A Best Practice for On-Site Power Quality Measurement Campaigns Guide

EMRP
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SMART GRID METROLOGY

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Contents

1 Foreword

The emergence of smart grids that implement wide spread renewable generation in distributed generation networks, exposes issues related to the quality of the power as seen by the consumer. Power Quality (PQ), the level of voltage fluctuation, harmonic content and reliability of the available energy has significant impact on electricity consumers. PQ measurement and mitigation techniques are essential to the integration of smart grids and renewable energy.

On-site campaigns are required to provide measurement data for grid designs in order to determine and extrapolate the aggregate PQ effects in networks, particularly following modifications such as large-scale renewable integration.

Such PQ campaigns are typically carried out for Distribution Network Operators (DNO), Transmission Network Operators (TSO) and manufacturers of generation or other plant.

This Best Practice Guide outlines the experience gained from 10 on-site PQ measurement campaigns at all voltage levels as conducted between 2012and 2017 as part of the European Metrology Research Programme project “Metrology for Smart Grids”.

2 Planning and Implementing a Measurement Campaign

2.1 Defining the Aims of the campaign

At the outset it is important to set-out clearly defined objectives and ensure that all parties are in agreement with these aims.

For commercial work, such aims are defined by some form of contact or agreement between the network/site operator and the measurement institute.

For academic research surveys, such a contract may not exist, however it is still important to understand the expectations of all parties and clearly define the roles of each and the expected outcomes of the campaign.

Matters relating to intellectual property, ownership of the data and the right to publish results should also be understood at the outset. For example some network operators or manufacturers may not want data relating to their network to be published; however they may allow publication using anonymized data.

2.2 Safety Requirements and personal equipment

There are safety implications at all voltage levels and specific safety issues will be dealt with in each of the Sections of this document.

Particular safety procedures will operate for each given network operator and different legislation will be in force in different countries. Most network operators will require a risk assessment before installation. Many operators will require staff to attend a safety briefing or to attend course before working in substations or switchyards.

Generally an “Approved Person” will need to be present during all work. Such personnel will normally be provided by the site operator.

Whenever possible, do not work with live conductors. Always follow the 5 Golden Rules (isolate it, make it safe, lock it out, test it and earth it). Never assume absence of voltage, always test live conductors before performing tasks.

It is normal that the details of the installation will need to be recorded in some form of log. Equipment that is to left unattended will need to meet safety requirements of the site operator and will need to be clearly labelled with contact details.

Personal protective clothing is generally required which could include safety helmet, eye protection, safety boots, gauntlets and fire-proof overalls. It is important to confirm these details and procure the necessary items prior to the site visit.

2.3 Planning Questionnaire and Pre-Campaign Site Visit

Planning ahead is critical to the success of the campaign and can save much time and potential embarrassment when arriving at the site.

To this end a “questionnaire” template is given in Appendix A of this report that lists many of the important planning questions that need to be resolved prior to starting the campaign. Many of these questions are best answered with in a pre-measurement site-survey if logistics permit.

The parameters to be measured, the commencement date, the survey length need to be agreed between parties. Such dates maybe dependant of system outages (e.g. high voltage systems) and it may be necessary to leave equipment installed for long periods between two planned system outages, the first outage to install and the second to remove the measurement equipment.

If it is possible to complete a site-survey many of the questions listed in Appendix A can be easily answered, otherwise it will be necessary to rely on the knowledge of the local engineers, who in some cases may not have the best recollection of the configuration of the installation in question.

It will be necessary to obtain copies of circuit diagrams/single line diagrams of the local network both to define the measurement points in the system and to aid measurement analysis when results are available. It can be useful to resolve these diagrams with the geographical/physical site-layout during the initial-visit and/or using satellite pictures (e.g. *Google Maps*). For example several substations on an LV feeder can be identified ahead of an installation using *Google Street View*. In a HV switch yard, *Google Earth* can be used to identify the transformers and switch gear shown on the single line diagram.

A full understanding of where the measurement equipment can be positioned and safely located for a long-period needs to be agreed with the site operator. In many cases safety paperwork and signage will be required and requirements need to be clearly understood.

The method of connection to the installation for voltage and current measurements will depend on the type of installation and what is available. A separate section for LV, MV and HV describing possible connection issues are included below.

If auxiliary cable-runs need to be installed for connections to instrument transformers, this may also require prior permission. Such cable runs may be possible in existing conduits or it may be necessary to ran cables in temporary trucking to avoid damage from people, weather or animals. Fusing or other protection for auxiliary cable-runs, maybe required by the site operator.

2.4 Connections to a LV Installation

2.4.1 LV Voltage Connections

Voltage connections at LV can be achieved relatively easily. Most PQ analysers are designed to accept three phase LV inputs directly and require no external VTs.

Special *Dolphin Clips* can often be used for connection on a substation fuse board. These have the advantage that live connection can be made, avoiding the need for outage. Such clips should be themselves fused Cat III according to IECXXXXXXX. A possible vendor for these connectors is Multi-Contact (http://www.multi-contact.com/). The fusing at the clip-end is very important as the trailing connection wire could burn/explode if a fault occurs causing a personnel hazard.

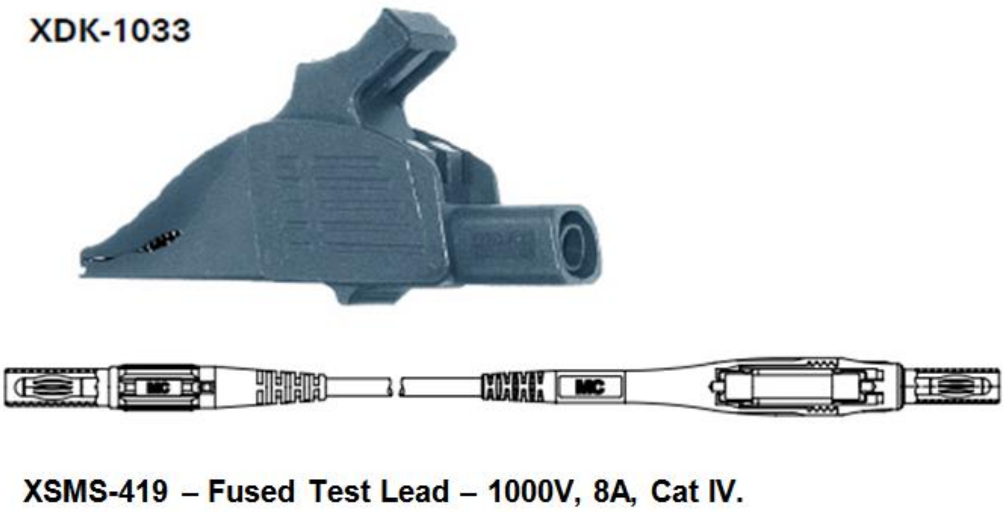


Fig. 1, Cat.III/IV, Clip-on Voltage Connectors for LV Installations

Suitable safety arrangements will be required if leaving the trailing connections for long periods of time. If installed in a lockable substation and suitable signage with contact details is displayed, this may be sufficient for the network operator. In other cases safety barriers maybe needed to cordon-off the area.

Some operators may require a more permanent installation involving wiring into terminals (requiring an outage). Wires may need to be clipped to walls or run into existing cable-trays or trunking.

2.4.2 LV Current Connections

Current connections at LV are most usefully made using clamp-on or split transducers. These devices can be positioned around feeder cables without the need to break the circuit causing a system outage.

Different clamp-on transducer technologies exist and these should be considered when planning the measurement. It is particularly important to consider the frequency response both in amplitude and phase in the context of the desired accuracy of the measurement. Frequency response is important because most current waveforms are highly distorted due to the high-penetration on non-linear loads on a typical LV network. Many clamp-on CTs have a very poor frequency response, particularly for phase.

Relatively good frequency response can be obtained using Rogowski coils. These devices can either be rigid or flexible. They have a split so that they can be wrapped around a bus-bar.

When installing such clamp-on transducers on horizontal plane conductors, it is likely that they will “hang” on the feeder conductor making physical contact between a part of the transducer and the cable or bus-bar.   If the conductor is un-insulated (Fig. 2), it is very important to ensure that the insulation of the transducer or clamp is sufficient. It may be possible to use auxiliary insulation to ensure this condition is met.

Fig. 2, Flexible Rogowski Coil hanging on a bus-bar, in this case it has not been possible to centre the bus-bar in the coil aperture. As the bar is live, the insulation material of the coil must be sufficient to withstand the voltage.

In many cases bus-bars are connected directly to a sub-station transformer, before the fuses. Any installation at this point must be carefully considered with appropriate risk assessment.   Any faults at this point could cause an explosion of the sub-station transformer. Clearly such connections are at the discretion of the site operator.

Safe installation of clamp-on transducers on live bus-bars needs to be carefully considered. Such installations should be made by properly trained personnel (most likely an engineer associated with the test-site) who are using the correct personal protective clothing and equipment such as facial visors, insulating gauntlets and fire-proof overalls.

Installation of rigid device in cramped conditions can be dangerous and extreme care will need to be taken to ensure the device does not cause the bus-bar to be put under any mechanical pressure which could cause faults to earth or an adjacent phase. In such cases flexible Rogowski coils maybe a better option.

In general the accuracy of the current measures with clamp-on devices will be affected by the physical position of device. Small changes in rotation, relative position of the current carrying conductor (w.r.t the centre of the clamp-on transducer aperture loop), and closeness to bends in the current carrying conductor will all cause relatively large changes in results. These problems are explored in more detail in [1] and such errors should be accounted for in the uncertainty budget. Flexible coils are particularly vulnerable to such errors. Fig. 3 shows two Rogowski coils concentrically positioned; this is easy to achieve in the case of vertical conductor.

