ALTERNATIVE TESTING MINIMUM REQUIREMENTS:

Low Voltage Current Transformer Metering Installations

PREPARED BY:	Metering and Settlements
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FINAL

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Version Release History

VERSION	DATE	DETAILS
V0.1	January 2012	Initial draft release for the inspection, maintenance and testing of low voltage *current transformer metering installation*(s).
V0.2	March 2012	Incorporated CTTWG feedback, technical review and following the review by independent experts.
V1.0	April 2012	First live final version.
V1.1	May 2012	Updated document to include all LV *CT*s as part of sample testing, with associated changes to the inspection requirements. Also new paragraph in section 6 for submission of results.

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1. GENERAL

This alternative testing document details the minimum requirements (Requirements), which responsible persons must include in their asset management strategy when seeking *AEMO* approval for an alternative testing practice and that *Metering Provider*s, when operating on behalf of *responsible person*s must comply with when undertaking inspection, maintenance and testing services for low voltage *current transformer metering installation*s.

1.1 Purpose

These Requirements are established to facilitate clause S7.3.1(c)(2) of the *Rules* and outlines the obligations, technical requirements, measurement process and performance requirements that are to be performed, administered and maintained by a *responsible person*.

These alternative testing Requirements outline the:

a) Obligations and technical/operational requirements in the inspection, maintenance and testing of low voltage *current transformer metering installation* by a *responsible person*; and

b) Responsibilities assigned to the *Metering Provider* in support of the *responsible person*'s approved asset management strategy.

1.2 Interpretation

In this document words that are shown in italics have the meaning specified in the *Rules*.

A reference in this document to a provision in the *Rules* is taken to be a reference to that provision as renumbered from time to time.

In this document words in the singular include the plural and words in the plural include the singular.

In this document diagrams are provided as an overview. If there are ambiguities between a diagram and the text, the text shall take precedence.

1.3 Document Responsibility

There is no obligation under the *Rules* for *AEMO* to prepare this document. It is provided to assist *responsible person*s to develop asset management strategies that define alternative testing practices, other than time-based practices, as permitted under clause S7.3.1(c)(2) of the *Rules*.

2. BACKGROUND

2.1 Australian Energy Regulator

In March 2011, the Australian Energy Regulator (*AER*) requested information from the Australian Energy Market Operator (*AEMO*) on the status of testing of *instrument transformer*s in the National Electricity Market (*NEM*) in relation to obligations set out in the *Rules*.

AEMO prepared a report outlining that testing and inspection of *instrument transformer*s on *high voltage* (*HV*) sites has generally been completed in accordance with the *Rules*, however testing and inspection of *current transformer*s (*CT*s) on low voltage (LV) sites have been lacking. The report indicated that the information provided to the *AER* was based on Metering Asset Management Plans (MAMPs) prepared by *Metering Provider*s and that not all *instrument transformer*s were accounted for as most contractual agreements between *responsible person*s and *Metering Provider*s did not cover the testing of all *instrument transformer*s.

Subsequent to this, the *AER* sent a formal request to all the *responsible person*s in the *NEM* to provide details of the number of LV *CT*s for which each *responsible person* was responsible and to indicate how many have been tested.

The *responsible person*s identified to the *AER* that it was not viable to test all LV *CT*s in line with the requirements of the *Rules* due to the disruption caused to the customer and the challenges in arranging outages to undertake the testing.

The *AER* requested *AEMO* and the industry to consider alternative testing strategies that would satisfy the requirements of the *Rules*.

2.2 Current Transformer Testing Working Group

A proposal was made to the IEC/RMEC that a project be instigated to develop appropriate alternative testing strategies for LV *CT* testing. This led to the formation of the Current Transformer Testing Working Group (CTTWG).

The CTTWG published a ‘Proposed Strategy For In-Service Testing of LV Current Transformers’ in November 2011. In summary, the CTTWG preferred alternative strategy for LV *CT* sites in the *NEM* is to perform sample testing, where appropriate by variables, in tandem with an enhanced inspection regime for all LV *CT*s. The CTTWG output confirms that a guideline for the acceptance of alternative testing strategies that would be endorsed by *AEMO* is to be developed by *AEMO* under clause S7.3.1(c)(2) (this document).

3. SAMPLE TESTING METHODOLOGY

3.1 Flow Charts

The charts provided in Figures 1, 2 and 3 present an overview of the steps the *responsible person* needs to perform to determine the appropriate sample testing method and the subsequent actions required to complete the sample testing process.

