Top and Tail Transformation
A Grand Challenge in Energy Networks

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Consumer attitudes to changes in electricity supply voltage

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Executive Summary

This report forms part of 'Transformation of the Top and Tail of Energy Networks' (TTaT), an Engineering and Physical Research Council (EPSRC) Grand Challenge research programme. The report was co-funded by the UK Energy Research Centre (UKERC) Technology and Policy Assessment (TPA) theme as it informs the TPA project which is exploring the available evidence on public attitudes to voltage quality[1].

The TTaT programme was conceived to address network capacity constraints in order to facilitate the transition to a low carbon economy. If UK targets for low carbon technologies are to be met then additional transmission and distribution network capacity will be required. The UKERC TPA team's remit is to conduct systematic reviews of the evidence, supplemented by primary research and wider stakeholder engagement where required, to address contentious issues in the energy policy arena.

This contribution is concerned with the low voltage, consumer side of distribution networks and builds upon an earlier TTaT report concerning the 'Impact of Wider Voltage Tolerance on Consumer Electronics and Wider Socialised Costs' (Frost & Mitcheson, 2013). This report aims to contribute to the understanding of the consumer's attitudes to power quality with a view to informing policy development. By better alignment of thermal capacity and voltage constraints, adopting a voltage range with a lower permissible limit has been shown to be an alternative to system reinforcement (ibid). However if supply voltages are reduced, there is a risk that some appliances may malfunction or provide reduced quality of service (QoS).

Examining consumers' attitudes to the possibility of such malfunction provides a tangible starting point for consideration of the impacts of a regulatory change. However, this report also sheds light on the uncertain context in which this change is being proposed, and this introduces uncertainties as to the likely impacts of change upon the consumer. One of the complexities, for example, is that currently solar photovoltaic (PV) systems can cause voltages to rise above regulatory limits. Accordingly the original TTaT scope of reduced voltages, becomes less relevant and investigation was extended to cover attitudes to over-voltage conditions.

Because of the lack of literature on consumers' understanding and attitudes related to power quality (PQ), and QoS, a pilot study was conducted, comprising 30 semi-structured interviews. As well as exploring experiences and attitudes to appliance malfunction, the interviews aimed to establish prior knowledge about voltage, and understanding of the Distribution Network Operator's (DNO) role in supplying power and managing PQ.

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[1] See http://www.ukerc.ac.uk

While interviewees had little existing experience of actual problems, when asked to imagine issues arising in a future scenario, they responded in a fairly consistent pattern. In summary those interviewed, on average:

- Had little knowledge or experience of, power quality (PQ) related, quality of service (Qos) issues;
- In terms of QoS, were most concerned about potential food spoilage from failed refrigeration;
- Had a reasonable knowledge of the existing nominal voltage and possible extremes;
- Had a reasonable understanding of the risks associated with voltage extremes;
- Had little knowledge or understanding of the role of the DNO;
- Considered their supplier to be the main actor to contact and handle PQ/QoS issues;

The interviews moved on to explore attitudes to roles and responsibilities in a future scenario of increased adoption of low carbon technologies and widespread smart metering. In this setting the interviewees, on average:

- Expected the DNO to use smart meter data to manage voltage;
- Rated managing safety as the DNO's primary role;
- But also believed cost efficiency is important;
- Would trust their supplier ***and*** DNO to provide information;
- But would continue to call their supplier in the event of QoS issues;
- May turn off appliances to minimise damage in the event of high voltages.

To use these observations to inform policy however requires that a position is taken with regards to whether consumers should play an active or passive role in monitoring voltage and this possibility depends on whether voltage data will be communicated via a smart meter 'in home display' (IHD).

However, given that current regulatory misalignment is already introducing risk, irrespective of delivering a TTaT regulatory change, the following areas of policy would benefit from review:

- Are G83 voltage upper limits appropriate and safe?
- Responsibilities with regards to the costs incurred by under and over-voltage events;
- European voltage standards and testing requirements;
- Smart meter IHD requirements with a view to including voltage trends and events;
- Education of the public (if engagement is appropriate), about DNO's role, and when and how to them contact in the event of QoS or PQ issues.

With the rapidly changing 'demand–side' environment these issues may become more pressing and if unresolved negative events could result in an erosion of trust in the technologies and the organisations delivering them, slowing progress to de-carbonisation.

Glossary

AC	Alternating Current
BaU	Business as Usual
DC	Direct Current
DCC	Data Communications Company
DR	Demand Response
DSM	Demand Side Management
DUoS	Distribution Use of System (charges)
EPSRC	Engineering and Physical Research Council
EV	Electric Vehicle
FIT	Feed in Tariff
HP	Heat Pump
HV	High Voltage (typically 11kV in distribution)
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IHD	In Home Display
LV	Low Voltage (residential supply voltage)
PQ	Power Quality
PV	Photovoltaic
QoS	Quality of Service
RHI	Renewable Heat Incentive
RMS	Root Mean Square
TTaT	Transformation of the Top and Tail of Energy Networks

1 Introduction

This report forms part of the Transformation of the Top and Tail of Energy Networks (TTaT) research programme, an Engineering and Physical Research Council (EPSRC) Grand Challenge, and also forms an input to the UK Energy Research Centre (UKERC) Technology and Policy Assessment (TPA) theme project which is exploring the available evidence on public attitudes to voltage quality[2]. It builds upon an earlier TTaT report, concerning the 'Impact of Wider Voltage Tolerance on Consumer Electronics and Wider Socialised Costs' (Frost & Mitcheson, 2013), by examining the potential impacts of a regulatory change from the consumer's perspective. It was originally conceived that this analysis would comprise a systematic literature review (Bilton & Spiers, 2015) but a lack of existing material necessitated some gathering of new evidence in the form of semi-structured interviews.

1.1. Policy context

UK energy policy is promoting the decarbonisation of grid level electricity generation, increased deployment of low carbon distributed energy generation, at the same time as significant changes in electricity demand. The changing landscape on the 'demand side' of the electricity system is largely driven by government policy promoting electric vehicles (EV), heat pumps (HP) and photo-voltaic solar panels (PV) (Emhemed & Burt, 2013).

Electricity distribution systems are emerging as a potential bottleneck to the deployment of low carbon technologies. The new loads of EVs and HPs pose a challenge because, in residential terms, they are high power loads and often coincide with existing evening peak demand; and this determines what is known as the thermal capacity requirement for distribution network assets (ibid). In addition, as the electrical load through a cable is increased, then voltage decreases. PV poses an opposing challenge in that if levels of generation approaches levels of demand then voltage can rise. This is more likely in summer when demand is low and PV generation high. With existing industry norms, that is running low voltage (LV) systems at the top end of the regulatory range, over-voltage is very likely with even modest PV penetration (Bilton, et al., 2014).

Whilst these 'demand side' technologies are a long way from being ubiquitous, and the success of policy uncertain, if adopted in significant numbers then issues will arise (ibid). In addition to low carbon technologies, smart meters are due to be installed in all residential and small businesses across the UK by 2020. Whist the original cost-benefit justification for smart meter roll-out in the UK was 'energy saving' (DECC, 2009),

[2] See http://www.ukerc.ac.uk

subsequent research has shown that, using time varying pricing, there is significant potential for flexibility in shifting or reducing demand at times of high price (and visa-versa) (Schofield, et al., 2014).

In addition, and pertinent to TTaT, the Distribution Network Operator (DNO) will be able to profile voltage at any property, as well as receiving alerts when voltage is outside regulatory limits. In addition customers ***may*** be able to read the system voltage from their 'in home display' (IHD) (DECC, 2014). These metering functions could facilitate a significant change in the consumer's relationship with the wider electricity systems, with dynamic prices reflecting wholesale market conditions and voltage data reflecting the effect of localised power flows.

1.2. Responding to changing power flows

There are a number of approaches to mitigating the effects of changing power flows on the distribution system, approaches include:

- Cable and/or transformer replacement would be the traditional means of accommodating load growth, but this would very costly if widespread. Lower impedance cable can also ameliorate over-voltage conditions;
- Meshing or re-meshing of the low voltage (LV) network is also being considered to reduce stress by using spare capacity from adjoining circuits. This approach requires new technology to manage these connections dynamically, since load flows for different sectors change with seasonal and diurnal cycles (UK Power Networks, 2015);
- Demand Side Management (DSM), including energy efficiency, and demand response (DR) activities could free up capacity. Residential efficiency savings could still yield around an additional 20% peak reduction (Bilton, Schofield, & Strbac, 2013). However the delivery of DSM is not a role typically associated with distribution companies, except where vertically integrated systems are the norm, as in the US;
- Relaxation of the voltage regulatory lower limit. With this approach no physical system change is required. Instead the voltage is allowed to fall below existing regulatory limits, in effect increasing the amount of power that can be delivered through a given cable.

The Transformation of the Top and Tail of Energy Networks (TTaT) project is concerned with the fourth approach. In a previous TTaT report, Frost and Mitcheson (F&M) (Frost & Mitcheson, 2013) show that if voltage supply limits were to allow for greater voltage drop then considerable cable capacity is released. This would allow:

- Additional cable loading, without damage (provided current flow is within the cables thermal limits);
- And/or the reduction of transformer secondary voltages, to facilitate more PV adoption without over-voltage.

This report examines the likely impacts of such changes to the consumer, and consumer attitudes to such change and the implications for policy development.
Based on initial observations, relaxing the voltage regulations would appear to be an attractive option, given the high potential costs of cable replacement. However such a change is not without risk. Changes to regulations have the potential to affect the consumer's experience, in terms of the effects of changes to Quality of Service (QoS), and in extremis, risk of appliance failure and associated consequences. These are reasonably well covered by F&M in technical terms, but less so in terms of their impact upon the household.

If voltages are kept within the limits proposed by F&M, then the risk of appliance malfunction appears low. However, the low voltage systems often experience 'needle peaks' of load (Hand, Kelly, & Samuel, 2015), and voltage may fluctuate around a measured average. From here, we consider the potential risks associated with:

- Short term breaches of regulatory limits, which are not typically measured or accounted for;
- Long termer under-voltage, typically caused by lack of supply capacity;
- Over-voltage caused by solar PV.

Increased feeder loading will cause lower voltages, most evident at network extremities and in periods of high demand, such as winter evenings. At such locations and times, some appliances will deliver a lower QoS. For example, power quality (PQ) symptoms that people will be familiar with are dimming lights, and cooker-clocks resetting etc. See Chapter 3 for a fuller list of QoS issues related to PQ.

More serious consequences of under-voltage may include the stalling of Single Phase Induction (SPI) motors in refrigeration devices, for example, and over-current in electronic power supplies. Some effects may be tangible but low risk, others may go unnoticed, for example temporary refrigeration failure.

1.3. Report structure

In the following chapter we introduce the role of the DNO and the current practices surrounding power quality. The potential consumer experiences are the focus of Chapter 3, which developing upon F&M's report, characterises the likely effects of voltage deviations on the most common residential energy services.

Based upon these findings, in Chapter 4, we move to a social science perspective and examine consumer understanding of, and associated attitudes to:

- Quality of Service (QoS) issues with appliance;
- Existing voltage levels;
- Roles and responsibilities, in the case of QoS issues.

An initial literature review revealed a dearth of prior analysis on these subjects, suggesting some need for data gathering activity. To this end, the classification of impacts to the consumer, as defined in the preceding Chapter 3, is used to inform a semi-structured interview schedule.

As part of the interview schedule development, Chapters 3's 'summary of impacts' content, and the questionnaire schedule were reviewed by an Imperial College expert group comprising F&M and Professor Tim Green.

A review of attitudes is somewhat complicated by the fact that a 'no change' scenario of power quality management is, as revealed in Chapter 5, potentially more risky than a reduction of supply voltage scenario. This is because currently solar panels can increase voltage above the 253V regulatory limit. The relative likelihood of over-voltage or under-voltage events will be highly site specific and dependent on the how 'demand side' technologies are deployed.

In order to manage this complexity, policy and DNO practice scenarios are considered independently from perception about specific QoS impacts. Following a summary of the interview findings, these separate threads are then integrated in the Synthesis chapter. The report concludes with policy recommendations and identifies to how transition risks might be minimised through consumer engagement and use of smart meter technology.

2. Management of electricity supply quality

2.1. Distribution Network Operators

Distribution Network Operators (DNO) are responsible for the delivery of electricity from the national transmission network to homes and businesses. This involves the maintenance and development of the physical aspects of the network, namely towers, cables, transformers and control gear; and the control of the network to ensure continuity and quality of supply (National Grid, 2015).

At the time of writing, seven companies were responsible for all of the UK's distribution networks: Electricity North West, Northern Ireland Electricity, Northern Powergrid, SP Energy Networks, SSE Power Distribution, UK Power Networks and Western Power Distribution (ibid).

