WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Company Directive

STANDARD TECHNIQUE: SD6J/2

Determination process for the connection of potentially disturbing electrical equipment

Policy Summary

This Standard Technique defines how the connection of potentially disturbing equipment shall be designed in order to control voltage fluctuations, flicker & harmonic voltage distortion. This policy applies to installations with a low or high voltage Point of Common Coupling and excludes Low Carbon Technology.

Author: **Simon Scarbro & Seth Treasure**

Implementation Date: **December 2020**

Approved by

Paul Jewell
DSO Development Manager

Date: **1st December 2020**

Target Staff Group	**Staff responsible for low and High voltage network design**
Impact of Change	**Amber – The change aligns with amendments to ENA EREC G5/5 which impacts on connection designs.**
Planned Assurance checks	**Following a training roll out – one planner per license area will be assessed**

IMPLEMENTATION PLAN

Introduction

This Standard Technique (ST) defines the design procedure required for the connection of potentially disturbing equipment to the WPD low voltage (LV) or high voltage (HV - 6.6kV & 11kV) network, excluding Electric Vehicle (EV) charge points and Heat Pumps (HP) which are detailed within ST: SD5G Part 1 & 2.

Main Changes

The design and connection procedure has been updated to align with the changes made to ENA EREC G5 regarding harmonic emissions, ENA EREC P28 regarding flicker and POL:SD4. In addition, a unbalance assessment has been created for customer connected equipment.

Impact of Changes

This policy will detail an iterative assessment procedure where each stage requires more data to enable a more refined determination process.

Target Staff Group	**Staff responsible for low and high voltage network design**
Impact of Change	**Amber – The change aligns with amendments to ENA EREC G5/5 which impacts on connection designs.**

Implementation Actions

A training programme in Q1 of 2021 will be provided by the DSO Development team.

Implementation Timetable

This policy is implemented with immediate effect.

REVISION HISTORY

Document Revision / Review Table		
Date	**Changes / Comments**	**Author**
December 2020	• The scope of the document has been expanded to include any rating of device • The scope of the document has been expanded to include HV Points of connection • A spreadsheet tool has been added for use whilst undertaking a stage 3 flicker assessment • A spreadsheet tool has been added to determine the impedance requirement for equipment compliant with BS EN 61000-3-12. • A spreadsheet tool has been added for use whilst undertaking a stage 1C-1 to 2C harmonic assessment. • A spreadsheet tool has been added for use whilst checking equipment harmonic current emissions. • An unbalance assessment requirement and associated spreadsheet tool has been added	Seth Treasure
February 2020	• Electric Vehicle charge points and Heat Pumps have been removed from this policy • WinDebut pictures updated • Table D1 amended to include split phase values • Examples updated to remove heat pumps	Seth Treasure

CONTENTS

APPENDIX

1.0 INTRODUCTION

1.1 This Standard Technique (ST) defines the design procedure required for the connection of potentially disturbing equipment to the WPD network, excluding EVs and HPs. This is necessary to control voltage fluctuations, voltage unbalance, flicker & harmonic voltage distortion.

1.2 This ST implements connection requirements for the Energy Network Association (ENA) Engineering Recommendation P28 (Flicker), P29 (Voltage Unbalance) and G5 (Harmonics).

2.0 SCOPE

2.1 This ST details the determination process to connect potentially disturbing equipment to the low and high voltage distribution system.

2.2 Determining the thermal requirement and connection arrangement for the installation is out of the scope of this document – see ST: SD5A, ST: SD5E or ST: SD4A and ST: SD4OA/B for LV and HV connections respectively.

3.0 POLICY

3.1 Connection Design for Disturbing Electrical Equipment Rated ≤75A per Phase With LV POCC

It is generally acceptable for customers to install small electrical equipment without specific evaluation of disturbance emission by the Distribution Network Operator (DNO). Equipment rated at ≤16A per phase which complies with BS EN 61000-3-3 and BS EN 61000-3-2 is not subject to conditional connection and so is exempt from connection design as potentially disturbing equipment.

WPD will however ensure that the phase to neutral impedance at the cutout is ≤ 0.47 ohms (for single phase LV connections).

3.1.1 Equipment that is rated >16A ≤ 75A per phase shall be subject to conditional connection to control disturbances, unless it complies with the technical requirements of BS EN 61000-3-3 and BS EN 61000-3-2 or is not deemed significant by WPD. Table 1 provides guidance on what equipment is considered significant by WPD.

Equipment Type/ Families of Products	Assessment Type	
	Voltage Fluctuations & Flicker Control Procedure (Figure 1)	Harmonic Control Procedure (Figure 2)
Electric boilers for central heating	✓	✓[1]
Air conditioners and commercial refrigeration equipment	✓	✓
Uninterruptible power supplies & industrial battery charging systems	✓	✓
Electric kilns	✓	✓[1,2]
Industrial/commercial converters (i.e. rectifiers, AC-DC converters [including adjustable speed power drives] & AC-AC converters)	✓	✓
Agricultural lighting control & industrial heating control	✓	✓
PV generators		✓
Wind turbines	✓	✓
Generation export limiting device[2]	✓	✓
Arc welders within scope of BS EN 61000-3-11 & -12 (e.g. non-professional)	✓	✓
Other equipment with stated Z_{max} to 61000-3-11 if known (e.g. electric shower)	✓	
Other equipment with stated S_{sc} to 61000-3-12 if known		✓
Equipment compliant with 61000-3-4		✓

Table 1 - Significant Equipment Rated >16A Per Phase Requiring Assessment if LV PCC

3.1.2 Applications to connect equipment of the type listed in Table 1, where the PCC is at LV, shall be assessed using design procedures detailed within section 5, 6 & 7, as appropriate.

3.2 Connection Design for Disturbing Electrical Equipment Rated >75A per Phase With LV POCC

3.2.1 Applications to connect equipment with a rating >75A per phase and where the point of common coupling is at LV (WPD network) shall be assessed by following the design procedures detailed within section 5, 6 & 7, as appropriate.

[1] The Harmonic Control Procedure is not required for if it is established that the resistive heating elements are simply switched in/out via thermostat/contactor (i.e. the load is linear) as opposed to through power electronics such as AC regulator (e.g. thyristor).
[2] E.G. an export limitation system compliant with the requirements of ENA EREC G100.

3.3 Connection Design for Disturbing Electrical Equipment With a HV POCC

3.3.1 Applications to connect equipment with a point of common coupling at HV shall be assessed by following the design procedures detailed within section 5, 6 & 7, as appropriate.

4.0 MINIMUM INFORMATION

4.1 The installer / customer / manufacturer shall submit a satisfactorily completed disturbing load form.

The data collection forms are available via the following link;

<Hyperlinks to Data Collection Forms>

Main forms:

Form C	Harmonics (>75A/phase or non-compliant with BS EN 61000-3-12/-2)Equipment Rated ≤75A/phase
Form D	Flicker (>75A/phase or non-compliant with BS EN 61000-3-11/-3)
Form X	Equipment Rated ≤75A/phase

4.2 The following information is mandatory;

- Customer information – Name, Address
- Equipment details – Phases, voltage, rating(kVA), loading per phase
- Type of equipment – AC to DC converter (e.g. 6/12 pulse converter, active front end converter, single phase rectifier), welder, Motor
- Relevant declarations of conformity

The following information is required for advanced assessments;

For an ENA EREC G5 stage 2C assessment (harmonics);

- Harmonic current emissions (2^{nd}-40^{th}) for the equipment at different power levels (10% intervals from 10 to 100% rating)

For an ENA EREC P28 stage 2 assessment (flicker);

- Rating of device (kW or HP)
- Number of starts for a given time e.g. minute or hour
- Maximum starting current or method of starting e.g. Direct on Line or Soft start
- Power factor on start up

For an ENA EREC P28 stage 3 assessment (flicker);

- D_{max} (Maximum voltage change)
- D_c (relative steady state voltage change)
- D_t (voltage change)
- P_{st} (Short term flicker severity)
- P_{lt} (Long term flicker severity)
- The impedance at which the device was tested

For an ENA EREC P29 assessment (voltage unbalance);

- Expected load per phase (demand or generation)

5.0 CONNECTION PROCEDURE – VOLTAGE FLUCTUATION & FLICKER

5.1 To ensure that customer equipment does not cause undue ‘flicker’ which can cause annoyance (the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time) installations of equipment that are noted within Table 1 shall be designed to have an impedance at the point of supply which mitigates the flicker concern.

5.1.1 The voltage fluctuation and Flicker assessment shall be undertaken at the point of common coupling. Levels of voltage fluctuation and flicker on a sole use asset may exceed the defined limits however all shared assets must be within the tolerable range.

For example, the voltage drop at the PCC has been calculated to be 2.5% and the voltage drop at the POS has been calculated to be 3.5% when a motor starts. The limit for short term voltage fluctuation (P_{st}) has been determined to be 3% for a motor starting 4 times an hour. The connection can be accepted as the P_{st} at the PCC is < the limit.

5.1.2 For the determination of the impact of multiple installations of disturbing load connected to multiple points of connection. The assessment procedure shall be undertaken at the furthest node with the greatest impedance (worst served customer) and the connection design that satisfies the requirements at this node will be deemed to be adequate for all other connections with a lower impedance (better served customers).

5.1.3 For the determination of the impact of multiple items installed beyond one point of supply, the equipment items that are likely to cause undue flicker shall be assessed and the values of P_{st} shall be summated by using the attached spreadsheet from clause 5.3.2 below.

Where items of equipment are deemed to be compliant with BSEN 61000-3-3, these items of equipment can be excluded from any summation assessment.

5.1.4 Where a manufacturer assess equipment to be compliant with a flicker / voltage change standard, the test setup must include all of the key components (integral parts) that are required for the site installation of that product. Any additional items not included within the test will need to be assessed independently and the summation of the equipment needs to be assessed.

5.2 **For Equipment rated ≤ 75A with a LV POS**

5.2.1 Where equipment has been declared compliant with BS EN 61000-3-3 or if rated >16A and <75A, with the 'technical' requirements of BS EN 61000-3-3, the equipment shall have an unconditional connection. However, WPD shall ensure that the phase to neutral impedance at the cutout is ≤ 0.47 ohms (LV connections). Any costs associated with any required remedial works to decrease the phase to neutral impedance in line with the above requirement shall be fully charged to WPD. See ST: NC1P for guidance.

Equipment deemed to be compliant with the 'technical' requirements of BS EN 610003-3 may have a rating > 16A however the items have been tested and are compliant with the power quality limits relating equipment rated ≤ 16A.

5.2.2 Where equipment has been declared compliant with BS EN 61000-3-11 'subject to a service current carrying capacity ≥ 100A per phase', the impedance at the cutout shall comply with table 2.

Any costs associated with any required reinforcement works to decrease the phase to neutral impedance in line with the below requirement shall be fully charged to the customer. However, if the phase to neutral impedance at the POS is > 0.47, WPD will fund the reinforcement works to reduce the impedance to 0.47 ohms. See ST: NC1P for guidance.

Equipment Connection	**Maximum source impedance**
	$Z_{max\ 100A}$
Single Phase	0.25+j0.25 Ω = 0.3536 Ω
Split Phase	0.30+j0.30 Ω = 0.4243 Ω
Three Phase	0.15+j0.15 Ω = 0.2121 Ω

Table 2 – Maximum source impedance $Z_{max\ 100A}$

Please note that the service current carrying capacity does not need to be amended to be ≥100A unless the actual demand of the property requires it. The statement refers to the required impedance of the connection to maintain a good voltage level if the current flow reached 100A.

5.2.3 Where equipment has been declared compliant with BS EN 61000-3-11 'subject to a maximum impedance or Zmax', the impedance at the cutout shall comply with the 'stated requirement'.

For example, a manufacturer may have declared a disturbing load compliant with BS EN 61000-3-11 subject to an impedance of 0.3 ohms. Therefore, the impedance at the supply terminals shall be designed to be $\leq$ 0.3 ohms. Any costs associated with any required remedial works to decrease the connection impedance in line with the above requirement shall be fully charged to the customer. See ST: NC1P for guidance.

5.2.4 Where no declaration of conformity has or is able to be made and the individual rating of each item is $\leq$ 75A, the following processes apply;

Where equipment is compliant with the requirements of Appendix C, it may be connected without further investigation. This process is available for equipment rated up to 1.2kW single phase and 5.9kW three phase.

Or

An ENA EREC P28 stage 2 study shall be undertaken within an appropriate software package. For example, a study within WinDebut or Connect/LV compliant with the requirements detailed within Standard Technique: SD5N or SD5K as appropriate.

The step voltage change limit will ordinarily be determined by the software programme but a limit of 6% can be applied for devices that operate very infrequently – a device or operation that occurs less than once every three months

5.2.5 Where multiple items are being installed, the spreadsheet 'P28 Stage 2 Multi' can be used in coordination with the LV design software package to determine the summated flicker value.

5.2.6 Where equipment cannot be accepted for connection via the previous assessment procedures, a reinforcement scheme shall be implemented to enable the connection of the disturbing load. See Standard Technique: NC1P for guidance on the current charging methodology.

Alternatively, at the 11kV planner's discretion, an ENA EREC P28 stage 3 assessment can be implemented to determine the acceptability of the connection. However, this stage of assessment shall only be enacted where the following apply;

- The background levels of flicker are anticipated to be low

  &

- The reinforcement costs to satisfy a stage 2 assessment are disproportionate to the connection costs.

  &

- It is anticipated that the connection will pass a stage 3 assessment.

5.3 **For individual or multiple items of equipment rated > 75A per phase, with a LV POS**

For equipment rated >75A per phase and included within table 1 above or where the device is expected to cause flicker, there are two available processes to be able to determine the connection requirements.

Initial Assessment – Stage 2 assessment

5.3.1 An ENA EREC P28 stage 2 study shall be undertaken within an appropriate software package. For example, a study within WinDebut or Connect/LV compliant with the requirements detailed within Standard Technique: SD5N or SD5K as appropriate.

The step voltage change limit will ordinarily be determined by the software programme but a limit of 6% can be applied for devices that operate very infrequently – a device or operation that occurs less than once every three months.

