Discussion Paper on the Management of Harmonics

03 May 2013

INTRODUCTION

This document has been prepared as a discussion paper for the G5/4 Review Group. It provides an overview of the management of harmonics for Distribution and Transmission systems in UK and is intended to be used in the development of the G5/4 Review Group's working group report.

"The intention of Engineering Recommendation G5/4 and future G5/5 is to try to ensure that the levels of harmonics in the Transmission and Distribution Systems do not create a problem for other users of those networks or for the network itself."

"G5/4 is referenced in the Grid and Distribution Codes which are statutory requirements placed on operators of electricity supply networks."

The relevant standard for harmonic voltage distortion levels to be expected on electricity networks is BSEN 50160. The industry will generally comply with this Standard, although compliance with standards is voluntary unless they are mandated by EU Directives.

LEGISLATION AND STANDARDS

Some standards impose Transmission and Distribution Code obligations and these standards implement Distribution Code and Grid Code requirements. The content of these standards is subject to the governance of the Distribution and Grid Code Review Panels which will consult publicly on them.

There are other standards that do not impose direct Transmission and Distribution Code obligations, but are nevertheless considered to be material and binding on Transmission and Distribution Network Owners and Users and are subject to governance by the Panels.

It should be noted that the Grid Code & Distribution Code make reference to Engineering Recommendation G5/4 published by the Energy Networks Association.

TOPICS

The topics addressed here include:

- who is responsible for making sure a G5/4 assessment is performed;
- the scope of a G5/4 assessment (at time of connection);
- how compliance is assessed;
- Setting the harmonic limits;
- what ongoing responsibilities network owners and network users have
- the differences (if any) between what the Grid Code and the Distribution Code say.

1) Who is responsible for making sure a G5/4 assessment is performed;

Transmission Owners are required to comply with the SO-TO Code (STC) which specifies that the appropriate Grid Code provisions relating to harmonics should be applied at an Interface Point and at a Connection Site. The STC also stipulates that an Offshore Transmission Owner should carry out a Voltage Waveform Quality Assessment when building a new Offshore Transmission System or changing an existing one.

The Grid Code Connection Condition 6.1.5 (a) requires that the Electromagnetic Compatibility Levels for harmonic distortion on the Transmission System from all sources under both planned and fault outage conditions, (unless abnormal conditions prevail) shall comply with the compatibility levels[1] given in G5/4.

The Grid Code further requires that the planning criteria contained within ER G5/4 be applied for the connection of any nonlinear load to the Transmission System, and may result in harmonic emission limits being specified for these loads in the relevant Bilateral Connection Agreement.

A Distribution Owner is required by its Distribution License to apply and comply with the Distribution Code. The Distribution Code' (Section DPC 4.2.3.2) explicitly states that user's loads must comply with Engineering Recommendations G5/4. In order to prevent disturbance to other users of the system Distribution Owner has a duty to ensure that appropriate 'Planning' limits are applied at the design stage and that the 'Compatibility' limits are never exceeded once connected and operational.

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[1] Compatibility Levels and Planning Levels are specified in G5/4 for transmission and distribution systems to tie in with emission and immunity levels in LV and MV installations. Compatibility Levels are used as a reference for coordinating the emission and immunity of the equipment and Planning Levels are used by transmission and distribution system owners in evaluating the impact of all disturbing loads and generators on the utility supply.

G5/4 stipulates that the network owner should ensure the necessary assessment is performed. There is no restriction on which party actually undertakes the assessment. The assessment itself can be carried out by the network owner, sub-contracted or delegated to the connecting party subject to the necessary information exchange.

2) the scope of a G5/4 assessment (at time of connection);

G5/4 describes how a new load with the potential to cause a disturbance should be assessed for its impact on harmonic voltage distortion. Different tests are applied with different voltage levels and connection rating which are intended to limit the complexity of an assessment in proportion to the impact of a connection. A Stage 3 assessment is the most complex type specified.

In summary, a G5/4 Stage 3 Assessment;

- checks the connection design against Planning Levels for voltage distortion;
- considers all nodes affected(EHV, HV and MV);
- considers all system conditions within network model;
- aggregates existing measured background(taken during normal running period) and new source; and
- considers effect on transmission/distribution and existing users.

The assessment either results in a set of harmonic voltage emission limits at the connection point which will be then specified in the BCA (as stated in the Grid Code for example) or an otherwise agreed method of demonstrating compliance of a final connection design and any necessary harmonic mitigation.