UK Power Networks were responsible for London's distribution networks (known as LPN, EPN and SPN) and the cohort of interviewees, discussed in Chapter 4, came from the LPN network area which covers the bulk of Greater London.

2.2. Power quality

The electricity network is expected to provide reliable and uninterrupted power supply to consumers. To achieve this, electricity supply to consumers must be of an appropriate voltage, and frequency (i.e. voltage and frequency of supply must be within predetermined limits) and have a near sinusoidal waveform (Polycarpou, 2011).

Power Quality (PQ) is defined by the Institute of Electrical and Electronics Engineers (IEEE) standard as:

> 'The concept of powering and grounding electronic equipment in a manner suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment' (IEEE Standard 1100 1999).

For optimal operation, electrical loads require a stable and consistent power supply. On the other hand, low power quality electricity causes connected loads to operate at a reduced efficiency, or not to operate at all. It can also lead to reduced lifespan and ultimately the failure of appliances, resulting in higher economic and environmental costs, and posing dangers in households and places of work.

Power quality variations can be divided into two basic categories according to how they are measured (Melhorn, 1995):

- Disturbances: These are transient abnormalities in the voltage/current of supply. These are detected by measuring the peak magnitude of voltage supply.
- Steady-state variations: These include normal RMS voltage variations and harmonic distortion. These are measured from the sampling of voltage over a period of time.

See Table 1 for a summary of PQ issues.

Table 1, categories of power quality issues (ibid)

Power quality variation category	**Method of characterising**	**Typical causes**	**Example power conditioning solutions**
1) Harmonic distortion	Harmonic spectrum, statistics	Non-linear loads, system resonance	Filters, transformers
2) Impulsive transients	Peak magnitude, rise time, duration	Lightning, electro-static discharge, load switching	Surge arresters, filters, isolation transformers
3) Oscillatory transients	Waveforms, peak magnitude, frequency components	Line/cable switching, capacitor switching, load switching	Surge arresters, filters, isolation transformers
4) Voltage flicker	Variation in magnitude, frequency of occurrence, modulation frequency	Intermittent loads, motor starting, arc furnaces	Static VAr systems
5) Voltage sag/swell	RMS vs. time, magnitude, duration	Remote system faults, lack of system protection, poor maintenance, heavy load switching	Ferro-resonant transformers, energy storage, UPS
6) Under-voltages/ over-voltages	RMS vs. time, statistics	Motor Starting, load variations	Voltage regulators, ferro-resonant transformers
7) Interruptions	Duration	Typically a direct cause of sag/swell	Energy storage, uninterruptable power supplies, back-up generators

Table 1 demonstrates the range of power quality issues, metrics, their causes and some possible solutions. For the purpose and scope of this report, only 'steady state' under and over-voltage, and what are known as 'sag' and 'swell' issues will be discussed in depth since it is these issues which directly relate to TTaT. 'Sags' and 'swells' refer to short term under and over-voltage breaches of regulatory limits.

It is not the case however that these issues are mutually exclusive or independent, for example one power quality problem might cause appliances to behave sub-optimally, in turn causing other PQ issues. For further detail see the F&M report.

Under/over-voltage events and sag and swell events are related, in that short lived violation of regulatory limits will be exacerbated, if a 'steady state' voltage that is already close to limits. However the actual voltage level and other metrics of power quality for any given location are on the whole not currently known by the UK DNOs. This is symptomatic of the very simple incumbent metering technology. Currently, if a power quality problem exists, ***and it has noticeable effects to the consumer, then they may inform the DNO.***

The current situation with regards to supply voltage is itself complex in that UK and other European countries have different operating standards and these do not all align with appliance testing procedures:

> 'Many of the UK appointed Notified Bodies for the LVD and the **UK Authorities remain concerned** that with the UK electricity supply being 230V +10% -6% and much of Europe being 230 Volt +6% - 10% and the standards testing at rated voltage +/-6% that there is a small possibility that some electrical equipment may be unsafe at voltages for which it has not been tested.' (DTI, 2005)

Moreover it is important to be clear that existing practices mean that in areas with, for example, significant solar PV generation, over-voltage can occur. See Figure 1 for a simulated feeder model voltage profile based on 10% penetration of 3.6kW systems on a large LV circuit (Bilton, et al., 2014).

This over-voltage is made possible because although PVs have internal cut-out mechanisms to avoid dangerous over-voltage, this limit can be set to the voltage of 262V, the ENA's G83 engineering recommendation (ENA, 2014). Whilst this will avoid some unwanted 'spill', or loss, of solar energy, the next chapter shows us that this ***voltage is above levels*** which have been shown to cause stalling in refrigeration equipment and perilously close to levels causing permanent damage in a range of other appliances (see the following chapter for details).

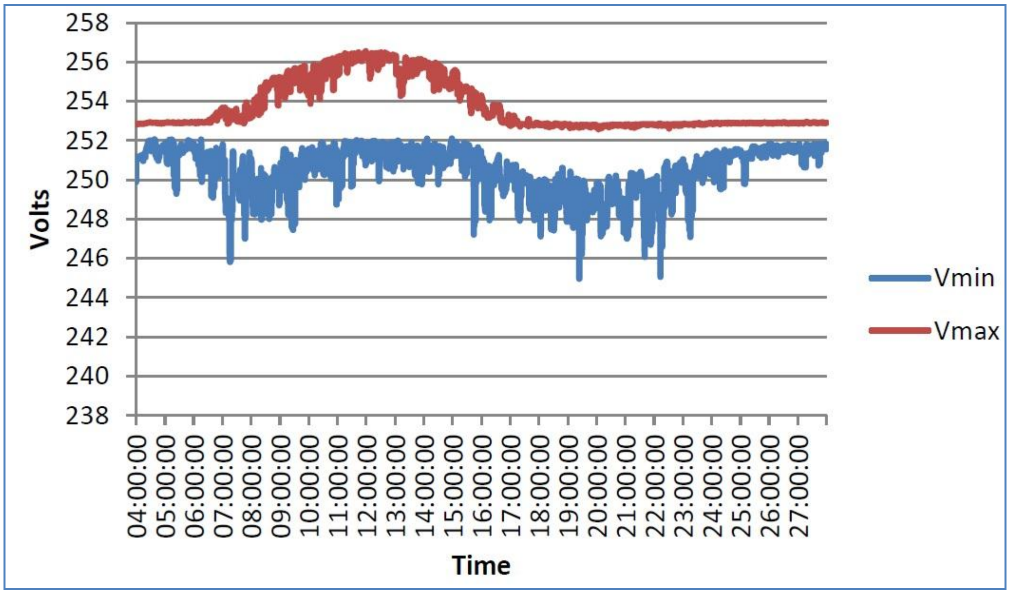

Figure 1. Simulated voltage minima and maxima for 10% PV penetration in London LV network, summers day (Bilton, et al., 2014).

An additional consideration is that technologies such as solar PV often form clusters due to, social network effects, be it cooperative or competitive (Bollinger, 2012) and due to widespread installation on new developments. This means that although nation or city-wide penetration levels may be low, issues may still arise because PV installations are clustered and/or not distributed evenly across phases[3].

There is a developing body of literature documenting the *fire risk* associated with PV installations:

> 'All new technologies can introduce new risks, and all new energy-handling systems can introduce new fire risks. Evidence is emerging from Europe and North America of the potential for fire hazards associated, directly or indirectly, with renewable energy power generating systems such as photovoltaics and wind turbines. Fires involving these systems can present some unique challenges for the fire service, building occupiers and insurers.' (Shipp, Holland, Crowder, Pester, & Holden, 2015).

In regard to UK installations, the discussion of risk is usually associated with poor installation and over-current, or arcing, potentially causing fire, not alternating current (AC) over-voltage (ibid). These issues arise on the direct current (DC) side of the system before the power is transferred, through what is known as an inverter, to the distribution network (ibid). However, the technical detail of how a PV installation causes a fire does not typically appear in the detail of press reports, for example, see the BBC

[3] It is beyond the scope of this report to explain how phase imbalance affects voltages.

report ‘Hove town hall fire 'caused by solar panels'’ (BBC, 2015). In this respect there can be attribution errors as to who or what is responsible, in other words, PVs are not inherently dangerous but may be blamed.

2.3. Heterogeneity in low voltage networks supply quality

The voltage for a given customer premise depends on the voltage at the secondary substation’s output, power flow conditions, and the associated cable capacity and condition.

Much of the UK’s distribution network asset base is aged and parts of network under significant stress, and this may be aggravated by low carbon technologies (Western Power Distribution, 2015). Low voltage (LV) distribution, or the ‘last mile’ of electricity supply, is the largest cable component of the systems, and is not routinely replaced. LV cables often pre-date, for example, the widespread use of plastic as a cable insulator. Given that cables have had joints added etc., for some cables for almost a century, what has emerged is a rather complex, non-uniform system and this is born out in DNO data sets seen in, for example, Low Carbon London (LCL). In practical terms this means that homes in close proximity may have very different voltage profiles, we can however generalise that voltage issues will be more prevalent at network extremities.

With parts of the system already under significant stress, any changes to power flow will impact the likelihood of faults on both the low voltage and the high voltage (HV) system. HV problems could rise due to the increased demand that can be delivered through the LV system; thus the LV voltage regulation changes cannot be considered in isolation. In the Low Carbon London project, smart data revealed that short term temporary supply failure affects most homes at least once a year (Bilton, et al., 2014).

2.4. Mitigating voltage rise

The primary power quality concern associated with increased PV penetration is over-voltage. A number of methods have been developed to mitigate the negative effects of PV integration to the distribution network, including:

- Network component reinforcement, cables and/or transformers;
- Output curtailment;
- Tap-changing transformers;
- Energy storage;
- Reactive power consumption.

The first approach is a traditional, infrastructure based approach in which voltage rise is, in effect, mitigated by reducing network impedance.

Curtailment is the control strategy used by individual LV connected inverters. The ENA engineering recommendation G83 defines the voltage thresholds and delay before inverters must stop feeding power to the network (ENA, 2014).

Tap changers allow the substation output voltage to be moved between a number of set-points, based on information about the voltage on the LV network being fed. Although these can mitigate over-voltage, they cannot totally eliminate it since they have a limited range and are remote from the generator.

Local energy storage appears to be a possibly viable solution for managing over-voltage (Hill, Such, Chen, & Gonzalez, 2012), since it can mitigate the problem with less loss of energy, when compared to straight curtailment. An additional benefit of this approach is that energy can be fed back into the system around peak, when capacity and energy are at a premium.

Centralised storage may also provide some benefit, but suffers from similar limitations to tap-changers. Reactive power consumption is another approach, but this is suitable for longer higher-voltages cables with adequate reactance since otherwise large amounts of reactive power absorption by the DG is required (Carvalho, Correia, & Ferreira, 2008).

In summary, if over-voltage is to be reduced or eliminated in UK LV networks, without spilling energy, operational voltage reduction on some networks will be necessary.

2.5. Summary

DNOs are responsible for the quality of the electrical power supplied to UK homes. Power quality measurement and management is a complex subject, but in terms of DNO responsibilities, voltage management is a primary concern.

In the UK, residential supply voltage is nominally 230V, but in practice this can vary considerably depending on DNO policy, location and time of day. While the full extent of voltage fluctuations is not currently known, they will tend to be most marked at network extremities and at sites with high power loads or micro-generation.

Whilst TTaT is primarily concerned with a reduction of the lower permissible voltage limit, from a consumer's perspective, under the existing or a TTaT regime, the voltage supplied may go both above and below regulatory limits. Moreover, because engineering and testing standards are currently misaligned, the correct operation of appliances may not be guaranteed, even if supplied at a voltage within regulatory limits.

If the planned nationwide roll-out of ‘smart metering’ occurs, and appropriate upstream IT systems are developed, DNOs will have much more detailed information about voltage on a site by site basis. Conversely there is no active programme to better align European appliance voltage and testing standards. The following chapter now looks at domestic appliances in more detail to establish the effects of voltage fluctuations.

3. Residential energy services and sensitivities to voltage

3.1. Introduction

Whilst a key DNO responsibility, as described in the previous chapter, is maintaining voltage between regulated limits, it is not clear that all appliances available for sale are safe to operate within these limits:

> 'The UK Government is of the view that equipment placed on the market in the UK must be safe at all operating voltages which the equipment will find itself exposed. We remain concerned that the standards may be inadequate by not testing over the whole voltage range.' (DTI, 2005)

Frost and Mitcheson (F&M) (Frost & Mitcheson, 2013) combine experimental data, mathematical models and literature review to shed light upon the technical effects of changes to supply voltage. In broad terms their finding is that significantly lowering supply voltage appears less problematic than significantly increasing supply voltage. Electronics and motors appear to be the most sensitive to over-voltage. In the case of electronics, internal voltages may rise above one or more components maximum rating, in turn causing failure. Motors will tend to run over their normal power rating leading to overheating, mechanical stress and damage.