3.1.1 Chart 1 - Sample Method Selection

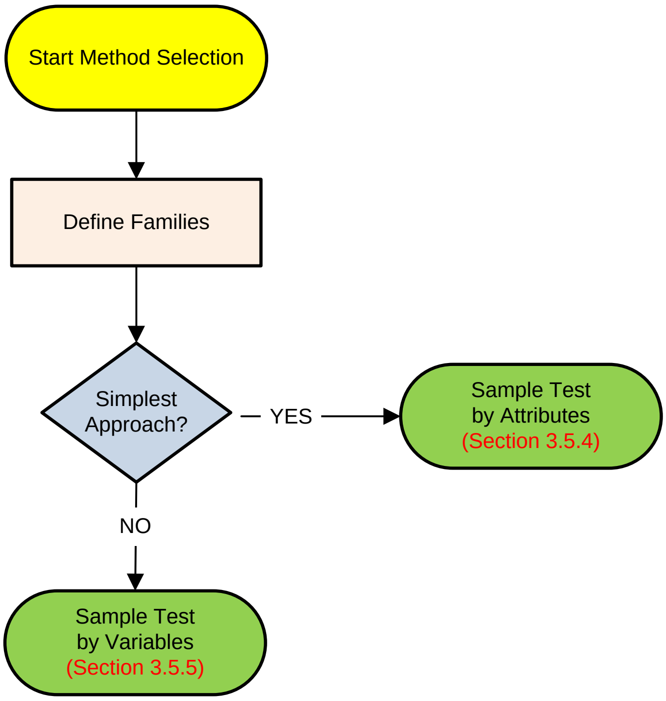

Figure 1: Sample Method Selection

3.1.2 Chart 2 - Sample Testing by Attributes

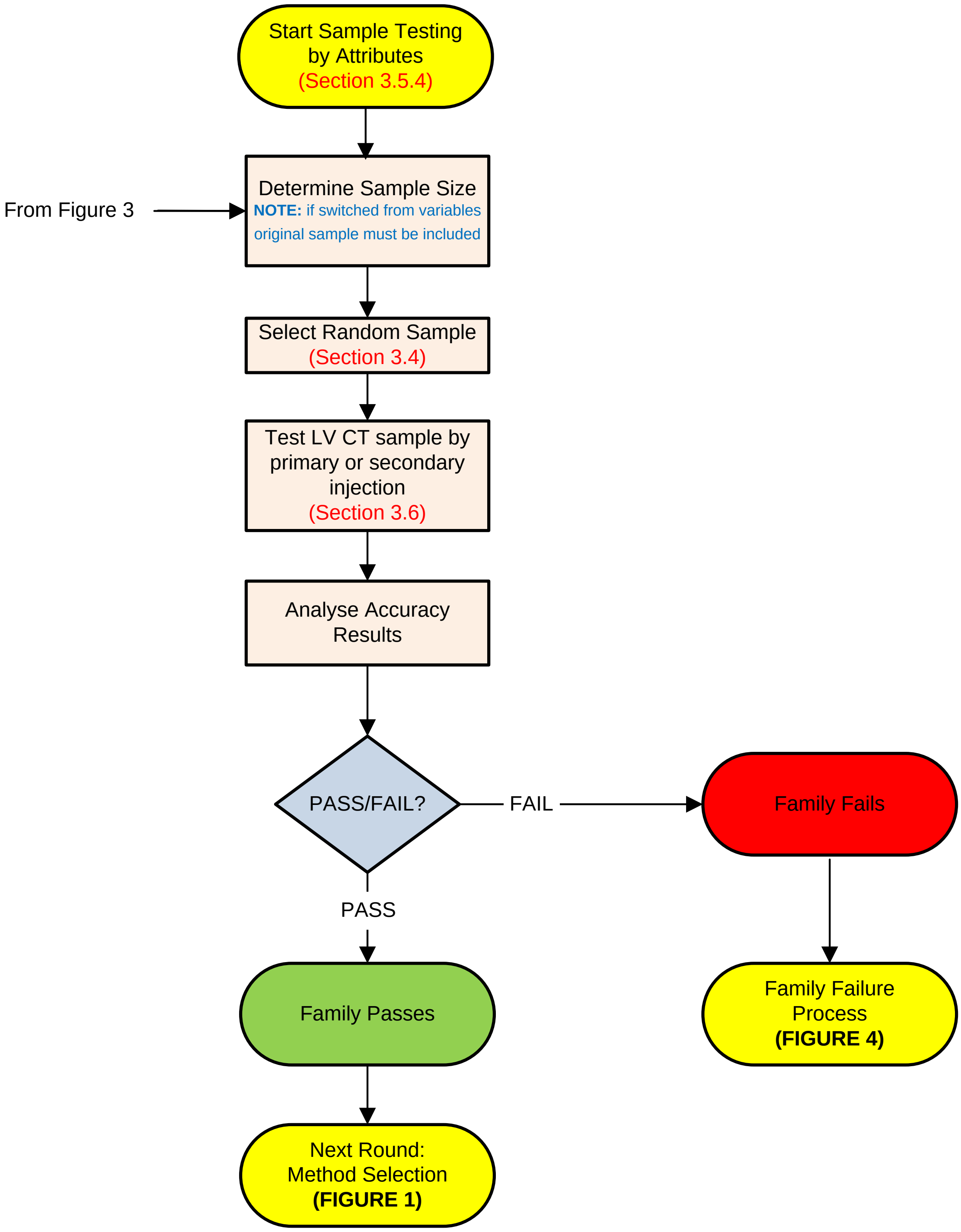

Figure 2: Sample Testing by Attributes

3.1.3 Chart 3 – Sample Testing by Variables

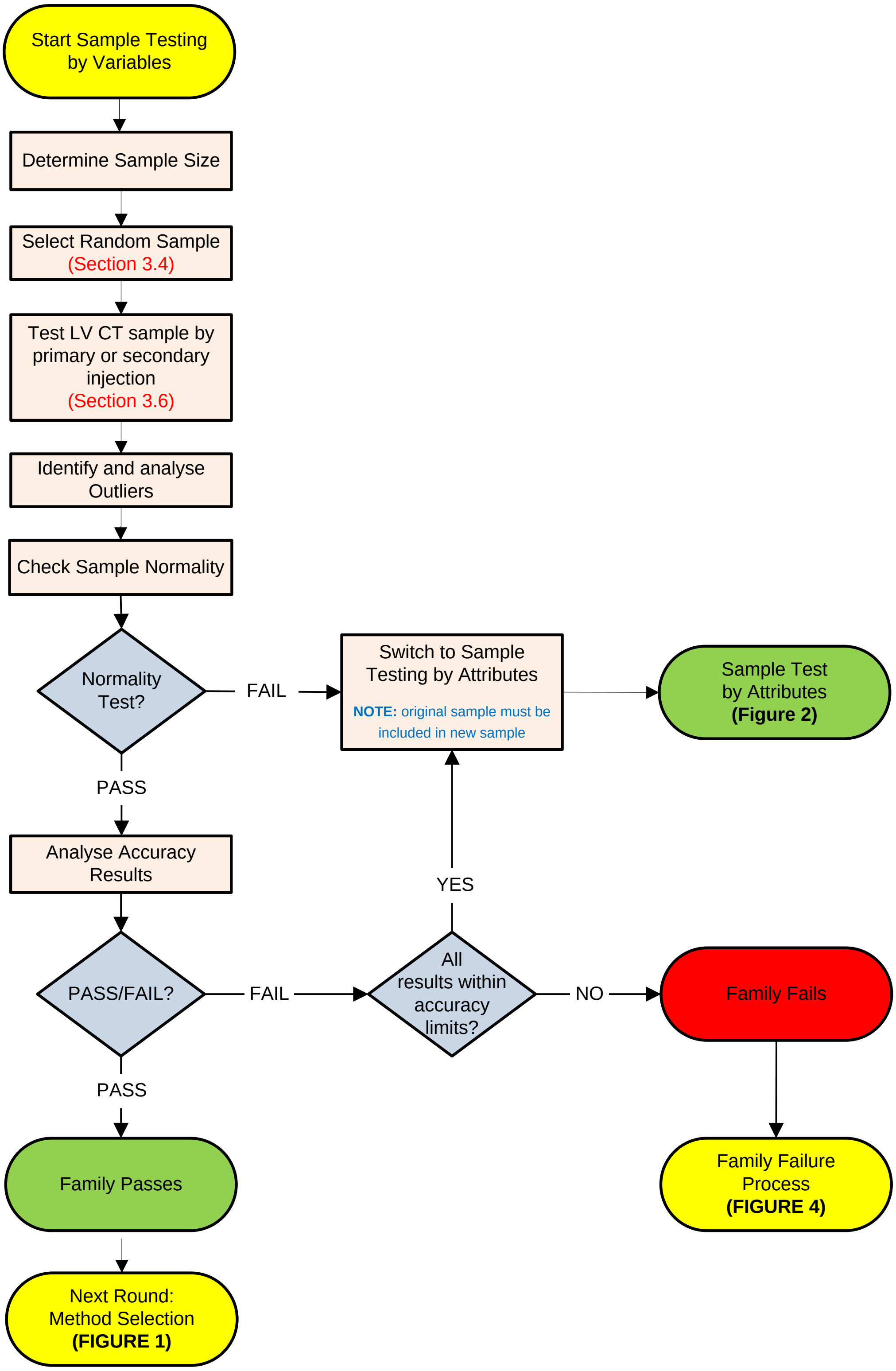

Figure 3: Sample Testing by Variables

3.2 Eligible Metering Installations

All LV *CT metering installation*s are eligible for sample testing provided an accompanying enhanced inspection in accordance with section 5 is performed.

3.3 Family Selection

Families are to be selected carefully before commencing sample testing.

Where applicable, the LV *CT*s shall be homogeneous with respect to the following characteristics:

3.3.1 Family Characteristics

a) Current transformer type.
   - A 150 / 300 / 600 : 5
   - B 400 / 800 / 1200 : 5
   - C 1000 / 2000 / 3000 : 5
   - S 200 : 5
   - T 800 : 5
   - U 2000 : 5
   - V 4000 : 5
   - W 1500 : 5

3.3.2 Sub-Family Characteristics

a) Manufacturer.
b) Geographical Location.
c) Date of manufacture or year of installation (10 year periods).
d) Design Standard of manufacture (minimum *AS* 1675, *AS* 60044.1).
e) Model and Type.

3.3.3 Example of Family and Sub-Family Selection

The following is a simplified example of how to create your families for sample testing. For this example there are three manufacturers (Man1, Man2 and Man3) and three geographical locations (Geo1, Geo2 and Geo3).

Layer 1 = current transformer type (i.e. Type T 800:5).

Following the completion of sample testing, the results find that the family has failed. The suspected cause of the failure appears to be related to a single manufacturer and potentially a geographical issue but there is uncertainty.

The next step would be to liaise with *AEMO* to create the sub-families based on the results found, to establish if a pattern can be identified.

Based on results, Man1 is the suspected faulty sub-family and since it is uncertain whether geographical issues are factor, there are two options when selecting sub-family groupings.

These two options are:

Layer 2 = Man1

or

Layer 2 = Man1 and Geo1 + Man1 and Geo2 + Man1 and Geo3

By choosing to retest the sub-family using the option 1 grouping, the whole population for the manufacture will need to be replaced if the sub-family fails.

By choosing to retest sub-family using the option 2 groupings, there is an equal chance that the manufacturer will fail in one, two or all three geographical locations. Option 2 although it requires more testing, is the more risk aversive approach as it potentially means that a smaller population will fail, which results in a smaller family replacement.

3.4 Sample Selection

3.4.1 Random Selection

The sample from each family shall be drawn at random as outlined in section 3.4.3, without replacement (i.e. each site chosen as part of the sample will be excluded from the next round of sample testing), until the population is exhausted.

Random selection is where a sample (*s*) is taken from a population (*p*) in such a way that each sample (*s*) has an equal probability of being chosen from population (*p*).

