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ER P28 Joint GCRP & DCRP Working Group

Phase 2 Review Report for ER P28

Issue 1 2016

Recommendations for Revision

PUBLISHING AND COPYRIGHT INFORMATION

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Contents

Introduction

P28 deals with the assessment of voltage fluctuations and associated light flicker produced by potentially disturbing equipment. P28 is referenced in both the Grid and Distribution Codes of Great Britain and is an 'industry standard' in this technical area.

As the current P28 was published in 1989 and the factors affecting development of electricity networks and equipment connected to them have since changed significantly, the Grid Code Review Panel (GCRP) and the Distribution Code Review Panel (DCRP) of Great Britain (GB) have sanctioned the review of P28 by a joint Working Group of various key stakeholders and third parties that will be materially affected by any revision of the document.

Since P28 was published, when traditional industrial loads were the main consideration for flicker, there has been a shift towards newer technologies (both load and generation) which incorporate power electronic switching devices, including inverters that are capable of flicker emission. These types of new technologies are capable of being connected as multiple installations and the aggregated impact on flicker limits needs to be addressed.

Threepwood Consulting Ltd (TCL) has been appointed by ENA to provide project management and secretariat services for the joint Working Group on behalf of the GCRP and DCRP. As part of this appointment, TCL is required to prepare a Report from the Phase 2 Review Phase [this document] on behalf of the ER P28 Joint GCRP & DCRP Working Group (subsequently referred to as the 'P28 WG') describing the recommendations for revision of P28 to be carried in the next phase [Phase 3].

The following documents prepared by the P28 WG provide the terms of reference, requirements and details concerning the review of P28. As such, this information is not replicated in this Report.

- Terms of Reference of the ER P28 Joint GCRP & DCRP Working Group [1].
- Project Initiation Document for ER P28 [2].

The Minutes of P28 WG meetings, which summarise the key issues and decisions have been used to compile this report. The Minutes of meetings of the P28 WG can be accessed at http://www.dcode.org.uk/dcrp-er-p28-working-group.html.

1 Purpose of this document

This document sets out recommendations to the joint GCRP and DCRP on the nature and extent of changes proposed for revision of P28. The recommendations are a summary of the initial outputs from the P28 WG following completion of the Phase 2 Review Phase.

The intention is that this document will guide the Phase 3 Revision Phase of the project.

2 Purpose and technical intent of P28 Issue 2

The revised issue of P28 (P28 Issue 2) will remain a 'customer facing' document, which is applicable to the connection of customer load/equipment only. In this context P28 Issue 2 will specify planning and emission limits for voltage fluctuations associated with the connection of customer load/equipment.

Overarching requirements with respect to voltage fluctuation will be retained within the Grid Code and Distribution Code[1]. Where possible and within scope, P28 Issue 2 will provide harmonised requirements/limits for voltage fluctuations currently in the Grid Code and/or Distribution Code.

P28 Issue 2 will consider voltage fluctuation requirements in DPC4 of the Distribution Code.

The intention is that P28 Issue 2 will contain concise recommendations and guidance. If necessary, any background and explanatory information will be contained within a new ENA Engineering Report (ERep) associated with P28 Issue 2. P28 Issue 2 will focus on planning limits and standard procedures for assessing the acceptability of voltage fluctuations.

P28 Issue 2 will include a clear statement of its purpose.

3 Terms & Abbreviations

ACE
Association of Chief Engineers [Legacy Electricity Supply Industry Standard]

BS EN
European Normalised British Standard

DCode
Distribution Code of Great Britain

DCRP
Distribution Code Review Panel of Great Britain

DG
Distributed Generation

EHV
Extra High Voltage [U_n > 230 kV]

EMC
Electromagnetic Compatibility

ENA
Energy Networks Association

EREC
Engineering Recommendation [ENA engineering document]

NOTE: Historically, the identifier ‘ER’ was used in relation to Engineering Recommendations. The terms ‘ER’ and ‘EREC’ are interchangeable for the purposes of this Report.

ERep
Engineering Report [ENA engineering document]

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[1] NOTE: Within this context the Distribution Code could include Compatibility Levels that network operators will be expected to meet. These Compatibility Levels (if specified) should be based on 95% probability levels for the entire system and would need to be higher than the Planning Levels defined in P28.

ETR
Engineering Technical Report [ENA engineering document]

EV
Electric Vehicle

GCRP
Grid Code Review Panel of Great Britain

HV
High Voltage [35 kV < U_n ≤ 230 kV]

IEC
International Electrotechnical Commission

IEEE
Institute of Electrical and Electronic Engineers

LCT
Low Carbon Technologies

LV
Low Voltage [U_n ≤ 1 kV]

MV
Medium Voltage [1 kV < U_n ≤ 35 kV]

PCC
Point of Common Coupling

POC
Point of Connection

POE
Point of Evaluation

PV
Photovoltaic

NOTE: Sometime referred to as ‘solar’.

RVC
Rapid voltage change

SSEG
Small Scale Embedded Generation

SQSS
Security and Quality of Supply Standard

TCL
Threepwood Consulting Ltd

TS
Technical Specification [ENA engineering document]

WG
Working Group

WTG
Wind Turbine Generator

4 Standards

4.1 General

P28 will be revised to align with requirements in the IEC 61000 series of Standards for power quality and EMC, wherever possible and appropriate to the UK network operator and user context.