3) How compliance with G5/4 is assessed;

It is not practicable to measure harmonics under all the system conditions which can be encompassed by a Stage 3 assessment. However, it is possible to validate the assessment and to confirm that mitigation measures (ie filters) perform as expected

Continuous harmonic voltage/current measurements can be recorded at the connection point just before to energisation of customer's system to establish the baseline for 'compliance' purposes and continuous harmonic voltage/current measurements can be repeated during and after commissioning of the customer's system both with and without disturbing load/generation.

In general, the background harmonics should be assessed over at least a 7 day period when the PCC fault levels are representative of post-connection conditions. Note that the minimum 7 day period may not be long enough to characterise the background harmonic levels; these levels can be subject to variation over longer periods due to seasonal and other changes in load pattern and network configuration.

Where constraints on a connected customer are specified, it is necessary to monitor that customer is compliant against his connection conditions, and it may be efficient to fit permanent harmonic monitoring. Such monitoring allows appropriate action to be taken should any filters or their components fail and allows the background for any subsequent connections to be established quickly.

4) what ongoing responsibilities network owners and network users have

Network owners have an obligation to manage voltage distortion on their networks both to limit the risk of damage to equipment and to facilitate the connection of new customers.

The Grid Code places an explicit obligation on NGET to ensure that harmonics on the Onshore Transmission System are kept at or below Compatibility Levels. This is achieved by applying a G5/4 assessment at the time of connection and by using continuous monitoring to identify changes in levels of distortion. These changes could come about as a result of:

1. Failures in customer mitigation equipment (noting that planned changes would be treated as a modification to the connection);
2. Changes in the local network; and/or
3. A general increase in background.

Where levels have the potential to exceed Compatibility Levels action needs to be taken which can range from increased vigilance through to de-energisation of equipment.

This is also necessary where a site is known to be at risk of high harmonic levels.

Network Operator or Owner is also responsible for;

- Reacting to customer complaints / equipment failure that may be caused by harmonics
- Ongoing measurements at key sites, e.g. Nuclear Sites, Traction loads etc
- Customer information requests (required by Transmission & Distribution LC)
- Monitoring 'new' technology (e.g.GenAVC, SVCs, Filters, HVDC etc)
- Problem solving

5) The differences (if any) between what the Grid Code and the Distribution Code say

Grid Code states;

Annex - Grid Code CC.6.1.5

Voltage Waveform Quality

CC.6.1.5 All **Plant** and **Apparatus** connected to the **National Electricity Transmission System**, and that part of the **National Electricity Transmission System** at each **Connection Site** or, in the case of **OTSDUW Plant and Apparatus**, at each **Interface Point**, should be capable of withstanding the following distortions of the voltage waveform in respect of harmonic content and phase unbalance:

(a) Harmonic Content

The **Electromagnetic Compatibility Levels** for harmonic distortion on the **Onshore Transmission System** from all sources under both **Planned Outage** and fault outage conditions, (unless abnormal conditions prevail) shall comply with the levels shown in the tables of Appendix A of **Engineering Recommendation** G5/4. The **Electromagnetic Compatibility Levels** for harmonic distortion on an **Offshore Transmission System** will be defined in relevant **Bilateral Agreements**.

Engineering Recommendation G5/4 contains planning criteria which **NGET** will apply to the connection of non-linear **Load** to the **National Electricity Transmission System**, which may result in harmonic emission limits being specified for these **Loads** in the relevant **Bilateral Agreement**. The application of the planning criteria will take into account the position of existing and prospective **Users'** **Plant** and **Apparatus** (and **OTSDUW Plant and Apparatus**) in relation to harmonic emissions. **Users** must ensure that connection of distorting loads to their **User Systems** do not cause any harmonic emission limits specified in the **Bilateral Agreement**, or where no such limits are specified, the relevant planning levels specified in **Engineering Recommendation** G5/4 to be exceeded.

(b) Phase Unbalance

Under **Planned Outage** conditions, the maximum **Phase (Voltage) Unbalance** on the **National Electricity Transmission System** should remain, in England and Wales, below 1%, and in Scotland, below 2%, unless abnormal conditions prevail and **Offshore** (or in the case of **OTSDUW**, **OTSDUW Plant and Apparatus**) will be defined in relevant **Bilateral Agreements**.