Although many appliances do manage to continue to operate at higher voltages, there is a significant population of devices that will fail at only a few volts higher than 253V. F&M do not advise that voltage regulations are relaxed to increase the maximum voltage. Figure 2 represents a summary of their findings on 'steady state' voltage tolerance. No evidence of damage or dysfunction of appliances was found for voltages within the current UK regulatory limits.

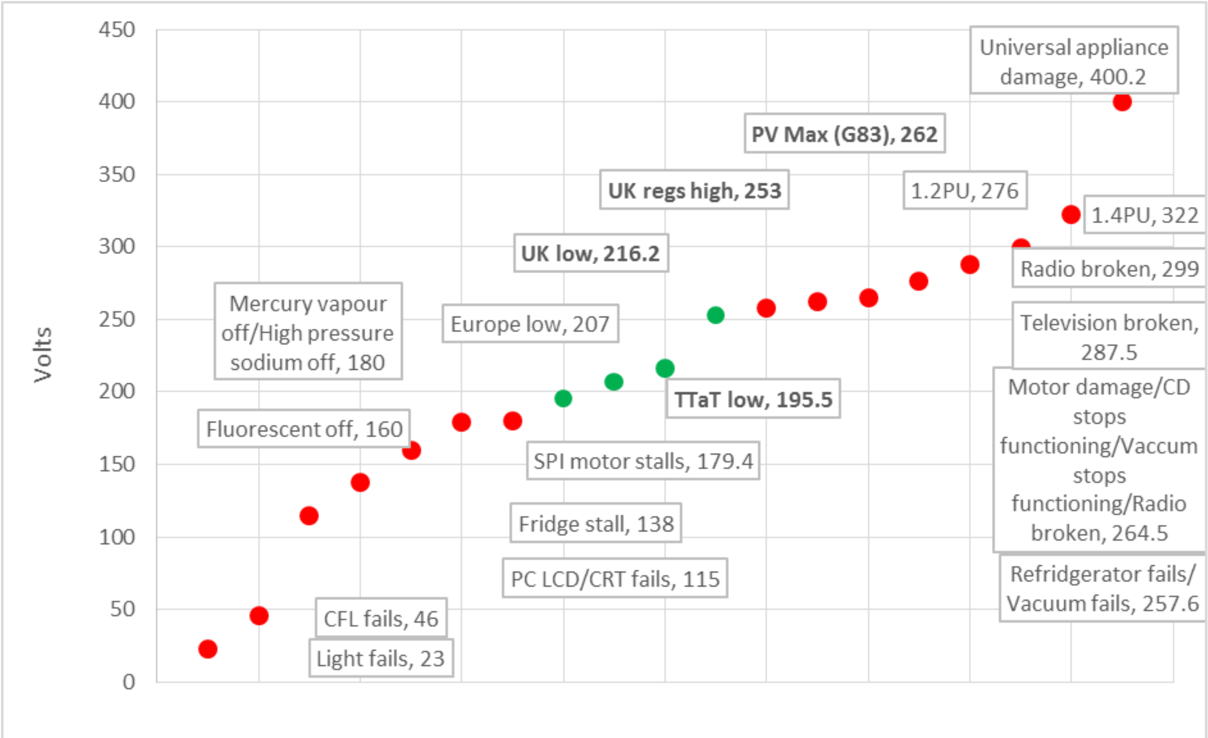

Figure 2, Practical effects of voltage levels on appliances behaviour.

Lowering the supply voltage will have a range of effects, rather than simple failure, and these will be expressed through changes in appliance operation, some of which may pose material risk. In the following section we attempt to characterise the modes of failure associated with 'under-voltage' in domestic appliances.

It is worth also noting the heterogeneity in the UK appliances population. Taking an appliance 'of concern' in terms of voltage reduction, the fridge-freezer as an example, a 'long tail' of older appliances are still in use. Figure 3 shows us, for example, that around half of all fridge-freezers in operation pre-date the current European appliance labelling scheme. Whether such appliances are more, or less, susceptible to voltage perturbations would emerge during a transition process.

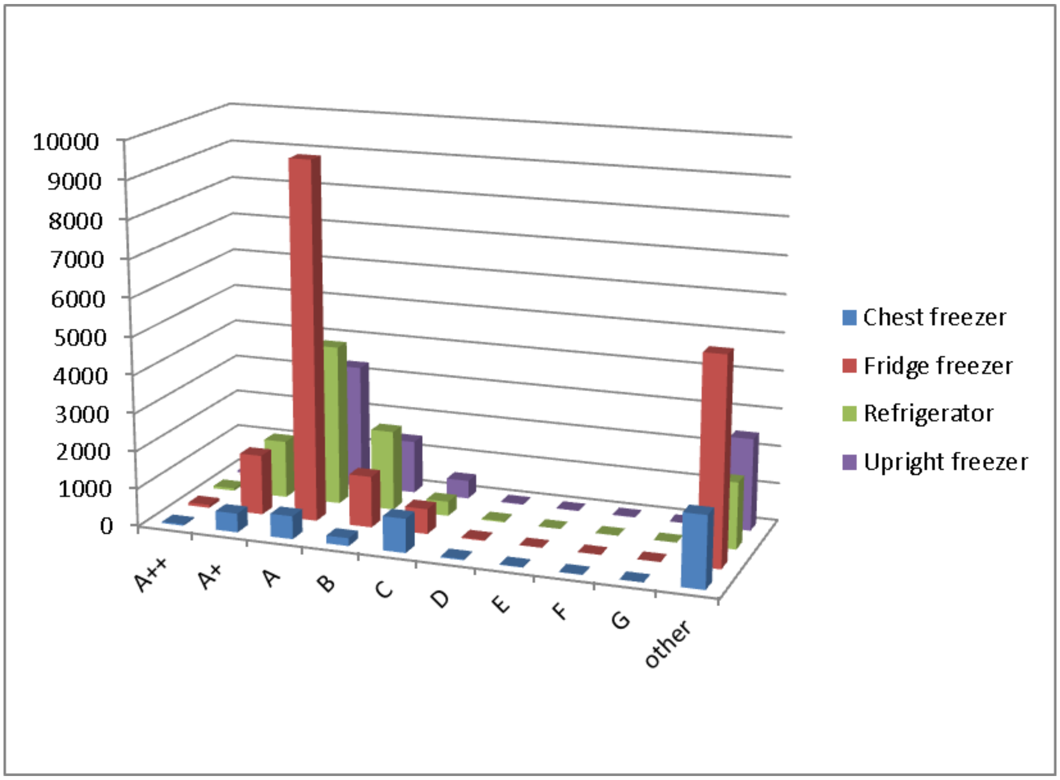

Figure 3, estimated cold appliance population by efficiency rating (x1000) (Bilton, et al., 2015)

The following section describes the impact of under-voltage on appliances, categorised by energy services type. Significant over-voltage is not considered any further since its effects typically result in damage and therefore increasing the high-voltage limit is not recommended (Frost & Mitcheson, 2013). Moreover the impact of over-voltage can be uniformly described as appliance damage, albeit at different voltage thresholds.

3.2. Impacts of under-voltage on domestic appliances

This section condenses the findings of F&M's report to summarise the types, and likelihoods of impacts associated with under-voltage. This summary is later used to inform the semi-structured interviews about attitudes to these impacts. Appliances are represented by service category with a qualitative summary of under-voltage impacts and their likelihood of occurrence. We assume that voltage conditions are, taken at a half hourly average, around the lower threshold of the proposed TTaT voltage of 195.5 (230 - 15%). In this scenario, the instantaneous voltage will be lower than the 195.5 for roughly 50% of the time.

Under these conditions some appliances are closer to their operation lower limit than others. In the tables to follow, the likelihood of these events is colour coded green, amber or red, depending on the voltage threshold at which problems are likely occur. Green indicates that the appliance type is resilient to voltages below 156.4 (195.5 - 20%), and red that malfunction can occur at voltages above 175.95 (195.5 - 10%), amber being between these extremes. Similarly the impact types are colour coded to indicate material risk (red), inconvenience/annoyance (amber) and no significant impact (green).

3.2.1. Lighting

The different lighting technologies respond differently to changes in supply voltage. Incandescent, including mains connected halogen, bulbs are a very simple technology. Whilst the emitted light is highly dependent on voltage level, the only failure mode will be associated with age, or steady state or transient over-voltage causing the filament to blow. Traditional fluorescent tubes on the other-hand require a minimum voltage to function and as a consequence will turn off, from experimental data, at around 160V. Although much less common in the residential setting, sodium and mercury lamps are similar in behaviour and fail at around 180V.

Lighting with electronic power supplies appear to be less sensitive to low voltage and this includes compact fluorescent lights (CFL). Excepting equipment with poorly designed circuits, a possibility that cannot be entirely eliminated, such lighting appears to be compatible with voltage reduction.

Table 2, under-voltage impacts associated with lighting technology.

Technology	Impact	Likelihood
Incandescent	Irritation from flickering and dimming	High
Fluorescent	Danger associated with darkness	Medium
Sodium/Mercury	Danger associated with darkness	High
CFL	Negligible	Negligible
LED	Negligible	Negligible

3.2.2. Cooking

The heating function of hobs and ovens will be only subtly affected by voltage since they tend to use thermostats and these will cause 'on periods' to extend or shorten in adjustment to voltage rise and fall respectively.

A fan has a load (torque) related to the speed of the motor, hence a fan motor is very unlikely to stall, instead its speed will reduce. This may impact the effectiveness of the oven but is unlikely to cause significant effects. Appliances with essential electronic components, such as microwaves, will fail at a similar voltage level to ICT products.

Table 3, under-voltage impacts associated with cooking appliances.

Technology	Impact	Likelihood
Motor	Reduced air circulation	Low
Electronics	Reset	Low
Heating element	Negligible	Low

3.2.3. Refrigeration

Low voltage supply can have a serious potential impact upon fridges and freezers in that repeated and/or extended failure introduces the risk of food spoiling. In the experimental data this occurred below 138V, or 180V for a Single Phase Induction (SPI) motor.

Table 4, under-voltage impacts associated with refrigeration technology.

Technology	Impact	Likelihood
Motor	Food spoiling	Medium
Electronics	Reset	Low

3.2.4. Wet appliances

Dishwashers, washing machines and tumble dryers appear to be at low risk in that the symptoms of under-voltage would be largely unnoticed and of little effect. Heating process would typically be compensated for by a thermostat operation, and motor operation is less critical than for refrigeration. Again electronics are resilient and likely to be, in most cases, last to fail due to under-voltage.

Table 5, under-voltage impacts associated with 'wet' appliances.

Technology	Impact	Likelihood
Motor	Stall	Medium
Heater	Slowed heating	Low
Electronics	Reset	Low

3.2.5. Consumer electronics and ICT

Consumer and ICT equipment appears to be of least concern with regard to under-voltage, with device failure happening well below proposed TTaT limits.

F&M identify the resilience of switch mode (SM) power supplies which can withstand wide voltages variations, but from the experimental data it is not clear whether such supplies are, on the whole, more resilient than common ‘bridge rectifier’ (BR) designs.

Table 6, under-voltage impacts associated with consumer electronics.

Technology	Impact	Likelihood
Power supply (SM)	Fail	Low
Power supply (BR)	Fail	Low

Table 7, under-voltage impacts associated with ICT.

Technology	Impact	Likelihood
Power supply (SM)	Fail	Low
Power supply (BR)	Fail	Low

3.3. Summary

This chapter has introduced voltage level as a key factor necessary for the correct operation of energy services in the residential setting. Summarising the data in F&M's report, over-voltage is more problematic than under-voltage, the former potentially causing damage, the later largely temporary malfunction. However the thresholds at which issues arise is very dependent on technology.

From the small sample of appliances reviewed, refrigerators and freezers appear to pose the biggest risk to consumers, if repeated/extended failure causes food to spoil and does so unnoticed. Lighting services, during under-voltage, may cause annoyance in terms of light quality, but fluorescents and vapour lighting can fail completely and hence cause danger, at voltages within 20% and 10% of the lower limit respectively.
In the following chapter we examine consumer attitudes to such, power quality and quality of service issues. It concludes with an interview schedule designed to examine understanding and attitudes related to electrical power distribution, quality and how it should be managed.

4. Consumer attitudes to power quality and quality of service

4.1. Introduction

The previous chapters have introduced the role of the DNO in providing electrical power to regulated standards of power quality (PQ), and the consequences when it is not maintained. In this chapter we explore power quality from the consumer's perspective. Social science studies have identified the importance of the consumer's attitudes and experiences in shaping outcomes of policy (Walker, Devine-Wright, High, & Evans, 2010). Resistance to wind-farms has, for example, has been linked to generator siting (Wolsink, 2005), and smart meters to concerns about data privacy or health effects (Krishnamurti, et al., 2012).