Equivalent BS EN Standards to the IEC 61000 series of Standards will be referenced, where they are published.

References to Standards within the current P28 will be updated according to Annex A. Whilst relevant clauses in Standards will be cross-referenced, P28 will be revised so that P28 Issue 2 can continue to be read as a 'standalone' document.

BS 5406 referenced for Stage 1 assessments has been withdrawn. Subject to a detailed review, it is proposed that Stage 1 assessments will reference test requirements in BS EN 61000-3-3 for household appliances and similar LV electrical equipment with a rated input current less than or equal to 16 A per phase and test requirements in BS EN 61000-3-11, as applicable to unconditional connection[2]. It is proposed to apply Stage 1 assessment criteria to SSEG equipment that complies with test requirements in BS EN 61000-3-3 (see 4.5 for multiple installations).

Definitions in P28 Issue 2 will be aligned with those in the relevant BS EN or IEC Standards as well as other relevant 'Industry Standards'.[3]

4.2 IEC & Equivalent BS EN Standards

Since P28 was published a significant body of work has been collected in IEC Standards and equivalent BS EN Standards that cover similar topics. The following current IEC 61000 Standards will be adopted/referenced in P28 Issue 2, wherever possible and appropriate.

- IEC 61000-3-3, *Electromagnetic compatibility (EMC). Limits. 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*
- PD IEC/TR 61000-3-7, *Electromagnetic compatibility (EMC). Limits. Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems*

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[2] Equipment tested under BS EN 61000-3-11 but which meets the technical requirements of BS EN 61000-3-3 may be connected via the unconditional connection route.

[3] 'Industry Standards' is a generic term to describe the various Codes, ENA Engineering Documents etc. published on behalf of network operators collectively.

- IEC 61000-3-11, *Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems. Equipment with rated voltage current ≤ 75 A and subject to conditional connection*
- PD IEC/TR 61000-3-14, *Electromagnetic compatibility (EMC). Limits. Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems*
- IEC 61000-4-15, *Electromagnetic compatibility (EMC). Testing and measurement techniques. Flickermeter. Functional and design specifications*
- IEC 61000-6-3, *Electromagnetic compatibility (EMC). Generic standards. Emission standard for residential, commercial and light-industrial environments*
- IEC 61000-6-4, *Electromagnetic compatibility (EMC). Generic standards. Emission standard for industrial environments*
- IEC 61400-21, *Wind turbines. Measurement and assessment of power quality characteristics of grid connected wind turbines*

Subtle differences in requirements between certain IEC Standards and equivalent BS EN Standards will need to be identified and addressed.

Acknowledgement will be given to the fact that manufacturers of equipment have a choice over the intended environment for their products in terms of EC conformity, where no dedicated product or product family EMC emission standard exists. The alternative 'Technical File' path that exists for manufacturers to demonstrate conformance to the EMC Directive without showing conformance to harmonised standards will also be acknowledged.

P28 Issue 2 will adopt BS EN 61000-4-15 in relation to flickermeters and BS EN 60868 for evaluation of flicker severity.

PD IEC/TR 61000-3-7 is proposed for review but will not be complete until the end of 2018. This is outside the timescales for revision of P28. A watching brief on the IEC work will be maintained during the revision of P28 to ensure any relevant changes can be considered and included in P28 Issue 2.

P28 Issue 2 will specifically reference and address any relevant voltage fluctuation requirements or limits stated in applicable European Network Codes, i.e. the Network Code on Requirements for Grid Connection Applicable to all Generators (RfG) and Network Code on Demand Connection (DCC).

4.3 ENA engineering documents

References to ENA Engineering Technical Report (ETR) 117 will be removed as this document was not published and any information and background associated with P28 Issue 2 will now be contained within a new ENA ERep, where necessary.

Appendix D of P28 is obsolete and will be removed from the revision. Libraries of impedance values for network components are now typically available and included in computer software models. As such all references to ENA Technical Specifications (TS) for network assets will no longer be referenced from a normative aspect.

ACE reports are now legacy documents and will no longer be referenced in P28 Issue 2. Any relevant requirements not addressed in current Standards, such as formulae for specific welder types, will be directly incorporated within P28 Issue 2. P28 Issue 2 will be updated with recommendations for connection of modern welder types not addressed anywhere else.

No other ENA engineering documents have been identified that will need to change as a result of the proposed revision of P28, with the exception of ENA EREC P5 [3]. Reference will be made to ENA EREC G83 [4] for SSEG, domestic heat pumps[4], WTG and PV connected directly to the LV network (see 8.1).

4.4 IEEE Standards

Associated IEEE Standards are considered to be of limited value given that they are being aligned to IEC Standards. Consequently, there is no intention to reference these in P28 Issue 2[5].

4.5 Multiple equipment installations[6]

BS EN 61000-3-3 does not currently provide limits for voltage fluctuations associated with multiple equipment installations. Whilst the terms 'Z_{sys3}' and 'Z_{sys4}' were introduced in BS EN 61000-3-11 to address the cumulative effect of multiple items of similar equipment installed in different installations the Standard acknowledges that issue may require more consideration. The review has not identified issues with planning limits being exceeded, where multiple equipment installations are installed on the same LV network providing individual equipment complies with limits in BS EN 61000-3-3 or BS EN 61000-3-11 and providing they are under independent control. Notwithstanding, the basis of the P_{st} limit for Stage 2 assessment, the number of connections, thought to be 8, for a P_{st} limit - 1, will be evaluated in light of multiple equipment installations. New recommendations for the value of the exponent 'm'[7], described in P28 Issue 1 and used to evaluate the combined effect of multiple sources of flicker, will be determined where there may be a high coincidence of voltage changes for high penetration of disturbing loads. Any requirements for multiple equipment installations being considered by CENELEC for EN 61000-3-11 will be included in P28 Issue 2.

