



Report for Initial Review of ENA Engineering Recommendation P29

for
Energy Networks Association

Confidential to Client

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1. Executive Summary

Threepwood Consulting Limited has conducted an initial review of ENA Engineering Recommendation P29 Issue 1: 1990 *Planning limits for voltage unbalance in the United Kingdom* to determine the requirements for subsequent revision.

Since the document was last amended in 1990 modern National and International Standards for Electromagnetic Compatibility (EMC) have been published and ER P29 needs to be aligned, where appropriate, with the terminology, concepts and requirements in these Standards.

Much of the technical content of ER P29 is still relevant and no major errors were identified. The document appears to have served the industry well since it was published. However, the technical content needs to consider any changes resulting from unbalanced demand/generation in single-phase connections that are known to cause voltage unbalance issues.

This review has found that new rotating machines specified to modern Standards (i.e. BS EN 60034-1, BS EN 60034-12 and 60034-26), now give rated power output at only 1% unbalance (as opposed to the 2% mentioned in ER 29 Issue 1) and need to be de-rated for voltage unbalance above this. There is no evidence to suggest that other new technology is more susceptible to voltage unbalance compared to traditional equipment referenced in the current ER P29. The current limit of 2% measured over 1 minute is still constrained by preventing heating and damage to three-phase rotating electrical machines caused by out-of-balance currents. However, any revision of ER P29 will need to address the current anomalies in measurement time cycles and aggregation intervals for power quality measurements that exist between ER P29 and BS EN 61000-4-30; this has been recently addressed in the Grid Code requirements for voltage unbalance.

Feedback from Member Companies, via the ENA Power Quality and EMC Group (PQ&EMC Group), confirms that ER P29 remains technically relevant and there is support for a 'Working Group' revision - similar to those for revision of ER G5 and ER P28.

In common with similar ENA power quality related engineering documents (Engineering Recommendation G5 and Engineering Recommendation P28) that are Distribution Code (DCode) Annex 1 Qualifying Standards, this initial review recommends that a Working Group Review of the document is required under the governance of the Distribution Code Review Panel.

2. Introduction

The Energy Networks Association (ENA) has commissioned Threepwood Consulting Limited (Threepwood Consulting) to conduct an initial review of a number of engineering documents due for revision as part of the 2016 Programme. The purpose of this initial review is to determine the requirements for subsequent revision of the documents.

This report relates to the initial review of ENA Engineering Recommendation P29 Issue 1: 1990 *Planning limits for voltage unbalance in the United Kingdom* (subsequently referred to as ER P29).

The findings and recommendations from the initial review of this document are presented in this short form report.

3. Overview of Document

ER P29 was first published in 1990 and provides recommendations and limits for voltage unbalance in public distribution networks operating at 132 kV and below.

The scope of ER P29 applies to the technical evaluation for new loads proposed for connection to the distribution network, which may give rise to voltage unbalance; it does not set generalised network limits. The document implies, although does not explicitly state, that the scope of ER P29 only applies to customer installations. This will need to be clarified in any revision.

The document is very similar to the following ENA Engineering Recommendations that address other power quality aspects arising from the connection of potentially disturbing loads.

- ER G5 – Harmonics.
- ER P28 – Voltage fluctuations.

Both ER G5 and ER P28 are currently being revised under the governance of both the Grid Code Review Panel and Distribution Code Review Panel. It is believed that any revision of ER P29 would need to follow a similar approach to revision of these documents due to common aspects that run across all these documents.

4. Review of Technical References

4.1 General

Publication of ER P29 predated modern National and International Standards for Electromagnetic Compatibility (EMC). Consequently, there are few external documents referenced in ER P29. Any revised ER P29 will need to be aligned, where appropriate, with the terminology, concepts and requirements in current EMC Standards. Further detail is provided in Clause 4.2 [of this report].

4.2 Standards

4.2.1 International Standards

The following IEC Standards have been identified as being applicable to the revision of ER P29.

- PD IEC/TR 61000-3-13, *Electromagnetic compatibility (EMC): Limits - Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems.*
- PD/IEC/TR 61000-3-14, *Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems.*
- IEC 61000-4-27, *Electromagnetic compatibility (EMC): Part 4-27: Testing and measurement techniques; Unbalance, immunity test.*
- BS EN 61000-4-30, *Electromagnetic compatibility (EMC): Testing and measurement techniques - Power quality measurement methods.*

ER P29 references IEC Publication 146 in relation to immunity of rectifier and inverter (i.e. converter) equipment to voltage unbalance. This Standard has been withdrawn and superseded by the IEC 60146 series of Standards that address semiconductor converter requirements, including immunity requirements.