There is a dearth of similar literature related to UK consumer attitudes to power quality, perhaps because of the tradition of security of supply and 'keeping the lights on' resulting in a very reliable system. Empirical studies have demonstrated that the general public have a low level of awareness of the wider system's operation:

> 'Findings suggest that electricity networks are represented predominantly in terms of technologies rather than organisations, specifically in terms of familiar, visible components such as cables or wires, rather than more systemic concepts such as networks. Transmission and distribution network operators were largely invisible to members of the public.'
>
> (Devine-Wright, Devine-Wright, & Sherry-Brennan, 2010)

We might then predict low levels of knowledge with regard to the role and responsibilities of the DNO. Conversely, if informed about the findings of the partnering F&M report, consumers might express attitudes about voltage quality, if connected to tangible effects on appliances (read visible components).

The extreme effects of non-compliance, as detailed in the previous chapter, could erode trust in low carbon technologies themselves and/or the institutions associated with the low carbon transition, and fuel public concern and resistance to change (Walker, Devine-Wright, High, & Evans, 2010).

In terms of QoS, some literature has examined attitudes to 'black-outs', that is total supply failure, and these have some surprising findings, most notably that attitudes to supply failure are not all negative (Devine-Wright & Devine-Wright, 2007).

The scarcity of information about consumer attitudes to voltage in the UK, suggests a need for some data gathering activity, but assuming low levels of awareness, it is not immediately clear what questions might elicit informative responses.

However, we can consider voltage fluctuation related issues through the lense of consumer experience, associated attitudes, risk perception and PQ management options. For example, can we distinguish between the objective/technical effects as described in the previous chapter and the consumer's experience of them, and how might this inform a process of regulatory transition?

In an environment of low awareness, when QoS symptoms are experienced, attribution errors may cause problems to be misdiagnosed or the wrong actor to be blamed. In turn this could erode trust which further exacerbates negative experiences.

Given the above, two key considerations in terms of consumers experience are attitudes to changes in the QoS experience, and perceptions about who manages power quality and its associated risks. Social science or consumer attitude research, can then inform decision-making about PQ-management strategies but in order to do this we need to anticipate debate around a change to voltage regulation. For example, how would these changes be introduced and the process communicated?

- Who/which sources of information would consumers trust on PQ/voltage issues?
- Who should receive communications?
- What terminology is best?
- Which perceived risks need to be addressed?
- Would local trials be useful to demonstrate lack of issues?

And post information or 'post change':

- Feeling they are being informed about risks;
- The impact of renewables;
- Feeling that voltage is being managed cost-effectively, fairly, transparently;
- Responsiveness of the responsible actor to QoS issues/complaints.

These aspects form a passive framing of the consumer in the sense that supply quality is 'something that happens to the consumer'. This is not the whole picture however, since the consumer's loads and more recently generation, affect local power quality.

We can envisage scenarios is which power quality symptoms might drive some behavioural changes and these may be beneficial or deleterious to system conditions. For example, a flickering light might be substituted, or simply switched off, when problematic. Here we can view the household appliances as providing feedback to the human actor as part of the wider system. It has similarly been shown that households with solar PV often change their behaviour in response to their distributed generator's (DG) output (McKenna & Thompson, 2014) (Keirstead, 2007).

In the previous chapter we mapped the likely effects of different voltage levels upon appliances, but this did not address consumer sensitivity to such issues (e.g. would flickering lights be less annoying than the TV not working). The absence of any significant body of literature on consumer attitudes to the quality of the electricity supply means that a systematic literature review is not possible, and to develop the subject further requires gathering of additional data.

To this end, a pilot study of semi-structured interviews was developed to establish ***existing experiences, understanding and attitudes to electricity supply quality and its management***. In addition, interviewees were also asked to imagine ***future scenarios*** and their likely responses following a TTaT regulatory change.

Developing an interview schedule specifically for TTaT allowed the scope of questions to include beliefs about how the system is managed as well as attitudes to impacts of voltage perturbations. Whilst in the previous chapter focused on the effects of under-voltage, as per the TTaT proposals, the interview schedule includes questions about over-voltage, since such conditions are part of the context in which TTaT would be applied.

4.2. Cohort selection

The cohort used for the semi-structured interviews comprised self-selected participants who were previously on the 'Economy Alert' tariff trial with EDF Energy, part of the Low Carbon London (LCL), a Low Carbon Network Fund project running from 2011 – 2014 (Carmichael, et al., 2014).

There were nearly 6000 homes metered in the LCL smart meter trial, with around 1000 of these completing the dynamic tariff trial. The group interviewed in this report were all members of the tariff trial who had also given permission for Imperial College to contact them in the future.

While the wider LCL cohort was large and well-balanced in terms of social demographic distribution, the small sample used here was formed of households who were able to answer the phone, agreed to talk, and were recruited on a first come first served basis. The resulting group was skewed towards male participants (21/30) and those over 55 years of age (24/30). Although these were otherwise typical householders, regarding experience of smart meters, they were untypical in that all had been part of the 'Economy Alert' trial.

However this prior experience does provide some benefits. Firstly by already having a smart meter at their home, it is not necessary to introduce and explain the concept of smart meters and how they might benefit the consumer. Also by being on the 'Economy Alert' tariff these participants had regular interaction with the smart meter 'in home display' (IHD) to check consumption and tariff information.

4.3. Interview design

The Appendix contains the complete interview schedule and this can be broadly divided into three sections. The first addressing the 'technical dimension', aims to ascertain pre-existing experience, understanding and attitudes relating to quality of service issues (QoS) and supply voltage. The second examines understanding and attitudes to the roles and responsibilities of service provision. A third tranche of questions, relating to future policy options, follows an information briefing which is intended to bring the interviewees 'up to date' with the TTaT concept and its implications.

The interview essentially comprises two types of question, free response and questions requesting a grading of from 1 – 5. Following a grounded approach (Charmaz, 2003), avoiding leading questions, the free response questions are intended to identify common patterns in the way the wider system is perceived. The questions requiring a grading are intended to distinguish the relative importance of the issues discussed. These interview questions are intended to provide a pilot for future study, in so far as the sample is relatively small, but the free response questions might provide leads as to what areas deserve closer study.

4.3.1. Existing quality of service experiences

In this section we avoid the abstract notion of 'voltage' and focus instead on consumer experience and attitudes towards the effects of deficient power quality. To make it relevant to the consumer, we need to associate voltage with something consumers care about, for example:

- QoS experience;
- Impact on appliances;
- Perception of risk/anxieties;

This provides us with a point of departure to ask the questions: 'To what extent are QoS already experienced and how are they understood?'; 'Do UK consumers currently experience or notice or imagine voltage PQ issues?'

The interviewee is asked to describe any unusual behaviour of appliances that they have experienced, with following requests for detail, what they felt about and what caused the issue. The causes of these events may not be understood by the consumer, for example the house wiring, or neighbours might be blamed.

4.3.2. Pre-existing attitudes to Power Quality and Quality of Service

In this section we move on to examine attitudes to quality of service (QoS) events that may become more prevalent under a TTaT voltage regime and knowledge of operational voltages.

Ownership and understanding of surge protector sockets

Firstly however, the opportunity is taken to examine the consumer's understanding of surge protector sockets. Since these devices are the only common product that claim to improve power quality, they provide a proxy for understanding of power quality. Thus if interviewees state that they have bought a surge protector, they are then asked why they bought it and what they believe it protects against. These questions precede questions about attitudes to specific PQ symptoms since these may prime possible beliefs as to the purpose of the surge protector.

Attitudes to voltage related malfunction

The questions in this section identify the under-voltage symptoms, derived from F&M, and ask the interviewee to grade their concerns if they were experienced. It might be assumed that concerns of food safety might rank more highly than lighting services, but there appears to be absence of previous research in this area. In order to test such assumptions, following self-reported effects, the interviewee is asked to grade the likely effects reported in F&M.

This allows the exploration of the inter-related but potentially separate dimensions of how much the consumer cares about the issue and how likely the risk is perceived to be. For example, there may be issues relating to different types of consumer with respect to PQ: e.g., if for example, consumers vary in level of awareness and risk-perception. Conversely the low levels of actual problems and of awareness to date mean that some of these potential distinctions may be too fine-grained.

Voltage prior knowledge

After asking the interviewees to describe any QoS experiences, they are a then asked about their knowledge of existing voltage ranges. This has been included to ascertain the levels of prior knowledge and the extent to which voltage data on a future meter IHD might be understood. If the interviewee states that voltage does not vary, then they were not asked to state the higher and lower limits.

4.3.3. Roles and responsibilities.

Following the questions on experience, the questions move on to examine understanding and attitudes surrounding the possible causes of QoS issues and roles and possibility for its management. To what extent does the consumer understand the difference between the roles and responsibilities of energy retail and power delivery? As identified earlier, the energy system is often perceived in terms of visible components and poorly understood in terms of organisations and responsibilities. Whilst the customer's relationship is with their energy provider, typically one of the big six, electricity power delivery and power quality is the responsibility of the distribution network operator.

In this section of the interview schedule, consumers are asked how satisfied they are with their electricity supply and who they believe to be responsible for supply quality. If they answer correctly, i.e DNO or UKPN, then they are asked to describe any interactions, and grade their level of satisfaction regarding the experience.

The interview then moves on to ask 'What would you do if you experienced voltage/PQ issues in the future?'. If the answer includes contacting an organisation, then we might expect it to tally with the agent identified as being responsible for power quality. In both cases, in the context of low awareness, we might expect the wrong actor to be named and this is likely to be their supplier, i.e. EDF in this instance.

The interviewer then asks 'Do you think consumers are adequately informed about power quality issues affecting or potentially affecting them?' and 'Do you trust that power quality is being managed properly?' These questions allow us to establish the level of trust in the current arrangements before they are queried as to who is actually responsible, since a lack of understanding may have affected perceptions of satisfaction. The interviewee is then asked to describe a DNO and name the company running their distribution network. If they cannot describe a DNO in a meaningful way then the interviewee must explain this before moving on. Here a flexible approached was used, based on the completeness of the interviewee's response. In answering this question the cohort selection becomes significant as:

- All of the LCL based cohort are under the UKPN LPN network;
- All the cohort are EDF customers;
- All have received personal communication from UKPN, so brand recognition would be expected to be higher than in the wider population.

4.3.4. Voltage management going forward

In this section we explore consumers' preferences in PQ management strategies. However to form an opinion on these issues requires some prior knowledge of the justification for change and likely impacts. The statement below, read verbatim to all interviewees, aimed to set the scene for the final questions:

- Technologies such as solar panels, heat pumps and electric vehicles are becoming increasingly popular;
- These technologies tend to make the electricity supply voltage fluctuate more than previously;
- Heat-pumps and electric vehicles will tend to reduce the supply voltage, solar panels will tend to increase the supply voltage.

- Researchers are proposing that supply voltage regulations be relaxed;
- This will allow greater fluctuations in Volts, with the lower limit being reduced;
- This should mean the DNO will need to replace less underground cable in the future;
- This should help you in terms of future electricity bills;
- Provided the voltage stays within these new limits then there would be little effect on QoS.

- However the voltage may occasionally go outside these limits;
- If the voltage falls below then lights may dim or, a freezer may stop working temporarily;
- If the voltage goes too high then equipment may be damaged;
- DNOs can adjust voltage to minimise these events;
- It will be possible for energy companies to monitor voltage through the coming 'smart meters'.

Once read out, the interviewee is asked if they understood the statement before the remaining questions commence, with clarification provided if required.

The first question 'Would you expect the DNO to check your voltage is within limits if this could be done with smart meters?' is fairly straight forward, but it does also test the extent to which the interview now associates supply quality with the DNO, even though the supplier is responsible for the meter.

The following question 'Would you use your smart meter display unit to check voltage, if you experience QoS issues?' is to establish if the consumer is likely to be active in identifying and responding to power quality issues.

Along similar lines, the following three questions investigate likely behaviour and sense of agency: ‘Would you be likely to replace GLS bulbs with CFLs or LEDs if they fixed light level issues?’ and ‘What might you do if you noticed that the voltage was above/below the regulatory limit?’ The former examines a simple but beneficial technology substitution where QoS can be corrected with the additional benefit of demand reduction. The second, and ‘free response question’ aims to capture likely behaviours in the event of receiving information from the smart meter IHD.

The activities of the DNO and consumers checking voltage, and the bulb replacement question are then revisited from the perspective of making these policy. Whilst the consumer may choose to monitor voltage, or swap bulb technology, as per the earlier questions, to what extent should this be mandated?

In order to establish the perceived priorities of the DNO going forward interviews are asked: ‘Can you grade the importance of these DNO roles: Managing safety, Facilitating low carbon technologies such as solar panels, Minimizing costs.’

Finally interviewees are asked ‘Who would you trust to inform you about power quality issues? DNO, supplier, council, government, citizen’s advice, neighbours, friends/family, media, other (please specify)’. This question aims to clarify the level in trust of consumers in various institutions but also the extent to which they now understand the DNOs role.

