Power Quality

Summary

This article provides an overview of how voltage harmonic distortion is managed on the distribution network and focuses on the current at future issues surround the connection of non-linear equipment to the distribution network.

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Note: a glossary and diagram key can be found in the DSOF introduction document on our website

Background

In an AC power system, harmonic distortion is the departure of the voltage or current waveform from a sinusoidal shape and is usually the result of operating non-linear equipment. Non-linear equipment is electronic equipment, usually power converters, which draw or produce distorted non-sinusoidal currents when energised by a sinusoidal voltage. Listed below are some examples of load and generation non-linear equipment that produce harmonic current emissions and distort the voltage waveform:

- Switch Mode Power Supplies (SMPS), generally low wattage power supplies for domestic, commercial and light industrial equipment, such as computers, servers, LED lighting, machine power supplies and other DC loads;
- Rectifiers with capacitors, used for AC-DC conversion for DC loads, such as battery charging equipment and other heavy DC loads;
- Silicon Controlled Rectifiers (SCR), such as Thyristor controlled rectifiers, used for lamp dimming, motor control and control of welding equipment;
- Variable Frequency Drives, usually implement a Pulse Width Modulation (PWM) switching technique to control the speed of motors, fans, machines, and traction equipment;
- DC-AC Inverters, commonly used with photovoltaic arrays and in wind turbine applications. Again, a PWM switching technique is usually implemented to control the semiconductor switching devices;
- AC Motors and Synchronous Generators, whilst not considered to be non-linear equipment, do produce harmonic current emissions. Due to variations in the internal windings and magnetic field, both can distort the voltage waveform. The voltage distortion is usually very small, about 1–2% Total Harmonic Distortion (THD), nonetheless it does still exist; and
- Other, new technologies, such as active front-end convertors, are becoming more common and in a lot of cases do not comply with an IEC or BS EN 61000 [1] series engineering standard that govern Electromagnetic Compatibility (EMC) and define harmonic current emission limits for equipment connecting to public power networks. High powered electric vehicle chargers and heat pumps are some examples of new or developing technologies that may not comply with existing EMC standards and require special consideration when connecting to the distribution network.

Focusing solely on harmonic distortion as a power quality issue; satisfactory operation of the electricity supply system and customers' equipment is only obtained where EMC between them exists. Harmonic distortion affects the efficiency and operation of both the distribution network and customer's equipment and can lead to the failure of equipment. Therefore it is imperative that harmonic distortion is kept within safe operating limits. Unlike statutory limits defined in the ESQC Regulations [2] for voltage and frequency; harmonic distortion is not governed by statue. The Distribution Code [3] is the enforcing document which requires Distribution Network Operators (DNOs) to comply with harmonic limits set out in *ENA Engineering Recommendation G5 Issue 4 Amendment 1 (G5/4-1) "Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Equipment to the Transmission and Distribution Networks in the United Kingdom"*. G5/4-1 [4] relates only to new connections to the distribution network and there is no obligation for the DNO to ensure voltage distortion on the network stays below planning levels. However G5/4-1 provides good guidance on the voltage distortion and network harmonic levels that should be achieved on the distribution network.

The IEC or BS EN 61000 series engineering standards specify compatibility levels for public supply system harmonics and immunity levels for electrical equipment up to 35kV. Equipment immunity levels describe the maximum electromagnetic disturbance or level of total harmonic distortion for which a particular device, piece of equipment or system remains capable of operating with a declared degree of performance. Compatibility levels describe the levels of electromagnetic disturbance or level of harmonic distortion for which Electromagnetic Compatibility should exist for most equipment. The Electromagnetic Compatibility levels are set lower than the equipment immunity levels as to provide headroom between the two levels for short deviations in increased levels, or bursts, of harmonic distortion. Experience has shown that there will be a sudden increase in equipment failures and customer complaints when harmonic component levels on the electricity network exceed the relevant compatibility levels. In order to avoid this situation occurring network planning levels are set lower that compatibility levels. Finally, if a piece of non-linear equipment complies with the IEC 61000 series engineering standards its maximum current harmonic emission levels will be known and will be within a specified limit. The relationship between EMC levels, as described above, is illustrated in Figure 1.