5 Limits

5.1 General

P28 Issue 2 will differentiate between planning limits for flicker severity and rapid voltage changes (RVCs). New recommendations for assessment and limits for RVCs (envelope of durations and magnitudes) will be separate from flicker assessment and limits.

Due cognisance will be taken of the recently approved revision of Grid Code limits on RVCs, which occur after planned transmission and transmission user operations (see GC0076).

The definition for RVC will follow IEC/BS EN Standards and will include any voltage changes (regardless of source) that occur within 2 seconds.

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4 Although EREC G83 does not directly reference 'heat pumps' the associated Distributed Generation Connection Guide for connecting generation under G83-1-1 Stage 1 does reference heat pumps (thermal) as distinct from micro CHP.

5 The trend has been for IEEE Standards to adopt requirements of IEC Standards.

6 This is intended to cover multiple items of similar high power equipment installed in different installations.

7 The value of 'm' represents the degree of coincidence of voltage changes for the main sources of disturbances in the general formula to derive the resultant P_{st} from several disturbance sources.

Although flicker severity values and voltage changes will continue to be evaluated at the point of common coupling (PCC), P28 Issue 2 will clarify the terms and concept of point of evaluation (POE) and point of connection (POC). This will consider the appropriateness of applying related definitions used in the Grid Code, which are modified versions of those in published Standards.

Clarification will be provided on how calculations of flicker severity (P_{st}) should be approached regardless of any software being used. The appropriateness of referencing the simple method of calculating P_{st} in BS EN 61000-3-3, without having to resort to the memory-time techniques in P28 Issue 1, will be considered.

Clear definitions of normal operating conditions, which occur frequently, and conditions under credible outage conditions[8] will be provided for the purpose of applying limits. Due cognisance will be given to the faults or combination of faults that are to be planned for under system security standard Engineering Recommendation P2 for distribution networks and the NETS SQSS for transmission systems. Planning limits in P28 Issue 2 will not apply to abnormal conditions, which will need to be defined in P28 Issue 2.

P28 Issue 2 will align with the concept and definitions in IEC/BS EN Standards of Planning, Compatibility and Emission Levels [see PD IEC/TR 61000-3-7], wherever possible and appropriate.

5.2 Voltage change

Limits for voltage change (including dips and swells) will be provided for transient and steady state conditions, which will be defined in P28 Issue 2. In this context 'transient' relates to RVC and specifically the window for setting RVC V_{max} limits. A probabilistic approach will be adopted, where different limits are specified for different expected number occurrences over a particular period of time. This will exclude voltage changes due to faults on the network as opposed to faults on the customer network. A probabilistic approach for setting limits is appropriate given it is consistent with the assessment procedure for evaluation against emission levels and planning levels in EMC standards (see 4.2) and it is not unduly pessimistic – striking an appropriate balance between the small risk of levels being exceeded and the cost, time and trouble required to mitigate the risk.

This will result in a relaxation of the 3% voltage step change limit in the current P28 for 'infrequent' occurrences and more clearly specified revised limits. The scope of voltage fluctuation will extend to routine disconnection as well as connection of customer loads/equipment.

Common recommendations for the categorisation of expected number of occurrences will be provided, e.g. less than once per year etc. This will clarify what is considered to be a 'frequent' or 'infrequent' occurrence, which would otherwise be subjective. G59 protection trips will be considered as a normal switching operation. A clear distinction will be drawn between frequent and infrequent occurrences and different limits for step voltage changes will be specified taking into consideration: normal operational events, normal switching events and emergency switching events.

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[8] Clause 3.18 of BS EN 61000-3-7 and its associated NOTE defines 'normal operating conditions', which includes faults or a combination of faults that are planned for under the system security standard.

Limits for RVC will be introduced given they are classified as voltage fluctuations and limits are set in the Grid Code and will be based on achieving compatibility with user equipment immunity levels and voltage limits for sensitive electronic equipment, e.g. compatibility with the ITIC curve. Any latest laboratory tests, the impact on equipment immunity, network operator protection settings and visual impact will need to be considered. Different planning levels for different systems and operating voltages will be considered, where specific values are set as opposed to ranges of values in Table 6 of IEC PD/TR 61000-3-7. P28 Issue 2 will include appropriate severity indices for RVC, if considered to be appropriate.

Recommendations relating to voltage change limits for energisation of customer transformers (transformer magnetising inrush) and frequency of occurrence will be included in P28 Issue 2 with other RVC considerations. This will include any impact on modelling RVC associated with different types and designs of transformers. A probabilistic approach will be adopted with respect to point-on-wave energisation of transformers and remanence to avoid unduly pessimistic results. An assessment of the potential risk will need to be carried out. An absolute maximum voltage dip not to be exceeded and a % probability of exceedance will be specified given the current deterministic approach may be unnecessarily restrictive and costly. Guidance on transformer remanence to be assumed for P28 Issue 2 studies will be provided, which will consider recommendations from relevant CIGRE reports and transformer manufacturers, where it can be substantiated.

