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Measurement Point for EDCOP Voltage Compliance

Essential Services Commission
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Disclaimer

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1 EXECUTIVE SUMMARY

This paper recommends an appropriate measurement point at which voltage variation limits are set in the Electricity Distribution Code of Practice (EDCOP)[1].

This paper has been prepared in response to a request for advice from the ESC about the appropriate point at which voltage variation limits are set. In providing this advice I have been provided with submissions from Victorian distributors made to the ESC in response to the Commission's proposal to set voltage variation limits at the meter.

This paper recommends that **the location for voltage compliance apply at the meter electrically closest to and applicable to the point of supply of a customer's electrical installation**. This definition should remove any ambiguity as to where voltage compliance should be measured, and avoid the need for any assumptions used in the calculation and reporting of the compliance measures.

2 METHOD AND APPROACH

The approach taken in this paper for identifying the recommended location for reporting voltage compliance considered:

- current compliance obligations within the EDCOP, specifically Clause 4.2.
- current Australian standards including:
    - AS 61000.3.100:2011 EMC Limits - steady state voltage limits in public electricity systems
    - AS/NZS 61000.4.30:2012 EMC Testing and measurement techniques – power quality measurement methods
    - AS/NZS 3000:2018 Electrical installations wiring rules
    - AS/NZS 4777.2:2020 Grid connection of energy systems via inverters
- high penetration of AMI smart meters in Victoria as an existing resource to measure and monitor voltage for compliance.
- feedback provided by distributors during the ESC's consultation of the EDCOP voltage amendments, particularly relating to:
    - Lack of information held on consumer mains cable types and lengths.
    - Computational complexity in calculating the estimated point of supply voltage from the meter voltage.
- typical residential customer maximum demands, solar PV system sizes and export limits, and the typical range of consumer mains cable types and lengths used in residential installations, to quantify expected voltage variations across the consumer mains.

[1] Electricity Distribution Code of Practice (EDCOP), Essential Services Commission.

The analysis method used for this paper involved:

- identifying current voltage compliance obligations and the limitations in being able to pragmatically monitor and report voltage compliance, given the physical location of compliance (being the point of supply) may be different to the metering point;
- reconciling the difference between the point of supply voltage and the metering point voltage by estimating the expected range of voltage variations across different consumer mains cables; and
- identifying what adjustments may be necessary to measured voltages or voltage limits, to appropriately cater for the impact voltage variations on consumer mains cables may have on distributors' voltage compliance reporting, in the context of reporting network-wide compliance.

2.1 Limitation of current voltage compliance obligations

Non-compliant steady-state voltage can reduce the output of customers' solar PV systems, trip off (i.e., interrupt) customer inverters, damage (or shorten) the life of customer appliances, or affect the operation of those appliances.

To avoid these issues, the EDCOP requirements for low-voltage steady-state voltage is to maintain the voltage at each customer's point of supply within defined limits, based on AS 61000.3.100. Compliance is achieved if the following conditions are observed at each low-voltage customer point of supply.

Table 1 – EDCOP low-voltage steady-state voltage compliance limits

EDCOP Compliance Limit	Voltage (V)	(% of 230V Nominal)	Comment
$V_{99\%}$	253	+10%	As defined in AS 61000.3.100 Being outside these soft-limits for no more than 1% of the time for each limit.
$V_{1\%}$	216	-6%	

Clause 4.2.1 of the current EDCOP (Version 14, dated March 2022), states that voltage compliance must be maintained at the point of supply as follows: *"Subject to clause 4.2.2, a* ***distributor*** *must maintain a nominal* ***voltage*** *level at the* ***point of supply*** *to the* ***customer's electrical installation*** *[...]"*

This approach of referring to the point of supply for compliance is consistent with AS 61000.3.100 which (according to its Preface and Scope), defines the acceptable limits of steady-state supply voltage variations at customer connection points to the public electricity network (i.e., being the agreed point of supply between the distributor's network and the customer's electrical installation).

