CIGRE Reference Paper : Power quality trends in the transition to carbon-free electrical energy systems

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Due to the accelerated shift towards a carbon-free electrical energy system, the power system is changing in terms of both planning and operation with an increasing integration of converter-interfaced renewable generation at all voltage levels. One area strongly affected by these changes is power quality where, if not managed correctly, it can result in equipment mis-operation, accelerated aging, tripping of plant, loss of production process, etc. Power quality is ultimately a customer-driven issue but failure to provide the adequate supply can also have negative impact on system operators, including customer complaints, reputational damage and financial liability.

Power systems globally are experiencing a transition towards decarbonisation of electricity production through large-scale deployment of central and distributed renewable energy sources (RES), which are gradually replacing conventional thermal plant. The connection of RES to the power system is mostly achieved using power electronic (PE) converters. Equipment interfaced through PE-converters can have both a positive or negative effect on power quality, depending on the type of disturbance evaluated and the applied control strategy of the PE-converter.

Presently, the understanding of the impact of PE-converters and some related phenomena is not fully developed. However, it is widely accepted that the consequences of degraded power quality can have severe financial implications and most studies in the US and Europe point to an excessively high level of cost if serious problems arise. This reference paper provides a high-level summary of the main and topical power quality issues in this changing environment with the aim of raising awareness of the main facets of power quality.

Harmonics

Harmonics can be present in voltage and current waveforms and are defined as “a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency”. Harmonic distortion is caused by non-linear devices connected to the power system. Unlike linear devices, a non-linear device reacts to a perfect sinusoidal voltage waveform with a distorted current

It is generally expected that power systems around the world will experience an increase in harmonic distortion as the green transition progresses. This is partly due to the sheer number of converter-interfaced equipment being connected and partly due to possible modification of existing distortion levels. However, emphasis on limitation of harmonic emissions is gaining more attention and driving a trend in the opposite direction, that harmonic emission of new plants, as a whole, is reduced at equipment level due to more advanced switching and control technologies being implemented and the stricter enforcement of grid code requirements. Moreover, with local resonance introduced by the use of cables, it will be difficult to generalise. A trend towards a more profound focus to undertake detailed analysis at the planning stages, to ensure adherence to statutory limits and hence secure power system operation is however manifesting.

Voltage variations

Voltage variations refer to the changes of the voltage waveform. This could take place throughout the day as slow variation due to gradual customer load variation and/or variable RES output or it could take the form of rapid voltage changes and dips caused by various switching operations. Larger and more frequent voltage variations can be expected due to increasing penetration of intermittent generation resources such as wind and solar. Such voltage variations can lead to both under voltage and over voltage where both situations can have an impact on network operation and on customer equipment; the effect will be strongest in areas

of the power system having low system strength. In distribution networks, over voltage can lead to excess energy consumption, transformer core saturation and stressing of insulation leading to their premature failure. Under voltage can lead to reduced energy consumption, malfunctioning of high-intensity discharge lamps and reduction of torque developed by mains connected motors.
Reduced system strength at transmission levels means that voltage dips, typically caused by system faults, transformer energization or large motor starting, can become more frequent and severe and will also propagate to downstream distribution networks. Intermittent power output, combined with a reduction in system strength will result in a higher volatility in the system voltage at transmission level making fast voltage variations a possible issue at high voltage levels.

Voltage unbalance

Voltage unbalance is defined as a "condition in a poly-phase system in which the magnitudes of the phase voltages and/or the phase angles between consecutive phase voltages, are not all equal Proliferation of technologies such as photovoltaic systems at the low voltage level is taking place as single-phase connections. single-phase PV connections can be altered between the phases but in places where only single-phase laterals are available, all connections end up on the same phase which can lead to significant voltage unbalance levels on three-phase low voltage systems. Other technologies that will have an impact include electric vehicle charging points and heat pumps at the low voltage level. These will have an increased level power capacity and are likely to introduce more voltage unbalance and hence their capacities may be limited depending on the fault level at the point of connection. Large scale wind and solar farms are often connected at remote locations supplied by relatively long un-transposed lines, and hence voltage unbalance can arise due to the lines although the wind or the solar farms inject balanced currents.

Concluding remarks

The power quality in the future power system is expected to be significantly affected by the shift towards a carbon-free electrical energy system. Several trends point to degraded power quality indices of future power systems due to the integration of many power electronics devices, use of power cables at all voltage levels, increasing amount of fluctuating production and generally reduced system strength. However, with the ability to control power electronics new possibilities are emerging and if used correct many of the challenges introduced can be mitigated by the same components that create them. Doing so successfully requires high focus on power quality studies both at individual connection and system wide level, focus on grid code requirements and their implementation and robust system monitoring with a strategic approach.

Further reading

This Reference Paper is a very short summary of a longer and wider paper prepared by a small task force made up of members from SC C4 - System Technical Performance. This paper provides an overview of power quality trends with increased use of power electronic converters in the power system.

Readers are encouraged to reach out and read the full paper in the flagship CIGRE Science & Engineering Journal's Volume No 17, February 2020 issue **(available soon on e-cigre)**.

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