3.4.2 Sample Size

Selected sample size is to be in accordance with the minimum required sample size *n* + 100% for the population (*p*) as outlined under the selected method of sample testing.

An additional 100% is chosen to cater for situations where reasonable endeavors have failed to facilitate the necessary in-situ testing, such as 'isolation not possible', 'installation decommissioned', or 'physical damage to the LV *CT*'.

3.4.3 Randomisation Method

The method for random selection of LV *CT*s is as follows:

a) All *NMI*s from the same family to be assigned number 1 to population (*p*).

b) Using a random number generator, generate numbers at random between 1 and population (*p*), until sample size (*n*) + 100% is reached (or population (*p*) where sample size (*n*) is > 50% of population (*p*)).

c) The sample size (*n*) will be determined by the sequential order of the randomly selected samples.

d) Then randomly pick one LV *CT* from the three to form part of the sample testing analysis (**Note:** all three require testing, but only the result of the test for the LV *CT* selected will be used when analysing results for sample testing).

3.5 Sample Testing Method Selection

3.5.1 Acceptable Quality Level (AQL) vs. Limiting Quality (LQ)

AQL looks at the manufacturer's risk and the rate of nonconforming items at which a lot will be rejected with low probability. AQL is used when a continuing series of lots is considered and is the quality level which for the purposes of sampling inspection is the limit of a satisfactory process average (*AS* 1199.0-2003, p 5).

LQ looks at the consumer's risk and the rate of nonconforming items at which a lot will be accepted with low probability. LQ is used when a lot is considered to be in isolation and is the quality level in percent nonconforming (*AS* 1199.0-2003, p 6).

A brand new LV *CT* on request comes with manufacturer test results. In the past LV *CT* test results were not always available and/or requested by the *responsible person*. However, every LV *CT* before sale was tested by the manufacture to the relevant standard, which implies 100% compliance at the time of installation meaning the manufacturer's risk is zero since no failed LV *CT*s would have been sold.

The alternative strategy is to sample test in-situ LV *CT*s, therefore, as manufacturer's risk is zero, these should not be classified as continuous series of lots after installation as each LV *CT* is exposed to different conditions throughout the operational life of the asset.

The analysis of in-situ LV *CT*s should be treated as isolated lots as the results have no direct feedback to manufacturer on quality, and instead, should focus on the consumer's risk as the highest risk exposure occurs after the initial manufacturer testing.

The most relevant option for in-situ LV *CT*s is to use LQ and not AQL.

An LQ value of 3.15 is selected as it will provide a 90% degree of confidence that any population with a percent nonconforming greater than or equal to 3.15% will be rejected by sample testing.

However in order to allow for sample testing by variables, *AEMO* acknowledge that LQ and AQL can be interchangeable and that there is an equivalent AQL value for every LQ value. LQ is at **minimum**, three times the desired AQL (*AS* 1199.2-2003, p 3). Table D5 shows equivalent AQL values for each preferred LQ value (*AS* 1199.2-2003, p 21).

For an LQ of 3.15 the equivalent AQL values are 0.4, 0.65 and 1 respectively as the lot sizes increase. For simplicity and achieving a reasonable balance of sample sizes and acceptance criteria between small and large families, an AQL of 0.65 has been selected.

3.5.2 Attributes vs. Variables

Attribute testing is based on a characteristic that is classified simply as conforming or nonconforming (e.g. go or no-go) with respect to a specified requirement or set of specified requirements (*AS* 1199.1-2003, p 11).

Sample testing by attributes method has the advantage in that it is fundamentally free of assumptions, and is simpler to use.

Variable testing is based on a characteristic that may assume more than one set of values to which a numerical measure can be assigned (StatCan, 2011).

Sample testing by variables method has the advantage in that it requires a smaller sample size (*AS* 2490-1997, clause 9(b), p 6).

3.5.3 Normality

Normality **does not need** to be assessed when sample testing by attributes.

Normality **needs** to be assessed at each test point, as outlined in Table 3, on the sample test data after each round of sample testing by variables is completed, before analysing the family or sub-family for acceptance.

The preferred and acceptable methods for assessing normality have been outlined in Appendix A.

3.5.4 Sample Testing by Attributes

Sample testing by attributes is based on *AS* 1199.1-2003 (p 19-20) for normal inspection using general inspection level II with the chosen AQL of 0.65. In the event of a change from sample testing by variables to sample testing by attributes, the test results taken as part of the sample testing by variables process are to be retained and form part of the sample size required under sample testing by attributes.

Table 1: Sample Sizes and Acceptance and Rejection Levels for Testing by Attributes

Family Size		AQL = 0.65		
Min	**Max**	**Sample Size (*n*)**	**Accept (Ac)**	**Reject (Re)**
1	25	ALL	-	-
26	50	13	0	1
51	150	20	0	1
151	280	32	0	1
281	500	50	1	2
501	1200	80	1	2
1201	3200	125	2	3
3201	10000	200	3	4
10001	35000	315	5	6
35001	150000	500	7	8
150001	500000	800	10	11

NOTE: Where the population size of the family is smaller than 26, attributes testing will be unable to demonstrate the required AQL. In this case 100% testing is necessary; therefore no Accept (Ac) and Reject (Re) parameters are required as only failed sites will require replacement. Family Size = number of LV *CT*s in the family.

3.5.5 Sample Testing by Variables

Sample testing by variables is based on *AS* 2490-1997 (Table II-A, p 20) for normal inspection using general inspection level II with the chosen AQL of 0.65.

Current error is to be assessed using the variable test - Acceptability Constant (*k*). Phase displacement and current error are correlated; therefore only limited information is added by phase displacement analysis. Phase displacement may be assessed by using the attributes test specified in the last two columns.

Table 2: Sample Sizes and k Value and Acceptance and Rejection Levels for Testing by Variables

			AQL = 0.65			
Family Size		Sample Size (*n*)	Acceptability Constant (*k*)	Outliers Permitted	Attributes for Phase Displacement	
Min	Max				Accept (Ac)	Reject (Re)
1	8	ALL	-	-	-	-
9	50	5	1.65	0	0	1
51	90	7	1.75	0	0	1
91	150	10	1.84	0	0	1
151	280	15	1.91	0	0	1
281	400	20	1.96	0	0	1
401	500	25	1.98	0	0	1
501	1200	35	2.03	1	0	1
1201	3200	50	2.08	1	1	2
3201	10000	75	2.12	1	1	2
10001	35000	100	2.14	1	2	3
35001	150000	150	2.18	1	3	4
150001	500000	200	2.18	1	3	4

NOTE: Where the population size of the family is smaller than 9, variables testing will be unable to demonstrate the required AQL. In this case 100% testing is necessary; therefore no Accept (Ac) and Reject (Re) parameters are required as only failed sites will require replacement. Family Size = number of LV *CT*s in the family. *k* = factor used in calculations.

3.5.5.1 Calculations

For each accuracy test point of the results observed, calculate the sample mean $(\bar{x})$ and sample standard deviation (s).

For **each** test point and **each** tap for multi-tap LV *CT*, determine the following inequalities.

$$\bar{x} + k \times s \leq U$$

$$\bar{x} - k \times s \geq L$$

Where:

U and *L* = upper and lower limits of the sample given for each accuracy test point in Table 3.

If the upper and/or lower limits are exceeded then a decision must be made and documented on what further action is to be taken according to this guideline.

3.5.5.2 Outliers

In variables testing according to Table 2, above, if an outlier result is identified during sample testing, it may be removed for families of 501 or larger. Only a maximum of one outlier may be removed. An outlier is defined as any measurement of accuracy that is more than twice the limits as outlined in Table 3.

An outlier must be analysed in isolation to determine the cause of error.

3.6 Test Points and Test Burden

To accommodate a cohesive sample testing regime, testing of LV *CT*s shall be done by either primary and/or secondary injection testing in-situ to the limits of error outlined at 25% of rated burden resistive - unity power factor (i.e. power factor = 1.0).

Table 3: Limits of Error (AS 60044.1)

% RATED CURRENT	Current Error Limits	Phase Displacement Limits (Minutes)	Phase Displacement Limits (crad)
5	±1.5	±90	±2.7
20	±0.75	±45	±1.35
100	±0.5	±30	±0.9

LV *CT*s must be **demagnetised** before the commencement of testing. LV *CT*s may be tested before demagnitisation; however the results can only be used to purely investigate effects of magnetisation and **will not** be considered part of the sample testing analysis by *AEMO*.