Whilst compliance can be measured with appropriate class A metering and measurement methods as described in Clause 4.1 of AS 61000.3.100 and AS/NZS 61000.4.30, it is unlikely that a permanently installed meter within the customer's electrical installation will be located at exactly the point of supply. A consumer mains cable is generally provided between the two locations. This can result in some differences in the voltage along the consumer mains between the metering point and the point of supply, which can vary according to customer load / generation levels, and the cable impedance. In the absence of a meter at the point of supply, Appendix C4 of AS/NZS 3000 provides guidance on how to calculate the estimated voltage drop (or rise) across the consumer mains cable in order to confirm compliance.

2.2 Reconciling the point of supply voltage with the metering point

Whilst it is possible for temporary metering to be installed at the point of supply to confirm individual customer voltage compliance, this approach is not a practical nor an efficient way to assess compliance on a broader scale across millions of customers. Victoria however, has a key advantage in that the vast majority of customers have distributor-owned AMI smart meters installed, with penetration levels close to 100% for residential customers. The AMI smart meters used in Victoria all have voltage measurement capability coupled with back-end processing, consistent with Clause 4.1 of AS 61000.3.100.

Notwithstanding, AS 61000.3.100 was developed on the basis of there not being high penetrations of AMI smart meters, and approaches compliance measurement on a population sampling basis (Appendix D). There is therefore a disconnect between the obligation to maintain nominal voltage levels at the point of supply versus how, in practice, the ESC can assess performance and compliance through utilising AMI smart meter data.

With the ubiquitous nature of AMI smart meters in Victoria, the more appropriate approach to monitor ongoing voltage compliance across millions of customers, is to use actual AMI voltage data. The measurement point for voltage levels should then be set at the AMI meter located electrically closest to the point of supply within the customer's electrical installation, with the measured value adjusted back (if necessary) to the point of supply by taking into account the voltage drop (or rise) across the consumer mains through the application of Appendix C4 of AS/NZS 3000.

Feedback provided by distributors during the ESC's consultation of the EDCOP voltage compliance and reporting proposed amendments, has indicated that the computational requirements and lack of information held by the distributors on the length and size of each consumer mains cable, means that adjusting metering point voltages back to the point of supply, using a calculation consistent with of Appendix C4 of AS/NZS 3000, is likely to be infeasible.

A desktop assessment was therefore undertaken to determine whether the magnitude of the range of expected voltage drops (or rises) across the consumer mains is material or not. This was based on typical load and generation patterns across the low-voltage residential customer base and the range of consumer mains cables typically used by customers within their electrical installations. This assessment was limited to residential customers only, where consumer mains are less likely to have been sized to Clause 1.6.3 of AS/NZS 3000, especially for older installations subsequently adding large solar PV systems or air-conditioning systems, without an associated upgrade of the consumer mains cable.

Based on the analysis results detailed in Chapter 3 of this paper, the 90^{th} percentile of customers' voltage variations across the consumer mains is expected to be around 0.6% (1.4 Volts) voltage drop and for solar customers only, 0.5% (1.2 Volts) voltage rise. These variations are calculated at peak demand or peak solar PV export conditions and generally over a few hours of a day. For much of the remainder of the one-week measurement period required by Clause 4.1 of AS 61000.3.100 used for measuring compliance, customer loads and generation patterns are significantly less than these extremes due to changing weather including milder temperature conditions and cloud cover. This has the effect of diluting the effects of voltage variations in the consumer mains contributing to any non-compliance. Under these more moderate conditions the 90th percentile of customers' voltage variations across the consumer mains is expected to be less than 0.2% (0.5 Volts).

2.3 The need to adjust metered voltages or voltage limits

Whilst the voltage variations across the consumer mains are beyond the control of distributors, the analysis illustrates that for the vast number of customers for the majority of the time, the influence of the voltage variations on the consumer mains is likely to be negligible on the distributor's compliance reporting results in the context of reporting network-wide compliance. Material differences in the reporting results are only likely to be observed if there is a *coincidence* of:

- customers with large voltage variations across their consumer mains due to their own extreme load/generation levels, or substantially undersized cables; and
- those same customers are connected to those parts of the distribution network that are already presented with excessively high or excessively low voltages by the distributor.

Given the above, it is recognised that the computational requirements needed to support the dynamic adjustment of AMI metering (or the voltage limits) by an amount according to the import/export conditions at each interval of time to reflect the voltage at the point of supply, is not warranted and overly onerous, given the magnitude of the expected voltage variation across the consumer mains for the bulk of customers for the bulk of time is relatively low.

