MSL Technical Guide 33

Electricity Metering: Advice for Class B Approved Test Houses

Introduction

The New Zealand requirements for revenue electricity metering are given in Part 10 of the Electricity Industry Participation Code ('the code') [1]. The code continues to be revised regularly, but the essential requirements for ensuring the accuracy of metering installations have not really changed over the last 20 years. The current version (23 February 2015) is some one hundred and five pages long and is structured so that compliance requirements can be audited almost by yes/no answers to each clause in turn. The downside to such auditable clarity is that the code is less helpful in explaining exactly how and why, technically, things need to be done.

This guide tries to clarify the basic technical/scientific aims of the code and offers practical guidance on some of the more challenging requirements. The advice given here will help Approved Test Houses (ATH) provide measurement information that is scientifically sound. With a focus on good measurement practice, this guide does not aim to address the equally important issues of good safety and engineering practices.

The primary aim of the code is to manage the dollars at risk due to any inaccurate data from a metering installation. While financial risk is inherent for market traders, it is essential that there can be complete confidence in the metering information used for market reconciliation. Scientific concepts of traceability to international measurement standards, including measurement uncertainty, are used to minimise unnecessary risks due to metering. In the code, all of these considerations are condensed into the technical requirements of Schedule 10.1.

Following an explanation of the key concepts in schedule 10.1, this guide looks primarily at issues faced by class B ATHs. There is no expectation that class B ATHs have an in-depth capability for evaluating measurement uncertainty, but they do need a basic capability to manage uncertainties in the certification process.

Schedule 10.1 Concepts

In Table 1 of schedule 10.1 the columns that summarise the requirements for accuracy of metering installations are under the heading 'Accuracy tolerances', divided into 'Maximum permitted error' and 'Maximum site uncertainty'. While the table appears on page 31 of the code, the key scientific explanatory information is in clause 22 of schedule 10.7 on page 80. This clause is more detailed because it is aimed at higher category sites and it clarifies that the concepts of error and uncertainty being used in the code have quite specific scientific meanings. It is important not to interpret them casually in terms of common language usage.

Although the actual measured value of the error of a metering site is just a single number, the additional step of calculating the uncertainty in that measured error leads to us representing our knowledge of the error as a range of values (an error interval). In Fig. 1 the range of values is represented as a horizontal line showing values extending from the measured error minus the uncertainty to the measured error plus the uncertainty. In a statistical sense this means that we are willing to bet that the actual error of the metering site lies somewhere on the horizontal line.

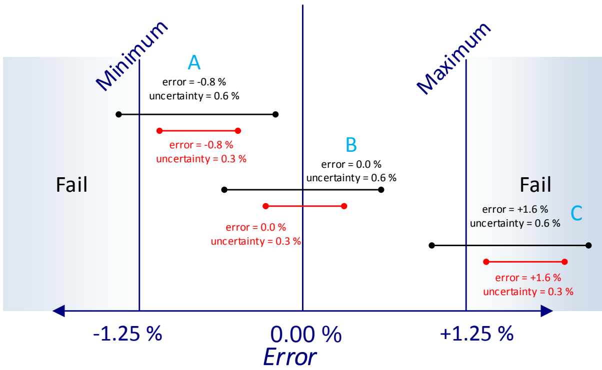

Figure 1. The maximum permitted error of ± 1.25 % is represented as an acceptable region lying between the vertical lines at -1.25 % and +1.25 %. Three scenarios (A, B, C) are shown where the black and red horizontal lines represent the same measured error within each scenario, but with an uncertainty of 0.3 % for the red line and 0.6 % for the black line.

The maximum and minimum permitted errors are shown as vertical lines rising from the horizontal error axis. When the error interval falls entirely between the maximum and minimum permitted errors the metering installation passes. If any part of the error interval extends into the fail regions, then the installation is deemed to fail. In scenario 'A' the black line fails and in scenario 'C' both the black and red lines fail. In scenario 'B' both the black and red lines pass.