Given the particular sensitivity of three-phase machines to voltage unbalance it is recommended that related product Standards are reviewed to verify immunity to voltage unbalance has not reduced with new products and technology.

4.2.2 BSI Standards

In addition to the UK implementation of the IEC Standards referenced in Clause 4.2.1, the following BSI Standard has been identified as being applicable to the revision of ER P29.

- BS EN 50160, *Voltage characteristics of electricity supplied by public distribution systems*.

Clause 6 of this Standard is relevant as it specifies indicative operational limits for voltage imbalance in high voltage networks that are not expected to be exceeded for a specified percentage of time. Whilst ER P29 sets planning levels for connections, as opposed to operational voltage limits in BS EN 50160, revision of ER P29 should consider circumstances under which unbalances exceeding the general 2% limit could be acceptable (e.g. networks with a disproportionate of single-phase and two-phase connected loads, where 3% unbalance at supply terminals could occur).

Another key change concerns Standards for rotating machines standards (i.e. BS EN 60034-1, BS EN 60034-12 and 60034-26), where the immunity is no longer 2%. Motors governed by these Standards now give rated power output at only 1% unbalance and need to be de-rated for voltage unbalance above this. There is a consequence for customers who specify 3-phase motors without consideration of the voltage unbalance that typically occurs in the network, which typically may include unwanted disruption due to motor failure and/or motor thermal/unbalance protection operation. This similarly affects 3-phase generators. One Member Company has experienced a few cases where customers are unaware of the de-rating requirement and have suffered consequences particularly on rural networks.

4.3 CIGRÉ Documents

ER P29 does not currently reference any CIGRÉ publications. However, this review has identified the following CIGRÉ publications that are relevant to any revision.

- Working Group CIGRÉ C4.07 Power Quality Indices and Objectives, Final WG Report, January 2004, Rev. March 2004.
- Joint Working Group CIGRÉ/CIRED C4.103 Voltage Unbalance Survey.

4.4 ENA Engineering Documents

In addition to ER G5 and ER P28 (see Clause 3), ETR 116 is referenced a number of times in relation to voltage unbalance due to British Rail AC Traction Supplies and other associated technical aspects of voltage unbalance.

Any revision of ER P29 will need to consider reviewing the technical content of ETR 116 in light of current Standards and technology given the technical aspects of both documents are complementary. Indeed, the planning limits in ER P29 are derived from analysis in ETR 116 of the effects of voltage unbalance on three-phase motor loads.

As ER P24 references ETR 116, there may be some impact on ER P24. ER P24 is currently under revision and the Chair of the P24 Working Group has been made aware of this review and the possible impact on the unbalance voltage aspects in ER P24.

5. Legislation

ER P29 does not reference any statutory Regulations in relation to voltage unbalance or limits. Although The Electricity Safety, Quality and Continuity Regulations (ESQCR) 2002 (as amended) does not contain explicit requirements for voltage unbalance, Regulation 27 does place requirements on duty holders to maintain voltages, except in exceptional circumstances, within permitted variations from the declared voltage.

In addition, ESQCR Regulation 3 places general duties on generators, distributors, suppliers and meter operators to prevent danger, interference with or interruption of supply, so far as is reasonably practicable. With respect to preventing 'interference', Regulation 3 is relevant to the revision of ER P29.

Regulation 26 of the ESQCR is relevant to voltage unbalance so far as a distributor's recourse to issuing: notices to consumers; other distributors; or owners requiring them to take remedial action to prevent interference from their installation.

Whilst BS EN 50160 is referred to in the Distribution Code (DCode), compliance is not a DNO Licence Condition in respect of limiting voltage unbalance in the distribution network.

Voltage unbalance is not explicitly referenced in the Electromagnetic Compatibility (EMC) Regulations 2006 (as amended).

In summary, other than reference to ESQCR, no other legislation has been identified that is relevant to the revision of ER P29.

6. Review of Document Structure

Although the document is well structured, alignment with the new ENA Standards template and associated ENA Engineering Recommendation governing the rules for structure, drafting and presentation of ENA engineering documents (ER G0) will be required.

From experience of revising ER G5 and ER P28, it is likely that the structure of ER P29 will need to change significantly to reflect that of relevant International or National Standards, namely PD IEC/TR 61000-3-13, to enable efficient cross referencing of requirements.

7. Review of Technical Relevance

7.1 General

Key causes of voltage unbalance on Member Company distribution networks are: unbalanced demand/generation, single-phase distribution transformers, 2-wire 11 kV systems, 25 kV traction connections & phase-phase connected welders.

