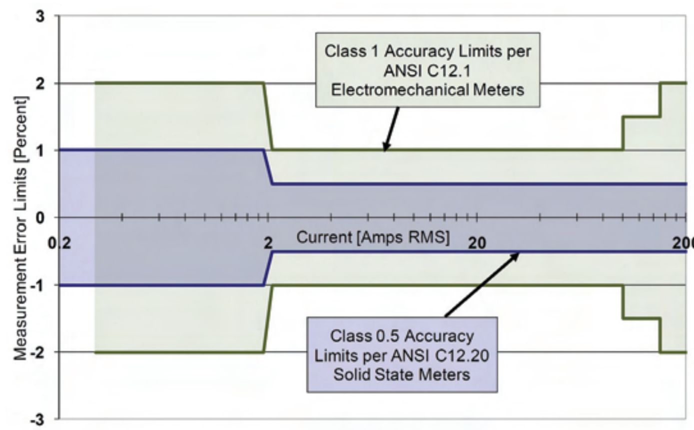



*Figure 2 – Accuracy Class Comparison*

Manufacturers and utilities use a range of tests and equipment to verify that meters adhere to the ANSI requirements. During the manufacturing process, it is common that each individual meter is calibrated and verified. Once a utility receives new meters, there is often another accuracy test, either on each meter or on a sample basis. States generally establish requirements for how utilities are to check accuracy when new meters are received and at intervals thereafter.

Regardless of their specified performance, solid state meters have been met with mistrust in some early deployments. The most significant of the complaints has been that the meters are simply inaccurate, resulting in higher bills. Given that these new meters are designed to the more stringent ANSI requirements, the factors that may lead to these observations and perceptions are important to understand.

1 American National Standards Institute, 1998, 2002, available from NEMA at http://www.nema.org/stds/c12-20.cfm

2 Data from Metering Standards ANSI C12.1-1988 and ANSI C12.20-2002

# Factors in How Digital Meters May Be Perceived

## *Changes in Billing Periods*

The duration of billing periods can vary from month to month, making it difficult to compare one month's bill to the next. If deployment of solid-state meters happens to correspond to a month with a billing period that is particularly long, then customers could incorrectly interpret the associated higher bill with the meter itself. An example of such a long billing period during new meter deployment occurred in January for many customers of Texas utility Oncor. Due to holidays, this billing period was as long as 35 days for some customers.

## *Complexity of Commissioning New Meters of Any Type*

When meters are replaced, and automated reading is instituted, care must be taken to associate the new meter with the correct billing address. Automated tools and processes may be used to aid in this process and are important to guarantee that the right consumption is associated with each residence.

When a meter is replaced, the metering and billing process for that month is more complicated than usual. A closing read from the old meter has to be captured and the associated consumption added to that from the new meter to cover the full billing period. Although the meter replacement process is generally automated to minimize opportunity for human mistakes, the data-splicing process adds complexity and opportunity for error.

If such an error were unreasonably large, it would be recognized as such by both the homeowner and the utility. If, however, a small error occurred, it could be difficult to distinguish from real consumption. It is therefore hypothetically possible that a bill could be in error for the month when the meter replacement occurred, even if both the old and the new meter were accurate.

## *Connectivity and Estimation*

Utility billing systems often have an estimating capability that can apply an algorithm to estimate a customer's bill until an actual read is collected. Historically, such estimation has been used when a manual meter read is missing and any errors in the estimation are corrected in the next bill.

When solid state meters are installed as part of an advanced metering infrastructure program, manual meter reading will halt as the automated process begins. New communication systems may not have good connectivity to every premise at first, so the number and frequency of estimated intervals may be elevated during the first few months after deployment. It is possible that such estimation could result in consumption from one month being billed in another, and hence more variation in bills.

## *Early Life Failures*

Products of many kinds exhibit changes in failure rate over time. As illustrated in Figure 3, these changes often follow a familiar trend. More products tend to fail either very early or very late in the service life of individual devices, with the rate of failure stabilizing at a low level during most of the useful life of the product.