5.3.2 Where multiple items are being installed, the spreadsheet 'P28 Stage 2 Multi' can be used in coordination with the LV design software package to determine the summated flicker value.

5.3.3 Where equipment is unable to be accepted via the previous assessment procedure the determination process shall progress to the stage 3 assessment procedure detailed below.

Advanced Assessment – Stage 3 assessment

5.3.4 Where the installation of equipment is unachievable or not cost effective by following the previous design methods, an ENA EREC P28 stage 3 assessment can be undertaken where the background level of flicker is measured at the PCC or nearest available location and the predicted emissions are summated using the linked spreadsheet to predict the installations compliance with the planning limits.

Measured data shall be taken for 14 days, the highest 95th percentile for 7 days shall be found by sliding a 7 day window across the data. Where it has not been possible to obtain 14 days' worth of data, the 99th percentile shall be chosen. The network measurements shall be undertaken during the expected time of use of the equipment that is intended to be connected.

Where three phases of measurement have been taken, the worst effected phase shall be used for the analysis.

5.3.5 Where back ground measurements are unable to be taken at the PCC, the measurements can be taken from a remote node and thereafter the values can be scaled to be that of the expected values at the proposed PCC. The method uses a scaling factor between the fault level at the measured node and the node of interest.

For example, it is proposed to connect a disturbing load (substation 'B') via a new HV extension (ringed) which is to be situated 1000m downstream from substation 'A'. The background flicker measurements have been taken at the existing substation location 'A', where the fault level has been calculated to be 100MVA and the fault level is expected to be 80MVA at the proposed new substation location.

The flicker measurements at position 'A' shall be scaled using the following formulae;

$$\text{Scaling factor} = \frac{Fault\ level\ at\ measured\ location}{Fault\ level\ at\ proposed\ location}$$

Therefore,

$$\text{Scaling factor} = \frac{100\ MVA}{80MVA} = 1.25$$

The calculation spreadsheet 'P28 Stage 3' includes a Scaling Factor tool for ease of conversion.

5.3.6 Where measurements of flicker are taken at LV for a connection with a point of supply at HV. The nominal HV-LV transformer tap scaling factor shall be used – for phase to neutral measurements a value of 44:1 shall be used.

5.3.7 The short term flicker level (P_{st}) and the long term flicker level (P_{lt}) shall be assessed by using an appropriate and approved power quality measurement device and the summation of the measured and predicted values shall comply with Table 3.

System Voltage	Planning Level	
	P_{st}	P_{lt}
LV	1	0.8
HV	0.9	0.7

Table 3 – Flicker Planning Levels

5.3.8 The following are acceptable sources of the predicted level of voltage fluctuation and flicker due to the connected equipment;

- Manufacturers information e.g. EMC test reports
- The output of software modelling tools e.g. WinDebut or Connect/LV

5.3.9 The ENA EREC P28 stage 3 assessment shall be undertaken by using the following spreadsheet - P28 Stage 3 calculation spreadsheet

A flow chart detailing the determination process for voltage fluctuation and flicker can be found within Appendix A.

6.0 VOLTAGE UNBALANCE

6.1 Where customers have more than one phase connected to their installation, it is important to maintain the connected phases at the same or similar voltages to mitigate against equipment damage or the operation of protective devices (looking for unbalanced voltages). Therefore, it is essential that customer connections are assessed for designed imbalances of load (e.g. more load connected to L1 than any other phase) to ensure that they do not affect their own connection and the wider distribution system.

Western Power can only distribute electricity, so the only way for WPD to maintain healthy voltages across the available phases is to stipulate requirements on connected customers.

There is no requirement for WPD to assess the wider WPD network for voltage unbalance, the assessment shall be undertaken solely for the customers proposed load.

6.1.1 For compliance with ENA EREC P29, all connections shall be designed to be balanced across all of the available phases, however where this is not possible, the quantity of unbalance shall be assessed and shall be maintained to a value not exceeding 2% (voltage unbalance – value for one minute period).

6.1.2 For compliance with ENA EREC G99, all generation connections shall comply with the below requirements;

- Maximum single phase installed capacity of 17kW
- Maximum split phase installed capacity of 34kW
- Maximum installed unbalance of 3.68kW for all three phase installations (this requirement will be waived for supplies that have been upgraded to three phase by WPD for the installation of LCT).

6.1.3 To assess the impact of unbalanced load, the following spreadsheet can be used to assess expected voltage unbalance. P29 Voltage Unbalance

6.1.4 Where high levels of voltage unbalance have been determined on the wider WPD network, it is advisable to inform customers of the expected level of unbalance so that customer equipment can be designed accordingly.

WPD are not required to maintain the level of unbalance to a specified level, customers equipment is expected to be designed to accommodate connection onto the system. For example, three phase motors have to be utilised at a lower demand to that of the full equipment capacity.

6.1.5 The result of unbalanced loads due to faults can be ignored and is out of the scope of this document.

7.0 CONNECTION PROCEDURE – HARMONICS

7.1 To ensure that customer equipment does not cause harmonic issues, installations of equipment that are noted within Table 1 shall be designed to have an impedance at the point of common coupling (PCC) to mitigate harmonic effects.

Harmonic distortion is the distortion of the pure sine wave to a curve with notches, flat tops and or to an irregular shape. Customer equipment that draws or generates non-sinusoidal current is said to be ‘non-linear’; the current is said to be ‘distorted’ from the ideal sine-wave of a purely resistive load. The distortion in the current waveform can be expressed mathematically as comprising of ‘harmonic currents’ at frequencies that are multiples of 50Hz, known a ‘harmonic orders’. A distorted current when drawn/injected into a network causes the voltage to become non-sinusoidal/distorted; this is known as ‘voltage distortion’ and, like with current distortion, can be expressed as comprising of harmonic voltages of certain harmonic orders. The amount of current distortion and specific harmonic orders involved depend upon the design of the non-linear equipment. Some technologies are less distorting or cleaner than others.

Devices that are known to cause distortion to the sine wave are typically devices that either control or convert the AC voltage e.g. AC-DC converters and soft starters associated with motor controls.

When customers apply to connect disturbing loads, it is incumbent on the DNO to assess the impact of the connection on the wider distribution system to mitigate the following concerns caused by harmonic distortion;

- Excessive heating within appliances (motors and electronic components)
- Erratic operation (timers running fast)
- High voltages
- Damage to insulation
- Overall ageing of customer appliances and WPDs assets

7.2 Where equipment has been declared compliant with the requirements of BS EN 61000-3-2 or, if rated >16A and $\leq$75 per phase, with the Class A requirements of BS EN 61000-3-2, the equipment shall have an unconditional connection, however, WPD shall ensure that the phase to neutral impedance at the PCC is $\leq$ 0.47 ohms (LV connections). Any costs associated with any required remedial works to decrease the phase to neutral impedance in line with the above requirement shall be fully charged to WPD. See ST: NC1P for guidance.

7.3 Where equipment has been declared compliant with the requirements of BS EN 61000-3-12 and the individual rating of each item is $\leq$ 75A per phase, the following spreadsheet (Harmonics) can be used to determine the connection requirement at the PCC.

7.4 Where equipment has been declared compliant with the requirements of BS EN 61000-3-12 subject to a minimum short circuit power (S_{sc}) of ‘x’ kVA/MVA, the following spreadsheet (Harmonics) can be used to determine the required impedance at the PCC.

7.5 Where an installer or manufacturer is able to provide harmonic current emissions of the device that is proposed to be connected, the following spreadsheet (G5 current limits spreadsheet) shall be used to determine the connection requirements.

NOTE: The harmonic current emissions are to be provided at 10% increments of the product rating.

7.6 Where equipment has no declaration of conformity or where the equipment is rated > 75A, but product details have been provided the ‘Power Quality’ spreadsheet (EREC G5.5 calculator tool) can be used to determine the required impedance at the PCC. The PCC may be either on the LV or HV network.

7.7 Where the installation of equipment is unachievable or not cost effective by following the stage 1B, 1C or 2A ENA EREC G5 assessment procedures (detailed within Spreadsheet EREC G5.5 calculator tool) background measurement data shall be obtained from the PCC.

Measured data shall be taken for 14 days, the highest 95th percentile for 7 days shall be found by sliding a 7 day window across the data. Where it has not been possible to obtain 14 days’ worth of data, the 99th percentile shall be chosen.

The network measurements shall be undertaken during the expected time of use of the equipment that is intended to be connected.

Where three phases of measurement have been taken, the worst effected phase shall be used for the analysis.

7.8 Where possible to improve the refinement of the assessment, a stage 2C assessment shall be undertaken instead of a stage 1D or 2B assessment.

7.9 Where no declaration of conformity documentation or product details are provided, no assessments are available and therefore the equipment may not be connected until enough information is made available to enable an assessment to be undertaken.

7.10 Where back ground measurements are unable to be taken at the PCC, the measurements can be taken from a remote node and thereafter the values can be scaled to be that of the expected values at the proposed PCC. The method uses a scaling factor between the fault level at the measured node and the node of interest.

For example, it is proposed to connect a disturbing load (substation 'B') via a new HV extension (ringed) which is to be situated 1000m downstream from substation 'A'. The background harmonic measurements have been taken at the existing substation location 'A', where the fault level has been calculated to be 100MVA and the fault level is expected to be 80MVA at the proposed new substation location

The harmonic measurements at position 'A' shall be scaled using the following formulae;

$$\text{Scaling factor} = \frac{Fault\ level\ at\ measured\ location}{Fault\ level\ at\ proposed\ location}$$

Therefore,

$$\text{Scaling factor} = \frac{100\ MVA}{80MVA} = 1.25$$

The calculation spreadsheet 'EREC G5.5 calculator tool' includes a Scaling Factor tool for ease of conversion.

7.11 Where measurements of harmonics are taken at LV for a connection with a point of supply at HV. The nominal HV-LV transformer tap scaling factor shall be used – for phase to neutral measurements a value of 44:1 shall be used.

The calculation spreadsheet 'G5.5 Current Limits Spreadsheet' includes a LV-HV conversion tool for ease.

NOTE: The same process applies whether the connection application concerns single or multiple customer connections on a given LV network. For multiple connections with identical equipment only the connection with the highest source impedance shall be considered.

8.0 LIST OF APPENDICES

Appendix	Title
A	Voltage Fluctuation and Flicker Assessment Flow Chart
B	Harmonic Assessment flow Chart
C	Unconditional Connection of Motors
D	Use Of Simple WinDebut Model To Derive Actual Source Impedance
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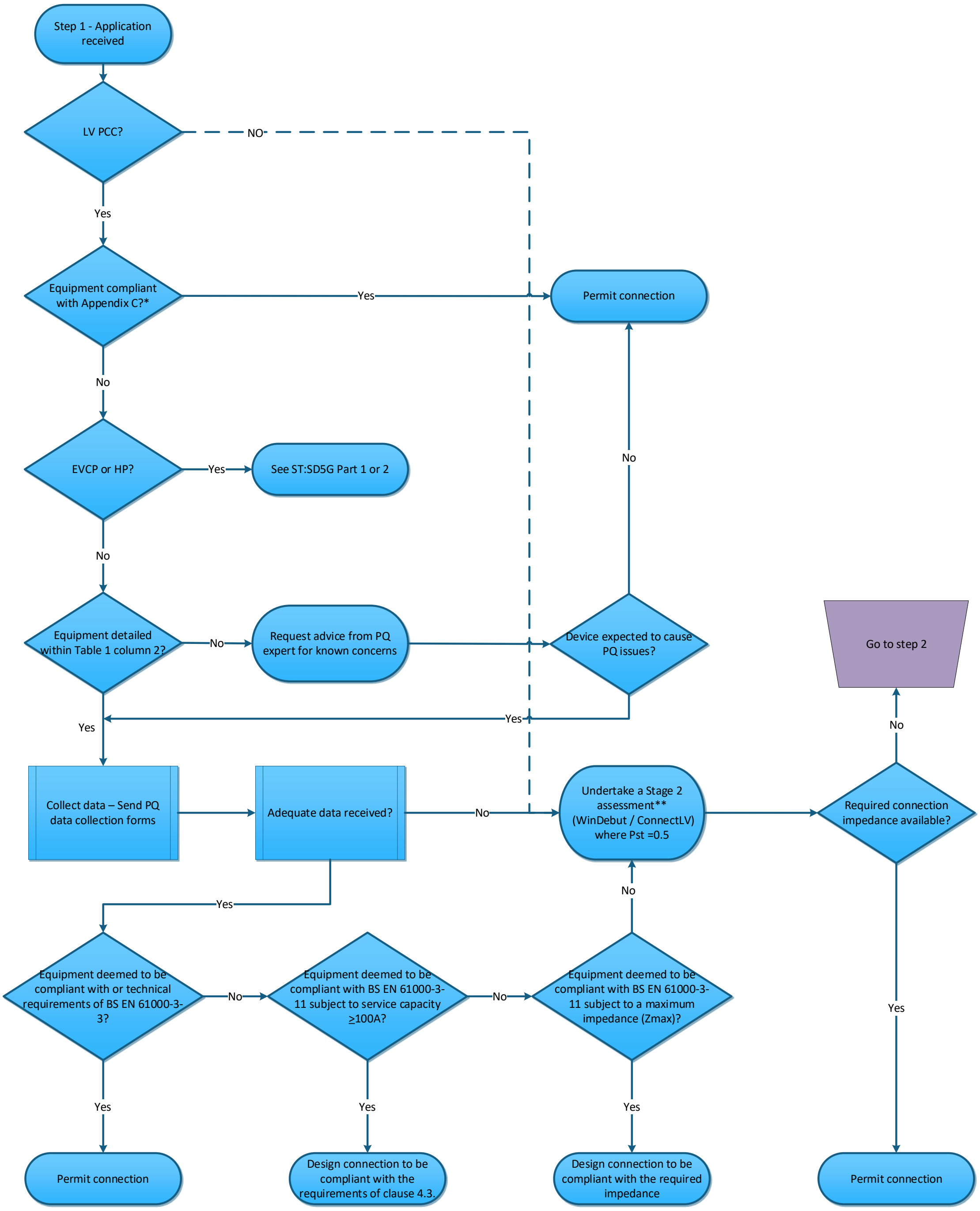
F	Worked Examples
G	Example Phase-Neutral Source Impedance
H	Background
I	Customer Responsibilities

