Company Directive

STANDARD TECHNIQUE : SD6J/1

Connection design - potentially disturbing electrical equipment rated ≤75A/phase subject to conditional connection

Policy Summary

This Standard Technique defines how the connection of potentially disturbing equipment rated ≤75A/phase shall be designed in order to control voltage fluctuations, flicker & harmonic voltage distortion. This policy applies to installations with an LV Point of Common Coupling and excludes Low Carbon Technology.

Author:	**Seth Treasure**
Implementation Date:	**February 2020**
Approved by	**Paul Jewell**
	DSO Development Manager
Date:	5 February 2020

Target Staff Group	Staff responsible for low voltage network design
Impact of Change	Green – The change has been aligned to current working practices
Planned Assurance checks	None

IMPLEMENTATION PLAN

Introduction

This Standard Technique (ST) defines the design procedure required for the connection of potentially disturbing equipment to the WPD network where the equipment is rated ≤75A/phase, 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 for Electric Vehicle charge points and Heat Pumps have been removed from this policy and have been included in a separate policy to simplify and ease the connection of Low Carbon Technology.

Impact of Changes

This policy will now only detail the acceptance / design procedure for equipment other than Electric Vehicle charge points and Heat Pumps.

Target Staff Group	Staff responsible for low voltage network design
Impact of Change	Green – The change has been aligned to current working practices

Implementation Actions

Team Managers shall ensure that appropriate staff are aware of, and follow, the requirements of this document.

Implementation Timetable

This policy is implemented with immediate effect.

REVISION HISTORY

Document Revision / Review Table		
Date	Changes / Comments	Author
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

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 where the equipment is rated ≤75A/phase, excluding EVs and HPs. This is necessary to control voltage fluctuations, flicker & harmonic voltage distortion.

1.2   This ST implements connection requirements for ENA Engineering Recommendation P28 (Flicker) and G5 (Harmonics).

2.0   SCOPE

2.1   This ST covers WPD connection design for LV installations with LV equipment rated ≤75A per phase, where there is an LV Point of Common Coupling[1] (PCC).

2.2   Sizing the connection and network for the maximum demand is not within the scope of this ST – see ST:SD5A or ST:SD5E.

2.3   Motors and welders not within the scope of the standards BS EN 61000-3-3, 61000-3-11, 61000-3-2 and 61000-3-12 are treated as per ST:SD6F and ST:SD5N.

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[1] The point on a network electrically nearest to a customer's installation at which other customers' loads/generators are, or may be, connected.

3.0 POLICY

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

3.1.1 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.

3.1.2 Equipment that is rated ≤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	✔	✔[2]
Air conditioners and commercial refrigeration equipment	✔	✔
Uninterruptible power supplies, electric vehicle charging systems & industrial battery charging systems	✔	✔
Electric kilns	✔	✔[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[3]	✔	✔
Arc welders within scope of BS EN 61000-3-2, -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		✔

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[2] 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).

[3] An example is the Coolpower EMMA GVS.

Table 1 - Significant Equipment Rated ≤75A Per Phase Requiring Assessment If LV PCC

NOTE: The Distribution Code DPC 5.2.1 states:

"Users shall contact the DNO in advance if it is proposed to make any <u>significant</u> 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.

3.1.3   Applications to connect equipment of the type listed in Table 1, where the PCC is at LV, shall be assessed using design procedures given in Figures 1 and 2, as appropriate.

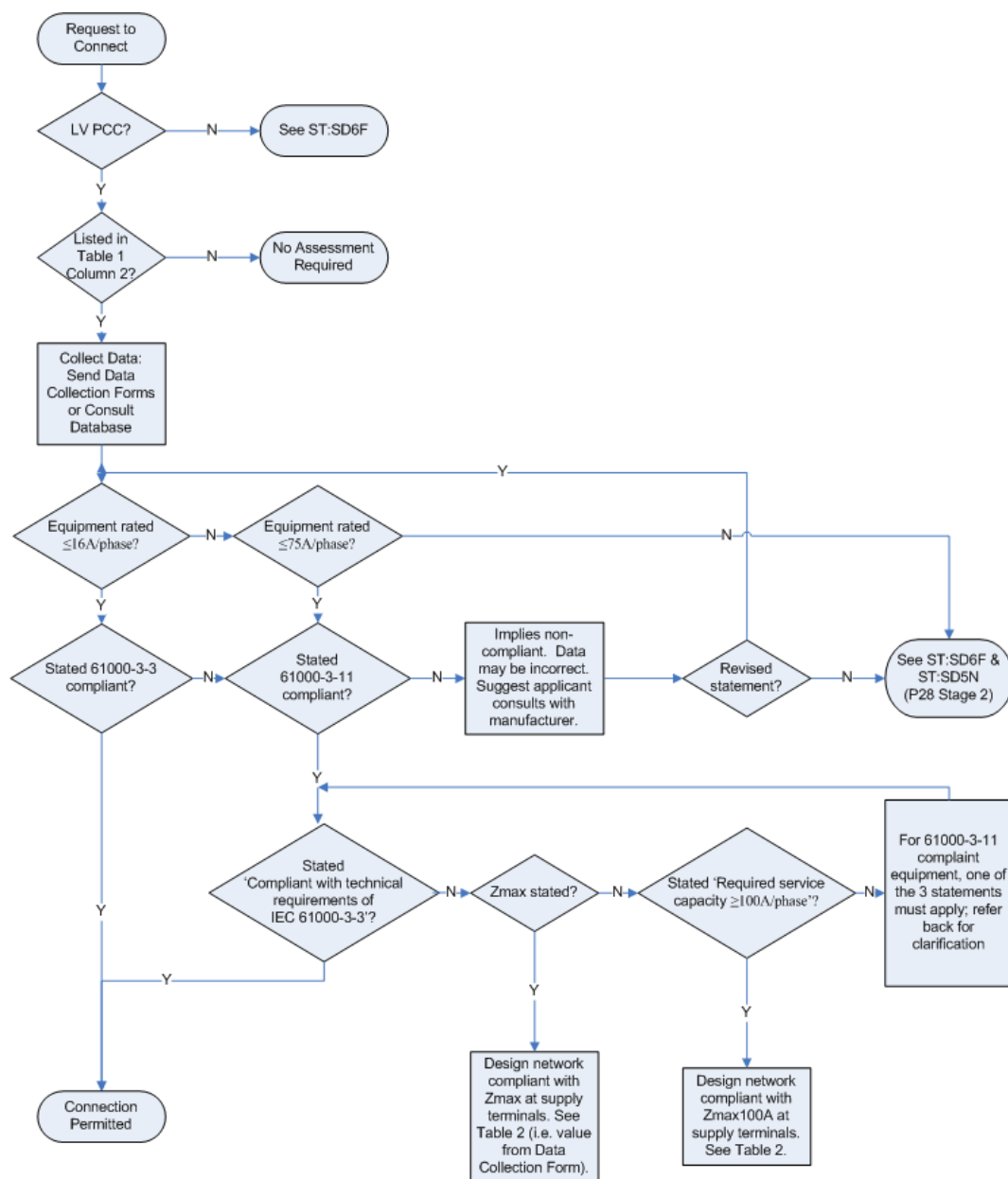### 3.1.4 Voltage Fluctuations & Flicker Control Procedure

