A Review of Electrical Metering Accuracy Standards in the Context of Dynamic Power Quality Conditions of the Grid

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Abstract— **Numerous changes in electrical grid schemes, like the inclusion of renewable energy, the rise of non-linear loads and the emergence of electric vehicle charging, increases variable power quality conditions of the grid. In this dynamic scenario where energy could flow in both directions and the waveforms could be highly distorted, accuracy becomes a crucial factor for the correct measurement of electrical energy and power values. Errors in the assessment of these values have significant ramifications for revenue, billing and/or control. This non-ideal power quality scenario produces an error in electricity meters, that is not yet well known since there is no standardised procedure to calibrate meters under typical or emerging distorted waveform conditions. Current standards relevant for revenue energy meters like EN 50470-3:2006 allows measurements error up to ±2.5% while local regulations could be even more permissive. In order to establish an electricity fair trade market and meet expectations from consumers and utilities, electricity meters should arguably comply with higher accuracy standards. In this paper, the pertinence and possible impact of including tests under distorted waveform conditions, as well as new accuracy requirements on standards applicable to electricity meters for billing purposes will be discussed.**

Index Terms-- **Accuracy, Electricity Meter, Power Quality.**

I. INTRODUCTION

The electrical grid is on the way to change the paradigm to the Smart Grid in several countries around the world. From the Electrical Generation, the transmission schemes, communications and new energy efficient devices been used by customers. The transformation will cover every aspect of the traditional grid.

While these innovations are thought to optimise the electricity production-usage, reduce the carbon emission and prevent electrical losses or shortfalls, there are some secondary effects. One of those non-desirable side effects is the Power Quality detrimental due to harmonic contents present in renewable generation sources and non-linear loads.

It is known that poor Power quality produces an error on electricity meters, and this error seems to be more significant in static meters than in electromechanical [1]. What is still uncertain is the relationship between Power quality and accuracy on electricity meters and there are many causes of this uncertainty. First, static meters are complex metering instruments that are constructed with different sensing technology and different approaches to calculate the energy consumption, depending on the processor they used and the calculation algorithm. Moreover, different sampling techniques and filters could be adopted by any particular Electronic Electricity Meter (EEM) manufacturer.

Second, even when all meters need to meet accuracy standards before they are allowed to be installed, such standards do not take into account real operative conditions where variable power quality is present.

In this paper, a review of electricity meter technology and the issues they faced when are exposed to non-sinusoidal voltage or current waveform is presented. Then, applicable standards related to accuracy are analysed. Finally, the pertinence of expanding the tests for electricity meters under non-sinusoidal waveform condition is discussed.

II. ELECTRICITY METERS

Electricity Meters have been existed for many years allowing customers and utilities to account the Electrical Energy Consumption. From the classic Electromechanical to the Solid State version, meters are a critical part of the correct monitoring and performance of the electrical grid [2]. Since the 90's, Electromechanical Meters have been replaced by Static versions and more recently by Smart Meters. Nevertheless, all types of meters are designed to measure perfect sine waveforms. In this section, a brief review of Meters technologies and the issues they faced under distorted waveform conditions is presented.

A. Electromechanical Electricity Meter

The principle of operation of Electromechanical Induction Meter has been widely described in the literature [1], [3], [4]. This analogue meter uses Ferraris' principle to produce torque in a free to rotate disk exposed to two 90 degrees-shifted alternating magnetic fluxes. One of these fluxes is produced by the voltage coil and the other is generated by the current coil. The rotation speed of the disk is proportional to the Electrical Power flowing across the meter and the number of revolutions, proportional to the Electrical Energy, is accounted by a mechanism.

Due to the moving parts, this type of meter suffer wear and tear and is also sensible to many environmental changes like temperature, humidity and vibration, among others, that could affect its accuracy [5]. The electromechanical meter has an expectancy life of at least twenty years, after which the disk could run slower and register up to 3% less electrical consumption as shown in Fig. 1 [2].