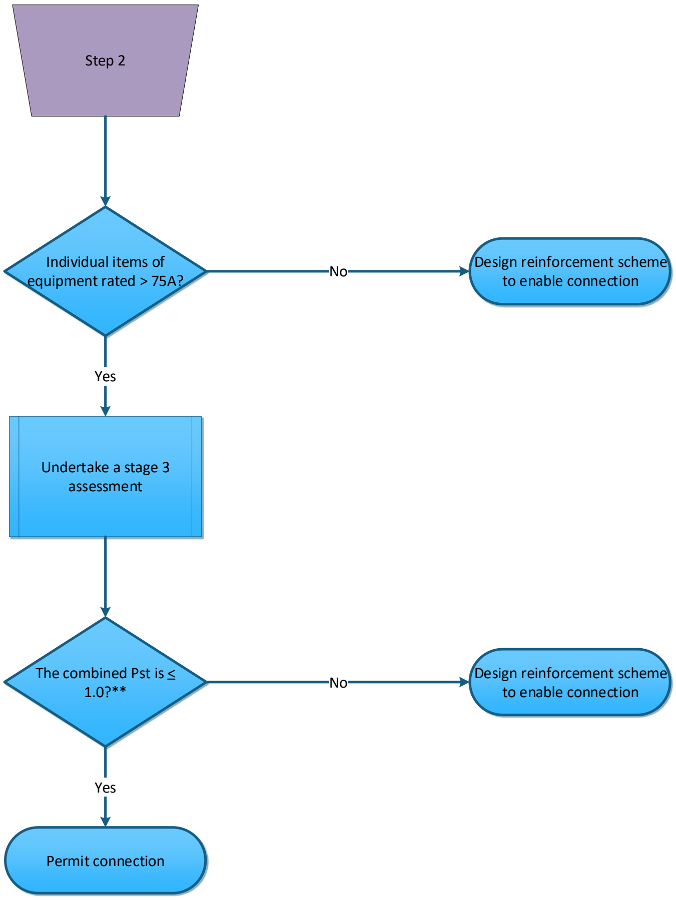
Voltage Fluctuations & Flicker Control Flow chart



Notes

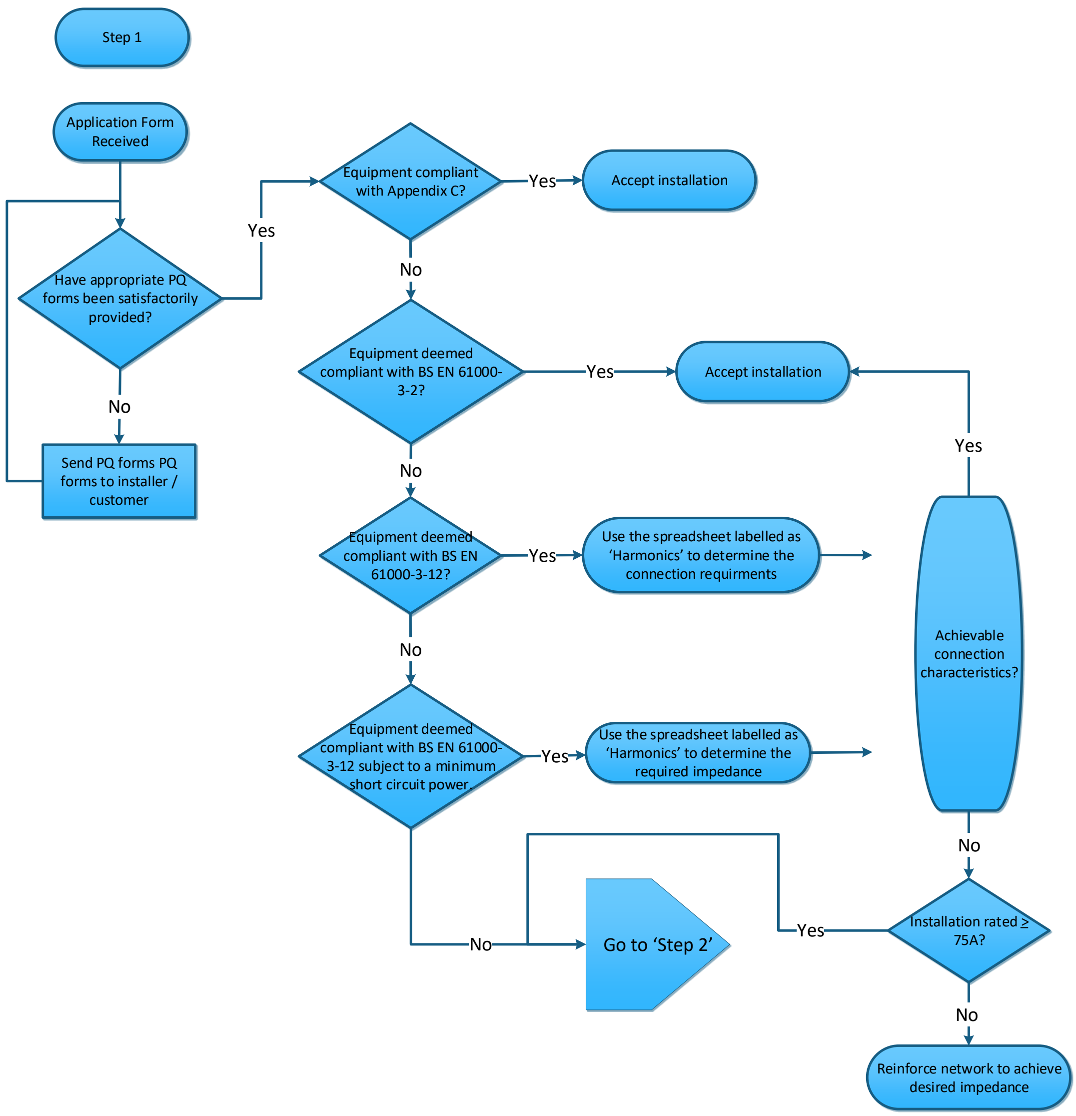
* Vacuum cleaners, hand held drills, white goods / domestic kitchen appliances are deemed to be typical house hold equipment that would be compliant with the requirements of Appendix C.

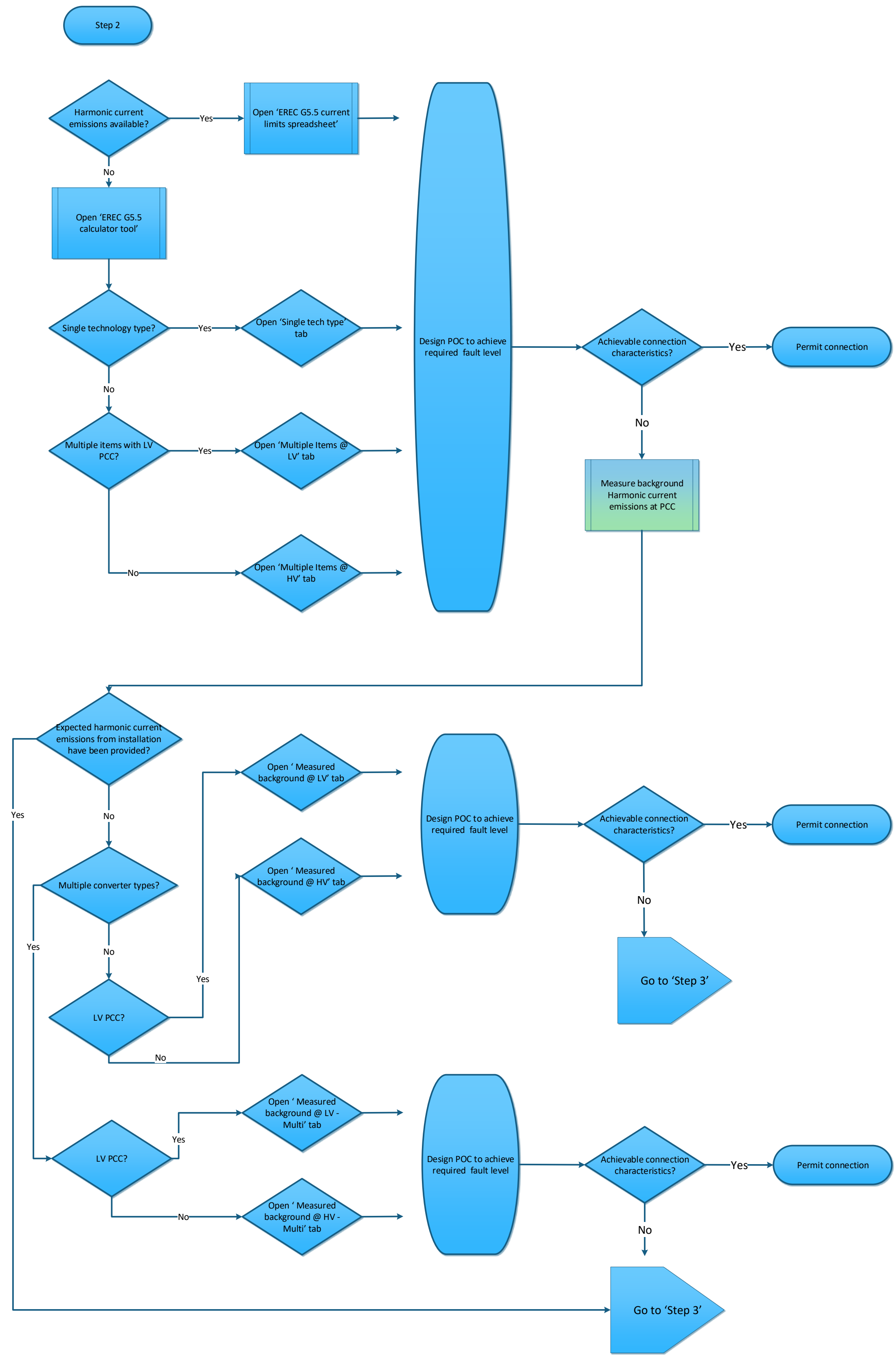
**When a customer has a HV PCC but is connecting LV equipment, WinDebut / Connect/LV can be utilised to determine the predicted flicker on the primary side of the transformer (HV network).



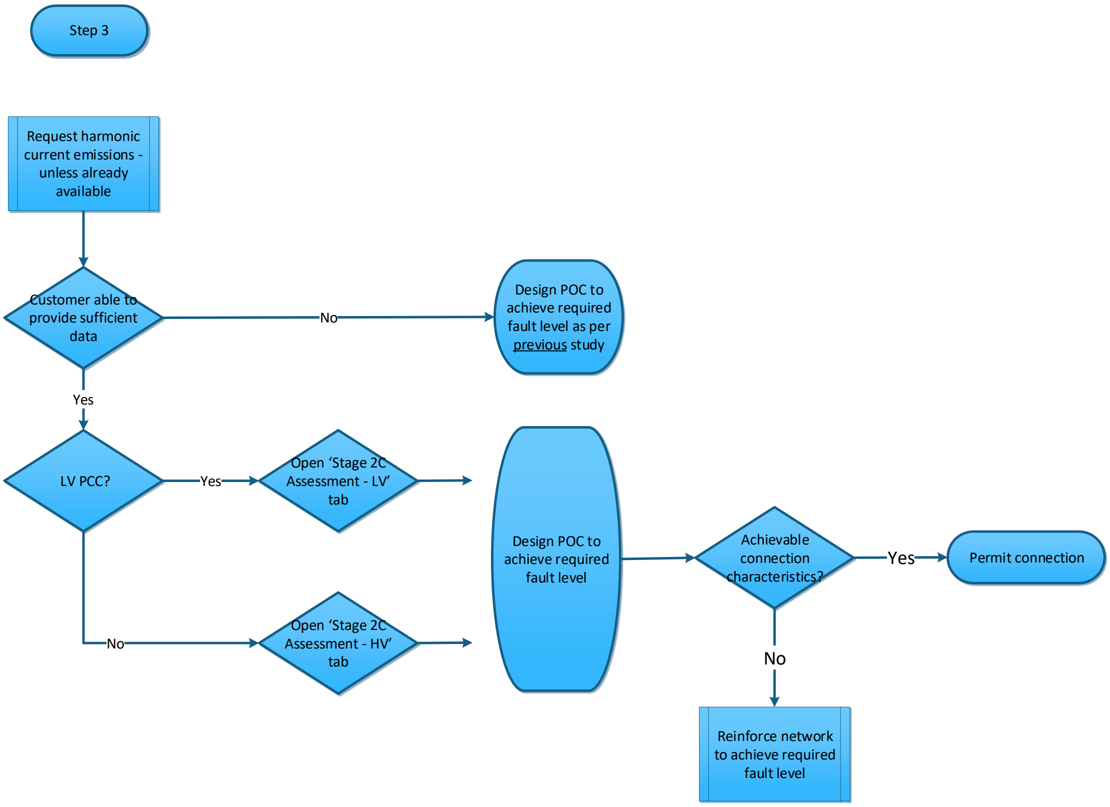
Step 2
Individual items of equipment rated > 75A?
No
Design reinforcement scheme to enable connection
Yes
Undertake a stage 3 assessment
The combined Pst is ≤ 1.0?**
No
Design reinforcement scheme to enable connection
Yes
Permit connection