Figure 1 – Flow Chart – Procedure for Connection Design – Voltage Fluctuation/Flicker Control

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 need be considered.

NOTE: For a given system of equipment comprising multiple integrated parts, the manufacturer should only make a single statement to cover the whole integrated system. For example, a heat pump system may comprise an indoor unit and an outdoor unit that together make up a heat pump system. Similarly, some electrical boiler systems are modular with multiple modules making up the overall boiler system. It is not acceptable to consider each system element separately as this does not control flicker adequately.

NOTE: See Appendix A for Data Collection Forms.

NOTE: 'Consult Database' refers to a possible MCS\Gemserve database.

NOTE: Z_{max} = Maximum permissible source impedance declared by the manufacturer in accordance with BS EN 61000-3-11 clause 4(a).

NOTE: $Z_{max\ 100A}$ = Source impedance defined in BS EN 61000-3-11 clause 6.3 associated with the statement that the equipment is intended for use only in premises having a service current capacity ≥100A per phase as per BS EN 61000-3-11 clause 4(b).

3.1.4.1   Table 2 details the maximum source impedance for each type of connection for the two terms, Z_{max} and $Z_{max\ 100A}$. The relevant source impedance corresponds to how the equipment is connected. For example, phase-neutral connected equipment requires phase-neutral source impedance whereas 3-phase connected equipment requires the 3-phase source impedance, also known as line impedance, which omits the neutral impedance.

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.

Equipment Connection	Maximum source impedance	
	Z_{max}	$Z_{max\ 100A}$
Phase-Neutral	As specified on Data Collection Form or in Database	0.25+j0.25 Ω = 0.3536 Ω
Phase-Phase		0.30+j0.30 Ω = 0.4243 Ω
3-Phase		0.15+j0.15 Ω = 0.2121 Ω

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

3.1.4.2   Appendix B details how to derive the actual source impedance for a given network and given equipment connection.

3.1.4.3   Worked examples are provided in Appendix E to illustrate the design procedure.
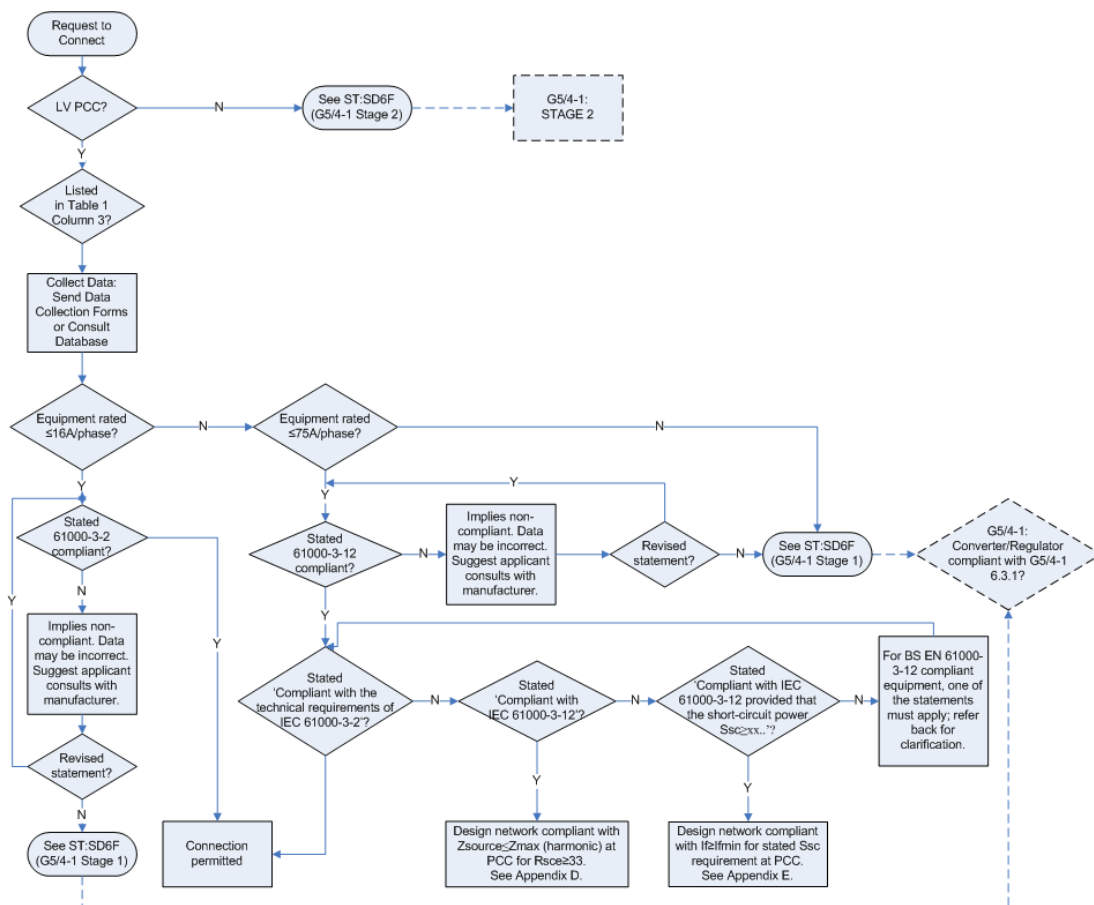
3.1.5 Harmonic Control Procedure