3.6.1 Additional Test Points

Extended range LV *CT*s must be tested at the extended range rating test point and against the same accuracy level as the 100% test point. The test results obtained will be reviewed and used for analysis after the first round of testing has been completed to determine if extended range LV *CT*s can be grouped with non extended range LV *CT*s into one family. These test results will not form part of the family assessment.

3.7 Testing Frequency

Initial round of LV *CT* testing, using a sample testing method, will be 12 months from 1 July 2012, in accordance with *AER* Compliance Bulletin No. 6 – December 2011.

The initial life for a new LV *CT* is 10 years from last test date (i.e. manufacturer or installation results). At the end of the initial life a sample test of that family of LV *CT*s must be performed.

The second sample testing will be required to be undertaken 5 years after the end of initial life sample test assuming that the LV *CT* family has passed that test.

Further sample testing will be required to be undertaken at 5 year intervals assuming the LV *CT* family continues to pass testing.

3.8 Overall Error Accuracy Requirements

Provided that the LV *CT* family or sub-family as sample tested passes, the requirements of this guideline and the associated meters meet the accuracy and testing requirements of the *Rules* (including an *AEMO* approved asset management strategy that defines an alternative testing practice other than time-based testing), then the sites where the family of LV *CT*s are installed are deemed to meet the overall error requirements of the *Rules*.

4. RULES FOR ACCEPTANCE AND NON-ACCEPTANCE

4.1 Acceptance

For sample testing by attributes, a family or sub-family of LV *CT*s shall be accepted if the number of nonconforming LV *CT*s found during sample testing is equal to or less than the acceptance number (Ac).

For sample testing by variables, a family or sub-family of LV *CT*s shall be accepted if:

a) the value calculated (ratio error) using the equations specified under section 3.5.5.1 is less than or equal to the upper limit and/or is greater than or equal to the lower limit and;
b) the number of nonconforming LV *CT*s found during sample testing (phase error) is less than the acceptance number (Ac).

4.2 Nonconforming Current Transformers

Notwithstanding family or sub-family acceptance, any nonconforming LV *CT* found during testing, whether part of sample or not, shall be replaced with a like for like LV *CT*. If no like for like LV *CT* can be found, all three LV *CT*s must be replaced.

Nonconforming LV *CT*s must be analysed to check for possible sub-family characteristic failures. The reasons that the non-conforming LV *CT* failed the accuracy test are to be determined through analysis, the results of which are to be recorded.

4.3 Non-Acceptance and Resubmission

For sample testing by attributes, a family or sub-family shall be deemed unacceptable if the number of nonconforming LV *CT*s found during sample testing is greater than the acceptance number (Ac).

For sample testing by variables, a family or sub-family shall be deemed unacceptable if:

a) the value calculated (ratio error) using the equations specified under section 3.5.5.1 exceed the upper and/or lower limits, or;
b) the number of nonconforming LV *CT*s found during sample testing (phase error) is greater than the acceptance number (Ac).

In the unlikely scenario that a family or sub-family has failed sample testing by variables where no accuracy results (i.e. ratio error and phase error) are outside the the limits as outlined in Table 3, it is permissible to switch to sample testing by attributes. In this scenario, additional samples will need to be tested and included with the original variables method results, until reaching the sample size (*n*) required by the attributes method.

In the event of a family or sub-family failure, the consequences of which are family or sub-family replacement, the *responsible person* must consult with *AEMO* to develop a strategy, including the timeframe, for the rectification of the family noncompliance.

AEMO, in assessing the proposed strategy, will consider a:

a) Retest of a sub-family, provided that sub-family characteristics have been identified.
b) Switch to attributes method if variables method used.
c) 100% retest of the family
d) Full family replacement.

4.4 Family and Sub-Family Failure Process

The following is the process *AEMO* will follow in determining the best course of action in the event of a family, or sub-family failure.

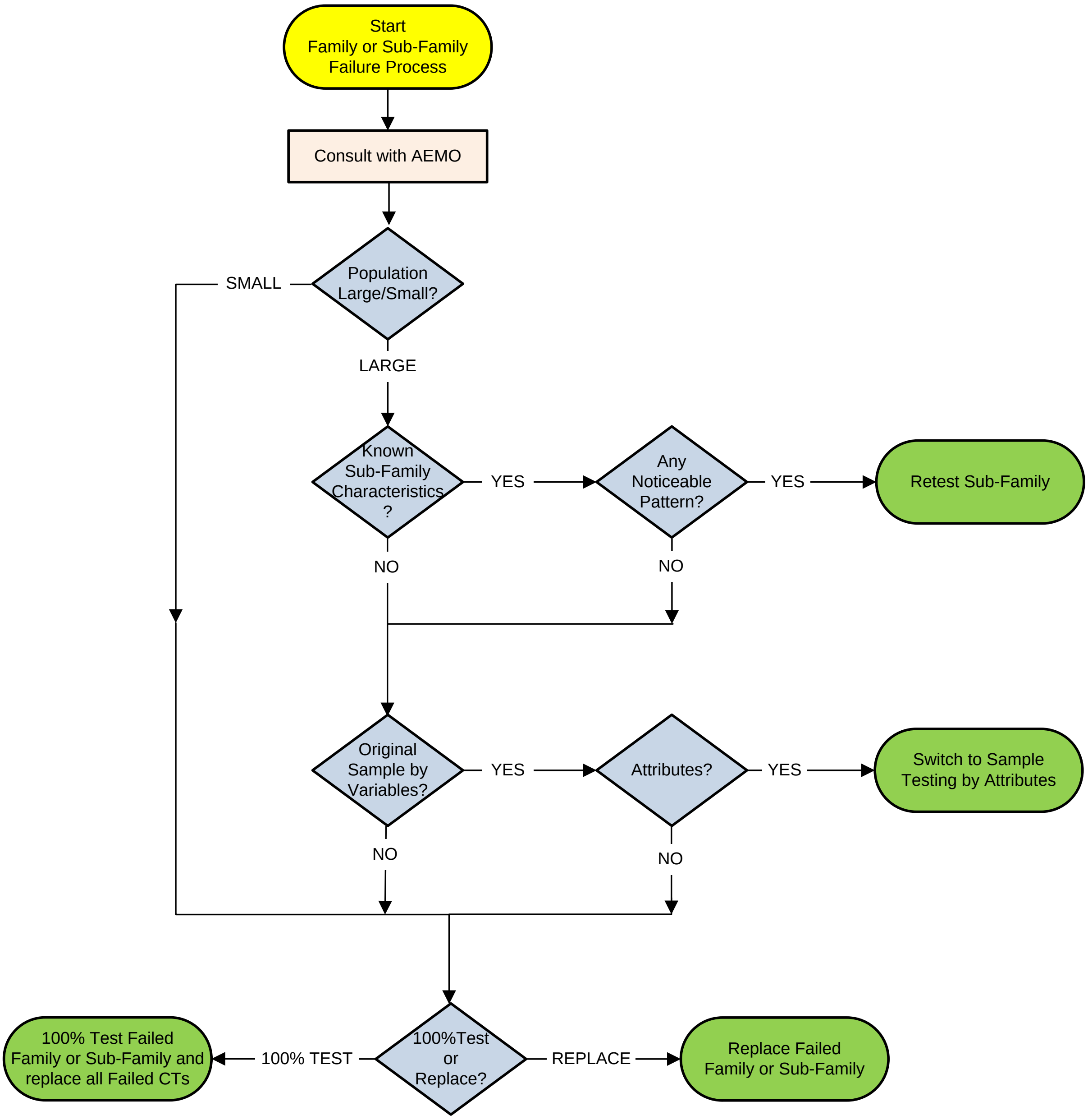

Figure 4: Family and Sub-Family Failure Process

5. INSPECTION REGIME METHODOLOGY

5.1 Current Methodology

Metering installation equipment is currently inspected in accordance with Table S7.3.3 ‘Period Between Inspection’ of the *Rules*. For the majority of LV *metering installations* (i.e. types 4, 5 and 6) an inspection is normally carried out when a meter test is performed. As some type 4, 5 and 6 LV *CT* meters may be subject to a sample testing process, some LV *CT*s are not inspected.

