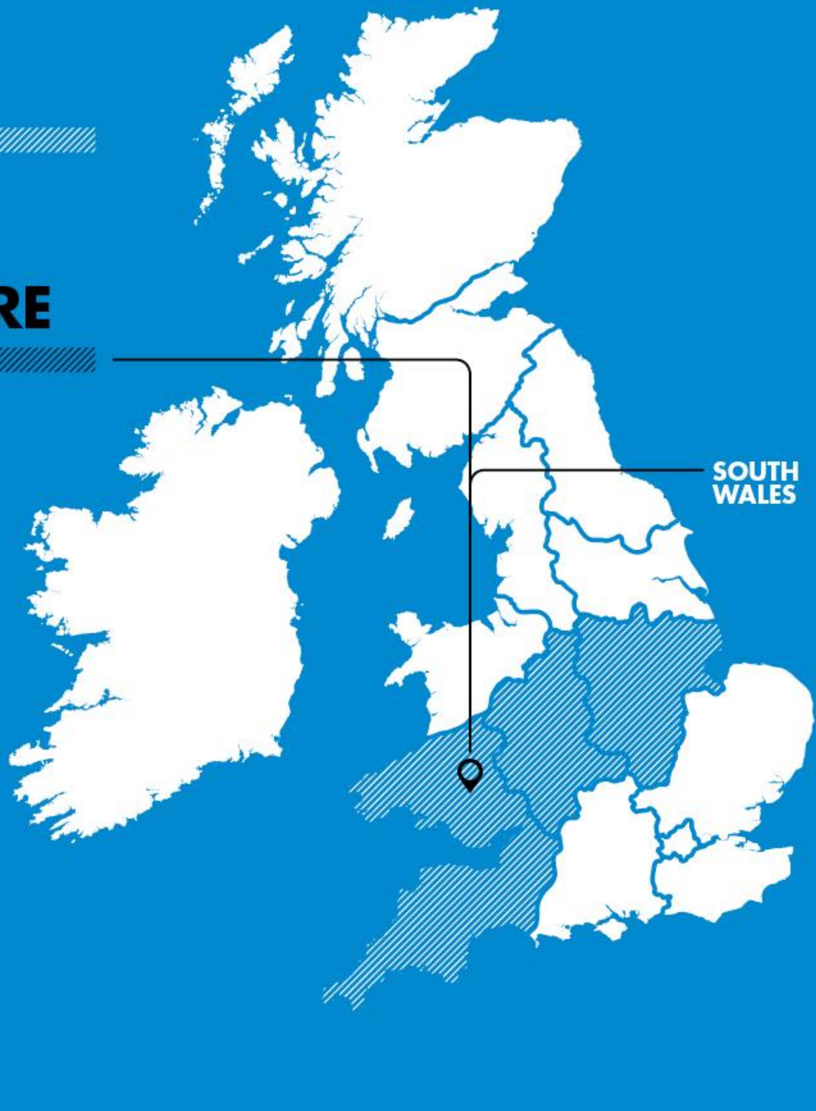
WESTERN POWER DISTRIBUTION

NETWORK TEMPLATES

LV NETWORK TEMPLATES FOR A LOW-CARBON FUTURE



Discussion Paper on Adoption of EU Low Voltage Tolerances

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1. INTRODUCTION

Western Power Distribution (WPD) submitted a Tier 2 project to Ofgem in 2010 entitled " LV Network Templates for a Low-carbon Future " [ref 1] It proposed widespread monitoring of HV/LV substations and LV feeder end voltages across wide areas of urban, suburban and rural areas of South Wales. The primary aims of the project were to establish a set of "templates" characterising different cluster types of load and associated voltage profiles to aid in future UK LV network planning and to identify headroom constraints and opportunities available against each template for the absorption of future low carbon stresses.

Iin the presentation to the Expert panel on 19th October 2010 , WPD stated that the Project would also aid understanding of the ability of UK to move to the wider EU low voltage tolerances. Since legislation would be required to enable such change, the Project itself made no claim on delivering the associated savings in maximum demand, energy or CO2.