A significant change since ER P29 was published has been the increase in single-phase distributed generation connected to the distribution network, particularly at low voltage (LV). Research carried out to date¹ suggests that such connections are causing a rise in voltage unbalance issues, especially where voltage unbalance is more noticeable on the network and is preventing the connection of three phase Distributed Generation (DG).

¹ WPD IFI Project - Network Unbalance Source Detection by Optimum Monitoring Project.

An initial review of published literature does not suggest that the current limits for voltage unbalance are inadequate or require changing. The current limit of 2% measured over 1 minute is constrained to prevent heating and damage to three-phase rotating electrical machines and three-phase converter equipment caused by out-of-balance currents.

This review has found that new rotating machines specified to modern Standards (i.e. BS EN 60034-1, BS EN 60034-12 and 60034-26), now give rated power output at only 1% unbalance (as opposed to the 2% mentioned in ER 29) and need to be de-rated for voltage unbalance above this. There is no evidence to suggest that other new technology is more susceptible to voltage unbalance compared to traditional equipment referenced in the current ER P29. Electronic equipment such as computers can generally withstand voltage imbalances of between 2% and 2.5%.

The limits in Clause 4.3 of ER P29 are considered to be too open to different interpretation. For example: it is not clear whether the limits are maximum values not to be exceeded or mean values over a sample period. Similarly, although 1 minute is stated as the sample period for the 2% limit, no period is stated for the worst case sustained voltage unbalance at the point of common coupling. Due cognisance needs to be taken of the measurement techniques in IEC 61000-4-27, *Electromagnetic compatibility (EMC): Part 4-27: Testing and measurement techniques; Unbalance, immunity test* and BS EN 61000-4-30: *Electromagnetic compatibility (EMC): Testing and measurement techniques - Power quality measurement methods*.

The 1 minute period associated with the 2% limit is at odds with the measurement time intervals and measurement aggregation intervals in BS EN 61000-4-30 - being 10 cycle measurement time interval and 150 cycle and 10 minute aggregation intervals for 50 Hz power systems. The limits in the Voltage Unbalance Report² are based on the arithmetic mean of 10 cycle time interval measurements aggregated over 10 minutes. It should be noted that although BS EN 61000-4-30 specifies 10-minute and 2-hour time intervals, typically Class A instruments permit the time interval to be user defined and can be set to 1-minute intervals if so desired. Any revision of ER P29 will need to address the current anomalies and align with measurement time cycles and aggregation intervals for power quality measurements in BS EN 61000-4-30.

Clarity is also required as to whether the 2% value represents the limit for short time (< 1 minute) voltage unbalances, whereas the values of 1.3% (for systems with a nominal voltage below 33 kV) and 1% (for systems with a nominal voltage no greater than 132 kV) represent long time (sustained) voltage imbalance.

National Grid has recently carried out a review of voltage unbalance limits in the Grid Code and the contents of the associated Report² should form a key technical reference.

It is believed that improved guidance could be provided on the duration and frequency of occurrences that are permitted to exceed the limits in Clause 4.3.

7.2 Feedback from Member Companies

It is understood from the Working Group reviewing/revising ER P24 that the magnitude of voltage unbalance limits in the Addendum to P24, that apply to traction loads, have been reviewed and there is no case for changing the limits. However, it has been recommended that the limits refer to a 10 minute arithmetic mean value as opposed to a 1 minute value. This recommendation should be reviewed as interference of 2% over a 1 minute time interval does not equate to a 2% limit over a 10 minute interval.

² Review of Voltage Unbalance Limit in The GB Grid Code CC.6.1.5 (b), F Ghassemi and M Perry, October 2014, National Grid.

The 1-minute interval reflects machine withstand and unbalance/thermal protection relay characteristics. Extending the time interval may increase the risk of damage/nuisance tripping.

ER P29 has been confirmed as a high priority review/revision of those ENA engineering documents, which are Annex 1 Qualifying Standards under the DCode. Given there is no other suitable technical reference then the document remains relevant.

Nominated ENA Standard Representatives from Member Companies were invited to provide feedback on the technical relevance of the document, in particular, what changes, if any, are required to meet their business processes and applications currently and in the medium term (i.e. 1 - 5 years). The responses from the PQ&EMC Group are captured in Appendix B. A summary is provided below.

On this basis, ER P29 is deemed to be a technically relevant document and requires a Working Group review/revision to ensure the document aligns with EMC Standards.

7.3 Low Carbon Networks Projects

A document search was carried out on the ENA Smarter Networks Portal, which identified a number IFI and Low Carbon Network Fund (LCNF) projects related to voltage unbalance. These are listed below.