4.4. Findings

4.4.1. Existing quality of service experiences

When asked 'Have you experienced problems with any of your electrical appliances?', the vast majority of respondents said 'no'. To confirm this lack of experience, the respondents were asked, 'Not even issues with temporary dimming of lights?', and this did reveal occasional issues, but these were not described as important or frequent. The exception to the above was a number of instances where issues were experienced but associated with causes other than power quality. For example, one respondent identified 'flickering light' when walking in certain areas, but this was fixed by re-wiring; another respondent complained of 'pixilating TV image' but only during bad weather, suggesting a problem with his satellite connection. Two respondents, unprompted, described full 'outages', one lasting 9 hours.

The responses gathered appear to confirm either, a good quality of supply in London, and/or the resilience of appliances to voltage variations. However this should be considered in relation to the cohort who were self-selected and tend to use modern lighting technologies such as CFL and LEDs and as such are less prone to dimming. Secondly, as described earlier, consumers at the end of feeders are more likely to experience problems and this was not a feasible recruitment criterion.

4.4.2. Pre-existing attitudes to Power Quality and Quality of Service

Ownership and understanding of surge protectors

Around a half of respondents reported buying surge protector sockets, with the majority reporting the reason as to protect 'IT' and 'expensive' consumer electronics. However there appeared to be a poor understanding of what the surge protection socket might do.

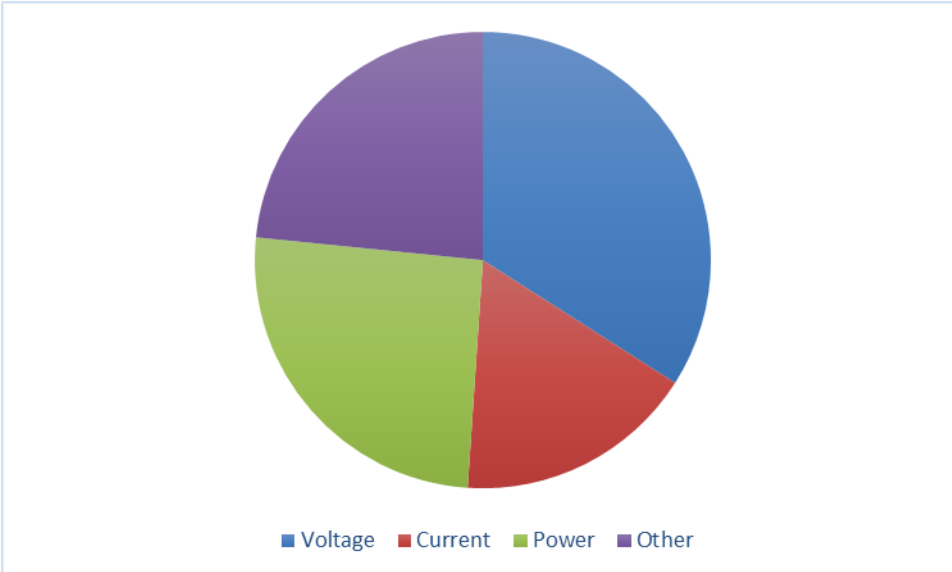

Figure 4, Surge protectors, ‘As you understand it what would these protect against?’

Four respondents conflated the surge protector with a residual current detector (RCD), answering yes but describing an RCD. Of the respondents with surge protectors, there was a range of answers as to their purpose, see Figure 4. Four respondents correctly identified that these devices protect against ‘voltage’ (V), one stating ‘episodic over-voltage’, three identified current (I), and two ‘power’ (P). Where V, I or P were identified, in some instances additional descriptions were offered, ‘Under and over current’, ‘Surges’, ‘Lightning’ as well as ‘Not lightning’. The remaining respondents identified a general lack of understanding, offering, ‘Don’t know’ and ‘Electricity’.

In summary it would appear that there is a sense amongst consumers that electronic devices are more sensitive than other appliance types and need to be protected. Other than the notion that the devices are ‘beneficial’ there is a low understanding of what the devices do. It appears that ‘surge protectors’ are bought as an ‘insurance’ against loss of expensive equipment, irrespective of need or understanding of potential risks. Similarly there appear to be a poor understanding of what RCDs protect against, with some respondents explaining that they offer over-voltage protection.

Concern about the possible symptoms of low supply voltage

The questions regarding concern about potential QoS experiences provided, on the whole, rapid responses with very few requests for clarification. Figure 5 shows the average grading for all thirty respondents from 1-5 (Very unconcerned - Very Concerned).

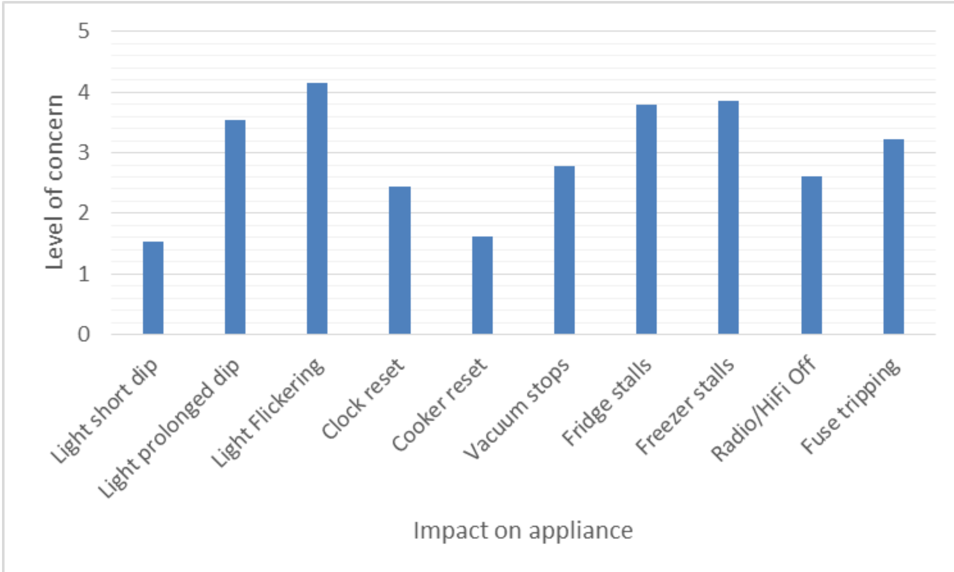

Figure 5, concern about possible future QoS issues.

Respondents tended to grade risks consistent with this average profile.
The only issues commonly graded as a five were flickering light and the fridge and freezer issues, which were automatically associated with safety. However one respondent, who had experienced a 9 hour outage, had explained that his freezer was the 'latest technology' and had not suffered any defrost in this period. This observation, that better insulated cold appliances will survive longer periods of disconnection, suggests that this maybe only concern for consumers with older models.

Flickering light was almost universally reported as an '***annoyance'***, whereas cold appliance failure as a '***worry'***. The overall picture appears to be one of stoicism with only more dramatic events yielding an average above 3, i.e. of being of any concern.

Voltage, prior knowledge

Just over two thirds (23) of respondents named a voltage, but only 10 reported believing that this can vary. Figure 6 represents all the reported voltage data from all respondents, including missing data.

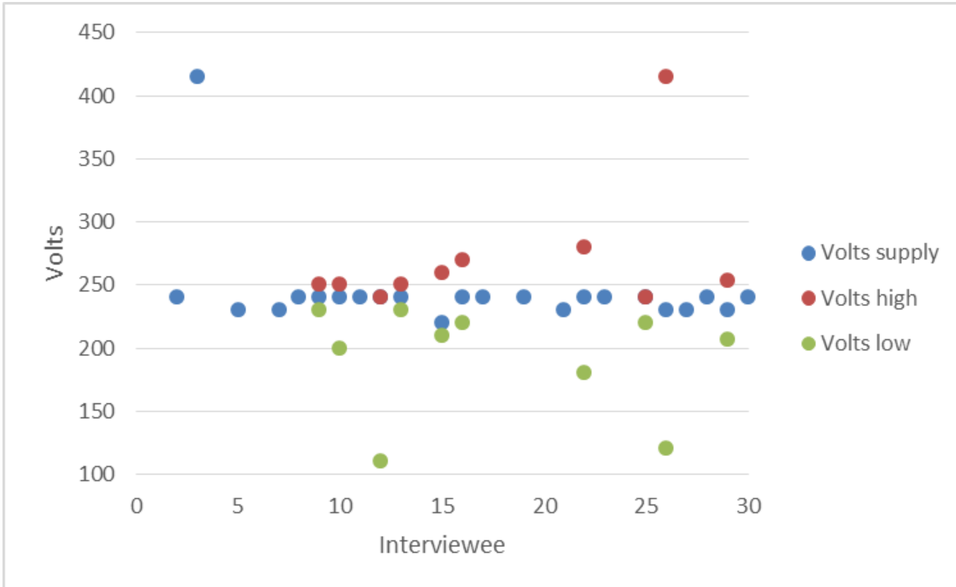

Figure 6, all reported voltage numbers.

This figure shows us that the UK nominal voltage is reasonably well known, with the majority of respondents stating '230' or '240'. One respondent, with experience in the building trade, stated '415' which a conflation with a three phase voltage.

Low and high voltages appear to be, on the whole, 'good guesses' and close to the ranges investigated by F&M. The average of reported low voltage is 192.7, very close to TTaT minimum 195, and high 270.8, just 8 Volts over the G83 maximum. Again the outliers are related to other system standards, the lows values are a conflation with European or US voltages 120 and 110, and the high of 415, a conflation with 3 phase systems.

In summary, consumers are reasonably aware of the existing voltage levels, but perhaps more surprisingly they provide reasonable estimates for high and low levels. This trend continued when asking 'As far as you know, what would be the consequences of an overly high/low voltage?' with responses close to the empirical effects described by S&M. With the free response answer, multiple effects were sometimes mentioned and all of these are represented in Figure 7.

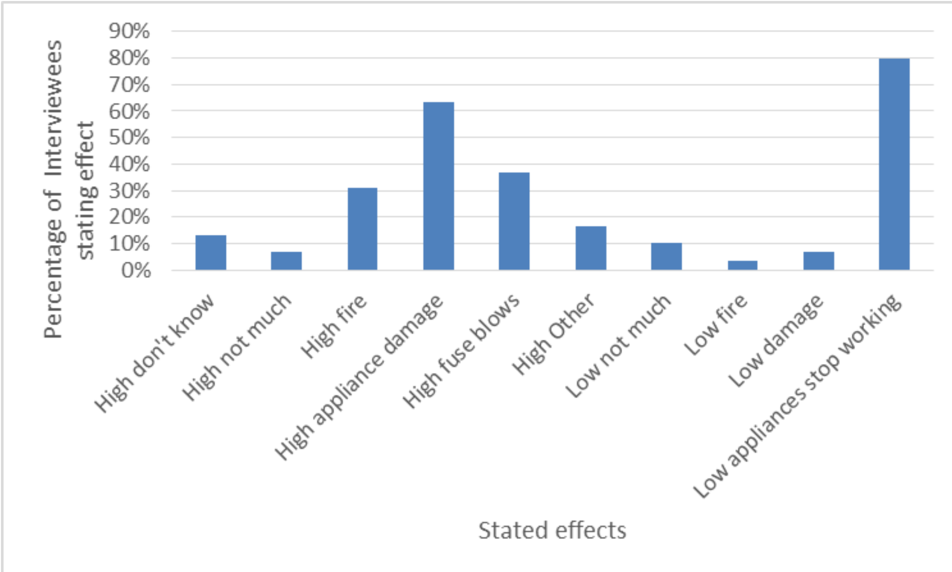

Figure 7, stated consequences of overly high and low voltage.

Respondents seem to know intuitively that overly high voltage can stress electrical items and this might cause damage. Interestingly the respondents who mentioned fire, did so as their first reaction. The 'High other' category comprised, 'Burn out', 'Blow up', 'Strain' and 'Overload'. Given that high voltage can damage items without blowing a fuse, and that fire is less likely than damage, the relative order of the top three high voltage impacts is not far wrong.

The responses to the low voltage question were also quite accurate with a general sense of it being less dangerous but affecting appliance operation (80% or respondents). The 'Low other' category comprised 'Blows fuse', 'Can't use too many things', 'Cooker turns down', 'Low light'.

4.4.3. Roles and responsibilities

On the whole customers were satisfied with the quality of their supply (scoring 4.6, where 1 = very dissatisfied and 5 = very satisfied) and this corresponds with a general view that power quality was being managed properly. See Figure 8 (where 1 = strongly disagree and 5 = strongly agree).