This discussion paper outlines relevant findings from the WPD LV Templates project and, draws these together with other key Government and national statements and data sources, in order to identify the range of benefits and potential issues that that could result from such adoption and proposes a way forward.

2. PRESENT UK LEGISLATION

The Electricity Safety Quality and Continuity Regulations 2002 ("ESQCR"s) came into force on 31st January 2003 [ref 2] . Regulation 27 (2) set the declared nominal low voltage to be 230V AC, and Regulation 27 (3b) set the permitted variation at +10% and -6% of that voltage. The associated Guidance to the ESCQRs [ref 3] was issued by the Department of Trade and Industry at the same time [Publication reference - URN 02/1544]; and included the following statement - *"All duty holders should note that in 1993 the UK government committed to harmonisation of low voltage tolerances across the European Community in accordance with CENELEC document HD 472 S1. In July 2001 the CENELEC Technical Board decided to extend the existing tolerance for low voltage systems (see regulation 27(3)(b)) to 2008, at which time it is possible that further consolidation of voltage tolerances across Europe will take place*".

The Harmonisation Document HD 472 S1 provides for a wider permitted tolerance on low voltage supplies; whilst the upper limit tolerance is the same as UK at +10% the lower limit is -10% rather than the -6% of current UK legislation. Whilst UK Government has not yet adopted the above commitment, HD 472 has since been superseded by EN 60038 - 2011 which contains the same tolerance band.

It is thus evident that UK Government has contemplated, committed to, and given notice of a future change in LV tolerance over a period of more than 20 years.

3 HOW IS WPD'S LV TEMPLATES PROJECT RELEVANT TO THIS DISCUSSION PAPER?

Present day electricity networks are gradual evolutions of those originally installed in cities over 100 years or more and throughout the countryside through rural electrification into the 1950s. As further demand or generation is attached, networks have been extended or strengthened, with network *design* being checked at that time using the design tools available. Whilst there are many years of data showing half hourly demands and voltages that occur at the EHV/HV substations (typically 33/11kV or 66/11kV), there has been no equivalent level of monitoring on the 11kV and low voltage networks due to unavailability of suitable and economic monitoring and related communication systems. Information on patterns of demand of individual customers has essentially been restricted to knowing their annual electricity energy consumption in kWh.

Consequently ,whilst distribution network operators take care in designing their networks to meet the above statutory voltage limits, in practice checks on actual levels are limited to spot checks or responding to customer complaint. Prior to the WPD LV Templates Project there had not previously been such an extensive monitoring project to investigate just how close, or not, actual low voltages are to the statutory limits and how those vary through the day, week, season and year.

The WPD LV Templates Project has taken the opportunity to addressed this information gap through monitoring 10 minute average voltages (a measure set out in EN 50160 [ref 4] at over 4,400 points on the LV network. These points, at the HV/LV substation and at the ends of low voltage feeders were deliberately selected to identify the highest and lowest LV network voltages experienced by customers. The measurements extended over a period of April 2012 to the end of February 2013 and captured over 177 million readings. It is understood to be the widest and most extensive LV monitoring project ever undertaken in UK. The findings of this work are reported in detail in WPDs report "Stresses on the LV Network caused by Low Carbon Technologies" [ref 5] . Tables 11 and 12 of that report, , show that over 99.4% of these 177 million voltage measurements were within limits, and of the small number outside, the majority were overvoltage and just 0.015% were below the lower limit;. This indicates that historic network planning has been successful in meeting statutory limits, and that any future move to expand the LV voltage tolerance from -6 to -10% would not in actuality either "legalise" supplies that were currently outside statutory limits or result in Customers facing actual voltages that were even outside the wider EU limits.