Harmonic Control Flow chart





Step 2
Harmonic current emissions available?
Yes
Open 'EREC G5.5 current limits spreadsheet'
No
Open 'EREC G5.5 calculator tool'
Single technology type?
Yes
Open 'Single tech type' tab
No
Multiple items with LV PCC?
Yes
Open 'Multiple Items @ LV' tab
No
Open 'Multiple Items @ HV' tab
Design POC to achieve required fault level
Achievable connection characteristics?
Yes
Permit connection
No
Measure background Harmonic current emissions at PCC
Expected harmonic current emissions from installation have been provided?
Yes
No
Multiple converter types?
Yes
No
LV PCC?
Yes
No
Open ' Measured background @ LV' tab
Open ' Measured background @ HV' tab
Design POC to achieve required fault level
Achievable connection characteristics?
Yes
Permit connection
No
Go to 'Step 3'
LV PCC?
Yes
No
Open ' Measured background @ LV - Multi' tab
Open ' Measured background @ HV - Multi' tab
Design POC to achieve required fault level
Achievable connection characteristics?
Yes
Permit connection
No
Go to 'Step 3'


Step 3
Request harmonic current emissions - unless already available
Customer able to provide sufficient data
No
Design POC to achieve required fault level as per previous study
Yes
LV PCC?
Yes
Open 'Stage 2C Assessment - LV' tab
No
Open 'Stage 2C Assessment - HV' tab
Design POC to achieve required fault level
Achievable connection characteristics?
Yes
Permit connection
No
Reinforce network to achieve required fault level

MOTORS THAT CAN BE CONNECTED WITHOUT DETAILED FLICKER ANALYSIS

C1 Small Rural Transformers 1-Phase 240V and 1-Phase 480V

Transformer	1-Phase 240V Motor		1-Phase 480V (split-phase) Motor	
	Frequent Start	Infrequent Start	Frequent Start	Infrequent Start
5kVA	N/A Ze>0.35Ω		N/A	
10kVA	0.28kW	0.62kW	N/A	
15kVA	0.30kW	0.66kW	N/A	
16kVA	0.30kW	0.66kW	N/A	
25kVA	0.32kW	0.71kW	N/A Ze>0.35Ω	
50kVA	0.35kW	0.78kW	0.97kW	2.14kW
100kVA	N/A		1.11kW	2.44kW

Table C1 – Maximum Motor Rating Without Flicker Analysis – See Assumptions Table C4

C2 3-phase Rural Distribution Transformers

Transformer	3-Phase 415V Motor		1-Phase 240V Motor	
	Frequent Start	Infrequent Start	Frequent Start	Infrequent Start
25kVA	0.79kW	1.73kW	0.26kW	0.58kW
50kVA	1.20kW	2.65kW	0.34kW	0.75kW
100kVA	1.67kW	3.68kW	0.41kW	0.91kW
200kVA	2.26kW	4.99kW	0.49kW	1.09kW

Table C2 – Maximum Motor Rating Without Flicker Analysis – See Assumptions Table C4

C3 Urban 11kV/415V

Transformer	3-Phase 415V Motor		1-Phase 240V Motor	
	Frequent Start	Infrequent Start	Frequent Start	Infrequent Start
≥300kVA	2.66kW	5.86kW	0.53kW	1.18kW

Table C3 – Maximum Motor Rating Without Flicker Analysis – See Assumptions Table C4

C4 Assumptions

	Table E1	Table E2	Table E3
Motor Starting	Direct-on-line		
Motor Starting Power Factor	0.3		
Frequent Start	No more than one start per minute		
Infrequent Start	No more than four starts per hour		
PME Earth Loop Impedance	0.35Ω		
HV Fault Level	10MVA	25MVA	75MVA
HV X/R Ratio	1.5	1.5	8

Table D4 – Assumptions Used in Producing Tables D1-D3

Note: 1 HP = 0.746kW and 1kW = 1.34HP

USE OF SIMPLE WINDEBUT MODEL TO DERIVE ACTUAL SOURCE IMPEDANCE

Single-phase Equipment

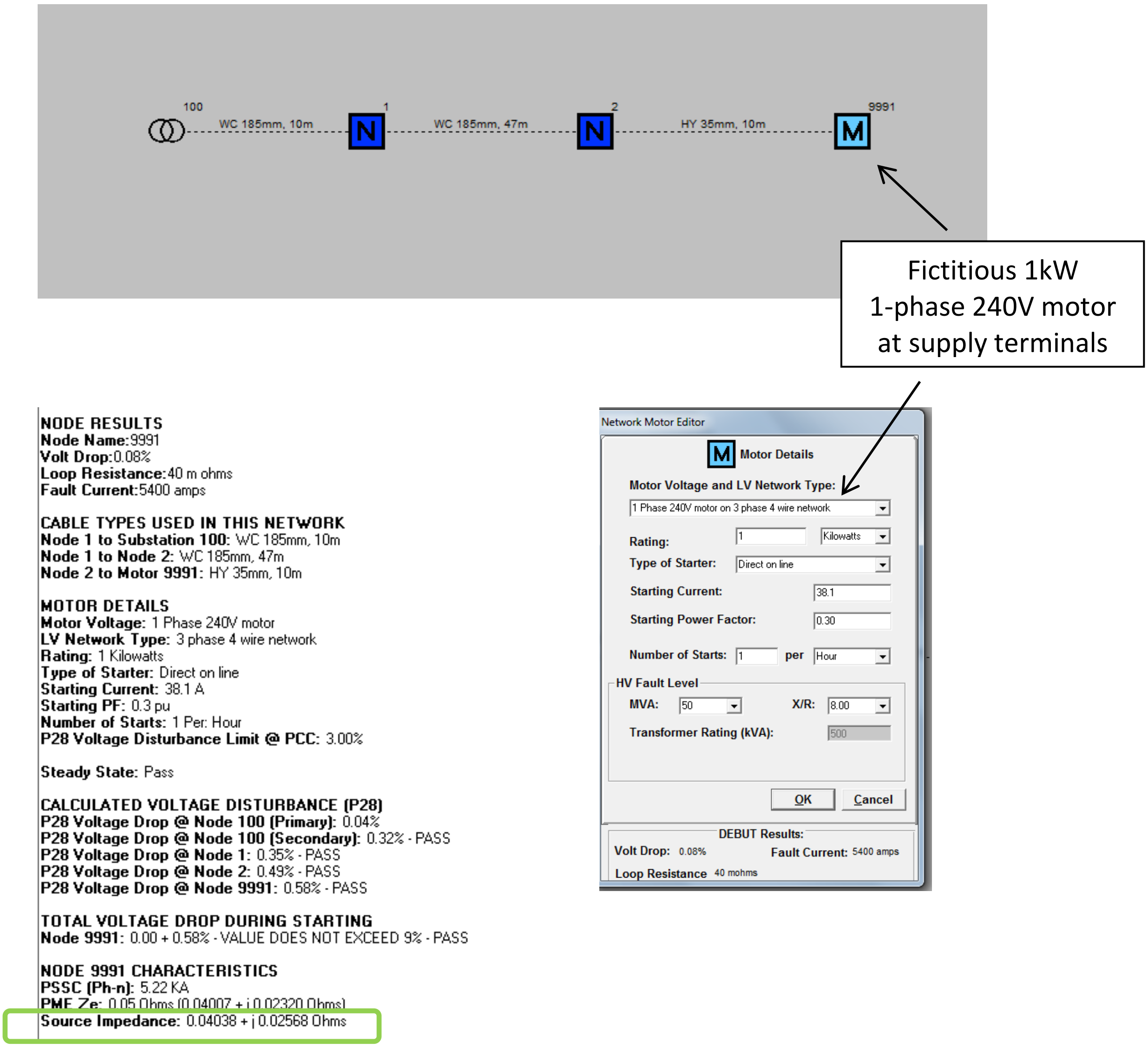


Figure D1 - Dummy 1-Phase Motor and Simplified Network - Impedance at the supply terminals

A fictitious single-phase motor is used to derive the phase-neutral impedance at the supply terminals.

The phase-neutral source impedance of the network at <u>the supply terminals</u>, $Z_{source\ 1\text{-}ph\ supply\ terminals}$ is given by

$$Z_{source\ 1\text{-}ph\ supply\ terminals} = \sqrt{(R_{source\ 1\text{-}ph\ supply\ terminals}^2 + X_{source\ 1\text{-}ph\ supply\ terminals}^2)} = \sqrt{(0.04038^2 + 0.02568^2)} = 0.0479\Omega$$

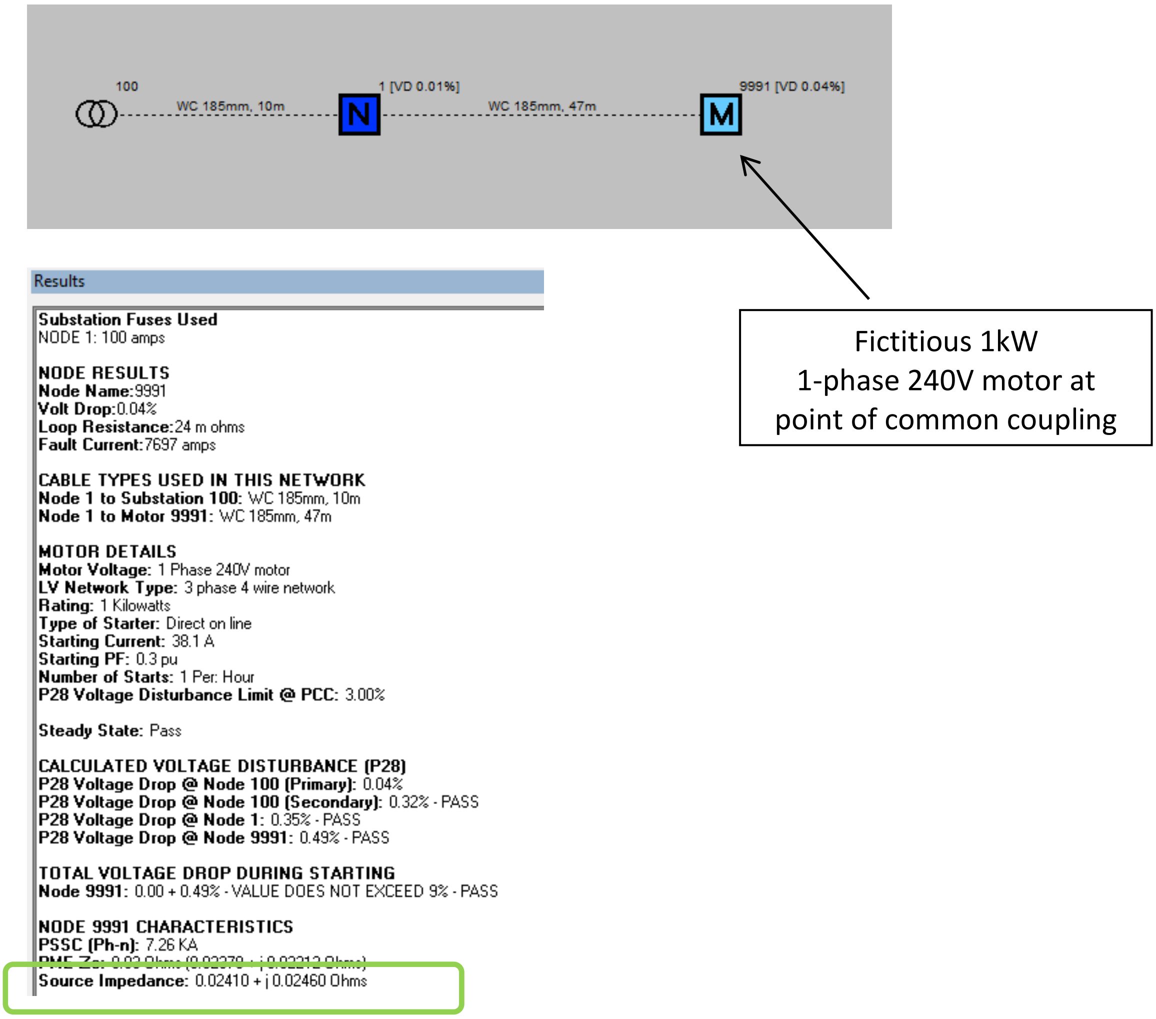


Figure D2 - Dummy 1-Phase Motor and Simplified Network - Impedance at the Point of Common Coupling (PCC)

The service cable has been removed and the motor positioned at the service joint which has been deemed to be the point of common coupling.

The phase-neutral source impedance of the network at the PCC, $Z_{source\ 1\text{-}ph\ PCC}$ is given by

$$Z_{source\ 1\text{-}ph\ PCC} = \sqrt{(R_{source\ 1\text{-}ph\ PCC}^2 + X_{source\ 1\text{-}ph\ PCC}^2)}$$
$$= \sqrt{(0.0241^2 + 0.0246^2)} = 0.0344\Omega$$

Three-phase Equipment

If the equipment is 3-phase then a fictitious 3-phase motor should be used to derive the 3-phase source impedance instead. For example:

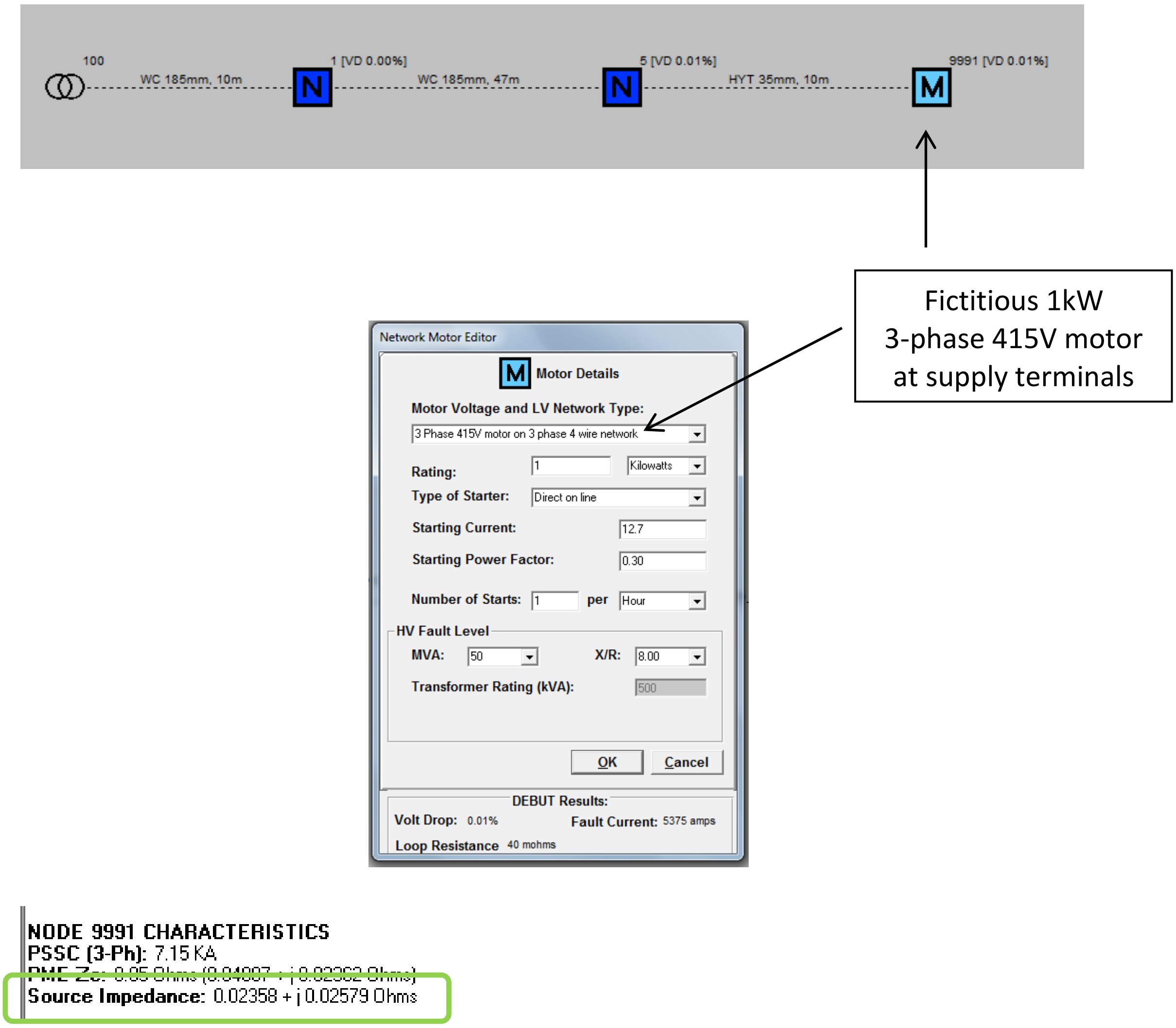


Figure D3 - Dummy 3-Phase Motor and Simplified Network - Impedance at the Supply Terminals

The three-phase source impedance of the network at the supply terminals, $Z_{source\ 3\text{-}ph\ supply\ terminals}$, is given by

$$Z_{source\ 3\text{-}ph\ supply\ terminals} = \sqrt{(R_{source\ 3\text{-}ph\ supply\ terminals}^2 + X_{source\ 3\text{-}ph\ supply\ terminals}^2)} = \sqrt{(0.02358^2 + 0.02579^2)} = 0.0349\Omega$$

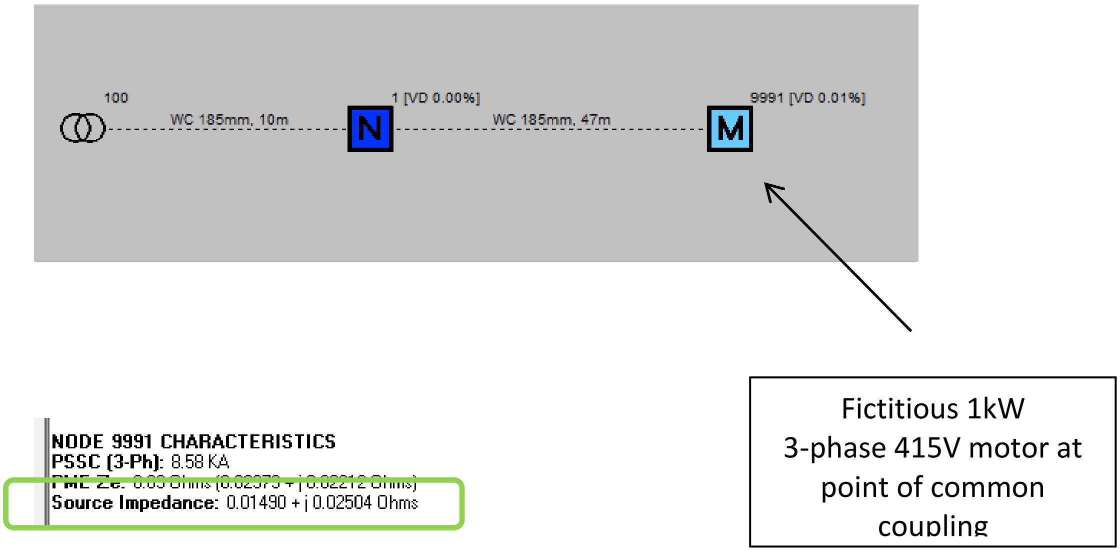


Figure D4 - Dummy 3-Phase Motor and Simplified Network - Impedance at the Point of Common Coupling (PCC)

The service cable has been removed and the three phase motor positioned at the service joint which has been deemed to be the point of common coupling.

The three-phase source impedance of the network at the PCC,
$Z_{source\ 3\text{-}ph\ PCC}$, is given by

$$Z_{source\ 3\text{-}ph\ PCC} = \sqrt{(R_{source\ 3\text{-}ph\ PCC}^2 + X_{source\ 3\text{-}ph\ PCC}^2)}$$

$$= \sqrt{(0.01490^2 + 0.02504^2)} = 0.02914\Omega.$$

Split Phase Equipment (480v)

If the equipment is split-phase then a fictitious 2-phase motor should be used to derive the split-phase source impedance instead. For example:

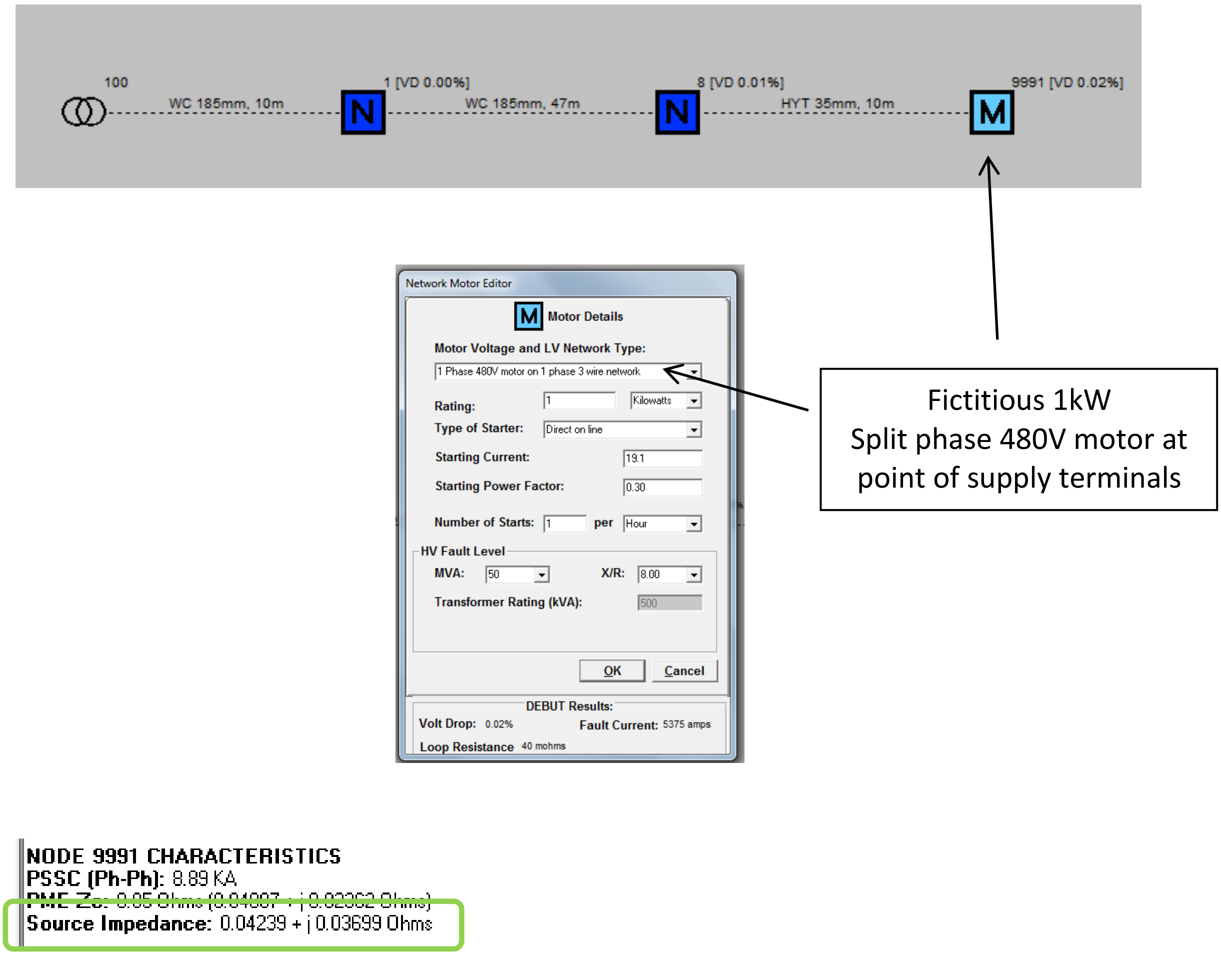
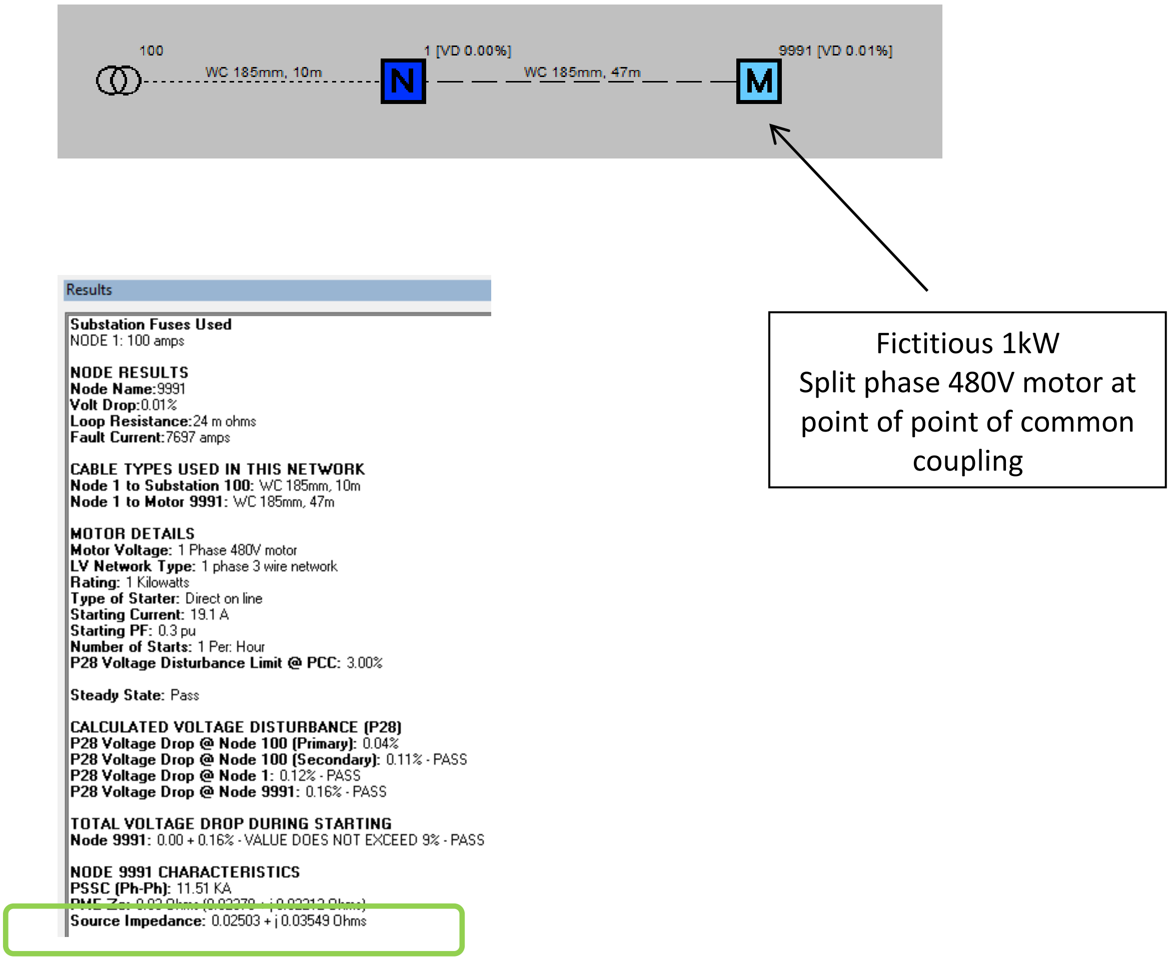


Figure D5 - Dummy split-Phase Motor (480v) and Simplified Network - Impedance at the Supply Terminals

The split-phase source impedance of the network at the supply terminals, $Z_{source\ 2\text{-}ph\ PCC}$, is given by

$$Z_{source\ 2\text{-}ph\ PCC} = \sqrt{(R_{source\ 2\text{-}ph\ PCC}^2 + X_{source\ 2\text{-}ph\ PCC}^2)}$$

$$= \sqrt{(0.04239^2 + 0.03699^2)} = 0.05626\Omega.$$



Results

Substation Fuses Used
NODE 1: 100 amps

NODE RESULTS
Node Name:9991
Volt Drop:0.01%
Loop Resistance:24 m ohms
Fault Current:7697 amps

CABLE TYPES USED IN THIS NETWORK
Node 1 to Substation 100: WC 185mm, 10m
Node 1 to Motor 9991: WC 185mm, 47m

MOTOR DETAILS
Motor Voltage: 1 Phase 480V motor
LV Network Type: 1 phase 3 wire network
Rating: 1 Kilowatts
Type of Starter: Direct on line
Starting Current: 19.1 A
Starting PF: 0.3 pu
Number of Starts: 1 Per Hour
P28 Voltage Disturbance Limit @ PCC: 3.00%

Steady State: Pass

CALCULATED VOLTAGE DISTURBANCE (P28)
P28 Voltage Drop @ Node 100 (Primary): 0.04%
P28 Voltage Drop @ Node 100 (Secondary): 0.11% - PASS
P28 Voltage Drop @ Node 1: 0.12% - PASS
P28 Voltage Drop @ Node 9991: 0.16% - PASS

TOTAL VOLTAGE DROP DURING STARTING
Node 9991: 0.00 + 0.16% - VALUE DOES NOT EXCEED 9% - PASS

NODE 9991 CHARACTERISTICS
PSSC (Ph-Ph): 11.51 KA
PME Zs: 0.03 Ohms (0.02270 + j 0.02312 Ohms)
Source Impedance: 0.02503 + j 0.03549 Ohms

Figure D6 - Dummy split-Phase Motor (480v) and Simplified Network - Impedance at the Point of Common Coupling (PCC)

The split-phase source impedance of the network at the point of common coupling, $Z_{source\ 2\text{-}ph\ PCC}$, is given by

$$Z_{source\ 2\text{-}ph\ PCC} = \sqrt{(R_{source\ 2\text{-}ph\ PCC}^2 + X_{source\ 2\text{-}ph\ PCC}^2)}$$

$$= \sqrt{(0.02503^2 + 0.03549^2)} = 0.0434\Omega.$$

Phase-Phase or 'Interphase' Equipment

If the equipment is connected across two phases only (i.e. 400V Phase-Phase) the following formula shall be used to derive the phase-phase source impedance, $Z_{source\ ph\text{-}ph}$:

$$Z_{source\ ph\text{-}ph} = 2 \times Z_{source\ 3\text{-}ph}.$$

FORMULAE FOR S_{equ}, S_{sc}, R_{sce}, I_{fmin} & I_f

This Appendix details the range of calculations used in the worked examples of Appendix E. These are associated with application of Figure 2 and concern control of harmonic current emissions and application of BS EN 61000-3-12.