If space and conditions safely permit, insulating spacers can be used to keep the current carrying conductor relatively central in the transducer aperture (Fig. 4). These could be specially made or improvised form materials such a rubber or foam (assuming sufficient insulation properties).

Fig. 4, A rigid and a flexible Rogowski coil concentrically spaced around a vertical conductor.

Fig. 3, A Rogowski coil centred on a horizontal conductor using packing material for spacing.

There is a 180 degree phase shift between the current measured by a clamp-on transducer if it is fitted the wrong-way-round. Normally the direction of current is indicated on the transducer although this is sometimes difficult to see. As substation can have low light levels, it is advisable to add a large label indicating the direction of current (Fig. 4) and also indicate the channel number/phase for the transducer in question. The actual phase should be check on the PQ instrument before leaving the site.

It is also important to check there is sufficient lead length between the transducer on the PQ analyser. Making an assessment of the position of the instrument and the point at where the transducers will be fitted can be carried-out at the initial site visit. If necessary it may be possible to make extension-leads for the transducers, however the implementations for the measurement performance should be assessed.

In some cases installed instrument CTs maybe available. If these are used, their measurement performance for the required PQ parameters and traceability must be carefully considered. (see below Section).

2.5 Connections to a MV Installation

Voltage connections at MV can be achieved through external voltage transformers. The voltage can be transformed one or multiple transformers before connected to a power quality analyser. If using permanently installed transformers make sure transformation factor is properly calibrated and taken into account in the uncertainty budget are calculated.

When PQ assessment is to be carried out at MV level, voltages from a few to some ten of kilovolts and currents up to hundreds of amperes are to be measured, depending on the characteristics of the MV grid. Transducers are then needed to reduce the quantities to be measured to levels compatible with the input characteristics of the PQ measuring instrument.

If available, current/voltage transducers already installed in the measurement site can be used, provided that their accuracy characteristics satisfy the PQ measurement requirements. Attention should be paid to the fact that protection transformers are characterized by lower measurement uncertainty compared to the measurement instrument transformers. Fig. 5 shows, as an example the, a voltage measurement unit (6.3 kV/√3 **/** 100 V/√3) in a 1.5 MVA Substation.

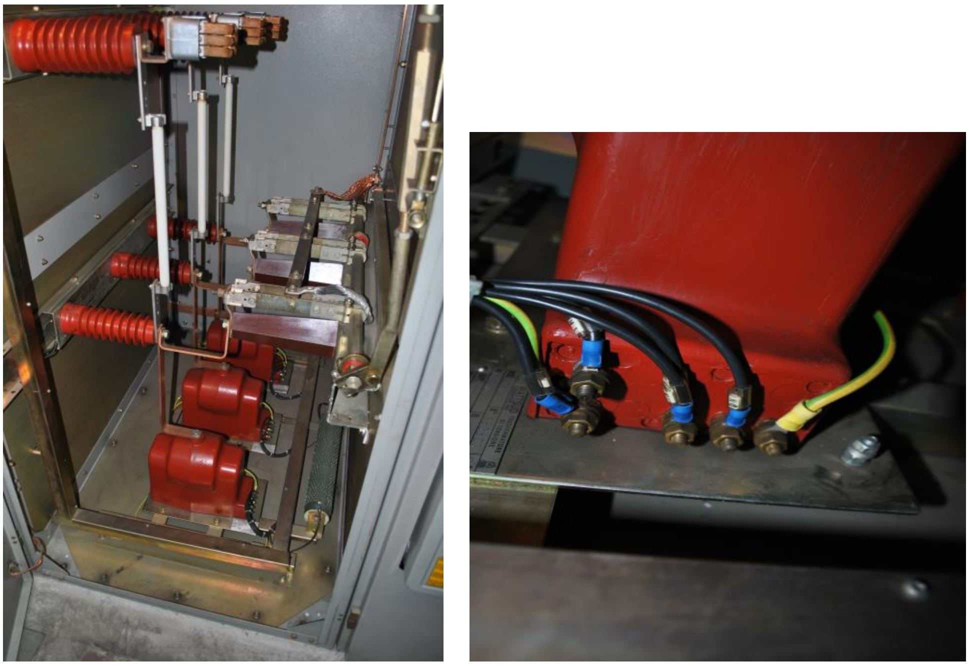


Fig. 5 – Metal-enclosed voltage measurement unit of a 1.5 MVA substation

Connections to the LV output of the VTs must be performed after disconnection of the measurement compartment from the plant, as the case of Fig. 5, or during a substation outage. The measuring system loading must not appreciably affect the VT burden.

As to the to the measurement of the CT secondary current, the series insertion of a measuring shunt needs the interruption of the LV CT circuit. Care has to be taken to avoid opening of the CT secondary circuit under operating conditions, to avoid dangerous overvoltages. As for the VTs, the introduced transducers must not modify the rated CT burden. Special devices are available to protect from open circuited CTs which use fast responding semiconductors to prevent over voltage (see: http://www.electromagnetic.biz/ElectronicProducts/OpenCircuitProtectionOCP/tabid/58/Default.aspx)

As an alternative, clamp-on current transformer, split-core or openable Rogowski coils can be used to avoid interruption of the secondary circuits. As a general safety rule, opening of the MV measurement/protection compartment and consequently direct contact with the transducers, cannot be performed without prior disconnection from the energised plant.

Suitably accurate and calibrated transducers will need to be connected if installed VTs and/or CTs are not available or if their performances are not known/of insufficient accuracy. MV resistive, capacitive or resistive-capacitive dividers with low power outputs can be used for phase-earth voltage measurement as an alternative to VTs. Combined instrument transformers, including both voltage and current transducers also exist.

Optical conversion and fiber optic transmission of the transducer LV signal ensure safe separation between the transducer output and the measurement system.

As regards the voltage transducers, firm connections to the MV busbars have to be established by means of bolted connections. Bare MV connections can be used if the voltage transducer is inside a closed compartment (e.g. a metal enclosed air-insulated switchgear unit). However, taking into account the layout, attention has to be paid to the respect of the electrical clearances between the introduced MV and LV components and conductors and the surrounding energised, earthed or floating elements.

The introduction of transducers inside any metal enclosed unit has to be carefully evaluated and agreed with both the site owner and the installer.

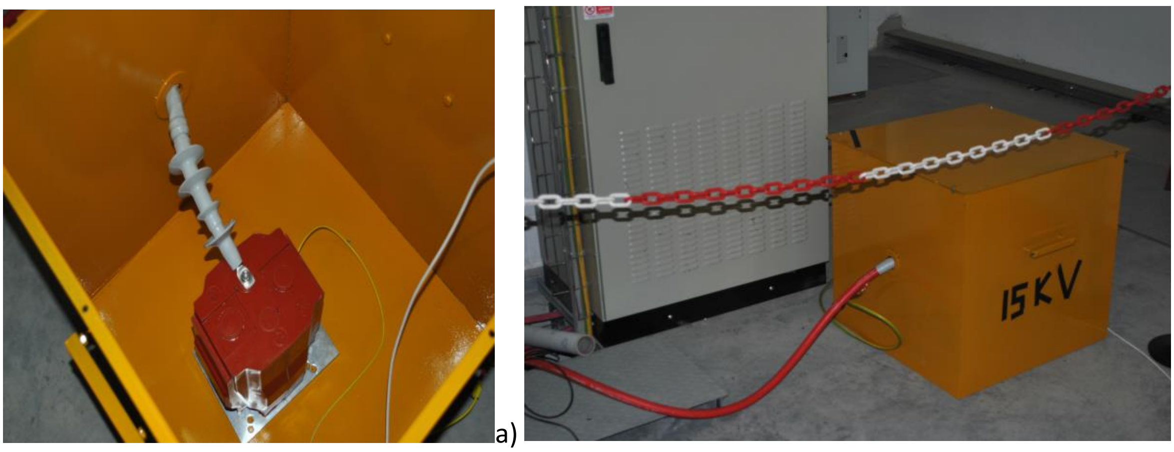
Similarly as shown for to the VTs in Fig. 5, the connection of the transducer to the MV must be made below a short-circuit current protection.

The divider LO connector has to be earthed. In order to avoid dangerous overvoltages at the measuring instrument input, a surge arrester can be connected between the LV divider output terminal and the earth, if not already being part of the divider LV arm.

Great care has to be taken in order to avoid ground loops. To this end, all ground connections should be made to the same physical point (e.g. substation earth).

All the connections have to be carried out with the agreement of the site owner and by trained personnel. If the voltage transducer cannot be located inside a metal-enclosed closed compartment, care must be taken to ensure that no casual contact with live conductor is possible. If a permanently gated and protected area is not available, the MV divider can be placed inside an earthed and closed structure, as shown in Fig. 6a. Connection to the MV busbar is made inside the switching unit and is established by making use of a MV insulated cable with suitable terminations, whose characteristics are set by the relevant standards.

Depending on the characteristics of the used transducers, due to stray capacitive couplings, the presence of the earthed structure can modify the scale factor of the divider. So its influence should be determined in the calibration phase.



a) b)

Fig. 6 – MV divider inside a grounded box (a) with MV connecting cable (b).

As regards the insulation, the transducer used must pass all the tests required by the relevant standard actually in force for the rated voltage. Prescribed test includes the partial discharge measurement test, power-frequency withstand voltage insulation test and lightning impulse test (type test only).