5.2 Proposed Methodology

To better support a regime of demonstrated compliance for LV *CT*s through sample testing, an enhanced inspection program of LV *CT metering installation*s must be incorporated as part of the alternative test strategy. The following inspection program items must be carried out as a minimum:

5.2.1 Inspection Frequency

100% of LV *CT metering installation*s shall be inspected over a 5 year period, commencing 1 July 2012 with a maximum completion date of 30 June 2017.

All type 3 LV *CT metering installation*s shall be inspected within the first 24 months of the 5 year period, commencing 1 July 2012 and completed by 30 June 2014.

The frequency of ongoing inspections of LV *CT metering installations* will be determined in accordance with section 6 of this document.

5.2.2 Minimum Testing and Inspection Requirements

The following are the minimum testing and inspection requirements:

a) Admittance test (preferred) or undertake primary/secondary ratio check.
b) Measure connected burden.
c) Compare the secondary current value at LV *CT* test block against meter register.
d) Position and tightness of *CT* metering links.
e) Check for corrosion, damage and atrophy.
f) Condition of the wires, terminals and potentials fuses.
g) Correct polarity of all voltage and current connections and phase relationships.
h) Correct applied phase rotation (for Ferraris disc meters).
i) Correct applied ratio to meter for connected *CT* ratio.

5.2.3 Information Gathering

To facilitate the population of a database of information relating to all installed LV *CT metering installation*s in the *NEM* and in support of family and sub-family considerations, the following information must be assembled in relation to all installed LV *CT*s:

a) Installation date.
b) Design standard of manufacture.
c) Connected ratio.
d) Available ratios and LV *CT* type/form.
e) Class accuracy.
f) Rated burden.
g) Manufacturer.
h) Encapsulated or exposed.
i) Serial number.

Additional comments relating to LV *CT*s subjected to non-standard installations and environments should be provided as this may assist in sub-family analysis.

5.2.4 Unknown CTs

In situations where an inspection is unable to ascertain details that would allow the LV *CT*s to be classified into a family as outlined in section 3.3, the LV *CT*s must at a minimum be either:

a) Accuracy tested for compliance to the test points and burden as per Table 3; or
b) Replaced with a new set of LV *CT*s.

5.2.5 Isolated CT failures

All LV *CT*s which are found to have failed or to be non compliant, including those found as a result of activities outside the alternative test strategy, must be analysed further to determine the cause of the non compliance.

All information about the particular LV *CT*s non compliance must be recorded and stored for review and future family grouping considerations. These records of random failures may assist in identifying potential failure patterns across the *NEM*.

5.2.6 Meter Testing

As part of the inspection, for risk mitigation purposes, all type 3 and type 4 **meters** installed at LV *CT metering installation*s are to be tested.

6. REVIEW OF GUIDELINE

A review of the Requirements will be undertaken by *AEMO* following completion of the initial round of testing. *AEMO* will undertake the review in liaison with the *AER* and with consideration to the findings and recommendations of the CTTWG and other *responsible person*s.

To facilitate the review, *responsible person*s, must provide *AEMO* with all test and inspection results, in an agreed format between *AEMO* and *responsible person*.

7. REFERENCES

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Appendix A PROCEDURE FOR ASSESSING NORMALITY

A.1 Introduction

It is necessary to perform a normality test on the test data before applying statistical methods that assume normality. This is done by determining that the test data observed follows a normal distribution curve. Normality can only be demonstrated where there is evidence that the test data aligns with the normality curve.

The preferred method for assessing data for normality is outlined in this appendix. The first stage is a graphical method that provides a normal probability plot of the sample data. Based on the shape of this normal probability plot, after exclusion and examination of outliers, normality can be quickly assessed to see whether the data appears to be normally distributed. The second stage is a statistical method, which looks at the skewness and the kurtosis of the data. The skewness and kurtosis values are used in the D’Agostino-Person (DP) omnibus test to calculate the probability (p-value) of the test data which signifies adherence or otherwise to normality for the family. The statistical method **must be** used to confirm the graphical method.

This method has been specifically chosen as it is easy to perform in Microsoft Excel and as it supports efficient assessment of the alternative testing strategy submitted for approval where sample testing by variables method is considered.

Further details in relation to the preferred method of normality test solutions can be found in Appendix B.

AEMO **will accept alternate** normality test methods (such as Anderson Darling and Kolmogorov-Smirnov) used by statistical packages (such as Minitab, Matlab and Prism), provided that a normal probability plot (using cumulative probability or z-values scale for y-axis) is shown and a p-value is determined.

A histogram **will not** be acceptable as it is not an objective method for testing normality, particularly for small sample sizes as discerning the shape of the histogram is difficult. In addition, the shape of the histogram can change significantly by merely changing the interval width of the histogram bars.

A.2 Preferred Method

A.2.1 Stage 1 – Graphical Method

A normal probability plot may be used to objectively assess whether the sample data comes from a normal distribution family. On a normal probability plot, sample data that follows a normal distribution will appear linear. If the normal probability plot is non linear, it cannot be assumed that the sample data follows a normal distribution.

A normal probability plot can be created by using the following steps:

1. Sort data from smallest to largest (ascending – e.g. -0.5 to 0).
2. Number the sorted data from 1 to *n*, where *n* is the sample size.
3. Calculate the cumulative probability for each sample number (n_i).

$$Cumulative\ Probability\ (c_p) = \frac{(n_i - \frac{3}{8})}{(sample\ size + 0.25)}$$

4. Determine the z-value from the standard normal distribution for each cumulative probability (c_p) calculated (**Note:** easiest way is to use excel).

$$\boldsymbol{Excel\ Function}:\ = NORMINV(c_p)$$

5. Plot the z-values (y-axis) against the sorted data values (x-axis).
6. Plot a line of best fit and assess whether linear or non linear.

A.2.2 Stage 2 - Statistical Method

A.2.2.1 Procedure for Finding Skewness

Skewness is defined as ‘A measure of the symmetry of a distribution. A positive value indicates that the distribution has a greater tendency to tail to the right (positively skewed or skewed to the right), and a negative value indicates a greater tendency of the distribution to tail to the left (negatively skewed or skewed to the left). Skewness is 0 for a normal distribution’ (Pyzdek, p 729).

The equation for skewness is:

$$Skewness\ (G1) = \frac{n}{(n-1)(n-2)} \sum \left(\frac{x_i - \bar{x}}{s} \right)^3$$

$$\boldsymbol{Excel\ Function}:\ = SKEW(x_1 : x_i)$$

The standard error of skewness (SES) then needs to be calculated as it will be used later to find the test statistic (Z_{g1}).

The equation for SES is:

$$SES\ = \sqrt{\frac{6n(n-1)}{(n-2)(n+1)(n+3)}}$$

A.2.2.2 Procedure for Finding Kurtosis

Kurtosis is defined as ‘A measure of the shape of a distribution. A positive value indicates that the distribution has longer tails than the normal distribution (platykurtosis); while a negative value indicates that the distribution has shorter tails (leptokurtosis). For the normal distribution, the kurtosis is 0’ (Pyzdek, p 726).

The equation for kurtosis is:

$$Kurtosis\ (G2) = \left\{\frac{n(n+1)}{(n-1)(n-2)(n-3)}\sum\left(\frac{x_i-\bar{x}}{s}\right)^4\right\} - \frac{3(n-1)^2}{(n-2)(n-3)}$$

$$\boldsymbol{Excel\ Function}:\ = KURT(x_1 : x_i)$$

The standard error of kurtosis (SEK) then needs to be calculated as it will be used later to find the test statistic (Z_{g2}).

The equation for SEK is:

$$SEK\ = 2(SES)\sqrt{\frac{n^2-1}{(n-3)(n+5)}}$$

A.2.2.3 D'Agostino-Pearson Omnibus Test

To test for normality, the D'Agostino-Person (DP) omnibus test uses the test statistics for both skewness and kurtosis to work out a single p-value for the sample data observed.

The steps below are used to test for normality.