E1 CALCULATION OF EQUIPMENT RATED APPARENT POWER, S_{equ}

Equipment	S_{equ}
1-phase 230V	230V x I_{equ}
Phase-phase 400V	400V x I_{equ}
3-phase 400V	√3 x 400V x I_{equ}

Note: I_{equ} = rated current of the equipment

E2 CALCULATION OF THREE-PHASE SHORT-CIRCUIT POWER, S_{sc}

$S_{sc} = (U_{nominal})^2/Z_{source} = (400V)^2/Z_{source\ 3\text{-}ph}$

where $Z_{source\ 3\text{-}ph}$ = line impedance of the source as given by WinDebut when modelled with a dummy 3-phase motor. See Appendix B.

E3 CALCULATION OF SHORT-CIRCUIT RATIO, R_{sce}

Equipment	R_{sce}
1-phase 230V	$S_{sc}/3S_{equ}$
Phase-phase 400V	$S_{sc}/2S_{equ}$
3-phase 400V	S_{sc}/S_{equ}

E4 CALCULATION OF MINIMUM SHORT-CIRCUIT POWER, S_{sc} FOR R_{sce} =33

Equipment	S_{sc}
1-phase 230V	3 x 33 x S_{equ} = 99 x S_{equ}
Phase-phase 400V	2 x 33 x S_{equ} = 66 x S_{equ}
3-phase 400V	33 x S_{equ}

E5 CALCULATION OF MINIMUM FAULT CURRENT VALUE, I_{fmin}

$I_{fmin} = S_{sc}/(\sqrt{3} \times 400V)$

E6 CALCULATION OF ACTUAL FAULT CURRENT, I_f, FROM SOURCE IMPEDANCE

Equipment	**I_f**
1-phase 230V	$230V/Z_{source\ 1\text{-}ph}$
Phase-phase 400V	$400V/(2 \times Z_{source\ 3\text{-}ph})$
3-phase 400V	$400V/(\sqrt{3} \times Z_{source\ 3\text{-}ph})$

NOTE: $Z_{source\ 1\text{-}ph}$ = phase-neutral source impedance as given by WinDebut when modelled with a dummy single-phase motor and $Z_{source\ 3\text{-}ph}$ = line impedance of the source as given by WinDebut when modelled with a dummy 3-phase motor. See Appendix D.

WinDebut and Connect/LV use 250V and 433V for fault calculations.

WORKED EXAMPLES

Example	Equipment	Phases	Number	Flicker Statement	Harmonic Statement
1	45A Kiln	1-ph	1 of	Z_{max}	61000-3-12
1a	45A Electric Boilers	1-ph	20 of	Z_{max}	61000-3-12
2	4kW UPS	3-ph	1 of	61000-3-3	S_{sc}
3	3.81kW Wind Turbine	1-ph	1 of	61000-3-3	S_{sc}
3a	3.81kW Wind Turbine	1-ph	15 of	61000-3-3	S_{sc}
4	45A AC/DC Converter	3-ph	1 of	61000-3-3	61000-3-12
5	18A Export Limiter	1-ph	1 of	61000-3-3	61000-3-12

Table F1 – Summary of Worked Examples

EXAMPLE 1

Application: Request to connect one Kiln.
Network PCC: LV
Manufacturer: **Hot Ceramics**
Model: B = Kiln system 45A 230V input.

BS EN 61000-3-11 Voltage Fluctuation/Flicker Statement

'This equipment complies with IEC 61000-3-11 provided that the source impedance is less than or equal to $Z_{max} = 0.17\ \Omega$ at the interface point between the user's supply and the public system. It is the responsibility of the installer or user of the equipment to ensure, by consultation with the distribution network operator if necessary, that the equipment is connected only to a supply with a source impedance is less than or equal to $Z_{max} = 0.17\ \Omega$.'

BS EN 61000-3-12 Harmonic Statement

'Equipment complying with IEC 61000-3-12.'

Design as follows…

Design for Acceptable Voltage Fluctuations/Flicker

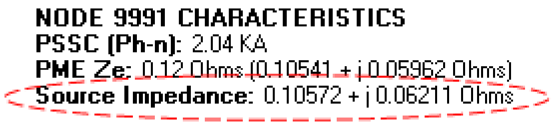
Step 1

As the proposed equipment is single-phase, use WinDebut to check the single-phase source impedance at the supply terminals.

Model the basic network from the supply terminals to the source in WinDebut. Insert a dummy single-phase motor and derive the single-phase source impedance at the supply terminals in accordance with Appendix D.

Derive $Z_{source\ 1\text{-}ph\ supply\ terminals}$ from $R_{source\ 1\text{-}ph\ supply\ terminals}$ + j $X_{source\ 1\text{-}ph\ supply\ terminals}$

For example…



$Z_{source\ 1\text{-}ph\ supply\ terminals} = \sqrt{(R_{source\ 1\text{-}ph\ supply\ terminals}^2 + X_{source\ 1\text{-}ph\ supply\ terminals}^2)} = \sqrt{(0.10572^2 + 0.06211^2)} = 0.12261\Omega$

Note: this differs slightly from the *PME Ze* value as *Source Impedance* in WinDebut uses the transformer impedance values from Engineering Recommendation P28.

Step 2

Check if $Z_{source\ 1\text{-}ph\ supply\ terminals} \leq Z_{max}$. Here $Z_{source\ 1\text{-}ph\ supply\ terminals} = 0.12261\Omega$ and $Z_{max} = 0.17\ \Omega$. Therefore, $Z_{source\ 1\text{-}ph\ supply\ terminals} < Z_{max}$.

In this case then the requirement is met. If $Z_{source\ 1\text{-}ph\ supply\ terminals} > Z_{max}$ then the network would need to be reinforced until $Z_{source\ 1\text{-}ph\ supply\ terminals} \leq Z_{max}$ to allow connection of this equipment.

Design for acceptable harmonic distortion

Note: In accordance with ENA EREC G5/5, when the above statement is made compliance with harmonic current limits assumes a minimum ratio of 3-phase fault level at the PCC.

Step1

Determine I_{equ} (or S_{equ}):

I_{equ} = 45A (or S_{equ} = 45A x 230V = 10.35kVA).

Step 2

Determine $Z_{max\ harmonic\ 1\text{-}ph\ PCC}$ from 'Harmonics' spreadsheet found within clause 5.3:

$Z_{max\ harmonic\ 1\text{-}ph\ PCC} = 0.176\Omega$ (for a whole current metered supply)

Step 3

Amend the basic network model dummy motor position to the PCC. Determine the single-phase source impedance at the PCC in accordance with Appendix D.

NODE 9991 CHARACTERISTICS
PSSC (Ph-n): 3.26 KA
PME Ze: 0.07 Ohms (0.05214 + j 0.05347 Ohms)
Source Impedance: 0.05246 + j 0.05595 Ohms

$Z_{source\ 1\text{-}ph\ PCC} = \sqrt{(R_{source\ 1\text{-}ph\ PCC}^2 + X_{source\ 1\text{-}ph\ PCC}^2)} = \sqrt{(0.05246^2 + 0.05595^2)} = 0.07670\Omega$

Step 4

Check if $Z_{source\ 1\text{-}ph\ PCC} \leq Z_{max\ harmonic\ 1\text{-}ph\ PCC}$. Here $Z_{source\ 1\text{-}ph\ PCC} = 0.0767\Omega$ and $Z_{max\ harmonic\ 1\text{-}ph\ PCC} = 0.176\Omega$. Therefore, $Z_{source\ 1\text{-}ph\ PCC} < Z_{max\ harmonic\ 1\text{-}ph\ PCC}$.

In this case then the requirement is met. If $Z_{source\ 1\text{-}ph\ PCC} > Z_{max\ harmonic\ 1\text{-}ph\ PCC}$ then the network would need to be reinforced until $Z_{source\ 1\text{-}ph\ PCC} \leq Z_{max\ harmonic\ 1\text{-}ph\ PCC}$ to allow connection of this equipment.

EXAMPLE 1A

Detail as for Example 1 but with 20 Electric Boilers connections across an LV network.

The method of Example 1 is applied to the electrically most remote Boiler connection. The connection with the highest source impedance and lowest fault level is checked.

EXAMPLE 2

Application: Request to connect one UPS.
Network PCC: LV
Manufacturer: **Black Start Ltd**
Model: UPS 4kW 400V three-phase input

BS EN 61000-3-11 Voltage Fluctuation/Flicker Statement

'This equipment complies with IEC 61000-3-3.'

BS EN 61000-3-12 Harmonic Statement

'This equipment complies with IEC 61000-3-12 provided that the short-circuit power S_{sc} is greater than or equal to 1.1MVA at the interface point between the user's supply and the public system. It is the responsibility of the installer or user of the equipment to ensure, by consultation with the distribution network operator if necessary, that the equipment is connected only to a supply with a short-circuit power S_{sc} greater than or equal to 1.1MVA.'

Design as follows…

Design for Acceptable Voltage Fluctuations/Flicker

See Figure 1. As it is stated that the equipment is compliant with IEC 61000-3-3 then connection is permitted.

Design for acceptable harmonic distortion

Note: In accordance with BS EN/IEC 61000-3-12, the stated required minimum short-circuit power, S_{sc}, is a 3-phase value at the Point of Common Coupling (PCC).

Step 1

Convert the 3-phase MVA value, S_{sc}, to a maximum impedance value, Z_{max} :

Open the 'Harmonics' Spreadsheet found within clause 5.4 – select the 'Fault level conversion' tab.

Enter a value of 1.1 MVA, set the configuration of the equipment to 'three' – a value of 0.145 ohms is provided.

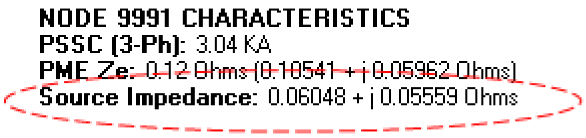
Step 2

As the proposed equipment is 3-phase, use WinDebut to check the 3-phase impedance at the PCC.

Model the basic network from the PCC to the source in WinDebut. Insert a dummy <u>3-phase</u> motor and derive the 3-phase (line) source impedance in accordance with Appendix D.

Derive $Z_{source\ 3\text{-}ph\ PCC}$ from $R_{source\ 3\text{-}ph\ PCC} + j\ X_{source\ 3\text{-}ph\ PCC}$.

For example…



$Z_{source\ 3\text{-}ph\ PCC} = \sqrt{(R_{source\ 3\text{-}ph\ PCC}^2 + X_{source\ 3\text{-}ph\ PCC}^2)} = \sqrt{(0.06048^2 + 0.05559^2)} = 0.08215\Omega$.

Step 3

Check if $Z_{source} \leq Z_{max}$. $Z_{source} = 0.08215\Omega$ and $Z_{max} = 0.145\ \Omega$.

In this case then the requirement is met. If $Z_{source} \geq Z_{max}$ then the network would need to be reinforced until $Z_{source} \leq Z_{max}$ to allow connection of this equipment.

EXAMPLE 3

Application: Request to connect one Wind Turbine.
Network PCC: LV
Manufacturer: **Windy Ridge**
Model: Wind Turbine 3.81kW 230V single-phase output

BS EN 61000-3-11 Voltage Fluctuation/Flicker Statement

'This equipment complies with IEC 61000-3-3.'

BS EN 61000-3-12 Harmonic Statement

'This equipment complies with IEC 61000-3-12 provided that the short-circuit power S_{sc} is greater than or equal to 0.858MVA at the interface point between the user's supply and the public system. It is the responsibility of the installer or user of the equipment to ensure, by consultation with the distribution network operator if necessary, that the equipment is connected only to a supply with a short-circuit power S_{sc} greater than or equal to 0.858MVA.'

Design as follows…

Design for Acceptable Voltage Fluctuations/Flicker

See Figure 1. As it is stated that the equipment is compliant with IEC 61000-3-3 then connection is permitted.

Design for acceptable harmonic distortion

In accordance with BS EN/IEC 61000-3-12, the stated required minimum short-circuit power, S_{sc}, is a 3-phase value at the Point of Common Coupling (PCC). However, the equipment is single-phase.