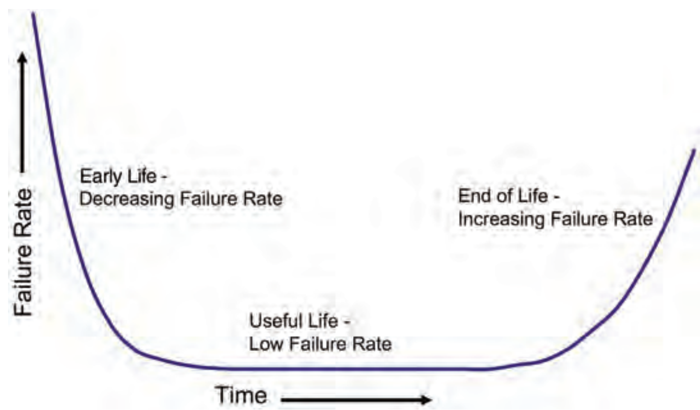



*Figure 3 – The Failure Rate Bathtub Curve*

Electricity meters are no exception. Both electromechanical and solid state meters have components and assemblies that can result in higher failure rates early in life, and wear-out after their useful life expires. A typical meter population is mature, is centered in the "useful-life" portion of the bathtub curve, and includes only a few new meters installed each year.

Today, the majority of solid state meters put into service are elements of advanced metering systems that are being mass deployed. These deployments can result in an entire meter population that is just a year or two old and therefore may experience sharply increased, but not unexpected, early-life-failure rates. If high registration were among the failure modes of a meter, then an exaggerated percentage of the population could experience higher bills during a new deployment.

## Extraordinary Weather

Extraordinary weather can occur at any time. Both record cold winters and hot summers have occurred in North America in recent years and can result in electric bills that are higher than normal. If such events coincide with a deployment of solid-state meters, some may conclude that the new meter is the cause.

One example of how extraordinary weather can result in higher consumption of electricity relates to the use of electric heat pumps used to heat homes in moderate climate zones. These heat pumps, while normally much more efficient than resistive heating, are typically designed with a second stage of electric resistance heat which is triggered when the heat pump itself can no longer satisfy the indoor set point temperature. As outdoor temperature declines, this second stage is called for more frequently. As was the case in many parts of the U.S. this past winter, extreme cold causes abnormally high dependence on second-stage electric heat and in-turn, unusually high electric bills.

## Growing Consumption

Average residential electricity consumption has risen for decades, with the addition of increasing numbers and types of electronic devices. Larger televisions, outdoor lighting, and new pools and spas are common additions that can result in notable increases in residential consumption. In other cases, faulty equipment can cause increases. Loss of refrigerant in an HVAC system or a duct that has fallen loose in an attic can cause devices to run excessively, unnoticed until exposed by an electric bill.

If these new purchases or equipment failures happen to coincide with a new electricity meter, one might assume that the resulting bill is the fault of the metering device.

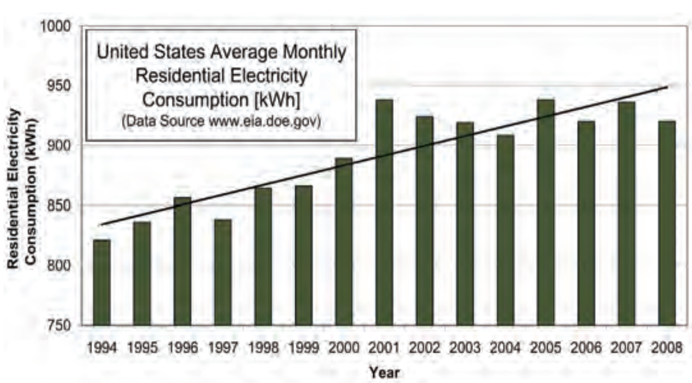



*Figure 4 – Residential Electricity Consumption vs. Time*

## New Rate Structures

New meters may enable new rate structures such as time-of-use or critical peak pricing. These programs offer to make the grid more efficient by motivating consumers to use less energy during times of peak consumption and more when energy is readily available. The improvement in load factor allows for better utilization of assets and, in some cases, deferral of infrastructure upgrades.

While new rate structures may benefit customers on average, individual results depend on the degree to which the consumer heeds the high and low price periods. Customers who select time-based rate plans and do not modify their behavior accordingly could experience higher bills, even though lower bills were possible. Because the new rate plans may go into effect about the same time as a meter-replacement, homeowners could mistakenly associate increased bills with metering errors.

## Replacing Defective Meters

Although electromechanical meters are extremely reliable, they do fail. The most common "failure" mode is reduced registration. Anything that increases the drag on the rotating disk can cause a meter to run slow, resulting in reduced bills. Worn gears, corrosion, moisture, dust, and insects can all cause drag and result in an electromechanical meter that does not capture the full consumption of the premise. Failure modes also exist that could cause an electromechanical meter to run fast, but are less common. Figure 5[3] illustrates this effect, based on the average registration versus years-of-service for a sample of 400,000 electromechanical meters.