- 'Understanding Networks with High Penetrations of Distributed Generation and other Low Carbon Technologies', IFI Project, Western Power Distribution.
- 'Network Unbalance Source Detection by Optimum Monitoring', IFI Project, Western Power Distribution.

The majority of projects relate to the impact of distributed generation and other low carbon technologies³ on distribution networks, in particular power quality aspects. The 'Network Unbalance Source Detection by Optimum Monitoring' IFI Project by Western Power Distribution will need to be reviewed in more detail although it is believed the project is primarily focussed on the development/application of modern monitors for detecting the source of the voltage unbalance and may be of little relevance based on a limited number of measurement points.

8. Conclusions

The scope of ER P29 applies to the technical evaluation for new loads (customer installations) proposed for connection to the distribution network; there is no reason for the scope to fundamentally change.

ER P29 predates modern National and International Standards for Electromagnetic Compatibility (EMC) and any revised ER P29 will need to be aligned, where appropriate, with the terminology, concepts and requirements in current EMC Standards.

This review has found that new rotating machines specified to modern Standards (i.e. BS EN 60034-1, BS EN 60034-12 and 60034-26), now give rated power output at only 1% unbalance (as opposed to the 2% mentioned in ER P29) and need to be de-rated for voltage unbalance above this. There is no evidence to suggest that other new technology is more susceptible to voltage unbalance compared to traditional equipment referenced in the current ER P29.

³ Understanding Networks with High Penetrations of Distributed Generation and other Low Carbon Technologies - Western Power Distribution.

The existing voltage unbalance limit of 2% in ER P29 that applies to short periods was found to be consistent with the range of voltage unbalance permitted in BS EN 50160 for voltages of 150 kV and below, noting that there is a difference between the planning levels in ER P29 and operational voltage limits in BS EN 50160.

Feedback from the Working Group reviewing/revising ER P24 indicates that the magnitude of voltage unbalance limits for traction loads remain satisfactory and there is no case for changing the limits other than referring the limits to a 10 minute arithmetic mean value as opposed to a 1 minute value.

Other than referencing relevant requirements of ESQCR, in particular Regulation 27, no other legislation has been identified that is relevant to the revision of ER P29.

Although the document is well structured, alignment with the new ENA Standards template and associated ENA Engineering Recommendation governing the rules for structure, drafting and presentation of ENA engineering documents (ER G0) is required.

Much of the technical content of ER P29 is still relevant and no major errors were identified. The document appears to have served the industry well since it was published. However, the technical content needs to consider any changes resulting from the increase in single-phase DG connections that are known to cause voltage unbalance issues.

Nothing in this initial review suggests that the existing limits for voltage unbalance are inadequate or require change. The current limit of 2% measured over 1 minute is still constrained to prevent heating and damage to three-phase rotating electrical machines and three-phase converter equipment caused by out-of-balance currents. However, any revision of ER P29 will need to address the current anomalies in measurement time cycles and aggregation intervals for power quality measurements that exist between ER P29 and BS EN 61000-4-30.

In summary, ER P29 is still deemed to be a technically relevant document that requires detailed review/revision to ensure the document aligns with latest EMC Standards.

9. Recommendations

The main recommendation is that ER P29 is subject to “Working Group Revision”, on account of the similarities with the revision of ER G5 and ER P28. Any revision of ER P29 should follow a Working Group approach under the governance of the DCRP similar to that of ER G5 and ER P28 - due to common aspects that run across these documents and given its status as a DCode Annex 1 Qualifying Standard.

The main focus for the revision of ER P29 should be alignment, where appropriate, with the terminology, concepts and requirements in current EMC Standards. In addition, the revision should address the other technical requirements/comments highlighted in this report.

The Power Quality and EMC Co-ordination Group (PQ&EMC Group) should be invited to participate in and comment on the draft revisions of ER P29.

Any revision of ER P29 should consider reviewing the technical content of ETR 116 in light of current Standards and technology and given the technical aspects of both ER P29 and ETR 116 are complementary.

The recent review of voltage unbalance limits in the Grid Code and the contents of the associated Voltage Unbalance Report published by National Grid should form a key technical reference.

It is recommended that revision of ER P29 should follow completion of the revision of ER G5 and ER P28 given that the people who would sit on the ER P29 Working Group may well be the same as those currently involved with the revision of ER G5 and ER P28. This approach would allow learning points on common aspects from the revision of ER G5 and ER P28 to be incorporated in ER P29.



