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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?

Comments on question 1:

Possible approach to make harmonic performance studies of large inverter-based generation parks less conservative for low harmonic orders

Different approaches are applied to assess the harmonic performance of a new disturbing installation to verify the need for mitigation solutions. In many cases, harmonic studies are performed to capture worst case operating condition. This approach may lead to overrated harmonic emissions and oversized mitigation solutions.

This contribution presents an example of divergence between harmonic performance study results and the measured harmonic voltage at the PCC of a Wind Farm (WF) complex. A possible approach to minimize these differences is proposed. The contribution focus on the even harmonics because they are less influenced by the background voltage distortion, therefore they are taken as standard for the adjustments proposed in the criteria for the definition of impedance loci typically used in worst case studies.

The WF complex object of this example is located in the southern end of Brazil and is composed of two wind farms: WF1 with an installed capacity of 90 MW and WF3 which has a rated capacity of 73,2 MW. WF2 operated a short period (10/2013 to 04/2015), but it was discontinued due to non-technical reason.

It is important to note that, in Brazil, Individual Limits of harmonic voltage are used to evaluate the impacts of a new installation in voltage distortion. Regarding measurements, the ISO applies the Global Limits to manage the overall voltage distortions caused by all installations. The harmonic performance study must be carried out with the classical methodology of filter design stated at IEC 62001-1 and do not assess the modification of the existing voltage distortion at the PCC caused by the interaction of the customer and utility impedances.

The harmonic performance studies of these WFs indicated violations of the Individual Limits, as presented in Table 1. This situation compelled the WFs to design filters to meet the distortion limits. However, based on the continuous monitoring of voltage distortions at the PCC of these WFs, the owner of the projects contested the results of the studies and did not install filters until the measurements in this contribution were presented.

Table 1 – Harmonic distortions obtained by study – Vh (%)

h	2	3	4	5	6	7	THD
Individual Limits (%)	0.30	0.60	0.30	0.60	0.30	0.60	1.50
V(%)	0.98	1.54	1.29	4.14	0.13	0.60	4.77

The harmonic impedance envelopes considered in the study were defined considering scenarios of complete network topology and contingency (n-1) of various equipment beyond the 3rd

neighborhood of the PCC. Each harmonic impedance envelope that represents the utility impedance was composed by the harmonic frequency in question and inter-harmonic frequencies until h±½ with a frequency step resolution of 6 Hz.

The measurements were separated in 3 periods to verify the influence of each WF at the harmonic voltage at the PCC, as follow:

- pre-park measurement campaign held between May 11th and 17th, 2011;
- since the entry of WF1 into operation on 11/2011 until 07/2015;
- after the entry of WF3 into operation on 08/2015 until 07/2021.

Figure 1 shows the 95th daily percentile (P95) from the even harmonics measured at the PCC over the course of about 10 years. The figures have extremely low values in relation to the distortion limits, despite having been somewhat elevated in relation to the pre-park measurement campaign. Moreover, the voltages measured for the 2nd and 4th harmonics are substantially lower than the values calculated in this study, as shown in Table 1.

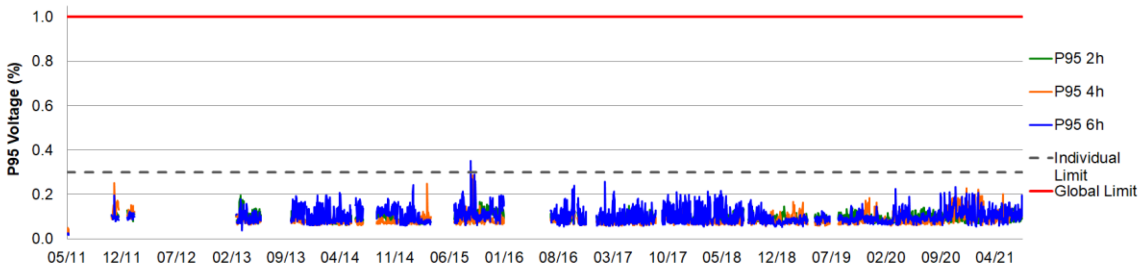

Figure 1 – P95 of 2nd, 4th and 6th harmonic

Figures 2 and 3 show statistical calculations of these measurements comparing the 3 situations: pre-park; WF1 in operation (including some periods when WF2 was also operational); and WF1 and WF3 in operation.

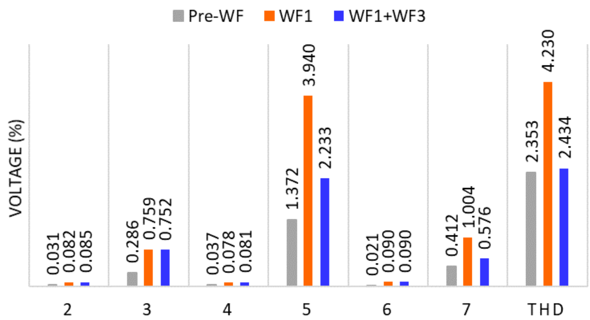

Figure 2 – Average of the P95 of the harmonic voltages measured per period at the PCC

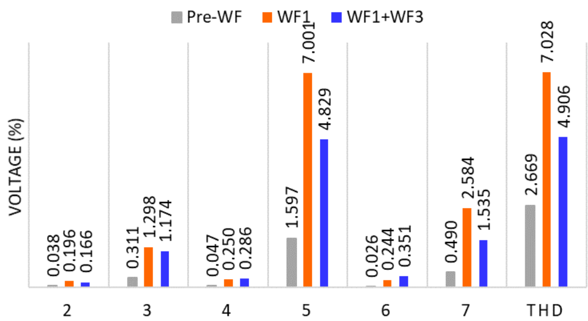

Figure 3 – Maximums P95 of the harmonic voltages measured per period at the PCC

Comparisons among Table 1, Figure 1 and 2 for even harmonics clearly shows that the study overestimated distortion results for the low order even harmonic voltages in relation to the values measured over a long period of time.