The voltage fluctuation aspects of DPC4 in the DCode, in particular those in DPC4.2.3.2, will be reviewed. Recommendations in P28 Issue 2 will be either aligned with the DCode or a modification to the DCode will be proposed to ensure alignment with P28 Issue 2.

The application of transfer coefficients for assessing the attenuation of voltage change from higher to lower levels will be addressed. P28 Issue 2 will conclude whether flicker contributions from lower to higher voltage levels can be neglected given the significant attenuation that takes place.

Voltage fluctuations caused by customer on-load tapchangers will be explicitly within the scope of P28 Issue 2 and the requirement for such voltage fluctuations to comply with voltage change limits.

P28 Issue 2 will provide guidance on the use of impedances for RVC studies (see 5.2), which are appropriate to the time period being studied.

Voltage change limits will apply to circumstances that result in a voltage increase such as tripping of loads. Normal / abnormal circumstances which should be considered or disregarded will be stated in P28 Issue 2.

5.3 Flicker

It is proposed to define different P_{st} limits for different voltage levels similar to the principle in the current issue of P28 and PD/IEC/TR 61000-3-7.

Further consideration is required as to whether Stage 1 simplified assessment should be extended to connection of HV users (particularly where demand is small compared to short-circuit level).

The WG agreed there was scope to explore whether measured values of P_{st} are regularly exceeding $P_{st} = 1$ and whether P_{st} planning levels at MV and HV should be increased. There was a consensus to increase planning levels at HV/EHV.

6 Evaluation of background levels

To date the review has not identified regular occurrences of voltage complaints or flicker headroom being breached under the current P28 Stage 2 assessment method, which does not require existing background levels of flicker severity to be measured. However, the validity for the Stage 2 limit of $P_{st} \leq 0.5$ will be checked, in particular for wind farm connections and similar connections, where co-incident voltage changes may exist.

P28 Stage 3 assessments requiring background levels of P_{st} to be measured are infrequent. Notwithstanding this, P28 Issue 2 will provide improved guidance on measurement and evaluation of background levels.

- Consideration will be given to recommending a typical measurement period for determining background levels of P_{st} (e.g. one week as sub-clause 4.4 in PD/IEC/TR 61000-3-7). Shorter measurement periods will be allowed providing this is representative of expected operation of the equipment being assessed over one week
- Consideration will be given to recommending a probabilistic approach for determining the background level to be used based on the samples of P_{st} levels measured over the measurement period (e.g. 95^{th} percentile)

The method of subtracting background levels of P_{st} from measured levels of P_{st} with disturbing equipment connected will follow the recommended summation law in the current P28 and PD/IEC/TR 61000-3-7.

A background level (i.e. $P_{st} < 0.35$) will be considered negligible for simplified assessment, in accordance with PD/IEC/TR 61000-3-7.

It is proposed that typical background levels of P_{st} based on actual measurements will be recommended for different voltage levels and networks based on available measurements and data provided by network operators. It is proposed that these levels will be used in the absence of data. This may be the case for connection of new substations/networks, where some data may not be available in these situations.

7 ‘First-come, first-served’ versus allocation of rights

There was no evidence that the current ‘first-come, first-served’ approach has resulted in any particular problems for stakeholders, e.g. voltage complaints, flicker headroom being used up. Notwithstanding, this approach may no longer be appropriate as it does not align with modern approaches to the proportional allocation of rights approach in IEC Standards and in the revision of EREC G5 for Harmonics.

The WG will investigate a potentially simpler and fairer approach for allocating flicker headroom for Stage 3 assessment than that described in PD/IEC/TR 61000-3-7.

The pros and cons for maintaining the status quo versus a change in approach will be considered as any change will need to be justified and supported by evidence. In particular, the commercial implications on network operators of any change in approach will need to be assessed as this would impact on current charging methodologies.

P28 Issue 2 will need to take into account generation as well as demand and consider a practical parameter for apportioning flicker[9]. The proposed new approach will take into account transfer coefficients and background levels (either measured values or typical values) at remote nodes. It is proposed that the recommended flicker apportionment method will be tested for a number of distribution network examples and validated by actual measurements. The new approach should include recommendations to identify the source of high background levels. As part of the evaluation of this proposal, it will be necessary at an early stage to carry out a more robust investigation of the technical, commercial and regulatory impact/consequences of such a change to the allocation of rights.

Further work will be carried out to confirm that the Stage 2 assessment methodology and assumptions for the P_{st} limit ≤ 0.5 is still valid for networks with greater number of DG connections. This will consider results of studies from the Smart Grid Forum WS7.

Similarly, the work will investigate whether the Stage 2 assessment method is still valid and does not introduce unacceptable risk of nuisance flicker levels.

P28 Issue 2 will provide guidance on how competing connection applications should be dealt with and how future changes to customers' connections, e.g. reduced demand, should impact on their right to produce voltage fluctuations and flicker.

The P28 WG has recommended that any change in method should not be applied retrospectively to existing user allocations as this could be difficult to administer and unfairly penalise those users that were connected under the previous P28 methodology. However, a method for determining existing user allocation will need further thought and consideration. The impact on new users is not believed to be significant given the limited number of Stage 3 assessments currently being carried out. Compatibility will need to be ensured with relevant conditions in the DCode and Electricity Safety, Quality and Continuity Regulations, which may be retrospective.