Furthermore, the dynamic nature of the voltage variations does not warrant the use of fixed adjustments to the voltages or the voltage limits either, as this would tend to mask any wider scale non-compliance issues occurring in the network.

The analysis also shows that prescribed voltage rise (AS/NZS 4777 -2%) and drop (AS/NZS 3000 -5%) accountabilities for customers' installations applies only in part to the consumer mains, rather mainly to the voltage variations in the wiring between the customer switchboard and their appliances.

Regardless of AS 61000.3.100 describing the point of supply voltage (not the meter voltage) as the point of compliance measurement, AS/NZS 61000.4.30 Section B.3.1 provides for the measurement to be taken as close as possible to the point of supply, but not necessarily at the point of supply, if there are cost and convenience issues in locating the meter at the point of supply. In the Victorian context, the AMI smart meter is as close as possible to the point of supply, without having the cost burden of installing another meter.

3 DETAILED ANALYSIS

3.1 Voltage variations across the consumer mains

The voltage drop (or rise) across the consumer mains cable may need to be taken into consideration when interpreting literal compliance for any specific (individual) customer, given the point of supply may not be located close to the meter. This is illustrated in two examples below.

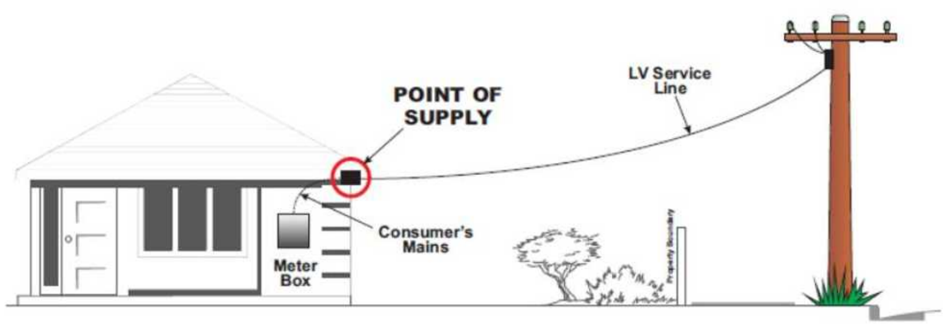

Figure 1 - Typical Overhead Line Connection

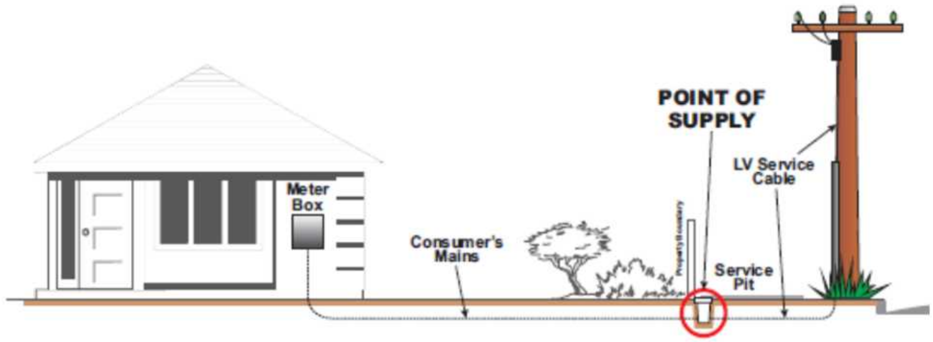

Figure 2 - Typical Underground Line Connection

This is particularly the case if the consumer mains is very long, or supplies older (typically 45 years old or more) residential premises that may not have been rewired and have undersized consumer mains cables (e.g., 6mm to 16mm), and have subsequently installed large air-conditioners or solar PV systems, without an associated upgrade of the consumer mains.

Clause 1.6.3 of AS/NZS 3000 requires the consumer mains to be designed and installed to support the electrical installation's overall maximum demand. Furthermore, Clause 1.6.4 of AS/NZS 3000 requires the voltage at the terminals of electrical appliances is suitable for those appliances, meaning that the installation needs to keep voltage drops (and rises) within acceptable levels. Clause 3.6.2 of AS/NZS 3000 specifies this maximum allowable voltage drop for the design of an electrical installation between the point of supply and any electrical appliance as 5% of the nominal voltage. Furthermore, Clause 4.5.2 (Table 4.3) of AS/NZS 4777.2 requires the limit for sustained operation for voltage variations at a customer's inverter to be limited to 258 V (i.e., a 2% voltage rise above the allowable $V_{99\%}$ limit of 253 V at the point of supply in Clause 5.1 (Table 2) of AS 61000.3.100).