As regards use of current transducers, the use of split-core or openable Rogowski coil can ensure accurate frequency response up to several kilohertz and insertion without need of breaking the power circuit. If the Rogowski coils are placed on bare MV busbars, they have to be equipped with suitable insulation for the involved MV level and pass all the relevant tests.

If coils are placed around insulated MV cables, as shown in Fig. 7, the presence of currents flowing in the grounded cable shield and the possible perturbing effect on the current measurement has to be verified.

Even if less accurate with respect to the rigid ones, openable flexible coils with a reduced diameter can in particular be used in harsh and narrow environment. By the use of a suitable insulating support they can be centered on the MV conductor. Attention has to be paid to the position of the coil opening gap with respect to the other conductors. The coil should be rotated so that the gap is as far as possible from the other MV conductors. Effects of close positioned other phase conductors can be quantified in laboratory. The use of shielded coils allows mitigation of the electromagnetic field interference.

Fig. 7 – Rogowski coil on a MV insulated cable.

The presence of other significant magnetic field sources has also to be considered. In particular, the proximity to LV cables where much higher currents are flowing cannot be disregarded. Quantification of the LV conductor effects can be performed by measuring the Rogowski coil induced stray voltage, when the coil, not linked to any conductor, is placed at increasing distances from the external magnetic fields sources. Measurements of the existing stray magnetic fields by suitable LF magnetic field meter can be useful to identify the better position for the coils.

If coils are equipped with integrators, attention should be paid to the choice of the selection of the better transformation ratio (e.g. 100 A/V) with reference to the maximum expected peak currents. The integrator maximum output voltages have to be matched to the input of the measuring instrument.

As a general safety rule, the whole measurement area should be enclosed and located in a zone with restricted access.

2.6 Connections to a HV Installation

It may be possible to use existing installed VT and or CT to make connections to the PQ analyser. Any transducers must have sufficient frequency characteristics in order to measure harmonics. When the frequency response is not known, it can sometimes be verified by "type-test" by measuring a device of the same design in the lab. This will not give the ratio error of the device, however this will not always be important in a PQ verification.

If installed CT/VTs are not suitable or not available other transducer methods must be sort. Unless safe LV connections are already available via instrument CT/VTs, HV installations will need to be made during a planned system outage.

Even if a suitable installed CT is available, there remains the issue of converting the secondary current to measurable voltage. As this current is often relatively low (1 or 2A), this can be difficult to measure using Rogowski coils and clamp on CTs generally have a very poor frequency response, particularly in phase.

In such cases it may be possible to connect a wideband current shunt in series with the existing CT secondary burden. As with MV working, with the permission of network operators it may be possible to connect additional burden shunts in CT secondary's to measure current. These should be overrated beyond the system fault saturation current, to absolutely ensure that they cannot be open-circuited. If possible carry out destructive tests on the proposed shunt design in a laboratory to understand the failure current and failure modes of the shunt. Also consider using the open circuit protector detailed here:
http://www.electromagnetic.biz/ElectronicProducts/OpenCircuitProtectionOCP/tabid/58/Default.aspx
On no account should the shunt be fuse protected as this will open the CT secondary. All connections to CT secondary's need to be strain-relieved, so that accidental contact by personnel cannot pull connections off the circuit. Signage should be used to indicate that the shunt is part of the CT secondary and must not be removed. At all times, full agreement and understanding of the hazards by the network operator must be obtained.

For voltage, it may be possible to make a capacitive divider making use of the capacitive tap on the current transformers (CTs), where the high-voltage arm of a divider can be formed by the CT tap and the lower arm capacitance chosen accordingly to give the desired ratio. A cabinet containing the lower voltage arm of the divider would be attached to the support structure of the CTs. The divided output voltage could be connected to a local measurement house using screened multi-conductor cables.

Alternatively (see Fig.8) in generation or HVDC stations, it may be possible to use an additional tap on a system/convertor transformer making use of the capacitive bushing tap connectors which are sometimes fitted to each phase of the converter transformers (accessible only during outage). With the bushing capacitance forming the high- voltage arm of a capacitive divider, the low-voltage arm can be completed by use of external capacitors to ground selected to obtain an output voltage of the order 200 V (sufficient signal to noise ratio) [2]. The three-phase low-voltage arms of the dividers should be implemented together with overvoltage protection inside a suitable weather proof cabinet fixed to the outside wall of the transformer building with connections to the upper-arm bushing using screened twisted pair cable for each phase.

A further possibility is to use HV capacitors making use of the available earth connection. Monitoring the current flow through this earth connection using a clamp-on non-invasive CT can sometimes be used to infer the voltage behaviour. Such a system will require careful characterization (see comments about low current clamp-on device above).

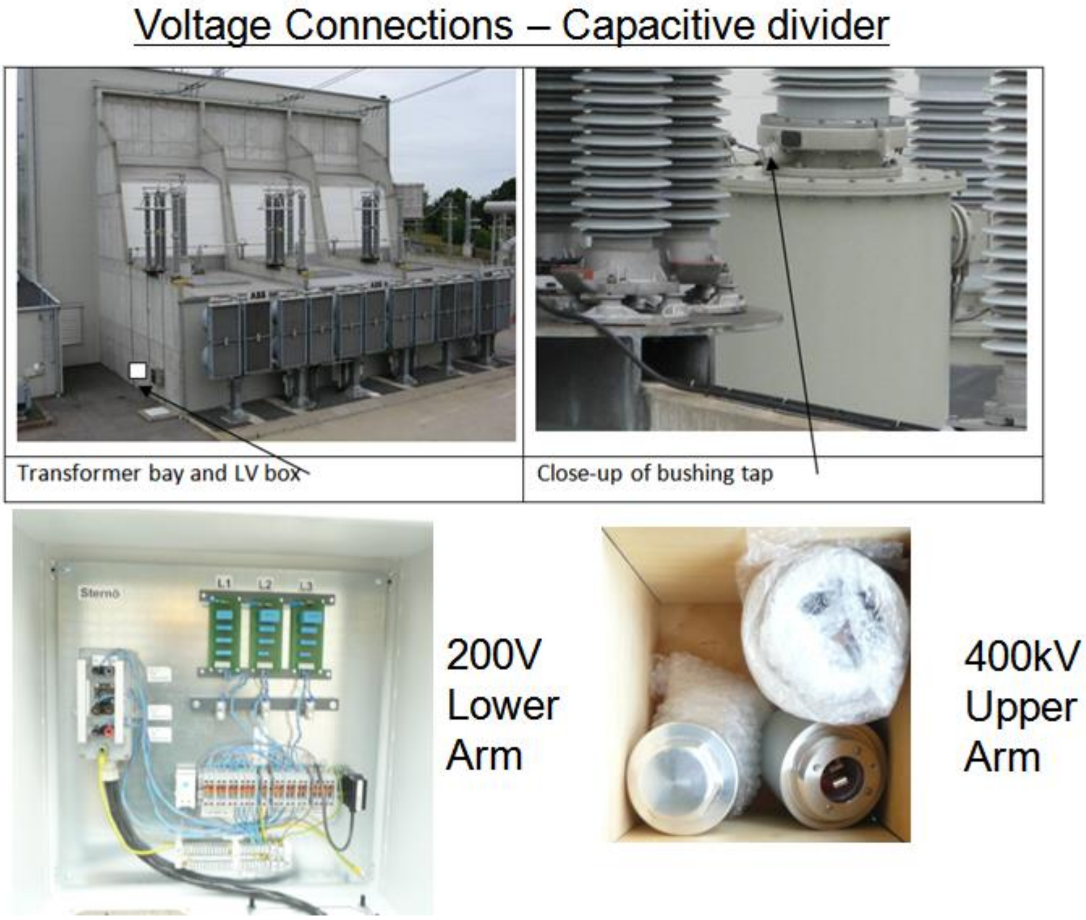


Fig.8, Example method of making an HV connection.

2.7 Calibration/Traceability for Installed Instrument Transformers (type-test)

Key components of the measurement system are the transducers that transform the voltage and current levels to useable level for a given PQ analyser. In many cases it will not be possible to break the circuit to install transducers, so either existing metering transformers must be used or other non-invasive methods employed.

If transducers are fitted as part of the campaign, it should be possible to calibrate the individual devices prior to fitting. Corrections can then be applied to the results if necessary.

Calibration should be performed under conditions that reproduce as close as possible those expected on-site. If Rogowski coils are used for current measurement, the shape, position and path of the primary conductor with respect to the coil plane can influence the measurement results, as a function of the construction characteristics of the coil (flexible/rigid coil, presence and dimension of a coil gap). If voltage unshielded dividers are used, proximity effects have to be carefully considered. Temperature dependence of the transducers should also to be determined or the temperature coefficients given by the manufacturer both for coils and integrators should be taken into account.

If installed transformers are to be used, their response needs to be understood insofar as its effect the measurement of the various PQ parameters of interest. For example if measuring current harmonics using an installed CT, the amplitude and phase frequency response of the CT will have a direct effect on the measurement. The extent of this effect can perhaps be determined using historical or manufacturer's data if this available. Alternatively a "type-test" of a transducer of the same design can be performed and the performance of the installed device inferred. Whilst this is not a traceable measurement, it is a pragmatic solution provided the risks are understood, namely that the installed device has deteriorated, compared to the test piece. Details of the installation (e.g. wiring types and cable lengths) should also be reviewed in respect of how they may affect the measurement.