8 Other technical issues

8.1 New technologies

8.1.1 General

P28 Issue 2 will cover recommendations for voltage fluctuations with the following new equipment being connected to the network.

- Heat pumps
- Electric vehicles
- Wind turbine generators (WTG)
- Photovoltaic (PV) solar installations
- Energy storage
- New types of welder (e.g. single-phase AC/DC welders)

P28 Issue 2 will consider Stage 1 assessment requirements for new types of equipment, connected directly to the LV network with reference to requirements in EREC G83 [4].

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[9] An alternative parameter, such as fault level, may be considered as opposed to system capacity based allocation [Annex C of PD IEC/TR 61000-3-7].

Any assumptions about conditions that affect new equipment will be covered.

The review did not find any particular evidence that similar disturbing equipment, e.g. heat pumps, in multiple installations connected to the same LV network has resulted in network planning limits being exceeded - providing that individual equipment conforms to BS EN 61000-3-3 or BS EN 61000-3-11, the actual impedance at the supply terminals of customer equipment does not exceed the test (reference) impedance and the equipment is controlled independently. This aligns with conclusions from the recent revision of BS EN 61000-3-11. However, caution needs to be exercised where voltage fluctuations may arise when equipment and energy storage devices interact together or where multiple installations may be controlled dependently (e.g. Demand Side Management Schemes[10]). Guidance concerning the frequency of switching may be required for multiple installations under certain network conditions. P28 Issue 2 will consider the impact of multiple equipment installations that may be controlled dependently.

8.1.2 Heat pumps

P28 Issue 2 will consider unconditional connection of smaller heat pumps that conform to voltage fluctuation and flicker limits in BS EN 61000-3-3.

As part of the review of Stage 2 assessment, consideration will be given to modelling the connection of multiple heat pump installations to draw out any particular recommendations for conditional connection of such equipment to assist developers.

P28 Issue 2 will highlight that heat pumps equipped with ‘soft start’ technology or other technology that reduces the magnitude of inrush currents during motor starting will mitigate against voltage complaints, particularly in rural networks where the source impedance is high.

8.1.3 Electric vehicles (EV)

P28 Issue 2 will not provide special considerations for EV chargers except to confirm that they must conform to limits in BS EN 61000-3-3 or BS EN 61000-3-11 and that the actual impedance at the supply terminals of customer equipment does not exceed the test (reference) impedance. P28 Issue 2 will confirm the following interpretation of ‘conditional’ and ‘unconditional’ connection in both the above standards.

“IEC 61000-3-3 is applicable to electrical and electronic equipment having an input current equal to or less than 16 A per phase, intended to be connected to public low-voltage distribution systems of between 220 V and 250 V line to neutral at 50 Hz, and not subject to conditional connection. Equipment which does not comply with the limits of this part of IEC 61000-3-3 when tested with the reference impedance Zref and which therefore cannot be declared compliant with IEC 61000-3-3 may be retested or evaluated to show conformity with IEC 61000-3-11. IEC 61000-3-11 is applicable to electrical and electronic equipment with rated current < 75 A but is primarily applicable to electrical and electronic equipment having a rated input current from 16 A up to and including 75 A and is subject to a conditional connection.

[10] DSM schemes could range from prescriptive arrangements to turn demand on/off to sending signals for customers to behave in a common way via tariffs.

It should be noted that equipment tested under IEC 61000-3-11 can connect via the unconditional connection route if the equipment meets the technical requirements of IEC 61000-3-3."

P28 Issue 2 will consider recommendations for application of the Stage 2 assessment process to connection of EV connection points ≤ 75 A per phase.

8.1.4 Wind turbine generators (WTG)

P28 Issue 2 will differentiate between continuous operation of wind farms and switching actions. There is empirical evidence that there is minimal flicker from continuous operation of modern WTG fitted with inverter technology.

Recommendations will focus on connection of fixed speed WTG and the energisation of wind turbine step-up transformers. P28 Issue 2 will adopt BS EN 61400-21 as a normative reference for measurement and assessment of power quality characteristics for wind turbines and wind farms. Relevant amplification and clarification of the principles/requirements in BS EN 61400-21 will be included in P28 Issue 2.

8.1.5 PV (solar)

As there is no published Standard for measurement and assessment of power quality characteristics of PV installations, P28 Issue 2 will provide recommendations, as far as appropriate for assessing voltage fluctuation and flicker against P28 planning limits. Special consideration will be given to assessment of PV inverters and standard test conditions, taking into account specialist advice from relevant PV stakeholders in GB and elsewhere, as appropriate. P28 will consider any recommendations impacting voltage fluctuation from DNO/National Grid PV inverter constraining[11]. More work will be carried out to establish whether guidance on curves and parameters can be provided for PV similar to those that exist for WTG noting that there are differences in recording PV (solar) inverters and wind turbine generators (WTG) due to software programming. This may be problematic given there is no agreement across the industry concerning which methodology should be adopted. It is proposed to compare a sample of test results obtained for similar inverters used in WTG and PV installations. Where any significant differences in results are found then these will be reviewed to determine any recommendations for assessing PV installations.

8.1.6 Energy storage

It is intended that general recommendations for connection and operation of energy storage devices will be included in P28 Issue 2, where appropriate.