In order for a DNO to operate an electricity network where EMC exists between the network and customer's equipment, is efficient, and has predictable behaviour, it is necessary that the connection of non-linear customer equipment is controlled in accordance with G5/4-1. This will help to ensure voltage distortion does not become excessive.

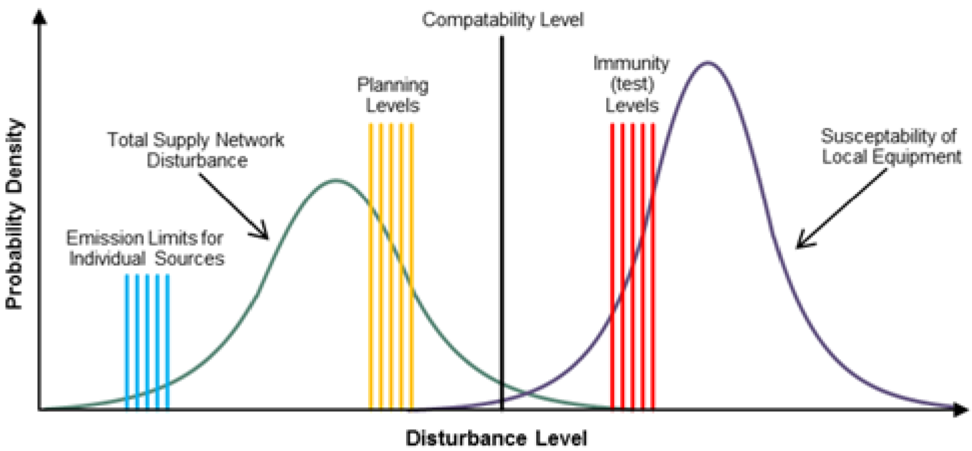

Figure 1: Relationship between Planning Levels, Network Disturbance Levels, and Equipment Immunity Levels as described by G5/4-1

Network Impact

As already discussed, harmonic distortion is usually caused by the connection and operation of non-linear equipment connected to the distribution network. It is the responsibility of the DNO to ensure that new connections do not cause network harmonic levels to exceed planning levels, as described in G5/4-1, in order to maintain EMC between the network and customer equipment. Harmonic distortion affects all voltage levels on the distribution network, hence, careful planning and assessment of new connections is required at all voltage levels. Table 1 provides a summary of the THD planning limits for different voltage levels. A more detailed breakdown of the harmonic component planning levels for different voltage levels can be found in G5/4-1.

Table 1: Summary of THD Planning Levels

System Voltage at the Point of Connection	Applicable WPD Networks	THD Limit
400V	LV	5%
6.6kV, 11kV & 20kV	6.6kV & 11kV	4%
22kV to 400kV	33kV, 66kV & 132kV	3%

With the continued growth of low carbon technologies, such as PV, wind generation, electric vehicles and heat pumps connecting to the distribution network, the need to carefully asses, plan and measure the network harmonic levels is increasing. Each voltage level on the distribution network presents its own challenges, both in terms of its harmonic performance and planning processes. This section discusses the harmonic related issues at each voltage level on the distribution network. In addition to this, other issues such as harmonic measurement, monitoring, and management are also discussed.

Low Voltage Network (400V)

The low voltage network is the most accessible voltage level for customers seeking new or marginally higher capacity electricity connections. Connections to this voltage level are usually straight forward and require very minimal reinforcement work. This voltage level services domestic, commercial, and small manufacturing customers, including homes, shops, schools, and small businesses to name a few.

Assessment Procedure for New Connections

The assessment procedure for connecting non-linear equipment to the LV network is usually a desktop study and does not require measurement of the harmonic levels on the network. A Stage 1 Assessment, described in G5/4-1, may be undertaken by assessing the following:

- Compliance with the relevant IEC 61000 standards;
- The power rating and type of convertor used as described by G5/4-1 Table 6; and
- The harmonic current emissions from the non-linear equipment as described by G5/4-1 Table 7.

Where the harmonic current emissions from a particular piece of equipment are higher than the prescribed limits a Stage 2 assessment is required. A Stage 2 assessment involves assessment of convertor technology and rating, assessment of equipment harmonic current emissions, measurement of network harmonic levels, and determining the impact of connecting the new proposed equipment. This can be a time consuming activity.