Figure 2 – Flow Chart – Procedure for Connection Design – Harmonic Distortion Control

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 one with the lowest fault level at the PCC need be considered.

NOTE: In accordance with BS EN 61000-3-12, when individual self-contained items of equipment (possibly, but not necessarily, of different manufacture) are assembled in a rack or case compliance with the standard shall be achieved either for the system as a whole or for each individual self-contained item at the manufacturer's discretion. For a given system of equipment comprising multiple integrated parts, only one statement should be made to cover the whole system. For example, a heat pump system may comprise an indoor unit and an outdoor unit that together make up a heat pump system. Similarly, some PV inverter systems are modular with multiple micro-inverter modules making up the overall PV system. It is not acceptable to consider each system element separately as this does not control harmonic emissions adequately.

NOTE: Appendix A gives the Data Collection Forms.

NOTE: 'Consult Database' refers to a possible MCS\Gemserve database.

NOTE: Z_{source} = source impedance at the PCC.

NOTE: $Z_{max\ (harmonic)}$ = maximum source impedance at the PCC corresponding to R_{SCE} = 33 for the given equipment connection. See Table D1.

NOTE: I_f = actual fault current at PCC applicable. Whether this is the single-phase, phase-phase or 3-phase value depends on the equipment connection. See Appendices C and E.

NOTE: I_{fmin} = fault current corresponding to R_{sce} = 33 or S_{sc} as appropriate. Whether this is the single-phase, phase-phase or 3-phase value depends on the equipment connection. See Appendix C and E.

NOTE: R_{sce} is a short-circuit ratio at the PCC as defined in BS EN 61000-3-12. It is a proportional to the ratio of the 3-phase short-circuit fault level at the PCC to the rated apparent power of the equipment. See Appendix C.

NOTE: S_{sc} is the 3-phase short-circuit fault level at the PCC.

3.1.5.1   Appendix E details how to determine whether $Z_{source} \leq Z_{max\ (harmonic)}$ and $I_f \geq I_{fmin.}$. .   Appendix D provides minimum fault level and corresponding maximum source impedance for R_{sce} = 33 by equipment rating; this is used to derive $Z_{max\ (harmonic)}$ simply.

3.1.5.2   Where design for $Z_{source} \leq Z_{max\ (harmonic)}$ or $I_f \geq I_{fmin}$ is the limiting factor in sizing the network, it may be possible to produce a lower cost scheme if the customer provides the actual current emissions and a detailed G5 assessment is conducted with the permitted currents in Table 7, scaled for fault level.

4.0 LIST OF APPENDICES

Appendix	Title
A	Data Collection Forms
B	Use Of Simple WinDebut Model To Derive Actual Source Impedance
C	Formulae For S_{equ}, S_{sc}, R_{sce}, I_{fmin} & I_f
D	Minimum Fault Level/Maximum Source Impedance For R_{sce}=33
E	Worked Examples
F	Example Phase-Neutral Source Impedance
G	Background
H	Superseded Documentation
I	Record of Comment during Consultation
J	Associated Documentation
K	Key Words

DATA COLLECTION FORMS
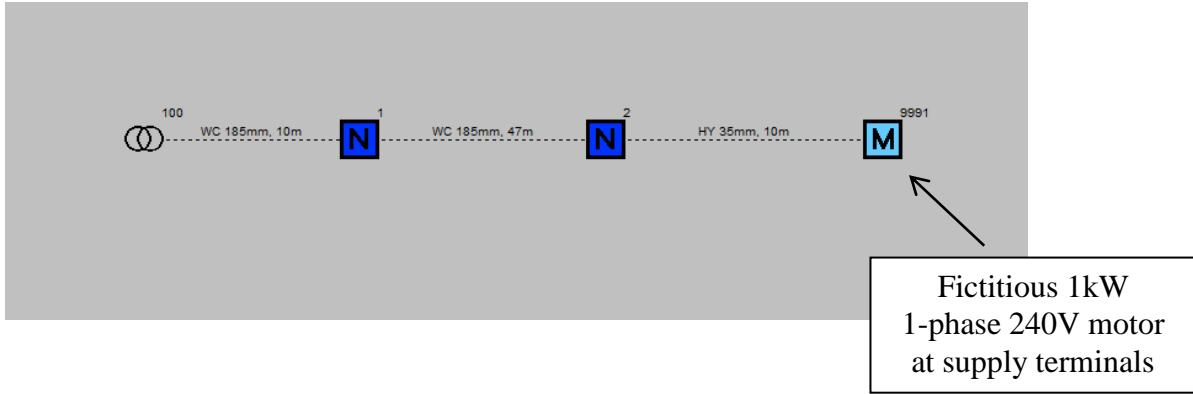
<Hyperlinks to Data Collection Forms>

Main forms:

Form X	Equipment Rated ≤75A/phase

Related Forms:

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

USE OF SIMPLE WINDEBUT MODEL TO DERIVE ACTUAL SOURCE IMPEDANCE

Single-phase Equipment

Fictitious 1kW 1-phase 240V motor at supply terminals

NODE RESULTS
Node Name: 9991
Volt Drop: 0.08%
Loop Resistance: 40 m ohms
Fault Current: 5400 amps

CABLE TYPES USED IN THIS NETWORK
Node 1 to Substation 100: WC 185mm, 10m
Node 1 to Node 2: WC 185mm, 47m
Node 2 to Motor 9991: HY 35mm, 10m

MOTOR DETAILS
Motor Voltage: 1 Phase 240V motor
LV Network Type: 3 phase 4 wire network
Rating: 1 Kilowatts
Type of Starter: Direct on line
Starting Current: 38.1 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): 0.32% - PASS
P28 Voltage Drop @ Node 1: 0.35% - PASS
P28 Voltage Drop @ Node 2: 0.49% - PASS
P28 Voltage Drop @ Node 9991: 0.58% - PASS

TOTAL VOLTAGE DROP DURING STARTING
Node 9991: 0.00 + 0.58% - VALUE DOES NOT EXCEED 9% - PASS

NODE 9991 CHARACTERISTICS
PSSC (Ph-n): 5.22 KA
Source Impedance: 0.04038 + j 0.02568 Ohms
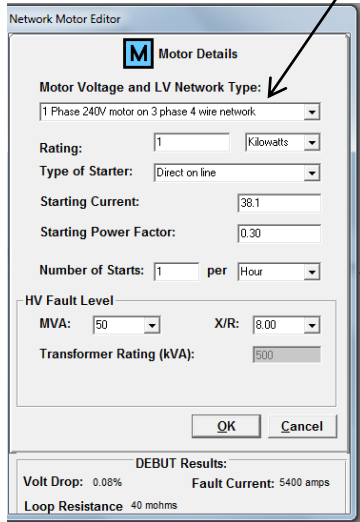
Figure B1 - Dummy 1-Phase Motor and Simplified Network - Impedance at the supply terminals

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>, $Z_{\text{source 1-ph supply terminals}}$ is given by

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

Results

Substation Fuses Used
NODE 1: 100 amps

NODE RESULTS
Node Name:9991
Volt Drop:0.04%
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 240V motor
LV Network Type: 3 phase 4 wire network
Rating: 1 Kilowatts
Type of Starter: Direct on line
Starting Current: 38.1 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): 0.32% - PASS
P28 Voltage Drop @ Node 1: 0.35% - PASS
P28 Voltage Drop @ Node 9991: 0.49% - PASS

TOTAL VOLTAGE DROP DURING STARTING
Node 9991: 0.00 + 0.49% - VALUE DOES NOT EXCEED 9% - PASS

NODE 9991 CHARACTERISTICS
PSSC (Ph-n): 7.26 KA
PME Ze: 0.03 Ohms (0.02379 + j 0.02212 Ohms)
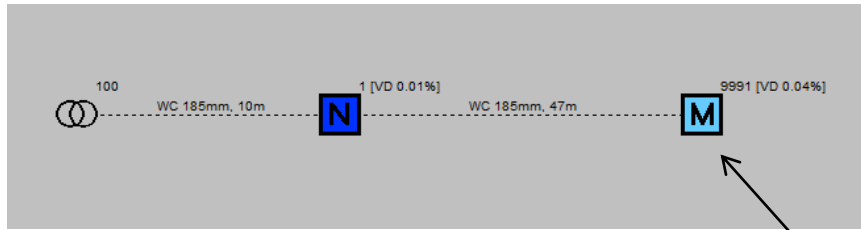Source Impedance: 0.02410 + j 0.02460 Ohms

Fictitious 1kW
1-phase 240V motor at point
of common coupling

Figure B2 - 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 <u>PCC</u>, $Z_{\text{source 1-ph PCC}}$ is given by

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

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:

NODE 9991 CHARACTERISTICS
PSSC (3-Ph): 7.15 KA
PME Zs: 0.05 Ohms (0.04887 + j 0.02362 Ohms)
Source Impedance: 0.02358 + j 0.02579 Ohms

Figure B3 - Dummy 3-Phase Motor and Simplified Network - Impedance at the Supply Terminals

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

$$Z_{\text{source 3-ph supply terminals}} = \sqrt{(R_{\text{source 3-ph supply terminals}}^2 + X_{\text{source 3-ph supply terminals}}^2)} =$$
$$\sqrt{(0.02358^2 + 0.02579^2)} = 0.0349\,\Omega$$
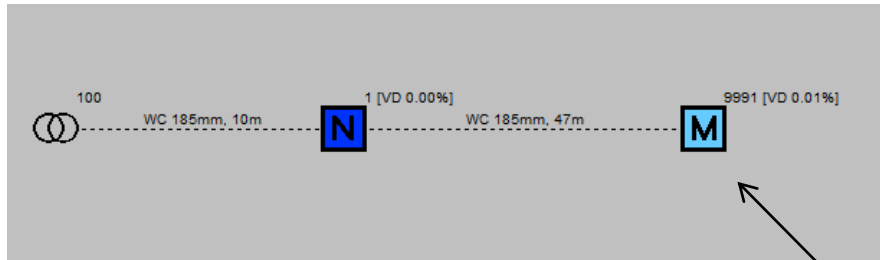
NODE 9991 CHARACTERISTICS
PSSC (3-Ph): 8.58 KA
PME Ze: 0.03 Ohms (0.02373 + j 0.02212 Ohms)
Source Impedance: 0.01490 + j 0.02504 Ohms