Looking at scenario 'A', it can be seen that the larger error interval (black) fails even though the measured error is identical, at -0.8 %, to that of the red interval which passes. So it can be seen that a metering installation might be failed unfairly because it has been calibrated against less accurate equipment (black interval), while better equipment could have achieved a lower uncertainty (red interval) and given a pass. It is for this reason that the code imposes a maximum permitted site uncertainty in Table 1. This sets a minimum standard for test equipment so that there is not only confidence in the accuracy of the metering installations that pass, but also confidence that metering installations are not failed unfairly.

Selected Component Metering

For low category sites, the code offers a simplified path for complying with the requirements for metering installation accuracy. Manufacturers provide metering equipment that meets internationally agreed specifications, usually IEC standards. Complying with IEC standards ensures that the equipment will meet at least the minimum requirements for operating successfully in the field. **One note of caution is that the number chosen to label the IEC accuracy class of a meter or transformer does not equal the maximum permitted error requirement that the device will meet.** The class number reflects a typical accuracy for the device so, for example, a class 2 meter might not pass a requirement for a maximum permitted error of even 3 %.

Clause 11 of Schedule 10.7 explains the selected component procedure. Table 1 of Schedule 10.1 lists the IEC accuracy class specifications for the selected components. We will now look at what needs to be done to provide assurance not just that the process has been followed, but that the metering installations meet the maximum permitted error requirements.

(a) Meter Only

It is possible to make a detailed error calculation [2] for any fully calibrated and tested meter in a category 1 installation. However, under the selected metering approach we are likely to know only that the meter has been tested to conform to a specific standard, say IEC 62053-21. A recommendation [3] from the International Organization of Legal Metrology (OIML) is to use a simplified calculation that gives a maximum permissible error for a meter that complies with the IEC standard. Each different source of error (e.g. voltage, frequency) is allowed a maximum value in the standard. It is reasoned in [3] that taking the square root of the sum of the squares of each error source gives the maximum error that a compliant meter could have.

Power Factor:	unity		0.5 inductive	
Class:	2	1	2	1
Maximum % error shift permitted for:				
base error	2.0	1.0	2.5	1.5
voltage variation	1.0	0.7	1.5	1.0
frequency variation	0.8	0.5	1.0	0.7
variation of harmonics	1.0	0.8	1.0	0.8
temperature variation	0.1	0.05	0.15	0.07
Combined maximum permissible % error	2.6	1.5	3.2	2.1

Table I. The maximum permissible error for single phase class 2 and class 1 meters complying with IEC 62053-21 and operated above 10 % of the base current. The maximum error depends on power factor. See Annex B.1 of [3].

Unfortunately, in Table I **the calculation does not show either the class 2 meter achieving a ±2.5 % error or the class 1 meter a ±1.25 % error as required in Table 1 of Schedule 10.1.** The code does point out that it is allowable to use a more accurate class of meter as a selected component. A class 1 meter comfortably meets the accuracy requirements of category 1 metering installation even at 0.5 power factor.

In reality many meter manufacturers produce meters to much better tolerances than the maximum error levels allowed in the IEC standards. This is acknowledged in [3] and two alternative simplified calculation methods are offered which use detailed information from the type-testing reports for specific meter models.

Table II uses measurements from a test report for a specific make and model of meter. It is not unusual for a manufacturer to be able to guarantee a base error well within the class accuracy specification[1]. It can be seen that the maximum error of the meter is well within the 2.5 % requirement.

Power Factor:	unity	0.5 inductive
Class:	2	2
Maximum % error shift permitted for:		
base error	0.2	0.4
voltage variation	0.0	0.1
frequency variation	0.0	0.2
variation of harmonics	1.0	1.0
temperature variation	0.1	0.15
Combined maximum permissible % error	1.0	1.1

Table II. The maximum permissible error for a specific make and model of a single phase class 2 meter operated above 10 % of the base current. Maximum errors are as reported for a tested sample. The maximum error depends on power factor. See Annex B.2.1 of [3].