8.2 Co-ordination of outages

P28 Issue 2 will be amended to include recommendations for normal/outage conditions to be considered in network studies and the frequency of occurrence for planned/unplanned outages. Any recommendations will be based on minimum fault levels for credible network operating conditions in ENA EREC P2[12], where appropriate. Network operating conditions in summer and winter will be considered so the impact of different distributed generation profiles are taken into account.

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[11] There are proposals for DNOs and National Grid to have the ability to control the power output from certain PV inverters connected to the grid, where there is an imbalance in generation and demand.

[12] ENA EREC P2 is currently under review and liaison with the associated WG will be required.

Guidance will be provided by P28 Issue 2 to network operators regarding the impact that outages on the transmission system may have on voltage fluctuation and flicker further down the network.

8.3 Exceedance of planning limits

Although exceedance of planning levels is not believed to commonly occur, evidence will be obtained to support this assumption. P28 Issue 2 will provide additional guidance to users where measured or simulated flicker severity limits are marginally exceeded, particularly for infrequent occurrences. This may include more detailed evaluation of background levels during the times the disturbing equipment is to be energised or operated.
Consideration will be given as to whether P28 Issue 2 planning limits for flicker severity can be exceeded by small margin for infrequent events, e.g. no more than once per year. Consideration will be given to adopting a probabilistic approach e.g. where the 95% probability value of P_{st} may exceed the planning limit by a defined factor - similar to the method in PD IEC/TR 61000-3-7.

9 Conclusions

The following conclusions have been drawn at this stage with reference to the proposed scope of review in the Terms of Reference for the P28 WG.

P28 Issue 2 will include a major update of technical references and associated Standards in P28 based on relevant IEC/BS EN Standards – mainly IEC 61000 series Standards. No referencing of IEEE Standards is foreseen.

BS EN 61000-3-3 and BS EN 61000-3-11 do not currently address flicker severity limits for multiple LV installations. Although the review of P28 has not identified any particular issues, P28 Issue 2 will include guidance for assessment of multiple equipment installations, including, the value of the exponent to be chosen, where there is a high penetration of SSEG[13]. The timeframes for revision of P28 (i.e. within the next 12 months) will not permit proposed work by relevant IEC Standards Committees on considerations for multiple LV installations and SSEG to be incorporated at this stage.

It is likely that certain requirements in the Grid Code concerning RVC and Distribution Code concerning voltage fluctuation (e.g. section DPC 4.2.3.3 on Voltage Step Changes), in particular as a result of transformer energisation, will need amendment. The P28 WG will identify and recommend any modifications to the DCode and whether certain requirements can be migrated to P28 Issue 2. It is expected that the DCRP will consider how proposed amendments to the DCode will be taken forwards. It is not envisaged that other ENA engineering documents that currently reference P28 will need to change. However, new guidance notes on the application of P28 may be required to be captured in an accompanying ENA ERep to P28 Issue 2.

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[13] Noting that the requirements in BS EN 61000-3-3 and BS EN 61000-3-11 are intended to obviate the need to control collective action of multiple equipment.

The current general limit of 3% voltage step change in P28[14] is not suitable as it does not take into account 'infrequent' occurrences or RVCs, where larger voltage step changes may be permissible without resultant voltage complaints. P28 Issue 2 will need to include an envelope of voltage step change limits to cover the range of permissible voltage fluctuations including RVC.

The scope of P28 Issue 2 will be extended to consider assessment of transformer magnetising inrush and other RVCs. Voltage change limits will be provided for RVCs in addition to steady state conditions at present. Due cognisance will be taken of the recently approved revision of Grid Code limits on RVCs, which occur after planned transmission and transmission user operations (see GC0076).

Although for a given voltage disturbance, illuminance variation may be less and therefore flicker may be less perceptible for modern lighting than traditional tungsten filament light bulbs, the evaluation of flicker severity in P28 Issue 2 should still be based on the standard flickermeter defined in IEC 61000-4-15. There is insufficient evidence or industry consensus at present to adopt any changes to the design or function of the standard flickermeter.

In general, a more probabilistic approach should be adopted in P28 Issue 2 than the traditional deterministic approach (i.e. based on worst case conditions), where there is randomness of events.

It is intended that P28 Issue 2 will allow for different planning limits to be set for LV, HV, MV and EHV systems and operating voltages to align with relevant IEC Standards. This will allow advantage to be taken of lower flicker emissions in HV and EHV networks.

There are a number of areas where P28 is unclear including definition of conditions, frequency of occurrence and guidance on data to be used for models/calculations (e.g. which fault level to consider, what value of remanence etc.) and the required accuracy of such data.

P28 Issue 2 will elaborate on the measurement and evaluation of background levels necessary for flicker assessment and will propose typical values in the absence of actual data for situations.

The current 'first-come, first-served' method for allocating available flicker headroom could be considered to be unfair for users. Although this method has served the industry well without any particular issues, a fairer method similar to the 'equal rights' method in PD IEC/TR 61000-3-7 may be justified subject to impact assessment of the technical, commercial and regulatory issues. This should take into account generation as well as demand. To date the review has not identified any lessons learned from other countries that have moved from 'first-come, first-served' to 'equal rights. This will need to be explored further. In terms of RVC, allocation may be in terms of number of occurrences.