Step 1

Convert the minimum 3-phase MVA value, S_{sc}, to a maximum single phase impedance requirement, Z_{max}:

Open the 'Harmonics' Spreadsheet found within clause 5.4 – select the 'Fault level conversion' tab.

Enter a value of 0.858 MVA, set the configuration of the equipment to 'single' – a value of 0.185 ohms is provided.

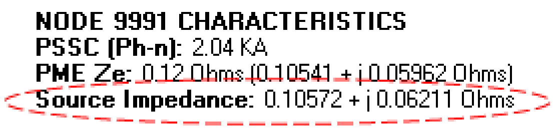
Step 2

As the proposed equipment is single-phase, use WinDebut to check the single-phase impedance at the PCC.

Model the basic network from the PCC to the source in WinDebut. Insert a dummy single-phase motor and derive the single-phase source impedance in accordance with Appendix D.

Derive $Z_{source\ 1\text{-}ph\ PCC}$ from $R_{source\ 1\text{-}ph\ PCC}$ + j $X_{source\ 1\text{-}ph\ PCC}$.

For example…



$Z_{source\ 1\text{-}ph\ PCC} = \sqrt{(R_{source\ 1\text{-}ph\ PCC}^2 + X_{source\ 1\text{-}ph\ PCC}^2)} = \sqrt{(0.10572^2 + 0.06211^2)} = 0.12261\Omega$.

Step 3

Check if $Z_{source} \leq Z_{max}$. $Z_{source} = 0.12261\Omega$ and $Z_{max} = 0.185\ \Omega$.

In this case then the requirement is met. If $Z_{source} \geq Z_{max}$ then the network would need to be reinforced until $Z_{source} \leq Z_{max}$ to allow connection of this equipment.

EXAMPLE 3A

Detail as for Example 3 but with 15 Wind Turbines connections across an LV network.

The method of Example 3 is applied to the electrically most remote Wind Turbine connection. The connection with the highest impedance is checked.

EXAMPLE 4

Application: Request to connect one AC/DC Converter.
Network PCC: LV
Manufacturer: **One Way Wave**
Model: AC/DC Converter 45A 400V three-phase input

BS EN 61000-3-11 Voltage Fluctuation/Flicker Statement

'This equipment complies with IEC 61000-3-3.'

BS EN 61000-3-12 Harmonic Statement

'Equipment complying with IEC 61000-3-12.'

Design as follows…

Design for Acceptable Voltage Fluctuations/Flicker

See Figure 1. As it is stated that the equipment is compliant with IEC 61000-3-3 then connection is permitted.

Design for acceptable harmonic distortion

Note: In accordance with ENA EREC G5/5, when the above statement is made compliance with harmonic current limits assumes a minimum ratio of 3-phase fault level at the PCC, $S_{sc\ PCC}$, to the rated apparent power of the equipment.

Step1

Determine I_{equ} (or S_{equ}):

I_{equ} = 45A (or $S_{equ} = \sqrt{3} \times 45 \times 400V = 31.177kVA$).

Step 2

Determine $Z_{max\ harmonic\ 3\text{-}ph\ PCC}$ by using the spreadsheet 'Harmonics' found within clause 5.3.

Select the appropriate metering type (in this case whole current metering), enter a value of 31.177kVA, a quantity of 1.

$Z_{max\ harmonic\ 3\text{-}ph\ PCC} = 0.177\Omega$.

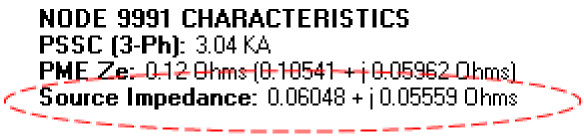
Step 3

As the proposed equipment is 3-phase, use WinDebut to check the 3-phase source impedance at the PCC.

Model the basic network from the PCC to the source in WinDebut. Insert a dummy 3-phase motor and derive the 3-phase (line) source impedance at the PCC in accordance with Appendix D.

Derive $Z_{source\ 3\text{-}ph\ PCC}$ from $R_{source\ 3\text{-}ph\ PCC} + j\ X_{source\ 3\text{-}ph\ PCC}$.

For example…



$Z_{source\ 3\text{-}ph\ PCC} = \sqrt{(R_{source\ 3\text{-}ph\ PCC}^2 + X_{source\ 3\text{-}ph\ PCC}^2)} = \sqrt{(0.06048^2 + 0.05559^2)} = 0.08215\Omega$.

Step 4

Check if $Z_{source\ 3\text{-}ph\ PCC} \leq Z_{max\ harmonic\ 3\text{-}ph\ PCC}$. Here $Z_{source\ 3\text{-}ph\ PCC} = 0.08215\Omega$ and $Z_{max\ harmonic\ 3\text{-}ph\ PCC} = 0.177\Omega$. Therefore, $Z_{source\ 3\text{-}ph\ PCC} < Z_{max\ harmonic\ 3\text{-}ph\ PCC}$.

In this case then the requirement is met. If $Z_{source\ 3\text{-}ph\ PCC} > Z_{max\ harmonic\ 3\text{-}ph\ PCC}$ then the network would need to be reinforced until $Z_{source\ 3\text{-}ph\ PCC} \leq Z_{max\ harmonic\ 3\text{-}ph\ PCC}$ to allow connection of this equipment.

EXAMPLE 5

Application: Request to connect an Export Limiting device.
Network PCC: LV
Manufacturer: **Shadow ltd**
Model: 18A 230V single-phase limiter

BS EN 61000-3-11 Voltage Fluctuation/Flicker Statement

'This equipment complies with IEC 61000-3-3.'

BS EN 61000-3-12 Harmonic Statement

'Equipment complying with IEC 61000-3-12.'

Design as follows…

Design for Acceptable Voltage Fluctuations/Flicker

See Figure 1. As it is stated that the equipment is compliant with IEC 61000-3-3 then connection is permitted.

Design for acceptable harmonic distortion

Note: In accordance with ENA EREC G5/5, when the above statement is made compliance with harmonic current limits assumes a minimum ratio of 3-phase fault level at the PCC.

Step1

Determine I_{equ} (or S_{equ}):

I_{equ} = 18A (or S_{equ} = 18 x 230V = 4.14kVA).

Step 2

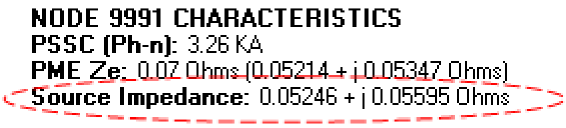
Determine $Z_{max\ harmonic\ 3\text{-}ph\ PCC}$ by using the spreadsheet 'Harmonics' found within clause 5.3.

Select the appropriate metering type (in this case whole current metering), enter a value of 4.14 kVA, a quantity of 1.

$Z_{max\ harmonic\ 1\text{-}ph\ PCC}$ = 0.44Ω.

Step 3

Determine the single-phase source impedance at the PCC in accordance with Appendix D.



$Z_{source\ 1\text{-}ph\ PCC} = \sqrt{(R_{source\ 1\text{-}ph\ PCC}^2 + X_{source\ 1\text{-}ph\ PCC}^2)} = \sqrt{(0.05246^2 + 0.05595^2)} = 0.07670\Omega$

Step 4

Check if $Z_{source\ 1\text{-}ph\ PCC} \leq Z_{max\ harmonic\ 1\text{-}ph\ PCC}$. Here $Z_{source\ 1\text{-}ph\ PCC} = 0.0767\Omega$ and $Z_{max\ harmonic\ 1\text{-}ph\ PCC} = 0.440\Omega$. Therefore, $Z_{source\ 1\text{-}ph\ PCC} < Z_{max\ harmonic\ 1\text{-}ph\ PCC}$.

In this case then the requirement is met. If $Z_{source\ 1\text{-}ph\ PCC} > Z_{max\ harmonic\ 1\text{-}ph\ PCC}$ then the network would need to be reinforced until $Z_{source\ 1\text{-}ph\ PCC} \leq Z_{max\ harmonic\ 1\text{-}ph\ PCC}$ to allow connection of this equipment.

EXAMPLE PHASE-NEUTRAL SOURCE IMPEDANCE

	Phase-Neutral Source Impedance (Ω)					
LV Circuit Length (m)	**0**	**100**	**200**	**300**	**400**	**500**
Conductor						
AO 0.025	0.1175	0.3227	0.5448	0.7693	0.9945	1.2201
AO 0.05	0.1175	0.2330	0.3541	0.4765	0.5994	0.7226
AO 0.1	0.1175	0.1935	0.2704	0.3476	0.4247	0.5020
AO 0.15	0.1175	0.1807	0.2536	0.3078	0.3713	0.4348
AO 50	0.1175	0.2330	0.3541	0.4765	0.5994	0.7226
AO 100	0.1175	0.1934	0.2703	0.3473	0.4244	0.5016
AO 150	0.1175	0.1808	0.2443	0.3079	0.3715	0.4351
CO 0.0225	0.1175	0.3497	0.6006	0.8538	1.1077	1.3620
CO 0.05	0.1175	0.2337	0.3554	0.4784	0.6019	0.7256
CO 0.1	0.1175	0.1943	0.2719	0.3497	0.4277	0.5057
CO 0.15	0.1175	0.1822	0.2472	0.3121	0.3771	0.4421
CO 70	0.1175	0.1941	0.2714	0.3489	0.4263	0.5039
CO 100	0.1175	0.1831	0.2489	0.3148	0.3806	0.4464
HY 25	0.1175	0.3196	0.5529	0.7903	1.0290	1.2681
HY 35	0.1175	0.2478	0.4026	0.5620	0.7229	0.8846
CC 16	0.1175	0.3161	0.5446	0.7772	1.0109	1.2452
CC 25	0.1175	0.2367	0.3777	0.5231	0.6701	0.8177
CC 35	0.1175	0.2027	0.2973	0.3947	0.4931	0.5920

Table G1 – Source Impedance by circuit length for a 25kVA 1-ph transformer

NOTE: Values in cells shown with grey shading exceed Z_{ref}. See Appendix H for explanation of Z_{ref}.

Transformer Type	Phase-Neutral Source Impedance (Ω) at Transformer LV Terminals
5 kVA 1-phase	0.5663
10 kVA 1-phase	0.2855
15 kVA 1-phase	0.1925
16 kVA 1-phase	0.1808
25 kVA 1-phase	0.1175
50 kVA 1-phase	0.06164
100 kVA 1-phase	0.03301

Table H2– Source Impedance at 1-phase Transformer Terminals by Rating

NOTE: Value in cell shown with grey shading exceeds Z_{ref}. See Appendix H for explanation of Z_{ref}.

H1.0 BACKGROUND

In line with the Distribution Code, POL:SD5 requires that connections shall be designed to ensure compliance with:

- Engineering Recommendation P28 to limit flicker and voltage fluctuations
- Engineering Recommendation G5 to limit harmonic voltage distortion.

Both of these Engineering Recommendations contain a 3-stage approach – each stage has increased complexity with Stage 1 being simplest. Equipment proposed for connection with an LV PCC and rated ≤75A falls within Stage 1. At present, however, the standards referred to in Stage 1 of each document are superseded in part, namely:

- P28 refers to BS 5406 which is now withdrawn; the nearest equivalent current standards are BS EN 61000-3-3 and BS EN 61000-3-11.
- G5 refers to IEC TR 61000-3-4; the latter is replaced by BS EN 61000-3-12 for equipment rated up to 75A per phase.

The IEC 61000 series of standards deals with 'electromagnetic compatibility' (EMC) which is the ability of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. Part 3 of the IEC 61000 series of standards deals with emissions and immunity of equipment. Specific standards within the IEC 61000-3-X series are of particular note to Distribution Network Operators as they deal with the limitation of:

- Emission of voltage changes, voltage fluctuations and flicker and impressed on the public low voltage system.
- Emission of harmonic currents into the public low-voltage systems.

See Table H1 which gives the UK implementation of these IEC standards. The standards apply to all equipment intended to be connected to public low-voltage systems. They do not apply to equipment only intended to be connected to private low-voltage systems interfacing with the public supply only at HV. Compliance with these standards is now a requirement for all equipment within their scope because of the Electromagnetic Compatibility Directive. They are 'horizontal' EMC standards; this means that they apply regardless of the type of equipment or of any generic or product-family EMC standards which may also apply. Note however that harmonic producing equipment designated by the manufacturer as 'professional equipment' and that does not comply with the standards is subject to special treatment.

PQ Parameters Controlled	Standard	Title
Voltage changes, voltage fluctuations & flicker	BS EN 61000-3-3	Limitation of voltage changes, voltage fluctuations & flicker in public low-voltage supply systems, for equipment with rated current ≤16A per phase and not subject to conditional connection
	BS EN 61000-3-11	Limitation of voltage changes, voltage fluctuations & flicker in public low-voltage supply systems – equipment with rated current ≤75A and subject to conditional connection
Harmonic distortion	BS EN 61000-3-2	Limits for harmonic current emissions (equipment input current ≤16A per phase)
	BS EN 61000-3-12	Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16A and ≤75A per phase

Table H1 – Standards for control of voltage changes, voltage fluctuations and flicker for equipment to be connected to public LV networks

H1.1 Voltage Changes, Voltage Fluctuations, Flicker and Maximum Source Impedance

Equipment compliant with BS EN 61000-3-3 is not subject to conditional connection. To verify compliance with this standard, voltage changes, voltage fluctuations and flicker produced using a reference source impedance, Z_{ref}, are checked against the limits of Table H2. The values for Z_{ref} are shown in Table H3 and represent the source impedance at the supply terminals. Equipment rated at ≤16A per phase which does not comply with this standard using Z_{ref} may be evaluated to show conformity with BS EN 61000-3-11 instead which allows the use of a lower source impedance.