It is very important that the metering installation designer has access to full test reports for the make and model of chosen meter. A simple calculation of the maximum permissible error can then be completed. It can be assumed that a category 1 metering installation is certifiable if the maximum meter error at 0.5 lagging[2] power factor is within the Schedule 10.1 requirements. Doing this fulfils the ATH's responsibility in clause 3.1(b) of schedule 10.7 to approve that the design report confirms that the metering installation 'will provide the required accuracy'.

As type-test reports are produced from tests on only a few units from the manufacturer, it is important to also check accuracy results for production batches. Note that the concept of 'maximum permissible error' is essentially the same as 'maximum permitted error', but avoids using the separate uncertainty term of Table 1 of Schedule 10.1. The control of uncertainty occurs in the approved test laboratory report. Measurement results in the test report must have uncertainties that are no larger than the maximum overall uncertainties listed in Table 6 of Schedule 10.1 for different classes of meters[3].

(b) Meter with a CT

A selected component solution is also possible when combining a meter and current transformer (CT) for category 2 and some category 3 installations. A similar simplified approach can be taken for calculating a maximum permissible error. CTs complying with classes 1 and 0.5 of IEC 60004-1 are identified as suitable.

One complicating feature of a CT is that the effect of its phase displacement on the metering installation error depends on the power factor of the load. A sufficiently accurate calculation is to multiply the CT phase displacement (in centiradians) by the tangent of the phase angle (between voltage and current) to give the additional % error due to the phase displacement. It is still common to give transformer phase displacements in

[1] *Note that a class 2 meter cannot be used where the code requires a class 1 meter.*

[2] *One survey found the average power factor for a domestic consumer was about 0.7 lagging.*

[3] *Also, see clause 3.3(a) of Schedule 10.4.*

minutes. A summary of the factors needed for the calculation is given in Table III.

multiply minutes by	0.029	to give centiradians
mutliply centiradians by	0.0	to give % error at unity power factor
mutliply centiradians by	0.75	to give % error at 0.8 power factor
mutliply centiradians by	1.73	to give % error at 0.5 power factor

Table III. Multiplying factors for calculating metering installation error due transformer phase displacement.

In Table IV the additional maximum permissible error for a metering installation is calculated for CTs that meet class 1 and 0.5 requirements. **Using only the IEC specification, there are quite large errors for non-unity power factors.** The IEC specification allows these errors to be about three times larger by the time the current is as low as 5 % of full scale[4]. The error due to the CT is added to the error due to the meter by taking the square root of the sum of the squares of the two errors. Using the calculations in Table I and Table IV for a power factor of 0.5, a class 2 meter with a class 1 CT could have an error interval as large as ±4.6 %.

Power Factor:	unity		0.8		0.5	
Class:	1.0	0.5	1.0	0.5	1.0	0.5
Maximum % error shift permitted for:						
base error	1.0	0.5	1	0.5	1	0.5
phase displacement	0.0	0.0	1.4	0.7	3.1	1.6
Combined maximum permissible % error	1.0	0.5	1.7	0.8	3.3	1.6

Table IV. The maximum permissible metering % error due to the CT at 100 % current for class 1 and class 0.5 CTs.

In reality it is not difficult to achieve a much better performance, but only by using some more detailed information about the CT. The IEC limits apply over a wide range (25 % to 100 %) of rated burden, while a metering installation is designed for a specific fixed burden. Many manufacturers will produce CTs that have a base error very close to zero at the rated burden.

Again the strong recommendation is that the metering installation designer has access to full test reports for the make and model of both the chosen CT and the meter. It is then possible to determine the realistic actual maximum ratio error and phase displacement when the CT is used with the designed burden. For example if we imagine the CT is to be combined with the meter specified in Table 2 then it would be prudent to be able to demonstrate that the metering installation meets the code accuracy requirements at 0.5 power factor and 10 % current. The meter contributes 1.1 % to the maximum permissible error and this leaves a maximum error of 2.2 % for the transformer ($\sqrt{\mathbf{1.1^2 + 2.2^2}} \cong \mathbf{2.5}$). If we assume the ratio is within 0.5 % then the maximum permissible phase defect is 1.3 centiradians (43 minutes). If the ratio error was as large as 2 % then the phase defect would need to be less than 0.6 centiradians (20 minutes).

