Grid Code Review Panel – Issue Assessment Proforma

Voltage Fluctuations

PP 11/51[1]

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Summary

The Grid Code sets out criteria relating to Voltage Fluctuations at a Point of Common Coupling within CC.6.1.7. This clause includes references to step changes, voltage excursions and a cross reference to Engineering Recommendation P28 for the transmission system in Scotland. The current text references many related but different criteria and would ideally be modified for the sake of clarity.

CC.6.1.7 (a) states that voltage excursions other than steps may be allowed up to a level of 3%. This requirement applies regardless of the impact of an excursion, either in duration, frequency or repetitiveness of occurrence.

Excursions of greater than 3% have been observed coincident with the energisation of transmission user transformers. These excursions have been short-lived and occur infrequently.

This paper recommends revisions to the Voltage Fluctuation criteria in the Grid Code which give due account to short lived, infrequent and non-repetitive voltage changes. This would remove the need for additional investment in equipment and changes to connection designs whilst maintaining current standards of safety, security and quality of supply to customers.

Users Impacted

High

Generation and demand with large transformers or motors connecting at locations on the transmission system with a low short circuit level in proportion to the size of equipment energised from it.

Medium

None

Low

Demand fed from locations on the transmission system with a low short circuit level in proportion to the size of equipment energised from it.

Description & Background

Grid Code, SQSS and Engineering Recommendation Context

The voltage change criteria applicable to the National Electricity Transmission System (NETS) are set out in a number of documents.

The SQSS sets out step change limits applicable to operational switching and to secured events (ie faults) which the NETS needs to be designed and operated within. A 3% limit applies to operational switching, with 6% and 12% applied to secured events. The SQSS also includes a cross reference to Engineering Recommendation P28.

[1] The Code Administrator will provide the paper reference following submission to National Grid.

Description & Background (Cont.)

The Grid Code specifies criteria on Voltage Fluctuations to be applied "at a Point of Common Coupling with a fluctuating Load" in CC.6.1.7. Voltage fluctuations are changes in voltage following a number of possible patterns including dips, ramps and steps.

Note that the Voltage Fluctuation criteria within CC.6.1.7 includes Flicker, but it is not considered necessary to review this as the treatment of flicker is well defined in IEC documentation and the Grid Code is consistent with this.

The Grid Code also sets out requirements on transmission users to ride through faults, including events where voltage goes to zero for up to 140ms, or for longer in some circumstances.

Impact of Voltage Fluctuations

Voltage Fluctuations of limited magnitude, duration and frequency affect power quality but do not have a direct impact on the safety and security of a network. Their impact can be observed on perceived levels of electric lighting for example.

Beyond a certain point Voltage Fluctuations can impact adversely on the operation of network customers' equipment (eg motors, computing equipment), including generating station auxiliaries. Some industrial processes are known to use low voltage relays to protect the equipment concerned. There is therefore a continuing need to manage Voltage Fluctuations.

Impact of the Current Grid Code Criteria

CC.6.1.7 imposes an absolute ceiling on the magnitude of voltage fluctuations. The requirement as currently expressed is equally applicable to events which occur frequently (eg a number of times per day) or occur once or twice a year, and events which are short lived or events which have a semi-permanent effect.

Additional equipment can be needed in order to make sure that the 3% limit can be met under all circumstances. Mitigation measures can include Point on Wave controlled switching equipment, additional switchgear and reconfiguration and/or re-design of the transmission network.

Where the voltage excursion is short lived (in the case of transformer energisation this is likely to be less than 1 second) and is caused by re-energisation after maintenance, this can mean that additional equipment is needed to deal with an effect which occurs for a few seconds over the lifetime of the plant concerned. In cases where no transmission users are adversely affected, the case for such investment is weak.

Proposed Solution/Next Steps

The following proposals are based on a review of international experience, equipment specifications and academic research. The numbered references quoted in the text below within square brackets are listed in an attached document.

Definitions

EN 50160 [1] defines a supply voltage 'dip' as a sudden reduction of the supply voltage to a value between 90% and 1% of the declared voltage, followed by a voltage recovery after a short period of time. Conventionally the duration of a voltage dip is between 10 ms and 1 minute.

Proposed Solution/Next Steps (Cont.)

The depth of a voltage dip is defined as the difference between the minimum root mean square (rms) voltage during the voltage dip and the declared voltage. Voltage changes which do not reduce the supply voltage to less than 90 % of the declared voltage are not considered to be dips.