Equipment falling within the scope of BS EN 61000-3-11 may be subject to conditional connection. When compliance with the limits in the standard is only achieved by keeping the upstream network source impedance below a determined value lower than Z_{ref} above then the manufacturer is required to make one of two statements:

a) '*This equipment complies with IEC 61000-3-11 provided that the source impedance, Z_{max} ≤ xx…*' because of the requirement to '*determine the maximum permissible system impedance Z_{max} at the interface point of the user's supply in accordance with 6.2, declare Z_{max} in the equipment instruction manual and instruct the user to determine in consultation with the supply authority, if necessary, that the equipment is connected only to a supply of that impedance or less*'

b) '*This equipment complies with IEC 61000-3-11 provided that the service current capacity ≥100A per phase*' because of the requirement to '*test the equipment in accordance with 6.3 and declare in the equipment instruction manual that the equipment is intended for use only in premises having a service current capacity ≥100 A per phase, supplied from a distribution network having a nominal voltage of 400/230 V, and instruct the user to determine in consultation with the supply authority, if necessary, that the service current capacity at the interface point is sufficient for the equipment. The equipment shall be clearly marked as being suitable for use only in premises having a service current capacity equal to or greater than 100 A per phase*.'

In a note associated with the above, the standard states: *'For options a) and b), if the supply capacity and/or the actual system impedance Z_{act} have been declared to, or measured by, the user, this information may be used to assess the suitability of equipment without reference to the supply authority.*'

Thus, the responsibility is initially on the customer to ensure compliance.

In theory, BS EN 61000-3-11 can deal with the issue of multiple connections on a network by scaling down the Z_{max} value so that it is not necessary to consider the impedance at the Point of Common Coupling to cover off the cumulative effect of multiple connections. This scaling down to cover off the cumulative effect of multiple connections is not done within BS EN 61000-3-3.

The limits specified within the above standards are detailed in Table H2.

Parameter	Limit
Short-term flicker[3], P_{st}	1.0
Long-term flicker[4], P_{lt}	0.65
Relative voltage change d(t)	3.3% for more than 500ms
Relative steady-state voltage change[5], d_c	3.3%
Maximum relative voltage change, d_{max}	4% - no additional conditions
	6% - manual switching
	6% - switched automatically more frequently than twice per day, and also has either a delayed restart (the delay being not less than a few tens of seconds), or manual restart, after a power supply interruption.
	7% - equipment which is attended whilst in use (for example: hair dryers, vacuum cleaners, kitchen equipment such as mixers, garden equipment such as lawn mowers, portable tools such as electric drills),
	7% - equipment which is switched on automatically, or is intended to be switched on manually, no more than twice per day, and also has either a delayed restart (the delay being not less than a few tens of seconds) or manual restart, after a power supply interruption.

Table H2 – Limits from BS EN 61000-3-3 and BS EN 61000-3-11

Equipment Connection	Impedance at Connection Point
Phase-Neutral	0.4+j0.25 Ω = 0.4717 Ω
Phase-Phase	0.48+j0.3 Ω = 0.5660 Ω
3-Phase	0.24+j0.15 Ω = 0.2830 Ω

Table H3 – Reference Impedance, Z_{ref}, according to IEC 60725

H1.2 Harmonic Distortion

Equipment compliant with BS EN 61000-3-2 is not subject to conditional connection. Professional equipment which falls within the scope of this standard but which does not comply with it may be designated by the manufacturer as 'professional equipment' requiring application to the supply authority for permission to connect. Other equipment falling within the scope of this standard that does not comply cannot be retested or evaluated to show conformity with BS EN 61000-3-12. This is different to the approach in the flicker control standard BS EN 61000-3-11.

[3] Short-term flicker severity is the flicker severity evaluated over a short period (in minutes); P_{st} = 1 is the conventional threshold of irritability.

[4] Long-term flicker severity is the flicker severity evaluated over a 2-hour period using successive *P*st values.

[5] For example, no load to full load.

Equipment falling within the scope of BS EN 61000-3-12 is subject to conditional connection. Compliance with the current emission limits in the standard is checked at a specific ratio of 3-phase short-circuit fault level at the PCC to equipment rating. Thus, compliance is achieved provided that the ratio is at least equal to the specified ratio. The standard states:

> '*For equipment complying with the harmonic current emission limits corresponding to R_{sce} = 33, the manufacturer shall state in the instruction manual supplied with the equipment: "Equipment complying with IEC 61000-3-12"'*

Where the equipment does not comply when R_{sce} = 33 then the manufacturer must state:

> "*This equipment complies with IEC 61000-3-12 provided that the short-circuit power S_{sc} is greater than or equal to xx at the interface point between the user's supply and the public system. It is the responsibility of the installer or user of the equipment to ensure, by consultation with the distribution network operator if necessary, that the equipment is connected only to a supply with a short-circuit power S_{sc} greater than or equal to xx*."

where 'xx' is the value of 3-phase short-circuit fault level at the Point of Common Coupling corresponding to the minimum value of R_{sce} for which the relevant limits are not exceeded.

Note that the R_{sce} = 33 requirement implies lower values of source impedance than the reference impedance, Z_{ref}, used for unconditional connection with respect to BS EN 61000-3-3 (flicker), noting that Z_{ref} applies at the supply terminals and R_{sce} at the PCC. Typical sizes of heat pump units for new accommodation are 18A for small and 34A for large. The typical size for a retrofit unit is 47A. The resulting maximum phase-neutral source impedances at the PCC are ≤0.3872 Ω for 18A, ≤0.2050 Ω for 34A and 0.1483Ω for 47A. Thus, this requirement is very onerous for the larger equipment ratings.

BS EN 61000-3-2 and -12 are intended to deal with the issue of the cumulative effect of multiple connections on a network by selection of the harmonic current limits.

H2.0 Policy Considerations

Although there are duties on installers and customers arising from the above, these appear to be largely ineffective. Experience has shown that the statements required by the standards are not always made or easy to find and rarely acted upon by installers. Some manufacturers have also been found to be unaware of the relevant standards. However, the DNOs have a duty under Regulation 3 of the ESQC Regulations 2002 to prevent interference so far as is reasonably practicable. Therefore, to ensure the source impedance is suitable for connection of possibly disturbing equipment a more pro-active policy than simply responding to requests for Z_{max}, R_{sce} and S_{sc} is required. Thus, it is necessary to identify relevant equipment, as far as is reasonably practicable, and seek to design to ensure the network source impedance is sufficiently low and conversely the fault level sufficiently high.

H2.1 Flicker and Source Impedance

At present, we effectively state a phase-neutral source impedance of 0.25 Ω for all new connections, by virtue of this being the same as the earth loop impedance for PME. We design to a resistive phase-neutral source impedance limit of 0.22 Ω in WinDebut for new supplies of up to 100A. Therefore, equipment that conforms to BS EN 61000-3-3 can be unconditionally connected due to the equipment being assessed and deemed acceptable with a reference impedance, Z_{ref}, of 0.4717 Ω = 0.4 + j0.25 Ω for single-phase equipment as per Table H3. However, there may be some risk with multiple installations of equipment compliant with BS EN 61000-3-3 that the summation of flicker could exceed the limit of P_{st} (1.0). Furthermore, there may also be risk of P_{st} exceeding 1.0 at sites with source impedance exceeding Z_{ref}.

H2.1.1 Flicker from Multiple Connections of BS EN 61000-3-3 Compliant Equipment

WinDebut has a phase-neutral source resistance limit of 0.135 Ω for the main without the service. This can be seen as the source resistance at the PCC and corresponds to an impedance of around 0.144 Ω. This has been determined to ensure that the summation of Low Carbon Technologies will never exceed the harmonic limit of the network, it has been determined that the network will reach its thermal capacity prior to the power quality capacity.

For existing networks, predating WinDebut, the phase-neutral source impedance at the PCC may be higher than 0.144 Ω. Examples include networks with small size transformers or long, small sized conductors. Note that IEC TR 60725 quotes that 98% of residential customers have a phase-neutral source impedance at the supply terminals of less than 0.64 Ω and 90% less than 0.34 Ω, equating to around 0.512 Ω and 0.27 Ω, respectively, at the PCC. In this case, equipment which just passes BS EN 61000-3-3 for short-term flicker would produce a maximum P_{st} of around 0.512/0.4717 x 1.0 = 1.085 and 0.27/0.4717 x 1.0 = 0.576 at the PCC for source impedance of 0.512 Ω and 0.27 Ω, respectively. Multiple connections, where the flicker is combined at the PCC using a cube, sum and cubed root formula could therefore be problematic in a small number of cases:

$$P_{st\ combined} = \sqrt[3]{(P_{st\ background}^3 + P_{st\ source1}^3 + P_{st\ source2}^3 + \ldots P_{st\ sourceN}^3)}$$

However, for the inclusion of low carbon technologies, WPD are fully funding the improvement of the networks to reduce the impedance at both the PCC and supply terminals. See SD5G Part 1 for guidance. As the number of installations of Low Carbon Technologies is due to increase to meet government targets and as WPD are in turn reinforcing networks to enable the decarbonisation of the country, this will also in turn enable the connection of devices outside of the LCT banner.

H2.1.2 Flicker From Multiple Connections of BS EN 61000-3-11 Compliant Equipment

BS EN 61000-3-11 uses the same voltage change, voltage fluctuation and flicker limits as BS EN 61000-3-11. Experience to date has revealed equipment specific phase- neutral Z_{max} values stated by manufacturers ranging from 0.17 Ω to just under Z_{ref}.

BS EN 61000-3-11 has a control in clause 6.2.2 aimed at dealing with the effect of multiple connections by scaling down the Z_{max} stated. This uses $Z_{ref}\ (1/P_{st})^{3/2}$. Whilst some manufacturers have been seen to apply this technique there is some confusion over the wording of clause 6.2.2 as to whether it applies to automatically switched equipment. This is being pursued with the relevant standards committee. If it proves that the stated Z_{max} has not been derived as above then it would be necessary to derive a lower $Z_{max'}$ than the stated one from $Z_{max'} = 0.3892(Z_{max}^{2/3})$ to allow for multiple connections. This scaling down to cover off the cumulative effect of multiple connections is not done within BS EN 61000-3-3.

In conclusion, multiple connections of equipment compliant with BS EN 61000-3-11 is not expected to be problematic in the majority of cases provided the network is designed to achieve the associated lower source impedance, Z_{max} or $Z_{max\ 100A}$, at the supply terminals.

H2.2 Harmonic Distortion and Fault Level

BS EN 61000-3-2 and -12 are intended to deal with the issue of the cumulative effect of multiple connections on a network by selection of the harmonic current limits. For BS EN 61000-3-12 the effectiveness of the limits is dependent on the network having a sufficiently high fault level. As the penetration of harmonic equipment increases it may be necessary for the relevant standards committees to consider reducing the permitted harmonic current emissions.

A key decision DNOs have to make is whether to ensure $R_{sce} \geq 33$ at the PCC as this imposes onerous source impedance requirements. It is clear that the values required for harmonic control are much lower than for flicker control using Z_{ref}. BS IEC 61000-3-4 predates BS EN 61000-3-12 but covers the same issue; it states that *'Equipment complying with Table 1 for the emission of harmonic currents into the public supply system can be connected at any point of the supply system provided the short-circuit ratio R_{sce} is equal to or higher than 33.'* Thus, the intention is that the requirement is conditional. Furthermore, values for typical ratings are much lower than Z_{ref}; for a typical retrofit unit rated at 47A single-phase this equates to a phase-neutral source impedance of 0.1483 Ω. Thus, we deduce that to adequately control harmonic distortion it is necessary to design the network to meet the minimum fault level corresponding to $R_{sce} \geq 33$ and networks must be designed to ensure it is met.

CUSTOMER RESPONSIBILITIES

NOTE: The Distribution Code DPC 5.2.1 states:

"Users shall contact the DNO in advance if it is proposed to make any significant change to the connection, electric lines or electrical equipment, install or operate any generating equipment or do anything else that could affect the DNO's Distribution System or require alterations to the connection."

NOTE: The National Terms for Connection states:

"You must contact us in advance if you propose to make any significant change to the connection or to the electric lines or electrical equipment at the premises, or if you propose to do anything else that could affect our network or if you require alterations to the connection."

NOTE: BS 7671 (The Wiring Regulations) states:

"132.16 Additions and alterations to an installation

No addition or alteration, temporary or permanent, shall be made to an existing installation, unless it has been ascertained that the rating and the condition of any existing equipment, including that of the distributor, will be adequate for the altered circumstances."

NOTE: Products placed on the market have to comply with the protection requirements of the EMC Directive; in practice this means complying with the 'harmonised' standards published in the Official Journal of the European Union. Standards EN 61000-3-2, -3, -11 and -12 are published in that Journal as Product Family Standards and so apply to all equipment intended for connection to the public LV network within their scope.

APPENDIX J

SUPERSEDED DOCUMENTATION

This document supersedes ST: SD6J/1 dated February 2020 which has now been withdrawn.

APPENDIX K

RECORD OF COMMENT DURING CONSULTATION

No comments received.

APPENDIX L

ASSOCIATED DOCUMENTATION

POL:SD5	LV System Design
ST:SD5A	Design of Low Voltage Domestic Connections
ST:SD5G	Connection of Low Carbon Technology
ST:SD5K	Use of WinDebut Software
ST:SD5N	Use of WinDebut Software for Assessing Motor and Welder Voltage Disturbance (Flicker)
ST:SD5O	Load Approval at Domestic Properties Requiring No Detailed Investigation
ST:SD6F	Dealing with Potentially Disturbing Electrical Loads/Equipment
Engineering Recommendation G5	Planning Levels for Harmonic Voltage Distortion and the Connection of Non-linear Equipment to Transmission Systems and Distribution Networks in the United Kingdom.
Engineering Recommendation P28	Planning Limits for Voltage Fluctuations Caused By Industrial, Commercial and Domestic Equipment in the United Kingdom
BS EN 61000-3-2	Limits for harmonic current emissions (equipment input current ≤16A per phase)
BS EN 61000-3-3	Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection
BS EN 61000-3-11	Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75A and subject to conditional connection
BS EN 61000-3-12	Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16A and ≤75A per phase
IEC TR 61000-3-4	Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16A

KEY WORDS

Boiler, Connection, Flicker, Harmonic, Kiln, PV, PCC, UPS, WinDebut, Wind Turbine.