1. Calculate the test statistics (Z_{g1}) and (Z_{g2}).

$$Test\ Statistic\ (Z_{g1}) = \frac{G1}{SES}$$

$$Test\ Statistic\ (Z_{g2}) = \frac{G2}{SEK}$$

2. Calculate the D'Agostino-Person (DP) test statistic.

$$\text{D'AgostinoPerson}\ (DP) = {Z_{g1}}^2 + {Z_{g2}}^2$$

3. Calculate the p-value with two degrees of freedom (df) or use linear interpolation to find the p-value from Table A1.

$$\text{p-value} = \mathrm{P}(X^2(2) > DP)$$

$$\boldsymbol{Excel\ Function}: = CHIDIST(DP, 2)$$

Table A1: X^2 Values for Certain p-values

Degrees of Freedom (df)	X^2 Value = D'Agostino-Person (DP) Value													
2	0.010	0.020	0.051	0.103	0.211	0.575	1.386	2.773	4.605	5.991	7.378	9.210	10.597	13.816
Probability (p-value)	**0.995**	**0.99**	**0.975**	**0.95**	**0.90**	**0.75**	**0.50**	**0.25**	**0.10**	**0.05**	**0.025**	**0.01**	**0.005**	**0.001**
	NONSIGNIFICANT									**SIGNIFICANT**				

Note: A p-value of 0.05 or less is regarded as statistically significant. This means that the observed deviation from the null hypothesis is significant and there is reason enough to reject the impression that the population is normal. A p-value of greater than 0.05 is regarded as statistically nonsignificant, therefore cannot reject the impression that the population is normal*.

*Remember, you never accept the null hypothesis, so you can't say from this test that the distribution *is* normal.

Appendix B EXAMPLES OF NORMALITY TEST

B.1 Sample Data – 45 Samples

Table B1: Measured Data and Normal Probability Plot Steps

Measured Data Ratio Error %	STEP 1: Sorted Data Ratio Error %	STEP 2: LV CTs Numbered	STEP 3: Cumulative Probability (Cp)	STEP 4: z-value
-0.230	-0.440	1	0.01381	-2.20258
-0.290	-0.400	2	0.03591	-1.80024
-0.180	-0.350	3	0.05801	-1.57169
-0.290	-0.330	4	0.08011	-1.40433
-0.220	-0.320	5	0.10221	-1.26906
-0.180	-0.290	6	0.12431	-1.15371
-0.190	-0.290	7	0.14641	-1.05196
-0.400	-0.270	8	0.16851	-0.96008
-0.200	-0.270	9	0.19061	-0.87566
-0.250	-0.260	10	0.21271	-0.79706
-0.190	-0.260	11	0.23481	-0.72311
-0.180	-0.250	12	0.25691	-0.65291
-0.200	-0.250	13	0.27901	-0.58580
-0.240	-0.240	14	0.30110	-0.52123
-0.102	-0.230	15	0.32320	-0.45876
-0.190	-0.230	16	0.34530	-0.39803
-0.180	-0.220	17	0.36740	-0.33874
-0.320	-0.220	18	0.38950	-0.28062
-0.210	-0.210	19	0.41160	-0.22343
-0.220	-0.200	20	0.43370	-0.16696
-0.270	-0.200	21	0.45580	-0.11102
-0.180	-0.200	22	0.47790	-0.05542
-0.230	-0.200	23	0.50000	0.00000
-0.148	-0.200	24	0.52210	0.05542
-0.150	-0.200	25	0.54420	0.11102
-0.113	-0.200	26	0.56630	0.16696
-0.180	-0.190	27	0.58840	0.22343
-0.260	-0.190	28	0.61050	0.28062
-0.180	-0.190	29	0.63260	0.33874
-0.150	-0.190	30	0.65470	0.39803
-0.330	-0.180	31	0.67680	0.45876
-0.190	-0.180	32	0.69890	0.52123
-0.260	-0.180	33	0.72099	0.58580
-0.270	-0.180	34	0.74309	0.65291
-0.440	-0.180	35	0.76519	0.72311
-0.200	-0.180	36	0.78729	0.79706
-0.200	-0.180	37	0.80939	0.87566
-0.109	-0.150	38	0.83149	0.96008
-0.098	-0.150	39	0.85359	1.05196
-0.101	-0.148	40	0.87569	1.15371
-0.250	-0.113	41	0.89779	1.26906
-0.200	-0.109	42	0.91989	1.40433
-0.200	-0.102	43	0.94199	1.57169
-0.200	-0.101	44	0.96409	1.80024
-0.350	-0.098	45	0.98619	2.20258

B.2 Sample Data – 90 Samples

Table B2: Measured Data and Normal Probability Plot Steps

Measured Data Ratio Error %	STEP 1: Sorted Data Ratio Error %	STEP 2: LV CTs Numbered	STEP 3: Cumulative Probability (Cp)	STEP 4: z-value
-0.230	-0.440	1	0.00693	-2.46112
-0.290	-0.405	2	0.01801	-2.09680
-0.180	-0.400	3	0.02909	-1.89440
-0.290	-0.370	4	0.04017	-1.74876
-0.220	-0.360	5	0.05125	-1.63289
-0.180	-0.350	6	0.06233	-1.53553
-0.190	-0.340	7	0.07341	-1.45088
-0.400	-0.330	8	0.08449	-1.37550
-0.200	-0.320	9	0.09557	-1.30723
-0.250	-0.320	10	0.10665	-1.24455
-0.190	-0.310	11	0.11773	-1.18642
-0.180	-0.310	12	0.12881	-1.13204
-0.200	-0.310	13	0.13989	-1.08082
-0.240	-0.310	14	0.15097	-1.03228
-0.102	-0.300	15	0.16205	-0.98607
-0.190	-0.300	16	0.17313	-0.94187
-0.180	-0.290	17	0.18421	-0.89943
-0.320	-0.290	18	0.19529	-0.85856
-0.210	-0.290	19	0.20637	-0.81908
-0.220	-0.290	20	0.21745	-0.78083
-0.270	-0.290	21	0.22853	-0.74369
-0.180	-0.280	22	0.23961	-0.70755
-0.230	-0.280	23	0.25069	-0.67231
-0.148	-0.270	24	0.26177	-0.63789
-0.150	-0.270	25	0.27285	-0.60421
-0.113	-0.270	26	0.28393	-0.57120
-0.180	-0.270	27	0.29501	-0.53880
-0.260	-0.260	28	0.30609	-0.50695
-0.180	-0.260	29	0.31717	-0.47561
-0.150	-0.260	30	0.32825	-0.44474
-0.330	-0.260	31	0.33934	-0.41428
-0.190	-0.260	32	0.35042	-0.38420
-0.260	-0.250	33	0.36150	-0.35446
-0.270	-0.250	34	0.37258	-0.32504
-0.440	-0.250	35	0.38366	-0.29589
-0.200	-0.250	36	0.39474	-0.26699
-0.200	-0.250	37	0.40582	-0.23832
-0.109	-0.240	38	0.41690	-0.20984
-0.098	-0.240	39	0.42798	-0.18152
-0.101	-0.240	40	0.43906	-0.15336
-0.250	-0.240	41	0.45014	-0.12531
-0.200	-0.240	42	0.46122	-0.09736
-0.200	-0.230	43	0.47230	-0.06949
-0.200	-0.230	44	0.48338	-0.04167
-0.350	-0.230	45	0.49446	-0.01389
-0.210	-0.230	46	0.50554	0.01389
-0.230	-0.230	47	0.51662	0.04167
-0.130	-0.220	48	0.52770	0.06949