The control of transformer burdens is addressed in many clauses of the code and clearly the burden is fixed. However, the assumptions behind the requirements for selecting a burden are not explained. From the scientific perspective the real judge of whether or not the connected burden is appropriate is that the metering installation can be shown to meet the accuracy requirements of the code with the connected burden.

[4] *The meter calculation assumed a current greater than 10 %.*

Comparative Recertification

The code recognises that it can be impractical to disconnect current transformers from some metering installations for the purpose of calibration. However, there is still a need to certify such installations and so clause 12 of Schedule 10.7 describes comparative recertification. In particular, clause 12.3(c) requires that “the overall metering installation accuracy meets the requirements of Table 1 of Schedule 10.1”. How to calculate a full site error and uncertainty using a field instrument with clamp CTs at the prevailing load is not explained.

Taking a simple view, comparative recertification provides just two numbers that need to be analysed. These are the reading from the portable standard and the reading from the metering installation. It is a requirement that the installed meter has been certified (clause 12.2(b), Schedule 10.7) and so the maximum error for the meter is known. Similarly the maximum error for the portable standard is known.

clamp CT	typical		high performance	
Power Factor:	unity	0.5 inductive	unity	0.5 inductive
Uncertainty for:				
clamp CT ratio	0.3	0.3	0.1	0.1
clamp CT phase effect	0.0	1.5	0.0	0.15
Portable meter	0.2	0.2	0.2	0.2
Portable standard total	0.5	1.6	0.5	0.5

Table V. The maximum error of the portable standard is calculated at two power factors and with two different clamp CTs. All values are as % error.

In Table V the maximum error is calculated for a portable standard used at two power factors with two different clamp CTs. The ‘typical’ clamp CT has a maximum error of 0.3 % with a maximum phase displacement of 0.5° and the ‘high performance’ clamp CT has a maximum error of 0.1 % with a maximum phase displacement of 0.05°. At unity power factor the maximum error of the portable meter with clamp CTs is under 0.6 % for both types of clamp CT. Only the ‘high performance’ clamp continues to better 0.6 % at a power factor of 0.5.

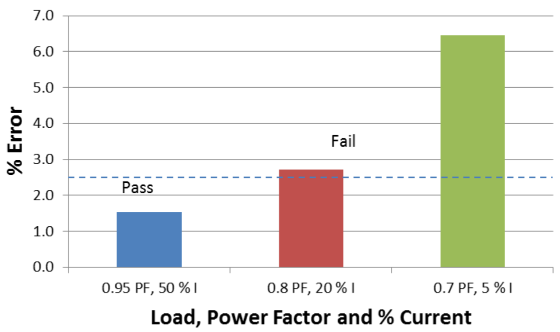

Figure 2. Metering installation error at three different loads (0.95 PF, 50% I; 0.8 PF, 20 % I; 0.7 PF, 5 % I). Using IEC specifications for a class 1 CT and class 1 meter.

Even though it is practical to achieve an uncertainty of better than a 0.6 % with a portable standard, there is an unavoidable limitation to this method for certifying a metering installation. The field measurement can only confirm that the installation is accurate at the prevailing load and the environmental conditions at the time of measurement. It remains possible that the installation might fail at, say, a different current, power factor or temperature. In Fig. 2 the maximum error of a metering installation has been calculated for three different loads. The 2.5 % accuracy requirement is met only for the first load at 0.95 power factor and 50 % current. It might seem that the low 5 % current for the 0.7 power factor load means it is unimportant in terms of the total bill. In fact fourteen hours at the low current uses as much energy as one hour at the high current. The consumer is entitled to have both loads measured accurately.