EN 50160 defines a Rapid Voltage Change (RVC) as voltage variation less than 10%. IEC 61000-2-1 [2] quotes that: "Voltage fluctuations can be described as a cyclical variation of the voltage envelope or a series of random voltage changes the magnitude of which does not normally exceed the range of operational voltage changes mentioned in IEC 38 (up to ± 10 %)."

Characterisation and Quantification of a Rapid Voltage Change

A Rapid Voltage Change is defined [13] as the change in the rms value of a voltage signal that moves from a steady state value to a maximum change and then gradually varies and settles at a new level determined by $V_{steadystate}$. It is characterised by maximum depth, ΔV_{max}, duration (T) and new steady state value (see Figure 1).

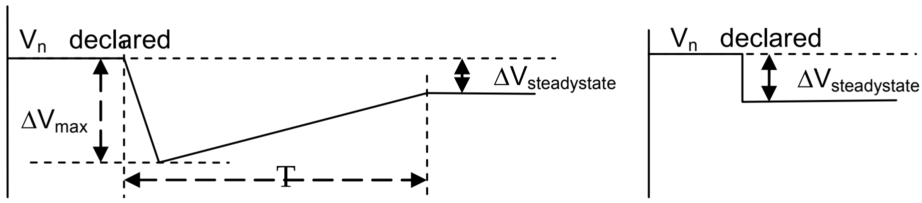

Figure 1- RVC Characterisation

In order for the event to be classified as an RVC, ΔV_{max} should be less than ±10%. Voltage changes with larger depth are generally classified as voltage dips.

References [14] and [15] have provided significant contribution in the analysis of RVCs. SINTEF and Norwegian Water Resources and Energy Directorate have published the result of their investigation in Reference [14].

Their work included a survey for visibility of light when voltage changes. Ninety six people of different age groups (students to pensioner) took part.

The results of the survey suggested:

- Even a 2% instantaneous voltage change is visible for the majority of the population (67%). For 5% instantaneous voltage change 100% of population noticed the change in light;
- There was a marked difference between the light perceptions of population when RVCs caused by motor start were considered. For the maximum voltage change of 5% and time to stationary voltage of 0.5 second, 68% of population noticed the light change; and
- Most people will notice a change in light when the rate of change of rms of voltage averaged over one second is greater than 0.5% ($dV/dt \geq 0.5\%$).

We understand that these findings were used in the development of limits for RVCs in the Norwegian Grid Code which were set at ±10%. Exactly the same limits have been used in the Swedish Grid Code. It should be noted however that RVCs due to inrush current from transformers appear to be excluded from this criteria, along with faults, fault restoration and actions taken to improve quality of supply as a whole.

Review and Assessment

The main objective of this review is to establish whether the effect of Rapid Voltage Changes is an immunity and compatibility issue (which causes damage or disruption) or an issue of nuisance to customers. An extensive literature survey was carried out and a large number of references were collected to determine:

1. Impact of voltage variations other than voltage dips on domestic and industrial equipment;

2. Relationship between equipment immunity levels and voltage variations; and

3. Human eye perception sensitivity level to less frequent voltage variations.

Immunity of Electrical Equipment

Reference [3] sets out the test procedure for equipment connected to a low voltage (up to 1kV) network, which include domestic appliances. Class 1 products are tested on a case by case basis. Class 2 products are tested for defined voltage changes up to 70% of the nominal voltage for 25 cycles (0.5 second) and Class 3 products are tested up to 70% for 250 cycles.

Reference [4] requires that all products with currents less than 16A per phase are tested for voltage changes. For Class 1, no test is required. Class 2 the change in voltage ΔV is +/-8% of V_n for equipment intended for connection to public networks or other lightly disturbed networks. For Class 3, ΔV=+/-12% of V_n for equipment connected to heavily disturbed networks (i.e. industrial networks). The test duration is relatively long at 5 seconds.

CIGRE working group C4.110 published their report [5] in 2010 after investigating a wide range of equipment and industrial processes. All equipment and processes examined withstood voltage changes of up to 10%. A large number of processes were examined in a separate exercise looking at Process Immunity Time (PIT) [11] and shown to withstand voltage changes of 20% for at least 3 seconds.

ERA Technology surveyed voltage dip immunity in industrial and commercial power distribution systems in 1999 [6]. The report concludes that the immunity levels of all equipment surveyed were higher than 10% voltage change. It appeared that the most sensitive equipment type was variable speed drives which could ride through a voltage change of 100% for about 60 to 70 ms.