The 5% and 2% values relate to the maximum voltage drop and voltage rise (respectively) between the point of supply and any appliance (including inverters) within the customer electrical installation (as shown). i.e., NOT between the point of supply and the meter.

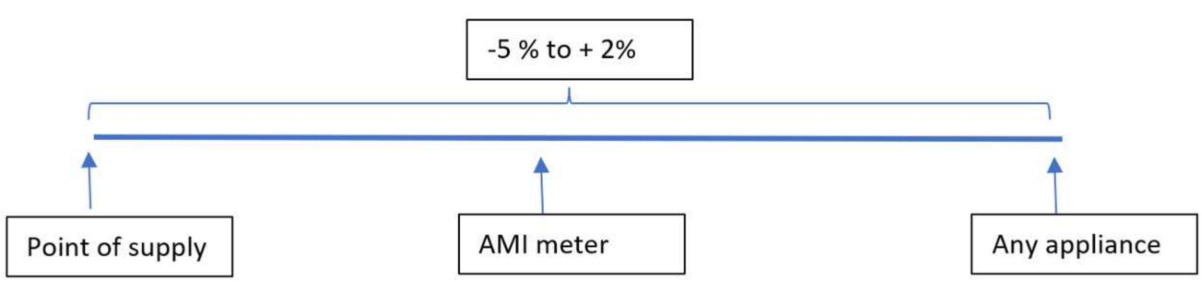

Figure 3 – Allowable voltage drop and rise within a customer electrical installation

The voltage drop or voltage rise between the point of supply and the meter must be designed to be less than these values, to accommodate voltage drop or voltage rise between the meter and any appliances, in order for the installation to be compliant with AS/NZS 3000.

3.2 Calculating the estimated voltage at the point of supply from the meter

If the conductor type, number of phases and length between the point of supply and the AMI meter is (approximately) known, then by applying the formula in Appendix C4 of AS/NZS 3000 and utilising the AMI meter's voltage, bi-directional real and reactive energy, and/or current sampled measurement values, the estimated voltage difference can in theory be calculated as follows:

$$\%\text{Voltage (Drop or Rise)} = \text{Current (Amps)} \times \text{Length (metres)} \div \text{Am\_per\_\%}V_d$$

where Am_per_%V_d is taken from Table C8 of AS 3000 as follows:

- *818 for 16mm^2 consumer mains cable size;*
- *1289 for 25mm^2 consumer mains cable size; and*
- *1773 for 35mm^2 consumer mains cable size.*

If active energy is exporting to the grid, then %Voltage can be assumed to be a voltage rise, otherwise it can be assumed to be a voltage drop.

Hence, for consistency the voltage variation limits could be maintained at the point of supply, but the AMI voltage data could (in theory) be adjusted for each measurement sample to reflect the estimated value at the point of supply using:

$$\text{Point of Supply (Volts)} = \text{Measured AMI Voltage (Volts)} + (\min(5, \%\text{Voltage Drop}) - \min(2, \%\text{Voltage Rise})) \div 100 \times 230$$

The effort and complexity needed to incorporate such a formula in the compliance reporting, depends on whether the magnitude of the voltage variations across the consumer mains is material or not. This is assessed as follows.

3.3 Typical magnitude of consumer mains voltage variations

Applying the method described above to typically observed household import and export levels (per phase), and consumer mains cable types and maximum lengths, the following range of voltage rise (and drop) variations can be expected to occur across the consumer mains between the point of supply and the AMI meter.