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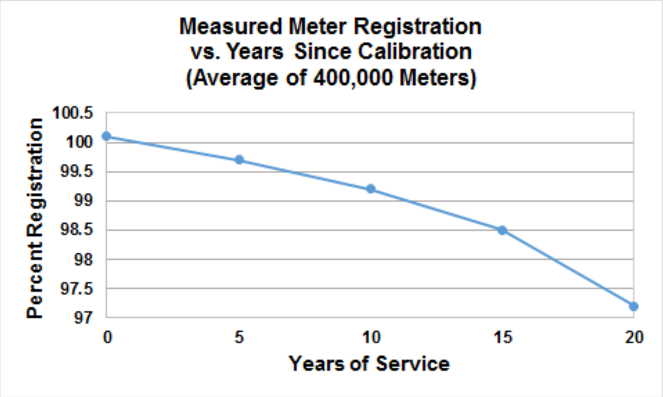


Fig 1. Electromechanical Meter Registration Loss vs. Time [2].

Under distorted waveform conditions, electromechanical meters have shown an acceptable performance compared with electronic meters, according to different laboratory-based tests results [1], [6]–[8].

In [6] and [7], analogue meters under non-sinusoidal condition tend to register less energy consumption (negative error), but such error seems to be negligible and favourable to the consumer [9].

In [1], three different Distorted Load Sets were run and in all cases, the electromechanical meter shows more accurate measurements than electronic meters, with an error range from -0.3% to 1.9%, compared to a calibrated energy system analyser.

By the other hand, disturbances such as Frequency changes, unbalance and low order harmonics seems to have a more significant impact in the measurement error of electromechanical meters, according to the laboratory tests in [10].

B. *Static Electricity Meter*

The Static Electricity Meter, unlike Electromechanical, has not moving parts; it is an Electronic device composed of different sub-systems such as Power supply, Metering engine and processing engine. The most sophisticated meters, known as Electricity Smart Meter, also includes communication capabilities and other features.

Static Meter could have different types of sensor for the voltage and current signals e.g. resistive divider, voltage transformer (VT), current transformer (CT), Rogowski Coil, Hall Effect-based sensor or shunt resistor.

Each sensor has advantages and disadvantages [11] as can be observed in Table I and therefore could lead to different accuracy issues, depending on particular working conditions.

The analogue signals from the sensor are converted to a digital format after proper conditioning. Then, a Digital Signal Processor (DSP) or a microcontroller with DSP capabilities does all the calculations for relevant Electrical parameters [12].

Nowadays, it is common to find Energy Metering Integrated Circuits (IC) inside the Static meters. These specialised IC's perform Signal Conditioning, Analogue to Digital Conversion and Computation, all in the same chip.

TABLE I
ADVANTAGES AND DISADVANTAGES OF DIFFERENT CURRENT SENSORS [11]

Characteristic	**Current Transformer**	**Hall Sensor**	**Rogowski Coil**	**Shunt Resistor**
Linear amplitude and phase	0	-	++	++
Wide range – 5 decades	0	+	++	0
Wide bandwidth	0	0	++	+
No DC saturation	-	-	++	++
Low temperature coeficient	+	-	++	0

Furthermore, Energy Measurement Chips usually has the ability to calculate additional parameters such as RMS voltage, RMS current, active power, reactive power, apparent power, harmonics measurements, line frequency and power quality measurements [13]. All the calculations can be done with high accuracy, fulfilling (and many times overcoming) relevant IEC and/or ANSI standards.

However, Energy Measurement Chips from different vendors could implement different approaches to calculate electrical Energy and Power as well as other parameters. For example, to calculate RMS values such as current and voltage, a *Squared-Average* method (Fig 2) or a *Mean Absolute* Value approach (Fig 3) can be used [13].

The Mean Absolute Value method to calculate the RMS value is high accurate, but only for the fundamental signal. Therefore, in presence of harmonic contents, this approach can be inaccurate.