Distribution Code also states;

DPC4.2.3.2 Voltage Disturbances

Distortion of the **System** voltage waveform, caused by certain types of **Equipment**, may result in annoyance to **Users** of the **DNO's Distribution System** or damage to connected **Apparatus**. In order to limit these effects the following shall apply to **Users'** loads connected to the **DNO's Distribution System:-**

(a) Voltage fluctuations shall comply with the limits set out in DGD Annex 1, Item 9 Engineering Recommendation P28, "Planning limits for voltage fluctuations caused by industrial, commercial and domestic equipment in the United Kingdom".

(b) The harmonic content of a load shall comply with the limits set out in DGD Annex 1, Item 1 Engineering Recommendation G5/4-1, "Planning levels for harmonic voltage distortion and the connection of non-linear equipment to transmission and distribution systems in the United Kingdom."

(c) **Phase (Voltage) Unbalance**shall comply with the levels laid down in DGD Annex 1, Item 10 Engineering Recommendation P29, "Planning limits for voltage unbalance in the United Kingdom for 132kV and below".

(d) Traction supplies shall comply as appropriate with the requirements of DGD Annex 1, Item 6. Engineering Recommendation P24 "A.C. traction supplies to British Rail".

Under certain circumstances the **DNO** may agree to other limits or levels.

ER G5/4 describes permissible harmonic voltage distortion levels for the network in two parts, the planning levels and the compatibility levels at all voltages from 400V to 400kV. **The Planning Level is used at the design stage whereas the Compatibility Level provides limits to which the voltage must conform at all times at the operational stage.**

Planning levels can be therefore considered as internal quality objective.

6) Long-term (thermal) effects on equipment:

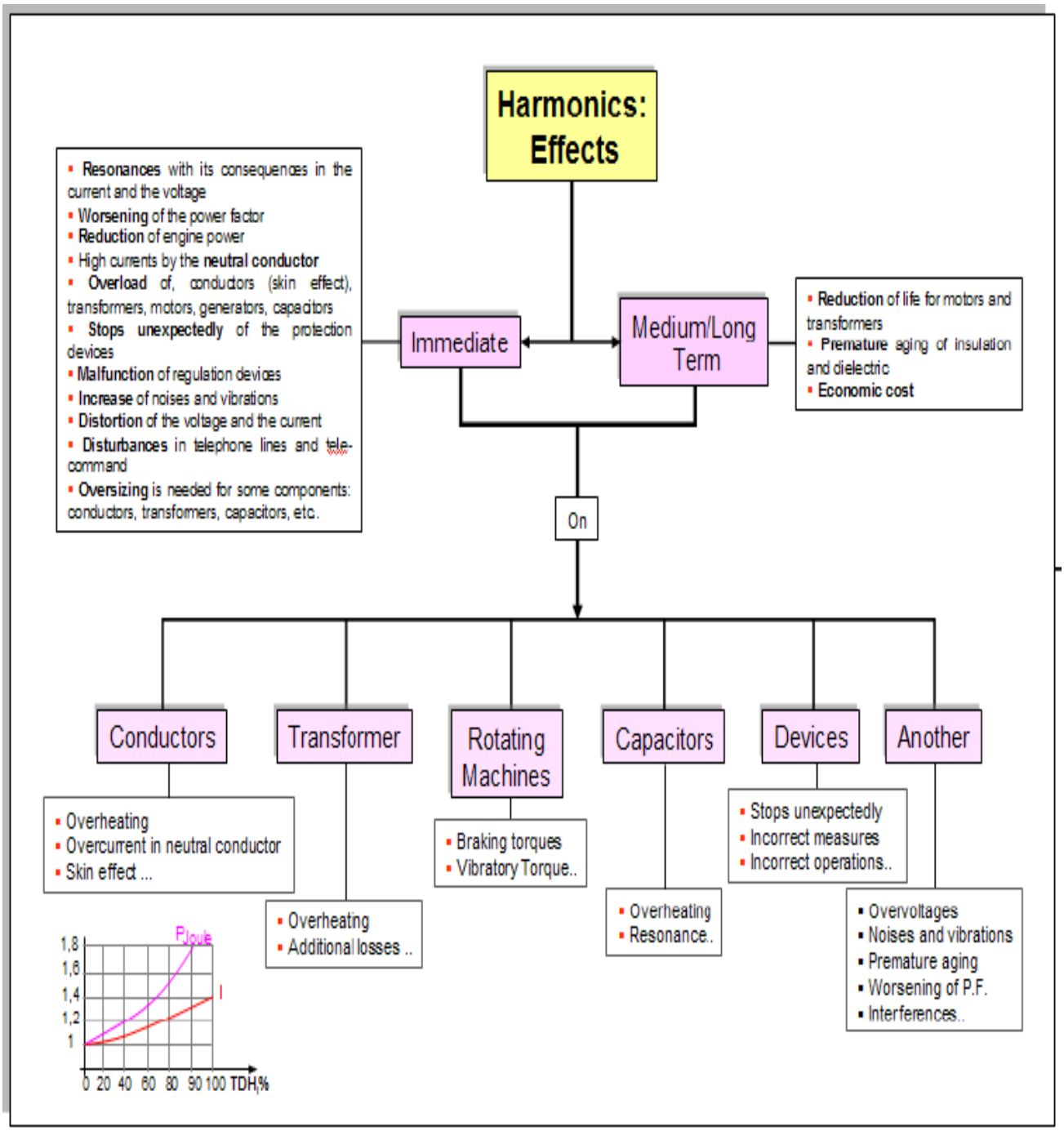
Lines (OHL+UGC) experience higher stress due to harmonics, depending on the frequency and therefore local temperature rise which is increasingly declare from about 1000 Hz due to the skin effect In networks with a forth conductor (LV-TN & TT systems) as a return conductor this can lead, where harmonic components are present in the voltage, to a current with a frequency of 150 Hz (3rd Harmonic) in the neutral conductor. Where there is a high degree of non-linear consumers higher stress in the neutral conductor compared with the phase conductors can occur.