Fictitious 1kW
3-phase 415V motor at
point of common
coupling

Figure B4 - 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.
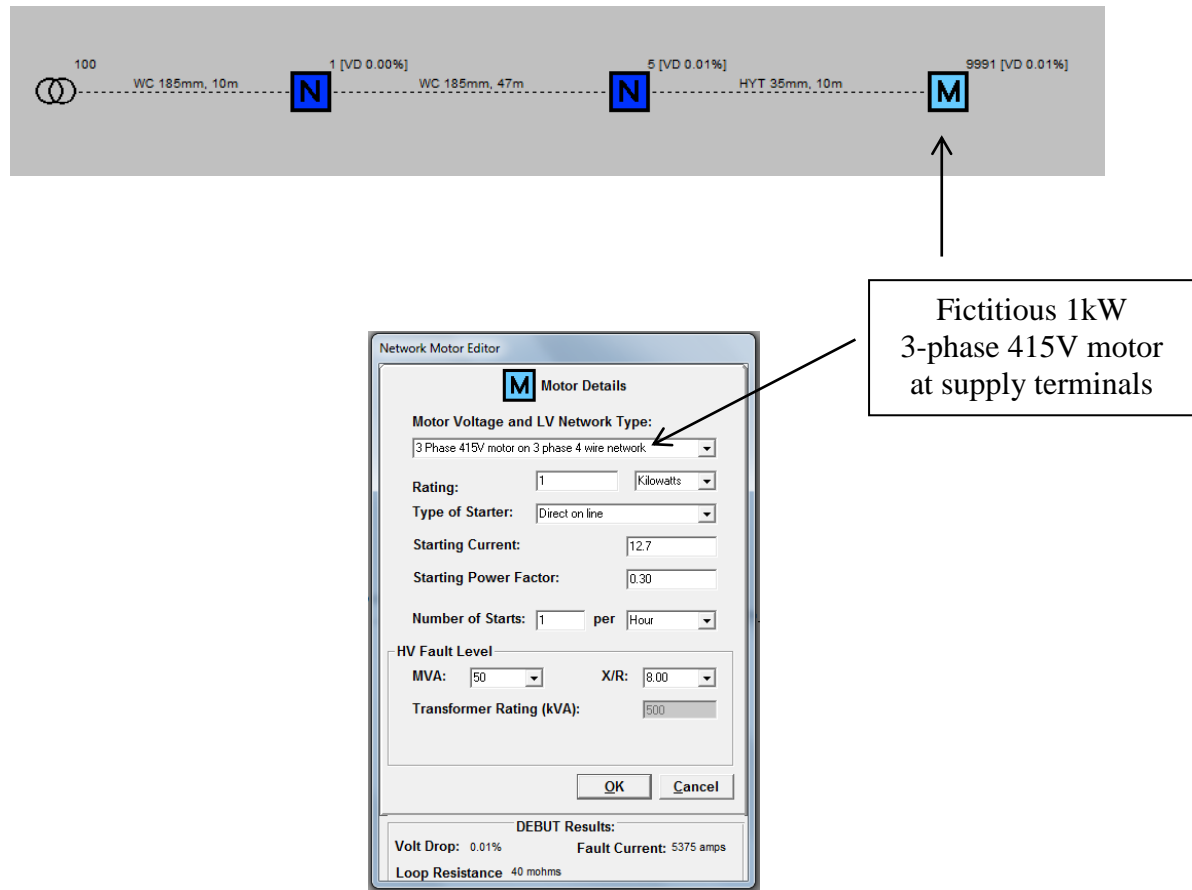
The three-phase source impedance of the network at the PCC, $Z_{source\ 3\text{-}ph\ PCC}$, is given by

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

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

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 B5 - Dummy split-Phase Motor (480v) and Simplified Network - Impedance at the Supply Terminals

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

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

$$= \sqrt{(0.04239^2 + 0.03699^2)} = 0.05626\Omega.$$
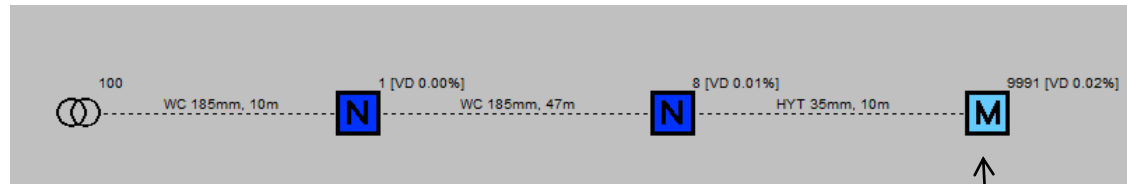
Fictitious 1kW
Split phase 480V motor at point of point of common coupling
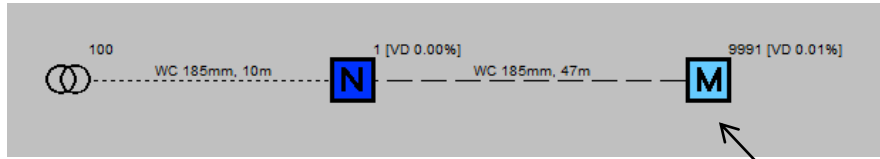
Results

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 Ze: 0.03 Ohms (0.02278 + j 0.02213 Ohms)
Source Impedance: 0.02503 + j 0.03549 Ohms

Figure B6 - 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, $Z_{\text{source 2-ph PCC}}$, is given by

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

$$= \surd(0.02503^2 + 0.03549^2) = 0.0434\Omega.$$

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, $Z_{\text{source ph-ph}}$:

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

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.

C1   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

C2   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.