The line Frequency can be also obtained by different techniques, such as Fourier analysis or zero crossing detection. Nonetheless, zero crossing technique could lead in misread of the frequency under high distorted waveform conditions [8].

As can be noticed, the static meter is a much more complex system than electromechanical and hence, the susceptibility to error is higher.

Accuracy-related issues, when Static meters are exposed to distorted waveform conditions have been reported in literature during the last years [1], [8], [9].

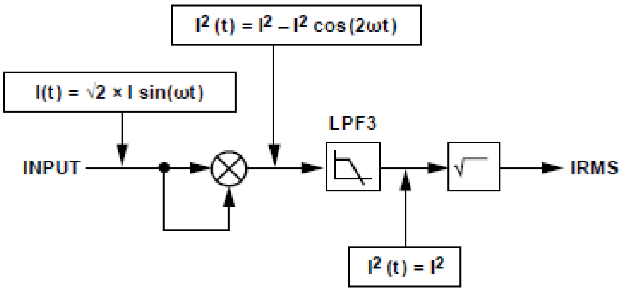


Fig 2. Squared-Average method for RMS current value calculation for the ADE5166/ADE5169/ADE5566/ADE5569 Energy Measurement Chips (Courtesy of Analog Devices, Inc.).

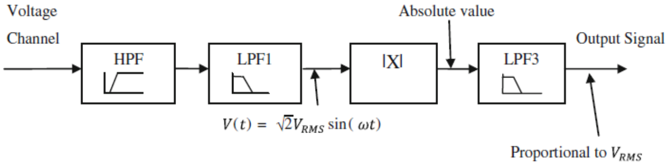


Fig 3. Mean Absolute Value method for voltage RMS calculation [13].

The results of distorted load sets tests in [1] shows that static meters could have accuracy errors from -6.6% to 6.5%, compared with the measures of a calibrated energy system analyser.

More surprising and disturbing results can be found in [8], where ten Static Energy Meters were submitted to experimental tests which include an electrical heater (resistive), 30 Compact Fluorescent Lamps (CFL) and 20 Light Emitting Diode (LED) lamps. The loads were controlled by a Dimmer at 0°, 45°, 90° and 135°. The High distorted waveforms due to the LED+CFL lights, with dimmer at 90° and 135°, can be observed in Fig. 4. The tests were run several times and the results compared with the measures of a Ferraris Electromechanical Meter. The deviation of the Energy Meters appears in Table II, and some of them are extremely high.

III. STANDARDS

International standards from both the International Electrotechnical Commission (IEC) for Europe and the American National Standards Institute (ANSI) for North America have been defined accuracy classes for Electricity Meters. These classifications are identified by a number or letter that represents the minimum accuracy permissible, expressed as percentage of the nominal full-scale reading. For example, ANSI C12.20 specifies the 0.2 and 0.5 classes for electricity meters (±0.2% and ±0.5% respectively) and IEC 62053-22 specifies the same level of accuracy for their own classes 0.2S and 0.5S.

Standards like IEC-62052, IEC-62053 and ANSI C-12 provides requirements for revenue meters that lack of definitions for non-sinusoidal waveform [12]. These standards apply to electromechanical or static meters and cover different tests and test conditions.