The guidance in P28 will be updated to fully cover the variety of LCT equipment now being connected to the LV network including: heat pumps, EVs, WTGs, PV and energy storage. This should not diminish the importance of ensuring traditional technologies are still fully catered for.

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[14] P28 Issue 1 allows the Network Operator to exercise discretion in the application of the general limit of 3% voltage step change.

Guidance on credible network outage conditions with maximum and minimum fault levels needs to be provided based on ENA EREC P2.

P28 Issue 2 will consider additional guidance where flicker severity limits are marginally exceeded, particularly for infrequent occurrences.

Any recommendations in P28 Issue 2 should consider the wide number of software systems and provide guidance as to what procedures, input parameters and factors are appropriate for simulation.

10 Recommendations

It is recommended that the Grid Code Review Panel and Distribution Code Review Panel jointly review the acceptability of the proposed changes to the scope and technical content of P28 as summarised in this report.

It is the recommendation of the P28 WG that the summary of proposed changes in this report form the basis of draft modifications to P28 during Phase 3 of the associated project to review/revise P28.

Annex A
(normative)

Status of References in P28 Issue 1

Existing Ref	Title	Status	Comments
BS 125	Specification for Hard-drawn Copper and Copper-cadmium Conductors for Overhead Power Transmission Purposes	Superseded, Withdrawn	Defines DC resistance values in P28 (Appendix D). Replaced by BS 7884:1997 Specification for copper and copper-cadmium stranded conductors for overhead electric traction and power transmission systems, which is Confirmed, Current. Need to decide whether these standards need to be listed in revised P28.
BS 215	Specification for Aluminium Conductors and Aluminium Conductors, Steel reinforced, for Overhead Power Transmission	Confirmed, Current	Defines DC resistance values in P28 (Appendix D). Other BS EN Standards exist for aluminium alloy conductors (e.g. BS EN 50183: 2000). Need to agree whether these standards need to be listed in revised P28.
BS 1320	High Voltage Overhead Lines on Wood Poles for Line Voltages up to and including 11 kV with Conductors Not Exceeding 0.05 sq in. (Withdrawn November 1977)	Withdrawn	Superseded by ENA TS 43-40 Specification for single circuit overhead lines on wood poles for use at high voltage up to and including 33 kV.
ESI Standard 09-8	Impregnated Paper Insulated 600/1000 V Cable with Three Solid Aluminium	Current	Cable no longer purchased. Replaced by ENA TS 09-9 waveform cables.

Existing Ref	Title	Status	Comments
	Phase Conductors and Aluminium Sheath/Neutral Conductor (CONSAC)		
ESI Standard 09-9	Polymeric Insulated, Combined Neutral/Earth (CNE) Cables with Solid Aluminium Phase Conductors and Concentric Aluminium Wire Waveform Neutral/Earth Conductor	Current, Under Review	Currently under review.
ESI Standard 35-1	Distribution Transformers (from 16 kVA to 1000 kVA)	Current	Recently revised in 2014 and covers distribution transformers up to 2 000 kVA (Appendix D).
ESI Standard 43-10	11 kV Single Circuit Overhead Lines of Light Construction on Wood Poles. (Withdrawn November 1988)	Superseded	Superseded by ENA TS 43-40 Specification for single circuit overhead lines on wood poles for use at high voltage up to and including 33 kV.
ESI Standard 43-20	11 kV and 33 kV Single Circuit Overhead Lines of Heavy Construction on Wood Poles. (Withdrawn November 1988)	Withdrawn	Superseded by ENA TS 43-40 Specification for single circuit overhead lines on wood poles for use at high voltage up to and including 33 kV.
CE Specification C2 (1955)	Impregnated Paper Insulated solid Type Lead or Lead Alloy Sheathed Power Cables for Voltages up to and including 22 kV. (Withdrawn 1973)	Withdrawn	Replaced by more modern polymeric cable standards (e.g. BS 7870-4.10).
BEB Specification C6 (1960)	Impregnated Paper Insulated Solid Type Lead or Lead Alloy Sheathed Power Cables having Aluminium Conductors for Voltages up to and including 22 kV. (Withdrawn 1973)	Withdrawn	Replaced by more modern polymeric cable standards (e.g. BS 7870-4.10).
BEB Specification L1 (1962)	Medium and Low Voltage Overhead Lines on Wood Poles. (Withdrawn June 1978)	Withdrawn	Part superseded by ENA TS 43-40 Specification for single circuit overhead lines on wood poles for use

Existing Ref	Title	Status	Comments
			at high voltage up to and including 33 kV.
BEB Specification T.1 (1958)	Transformers from 5 kVA to 1000 kVA for Use on Standard 415 V and 240 V Systems. (Withdrawn 1973)	Withdrawn	Replaced by ENA TS 35-1
UIE (1986) Disturbances Working Group	Flicker Measurement and Evaluation.	Superseded?	Replaced by: 1. Electromagnetic Compatibility (EMC) – Part 4: Testing and Measurement Techniques – Section 15: Flickermeter – Functional and Design Specifications, IEC Standard 61000 - 4 - 15, Edition 1.1, Feb. 2003. 2. BS EN 60868-0:1993, IEC 60868-0:1991 Flickermeter. Evaluation of flicker severity
UIE (1988) Disturbances Working Group	Connection of Fluctuating Loads	Superseded	Replaced by EMC Standards in particular IEC 61000 series: 1. PD IEC/TR 61000-3-7 2. IEC 61000-3-3 3. IEC 61000-3-11 4. IEC 61000-3-12
IEC 725 (1981)	Considerations on reference impedances for use in determining the disturbance characteristics of household and similar electrical equipment.	Superseded?	Replaced by PD IEC/TR 60725:2012 Consideration of reference impedances and public supply network impedances for use in determining disturbance characteristics of electrical equipment having a rated current ≤ 75 A per phase