-0.200	-0.220	49	0.53878	0.09736
-0.130	-0.220	50	0.54986	0.12531
-0.310	-0.220	51	0.56094	0.15336
-0.310	-0.220	52	0.57202	0.18152
-0.270	-0.210	53	0.58310	0.20984
-0.220	-0.210	54	0.59418	0.23832
-0.360	-0.210	55	0.60526	0.26699
-0.220	-0.200	56	0.61634	0.29589
-0.310	-0.200	57	0.62742	0.32504
-0.300	-0.200	58	0.63850	0.35446
-0.220	-0.200	59	0.64958	0.38420
-0.405	-0.200	60	0.66066	0.41428
-0.200	-0.200	61	0.67175	0.44474
-0.240	-0.200	62	0.68283	0.47561
-0.200	-0.200	63	0.69391	0.50695
-0.120	-0.200	64	0.70499	0.53880
-0.280	-0.200	65	0.71607	0.57120
-0.260	-0.200	66	0.72715	0.60421
-0.250	-0.190	67	0.73823	0.63789
-0.240	-0.190	68	0.74931	0.67231
-0.280	-0.190	69	0.76039	0.70755
-0.250	-0.190	70	0.77147	0.74369
-0.260	-0.180	71	0.78255	0.78083
-0.110	-0.180	72	0.79363	0.81908
-0.290	-0.180	73	0.80471	0.85856
-0.340	-0.180	74	0.81579	0.89943
-0.130	-0.180	75	0.82687	0.94187
-0.290	-0.180	76	0.83795	0.98607
-0.310	-0.180	77	0.84903	1.03228
-0.200	-0.150	78	0.86011	1.08082
-0.260	-0.150	79	0.87119	1.13204
-0.210	-0.148	80	0.88227	1.18642
-0.230	-0.130	81	0.89335	1.24455
-0.230	-0.130	82	0.90443	1.30723
-0.320	-0.130	83	0.91551	1.37550
-0.270	-0.120	84	0.92659	1.45088
-0.370	-0.113	85	0.93767	1.53553
-0.240	-0.110	86	0.94875	1.63289
-0.290	-0.109	87	0.95983	1.74876
-0.250	-0.102	88	0.97091	1.89440
-0.240	-0.101	89	0.98199	2.09680
-0.300	-0.098	90	0.99307	2.46112

B.3 Normal Probability Plots and Statistical Method Examples

B.3.1 45 Samples - Uncertain of Normality

The following normality probability plot uses the 45 data samples from section B.1.

The normal probability plot shows a set of data points which may be normally distributed however it is uncertain as the data points move away (highlighted by circle) from the linear line.

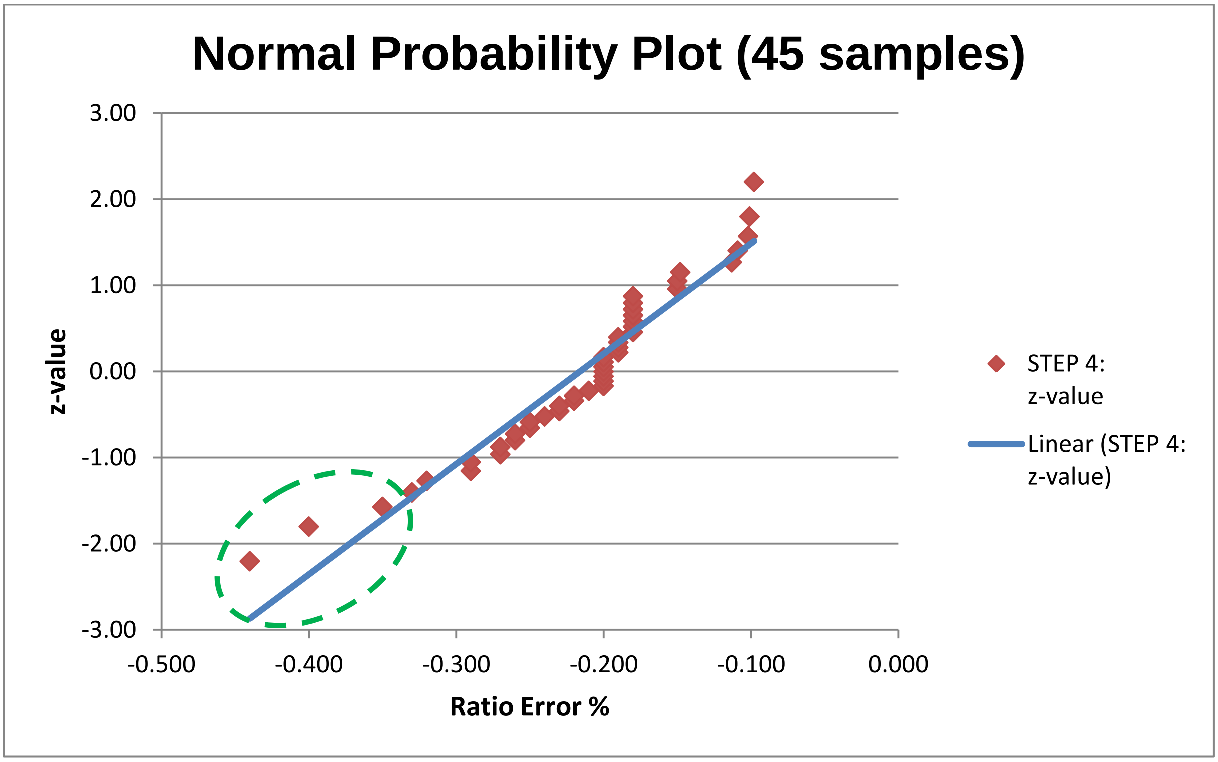

Figure B1: Normality Plot for 45 Samples

Normality can be further verified by using the statistical method as outlined in Appendix A of this document to find and calculate the p-value.

Calculate skewness and standard error of skewness (SES)

$\boldsymbol{Excel\ Function}: = skew(x_1 : x_i)$ **Note:** using the range for STEP 1 data.

$G1 = skew(-0.440: -0.098) = -0.926$

$$SES = \sqrt{\frac{6n(n-1)}{(n-2)(n+1)(n+3)}} \quad \boldsymbol{where}: n = sample\ size$$

$$SES = \sqrt{\frac{6 \times 45(45-1)}{(45-2)(45+1)(45+3)}} = 0.354$$

Calculate kurtosis and standard error of kurtosis (SEK)

$\boldsymbol{Excel\ Function}:\ = kurt(x_1 : x_i)$ **Note:** using the range for STEP 1 data.

$G2 = kurt(-0.440 : -0.098)\ = 1.390$

$$SEK\ = 2(SES)\sqrt{\frac{n^2 - 1}{(n-3)(n+5)}} \quad \boldsymbol{where}:\ n = sample\ size$$

$$SEK\ = 2(0.354)\sqrt{\frac{45^2 - 1}{(45-3)(45+5)}}\ = 0.695$$

Perform D’Agostino-Pearson Omnibus Test

Step 1: Calculate the test statistics (Z_{g1}) and (Z_{g2}).

$$Test\ Statistic\ (Z_{g1})\ = \frac{G1}{SES}$$

$$Z_{g1}\ = \frac{-0.926}{0.354}\ = -2.618$$

$$Test\ Statistic\ (Z_{g2})\ = \frac{G2}{SEK}$$

$$Z_{g2}\ = \frac{1.390}{0.695}\ = 2.001$$

Step 2: Calculate the D’Agostino-Person (DP) test statistic.

$$\text{D’AgostinoPerson}\ (DP) = \ {Z_{g1}}^2 + {Z_{g2}}^2$$

$$DP = \ (-2.618)^2 + (2.001)^2\ \ = 10.861$$

Step 3: Calculate the p-value with two degrees of freedom (df).

$$\text{p-value} = \ \text{P}(X^2(2) > DP)$$

$\boldsymbol{Excel\ Function}:\ = CHIDIST(DP, 2)$

$$\text{p-value} = CHIDIST(10.861,2)\ \ = 0.00438$$

The p-value is calculated to be less than 0.05. This indicates that there is a significant difference and the likelihood that the test data comes from a normally distributed population is extremely minimal. Normality is therefore not demonstrated.

B.3.2 90 Samples – Strong Likelihood of Normality

The following normality probability plot uses the 90 data samples from section B.2.

The normal probability plot shows a set of data points which much more resembles a linear result. Although not entirely clear, the result itself provides better confidence that these test results have come from a normally distributed population.