PQ analysers may have several ranges and the most appropriate range for the transducer in use should be selected keeping in mind that the waveform (particularly current) may not be sinusoidal. In such cases the expected peak value of the waveform should be considered rather than the rms value and an instrument range (often given in rms) should be selected accordingly. Having determined the range, the PQ analyser should be calibrated according to the parameters and uncertainties required for the outcome of the campaign.

Uncertainty budgets [3] will generally be required for the measurement campaign. Initial estimates of uncertainty will be required in the planning stage to ensure that the expectations of the campaign are met. An uncertainty budget will be particularly important if the results are being used for the basis of investment decisions, contractual compliance or revenue settlement. If a given PQ parameter is calculated using a complex algorithm, the propagation of electrical measurement uncertainties through the algorithm to determine the final uncertainty is non-trivial. In such cases it may be necessary to employ Monte-Carlo techniques [4].

2.8 List of equipment /check-list

Prior to the site installation it may be useful to make a list of equipment to be needed on-site. This would obviously include the measurement equipment, but would also need to consider tools, cables and other consumables. An example equipment list is shown in Appendix C.

An installation check list can also sometimes be useful; on-site working is stressful and having a list of tasks can help smooth the operation ensuring that essential task do not get missed. Some items for such a list might include:

i) Verify the data and time for the analyser/PC clock (if GPS is not used) for a suitable time stamping.
ii) Perform a phasor verification for a correct sequence order in phases.
iii) On applicable 3-phase installations, agree with all personnel, whether to connect in Star (Wye) or Delta.
iv) Free data memory/disk space before starting the measurement campaign.
v) Check remote communications with colleague at base.
vi) Note installation detail in a work sheet/log book (especially technical problems).
vii) Take photographs for later inspection.
viii) Ensure marked signs (caution!) to indicate the place of working.
ix) Leave contact details in case any problem occurs during or after the installation.
x) Check all earths with multimeter

2.9 Understanding PQ Parameters

There is a large selection of PQ parameters defined in various normative standards. Appendix B lists some of the more common PQ Standards and gives some commentary on their use. The choice of parameters to measure will need to be determined by discussion; some network operators will have their own preferred set of parameters of interest depending on the aspects of the network operation they are concerned with. For example if a large amount of renewable energy is to be retro-fitted to a distribution network, the DNO may be concerned at the voltage quality effects.

2.10 Remote control and Data Collection

In many cases it is necessary to monitor or control the measurement equipment remotely. This may be necessary for safety reasons if the equipment is left in a HV area or more likely for long campaigns to avoid the need for regular visits/access to the site. Furthermore it is highly desirable to be able to collect data remotely to allow analysis to take place in parallel with on-going measurements.

Data is generally logged on some form of storage media (e.g. a hard disk). It is important to ensure that all un-necessary data is cleared at the start of a campaign to maximise disk space. A calculation should also be conducted to ensure sufficient space exists to log data for the duration of the campaign or until data can be collected or downloaded. Also consider back-up of data, e.g. RAID systems can be useful.

The scope for remote working will be in-part defined by the facilities of the instrument/ associated software. An instrument that is controls by a PC can be relatively easily controlled using remote desktop software of the type used in the PC support industry. One such package is *Teamviewer* (http://www.teamviewer.com/en/index.aspx). This uses an internet connection to take control on the remote PC from the user's local location allowing access to the PC. Data can be readily downloaded from the remote PC using such packages.

Clearly such remote working software relies on an internet connection at the site. In some cases such connections maybe available in the site build, however in remote substations this is unlikely. It can be useful to have an on-site contact if internet connection is lost during a measurement campaign. It then might be possible to avoid a long day of travelling if an on-site technician can resolve the problem by a reboot of the PC or internet router or internet switch.

If wired network connections are required ensure that a sufficient length RJ45 Ethernet cable is taken to the site visit. The route and length of this wiring should be assessed at the pre-site visit if possible.

If no internet connection is available, or it is not possible to obtain permission to use such a connection, then wireless 3G (or even 4G) maybe an option depending on communication network coverage. Most networks have web-tools to check coverage by postal code. If 3G is available, USB "dongles" can be purchased to access the network.

Remote SMS controlled power switches are a useful means of rebooting latched up PC and Modems. For this to work with laptops, the battery must be removed. All passwords and start pages requiring user intervention must also be removed so that the PC boots on power cycle. It is also important to ensure that the chosen communications software (e.g. Teamviewer) starts on boot. USB powered dongle type Modems (without internal batteries) are ideal in this scenario, as a latched-up Modem (which happens surprisingly often) can be remotely rebooted using a SMS controlled power cycle of the PC.

If 3G coverage does not reach the site, then GSM maybe available. This relatively slow 56k connection can be accessed using a GSM modem, although the remote desktop experience with this sort of technology can be very frustrating.

All wireless technologies require good antenna line-of-sight. If windows do not exist in the measurement building, it may be necessary to drill a hole in the wall and pass the antenna outside using an extension cable. Such matters should be determined during the site visit.

When installing such remote equipment it is essential to have a colleague back at base available on the telephone to test the connection/remote desktop during the installation.

2.11 Environmental Sensors

In many cases it is desirable to monitor the temperature of the instrumentation during the site campaign. This may be necessary to ensure extremes of temperature are not in-danger of being exceeded or to use temperature to make some corrections to the instrumentation for temperature coefficient errors.

Temperature could also be useful to correlate against changes in electrical load.

If measurements are being made on a renewable energy installation such as solar PV or wind, it will be necessary to measure solar radiation and/or wind speed such that PQ results can be suitable correlated with theses environmental parameters.

Weather data websites such as https://www.wunderground.com/, amateur weather sites, and government meteorological sites can also be used to help analysis of renewable performance.

Many sensors will need to be mounted outside, possibly on the roof of the substation. It may be necessary to drill holes in the substation building to allow the cables for the sensors to pass through the wall. Issues relating to theft and vandalism should also be considered.

When measuring on wind turbines wind speed measurements should typically be measured a hub height. The company running the site usually has a preinstalled measurements setup that can be interfaced by the PC. It is often necessary to write a small software application to decode the data streaming for wind speeds to be saved together with the PQ measurements.

Data logging applications running on the controlling remote PC are a useful means of achieving this. If the PQ instrumentation and/or logging equipment have independent time clocks, it is important to ensure that these are synchronized to ensure that time tagged results can be properly correlated. One common source of error is “daylight saving time”. It may be worth considering timing everything to UTC.

Multiple site PQ measurements may be synchronized using GPS (as per PMU operation- see later Section). In such cases the issues relating to antenna line-of-sight as discussed above are again applicable.

2.12 Logistics

Collecting together all equipment and transporting it to site maybe seem a trivial matter, but should also be planned carefully. The hire of a vehicle of sufficient size, the availability of packing crates, use of bubble wrap to safely pack vulnerable equipment, facilities for strapping items down in the vehicle should all be considered.

Also bear in mind extremes of temperature in transport. In cold conditions it may be necessary to allow conditioning time following the set-up of equipment in a heated building, before switching-on the equipment, so allowing condensation to dissipate.

Also remember it maybe raining heavily on-site and packing cases should have waterproof lids. Ensure each packing case is light enough to be manoeuvred by one person in tight spaces.

3 Data Analysis

3.1 Data Handling

PQ campaigns over several months can produce vast quantities of data. If a local PC is connected to the measurement equipment, large hard disk drives can often provide the capacity for the entire campaign. This can be readily calculated to ensure sufficient capacity is available. However, simple local storage makes non-provision for data back-up in the event of hardware failure, damage or theft. Depending on the value of the data (uniqueness, timeliness of the campaign), various data backup schemes may be considered such a RAID storage (only protects against primary HDD failure) or data upload using a fast internet connection if available.

Data Upload to a remote server also has the advantage that data analysis can be carried-out as the campaign progresses, rather than waiting until the end of the measurements. This will allow gaps in the data or measurand-set to be identified prior to the decommissioning of the apparatus.

Data upload can be achieved manually using an application such as *Teamviewer* or automatically by using other software (possibly custom written) to upload data to a cloud or resource such as an FTP server.

Organizing the data is very important to allow users to identify and correlate various events. This maybe simply achieved by some form of file-naming regime relating to the measurement time. For proprietary PQ apparatus, such schemes may be incorporated into the product output files.

Other systems use database structures using tools such as SQL to interrogate the data set.

3.2 Data Analysis

The nature of the analysis is very much related to the aims of the measurement campaign. The purpose of the analysis being to identify the behaviour of a particular set of PQ parameters as correlated to some other event(s). For example, what is the effect on a substation voltage level supplying a PV installation when the solar radiation changes.

Such analysis must present results such that they can be readily interpreted and visualised by a variety of users. Whilst time-series graphs are useful, other plots can often reveal aspect of the data that are not obvious. For example a plot of harmonic distortion level against time for a solar plant may be useful if the solar radiation is also plotted against time. However a plot of distortion against solar radiation can display any correlations more explicitly.

Presentation of results for many months of data can be a very difficult task and the effort required to analyse and visualise the data should not be underestimated. Having decided on an analysis approach, custom software or *Excel Macros* can sometimes help automate the task.

It may also be useful to consider varying levels of time granularity when presenting results over long periods. This might be in the form of high-level summary plots to show the trends in parameters to help the user identify specific periods of interest, which can be examined in a higher level of detail as appropriate. For example, a high level scoring system for level of solar radiation may help user identify period in the data to examine the effects of PV generation.

Interpretation of the results, drawing conclusions and making recommendations will also be required. This may include comparison to a base-line, for example how has a parameter changed due to some intervention in the network. Such comparisons would generally require a before and after study and would need to be identified at the planning stage.