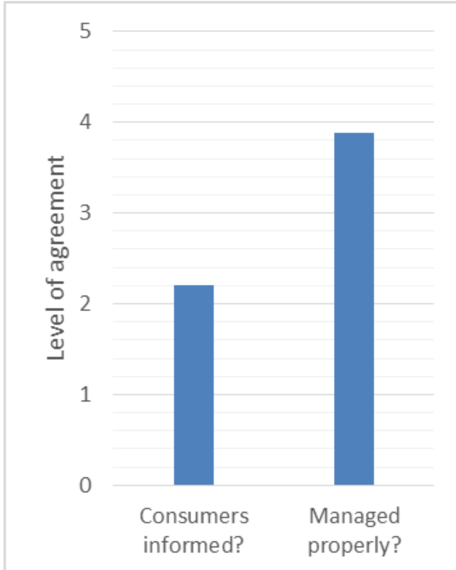

Figure 8, attitudes to power quality

The question of whether consumers were adequately informed or not, was more problematic to answer, in that the interviewees had very little prior knowledge of PQ. In this sense the preceding questions framed these responses because they had exposed a lack of understanding in the interviewee.

However, a practical consideration for the consumer is what to do when issues do arise. When asked 'What would you do if you experienced voltage/PQ issues in the future?' the vast majority said "Call EDF", i.e. their supplier. Some latent understanding of a network exists in that some respondent's first state 'talk to neighbours' as a means to identify if the problem is associated with just their home or the network. Thus far it is clear that respondents, currently judge their supplier to be responsible for power quality.

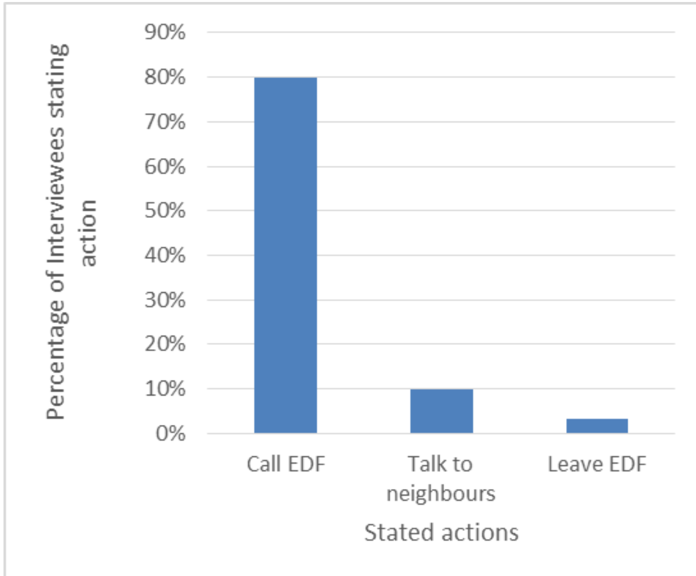

Figure 9, 'What would you do if you experienced voltage/PQ issues in the future?'

This brings us onto the question of existing knowledge about Distribution Network Operators (DNOs). Here the responses were most marked with three quarters of interviewees having no idea as to what a DNO was. Since the question was 'free response' it was necessary to assess responses qualitatively, when more than 'no' was offered. Although the responses were never comprehensive, a positive assessment was made if some key elements of the network and operational activity were mentioned. If the qualitative assessment demanded an accurate result, no correct answer occurred. However around 23% of respondents made good guesses based on the words 'distribution network operator', albeit after the initial framing questions of the interview. One very detailed description explained the DNO in terms of an individual as opposed to an organisation.

Naming the specific DNO was only successfully done by one respondent, and this is a little surprising since all the respondents were previously part of Low Carbon London which was UKPN branded. Figure 10 shows the low number of accurate responses received in respect to the understanding of DNOs.

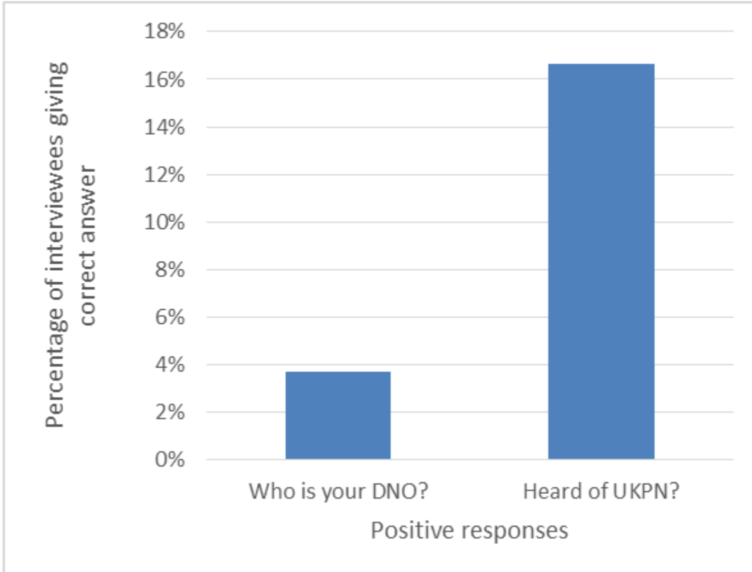

Figure 10, prior knowledge of roles and responsibilities.

4.4.4. Voltage management going forward

Prior to asking further questions the ‘Information briefing’ (see the previous chapter) was read out to the interviewee and they were then asked to confirm that they had understood it. Only one respondent asked for minor clarification. The intention of the information briefing was to make the interview aware of the potential effects of regulation changes and allow them to imagine future scenarios.

Firstly, immediately after the briefing, the interviewee was asked if they expected DNOs to measure voltage (when made possible through smart meters), and whether they would themselves do so in the event of a QoS incident. In addition they were asked if they would substitute traditional light bulbs with CFL or LED to correct a lighting issue.

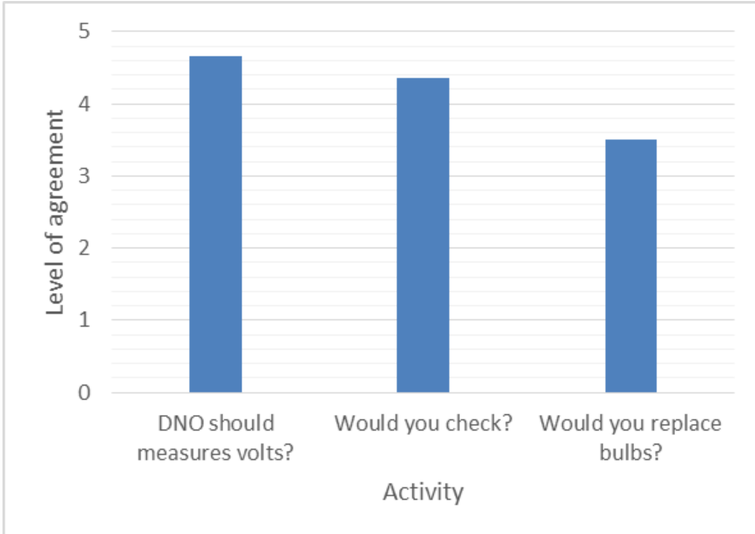

Figure 11, approval for activities.

As seen in Figure 11, there was near total agreement that the DNO should monitor voltage through smart meters (where 1 = strongly disagree and 5 = strongly agree). The majority of respondents also agreed that they were likely to check the IHD themselves if they noticed QoS symptoms.

The substitution of bulbs question seemed to be viewed as a little old fashioned, as it emerged that many corresponded had mainly energy saving bulbs, or as discussed lighting issues were not considered of great concern.

The following question required the interviewee to imagine themselves in a future scenario, where the IHD is informing them of a voltage outside regulatory limits. The interview was now within the context of some understanding of voltage, the possible risks of voltage perturbations, and the role of the DNO. The high voltage question was asked first followed by low voltage, the combined responses were then categorised by common responses, see Figure 12. Note, again with the free response some interviewees provided multiple answers.

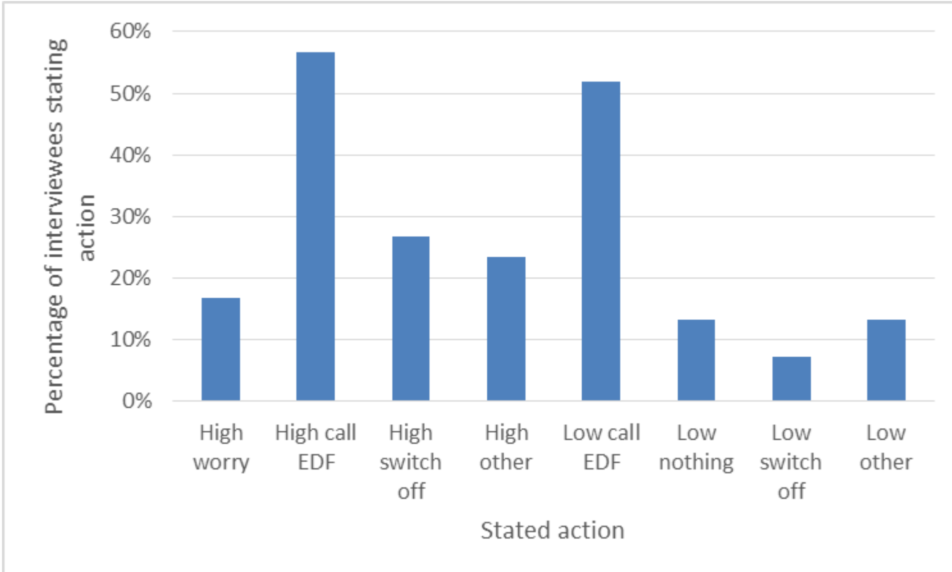

Figure 12, 'What might you do if you noticed that the voltage was above/below the regulatory limit?'

The first observation is that, despite being informed about the DNO's role, the most likely response to an observation of over or under-voltage is for the customer to call thier supplier. The 'worry' group (5) also declared calling EDF as their next suggestion, except for one. The defensive action of turning off appliances was mentioned by seven interviewees. Other responses comprised: 'Nothing', 'Be vigilant', 'Don't know', 'Keep an eye on appliance', 'Nothing, I expect it to be managed', 'Buy surge protector'.

Approaching the end of the interview the subject of roles was returned to in terms of approval for power quality management policies. This question repeated the activities introduced earlier but from the perspective of making them policy, see Figure 13. The notion that the DNO should monitor voltage gained strong approval, but the idea that the customer monitors voltage as a 'policy' averaged neutral. The question of whether customers should be responsible for monitoring voltage produced polar responses, with a split between strong/agreement and strong/disagreement. The disagreements tended to be concerned with the idea that consumers would not be reliable and/or it is not their responsibility; these attitudes resulted in the 'ambivalent average'.

The proposed policy of 'free bulbs' where appropriate gained wide approval, but this was largely from a perspective of 'something for nothing'.

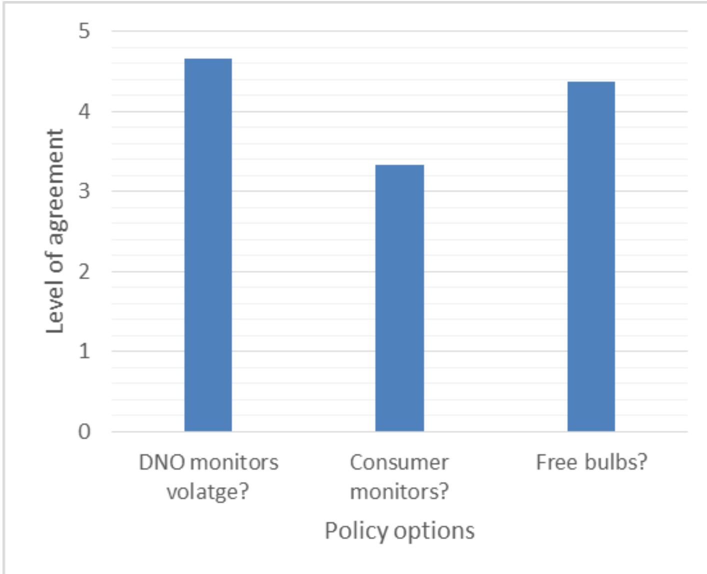

Figure 13, approval for simple policies.

When asked to grade the importance of three DNO roles, see Figure 14. ‘Managing safety’, unsurprisingly gets strong agreement, followed by ‘Minimising costs’, and ‘Enabling low carbon technology’ third.