In summary, the WPD Project has confirmed that -

- The current system behaves extremely well with existing limits consistently being met
- The very low number of voltage measurements outside present day limits are predominantly over-voltage rather than under voltage issues
- Consequently adoption of the wider EU LV voltage limits coupled with a decrease in target LV operating voltage could be contemplated without the prospect of discovering widespread instances of undervoltage

4. WHAT WOULD BE THE EFFECT OF LV VOLTAGE REDUCTION AND HOW WOULD IT BE ACHIEVED?

If all electricity demand were purely resistive, Ohms law would mean that instantaneous power demand (ie kW) would drop in proportion to the square of the voltage, so, using a simple figure to illustrate the point a 10% drop in voltage would reduce demand by 19% (0.9 x 0.9) . In practice the demand on the UK electricity networks comprises a mix of demand types, including motors, which do not respond in such fashion.

In times of severe system stress, National Grid can call on network operators to reduce demand through widespread application of voltage reduction in two steps; -3% and -6%.
(The Grid Code - OC6)] [ref 6)] These are applied by sending signals to the automatic voltage control equipment at grid or primary substations which control the on load tap changers fitted to 33/11 kV and higher voltage distribution network transformers. It had traditionally been the case that demand reduction of 10% would be achieved from a 6% voltage reduction. However, during actual events since 2006/7 and subsequent trial involving domestic, commercial and large industrial demand groups, a 3% voltage reduction gave an average of 3.4% demand reduction against the 5% historically expected.(source - National Grid - Grid Code OC6 Demand Control Working Group) [refs 7 & 8] Consequently the estimation has been reduced to a 3% voltage reduction producing a 3% demand reduction. Further voltage reduction system tests are planned to be undertaken in September and October 2013 [ref 9]

The above studies relate to the drop in instantaneous *demand* (kW), but not to the reduction in *energy* demand (kWh). For example, if the voltage supplied to a nominally 3kW electric kettle were reduced, it would produce less than 3kW, but it would still boil the water, albeit over a longer period, so the kWh usage would be the same. A light bulb however would produce less output but the time it was on would not be influenced. Motors may take higher current to compensate for reduced voltage. Thus as above, the mix of demand types means that there is not a straightforward relationship between *demand* reduction and *energy* reduction. Arguably the best data to date has come from the above National Grid / GCRP tests, which have quoted a 1 for 1 relationship; 1% voltage reduction producing both a 1% demand reduction and a 1% energy reduction. [ref 10]This is a higher level of reduction than that used in the above WPD LV Templates project "Stresses" paper [ref 5] to provide an estimate of benefit.

There are other sources of data relating to energy reduction arising from voltage reduction to the low voltage supplies to individual customer demands; typically in the industrial and commercial sectors. Various companies market voltage step down transformer arrangements aimed at reducing voltage to so called "optimum" levels, to reduce energy consumption. One such Company is Powerperfector which publishes a number of case histories relating to its installations, which include the offices of DECC and Ofgem, quoting annual kWh savings of 11% for Whitehall Place from a 10% voltage reduction, and 9.1% for Ofgem's Millbank offices. Whilst such individual examples assist the argument that voltage reduction leads to demand reduction, they cannot be compared to the National Grid experience as they are effectively self selecting; if it were not viable, the installation would not have occurred.

5 WHAT WOULD BE THE VALUE OF A NATIONAL REDUCTION IN SUPPLY VOLTAGE?

If it were accepted that UK would adopt the wider EU low voltage tolerances of +/- 10%, the WPD LV Templates project provides good evidence that supplies are within the existing lower -6% tolerance, it means that the additional 4% tolerance is all truly available to use.
For reasons further discussed below, a widespread reduction of 2.5% in HV and LV supply voltage is explored here. It would provide some leeway and still maintain 3.5% of the National Grid / GCRP OC6 voltage control demand response.

Such reduction in voltage could be readily achieved across networks through alteration of the automatic voltage control relay target HV (normally 11kV) voltages at primary substations. If it were necessary *in the exception* to increase end LV supply voltages to customers this might still be possible by taking outages for off circuit adjustment of HV/LV transformer taps since UK HV/LV ground mount distribution transformers are equipped with +/- 2.5 and 5% off circuit tapping switches, and UK pole mounted transformers normally have in tank +/- 5% bolted link taps. This is also a reason why a figure of 2.5% voltage reduction is discussed here. Diagram 1 attached, illustrates a "before" and "after" scenario of voltages and tap positions on an LV network from a distribution substation.