C3   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}

C4   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}

C5   CALCULATION OF MINIMUM FAULT CURRENT VALUE, I_{fmin}

$I_{fmin} = S_{sc}/(√3 \times 400V)$

C6 CALCULATION OF ACTUAL FAULT CURRENT, I_f, FROM SOURCE IMPEDANCE

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

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

MINIMUM FAULT LEVEL/MAXIMUM SOURCE IMPEDANCE FOR R$_{sce}$=33

Equipment Rating (A)	Equipment rating (kVA)			Minimum short circuit power (kVA)			Minimum fault current (A)			Maximum source impedance at PCC (ohms)		
	1 phase	split phase	three phase	1 phase	split phase	three phase	1 phase	split phase	three phase	1 phase (1)	split phase (2)	three phase (3)
16	3.680	7.36	11.085	121.440	242.88	365.809	528	528	528	0.436	0.871	0.437
17	3.910	7.82	11.778	129.030	258.06	388.672	561	561	561	0.410	0.820	0.412
18	4.140	8.28	12.471	136.620	273.24	411.535	594	594	594	0.387	0.774	0.389
19	4.370	8.74	13.164	144.210	288.42	434.398	627	627	627	0.367	0.734	0.368
20	4.600	9.20	13.856	151.800	303.6	457.261	660	660	660	0.348	0.697	0.350
21	4.830	9.66	14.549	159.390	318.78	480.124	693	693	693	0.332	0.664	0.333
22	5.060	10.12	15.242	166.980	333.96	502.987	726	726	726	0.317	0.634	0.318
23	5.290	10.58	15.935	174.570	349.14	525.850	759	759	759	0.303	0.606	0.304
24	5.520	11.04	16.628	182.160	364.32	548.713	792	792	792	0.290	0.581	0.292
25	5.750	11.50	17.321	189.750	379.5	571.577	825	825	825	0.279	0.558	0.280
26	5.980	11.96	18.013	197.340	394.68	594.440	858	858	858	0.268	0.536	0.269
27	6.210	12.42	18.706	204.930	409.86	617.303	891	891	891	0.258	0.516	0.259
28	6.440	12.88	19.399	212.520	425.04	640.166	924	924	924	0.249	0.498	0.250
29	6.670	13.34	20.092	220.110	440.22	663.029	957	957	957	0.240	0.481	0.241
30	6.900	13.80	20.785	227.700	455.4	685.892	990	990	990	0.232	0.465	0.233
31	7.130	14.26	21.477	235.290	470.58	708.755	1023	1023	1023	0.225	0.450	0.226
32	7.360	14.72	22.170	242.880	485.76	731.618	1056	1056	1056	0.218	0.436	0.219
33	7.590	15.18	22.863	250.470	500.94	754.481	1089	1089	1089	0.211	0.422	0.212
34	7.820	15.64	23.556	258.060	516.12	777.344	1122	1122	1122	0.205	0.410	0.206
35	8.050	16.10	24.249	265.650	531.3	800.207	1155	1155	1155	0.199	0.398	0.200
36	8.280	16.56	24.942	273.240	546.48	823.070	1188	1188	1188	0.194	0.387	0.194
37	8.510	17.02	25.634	280.830	561.66	845.933	1221	1221	1221	0.188	0.377	0.189
38	8.740	17.48	26.327	288.420	576.84	868.796	1254	1254	1254	0.183	0.367	0.184
39	8.970	17.94	27.020	296.010	592.02	891.659	1287	1287	1287	0.179	0.357	0.179
40	9.200	18.40	27.713	303.600	607.2	914.522	1320	1320	1320	0.174	0.348	0.175
41	9.430	18.86	28.406	311.190	622.38	937.385	1353	1353	1353	0.170	0.340	0.171
42	9.660	19.32	29.098	318.780	637.56	960.249	1386	1386	1386	0.166	0.332	0.167
43	9.890	19.78	29.791	326.370	652.74	983.112	1419	1419	1419	0.162	0.324	0.163
44	10.120	20.24	30.484	333.960	667.92	1005.975	1452	1452	1452	0.158	0.317	0.159
45	10.350	20.70	31.177	341.550	683.1	1028.838	1485	1485	1485	0.155	0.310	0.156
46	10.580	21.16	31.870	349.140	698.28	1051.701	1518	1518	1518	0.152	0.303	0.152
47	10.810	21.62	32.563	356.730	713.46	1074.564	1551	1551	1551	0.148	0.297	0.149
48	11.040	22.08	33.255	364.320	728.64	1097.427	1584	1584	1584	0.145	0.290	0.146
49	11.270	22.54	33.948	371.910	743.82	1120.290	1617	1617	1617	0.142	0.284	0.143
50	11.500	23.00	34.641	379.500	759	1143.153	1650	1650	1650	0.139	0.279	0.140
51	11.730	23.46	35.334	387.090	774.18	1166.016	1683	1683	1683	0.137	0.273	0.137
52	11.960	23.92	36.027	394.680	789.36	1188.879	1716	1716	1716	0.134	0.268	0.135
53	12.190	24.38	36.719	402.270	804.54	1211.742	1749	1749	1749	0.132	0.263	0.132
54	12.420	24.84	37.412	409.860	819.72	1234.605	1782	1782	1782	0.129	0.258	0.130
55	12.650	25.30	38.105	417.450	834.9	1257.468	1815	1815	1815	0.127	0.253	0.127
56	12.880	25.76	38.798	425.040	850.08	1280.331	1848	1848	1848	0.124	0.249	0.125
57	13.110	26.22	39.491	432.630	865.26	1303.194	1881	1881	1881	0.122	0.245	0.123
58	13.340	26.68	40.184	440.220	880.44	1326.057	1914	1914	1914	0.120	0.240	0.121
59	13.570	27.14	40.876	447.810	895.62	1348.921	1947	1947	1947	0.118	0.236	0.119
60	13.800	27.60	41.569	455.400	910.8	1371.784	1980	1980	1980	0.116	0.232	0.117
61	14.030	28.06	42.262	462.990	925.98	1394.647	2013	2013	2013	0.114	0.229	0.115
62	14.260	28.52	42.955	470.580	941.16	1417.510	2046	2046	2046	0.112	0.225	0.113
63	14.490	28.98	43.648	478.170	956.34	1440.373	2079	2079	2079	0.111	0.221	0.111
64	14.720	29.44	44.340	485.760	971.52	1463.236	2112	2112	2112	0.109	0.218	0.109
65	14.950	29.90	45.033	493.350	986.7	1486.099	2145	2145	2145	0.107	0.214	0.108
66	15.180	30.36	45.726	500.940	1001.88	1508.962	2178	2178	2178	0.106	0.211	0.106
67	15.410	30.82	46.419	508.530	1017.06	1531.825	2211	2211	2211	0.104	0.208	0.104
68	15.640	31.28	47.112	516.120	1032.24	1554.688	2244	2244	2244	0.102	0.205	0.103
69	15.870	31.74	47.805	523.710	1047.42	1577.551	2277	2277	2277	0.101	0.202	0.101
70	16.100	32.20	48.497	531.300	1062.6	1600.414	2310	2310	2310	0.100	0.199	0.100
71	16.330	32.66	49.190	538.890	1077.78	1623.277	2343	2343	2343	0.098	0.196	0.099
72	16.560	33.12	49.883	546.480	1092.96	1646.140	2376	2376	2376	0.097	0.194	0.097
73	16.790	33.58	50.576	554.070	1108.14	1669.003	2409	2409	2409	0.095	0.191	0.096
74	17.020	34.04	51.269	561.660	1123.32	1691.866	2442	2442	2442	0.094	0.188	0.095
75	17.250	34.50	51.962	569.250	1138.5	1714.730	2475	2475	2475	0.093	0.186	0.093