Table 2 – Typical voltage variations across the consumer mains

Voltage Rise (Drop) Estimations (%) on Consumer Mains (between point of supply and the AMI meter)					
16 mm2 cable (63A)	export kVA/ph			import kVA/ph	
Distance from Point of Supply to AMI Meter (m)	-5	-2	0	3	6
10	*0.3%*	*0.1%*	*0.0%*	*-0.2%*	*-0.3%*
15	*0.4%*	*0.2%*	*0.0%*	*-0.2%*	*-0.5%*
20	*0.5%*	*0.2%*	*0.0%*	*-0.3%*	*-0.6%*
25 mm2 cable (80A)	export kVA/ph			import kVA/ph	
Distance from Point of Supply to AMI Meter (m)	-5	-3	0	3	10
10	*0.2%*	*0.1%*	*0.0%*	*-0.1%*	*-0.3%*
20	*0.3%*	*0.2%*	*0.0%*	*-0.2%*	*-0.7%*
30	*0.5%*	*0.3%*	*0.0%*	*-0.3%*	*-1.0%*
35 mm2 cable (100A)	export kVA/ph			import kVA/ph	
Distance from Point of Supply to AMI Meter (m)	-5	-3	0	3	12
10	*0.1%*	*0.1%*	*0.0%*	*-0.1%*	*-0.3%*
25	*0.3%*	*0.2%*	*0.0%*	*-0.2%*	*-0.7%*
40	*0.5%*	*0.3%*	*0.0%*	*-0.3%*	*-1.2%*

Represented graphically, the magnitude of the voltage variations changes linearly with the import or export levels from the customer's electrical installation at typically less than 0.1% per 1 kW of import/export.

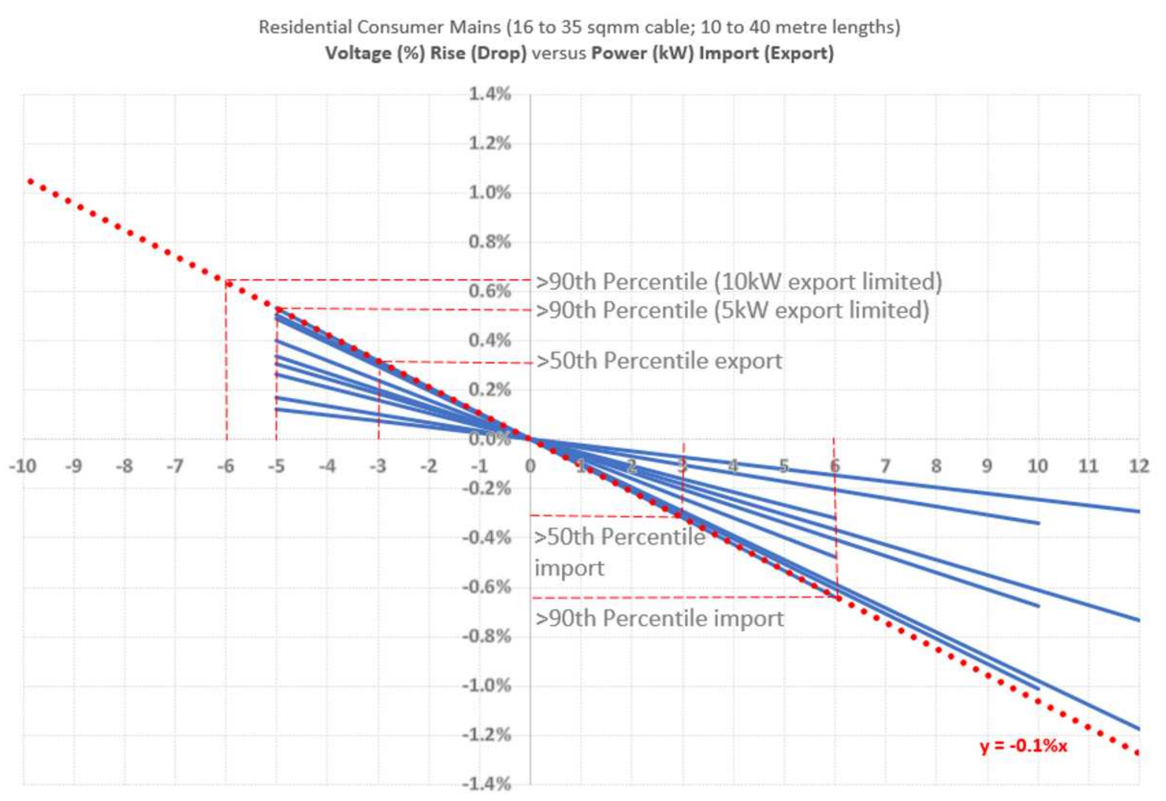

Figure 4 – Typical voltage variations across the consumer mains

Whilst the consumer mains cable type and length may not be known, the magnitude of the voltage changes are typically within ±0.3% for the 50th percentile customer.