The implications of the results for the network being studied will interest the network operator. Such interpretation will require information and possibly modelling and will need to be carried-out in collaboration with the network operator. In some cases the results of the PQ study may be used to refine network models which may be in error due to a lack of historical information about the wiring configurations.

4 Wide Area PQ Measurement Campaigns and Harmonic Propagation.

Synchronised grid measurements using GPS enabled digitiser, phasor measurement units (PMUs) and digitising PMUs – so called Waveform Measurement Units (WMU) have potential as the basis for new tools to manage grid power quality (PQ) including power system harmonics.

The causes of power system harmonics can be single large sources of disturbance connected to the grid or aggregated smaller non-linear loads that have correlated characteristics. These disturbances may decay with distance from their source, but can also amplify depending on the grid configuration.

Harmonic pollution on a grid rarely knowingly affects consumers, however it has significant reliability and cost implications for the grid infrastructure, causing over-heating in equipment/conductors, incorrect meter readings and oscillating torques on generators.

For power system management purposes, network operators need to understand the level of harmonics in their networks so that they can take the most cost-effective measures to mitigate them. This may be in the form of tuned filters or the installation of new transformers and cables, all of which required significant investment in terms of civil and electrical engineering.

Network operators use on-site measurement surveys to plan for new connections of large loads or generators [see: “Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Equipment to Transmission Systems and Distribution Networks in the United Kingdom”, G5/4, Published 2005 by The Energy Networks Association, London, UK]. These surveys determine the base level of harmonics, such that the effect of the new disturbance can be calculated to ensure harmonics will not exceed safe levels.

Whilst these and other surveys can be used to determine the local effect of a particular disturbing influence, its effect on the wider network remains unknown. For example, the generation of local harmonics by a large renewable installation could be significant, triggering the need for expensive mitigation equipment; however, if that disturbance had been "naturally" attenuated once at the wider grid level, the need for this mitigation can be relaxed. Conversely resonances in the network could give rise to an increase in the disturbance at the wider network level.

The nature of the harmonic propagation will depend on each specific network topology and impedance. Reconciliation of the results with the grid topology model is necessary to assess the system-level impact of various harmonic disturbances, leading to improved grid management/planning and appropriate constraints in future normative standards and grid codes.

4.1 Planning a Multiple Site Measurement Campaign

Whilst planning multiple site campaigns has much in common with the planning of single site measurements, the coverage of the network of interest needs to be planned in order to get the best out of the number of available instruments.

It is first necessary to obtain circuit/line diagrams of the network of interest in order to plan connection point. For a given distribution network, areas of high load and generation will be of obvious interest for monitoring, for examples substations in substantial residential or industrial areas. Renewable power parks and other generation sites may be of interest. Also of interest are more remote areas which may be connected on spurs ("thin" connections) of the main network. Understanding the local demographics may also assist the process. If history of customer PQ complaints exist, this will also inform choices.

It will be necessary to study and possible model the network to make a selection of the measurement sites, but also to consider accessibility and practicality. For example, the existence of CTs and VTs, secure (lockable) locations to prevent theft, 3G coverage, road access, and access permissions will all need consideration.

4.2 Instrumentation and synchronisation

For amplitude only measurements, simple PC or other clock time stamped measurements for inter-site comparisons may be sufficient. However it is surprising how quickly PC clocks drift and confusion can quick result if time errors build up between multiple sites. MSF clocks may help, or GPS timing to keep the PC clocks correctly set.

Where phase between sites is of interest some remote timing mechanism will be needed. Fibre optic or Ethernet timing may be used, although the most common method is to use GPS which provides a so-called one pulse per second (1PPS) signal to time samples taken within the PQ instrument, PMU or WMU. Instrument vendors will use the PPS to calculate the phase, and utilise the GPS receivers time strings to time stamp files of results. PPS is accurate to around 0.1us and the phase accuracy between WMUs should be better than 10 milli degrees when using GPS.

When installing such instruments, the strength of the GPS signal must be checked and it is often necessary to position the antenna outside of a given substation building using a hole or airbrick. Powered antenna and extension leads should be used if necessary.

4.3 Handling Data from Multiple Sites

PQ data from one site is often daunting from a point of view of handling, storage and analysis (see earlier Sections) but multiple sites requires further planning and infrastructure.

It may be necessary to develop or purchase some form of data consolidation software to download and collate data from the multiple sites. Such software may also provide a "dashboard" for network status and daily (or regular) summary reports as overviews of the data.

An example 6 site measurement campaign is reported at ["Multiple-Site Amplitude and Phase Measurements of Harmonics, for Analysis of Harmonic Propagation on Bornholm Island", P.S.Wright, A.Christensen, P.Davis, and T.Lippert, Submitted to IEEE I&M, June 2016]. In this case, each site PC had a 3G cellular-connection and custom software was developed that used a compression-algorithm to prepare each day's data for scheduled uploading to a server.

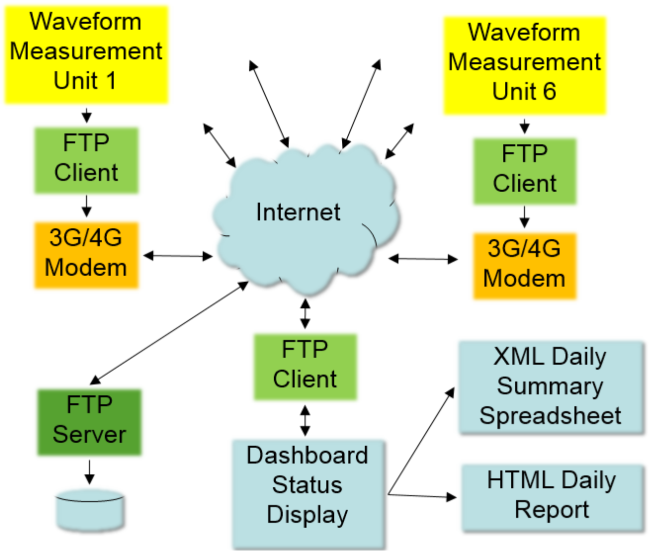


Fig. 9, possible data collection and handling structure for a multiple site measurement

FTP client and server structures were used to upload the data as shown in Fig.9. The server software automatically concentrates the data into a daily tabbed spreadsheet using XML with summary statistics.

Status telemetry for each measurement site (e.g. number of errors, GPS lock, temperature, disk space) is uploaded every minute and is displayed on a central at-a-glance status display which also shows the inter-site phase, the three phase voltage and current magnitudes as shown in Fig.10.

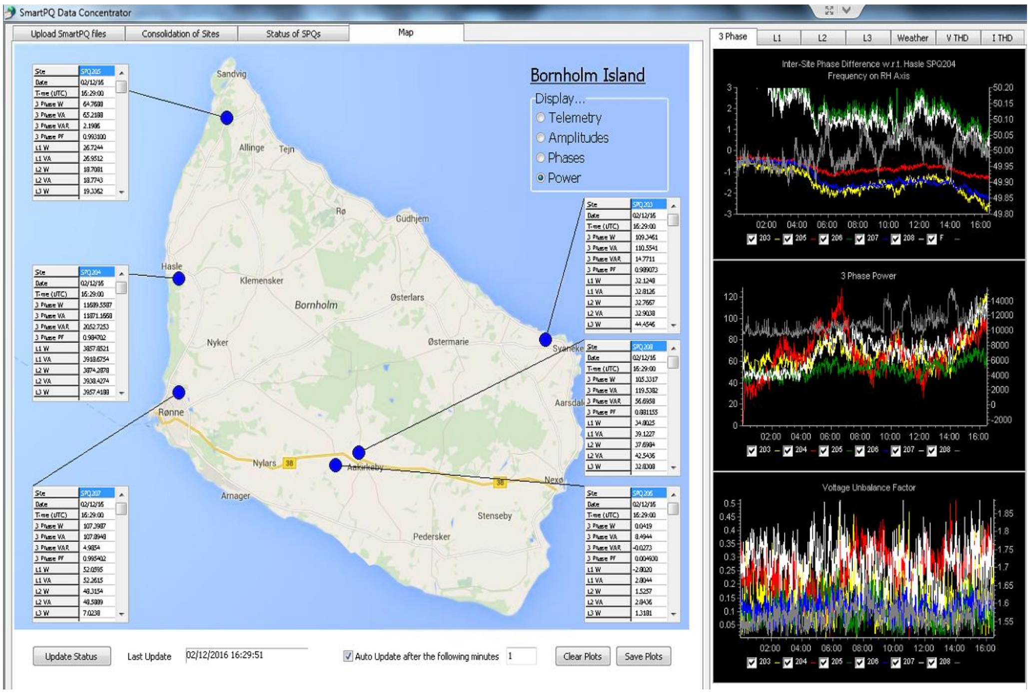


Fig.10, Dashboard display of Bornholm Island 6 WMU measurement Campaign. Display updates regularly (e.g. once per minute).

