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COUNTRY :	The Netherlands	PREF. SUBJECT :	1
REGISTRATION NUMBER : 1144		QUESTION N° :	1

Overview of harmonic compliance studies of large windfarms in The Netherlands

C4 – Preferential subject 1, Question 1:
"On the subject of management of power quality disturbances in evolving power systems, what are the difficulties/drawbacks with the existing approaches which require focus/development ensuring that the regulatory mechanisms, engineering methodologies and solutions are practical, robust and cost-effective?"

Overview of harmonic studies
In support of various wind farm (WF) developers, Energy Solutions performed as well as reviewed many pre-connection harmonic compliance studies of type D WF in the past years.
Main characteristics of the studies:

- WF power level between 80 MW and 400 MW, 15 – 90 Wind Turbine Generators
- Connection point voltage level: 50 kV – 150 kV
- Connected directly to TSO, directly to DSO or to TSO via privately owned distribution system
- Scope:
  - Wind Turbine Generators (WTG) + array cables (offshore only)
  - WTG + array cabling + step up transformer
  - WTG + array cabling + step up transformer + export cable (up to 55 km)
- Number of studies performed/reviewed : 11

Assessment methodology
TSO /DSO provides impedance envelopes for each (group of) harmonic order and limits for each harmonic order.
WF to determine maximum voltage distortion U_{hi} (%) per harmonic order over complete impedance envelope at PCC taking all possible operational states of WTGs and WF passive components into account

Assessment in practice
Although in earliest studies both harmonic amplification of background harmonics as well as incremental voltage distortion by the WF were required to be assessed, currently limits only apply to incremental harmonic voltage distortion U_{hi} (%) caused by the WF.

Principally, individual WTG contributions shall be calculated using worst case assumptions : phase correct summation with the same phase angle for each WTG and maximum emission over all power bins.

Due to the worst case approach of both WF and grid impedance, some low order harmonic orders usually exceed limits (in range of h = 2 - 25) where compliance still can be achieved by:

1. TSO/DSO checking exceedance plot on actual loci / grid impedance curves
2. Emission U_{hi} reduced by phase angle randomization for even / triple harmonics

In Figure 1 two examples of an exceedance plot for harmonic order h = 2 and h =11 is shown where for the complete grid impedance envelope the harmonic voltage distortion Uhi has been determined. Green colour shows the compliant area.

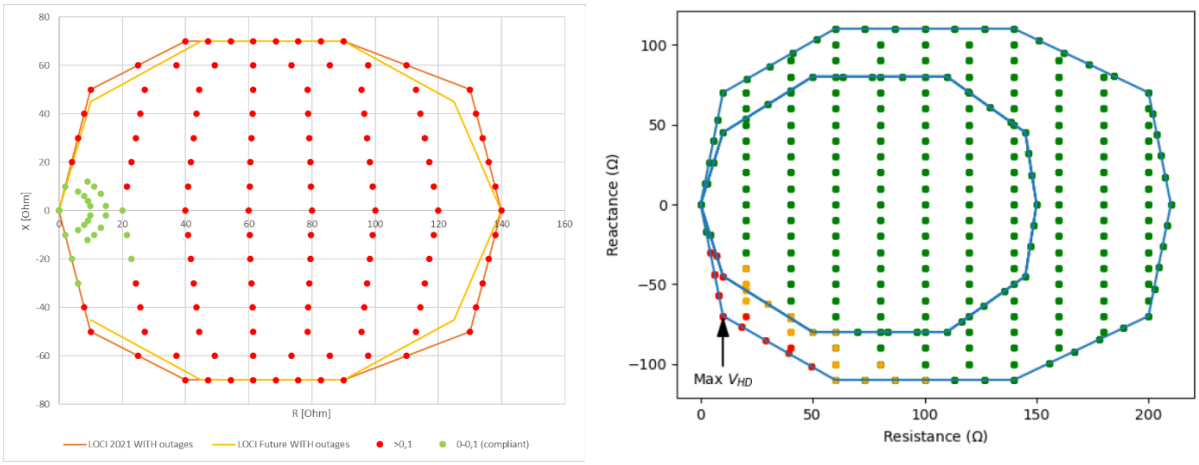

Figure 1. Two examples of exceedance plots for harmonic order h=2 (left) and h = 11 (right) for two different wind farms.