With the growth of low carbon technologies, it is becoming more common to see requests for the connection of non-linear load equipment that do not comply with an IEC 61000 series standard for harmonic current emissions, primarily equipment rated above 75A per phase. The increasing volume of non-compliant equipment connecting to the distribution network is placing a large demand on DNO resources, both in terms of planning and network design. For the cases where non-linear load equipment cannot be connected to the distribution network, either because the network fault level is not high enough or the equipment's current emissions exceed the IEC 61000 series limits, it may be necessary for the customer to install harmonic filters.

Harmonic Measurement

Measurement of harmonic levels on the LV network is relatively straight forward and accurate measurements can be obtained. The equipment used to measure harmonic levels is usually designed for use at 230/400V AC, which means it can be connected directly to the LV network without the use of measurement transformers or transducers. The harmonic measurement equipment can be connected at the Distribution Substation or, ideally, at the customers Point of Common Coupling (PCC).

Impact on Operability

As the LV network serves the largest amount of customers and LTCs are becoming more available, it is expected that harmonic levels on the LV network will increase and the capacity for new connection will decrease. This coupled with the fact that high power non-linear equipment is becoming more common means that more in depth planning, harmonic background measurements and reinforcement to achieve required fault levels, may be required on the LV network in order to manage harmonic levels.

High Voltage Networks (6.6kV & 11kV)

The High Voltage network is the next most accessible voltage level for customers. This voltage level services larger customers such as large businesses, manufacturing facilities, hospitals, and universities, as well as the LV distribution network. Connections on the 11kV network are usually more secure due to its design and the requirement to comply with P2/6 [5].

Assessment Procedure for New Connections

The assessment procedure for connecting non-linear equipment to the HV network is a Stage 2 assessment as described by G5/4-1*.* G5/4-1 provides aggregated power limits for some common types of power electronic equipment, such as 6-pulse convertors, and stipulates the harmonic current emission limits to be applied for this type of assessment. In some cases the harmonic levels on the network will have to be measured and the proposed equipment current emissions will have to be assessed. The Stage 2 assessment ensures that connection of the proposed equipment does not cause the network THD and harmonic component voltages to exceed the limits set out in G5/4-1. In order for this assessment to be carried out the network impedance and fault level must be calculated. The calculation of network parameters and assessment of network harmonic performance is a specialist and time consuming task. While the customer does have the option to appoint a third party consultant to carry out the assessment the DNO will usually carry out the assessment at this voltage level. That said, the DNO will always validate the study carried out by a third party consultant, which again is a specialist and time consuming task. For the cases where the proposed equipment cannot be connected to the network after a stage 2 assessment has been completed, mitigation measures may have to be put in place or a Stage 3 assessment will have to be completed.

Harmonic Measurement

In many cases a measurement of the network harmonic levels will be required as part of the Stage 2 assessment before non-linear equipment can be connected to the network. The equipment used to measure harmonic levels is usually designed for use at 230/400V AC which means it cannot be connected directly to the HV network. Instead the measurement equipment must be connected to voltage transformers (VT) and current transformers (CT). The VTs and CTs that the measurement equipment is connected to are located in primary substations or switching stations. Depending on the configuration of the substation there may be either of the following VTs and CTs to connect to:

- Protection VTs and CTs, usually mounted in switchgear.
- Metering CTs and VTs.

Measuring network harmonic levels through VTs and CTs is not ideal as the transformers can attenuate or amplify harmonic components and introduce phase shift errors. This can lead to inaccuracies in the harmonic measurements and is a known issue. Higher order harmonic components are usually affected and consideration can be given when assessing new connections with known high order harmonic components. Connection to VTs and CTs is convenient as this equipment is often already installed in substations and HV works are not usually required to obtain measurements.

Impact on Operability

In certain areas, across all four WPD licence areas, it is being observed that there is limited capacity to connect non-linear equipment to the HV network. This is due to the following:

- Length of circuit feeders. Much of the HV network can be classified as being high impedance and consequently has low fault levels. Both impedance and fault level have an effect on the harmonic performance of the network. Harmonic voltage distortion is higher on networks with higher impedances and lower fault levels. Generally speaking, this means that the further away from the source the proposed equipment is located, the higher the harmonic voltage distortion will be.
- Higher power non-linear equipment. Customers connected to the HV network are higher power users compared to those connected to the LV network. Voltage distortion is proportional to the equipment rating to network fault level ratio. This means that high power non-linear equipment can have more of an impact, especially on low fault level networks. With the arrival of new low carbon technologies such as electric vehicles and solar generation, higher power electronic converters are connecting to the distribution network.
- Increased amount of non-linear equipment connecting to the network. As new technologies develop and become common place in consumer and commercial markets, the amount of connection applications is increasing. Many Electronic products involve AC-DC or DC-AC conversion.

