Study Committee C4

Power System Technical Performance

Paper C4_10167_2022

Application of a Methodology for Determining Voltage Harmonic Contributions in a Low-Voltage Busbar

Ivan N. SANTOS, Bárbara M. GIANESINI, Giordanni da S. TRONCHA, Raquel C. F. GREGORY, Celso R. AZEVEDO JR, Vinícius H. F. BRITO

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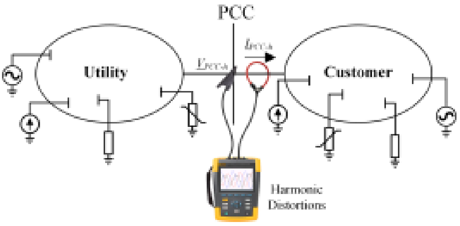
Motivation

- With the growing connection of nonlinear devices, high levels of harmonic voltages and/or currents are becoming a reality. Due to the potentially harmful effects that harmonic distortions may cause, their levels must be kept under the power quality standard limits.
- Utility and customers may inject harmonic currents into electric grid at the PCC (Point of Common Coupling). Nowadays, nonlinear devices can be found in different levels of the power system (generation, transmission, and distribution). Therefore, the harmonics at the PCC will be a composition of both sides' emissions.

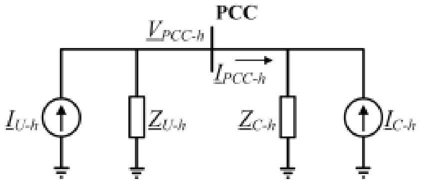


Voltage and current measurements at a PCC connecting a customer to a utility.

- The main challenge is to determine how much each side contributes to the harmonic distortions at this PCC. Then, the costs of mitigation solutions can be shared accordingly.
- Over the years, extensive research has been carried out to answer this question. The Superposition Method (or Voltage Harmonic Vector Method - VHVM) was the most popular approach, but it requires the knowledge of the harmonic impedances, which is a hard task to accomplish in practice.
- To overcome this drawback, the Dominant Impedance Method (DIM) has been proposed. Therefore, the present paper aims at evaluating, for the first time, the application of the DIM in the field to verify its response in a dynamic low voltage system.

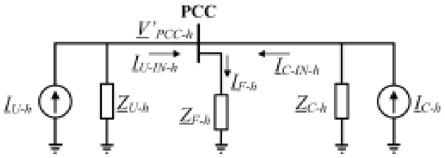
Dominant Impedance Method (DIM)

- Assuming a customer connected to a utility grid through a PCC, the Norton equivalent circuit, for a harmonic order *h*, is shown:



Norton equivalent circuit for a harmonic order *h* representing customer and utility connected to the PCC.

- The DIM follows the theoretical principle of the VHVM (superposition principle). Nevertheless, it does not require the knowledge of the harmonic impedances in its calculation. To achieve this goal, a "dominant impedance" is connected at the PCC, such as a passive tuned harmonic filter.



Norton equivalent circuit for a harmonic order *h* representing customer and utility connected to the PCC – passive tuned harmonic filter on.

- The filter is designed to have a considerably small impedance at *h* order. If the filter impedance is much smaller than the others, it is said to be dominant. Fulfilling this condition, the filter becomes the low impedance path for the harmonic current flow, which means that the harmonic currents from both utility and customer sides will mostly flow to the filter. Therefore, the following equations can be written:

$$I_{U-h} = I_{U-IN-h}$$

$$I_{C-h} = I_{C-IN-h}$$

$$I_{F-h} = I_{U-IN-h} + I_{C-IN-h}$$

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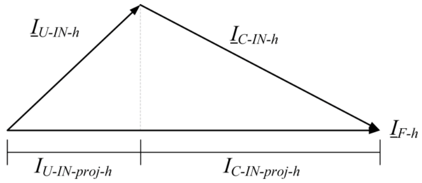
Dominant Impedance Method (DIM)

- According to the VHVM, $\underline{I}_{U-h}$ is proportional to the utility voltage contributions at de PCC. Similarly, $\underline{I}_{C-h}$ is proportional to the customer voltage contribution at the PCC. Therefore, by knowing these two current sources, the portions of responsibility from both sides can be calculated.
- In practice, $\underline{I}_{U-IN-h}$, $\underline{I}_{C-IN-h}$ and $\underline{I}_{F-h}$ can be measured by using PQ meters. Then, to find the utility and customer contribution percentages, the projections of of $\underline{I}_{U-IN-h}$ and $\underline{I}_{C-IN-h}$ onto $\underline{I}_{F-h}$ must be determined according to the following:

$$I_{U-IN-proj-h} = \left|\underline{I}_{U-IN-h}\right| . cos\left(\theta_{I_{U-IN-h}} - \theta_{I_{F-h}}\right)$$
$$I_{C-IN-proj-h} = \left|\underline{I}_{C-IN-h}\right| . cos\left(\theta_{I_{C-IN-h}} - \theta_{I_{F-h}}\right)$$



Projections of individual contributions on the total distortion at the PCC.