For these cases, DSO provided a graph with all impedance scans used to determine the grid impedance envelope, examples shown in Figure 2. For harmonic order h=2 (100 Hz, left) this graph shows that the grid impedance at that frequency has no variance and will always be lower than 5 Ohms and is therefore compliant. For harmonic order h=11 (550 Hz, right), the assessment is not so straightforward and the chance of an exceedance can't be fully eliminated. As the chance that an actual resonance between grid and wind farm will occur is very low (usually related to an N-2 grid outage situation), up till now costly mitigation measures such as a filter have been avoided by an operational agreement between wind farm and TSO/DSO: if the voltage distortion at PCC of the related harmonic order exceeds the planning level, the wind farm shall reduce power or (partly) switch-off.

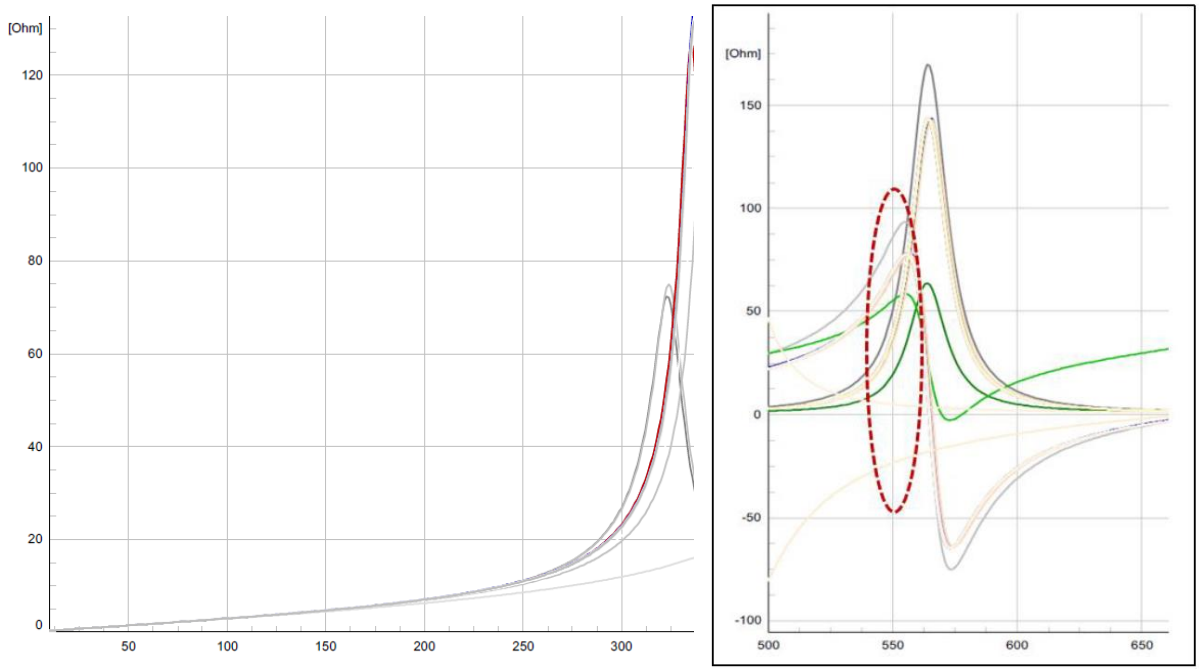

Figure 2. Impedance scans corresponding to the impedance envelopes of Figure 1

Conclusion and recommendations

Difficulties/drawbacks with the existing approaches:

- Although filter installations at WF side are avoided by above approach, administration and work load of the procedure (for both TSO/DSO and WF) is high and length of procedure can take up to 1 year. Also, the operational agreement has to be implemented (e.g. measurement procedure and follow up in case of exceedance).
- Only limited converter/WTG OEM (original equipment manufacturer) provide supporting measurements to substantiate phase angle randomization for even and triple harmonic orders.

Possible improvement would be for the

- TSO /DSO to provide more precise impedance data, for example an impedance envelope for each single harmonic order instead of grouped scans combined with a split between N, N-1 and N-2 grid states. Alternatively, impedance scan data could be provided. In both cases this will lead to a high amount of simulations but with scripting and current computer power, this is preferred above the above process with high administrative load.
- Converter / WTG OEM to perform - as a standard - measurements on prevailing angle ratio (PAR, IEC61400-21) and also provide substantiation how a low PAR of a certain harmonic order can be used to randomize phase angles in harmonic load flow simulations