Existing Ref	Title	Status	Comments
IEC 868 (1985)	Flickermeter Functional and Design Specifications.	Superseded	Replaced by BS EN 60868-0:1993, IEC 60868-0:1991 Flickermeter. Evaluation of flicker severity.
IEC 555 (1982) (in three parts)	Disturbances in supply systems caused by household appliances and similar equipment.	Superseded	Replaced by BS EN 61000-3-3:2013 Electromagnetic compatibility (EMC). Limits. 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
CENELEC EN 60.555	Equivalent to IEC 555.	See IEC 555 Above	See IEC 555 Above
BSI, BS5406 (1988) (in three parts)	Equivalent to EN 60.555. Disturbances in supply systems caused by household appliances and similar equipment.	See IEC 555 Above	See IEC 555 Above
The Electricity Council Report ACE 7 1963	Supply to Welding Plant (Associated with EREC P9)	Current	These legacy documents should not be referenced in revision of P28
The Electricity Council Report ACE 4 (1961) :	Supply to Collier Winders and Rolling Mills (Associated with EREC P8)	Current	These legacy documents should not be referenced in revision of P28
The Electricity Council Report ACE 26 (1970):	Supply to Arc Furnaces (Associated with EREC 7/2)	Current	These legacy documents should not be referenced in revision of P28
The Electricity Council Report ACE 48 (1977):	EHV or HV Supplies to Induction Furnaces (Associated with EREC P16)	Superseded	Replaced by ENA EREC P16
ENA EREC P16	EHV or HV supplies to induction furnaces	Current	Need to consider whether this should be revised. Not referenced in revision of EREC G5 (harmonics)

Annex B
(normative)

Proposed References

Ref	Title	Status	Comments
BS EN 61000-2-2: 2002	Electromagnetic compatibility (EMC). Environment. Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems	Current	
BS EN 61000-3-3: 2013	Electromagnetic compatibility (EMC). Limits. 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	Current	
DD IEC/TS 61000-3-5:2009	Electromagnetic compatibility (EMC). Limits. Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 75 A	Current	
PD IEC/TR 61000-3-7: 2008	Electromagnetic compatibility (EMC). Limits. Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems	Current	
BS EN 61000-3-11: 2001	Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems. Equipment with rated voltage current ≤ 75 A and	Current, Work in Hand	

Ref	Title	Status	Comments
	subject to conditional connection		
BS EN 61000-4-11:2004	Electromagnetic compatibility (EMC). Testing and measurement techniques. Voltage dips, short interruptions and voltage variations immunity tests	Current, Work in Hand	This part of EN 61000 defines the immunity test methods and range of preferred test levels for electrical and electronic equipment connected to low-voltage power supply networks for voltage dips, short interruptions, and voltage variations.
BS EN 61000-4-14:1999+A2:2009, Electromagnetic compatibility (EMC) — Part 4-14	Testing and measurement techniques — Voltage fluctuation immunity test for equipment with input current not exceeding 16 A per phase.	Confirmed, Current	Defines DC resistance values in P28 (Appendix D).
BS EN 61000-4-15:2011	Electromagnetic compatibility (EMC). Testing and measurement techniques. Flickermeter. Functional and design specifications	Current	
BS EN 61400-21: 2011	Measurement and assessment of power quality characteristics of grid connected wind turbines	Current	
BS EN 61000-4-30			
BS EN 61000-4-34:2007+A1:2009	Electromagnetic compatibility (EMC). Testing and measurement techniques. Voltage dips, short interruptions and voltage variations immunity tests for equipment with mains current more than 16 A per phase	Current	
IEC/TR 60725:2012	Consideration of reference impedances and public supply network impedances for use in determining disturbance characteristics of electrical equipment having a rated current ≤ 75 A per phase	Current	
IEEE 1453-2011	IEEE Recommended Practice--Adoption	Current	

Ref	Title	Status	Comments
	of IEC 61000-4-15:2010, Electromagnetic compatibility (EMC)--Testing and measurement techniques--Flickermeter--Functional and design specifications		

References

Standards publications

BS EN 61000-3-3, *Electromagnetic compatibility (EMC). Limits. 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, *Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems. Equipment with rated voltage current ≤ 75 A and subject to conditional connectio*n

BS EN 61400-21, *Wind turbines. Measurement and assessment of power quality characteristics of grid connected wind turbines*

BS 8888:2008, *Technical product specification – Specification*

Other publications

[1] *Terms of Reference_v2.2*, ER P28 Joint GCRP & DCRP Working Group,

[2] *Project Initiation Document for ER P28*, Issue 1 2015, ER P28 Joint GCRP & DCRP Working Group

[3] ENA EREC P5, *Design of low voltage underground networks for new housing estates*

[4] ENA EREC G83, *Recommendations for the Connection of Type Tested Small-scale Embedded Generators (Up to 16A per Phase) in Parallel with Low-Voltage Distribution Systems*

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