(1)   *Phase to Neutral impedance*
(2)   *Phase to Phase impedance*
(3)   *Phase impedance (line impedance)*

Table D1 – Minimum Fault Level & Maximum Source Impedance at Point of Common Coupling (PCC) by Equipment Rating

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 E1 – 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 B.

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

For example…


```
NODE 9991 CHARACTERISTICS
PSSC (Ph-n): 2.04 KA
PME Ze: 0.12 Ohms (0.10541 + j 0.05962 Ohms)
Source Impedance: 0.10572 + j 0.06211 Ohms
```

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

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

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

Design for acceptable harmonic distortion

Note: In accordance with BS EN/IEC 61000-3-12, when the above statement is made compliance with harmonic current limits assumes a minimum ratio of 3-phase fault level at the PCC, $S_{\text{sc PCC}}$, to the rated apparent power of the equipment, S_{equ}, of 3 x 33 = 99.

Step1

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

$I_{\text{equ}} = 45A$ (or $S_{\text{equ}} = 45A \times 230V = 10.35kVA$).

Step 2

Determine $Z_{\text{max harmonic 1-ph PCC}}$ from Table D1 of Appendix D:

$Z_{\text{max harmonic 1-ph PCC}} = 0.1549\,\Omega$.

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 B.

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

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

Step 4

Check if $Z_{source\ 1-ph\ PCC} \leq Z_{max\ harmonic\ 1-ph\ PCC}$. Here $Z_{source\ 1-ph\ PCC} = 0.0767\Omega$ and $Z_{max\ harmonic\ 1-ph\ PCC} = 0.1549\Omega$. Therefore, $Z_{source\ 1-ph\ PCC} < Z_{max\ harmonic\ 1-ph\ PCC}$.

In this case then the requirement is met. If $Z_{source\ 1-ph\ PCC} > Z_{max\ harmonic\ 1-ph\ PCC}$ then the network would need to be reinforced until $Z_{source\ 1-ph\ PCC} \leq Z_{max\ harmonic\ 1-ph\ PCC}$ 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 minimum fault current value, I_{fmin}:

$I_{fmin} = S_{sc}/(√3 \times 400V) = 1.1MVA/(√3 \times 400V) = 1588A$.

Step 2

As the proposed equipment is 3-phase, use WinDebut to check the 3-phase fault current 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 in accordance with Appendix B.

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

For example…


```
NODE 9991 CHARACTERISTICS
PSSC (3-Ph): 3.04 KA
PME Ze: 0.12 Ohms (0.10541 + j 0.05962 Ohms)
Source Impedance: 0.06048 + j 0.05559 Ohms
```

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

Derive the 3-phase fault current from $I_f = 400/(\sqrt{3} \times 0.08215\,\Omega) = 2811\text{A}$.

Note: this differs slightly from the *PSSC(3-ph)* value as *Source Impedance* in WinDebut uses the transformer impedance values from Engineering Recommendation P28.

Step 3

Check if $I_f \geq I_{fmin}$. Here $I_f = 2811\text{A}$ and $I_{fmin} = 1588\text{A}$. Therefore, $I_f > I_{fmin}$.

In this case then the requirement is met. If $I_f < I_{fmin}$ then the network would need to be reinforced until $I_f \geq I_{fmin}$ 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 minimum fault current value, I_{fmin}:

I_{fmin} = S_{sc}/($\sqrt{3}$ x 400V) = 0.858MVA/($\sqrt{3}$ x 400V) = 1238A.

Step 2

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

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

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

For example…

```
NODE 9991 CHARACTERISTICS
PSSC (Ph-n): 2.04 KA
PME Ze: 0.12 Ohms (0.10541 + j 0.05962 Ohms)
Source Impedance: 0.10572 + j 0.06211 Ohms
```

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

Derive the single-phase fault current from I_f = 230V/0.12261Ω = 1876A**.**

Note: this differs slightly from the *PSSC(1-ph)* value as *Source Impedance* uses the transformer impedance values from Engineering Recommendation P28.

Step 3

Check if $I_f \geq I_{fmin}$. Here I_f = 1876A and I_{fmin} = 1238A. Therefore, $I_f > I_{fmin}$.

In this case then the requirement is met. If $I_f < I_{fmin}$ then the network would need to be reinforced until $I_f \geq I_{fmin}$ 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   lowest   fault   level   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 BS EN/IEC 61000-3-12, 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, S_{equ}, of 33.