Appendix A: Commentary on References

Energy Networks Association Publications

Current Reference	Status	Revision	Comments
ER G5/3 <i>Limits for Harmonics in the UK Electricity Supply System</i>	Superseded, Withdrawn	N/A	ER G5/4 <i>Planning Levels for harmonic Voltage Distortion and the Connection of Non-Linear Equipment to Transmission Systems and Distribution Networks in the United Kingdom</i> is currently under review.
ER P24 <i>AC Traction Supplies to British Rail</i>	Current Under Review	Issue 1 1984	Currently under review by the ENA P24 Working Group.
ER P28 <i>Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom</i>	Current Under Review	Issue 1 1989	Currently under review by the ER P28 Joint GCRP & DCRP Working Group.
ETR 116 <i>Report on Voltage Unbalance due to British Rail AC Traction Supplies</i>	Current	Issue 1 1989	ETR 116 <i>Report on voltage unbalance due to British Rail AC traction supplies</i> . Suggest recommended for review by ENA P24 Working Group in parallel with ER P29.

No other ENA Engineering Documents have been identified as being relevant to the revision of ER P29.

International & National Standards

Current Reference	Status	Revision	Comments
IEC Publication 146 <i>Semi-conductor Converters</i>	Superseded, Withdrawn	N/A	Replaced by: BS EN 60146-1 <i>Semiconductor converters. General requirements and line commutated converters</i> .

The following Standards may be relevant to the revision of ER P29.

Proposed New Reference	Status	Revision	Comments
BS EN 60034-1 <i>Rotating electrical machines. Rating and performance</i>	Current, Work in hand	2010	Defines performance requirements for rotating electrical machines and immunity to voltage unbalance.

Proposed New Reference	Status	Revision	Comments
BS EN 60034-26 <i>Rotating electrical machines. Effects of unbalanced voltages on the performance of three-phase cage induction motors</i>	Current	2006	Defines performance requirements for rotating electrical machines and immunity to voltage unbalance.
BS EN 60146-1 <i>Semiconductor converters. General requirements and line commutated converters</i>	Current	2010	Several parts of this suite of Standards to be consulted for requirements for voltage imbalance immunity of converters.
BS EN 50160: 2010+A1:2015 <i>Voltage characteristics of electricity supplied by public distribution systems</i>	Current	2010 Amendment 2015	General guidance in relation to limits for voltage unbalance for LV and HV systems.
PD/IEC TR 61000-3-14 <i>Electromagnetic compatibility (EMC). Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems</i>	Current	2011	May also be relevant as it concerns emission limits for voltage unbalance.

Legislation

There are no legislation references in ER P29. The following legislation may be relevant to the revision of ER P29.

Additional Reference	Status	Revision	Comments
The Electricity Safety, Quality and Continuity Regulations (ESQCR) 2002 (as amended)	Current	2002 (as amended)	See Regulation 27 for implicit reference to keep supply voltages within permitted variations.

Appendix B: Technical Relevance

Summary of Feedback from ENA Member Company Standard Representatives

		SPN	NIE	NPGRID	NGRID	SSE	UKPN	WPD	ENW	COMMENTS
Q1	Do you use this engineering document to support your current business processes / practices?	NO RESPONSE	NO RESPONSE	NO RESPONSE	NO	NO RESPONSE	IN FULL	IN FULL	SEE COMMENTS	NGRID: National Grid is required to comply with the GB Grid Code. Internal guidance and processes are used to ensure compliance.
Q2	Does this engineering document meet your engineering requirements in its current format?	NO RESPONSE	NO RESPONSE	NO RESPONSE	NO	NO RESPONSE	IN FULL	IN FULL	SEE COMMENTS	NGRID: This document probably was one of the first in the field of PQ on unbalance. However, it requires revision in a number of areas. In its present form, it is not very relevant to transmission networks.
Q3	Are there any significant errors or omissions in this engineering document that you believe should be addressed in the next revision?	NO RESPONSE	NO RESPONSE	NO RESPONSE	NO	NO RESPONSE	NO	YES	SEE COMMENTS	
Q4	What is the extent of review you believe is required for the revision of this engineering document?	NO RESPONSE	NO RESPONSE	NO RESPONSE	WORKING GROUP REVIEW	NO RESPONSE	WORKING GROUP REVIEW	MAJOR REVISION WORKING GROUP REVIEW	SEE COMMENTS	UKPN: Currently we don't have any issues with the document but agree a review is due. WPD: We are supportive of a WG being set up to review and update EREC P29, like with G5 and P28. ENW: Happy to support the decision of majority of DNOs. NGRID: It is important to align the document with IEC and international standards.

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