The National Grid / GCRP studies referenced indicate that such a 2.5% voltage reduction would produce both a 2.5% average reduction in demand and energy on the networks to which it was applied. Such reductions could be attractive to both Government and end users because it would -

- produce an immediate increase in generation capacity margin
- produce a reduction in UK electricity generation sector greenhouse gas emissions an aid achievement of Kyoto targets
- provide the cost benefits of energy reduction to millions of end users who cannot afford investment in such "voltage optimisation" equipment currently marketed
- provide additional headroom capacity for connection of LV distributed generation and LV loads including low carbon transition demands such as EV charging and heat pumps

The quantification of these benefits is naturally complex; ,the WPD LV Templates report on network stresses sought to illustrate a scale of benefit to domestic customer bills based on a deliberately pessimistic assumption of a 1.5% energy reduction arising from a 2.5% voltage reduction and using Ofgem published figures of average cost to customers per kWh and average consumptions. It is now possible to enhance that estimate of scale using the National Grid / GCRP OC6 data and drawing on up to date DECC and Elexon data on energy use as referenced below.

DECC 2013 Digest of UK Energy Statistics ("DUKES") (Table 5.1 page 132) -[ref 11] shows total UK electricity energy use of 317,575GWh in the 12 months ending 29 Dec 2012. Of this 114,698 GWh from domestic customers and thus can be deduced to be supplied at low voltage, with a further 18,891 GWh from public administration and 78,206 GWh from Commercial use. However, the DUKES data does not separate these demand classes by voltage of supply and so it is necessary to seek other data sources to determine the overall level of supplies made at LV.

DECC estimated [ref 12] that in 2012 there were 23.3 million domestic Standard electricity customers and 3.9 million Economy 7 (E7) electricity customers in the UK, and that their average annual consumption in kWh in 2012 was 3780 kWh at Standard tariff and 6430 kWh of Economy 7, "giving an overall average per customer of 4160 kWh". (this calculation assumes that E7 customers do not also have standard rate connections, as it has added together the two customer counts) Table 3 of the same document shows an average [peak price per kWh at Standard rate of 12.66p / unit. and E7 at 15.28p /unit peak and 6.2p / unit off peak. Since the split between on and off peak units for Economy 7 customers is not known, the estimate of saving in domestic customer bills outlined below, will assume all E7 demand was at low rate, and thus represents a conservative assumption.

(Ofgem state [ref 13] that the average domestic electricity customer used 3,300kWh, but as that figure does not currently reflect either DECC or Elexon statistics, it has not been used)

In the period up to June 2013, Elexon have provided customer number and annual energy data covering each of the 8 Non Half Hourly Profile classes, of which Classes 1 & 2 cover domestic customers. Those show 22,699,632 profile class 1 domestic customers (the class 2 customers are domestic economy 7 users and thus included also with class 1 count) . In total the class 1 and 2 customers used 112,134 GWh in that later 12 month period. The equivalent demand of the other 6 Elexon non half hourly profile customers was 52,496,485 GWh. It is reasonable to assume that all of these will use supplies at LV, indicating a National level of some 164,631 GWh.