Areas of network with limited harmonic capacity (network disturbance levels approaching planning levels) can be observed in both rural and urban areas. Urban areas tend to have shorter, low impedance, feeders but may have a higher density of non-linear equipment. Rural areas tend to have longer, higher impedance feeders, but have a lower density of non-linear equipment. Due to the complexity of the network, variability of equipment density, and the different types of non-linear equipment, each connection request must be assessed on a case by case basis.

Extra High Voltage Networks (33kV, 66kV & 132kV)

The EHV network is primarily used to distribute electricity to the HV network. Large demand and generation customers may also connect directly to the EHV network; however there are far less EHV customers than those connected to the HV and LV networks. Customers connected to the EHV network tend to be large manufacturers and infrastructure operators but small to medium generation connections are more common. Generators in the region of 5MW to 50MW generally require connections on the EHV network. With the recent growth in distributed generation, particularly PV, a large number of small to medium power stations have connected to the EHV network. This is largely due to the reach of the EHV network in urban and rural areas and the capacity to accommodate generation connections.

Typical demand customers connected to the EHV network are large manufactures, steel works, cement works, traction operators and other large infrastructure operators. All of these demand customers have processes and equipment that impose disturbances on to the electricity network. The EHV networks have higher fault levels which permits larger rated disturbing loads to be connected. The largest disturbing demand customers are connected to the 132kV network in order for their processes and equipment to have minimal impact on power quality. Traction operators for example, operate 132/25kV transformers for electrification of the rail networks. While their power consumption is relatively low, the electronic power converters they use can be particularly disturbing and high fault levels are required to minimise voltage disturbances.

As more and more customers are connecting to the EHV networks and customers are increasing the utilisation of their existing electricity connections, increased levels of harmonic distortion are being witnessed. This is true for both generation and demand customers.

Assessment Procedure for New Connections

The assessment procedure for connecting non-linear equipment to the EHV network is a Stage 3 assessment as described by G5/4-1*.* The Stage 3 assessment is applicable to all voltage levels at or above 33kV and consists of:

- Measurement of the existing harmonic levels on the network;
- Calculation of the harmonic levels produced by the non-linear equipment; and
- Prediction of the new network harmonic levels as a result of the new non-linear equipment and change of network impedance.

The harmonic distortion levels are assessed at the Point of Common Coupling with existing or future customers and at other nodes on the network. As with the stage 1 and stage 2 assessments, harmonic planning levels are stipulated for the EHV network to ensure EMC is maintained between the distribution network and customer's equipment. The Stage 3 assessment is more complex and requires network harmonic measurements at local and remote locations, harmonic measurements at different voltage levels, and requires the use of network analysis software. This is a specialist task and can take weeks of work to determine the impact of connecting non-linear equipment.

Harmonic Measurement

EHV network harmonic levels are measured in a similar way to HV network. Low voltage harmonic measurement equipment is used to measure harmonic levels through VTs and CTs. As previously discussed, the CTs and VTs are usually used for system protection and are installed in the substation switchgear. The frequency response of the CTs and VTs is not linear which introduces error into the measurements. In general, transformer type voltage transducers have a suitable frequency response up to 1 kHz which places limitations on the ability to measure high order harmonic components. Using protection CTs and VTs can also place limitations on where harmonic measurement can be taken as they must already be installed to make use of them. Capacitive Voltage Transformers (CVTs) are a type of voltage transformer commonly used on 132kV network instead of ordinary VTs. CVTs cannot accurately measure harmonic voltages and hence, cannot be used for harmonic measurements without modification. Harmonic measurements on EHV network can be complicated if there are no CTs and VTs to connect to. Temporary measurement equipment can be installed but this would usually require an outage on the circuit to be measured. Temporary measurement equipment in the form for of VTs and CTs is expensive and can be expensive to install, especially at higher voltage levels.