Additional information is required to give confidence that the installation will remain accurate for all relevant conditions. Given that the meter has been separately certified, any possible accuracy failure would be most likely due to the CT. The greatest changes in CT error will be observed between full current, unity power factor and low current, poorer power factor. **It is strongly recommended that the comparative measurement is done over a period when there is a representative variation in current and power factor.** An extended day-night measurement will give greater confidence in the result.

With more time to make measurements over a range of currents and power factors and with a more detailed analysis, this method could come close to the accuracy of a fully calibrated approach. However, the simplified approach is allowed for in the code as a cost efficient solution.

Summary

A class B ATH must ensure that site certifications are based on measurements made with appropriate uncertainties. So it is important to ensure that all testing instruments have been calibrated by approved calibration laboratories and that type-test reports for metering components are from approved test laboratories. Approved laboratories are carefully defined in clause 1.1 of [4], allowing the use only of laboratories that have had independent audits of their quality systems and have also been assessed by technical experts in calibration and/or testing. It is still important to check that reports from these laboratories quote uncertainties that are not greater than the allowed maxima in Table 6 of Schedule10.1.

In this guide we have emphasised that the design report needs to take into account the tested performance of the particular meter and CT models used in the installation in order to ensure that the accuracy requirements of the code are met. This removes any risk from using components that only just meet the IEC specifications and so not meeting the code's accuracy requirements for the overall metering installation. Simple approaches to the uncertainty calculation for designers are given in Tables II and IV. In Fig. 3 the flow chart shows where the designer and ATH need to analyse and review the testing results.

For field calibrations using the comparative method a calculation needs to be made as in Table V. For the calculations the maximum error terms can be taken from the manufacturer's specifications. This is allowable so long as the calibration report for the field instrument confirms that it is within specification.

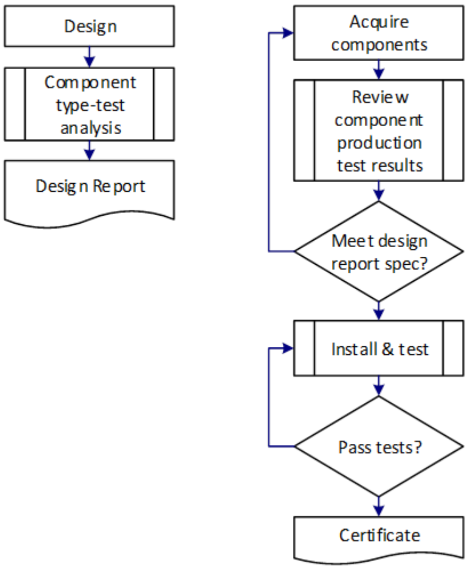

Figure 3. Flow chart showing where reviews of component type-test reports and of design reports are important in the design and certification process.

The simplified uncertainty calculations in the tables are conservative and give uncertainties no smaller than if a more detailed calculation is made. The calculations provide objective evidence that the accuracy requirements of the code are met. If there is any doubt about issues relating to uncertainty it is strongly recommended that additional advice is sought from either a class A ATH or from MSL.

Following this guide will ensure that a metering installation is accurate, but it is still vital not to overlook compliance with the detailed clauses of the code.

References

[1] Electricity Industry Participation Code, Part 10 – Metering, https://www.ea.govt.nz/code-and-compliance/the-code/part-10-metering/, 2015.

[2] Keith Jones and Tom Stewart, "Calculation of Metering Installation Error, Part 2 – A Solution", Callaghan Innovation report no.123, June 2014.

[3] International Organization of Legal Metrology, "OIML R 46-1/-2, Active electrical energy meters," http://www.oiml.org/en/files/pdf_r/r046-1-2-e12.pdf, 2012.

[4] Electricity Industry Participation Code, Part 1 – Preliminary Provisions, https://www.ea.govt.nz/code-and-compliance/the-code/part-1-preliminary-provisions/, 2015.

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