The software also produces daily HTML reports as an overview of the main measurement parameters and weather data. This is shown in Fig.11

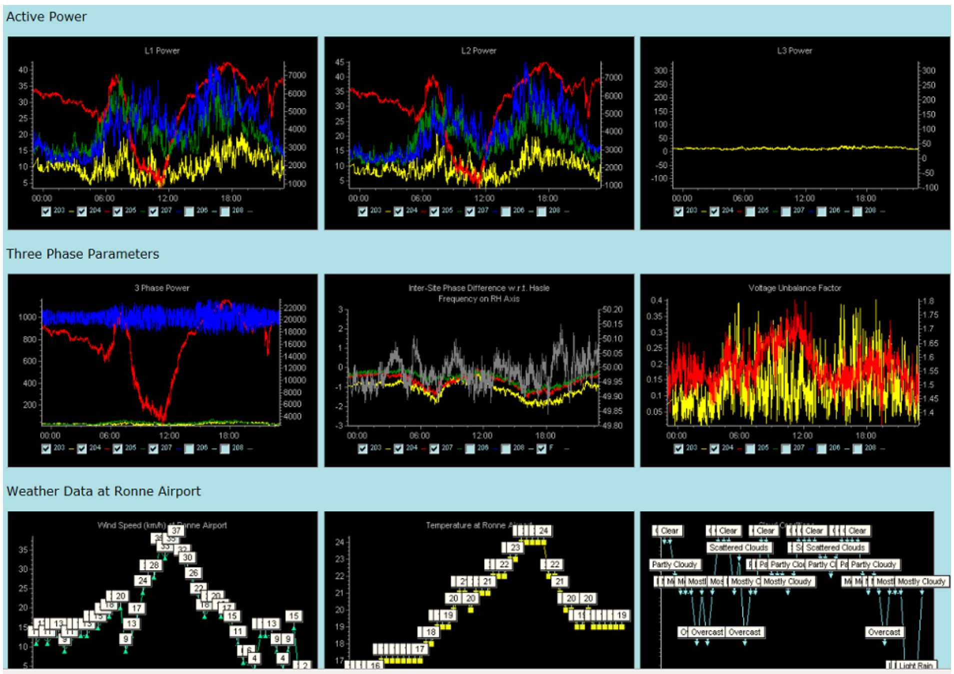


Fig.11, Extract from the Daily Measurement Summary HTML Report

The above example campaign on Bornholm in planned to last at least a year. This amounts to a significant data handling, analysis and presentation challenge, in-terms of the time taken to analyse the data. The philosophy used has been to collect data continuously and select data for analysis based on weather events, population events and an overview of the daily electrical values. Once data is selected there is then the matter of three separate phases on each of the instruments which all require separate analysis and presentation.

4.4 PQ Propagation

The purpose of PQ propagation studies is to use WMUs to determine the wide-area effect of a particular disturbing influence. For example, the generation of local harmonics by a large renewable installation could be significant, triggering the need for expensive mitigation equipment; however, if that disturbance had been "naturally" attenuated once at the wider grid level, the need for this mitigation can be relaxed. Conversely resonances in the network could give rise to an increase in the disturbance at the wider network level.

The nature of the harmonic propagation will depend on each specific network topology and impedance. Reconciliation of the results with the grid topology model is necessary to assess the system-level impact of various harmonic disturbances, leading to improved grid management/planning and appropriate constraints in future normative standards and grid codes.

Transient disturbances also propagate and can cause false protection trips, this may occur when a fault in one location causes a perturbation or transient that can cause a trip at a remote location. RoCOF relays for loss of mains protection are particularly vulnerable to such trips. Understanding how events propagate in a given network can help improve relay set points and reduce false trips.

4.4.1 Harmonic Propagation

Fig.12 shows the low-order harmonic voltage amplitudes for a method of presentation for four harmonic plots for WMUs connected in a wide-area measurement. They are plotted as a percentage of the mean fundamental voltage at the respective site. The spread in harmonics during the day is shown by the vertical bar, with the mean value given by the horizontal line.

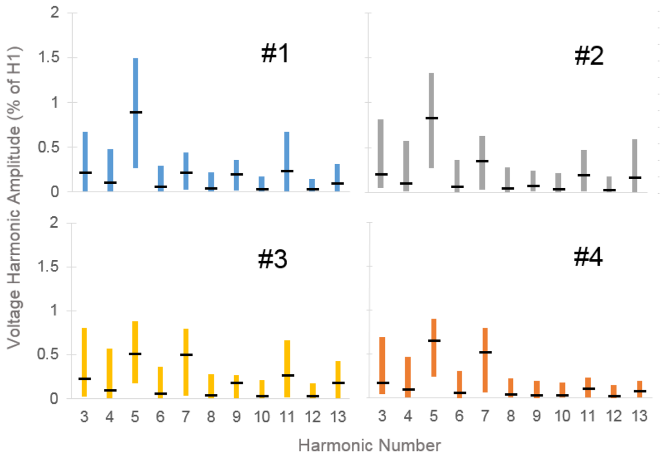


Fig.12. Harmonic voltages presentation from multiple sites. Vertical bars show the spread of the harmonic results. Horizontal marker shows the mean value.

Such a display allows the user to determine which sites are experiencing the highest and lowest levels of harmonics. However, changes in harmonic amplitude with daily or other behaviour are not shown and plots such as those shown in Fig.13 are required to determine the time varying behaviour of the harmonics.

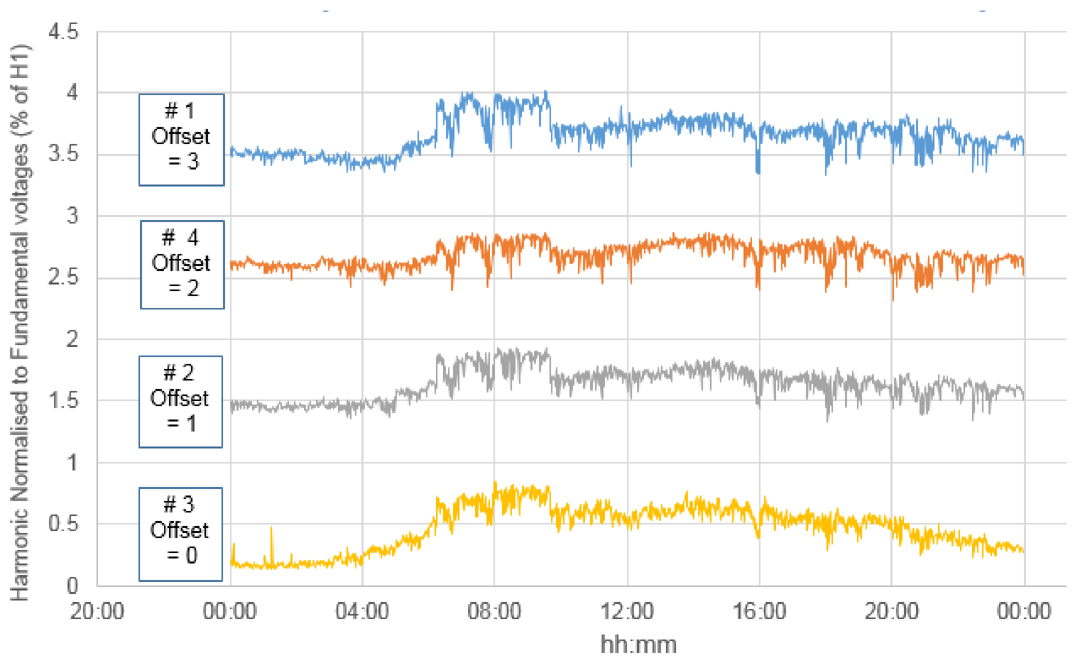


Fig.13, Normalised harmonic voltage plot (for H5) for the four sites. To improve clarity, the traces are offset by the amount shown in the left-hand adjacent boxes which sit on the respective y-axis zeros.

Evolutionary plots such as Fig.13 allow ready observation of time varying harmonics and common changes in harmonics such as the increase centred around 08.00h can be observed to determine the extent of disturbance and how it varies between sites.

Note the common use of colours between Figs. 12 and 13; although a trivial point assigning a colour to a given site can aid quick recognition. Offsetting the plots on the y-axis scale will aid clarity, rather than having the plot traces mixed together in the same space.

Such figures help to draw conclusions about the network in question. For example the harmonic increase centred around 8.00h in Fig.13 is more pronounced for site #1, but reduces and 'blurs" in time to some extent at site #3. Understanding weather and demographic trends can help interpret such events, for example the 8.00h increase in Fig.13 is probably caused by the population waking and preparing for the day in the morning peak load hour.

4.4.2 Transient Propagation

As explained above the capture of transients at multiple sites in a distribution network can be useful in understanding the propagation of disturbances, for setting protection devices and understanding network response.

Transient recorders can be used to save sample data of any event that exceeds a threshold of disturbance. This involves the continuous capture of samples waveform data (many samples per cycle). If an event occurs, the samples before and after the events will be stored to a file and time stamped, otherwise the samples will be discarded so as not to fill-up the recorders storage medium.

Fig.14 shows some captured waveform data from a phase to phase fault

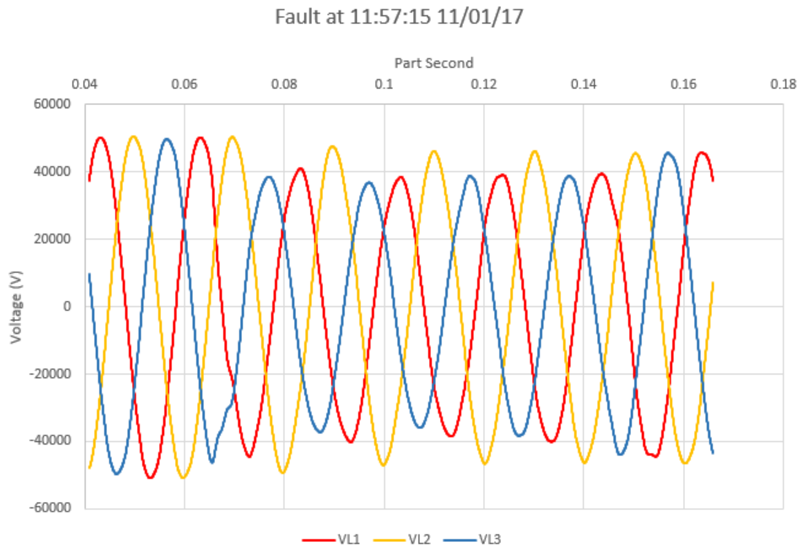


Fig.14, example captured waveform from a fault

The triggering algorithm is key to capture of events. Fig.14 uses a simple d/dt change from the last sample threshold which is highly dependent on which part of the cycle an events occurs. For example a fault on the high slope part of the waveform near the zero crossing may reduce the slope and be missed by the algorithm. Thresholds that use sine wave fits for Fourier methods are better at capturing events.