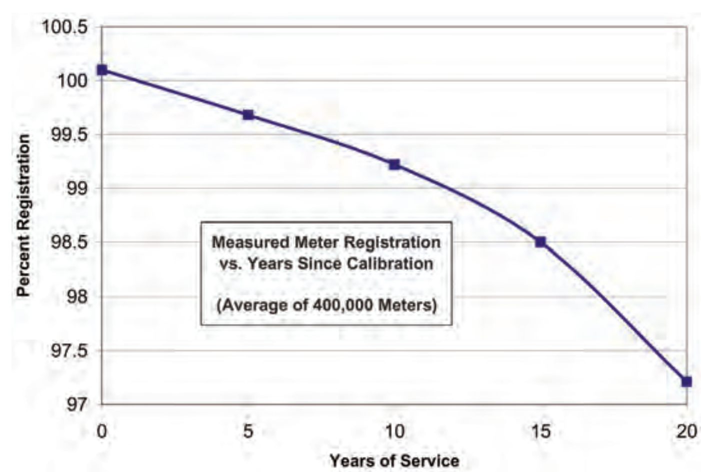
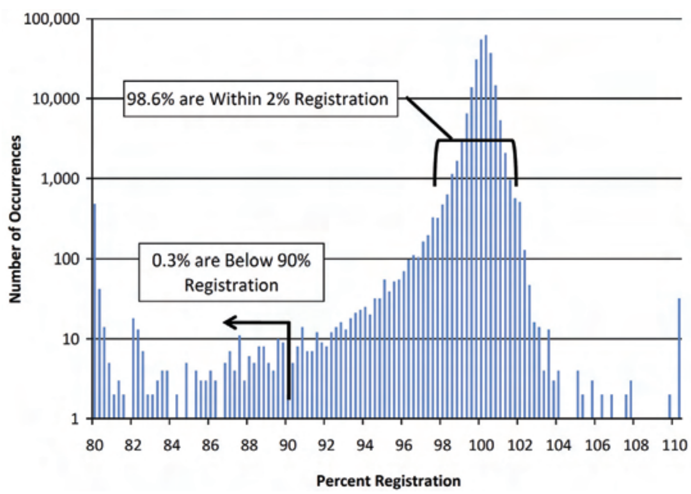



*Figure 5 – Electromechanical Meter Registration Loss vs. Time*

3 Data by permission from Chapman Metering, www.chapmanmetering.com

When all the meters in a service area are replaced, it is reasonable to expect that some of those taken out of service were inaccurate and running slow. Some may have gradually slowed over many years so that the homeowner never noticed and became accustomed to lower electricity bills. The sudden correction to full accounting and billing could naturally surprise these homeowners and result in questioning of a new meter. While the average meter might be only slightly slow, a few could be significantly so. As indicated in the distribution shown in Figure 6,[4] 0.3% of electromechanical meters tested registered less than 90% of actual consumption. Although 0.3% is small as a percentage, in a service area of a million meters, it represents 3,000 residences that might be under-billed by 10 to 20% prior to a new meter deployment.



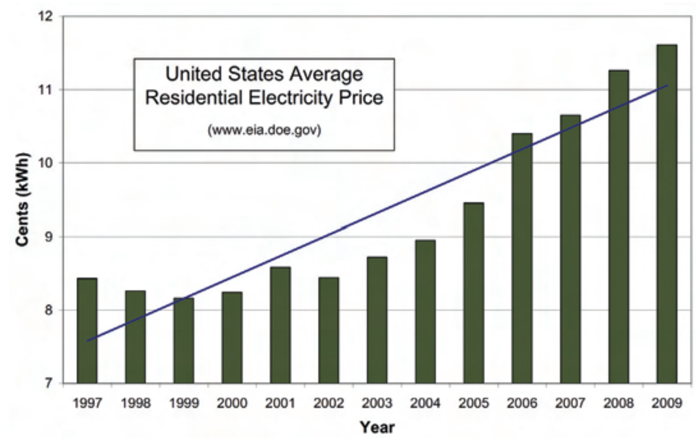

*Note the Logarithmic Vertical Scale for Better Resolution*

*Figure 6 – Electromechanical Meter Registration Distribution*

## Rising Electricity Costs

Although not the case everywhere, basic energy rates have risen in most areas as a result of increased costs of generating electricity and increased costs of the infrastructure required to deliver electricity to the consumer. As indicated in Figure 7, the average residential electricity price in the United States has increased at an average rate of 0.3 cents per kilowatt-hour per year over the last 12 years. In the event that a rate increase coincides with a rollout of new meters, homeowners experiencing higher bills might conclude that their new meter is in error.