To verify the influence of the criteria applied to define the impedance envelopes, and to propose a feasible and practical approach to make the result of harmonic performance assessment more realistic and equivalent to the voltage distortion verified in long-term measurements, a study using different criteria to define the utility impedance was performed and the result is presented in Figure 4. The simulation study results are compared to the 99.9th percentile of all P95 recorded in each of the periods (Pre-WF, WF1 alone and WF1+WF3). In the chart, the dark blue bars represent the results obtained with the ISO's criteria (ISO-IH), situation in which the envelopes include harmonic and inter-harmonic impedances (h-6Hz, h-12Hz, until h-½; h+6Hz, h+12Hz, until h+½) calculated for normal situations and outages of all system equipment. The blue and the light blue bars represent situations similar to the ISO's criteria regarding the consideration of inter-harmonic frequencies in the locus, but do not include transmission line (TL) outages for the blue bars (TL-IH) and do not include TL and power transformer (PT) outages for the light blue bars (TL-PT-IH). The results presented in the orange, yellow and green bars are obtained using impedance loci defined with the same system conditions established for the ISO-IH, TL-IH and TL-PT-IH, but in these cases the inter-harmonic frequencies are not used to define each locus. The grey and black bullets in the chart represent, respectively, the measurements made before the connection of the WFs at the PCC (99.9 Pre-WF) and after the connection of WF3 (P95 WF1+WF3).

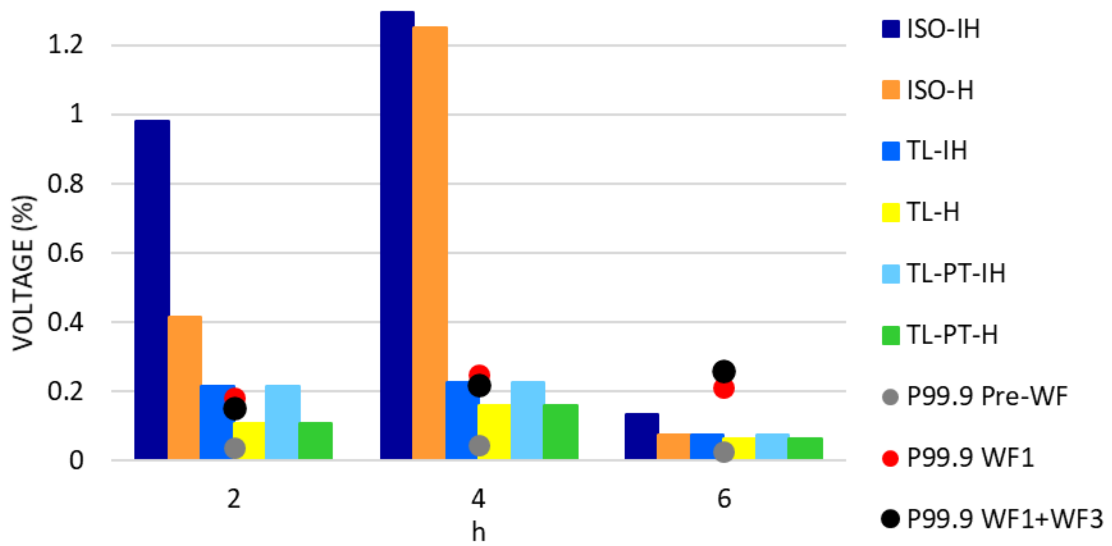

Figure 4 - Comparison of study and measurements results – even orders

Based on the assessment presented here (and other performed for other WF) some relevant conclusions are possible:

- it is not appropriate to adopt the same study criteria for the design of filters and for the verification of their need, at the risk of resulting in the installation of unnecessary equipment;
- when verifying the need for filters, it is advisable that the system harmonic impedance is represented in a more realistic way in the studies, covering probable scenarios, especially for low harmonic orders;
- the inclusion of inter-harmonic frequencies until h±½ with a frequency step resolution of $f_n/10$ for the definition of the impedance envelopes from 2nd to 4th harmonic, results in improbable voltage distortion levels;
- the consideration of harmonic impedances calculated in scenarios with TL and PT contingency can generate more severe results than those verified in the measurements when using the P95 of the harmonic voltages.

The contribution proposes that harmonic performance studies (for a diagnosis of generated voltage distortions) should be carried out without including the inter-harmonic frequencies in the impedance envelopes from the 2nd to the 4th harmonic. Such studies should also not consider the inclusion of calculated impedances in scenarios with a low probability of occurrence, i.e., scenarios with a duration of no more than 2% (about 1 week) or 5% of the time in a year.