A 2.5% reduction in just the LV supply energy use would thus amount to some 4115 GWh.
DECC 2013 DUKES data (Table 5C) [ref 11] for 2012 shows a provisional figure of 483 Tonnes of CO_2 / GWh of electricity supplied (457 Tonnes in 2010 and 440 Tonnes in 2011)

Taking that a voltage reduction applied at primary substation level would also apply to HV connected customers, the *annual* carbon reduction figure of an annual 1.98 Million Tonnes of CO2 is conservative for the current generation mix

The estimation of reduction in peak demand currently relies upon the National Grid / GCRP OC6 work, which indicates that a 2.5% reduction in voltage applied at primary substation level would produce a 2.5% reduction in demand. Maximum system demand in 2012 was 57,490 MW on 12th December 2102 (DUKES 2013 para 5.41) [ref 11] .In the absence of a breakdown of that maximum demand by supply voltage, an estimate split on the basis of non half hourly demand consumption of 164,631 vs total demand of 376,241 GWh (which includes electricity industry use and losses) gives a conservative approximation of 43% An indication of reduction in system peak demand is thus 618 MW.

The Transmission Entry Capacity of major generators for the same period was 81,742 giving a margin of 24252 MW, and thus a saving of 618 MW would (coincidentally) also represent an increase of 2.5% in current capacity margin, though that figure would increase with impending station closures.

For just the domestic customers, using the above DECC data from ref 12, a reduction of 2.5% in energy use would amount to a saving of some 2201 GWh at Standard rate and 626 GWh at E7 rates, representing a saving of £11.95 per Customer at Standard rate and at least £9.95 per E7 customer on the basis of the above unit rates.

At that rate, the value *to domestic customers* alone of such a reduction in energy would thus be some £ 315M p.a

6 HOW WOULD SUPPLY VOLTAGES OF CUSTOMERS BE VERIFIED?

The end of the mass roll out of smart meters across UK is scheduled to be completed by 2020 [ref 14] DECC Smart Meters Programme Delivery Plan, 10th May 2013 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197794/smart_meters_programme.pdf] . The latest (1st July 2013) specification of those smart meters [ref 15] includes a for a number of voltage quality measurements -

- Average RMS voltage
- RMS extreme over voltage detection
- RMS extreme under voltage detection
- RMS voltage sag detection
- RMS voltage swell detection

There are thus already established detailed plans for national roll out of devices which will provide widespread continual monitoring of voltages supplied, providing confirmation that supplies are within limits, and on the basis of the LCNF LV Templates project findings, exceptionally those instances where they are not.

7 ARE THERE ARGUMENTS AGAINST VOLTAGE REDUCTION ?

Whilst there are a great number of benefits, some stakeholders may argue that there are some adverse impacts, These may include unsuitability of older installations to satisfactorily operate beyond the presently existing -6% limit, though of course the majority of customer supplies would still sit within that tolerance even after a 2.5% voltage reduction. It is worth noting that UK Government signalled its intention to move to the +/-10% LV tolerance range some 20 years ago and reiterated this in the publication of the ESQCRs in 2002.

The existing policy of phasing out of tungsten light bulbs, which have a very strong light output to voltage relationship assists in the elimination of that issue, which would have been noticeable to many users.

Evidence of roll out of so called voltage optimisation equipment to the commercial and industrial and commercial LV customer base suggests that many of that class of user would see benefit rather than problem.

There could be some primary substations where the existing tap range of transformers is inadequate to accomplish the voltage reduction, but a change in the statutory range does not mean that reduction has to be implemented everywhere.

There would be some issues on Demand Response on deployment of Grid Code OC6 voltage reduction;

- a reduction of 2.5% in 11kV target volts coupled with a reduction of 4% in the lower voltage statutory limit can actually be argued to improve the relationship between maintenance of statutory limits and exceptional event (GC OC6) levels
- a 24/7 reduction in demand could provide an improvement in plant margin

8 NEXT STEPS

This discussion paper has been prepared in the light of the findings of the Western Power Distribution LCNF LV Network Templates project and more specifically, the findings of the extensive LV voltage monitoring it included. Whilst the above estimations of benefit have been made using current and robust Government and Elexon data, they are naturally indicative at this point due to an absence of availability of further data breakdowns. Western Power Distribution are to shortly meet with National Grid to seek their view on potential national level benefits

An extended period has elapsed since UK Government announced its intention to adopt European low voltage levels, since when there has been a proliferation of installation into the UK of products which are of common specification to other EU areas.