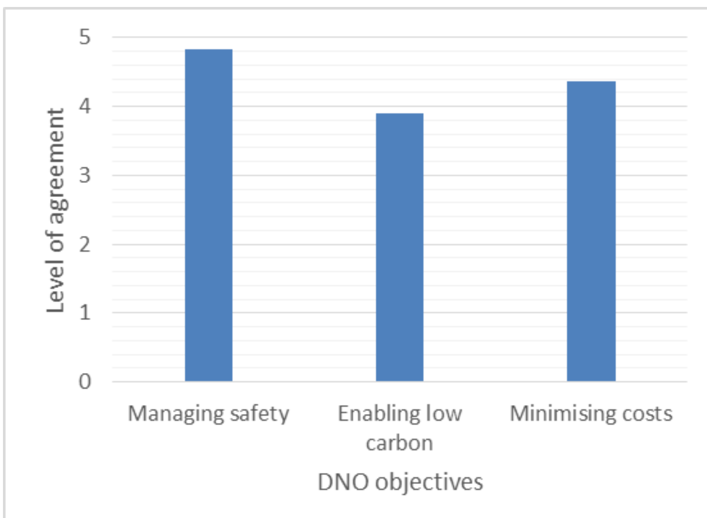

Figure 14, Importance of DNO roles.

The final question asks how much interviewees trust various groups to provide information on power quality.

In Figure 15 we see that, the supplier is considered the most trustworthy. DNOs received a slightly more mixed response in that some interviews claiming lower trust simply through lack of knowledge and interactions with the DNO. All other categories had more varied ratings resulting in an average close to neutral.

Figure 15, 'Who would you trust to inform you about power quality issues?'

5.Synthesis

In the previous chapters we introduced the notion of power quality, the roles and responsibilities in its management, and through semi-structured interviews examined consumer understanding and attitudes.

Whilst the interview cohort was a relatively small sample, and self-selected, there was a great deal of homogeneity in the results. The findings were that on average consumers:

1) Appeared to have little knowledge or experience of PQ related QoS issues. This is consistent with both good quality of supply in the UK and the resilience of many appliances. A more targeted group of consumers at network extremities, for example, may yield more information;
2) In terms of QoS, were most concerned about potential food spoiling from failed refrigeration. Lighting services become an annoyance if their light level is erratic. Otherwise consumers appear unconcerned by clock re-setting or other such inconveniences;
3) Had a reasonable knowledge of the existing nominal voltage and possible voltage extremes, although many consumers believe that voltage is constant;
4) Had a reasonable understanding of the risks associated with voltage extremes. Combined with the point above, the 'average consumer' is not far from being able to make judgments about smart meter voltage data;
5) Had little knowledge or understanding of the role of the DNO. This represents a key finding insofar as consumers are not aware of the services and costs associated with DNO activity, but more importantly whom they should contact in the event of PQ issues;
6) Considered their supplier to be the main actor to contact and handle PQ/QoS issues. This is consistent with the supplier being the single point of contact in the provision of electricity.

Following the information briefing, which introduced the value and possible effects of relaxing voltage regulations, the interviewees:

1) Expected the DNO to use smart meter data to manage voltage, this represents a shift from re-active to pro-active management, but the extent to which this will be reflected in DNO processes is uncertain;

2) Rated managing safety as the DNO's primary role, if not well managed then this is an area where trust in the DNO could be eroded, as well as potentially feeding negative attitudes towards PV (for example);
3) But also believed cost efficiency and enabling renewables to be important;
4) Would trust their supplier and DNO to provide information, this may however in part be consequence of their positive experience during Low Carbon London;
5) But would continue to call their supplier in the event of QoS issues, this poses a risk due simply to the delay in the correct parties communicating with each other;
6) May turn off appliances to minimise damage in the event of high voltages, this may pose a risk in that it may exacerbate voltage rise.

With these early observations we can identify possible risks in both a transition process to TTaT regulation, and day to day PQ management.

Firstly however we can consider the issue of lack of awareness of DNOs and their role in the energy system. Programmes such as the Low Carbon Network Fund have emphasised the need for 'consumer engagement' in smart grid projects (Newton, 2013), but it would appear that such engagement has not yet reach beyond the projects activities themselves.

5.1. The role of the DNO

Whether a low carbon transition can occur efficiently with the DNOs having such a passive relationship with the consumer is an open question, but it is in itself is problematic in higher-risk scenarios.

In a situation, for example, where damage or danger is imminent, whilst the consumer could call their supplier, ringing the DNO would be more efficient, and clearly in emergencies time is precious. The chief fire and rescue adviser recognises the need for institutional cooperation in the definition of risks and responses:

> 'Consideration must also be given to establishing and maintaining contact with electricity and electrical equipment suppliers or trade associations so that new initiatives within the industry can be identified and training interventions can be kept current.' (CFRA, 2013)

A TTaT regulatory change might warrant discussion between DNOs, suppliers, equipment manufacturers, fire authorities and consumer groups to establish best practice. A point of discussion could be 'If problems with PV initiated voltage rise do emerge: how should the various actors respond, both in the short and longer term?

And/or should the G83 recommendations be revisited in parallel to appliance testing standards?'.

The supplier in question was, on the whole, well-liked and there was some sense that consumers were comfortable using them as a single point of contact. The suppliers could become the custodians of PQ monitoring, protecting the consumer's interest by recording events and providing advice, but this would be a secondary role to that of the DNO managing PQ. The exception to this might be in a future scenario where local storage is available and power quality can be managed 'in-home'.

If we assume that a pro-consumer engagement strategy is appropriate, then a TTaT regulatory change might provide an opportunity to improve the general public's understanding of the wider system and the part that they play in it. Despite the DNO not being known or understood, the quality of existing supply seems to imply some trust in the DNO and this could provide a basis for further engagement.

5.2. Transition and roll-out scenarios

If a regulatory change takes place the DNOs will be in a position of having increased flexibility in the setting of substation voltages. In the case of a network experiencing over-voltage from PV, the transformer could be tapped down to reduce average voltage, as well as the amount of 'spilled' renewable energy, with the TTaT lower limit not being breached. This would not eliminate over-voltage, but would make it less likely.

In the case of a network experiencing low voltage constraints the substation voltage could be maintained around 253V, allowing more 'end of feeder' customers to be within the lower voltage limit.

The situation is, however, more complicated in a scenario where a network experiences, for example, both over-voltage in summer and under-voltage in winter. Here a change in the sub-station supply voltage would ameliorate one problem whilst aggravating another. Here seasonal tap adjustment might provide a solution but this is not a common practice and may be prohibitively expensive.

These scenarios are simplistic however since, in practice, there are a range of voltages on any given feeder, and all feeders are to some extent unique. Given the above there are a range of options for the DNO in terms of how they respond to a regulatory change, namely:

- Do nothing, with increased capacity due to lower allowable voltage minima;
- Wide-spread tap down of substation voltages to reduce over-voltage risk and spilled energy;
- Select tap settings based on local network health (though smart meter data).

The third approach allows for the consideration of the heterogeneity of the distribution system, the former two approaches involve risk in that they neglect local voltage conditions.

A ***do-nothing scenario*** may emerge, due to lack of DNO benefits and such an evaluation would include the potential costs accrued by the DNO. These are, currently, poorly defined in the DNO license conditions, since traditionally only disconnections are penalised and voltage has not been monitored due to lack of instrumentation (UK Government, 2015).

Following the roll-out of smart meters, there will be a glut of available data pertaining to network health but how this data will be used is undefined.

> 'The availability of smart meter data in itself does not necessarily eliminate the requirement to invest, but it provides DNOs with more detailed information to enable the best solution. As a result, DNOs can undertake required investments more efficiently by avoiding unnecessary spending in terms of the size and location of reinforcements, as well as in terms of the timing for the investment.' (Versmissen & Dimitropoulos, 2013)

With 'smart' meter data, cost of system reinforcement could be reduced, in a scenario of significant new loads, through better allocation of resources and this should benefit the consumer in terms of reduced Distribution Use of System (DUoS) pass through costs. However through smart meter data the DNO may also be made aware of problems that they were previously unaware of and which will include sites where voltage is regularly out of regulatory voltage limits, potentially incurring costs.

Given the above, prior to the better 'network visibility' facilitated by smart meters, it is unclear if DUoS costs will be reduced in the near term, following smart meter roll-out. The effects of a regulatory change upon the consumer are then unclear, and will depend on the DNOs actions, if any.

More certain is that the increase in load, facilitated by the TTaT lower limit, ***would increase losses as a proportion of load***, since they are proportional to the square of the current, and these costs are passed on to the consumer.

In a ***universal 'tap down' scenario,*** headroom for PV generation is created, whilst reducing the scope for additional load on a given system. This will not remove the potential for over-voltage, but it would lower its occurrence. To fully remove the potential for over-voltage would require resetting of inverter control gear to 253V, however because of the additional voltage headroom, less energy would be spilled.

Under lower voltage conditions, some appliances will consume less power, for example incandescent lights. This characteristic is often used by DNOs to reduce demand in emergencies, or in some networks as an efficiency measure (Dwyer, Nielsen, Stangl, & Markushevich, 1995) (Novitskiy & Schau, 2010). In the UK this represents a conflict of interest in the sense that DUoS charges, i.e. the DNOs income, are based on delivered energy.

Adopting a ***strategy based on network health***, using smart meter data would minimise risk of over and under-voltage but would require more complex supporting processes. Using a meter reading samples from both summer and winter, substation transformer taps could be set on a case by case basis to reduce breaches of regulation and/or minimise spilling of renewables. Again to remove totally the risk of over-voltage inverter control gear would need to be set appropriately.

Given the heterogeneity in network topologies and associated loads, it appears unlikely that a lower substation voltage setting could be universally applied. However if, as in London, many substations are set to the higher end of the regulatory limit, the option for tapping down could be widely applied. This would be of benefit in networks where micro-generation is present and causing over-voltage, or the spilling of renewable energy.

In light of the uncertainty of the current supply voltages of consumer premises, there may parts of the network where the TTaT lower limit is already occurring. As the TTaT lower limit appears relatively benign, it is the deviations below it, and above the upper limit of 253V that are of concern. In this respect, we can consider what is appropriate in terms of policy and responsibilities, independently of the regulatory limits i.e. if voltage can rise and fall out of limits, what is action required, and what might this comprise.

5.3. Management of under-voltage and over-voltage events

Irrespective of the strategy adopted by the DNO, there will be situations where under or over-voltage occurs. In these situations, if sufficient to cause the risks identified earlier, action should be taken by either the DNO or consumer or both.

The extent to which the DNO is notified with regard to short term breaches will depend on the sag and swell thresholds that are configurable in the smart meter (DECC, 2014). These events are dispatched automatically from the meter as opposed to voltage profiles which require the meter to be interrogated by the Data Communications Company (DCC).

There is currently little the DNO can do in the short term to reduce the incidence of under or over-voltage, other than increasing or reducing voltage using primary transformer tap changes which would impact thousands of consumers indiscriminately. The sag and swell information is however useful for establishing network health and could be part of a tap-setting strategy and for longer term planning.

Given appropriate IHD functionality, the consumer will have access to voltage data and as described in the previous chapter may act if they notice a high or low-voltage event. Low-voltage is not perceived to be as problematic as high voltage, and customers appear to have some sense of the possible impacts.

Given the interviewees stated actions in the event of over-voltage, there appears to be a need for clear information as to what to do, and who is responsible.

A phone call to the DNO may not be required if through the smart meter the DNO is already aware. This would have to be communicated back to the consumer if worry and unnecessary phone calls are to be avoided (in order to maintain trust). A call to the supplier is less appropriate, and introduces unnecessary call handling costs, moreover the supplier is not typically equipped to handle such queries and ask appropriate questions.

In terms of the consumers actions, turning off appliances might seem sensible, but in isolation could cause further voltage rise (assuming local DG control gear allows). This suggest that some guidance may be appropriate as to what actions should be taken in such situations. For example it might be appropriate to turn off low powered, sensitive equipment only since this will not greatly aggravate the situation, while protecting the appliances in question.

The availability of voltage information to the consumer may occur prior to the development of DNO policy or IT systems that handle voltage profile and sag/swell event data. In this scenario the DNO may be vulnerable to negative publicity or legal action when consumers record breaches of regulation concurrent with material damage. This further supports the notion of improving consumer understanding.

5.4. Product development and promotion

From the experimental results in F&M, it appears that many devices are resilient to low-voltage events, but going forward any new standards would have to be included in design processes and test procedures. Some appliances may require adaption, to ensure robust operation, but with the advent of ‘smart appliances’ it is not inconceivable that appliances could monitor the voltage of their supply. This information could be used in a number of ways. The appliance could respond defensively by adapting its behaviour and could report the issue to the consumer.

The SMETS2 smart meter specification does include voltage information, but requirements for voltage to be displayed does not appear in the IHD requirements specification (Ofgem, 2010). Whether IHD developers will include voltage information in their designs remains an open question.

5.5. Communication strategy development

The preceding sections present a complex and changing 'landscape' for both the consumer, DNO and supplier. The current situation of all actors being 'blind' to voltages, is set to change with the advent of smart meters.

With G83 allowing voltages above the regulatory limit, appliance malfunction or damage may already be a present danger. Where at present there is no widespread means to identify the causality of such damage, such events may already be occurring.

Given the above, and the rapidly changing environment, when smart meters are installed the suppliers may receive many calls that should more correctly be directed at the DNO. Whether these calls reflect material problems or are more related to anxiety suggests there is some need for education as to when it is appropriate to call the DNO.