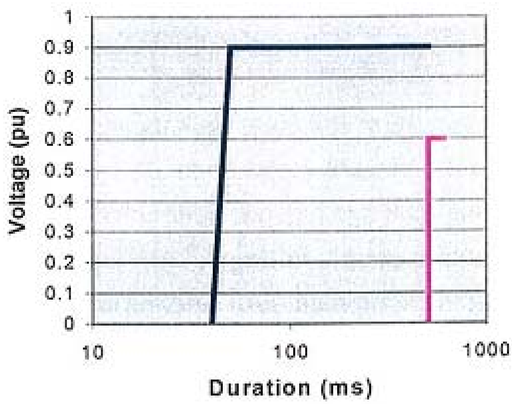

Figure 2: Sample measured maximum and minimum sensitivities of a variable speed drive

(Figure sourced from ERA Technology Ltd's "How to Improve Voltage Dip Immunity in Industrial and Commercial Power Distribution Systems" publication at www.era.co.uk)

Review and Assessment (Cont.)

Reference [7] shows that all commercially available variable speed drives tested did not trip for three phase voltage changes of motor start type of up to 72%.

Reference [8] studied the susceptibility of PCs, high pressure sodium (HPS) lamps, fluorescent lamps and industrial ac contactors for different voltage dip depth, angle and duration. The paper illustrates a generic curve that shows that all equipment maintains correct operation for 20% voltage dip lasting for 1 second. Reference [9] examined PCs, gas discharge lamps and industrial contactors. It states that all contactors tested tolerated 70% of voltage with dip duration effect. HPS lamps were found to be most sensitive when they can tolerate no voltage (100% dip) for only 0.5 to 1 cycle but they could ride through of voltage dip of 20% (voltage of 80%). More rigid lamp standards allow 90% of the nominal voltage for continuous operation.

Electric synchronous and asynchronous motors are more tolerant to voltage changes than other equipment because of their inertia. They can ride through voltages of 70% of nominal for longer than 1 second [10].

In conclusion, no evidence was found in amongst the literature surveyed that a voltage change of 10% over a limited period affects equipment and industrial processes supplied by the public network. Thus setting a limit for RVCs is not an equipment immunity problem rather an issue of visibility and annoyance to customers.

Application of Flicker Methodology

It is possible to apply the Flicker methodology to RVCs and infer a limit in number of occasions for a set period of time which is consistent with current power quality standards. For RVCs up to 12%, the equivalent limit is approximately 4 per day based on the 95th percentile of P_{st} and P_{lt} over one week [13].

Proposal

Rapid Voltage Changes (ΔV) should not exceed the following limits specified in Table 1 at the point of common coupling with the stated frequency of occurrence.

Category	Maximum number of occurrences (n)	$\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$
1	No Limit	$\%\Delta V_{max} \leq 1\%$ & $\%\Delta V_{steadystate} \leq 1\%$
2	For n ≤ 1 per 15 mins & n > 4 per day	$\%\Delta V_{max} \leq 3\%$ & $\%\Delta V_{steadystate} \leq 3\%$
3	Commissioning, Maintenance and Fault Restoration up to n ≤ 4 per day	$\%\Delta V_{max} \leq 12\%$ & $\%\Delta V_{steadystate} \leq 3\%$ (see Figure 2)

Table 1- Limits for Rapid Voltage Changes

Where: $\%\Delta V_{steadystate} = 100 * \%\Delta V_{steadystate} / V_0$ and $\%\Delta Vmax = 100 * \%\Delta V_{steadystate} / V_0$

Categories 1 and 2 Rapid Voltage Change

The proposed limits fall within the criteria currently specified within the Grid Code in magnitude.

Category 3 Rapid Voltage Change

For this category of Rapid Voltage Changes, operations are restricted to those required for commissioning, planned maintenance and fault restoration which are infrequent in nature. The cost benefit case for applying tighter limits is weak in these situations as the cost of mitigation would be spread across a limited number of short occurrences.

The proposed time dependant characteristic is shown in Figure 2.