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There are currently multiple issues facing the UK for which LV voltage reduction would offer some counter mitigation, that on the basis of WPD's findings, could entail low cost

- **Reduction of demand and customers bills**
- **Increase in national generation capacity margin**
- **Reduction in national CO_2 emissions**
- **Provision of additional headroom capacity to connect LV distributed generation and low carbon loads such as heat pumps and EV charging**

Whilst WPD promoted the issue of adopting EU voltage limits in its presentation to the Ofgem Expert Panel in October 2010, there has also recently been wider recognition of the potential for temporary voltage reduction. The recent Electricity North West CLASS proposal, considers remote controlled temporary voltage reduction, but not a change in statutory limits and the long term permanent benefits could accrue from that.

Consequently, it is strongly believed that there is now a case for initiating wider debate to underpin the issuing by DECC of a public consultation. Given the range of stakeholders potentially involved, initial discussion might be facilitated by the Energy Networks Association, or by Ofgem.

9 REFERENCES

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2 Electricity Safety Quality and Continuity Regulations 2002 ("ESQCR"s - S.I . 2002 No 2665 - http://www.legislation.gov.uk/uksi/2002/2665/pdfs/uksi_20022665_en.pdf

3 Guidance to the Electricity Safety Quality and Continuity Regulations 2002 - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82784/GuidElectSafety_Quality.pdf - page 38

4 EN 50160 – 2007 "Voltage characteristics of electricity supplied by public distribution networks"..
Clause 4.2 sets minimum standard voltage Un at 230V.
Clause 4.3.1 limits voltage variation to +/- 10%, with caveat " situations like those arising from faults or voltage interruptions , the circumstances of which are beyond the reasonable control of the parties, are excluded".
Clause 4.3.2 defines the above measurements – "during each period of one week, 95% of the 10 minute average r.m.s. voltages shall be within the range of UN +/- 10% " and ,"all 10 minute average r.m.s. values of supply voltage shall be within the range of Un +10/-15%

5 Stresses on the LV Network caused by Low Carbon Technologies" - Western Power Distribution - http://lowcarbonuk.com/downloads/StressReport.pdf

6 Grid Code OC6 - http://www.nationalgrid.com/NR/rdonlyres/33623B15-D351-4489-9BF9-11AF8E921BA5/55761/13_OPERATING_CODE_6_I5R0.pdf

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8 National Grid - Grid Code Working Group - Demand Control OC6 - minutes of meeting 10 April 2013 - item 11 - http://www.nationalgrid.com/NR/rdonlyres/10BE5987-67A3-4FB1-BFFB-B1B3E5C53933/60570/DemandControlThirdWorkgroupMinutes_final_.pdf

9 National Grid - Grid Code Working Group - Demand Control - OC6 - verbal update from WG Member 14 Aug 2013 - system tests are planned to be undertaken in September and October 2013

10 National Grid - Grid Code Working Group - Demand Control - OC6 - slide 8 of presentation by NG Tim Truscott 23rd May 2012
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http://www.nationalgrid.com/NR/rdonlyres/32879763-057D-4CF4-8C9D-194EC390B4F0/59528/DemandControlSecondWorkgroupMinutes1.pdf

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Domestic energy bills in 2012: The impact of variable consumption
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/170709/et_article_domestic_energy_bills_in_2012.pdf