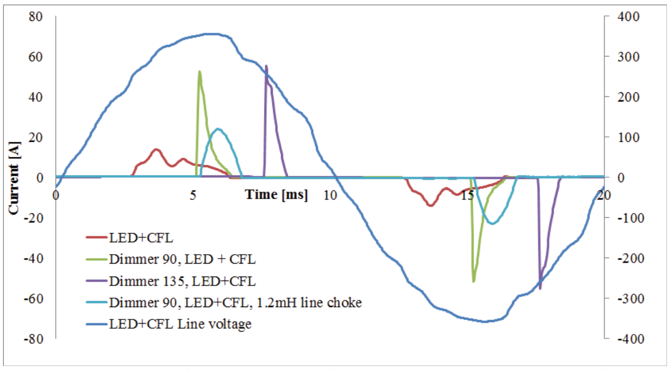
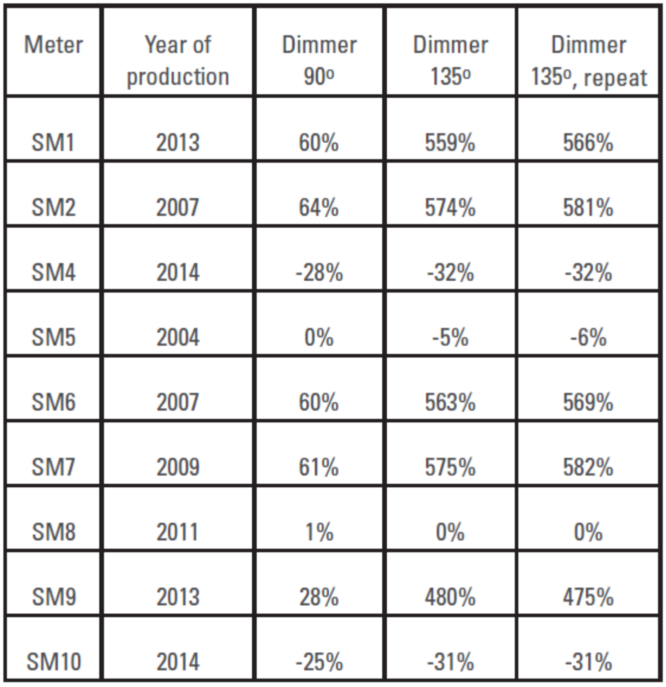


Fig 4. Current waveform LED+CFL lights, with dimmer at 90° and dimmer at 135° [8].

TABLE II
DEVIATION OF ENERGY METERS [8]



Meter	Year of production	Dimmer 90º	Dimmer 135º	Dimmer 135º, repeat
SM1	2013	60%	559%	566%
SM2	2007	64%	574%	581%
SM4	2014	-28%	-32%	-32%
SM5	2004	0%	-5%	-6%
SM6	2007	60%	563%	569%
SM7	2009	61%	575%	582%
SM8	2011	1%	0%	0%
SM9	2013	28%	480%	475%
SM10	2014	-25%	-31%	-31%

Regarding the accuracy, IEC 62053-11 standard indicates the limits of error due to variations of the current and other influence quantities and clearly states how should be the “normal” test conditions [14].

In spite of this existing high-accuracy standards, Electricity Meters used for billing purposes needs to meet the accuracy criteria from other international organisations like the European Measuring Instruments Directive (MID). MID approved meters need to accomplish accuracy limits shown in Table III. These limits are derived from the harmonised European standard EN 50470-3:2006 [15] which is related to IEC-62053-21:2003 and IEC-62053/22:2003 standards.

Since MID accuracy classes are derived from IEC standards, the test conditions shall be the same, such as the waveform distortion factor observed in Table IV.

TABLE III
MAXIMUM PERMISSIBLE ERROR LIMITS FOR MID APPROVED ELECTRICITY METERS [15]

MID Accuracy Class	**Maximum Permissible Error Limits**
Electricity Meters (Class A)	±2.5% at minimum current flow
	±2.0% at one fifth of maximum current flow
	±2.0% at the maximum current flow
Electricity Meters (Class B)	±1.5% at minimum current flow
	±1.0% at one fifth of maximum current flow
	±1.0% at the maximum current flow
Electricity Meters (Class C)	±1.0% at both minimum current flow
	±0.5% at one fifth of maximum current flow
	±0.5% at the maximum current flow

As can be observed in tables III and IV, MID requirements for accuracy are the same for Electromechanical or Static Meter even if static meters can achieve higher accuracy standards. Even more, some countries could have particular legislation to prescribe the limits of accuracy. The National Measurement & Regulation Office in the UK, for instance, considers any Electricity Meter “accurate if the permitted margins of error do not exceed +2.5% to -3.5% throughout the entire load range at which the meter is designed to operate” [15].