Where there is no neutral conductor, displacement voltage with respect to earth with frequency forms in the neural point of the network. Sometimes currents containing harmonics have larger di/dt at the zero crossing than a corresponding sinusoidal current with equal RMS or peak value. This can reduce the capability of circuit breakers. Vacuum CBs are less susceptible this than magnetically-blown switches. Fuses are generally less susceptible to harmonics, where only premature tripping occurs relative to the rated value, which in view of additional temp rise of the equipment to be protected can be very desirable.

With transformers, operation at non-sinusoidal voltage and/or with non-sinusoidal current leads to increased ohmic losses and also to a rise in the eddy current losses and hysteresis losses. Monitoring the current loading of the TX compensating winding can also be problematic (delta cct), if only the current in the neutral winding is measured, which would mean that the content of the 3rd harmonic would not be detected.

Inductive VTs can become saturated due to harmonics, thus increases the transformation error. CTs are generally less sensitive in this case, with only the phase-angle error being detrimentally affected. This needs to be considered for measuring harmonics…

Please note that ETR 122(Section 9) gives further information but also, below diagram briefly shows all the effects on components…


Harmonics: Effects
Resonances with its consequences in the current and the voltage
Worsening of the power factor
Reduction of engine power
High currents by the neutral conductor
Overload of, conductors (skin effect), transformers, motors, generators, capacitors
Stops unexpectedly of the protection devices
Malfunction of regulation devices
Increase of noises and vibrations
Distortion of the voltage and the current
Disturbances in telephone lines and tele-command
Oversizing is needed for some components: conductors, transformers, capacitors, etc.
Immediate
Medium/Long Term
Reduction of life for motors and transformers
Premature aging of insulation and dielectric
Economic cost
On
Conductors
Overheating
Overcurrent in neutral conductor
Skin effect ...
Transformer
Overheatng
Additional losses ..
Rotating Machines
Braking torques
Vibratory Torque..
Capacitors
Overheating
Resonance..
Devices
Stops unexpectedly
Incorrect measures
Incorrect operations..
Another
Overvoltages
Noises and vibrations
Premature aging
Worsening of P.F.
Interferences..
PJoule
I
1,8
1,6
1,4
1,2
1
0 20 40 60 80 90 100 TDH%

REFERENCES:

1. ENA ETR 122 Guide to the Application of Engineering Recommendation G5/4 in the Assessment of Harmonic Voltage Distortion and Connection of Non-Linear Equipment to the Electricity Supply System in the UK

2. BS EN 61000-4-30:2009 Testing and measurement techniques: Power quality measurement methods

3. BS EN 50160:2010 Voltage characteristics of electricity supplied by public Electricity Networks

4. PD IEC/TR 61000-3-6:2008 Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems

5. Distribution Code (Issue 19, December 2012)

6. Grid Code (Issue 5, 31 January 2013)

7. BS EN 61000-2-2:2002 Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems

8. BS EN 61000-2-12:2003 Compatibility levels for low frequency conducted disturbances and signalling in public medium-voltage power supply systems