Again, with a great deal of uncertainty surrounding the existing situation and corresponding DNO responses, the extent to which trust could be eroded is uncertain. However the current reactive approach to PQ management may be inappropriate in the context of a better informed consumer population equipped with smart meters. But what might a proactive approach comprise? Reflecting on the interview findings the following objectives may be appropriate:

- Educate the public about the basics of the role of the DNO;
- Explain what acceptable voltages ranges are, and when to contact the DNO;
- Communicate with customers in network areas of concern when smart meters reveal voltages close to regulatory limits;
- Define and communicate best practice for consumer actions during under and over-voltage events.

In practical terms, low voltage events are more likely to happen in proximity to the end of network feeders and high voltages at sites near PV installations. This might allow smart meter data reading, and communication costs to be minimised by targeting the most vulnerable locations. Such assumptions, and communications could be tested in pilot trials at suitable secondary substations.

In these processes, as well as managing risk and communicating about PQ and QoS, other messages about positive side-effects may help trust and alleviate resistance to change, for example:

- Lowering total system re-enforcement costs;
- Lowering disruption of earthworks;
- Potentially lowering energy use.

Such activities could also benefit from 'anchoring' narratives around existing understanding and beliefs, for example as identified in the preceding interviews:

- Current good level of service;
- Existing knowledge of voltage and possible risks;
- Supplier's role in relation to DNO role;
- Desire to save costs.

Appropriate media for education have not been explored in depth, but the development of smart meter connected IHDs will govern the extent and format which voltage data is communicated. It was beyond the scope of this report to discuss design activities with manufactures of IHDs; however engagement of DNOs, not just suppliers, with IHD designers appears appropriate. Moreover, IHD design requirements could be revisited to consider whether voltage data is appropriate for consumers.

6. Conclusions and Recommendations

The Transformation of Top and Tail project was conceived to address network capacity constraints to facilitate the transition to a low carbon economy. If UK targets for distributed renewable energy are to be met then additional distribution network capacity will be required.

By better aligning thermal capacity and voltage constraints, the proposed TTaT voltage range has been shown to be a possible alternative to system reinforcement (Frost & Mitcheson, 2013). As revealed in earlier chapters however, there is a great deal of uncertainty surrounding the state of existing networks, and the likely responses of the DNOs to any regulatory change.

This report has aimed to contribute to the understanding of the consumer's attitudes to power quality with a view to informing policy development.

Such analysis would typically include a systematic review of available literature on the subject, but searches revealed an absence of related studies. Because of the lack of literature on understanding and attitudes related to power quality, a pilot study was conducted, comprising 30 semi-structured interviews. Because of the uncertainty surrounding the impacts of a regulatory change upon the consumer, the interviews focused on prior experience, knowledge and attitudes to electricity supply quality and appliance quality of service.

The situation in terms of consumer experience of QoS is currently very good for those interviewed. The electricity consumers interviewed had very little experience of power quality problems, confirming the *a priori* assumption of low awareness.
While interviewees had little experience of actual problems, when asked to imagine issues arising in a future scenario they responded in a fairly consistent pattern. Repeating the summary from the discussion section, the consumers interviewed, on average:

- Appear to have little knowledge or experience of power quality related QoS issues;
- In terms of QoS, are most concerned about potential food spoiling from failed refrigeration;
- Have a reasonable knowledge of the existing nominal voltage and possible extremes;
- Have a reasonable understanding of the risks associated with voltage extremes;
- Have little knowledge or understanding of the role of the DNO;

- Consider their supplier to be the main actor to contact and handle PQ/QoS issues.

Following the 'Information briefing' on the purpose of TTaT, its context and implications, the questions revealed that, on average the interviewees:

- Expect the DNO to use smart meter data to manage voltage;
- Rate managing safety as the DNO's primary role;
- But also believe in cost efficiency;
- Would trust their supplier ***and*** DNO to provide information;
- But would continue to call their supplier in the event of QoS issues;
- May turn off appliances to minimise damage in the event of high voltages.

Because the limited sample and inability to target customers at the end of feeders, there may be consumers with more experience of QoS issues. A larger study, with a cohort including sites at the end of feeders and with micro-generation may be appropriate to establish existing worst case conditions and symptoms.

The implications of these findings, given the complex and changing LV landscape are not straightforward. Whether or not TTaT voltage standards are adopted, given the findings of F&M, lack of data on existing LV voltages, and G83 allowing over-voltage, some consumers may already be at risk.

While the DNO is responsible for power quality, going forward is it appropriate that they are the sole custodians of power quality data? This appears to be implicit in the smart meter and IHD requirement specification. Given that remote communications can fail, it may be appropriate that IHDs do allow voltage profiles and alerts to be communicated to the customer. This however would require some education of consumers as to what the data means. In terms of communication objectives, the following areas were identified as poorly understood:

- The role of the DNO in managing PQ;
- Acceptable voltages ranges;
- When to contact the DNO;
- Best practice during under and over-voltage events.

Combining these objectives could help spawn a more objective understanding of the electrical system amongst consumers, securing trust in the systems operators, and reducing risk. From the interviews conducted, it appears that there is on the whole some level of understanding and trust upon which to develop. In practical terms, however the lack of voltage data in smart meter IHD requirement documents, suggests this level of engagement is not currently foreseen. The DNOs trade association, the ENA, recognises that perceptions of the system will be challenged:

> ‘Moving towards a low-carbon future and tackling climate change is bringing new challenges to the operators of the UK and Ireland's energy networks. Society's perceptions of energy and electricity will be challenged too. How we generate it as a country, how we use it as individuals and even how we contribute to the supply of it through our homes and businesses.’ (ENA, 2015)

A question for policy makers and regulators is to establish the extent to which such perceptions should include the consumer’s understanding of the wider electrical system and engagement in the management of power quality. A situation of improved consumer understanding and participation would appear less risky than the current trajectory, that of ‘out of sight, out of mind’ for both the DNOs and the consumer.
In practical terms, irrespective of delivering a TTaT regulatory change, the following areas of policy would benefit from review:

- Are G83 voltage upper limits appropriate and safe?
- Responsibilities with regards to the costs incurred by under and over-voltage events;
- European voltage standards and testing requirements;
- Smart Meter IHD requirements with a view to including voltage trends and events;
- Education of the public (if engagement is appropriate), as per the objectives listed above.

With the rapidly changing ‘demand-side’ environment these issues may become more pressing and if not resolved negative events could result in an erosion of trust in low carbon technologies and the organisations delivering them, slowing progress to de-carbonisation.

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8. Appendix

8.1 Pre-existing QoS experiences interview. Prior to informing interviewee

LCL Ref		
Date		
Question	Data	
Have you experienced problems with any of your electrical appliances?	Yes/No	
Which appliances have you experienced problems with?	Lights (GLS, Fluorescent, CFL, Halogen, LED), Cooker, Fridge, Freezer, Dish washer, Washing machine, Tumble dryer, Clock, TV, Radio, PC, Hi-Fi, Other, Fuse-box, Other, None.	
What was the effect you noticed?	[Free response]	
How did this make you feel?	[Free response]	
Have you noticed what if anything that you think may trigger/be linked to these issues? E.g. weather/temperature conditions, having many appliances running at once, …	[Free response]	
Would you tend to blame:	The appliance?	
	The wiring in your home?	
	The local distribution cables and substations?	
	The electricity being supplied?	
	Other consumers in the local area?	
	Other? (please specify)	
	Not at all sure/no idea.	
How sure are you that the problems with the appliance were caused by the above?	Appropriate row above. Where: 5: Very sure 4: Sure 3: Neither 2: Unsure 1: Very unsure 0: Not applicable	

8.2 Existing understanding and attitudes to PQ and QoS

Ownership and understanding of surge protector sockets and attitudes to voltage-related malfunction

Have you ever bought a surge protector socket or socket-board?	Yes/No
What was your reason for buying it/them?	[Free response]
As you understand it what would these protect against?	[Free response]
How concerned would you be about the following power quality symptoms? Where: 5: Very Concerned 4: Concerned 3: Neither concerned or unconcerned 2: Unconcerned 1: Very unconcerned 0: Not applicable	
A dip in lighting brightness for a few seconds.	0 1 2 3 4 5
A period of dim light lasting minutes or hours.	0 1 2 3 4 5
Prolonged flickering of light.	0 1 2 3 4 5
Digital clock resets to wrong time.	0 1 2 3 4 5
Cooker clock resets to wrong time.	0 1 2 3 4 5
Vacuum cleaner temporarily stops working.	0 1 2 3 4 5
Fridge temporarily stops working.	0 1 2 3 4 5
Freezer temporarily stops working.	0 1 2 3 4 5
Radio/hi-fi turns off/ temporarily stops working.	0 1 2 3 4 5

Fuses tripping.	0 1 2 3 4 5

Voltage, prior knowledge.

Do you know the voltage of the electricity supply to your home?	[Free response] (Look at free response to see how they answer – how they appear uncertain? Do they raise the issue of fluctuation?)
Does this voltage vary?	Yes/No
What would be a high number?	Number
What would be a low number?	Number
As far as you know, what would be the consequences of an overly high voltage?	[Free response]
And too low a voltage?	[Free response]

8.3 Roles and responsibilities, prior knowledge.

How satisfied are you with your electricity supply? Where: 5: Very satisfied 4: Satisfied 3: Neither satisfied or unsatisfied 2: Unsatisfied 1: Very unsatisfied 0: Not applicable	0 1 2 3 4 5 [need to read them the scale meanings first]
Who do you believe to be responsible for the quality of your power supply?	Name
Have you had any interactions with them?	[Free response]
Was the experience satisfactory?	0 1 2 3 4 5
What would you do if you experienced voltage/PQ issues in the future? If they say call X/Y/Z company/organisation ask if they know what number to call.	[Free response]
Do you think consumers are adequately informed about power quality issues affecting or potentially affecting them? Where: 5: Strongly agree 4: Agree 3: Neither agree nor disagree 2: Disagree 1: Strongly disagree 0: Not applicable	0 1 2 3 4 5 [need to read them the scale meanings first]
Do you trust that power quality is being managed properly?	0 1 2 3 4 5
Do you know what a distribution network operator/DNO is?	[Free response] Explain DNO after negative response or poor description.
Do you know who is responsible for the distribution network in your area?	[Free response]
It's UK Power Networks. Have you heard of them before?	[Free response]

8.4 Information briefing

- Technologies such as solar panels, heat pumps and electric vehicles are becoming increasingly popular.
- These technologies tend to make the electricity supply voltage fluctuate more than previously.
- Heat-pumps and electric vehicles will tend to reduce the supply voltage, solar panels will tend to increase the supply voltage.

- Researchers are proposing that supply voltage regulations be relaxed.
- This will allow greater fluctuations in Volts, with the lower limit being reduced.
- This should mean the DNO will need to replace less underground cable in the future.
- This should help you in terms of future electricity bills.
- Provided the voltage stays within these new limits then there would be little effect on QoS.

- However the voltage may occasionally go outside these limits.
- If the voltage falls below then lights may dim or, a freezer may stop working temporarily.
- If the voltage goes too high then equipment may be damaged.
- DNOs can adjust voltage to minimise these events.
- It will be possible for energy companies to monitor voltage through the coming 'smart meters'

8.5 Questions post Information briefing

Would you expect the DNO to check your voltage is within limits if this could be done with smart meters? **Where:** 5: Strongly agree 4: Agree 3: Neither agree nor disagree 2: Disagree 1: Strongly disagree 0: Not applicable	
Would you use your smart meter display unit to check voltage, if you experience QoS issues?	0 1 2 3 4 5
Would you be likely to replace GLS bulbs with CFLs or LEDs if they fixed light level issues?	0 1 2 3 4 5
What might you do if you noticed that the voltage was above the regulatory limit?	[Free response]
What might you do if you noticed that the voltage was below the regulatory limit?	[Free response]
Which of the following power quality management policies would you support?	
DNO monitors voltage using smart meters?	0 1 2 3 4 5
Consumers monitor voltage and report issues to the DNO?	0 1 2 3 4 5
Free bulb replacement?	0 1 2 3 4 5
Can you grade the importance of these DNO roles:	
Managing safety?	0 1 2 3 4 5
Facilitating low carbon technologies such as solar panels?	0 1 2 3 4 5
Minimizing costs?	

	0 1 2 3 4 5

Who would you trust to inform you about power quality issues?	
DNO	0 1 2 3 4 5
Supplier	0 1 2 3 4 5
Council	0 1 2 3 4 5
Government	0 1 2 3 4 5
Citizen's Advice	0 1 2 3 4 5
Neighbours	0 1 2 3 4 5
Friends/family	0 1 2 3 4 5
Media	0 1 2 3 4 5
Other (please specify)	0 1 2 3 4 5