TABLE IV
SINUSOIDAL VOLTAGES AND CURRENTS WAVEFORM TOLERANCES FOR ACCURACY TEST CONDITIONS

Standard	Class	Distortion factor less than:
IEC 62053-11:2003 (Electromechanical)	0.5	2 %
	1	2 %
	2	3 %
IEC 62053-21:2003 (Static)	1	2 %
	2	3 %
EN 50470-3:2006 (Static)	A	3 %
	B	2 %
	C	2 %

Particular attention should be paid to the fact that for any case, the distortion factor of the sinusoidal waveform during accuracy test conditions shall be less than 3 %.

IV. TESTS UNDER DISTORTED WAVEFORM CONDITIONS

The “normal” operative conditions of the grid for electricity meters are no more like the quasi-perfect sinusoidal, considered by IEC and ANSI standards [9]. Even more, such conditions are changing fast and constantly. The upcoming changes on the electrical grid will also have implications for conditions of the electrical grid in a way that is still not well known. New lighting devices (LED and CFL), Electrical Vehicle Charging, Active Power Electronic Interfaces (switching power electronic converters), Renewable Power Sources, Power Line Communication and Underground Cables (replacing overhead lines all around the world) will change the levels of emission, immunity and transfer for electrical disturbances, especially on the low-voltage electrical systems [16].

As can be observed in Table V [16], there are different disturbances due to devices and technologies widely adopted in modern Electrical Grid. The analysis of the whole impact of these technologies is complex; the waveform distortion profile produced by a particular LED lamp, CFL or PV inverter could be different from vendor to vendor. Even more, there is almost an infinite number of possible combinations of such elements, which could either improve or deteriorate the Power Quality.

For this yet unpredictable Power Quality scenario, test and test conditions for electricity meters should be re-defined in a more likely “real” operative conditions. The inclusion of such tests in relevant standards will allow an Electricity Fair Trade, where customers will pay the amount of energy consumed (active or reactive), be penalized if deteriorate Power Quality of the grid (exceed permissible harmonic emission level) or rewarded if they improve Power quality of the grid (absorbs harmonic contents).

Some of the challenges to properly update accuracy standards are:

- define the test and test conditions under distorted voltage and current waveforms;
- define a new Maximum Permissible Error (MPE) for Electricity Meters for revenue;
- review of existing meters capabilities and limitations for the correct measurement of electrical energy consumption under distorted waveform conditions.

V. CONCLUSION

The Power Quality of the Electrical Grid, due to the effect of diverse emerging technologies and devices, are constantly changing the waveform conditions of voltage and current. These changes are more significant in the low-voltage electrical systems.

Current standards related to the accuracy of Electricity meters for revenue allows a measurement error up to ±2.0%, with a waveform distortion factor less than 3%. Such conditions are not representatives of the real working conditions.

Some Static meters, exposed to unlikely (but still possible) extreme working conditions, have presented high

TABLE V
DISTURBANCES ON THE LOW-VOLTAGE ELECTRICAL SYSTEMS DUE TO DIFFERENT TECHNOLOGIES/DEVICES

	Current Distortion	Voltage Distortion	Harmonic Emission	Interharmonic Emission	Supraharmonic Emmision	Unbalance	Capacitance Increase
LED and CFL	✓		✓		✓		
Dimmer		✓					
Renewable Power Sources (Solar and Wind)				✓	✓	✓	✓
Active Power Electronic Devices	✓		✓		✓		
Overhead lines to cables			✓				✓
Power Line Communication					✓		

measurement errors in the presence of distorted waveforms.

New accuracy requirements should ensure Electricity meters never exceeds the MPE at any working condition.

Regulatory bodies should promptly agree in how standards will include accuracy tests for existing and emerging distorted waveform conditions for an Electricity fair trade.

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