Step1

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

I_{equ} = 45A (or S_{equ} = √3 x 45 x 400V = 31.177kVA).

Step 2

Determine $Z_{max\ harmonic\ 3\text{-}ph\ PCC}$ from Table D1 of Appendix D:

$Z_{max\ harmonic\ 3\text{-}ph\ PCC}$ = 0.1555Ω.

Step 3

As the proposed equipment is 3-phase, use WinDebut to check the <u>3-phase</u> 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 B.

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

For example…

```
NODE 9991 CHARACTERISTICS
PSSC (3-Ph): 3.04 KA
PME Ze: 0.12 Ohms (0.10541 + j 0.05962 Ohms)
Source Impedance: 0.06048 + j 0.05559 Ohms
```

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

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 $Z_{max\ harmonic\ 3\text{-}ph\ PCC} = 0.1555\Omega$. 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 BS EN/IEC 61000-3-12, 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, S_{equ}, of 3 x 33 = 99.

Step1

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

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

Step 2

Determine $Z_{max\ harmonic\ 1\text{-}ph\ PCC}$ from Table D1 of Appendix D:

$Z_{max\ harmonic\ 1\text{-}ph\ PCC}$ = 0.3872Ω.

Step 3

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

```
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
```

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

Step 4

Check if $Z_{\text{source 1-ph PCC}} \leq Z_{\text{max harmonic 1-ph PCC}}$. Here $Z_{\text{source 1-ph PCC}} = 0.0767\Omega$ and $Z_{\text{max harmonic 1-ph PCC}} = 0.3872\Omega$. Therefore, $Z_{\text{source 1-ph PCC}} < Z_{\text{max harmonic 1-ph PCC}}$.

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

EXAMPLE PHASE-NEUTRAL SOURCE IMPEDANCE

LV Circuit Length (m)	Phase-Neutral Source Impedance (Ω)					
	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 F1 – Source Impedance by circuit length for a 25kVA 1-ph transformer

NOTE: Values in cells shown with grey shading exceed Z_{ref}. See Appendix G 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 F2– Source Impedance at 1-phase Transformer Terminals by Rating

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

G1.0   BACKGROUND

In line with the Distribution Code, POL:SD5/1 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 G1 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 G1 – Standards for control of voltage changes, voltage fluctuations and flicker for equipment to be connected to public LV networks

G1.1   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 G2. The values for Z_{ref} are shown in Table G3 and represent the source impedance at the <u>supply terminals</u>. 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 G2.

Parameter	Limit
Short-term flicker[4], P_{st}	1.0
Long-term flicker[5], P_{lt}	0.65
Relative voltage change d(t)	3.3% for more than 500ms
Relative steady-state voltage change[6], 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 G2 – 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 G3 – Reference Impedance, Z_{ref}, according to IEC 60725

G1.2 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.

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

[5] Long-term flicker severity is the flicker severity evaluated over a 2-hour period using successive P_{st} values.

[6] 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 <u>Point of Common Coupling</u> 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. Appendix D gives the complete set of calculated values for equipment rated at 16A through to 75A.

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.

G2.0   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.

G2.1   Flicker and Source Impedance

At present, we effectively state a phase-neutral source <u>impedance</u> of 0.35 Ω for new Protective Multiple Earth (PME) connections, which constitute the majority of new connections, by virtue of this being the same as the earth loop impedance for PME. We design to a <u>resistive</u> phase-neutral source impedance limit of 0.25 Ω in WinDebut for new; this applies to main and service so refers to the source impedance at the supply terminals. Equipment that conforms to BS EN 61000-3-3 and, therefore, can be unconditionally connected is checked with a reference impedance, Z_{ref}, of 0.4717 Ω = 0.4 + j0.25 Ω for single-phase equipment as per Table G3. However, from Table G2 it can be seen that this does allow flicker at the supply terminals to reach the annoying level (i.e. P_{st} =1.0). Thus, there may be some risk with multiple connections from the combined flicker. Furthermore, there may also be risk of P_{st} exceeding 1.0 at sites with source impedance exceeding Z_{ref}. Appendix F gives some examples.

G2.1.1 Flicker from Multiple Connections of BS EN 61000-3-3 Compliant Equipment

WinDebut has a phase-neutral source <u>resistance</u> limit of 0.20 Ω for the main without the service. This can be seen as the source resistance at the PCC and corresponds to an <u>impedance</u> of around 0.23 Ω. Thus, equipment which just passes BS EN 61000-3-3 for short-term flicker would produce a maximum P_{st} of around 0.23/0.4717 x 1.0 = 0.5 at the PCC of a network designed to the above limit. This flicker level is the same as is permitted by P28 Stage 2. Thus, this risk appears acceptable.

For existing networks, predating WinDebut, the phase-neutral source impedance at the PCC may be higher than 0.23 Ω. Examples include networks with small size transformers or long, small sized conductors – see Appendix F. 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:

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

However, high source impedances would tend to occur with small numbers of customers and so limiting the number of flicker sources on a given LV network. Furthermore, BS EN 61000-3-3 also has a long-term flicker limit of P_{lt} = 0.65 and this may tend to limit the P_{st} too. For example, for frequent switching P_{st} approaches P_{lt} and hence with a 0.512 Ω source impedance at the PCC the P_{st} would approach a maximum of 0.512/0.4717 x 0.65 = 0.71.

In conclusion, multiple connections of equipment compliant with BS EN 61000-3-3 are not expected to be problematic in the majority of cases.

G2.1.2 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.

G2.2   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. Appendix D tabulates the values. 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.

SUPERSEDED DOCUMENTATION

This document supersedes ST: SD6J dated November 2012 which has now been withdrawn.

RECORD OF COMMENT DURING CONSULTATION

No comments received.

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 $\leq$ 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 $\leq$ 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

APPENDIX K

KEY WORDS

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