13 Ofgem Factsheet 98 dated 16th January 2013 - "Updated - household energy bills explained" Typical domestic energy consumption figures
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14 DECC Smart Meters Programme Delivery Plan, 10th May 2013
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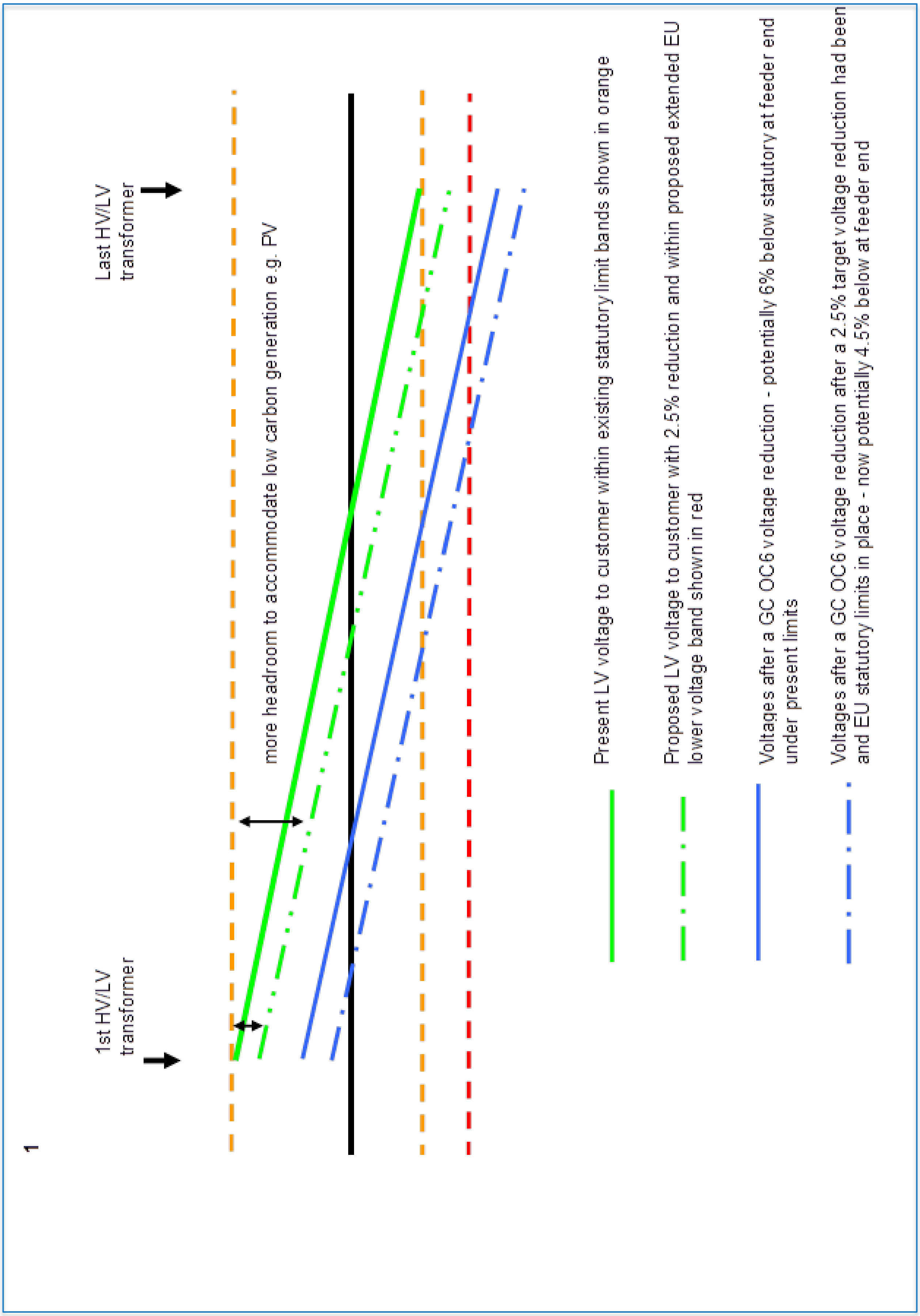
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1st HV/LV transformer
Last HV/LV transformer
more headroom to accommodate low carbon generation e.g. PV
Present LV voltage to customer within existing statutory limit bands shown in orange
Proposed LV voltage to customer with 2.5% reduction and within proposed extended EU lower voltage band shown in red
Voltages after a GC OC6 voltage reduction - potentially 6% below statutory at feeder end under present limits
Voltages after a GC OC6 voltage reduction after a 2.5% target voltage reduction had been and EU statutory limits in place - now potentially 4.5% below at feeder end