Impact on Operability

In a number of areas across the WPD licence areas it is being observed that network distortion levels are approaching planning levels, notably the 5^{th} harmonic. This means there is little network capacity to connect customers with non-linear equipment without implementing mitigation measures. The 33kV network has been affected by the rise in network harmonic levels which is largely due to the increase in customer generation and demand connections. In addition to this the 33kV network is susceptible to large disturbances on the 132kV network. For example, the transfer coefficient for the 5^{th} harmonic from the 132kV network to the 33kV network is 1, and for higher order harmonics up to the 27^{th} it can be greater than 1. Traction operators connected to the 132kV network are increasing the utilisation of their connections which means the harmonic current emissions from their sites is becoming more persistent. 33kV networks that are fed by the 132kV network in close proximity to traction operators are starting to see increased network harmonic levels as a result of their operations. This is known to be to be the case as rises in harmonic levels are observed on the same two phases that traction operators are connected to.

The rises in network harmonic levels on the EHV network may also be due to the same factors explained in the *High Voltage Networks (6.6kV & 11kV)* section. These are:

- Length of underground and overhead circuit feeders;
- Higher power non-linear equipment; and
- Increased amount of non-linear equipment connecting to the network.

Detailed Assessment

So far in this chapter, the impact of connecting non-linear loads to the distribution network has been discussed in detail. Both generation and demand customers' equipment can produce harmonic current emissions that cause harmonic distortion to the voltage waveform. The harmonic assessments that are carried out for each voltage level have also been discussed. It is the responsibility of the DNO to ensure EMC is maintained between the Distribution network and the customer's equipment. In most cases it is the customer's equipment that is the cause of harmonic related problems and the assessment procedures provide a method of assessing the impact of non-linear equipment.

Case Study – Harmonic Behaviour of Reactive Compensation

The connection of customer's non-linear equipment is not the only cause of harmonic related problems. The connection of reactive components such as inductors and capacitors alter the frequency response of the network and can lead to electrical resonance. Reactive components are used in VAR compensators and harmonic filters and can alter the network voltage. Since the impact of connecting non-linear equipment has been discussed in detail, this case study describes a case where reactive components operated by the DNO lead to network harmonic levels exceeding planning levels.

Camborne Bulk Supply Point (BSP) is a 132/33kV substation in the WPD South West licence area. The BSP has a 33kV 20MVAr capacitor bank that can be switched in to support the 33kV voltage level during times of high demand. The BSP feeds the Carn Brea 33/11kV primary substation (located next to Camborne BSP), as well as several other primary substations in the area Figure 2.

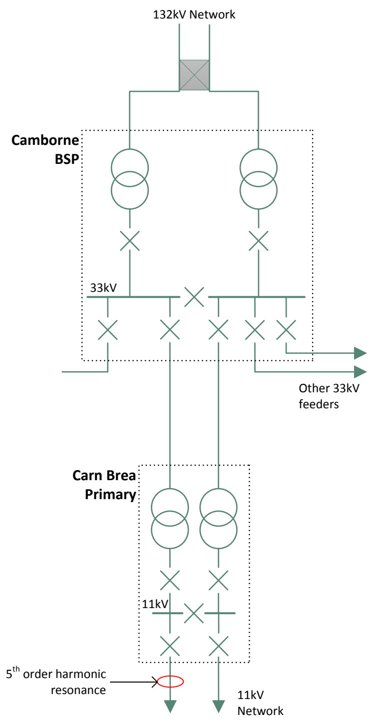

Figure 2: Camborne BSP Single Line Diagram – Prior to Harmonic Resonance Solution Being Installed

In 2003 an 11kV customer connected to the Carn Brea primary made a complaint about the quality of the voltage supplied to them as it was affecting their commercial processes. The network harmonic levels were measured at the customer point of connection. It was found that the 5th harmonic was exceeding network planning levels. Harmonic measurements were taken at different points around the 11kV network to try and determine the source of harmonic current emission. A single harmonic source or disturbing customer could not be found and a detailed network study of the local area was carried out.