Algorithms should work on the voltage waveforms and not the current because current is prone to normal load change unrelated to faults.

GPS time stamping for the samples allows for the transient captures from multiple sites to be compared.

5 Appendix A – Measurement Campaign Preparation Questionnaire

1) Identification of Case-study

Which type of case-study (Grid site, MV/LV Substation, HV/MV Substation, Smart Grid site, Wind farm, Railway environment) is considered? LV Substation – PV Housing Estate

2) Measurement site

a) Name of the measurement site

b) Where is the measurement site situated? Is there a map available?

c) How many measurement locations are planned and where are they with respect to the map(s) of the site? Substation

d) What voltage/current levels are involved? 415V / 300A

e) Is the system under investigation single-phase or polyphase? Is a neutral current measurement required? 3 Phase, no neutral measured

f) Is there sufficient space in the substation or building to install the measurement equipment? Yes

g) What auxiliary services exist at the site i.e. telephone, internet, 3G coverage, mains power, type of main power plug/socket? 230V UK plug outlets. No 3G. 2G coverage OK. No phone or internet.

3) Parameters to be measured

a) Are there relevant standards establishing the power quality parameters to be determined and/or limits values in relation to the faced case-study? If yes, list them (*).

61000-4-15, 4-7, 4-30, EN 50160

b) Which parameters will be measured (see Table I list as an example)?

V, I, P, Q, Phase, V harmonics, I harmonics, Flicker, Dips.

c) How are the voltage measurements performed (line-to-neutral, line-to-line, neutral-to-earth)?

Line to neutral

d) What is the expected order of magnitude/range of variation of the parameters to be measured?

e) Which are the prescribed limit values (if any)?

f) Which is the required/expected measurement uncertainty?

0.1%: Limited by Rogowski coil

g) When will the measurements be carried out?

Summer 2013

h) How long will the measurement of each (or a group of) parameters last?

5 months (initially 1 month)

i) Are there any auxiliary /environmental measurements required – e.g. solar radiation, GPS timing, wind speed? Ideally solar radiation – hourly data obtained from Met Office

4) Measurement procedures and measurement systems

a) Which is/are the relevant standard(s) concerning the measurement procedures to be adopted? (*)
What measurement procedures are adopted for each parameter to be measured?

According to IEC 4-30, (4-7, 4-15)

b) Which transducers/ measuring instruments/algorithms and data elaboration procedures are used in relation to the different parameters?

NPL digitizer with 440V voltage inputs and 3kA/300A Flexible Rogowski coils. NPL software implementing IEC algorithms. NPL asynchronous sampling routines. NPL Flickermeter.

c) Are the measurement system components and the used software commercially available or laboratory developed? NPL developed.

d) Are the used current/voltage transducers the ones already operating on the plant? If so what are the connection arrangements/terminations and length of cable runs? No

e) If not, does the connection of transducers require a service outage of the plant? And what are the physical arrangements for the installation and wiring of transducers? No

f) Which are the standards relevant to the tests to be performed on the measuring instruments/transducers before its on-site use? Calibrated at NPL

g) In the case of laboratory developed measuring devices, which calibration/ characterisation/ insulation /immunity/ emission tests have to be performed before the on-site use. Which are the relevant standards? EN61010-1, "Safety requirements for electrical equipment for measurement, control, and laboratory use –" – also EMC testing

h) In the case of commercial measuring devices have all the required calibration/ characterisation/ insulation /immunity/ emission tests been performed?

i) What is expected site temperature and can the measurement equipment operate at that temperature? -5°C to 35°C

j) Data handling – as applicable, particularly in the case of a monitoring study over prolonged periods, what arrangements have been made for data storage, backup and remote collection of data?

Storage to hard drive. Selective download using GSM network

k) Data analysis/visualization – what methods/tools/programs will be used to analyze, present and visualize the results from the study ?

Excel

5) Safety procedures

a) Which are the safety procedures and rules to be followed? List technical documents if any.

Protective clothing – shoes, overalls and helmets.

b) Does the site operator require any training certification for personnel? Safety briefing and risk assessment

c) Does the site operator require written statements or documentation regarding measurement equipment prior to connection to the network? Yes

d) Does the site operator require a risk assessment? Yes

(*) The same standard can indicate both power quality parameters with relevant limits and related measurement procedures, so there may be an overlap between answers to questions 3a and 4a

Table I – Information summary

PQ Parameter	Measurement needed (Y/N)	Measurement procedure	Measurement system			Measurement uncertainty
			Transducer	Measuring instrument	Algorithms	
Power frequency	Y	e.g. 61000-4-30, §5.1				
Magnitude of the supply voltage	Y					
Flicker	Y					
Supply voltage swells	Y					
Supply voltage dips	Y					
Voltage interruptions	Y					
Transient voltages	N					
Supply voltage unbalance	Y					
Voltage harmonics	Y					
Voltage interharmonics	N					
Mains signalling voltage on the supply voltage	N					
Rapid Voltage Changes	N					
DC component	Y					
Current magnitude	Y					
Inrush current	N					
Harmonic current	Y					
Interharmonic currents	N					
….						

6 Appendix B – PQ Normative Standards

STANDARDS GIVING INFORMATION ON THE PARAMETERS TO BE MEASURED AND LIMITS OF EMISSIONS/IMMISSIONS.

EMC 61000-2 ⇒limits

EN 61000-2-2:2002 Electromagnetic compatibility (EMC) - Part 2-2: Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public low voltage power supply systems

Gives compatibility levels to be considered in public low-voltage supply systems with regard to the above-mentioned phenomena. Compatibility levels are intended to serve as reference values for trouble-free operation for equipment installed in public power supply systems.
Compatibility levels (disturbance, emission and immunity levels) are specified.

EN 61000-2-4:2002 Electromagnetic compatibility (EMC) - Part 2-4: Environment - Compatibility levels in industrial plants for low-frequency conducted disturbances

This part of EN 61000 is concerned with conducted disturbances in the frequency range from 0 kHz to 9 kHz. It gives numerical compatibility levels for industrial and non-public power distribution systems at nominal voltages up to 35 kV and a nominal frequency of 50 Hz or 60 Hz. Compatibility levels are specified for electromagnetic disturbances of the types which can be expected at any in-plant point of coupling within industrial plants or other non-public networks, for guidance in a) limits to be set for disturbance emission into industrial power supply systems; b) the choice of immunity levels for the equipment within these systems.

EN 61000-2-12:2003 –Electromagnetic compatibility (EMC) - Part 2-12: Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems

This part of EN 61000 is concerned with conducted disturbances in the frequency range from 0 kHz to 9 kHz, with an extension up to 148.5 kHz specifically for mains signalling systems. Compatibility levels are specified for electromagnetic disturbances of the types which can be expected in public medium voltage power supply systems, for guidance in: a) the limits to be set for disturbance emission into public power supply systems (including the planning levels defined in 3.1.5); b) the immunity limits to be set by product committees and others for the equipment exposed to the conducted disturbances present in public power supply systems.

EMC 61000-3 ⇒Emission limits and immunity limits (not falling under responsibility of the product committee)

EN 61000-3-2:2006, A1:2009, A2:2009 – Limits for harmonic current emissions (equipment input current <=16 A per phase)

EN 61000-3-3:2008 - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current <=16 A per phase and not subject to conditional connection

61000-3-11:2000 Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current <=75 A and subject to conditional connection

61000-3-12:2005 Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and <=75 A per phase

EMC 61000-4 ⇒Test and measurement techniques

EN 61000-4-1:2007 – General

The object is to give applicability assistance to the technical committees of IEC or other bodies, users and manufacturers of electrical and electronic equipment on EMC standards within the IEC 61000-4 series on testing and measurement techniques and to provide general recommendations concerning the choice of relevant tests.

Applicability of the different 61000-4 –xx: see Table I in EN 61000-4-1.

EN 61000-4-7:2002– Electromagnetic compatibility (EMC) - Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

Applies to instrumentation intended for measuring spectral components (harmonics, interharmonics and other components) in the frequency range up to 9 kHz which are superimposed on the fundamental of the power supply systems at 50 Hz and 60 Hz. Defines the measurement instrumentation intended for testing individual items of equipment in accordance with emission limits given in certain standards (for example, harmonic current limits as given in EN 61000-3-2) as well as for the measurement of harmonic currents and voltages in actual supply systems.

EN 61000-4-15:1998 - Electromagnetic compatibility (EMC) - Part 4-15: Testing and measurement techniques - Flickermeter - Functional and design specifications

Gives a functional and design specification for flicker measuring apparatus intended to indicate the correct flicker perception level for all practical voltage fluctuation waveforms. A method is given for the evaluation of flicker severity on the basis of the output of flickermeters complying with this standard.