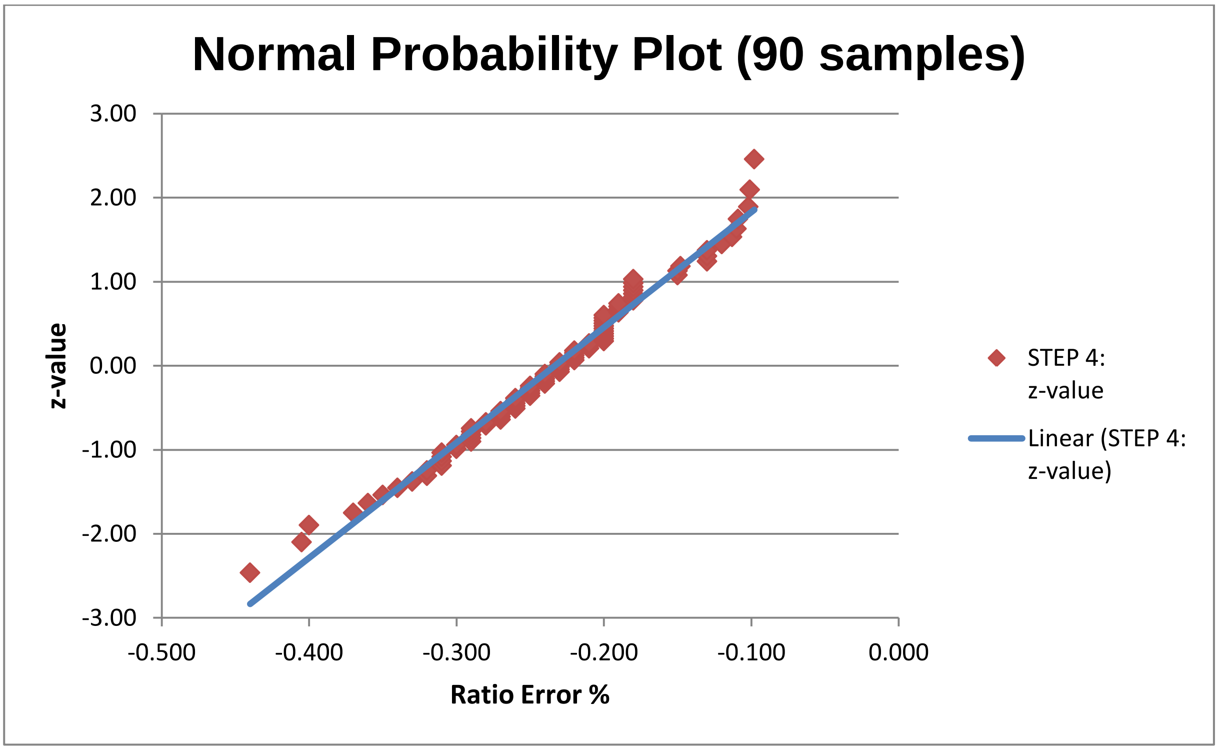

Figure B2: Normality Plot for 90 Samples

Normality can be further verified by using the statistical method as outlined in Appendix A of this document find and calculate the p-value.

Calculate skewness and standard error of skewness (SES)

$\boldsymbol{Excel\ Function}{:}\ = skew(x_1{:}\,x_i)$ **Note:** using the range for STEP 1 data.

$G1 = skew(-0.440{:}-0.098)\ = -0.342$

$$SES\ = \sqrt{\frac{6n(n-1)}{(n-2)(n+1)(n+3)}} \quad \boldsymbol{where}{:}\ n = sample\ size$$

$$SES\ = \sqrt{\frac{6 \times 90(90-1)}{(90-2)(90+1)(90+3)}}\ = 0.254$$

Calculate kurtosis and standard error of kurtosis (SEK)

$\boldsymbol{Excel\ Function}:\ = kurt(x_1 : x_i)$ **Note:** using the range for STEP 1 data.

$G2 = kurt(-0.440 : -0.098)\ = 0.220$

$$SEK\ = 2(SES)\sqrt{\frac{n^2 - 1}{(n-3)(n+5)}} \quad \boldsymbol{where}:\ n = sample\ size$$

$$SEK\ = 2(0.354)\sqrt{\frac{90^2 - 1}{(90-3)(90+5)}}\ = 0.503$$

Perform D'Agostino-Pearson Omnibus Test

Step 1: Calculate the test statistics (Z_{g1}) and (Z_{g2}).

$$Test\ Statistic\ (Z_{g1})\ = \frac{G1}{SES}$$

$$Z_{g1}\ = \frac{-0.342}{0.254}\ = -1.348$$

$$Test\ Statistic\ (Z_{g2})\ = \frac{G2}{SEK}$$

$$Z_{g2}\ = \frac{0.220}{0.503}\ = 0.438$$

Step 2: Calculate the D'Agostino-Person (DP) test statistic.

$$\text{D'AgostinoPerson}\ (DP) = \ {Z_{g1}}^2 + {Z_{g2}}^2$$

$$DP = \ (-1.348)^2 + (0.438)^2\ \ = 2.008$$

Step 3: Calculate the p-value with two degrees of freedom (df).

$$\text{p-value} = \ \mathrm{P}(X^2(2) > DP)$$

$$\boldsymbol{Excel\ Function}:\ = CHIDIST(DP, 2)$$

$$\text{p-value} = CHIDIST(2.008{,}2)\ \ = 0.3664$$

The p-value is calculated to be greater than 0.05. This indicates that there is a nonsignificant difference and a strong likelihood that the test data comes from a normally distributed population. Normality is considered to be demonstrated.

B.3.3 Example for Population not Normally Distributed

The following normal probability plot shows an example of a population of test values that is not normally distributed.

Unlike the previous examples, there is no data provided, as it is merely an example to demonstrate a population that is not normally distributed.

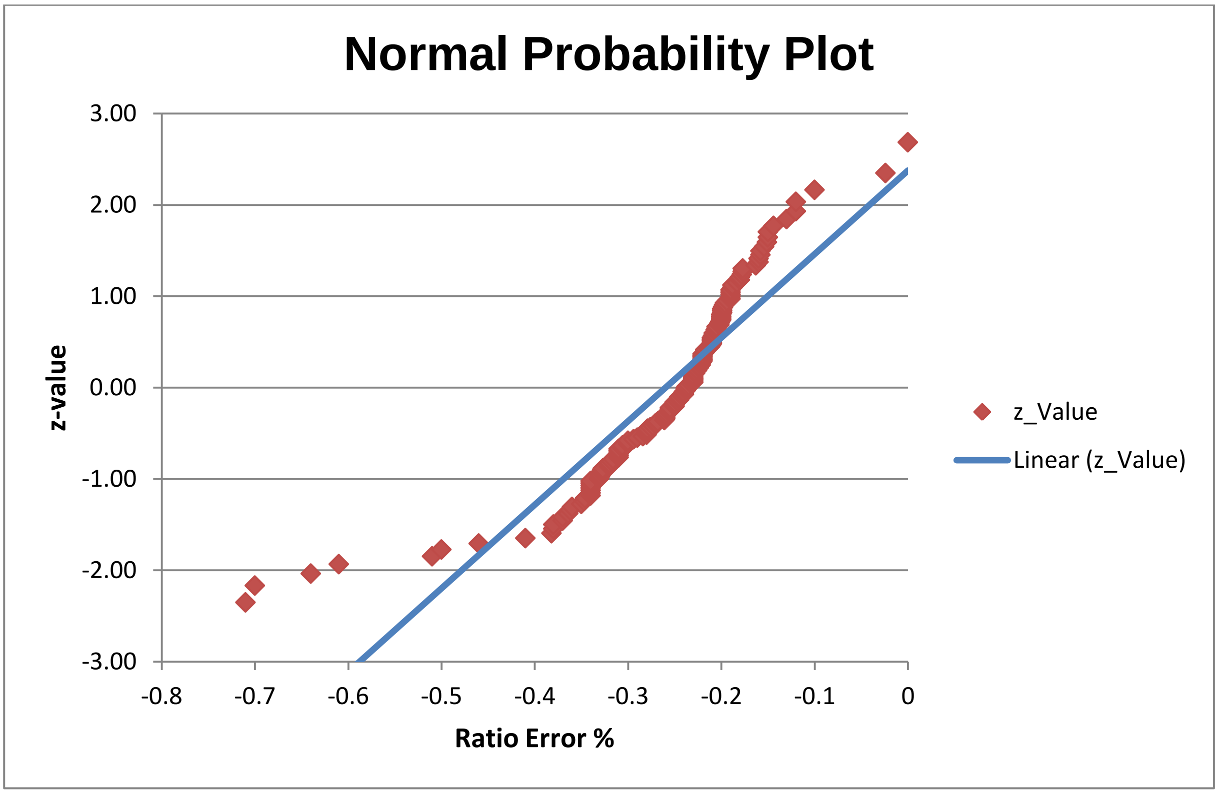

Figure B3: Normality Plot for Population not Normally Distributed

The p-value for this scenario is calculated to be 0 and is significantly less than 0.05. This indicates that there is an extreme significant difference and that the test data does not come from a normally distributed population.