Upon completion of the network study it was found that the 33kV 20MVAr capacitor bank used for voltage support was causing the problem. When the capacitor bank was switched in it was causing electrical resonance on the 33kV network. The resonant frequency on the 33kV network, with the capacitor back switched in, was found to be 250Hz which is the 5th harmonic for a 50Hz system. Resonance has the effect of increasing the harmonic impedance at a resonant frequency. The capacitor bank was confirmed to be the problem as the 5th harmonic was found only to be exceeding planning levels when the capacitor bank was switched in Figure 2.

The electrical resonance caused by the capacitor bank could have been removed simply by removing the capacitor bank from the network. This however was not an option as the capacitor bank is required to support the 33kV network voltage. The solution was to add a reactor shunt connected with the capacitor bank Figure 3. The series connected inductance changes the frequency response and its value was carefully chosen so that it has an attenuating effect on the 5th harmonic. A 33kV air core reactor was installed alongside the capacitor bank to solve the harmonic power quality issue.

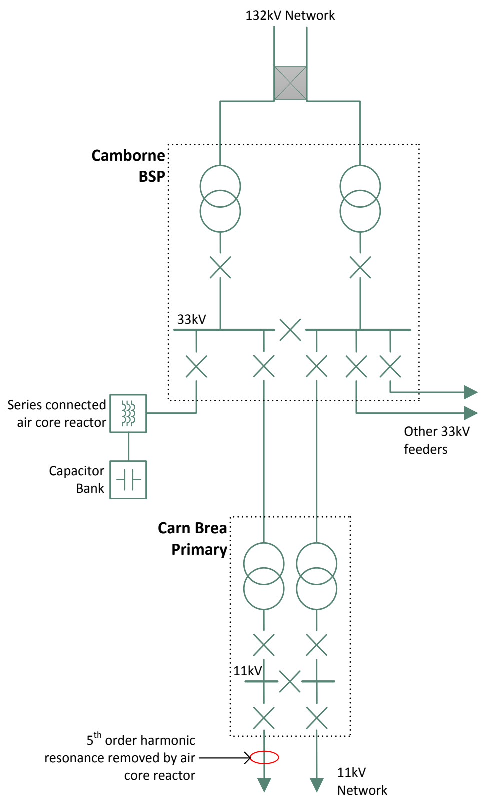

Figure 3: Camborne BSP Single Line Diagram – Post Harmonic Resonance Solution Being Installed

This case study is a good example of how reactive components can cause issues with power quality by altering the frequency response of the networks they are connected to. As more non-linear equipment connects to the distribution network and underground cable circuits become larger, the more likely it will be that mitigation measures will have to be taken to accommodate new connections. Customer installed harmonic filters and power factor correction equipment may be required when a customer's connection is considered to be disturbing. Installation of this type of equipment will enable a customer to connect to the distribution network. However as this case study has shown, reactive components, used in harmonic filters and power factor correction equipment, change the frequency response of the network and can cause issues with power quality and voltage rise. As the amount of non-linear equipment connections increases, careful consideration will need to be given when connecting reactive components to the distribution network.

Short Term Mitigation and Solutions

As discussed in this chapter there has been a recent and continued growth in the amount of non-linear equipment connecting to the distribution network. The arrival and development of low carbon technologies, such as solar generation, electrical vehicles and heat pumps, have largely contributed to this growth. It is becoming difficult, to connect new customers with non-linear equipment without implementing mitigation measures. This is either due to the non-linear equipment having high harmonic current emissions or the network harmonic levels being high. In order to accommodate new connections and continue to keep network harmonic levels within planning levels the following short term measures are suggested:

- Identification of areas of network, at all voltages levels, where harmonic levels are approaching or exceeding planning limits. Keeping concise and up to date records of network harmonic performance will help with network planning and quick assessment of new connections.
- Development of modelling guidelines for consultants. In many cases the customer will appoint a consultant to determine the impact their connection will have on network harmonic levels. This study applies the assessment processes described in G5/4-1. The development of guidelines for consultants would help improved the consistency in the studies that are submitted to WPD for review.
- Publish harmonic data to indicate 'hot spots'. Harmonic data could be published on WPD's online network capacity map to indicate areas with high harmonic planning levels. This will further help developers understand the networks issues in a given geographic area.
- For areas of network that have been identified as having high harmonic levels or that are experiencing high connection applications, harmonic mitigation measures can be predetermined. Knowing what mitigations measures are required in advance, whether it be customer or DNO installed mitigations measures, will help planners and customers assess new connections.
- As a short term measure, it has already been decided that in areas where harmonic levels are high or exceeding planning levels, customers will be allowed to connect non-linear equipment long as their harmonic emissions have a negligible impact. This is applicable to the 33kV network only. Negligible impact is considered to be if the customer's equipment does not cause the network harmonic levels to increase by more than 10%. The network harmonic levels are also not allowed to exceed more than 50% between planning levels and compatibility levels. This temporary measure has been put in place as an attempt not to prevent customer connections.
- Obtain equivalent circuits for customer networks. Equivalent circuits enable complex or large networks to be modelled with minimal and simple components. Equivalent circuits of customer's networks would enable WPD to include them in network models.
- Post-connection testing. For new or modified connections, post connection testing will help verify the harmonic performance of the network. It will also help to ensure that customer's harmonic current emissions are within the limits they have declared prior to connection.

Long Term Solutions

Non-linear equipment is common in consumer, commercial and industrial markets and its use is only set to increase. As the UK continues to change the way electricity is generated and consumed, the use of non-linear equipment will also increase. This means that there will be more devices with harmonic current emissions connected to the distribution network. DNOs will be able to maintain good visibility of large customers connecting non-linear equipment to the EHV and HV networks but it will be more difficult to manage connections on the LV network. It is anticipated that there could be significant organic growth of harmonic levels on the distribution network due to the increase of use of non-linear equipment. In order to prepare for and manage increasing network harmonic levels the following long-term solutions are suggested:

- Installation of power quality measurement points in BSP and primary substations. Where possible, dedicated power quality measurement panels could be installed in new and existing substations to enable easy connection of power quality measurement equipment. This will help simplify the power quality measurements but it is not yet a company design standard for new substations.
- Determine harmonic planning levels for harmonic above the 50th order. Currently G5/4-1 only provides planning limits harmonic levels up to the 50th order. Modern power converters are increasingly producing harmonic current emissions above the 50th order. The impact of this may have to be reviewed by the ENA G5 Review working group.
- Resolve frequency response limitation of VTs. High order harmonics cannot accurately be measured by VTs. CVTs present an even bigger problem with high order measurement accuracy and are commonly used on the 132kV network. Many power convertors are producing high order harmonic that cannot be measured by VTs or CVTs.
- Installation of permanently installed power quality measurement equipment. Permanently installing power quality measurement equipment at BSP or primary substations will enable the DNO to monitor the harmonic performance of the local network. This will help determine trends in the harmonic levels, the amount of harmonic capacity in the local area or quantify the severity of a harmonic problem. The data obtained from continuous harmonic measurements can also be used to identify the need for DNO operated harmonic filters or network harmonic filtering services from third party companies.
- Controlled allocation of harmonic network capacity to new customers. G5/4-1 currently allows customers to connect if their equipment does not cause the network levels to exceed planning levels. This means that a single customer with particularly disturbing non-linear equipment can use all of the harmonic capacity in an area of the distribution network. This could be viewed as a careless way to allocate network harmonic capacity, especially if harmonic mitigation measures can easily be put in place by the connecting customer. The ENA G5 Review working group are currently considering the issue of harmonic capacity allocation.
- Update G5/4-1 to cover new power converter technologies. As part of the G5/4-1 Stage 1 and 2 assessments for connecting non-linear equipment, equipment power ratings are given for standard power converter technologies to simply the assessment process. As new technologies emerge it will be important to update the G5/4-1 assessment procedures to enable DNOs to properly assess the impact of non-linear equipment on the distribution network.
- Development and maintenance of network harmonic models. This will enable the impact of customer connections to be carried out easily, as well as enabling detailed harmonic analysis of the distribution network.
- DSO harmonic services from external companies or customers. As DNOs transition to a DSO they will have the ability to procure network services from external companies or customers. If areas of the network are identified as needing harmonic filters, it may be appropriate for a third

party to provide a service rather than the DNO installing new equipment. For example, customers that have harmonic filters installed on their site may be able to provide harmonic filtering services to the network when they are not using them. This type of service would negate the need for a DNO to install harmonic filters and pay a customer for their services to the network.

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