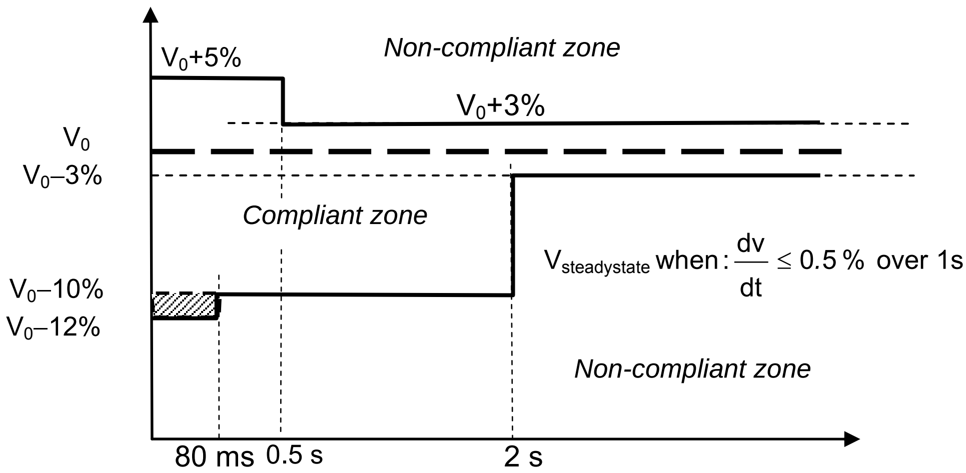

Figure 2- Limits for Category 3 Rapid Voltage Changes

Note also:

1) V_0 is the initial steady state system voltage;

2) All voltages are the rms of the voltage measured over one cycle refreshed every half a cycle as per IEC 61000-4-30 [16];

3) A steady state voltage is said to have reached when dv/dt ≤ 0.5%, with reference to the rms of voltage averaged over 1 second;

4) The shaded area is proposed as it is in accordance with 12% voltage change stipulated in NETS SQSS. The duration of the maximum allowable depth (V_0 - 12%) has been specified in coordination with fast acting voltage controllers;

5) The voltage changes specified are the absolute maximum allowed; applied to phase to ground or phase to phase voltages whichever is the highest. Thus in order to determine maximum voltage changes, assessments should consider propagation of voltage changes to other voltage levels through three phase transformers with different winding arrangements.

Impact & Assessment

<u>Impact on the National Electricity Transmission System (NETS)</u>
None as power quality will be maintained to current standards

<u>Impact on Greenhouse Gas Emissions</u>[2]
None

<u>Impact on core industry documents</u>
None

<u>Impact on other industry documents</u>
None

<u>Assessment against Grid Code Objectives</u>
Will the proposed changes to the Grid Code better facilitate any of the Grid Code Objectives:

(i) to permit the development, maintenance and operation of an efficient, coordinated and economical system for the transmission of electricity;
(ii) to facilitate competition in the generation and supply of electricity (and without limiting the foregoing, to facilitate the national electricity transmission system being made available to persons authorised to supply or generate electricity on terms which neither prevent nor restrict competition in the supply or generation of electricity) ; and
(iii) subject to sub-paragraphs (i) and (ii), to promote the security and efficiency of the electricity generation, transmission and distribution systems in the national electricity transmission system operator area taken as a whole.

This proposal will better facilitate objectives (i) and (ii) by ensuring that there is only a need to install additional equipment and/or modify connection designs to manage voltage fluctuations where absolutely necessary.

Supporting Documentation

Have you attached any supporting documentation	**[YES]**
If Yes, please provide the title of the attachment:	**References**

Recommendation
This section is used to identify what you would like the GCRP to do on the basis of the information provided in this proforma. Below are some possible examples:

The Grid Code Review Panel is invited to:

Approve this issue for progression to an Industry Consultation

[2] The most recent guidance on the treatment of carbon costs under the current industry code objectives can be found on the Ofgem website at: http://www.ofgem.gov.uk/Licensing/IndCodes/Governance/Pages/Governance.aspx

GCRP Decision (to be completed by the Committee Secretary following the GCRP) The Grid Code Review Panel determined that this issue should: **INSERT GCRP DECISION**

Document Guidance
This document is used to raise an issue at the Grid Code Review Panel, as well as providing an initial assessment. An issue can be anything that a party would like to raise and does not have to result in a modification to the Grid Code or creation of a Working Group.

The Grid Code Administrator, National Grid, is available to help any party complete this proforma. Please contact grid.code@uk.ngrid.com if you have any queries.

References

List of literature surveyed in the development of this proposal:

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[2] IEC 61000-2-1:1990, Guide to Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems.

[3] IEC 61000-4-11:2004, Electromagnetic compatibility (EMC) —Part 4-11: Testing and measurement techniques — voltage dips, short interruptions and voltage variations immunity tests.

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