3.4 Consumer mains in the context of reporting network-wide compliance

Based on the range of consumer mains cables, lengths and residential customer load and generation on days of high electricity demand[2] and solar PV export[3] respectively, the 90th percentile of customers' voltage variations across the consumer mains is expected to be around 0.6% (1.4 Volts) voltage drop and 0.5% (1.2 Volts) voltage rise[4], equivalent to 0.1% voltage drop for each additional 1 kW import per phase. This means most of the voltage drop contemplated by Clause 3.6.2 of AS/NZS 3000 is reserved for the wiring between the customer's switchboard and their appliances. For customers with extreme import (i.e., greater than 10 kW per phase), capturing approximately the 99th percentile of customers, the voltage drop across the consumer mains is expected to be around 1.1% (2.5 Volts).

[2] 50th percentile of customers' maximum demand of 3 kW. Less than 10% of residential customers are assumed to have maximum demands in excess of 6 kW.

[3] 50th percentile of customer's export of 3 kW. Less than 10% of residential customers are assumed to have export levels in excess of 5 kW, noting that 5 kVA (or lower) export limits are often applied by distributors.

[4] For solar customers only. Non solar customers are not expected to have a material voltage rise.

4 RECOMMENDATIONS

The calculation of the estimated voltage variation across the consumer mains could (in theory) be undertaken by distributors within their compliance reporting algorithms. However, feedback provided by distributors during the ESC's consultation of the EDCOP voltage compliance and reporting proposed amendments, has indicated that the computational requirements and lack of information held by the distributors on each consumer mains cable, means that adjusting metering point voltages back to the point of supply, using a calculation consistent with Appendix C4 of AS/NZS 3000, is likely to be infeasible.

It is recognised that the computational requirements and additional information needed to support the dynamic adjustment of AMI metering (or the voltage limits), is not warranted and overly onerous, given the magnitude of the expected voltage variation across the consumer mains for the vast number of customers for the majority of the time, is relatively low.

Furthermore, the dynamic nature of the voltage variations does not warrant the use of fixed adjustments to the voltages or the voltage limits either, as this would tend to mask any wider scale non-compliance issues occurring in the network.

The analysis also shows that prescribed voltage rise (AS/NZS 4777 -2%) and drop (AS/NZS 3000 -5%) accountabilities for customers' installations, applies only in part to the consumer mains, rather mainly to the voltage variations in the wiring between the customer switchboard and their appliances.

Regardless of AS 61000.3.100 describing the point of supply voltage (not the meter voltage) as the point of compliance measurement, AS/NZS 61000.4.30 Section B.3.1 provides for the measurement to be taken as close as possible to the point of supply, but not necessarily at the point of supply, if there are cost and convenience issues in locating the meter at the point of supply. In the Victorian context, the AMI smart meter is as close as possible to the point of supply, without having the cost burden of installing another meter.

Utilising the existing investment in AMI and setting voltage variation limits at the meter, will provide an effective, low-cost means of monitoring voltage compliance in Victoria across the population of customers, avoiding the cost burden of installing another meter, and avoiding the uncertainty and complexity of estimating point of supply voltages from the meter voltage.

For these reasons, it is therefore recommended that voltage variation limits be set at the meter and applied '*at the meter electrically closest to and applicable to the point of supply to the customer's electrical installation*'.[5] This definition should remove any ambiguity as to where voltage compliance should be measured.

[5] Application of AS 61000.3.100 V1% and V99% voltages in the low-voltage steady-state voltage regulations for Victoria in recent years, has provided distributors with a relaxation of their voltage compliance obligations compared to the +10% / -6% hard limits (i.e., for 100% of customers for 100% of the time) which were in force in previous versions of the VEDC. The application of the proposed wording in this paper is not expected to place distributors in a more stringent compliance position than what was in place prior to the adoption of AS 61000.3.100 for assessing low-voltage steady state voltage compliance.