4 Data by permission from Chapman Metering, www.chapmanmetering.com




*Note the Exaggerated Vertical Scale*

*Figure 7 – Average Residential Electricity Price vs. Time*

## Use of Embedded Software

Electromechanical meters utilized a set of gears and dials to keep a running count of how many times the disk rotated. This assembly, referred to as a "register," maintained a measure of the total power consumption that passed through the meter over time. Like a car's mileage odometer, each gear fed the next so that ten turns of the less significant dial were required to make one turn of the next. These registers had only one input, driven by the spindle of the meter's disk, and could not be moved from one reading to another by any other mechanism. Although simple and mechanical, the result was like a vault, locking-in and protecting the reading of cumulative consumption and immune to sudden shift or loss of data.

Solid state electronic meters are designed to provide this same register function, but using embedded software and non-volatile memory chips as the storage mechanism. Even before the recent deployment of "smart meters," millions of solid state meters have been deployed by utilities since the 1990s and the accuracy of their registration has not been an issue.

Still, as electronic devices, there is the possibility of imperfections in the embedded software or sensitivities in the electronic circuitry. Hypothetically, such imperfections or sensitivities could result in glitches that could affect the meter reading. An error of this nature that occurred only rarely would be difficult to detect prior to field deployment.

With electromechanical meters, modes of failure tend to be permanent. Once a meter or its register fails, due to wear, dust, etc, it is generally still found to be in a failed state when tested later. Software flaws, on the other hand, could create a transient glitch, leaving a meter that checks-out perfectly afterwards. This possibility complicates the diagnostic process for solid state meters and may make it difficult to discern the root cause of problems.

If it were to occur, the effect of a glitch in a solid state meter or in an AMI system may be mitigated using interval data. Typically, the homeowner's consumption is measured in individual time intervals, such as 15 minutes or 1 hour. This interval data is typically collected by the utility every few hours or daily. Verification of data is thereby made simple because the sum of the entries in each time interval must add up to the total. If a meter's aggregate reading were to suddenly shift, or if a single interval suggested an unrealistic level of consumption, then validation, estimation, and editing software in the utility office could automatically identify the problem and either correct it or flag the issue for customer service.

### *Voltage Transient Susceptibility*

The electronic circuits of solid state meters connect to the AC line to draw operating power and to perform voltage measurement. Although the line voltage is nominally regulated to a stable level, such as 240VAC, transients and surges can occur during events such as electrical storms. A range of electronic clamping and filtering components are used to protect the electronics from these voltage surges, but these components have limitations. The ANSI C12.1 metering standard specifies the magnitude and number of surges that meters must tolerate. In addition, some utilities have instituted surge withstand requirements for their meters that exceed the specification. In any case, surges that exceed the tested limits, either in quantity or magnitude, could cause meter damage or failure.[5]

Electromechanical meters had no digital circuitry. They utilized spark-gaps to control the location of arc-over and to dissipate the energy of typical voltage events. As a result, they were generally immune to standard surge events. This nature is evidenced in the section of ANSI C12.1 that specifies voltage surge testing, but allows that "This test may be omitted for electromechanical meters and registers."[6]

## Summary

Electromechanical meters are dependable products that have served society well. Over a hundred years, their design was optimized so that they provided an excellent combination of simplicity and reliability while providing a single measurement - cumulative energy consumption. Unfortunately, these products did not support the additional functionality needed to integrate customers with a smart grid, such as time of use and real time prices, a range of measured quantities, communication capability, and others.

For these utilities, the transition to solid-state electric meters is therefore not one of choice, but of necessity. Due in part to the large number of announced AMI programs, many homeowners in the United States will likely see their electromechanical meter replaced by a solid-state electronic device in the next five to ten years. During such a transition, there will likely be both real and perceived issues with solid-state designs that need addressing. Care must be taken to consider each case thoroughly and to use sound diagnostic practices to trace each issue to its root cause. Temptations to either blame or exonerate the solid state meter must be resisted. Ideally, each investigation should not only resolve any homeowner concerns, but also discover any product imperfections so that solid-state meter designs may be continually improved. When advanced metering functions are needed, reverting to electromechanical meters is not a viable option.

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5 *Testing and Performance Assessment for Field Applications of Advanced Meters*, EPRI, Palo Alto, CA. 2009. 1017833

6 ANSI C12.1-2001, Section 4.7.3.3 Test No. 17: *Effect of High Voltage Line Surges*

## EPRI Resources

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