EN 61000-4-30:2003 Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods

Defines the methods for measurement and interpretation of results for power quality parameters in 50/60 Hz a.c. power supply systems. Depending on the purpose of the measurement, all or a subset of the phenomena on this list may be measured. This standard is a performance specification. The uncertainty tests in the ranges of influence quantities in this standard determine the performance requirements. This standard does not set thresholds.

STANDARDS RELEVANT TO SPECIFIC ENVIRONMENTS

EN 61400-21 Wind turbines - Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines

Covers the definition and specification of the quantities to be determined for characterizing the power quality of a grid connected wind turbine; measurement procedures for quantifying the characteristics; and procedures for assessing compliance with power quality requirements, including estimation of the power quality expected from the wind turbine type.

EN 50160 - Voltage characteristics of electricity supplied by public distribution networks (Low and Medium voltage)

Defines, describes and specifies the main characteristics of the voltage at a network user's supply terminals in public low voltage and medium voltage electricity distribution networks under normal operating conditions. This standard describes the limits or values within which the voltage characteristics can be expected to remain over the whole of the public distribution network and does not describe the average situation usually experienced by an individual network user.

EN 50065-1:2001 Signaling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz Part 1: General requirements, frequency bands and electromagnetic disturbances

This standard applies to electrical equipment using signals in the frequency range 3 kHz to 148.5 kHz to transmit information on low voltage electrical systems, either on the public supply system or within installations in consumers' premises. It specifies the frequency bands allocated to the different applications, limits for the terminal output voltage in the operating band and limits for conducted and radiated disturbance. It also gives the methods of measurement.

EN 50163 Railway applications - Supply voltages of traction systems

Specifies the main characteristics of the supply voltages of tractions systems, such as traction fixed installations, including auxiliary devices fed by the contact line, and rolling stock, for use in– railways, guided mass transport systems such as tramway and trolleybus systems

EN 50388 Railway applications - Power supply and rolling stock – Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability.

This standard deals with the definition and quality requirements of the power supply at the interface between traction unit and fixed installations.

STANDARDS RELEVANT TO INSTRUMENTS TRANSFORMERS

EN 61869-1:2009 Instrument transformers - Part 1: General requirements

It is applicable to instrument transformers with analogue or digital output for use with electrical measuring instruments or electrical protective devices having rated frequencies from 15 Hz to 100 Hz. TC 38 decided to restructure the whole set of stand-alone Standards in the IEC 60044 series and transform it into a new set of standards composed of general requirements documents and specific requirements documents. This Standard is the first issue of this new series It contains the general requirements for instrument transformers and shall be read in conjunction with the relevant specific requirements standard for the instrument transformer concerned.

IEC 61869-3: 2011(**) Instrument transformers - Part 3: Additional requirements for inductive voltage transformers

This part of IEC 61869 applies to new inductive voltage transformers for use with electrical measuring instruments and electrical protective devices at frequencies from 15 Hz to 100 Hz.
Replaces IEC 60044-5 regarding inductive voltage transformers

IEC 61869-5: 2011(**) Instrument transformers - Part 5: Additional requirements for capacitor voltage transformers

This part of IEC 61869 applies to new single-phase capacitor voltage transformers connected between line and ground for system voltages Um ≥ 72,5 kV at power frequencies from 15 Hz to 100 Hz. They are intended to supply a low voltage for measurement, control and protective functions. The capacitor voltage transformer can be equipped with or without carrier-frequency accessories for power line carrier-frequency (PLC) application at carrier frequencies from 30 kHz to 500 kHz.
Replaces IEC 60044-5 regarding capacitor voltage transformers

EN 60044-1:1999, A1:2000, A2:2003 Instrument transformers - Part 1: Current transformers

Applies to current transformers for use with electrical measuring instruments and electrical protective devices at frequencies from 15 Hz to 100 Hz.

EN 60044-2:1999, A1:2000, A2:2003 Instrument transformers - Part 2: Inductive voltage transformers

Applies to inductive voltage transformers for use with electrical measuring instruments and electrical protective devices at frequencies from 15 to 100 Hz.

EN 60044-3:2003 Instrument transformers - Part 3: Combined transformers

Covers requirements, in addition to those given in EN 60185 and 60186, for transformers with combined voltage and current in the same casing.

EN 60044-5:2004 Instrument transformers - Part 5: Capacitor voltage transformers

This part of EN 60044 applies to single-phase capacitor voltage transformers connected between line and ground for system voltages Um 72.5 kV at power frequencies from 15 Hz to 100 Hz. They are intended to supply a low voltage for measurement, control and protective functions. The capacitor voltage transformer can be equipped with or without carrier-frequency accessories for power line carrier-frequency (PLC) application at carrier frequencies from 30 kHz to 500 kHz.

EN 60044-7:2000 Instrument transformers - Part 7: Electronic voltage transformers

Applies to electronic voltage transformers with analogue output, for use with electrical measuring instruments and electrical protective devices at frequencies from 15 Hz to 100 Hz. The standard covers optical arrangements with electronic components. Three-phase voltage transformers are not included, but some of the requirements apply.

EN 60044-8:2002 Instrument transformers - Part 8: Electronic current transformers

This part of EN 60044 applies to electronic current transformers having an analogue voltage output or a digital output, for use with electrical measuring instruments and electrical protective devices at nominal frequencies from 15 Hz to 100 Hz.

(**) Note: Not published as EN Standard as yet.

IEEE STANDARDS

IEEE Std 1250-2011: IEEE Guide for Identifying and Improving Voltage Quality in Power Systems

Discussions of ways to identify and improve voltage quality in power systems, as well as references to publications in this area.

IEEE Std 1159-2009: IEEE Recommended Practice for Monitoring Electric Power Quality

This recommended practice encompasses the monitoring of electrical characteristics of single-phase and polyphase ac power systems. It includes consistent descriptions of conducted electromagnetic phenomena occurring on power systems. This recommended practice presents definitions of nominal conditions and deviations from these nominal conditions that may originate within the source of supply or load equipment or may originate from interactions between the source and the load. Also, this recommended practice discusses measurement techniques, application techniques, and the interpretation of monitoring results.

IEEE Std. 1453-2005 IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems

Voltage fluctuations on electric power systems sometimes give rise to noticeable illumination changes from lighting equipment. This recommended practice provides specifications for measurement of the flicker phenomenon and recommends acceptable levels for 120 V, 60 Hz and 230 V, 50 Hz AC electric power systems. It does not make any flicker emission specifications for certification of individual products manufactured for use on these systems.

IEEE Std. 1459-2010 IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions

Provides definitions of electric power to quantify the flow of electrical energy in single-phase and three-phase circuits under sinusoidal, nonsinusoidal, balanced, and unbalanced conditions.

IEEE Std. 1547-2003 IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

This standard provides a uniform standard for interconnection of distributed resources with electric power systems. It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection.

IEEE Std. 1547.1-2005 IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems

This standard specifies the type, production, and commissioning tests that shall be performed to demonstrate that the interconnection functions and equipment of the distributed resources (DR) conform to IEEE Std 1547.

IEEE Std. 1124-2003 IEEE Guide for the Analysis and Definition of DC-Side Harmonic Performance of HVDC Transmission Systems

This guide contains information and recommendations pertaining to the analysis and specification of the performance on the dc side of a high-voltage direct-current converter station concerning the electrical noise at harmonic frequencies up to 5 kHz generated by converter stations in a dc transmission system. This guide also contains information and suggestions pertaining to measurement of dc filter performance and noise level induced in wireline communications circuits from harmonic currents on dc transmission lines.

Appendix B References

P. Clarkson, NPL *Report on Power quality Measurement Parameters for iMERA-Plus JRP T4.J01, Deliverable 4., Tasks 1 and 2*.

www.cenelec.eu

www.iec.ch

http://ieeexplore.ieee.org

7 Appendix C - Example Equipment List.

T:\data\AC Measurements Software\PSW Backup\EMRP Smart Grids\Best Practice Guide\ On Site check list.xls

Measurement Equipment	**Personal Equipment**
PQ Analyser	Hard hat
IEC Mains leads	Latex gloves
PC and associated leads	Overalls (fireproof)
Environmental Sensors	Safety boots
Current Transducers	Camera
Extension Leads for transducers (screen twisted pair)	Notebook
Cat IV crock leads	Pens
Spare fuses for CatIV leads	calculator
Spare mains fuses	cell phone
PC to Analyser interface lead	USB Memory stick
GPS Antenna (if applicable)	
Multi-way mains extension lead(s)	**Documentation**
Table/trolley/stand to house equipment	Instrument manuals
Signs to identify equipment	Site drawings and circuits
Mains plug adaptors (overseas)	Contact details
Tools & test equipment	**Communications**
Multimeter	Internet RJ45 Ethernet cable (long)
releasable cable ties	GSM Modem, PSU and aerial (if applicable)
Reel of earth wire	3G Dongle
Selection of ferules and terminals and crimp tool	
Crock Clips	
Reel of insulating tape	
Selection of tools (screwdrivers, spanners/sockets, cutters, plyers)	
Terminal blocks	
Wire brush/abrasive block for cleaning terminals	
Crates for moving equipment (with lids)	
Electric drill and masonry bits	
Cable clips/hammer	
Duck Tape	

8 References

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[4] Matthews, C.; Clarkson, P.; Harris, P.M.; Ihlenfeld, W.G.K.; Wright, P.S., "Evaluation of Flicker Measurement Uncertainties by a Monte Carlo Method," Instrumentation and Measurement, IEEE Transactions on , vol.60, no.7, pp.2255,2261, July 2011.