- Once finding the projections, the voltage contributions of the utility and customer are calculated according to:

$$\%V_{U-h} = \left(\frac{\left|I_{U-IN-proj-h}\right|}{\left|I_{U-IN-proj-h}\right| + \left|I_{C-IN-proj-h}\right|}\right) . 100\%$$

$$\%V_{C-h} = \left(\frac{\left|I_{C-IN-proj-h}\right|}{\left|I_{U-IN-proj-h}\right| + \left|I_{C-IN-proj-h}\right|}\right) . 100\%$$

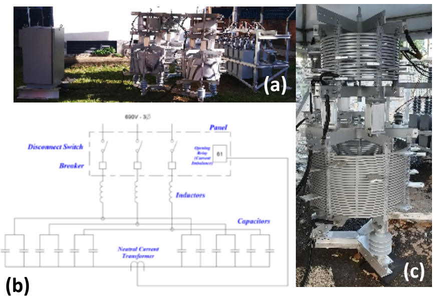
- The dominance index (DI) evaluates the filter dominance level. This index can be found by using the harmonic voltages measured at the PCC, with and without the passive tuned harmonic filter:

$$DI_h = \frac{\underline{V}_{PCC-h}}{\underline{V}_{PCC-h} + \underline{V}'_{PCC-h}}$$

- A DI higher than 0.8 is enough to guarantee satisfactory results.

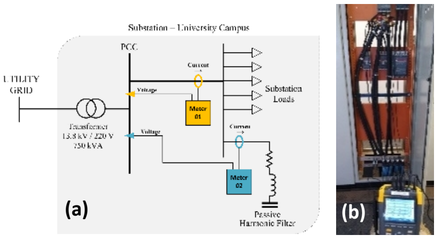
Application of the DIM in a Brazilian Real Site Substation

- The PCC chosen to apply the DIM is the low voltage side of a 750 kVA substation (13.8 kV / 220 V) located at a university campus in Brazil. The substation loads are considered as the customer (University) and the grid – upstream the substation – is the utility.
- A low voltage multi-tuned passive harmonic filter was used as a dominant impedance. The filter has a power of 40 kVAr (60 Hz – 220 V). The filter is single-tuned, but the tuning frequency can be changed as required.



Multi-tuned passive harmonic filter: (a) full arrangement, (b) three-line diagram, and (c) inductor tap adjustments.

- The voltage and current measurements have been carried out through Three-Phase Power Quality Analyzers. The PQ Analyzers were time-synchronized by GPS, and a 1-second period was chosen for the measurement aggregation. The measurements were carried out considering a daily time in order to cover different loading conditions.



Power Quality Analyzers installation: (a) one-line diagram, (b) field setup.

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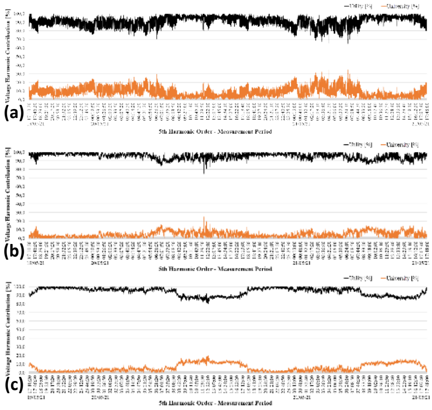
Results and Discussion

- The study focused on the 5th and the 7th orders since these are the most significant at the PCC. The filter tuning frequencies were very close to the nominal values (detuning close to zero).

Harmonic order	Tuning frequency (order)		
	Phase A	Phase B	Phase C
5th (300 Hz)	301.8 Hz (5.03)	300 Hz (5.00)	300.6 Hz (5.01)
7th (420 Hz)	421.2 Hz (7.02)	418.8 Hz (6.98)	418.8 Hz (6.98)

5th Harmonic Order

- The 5th harmonic distortion was 1.6% of fundamental voltage, far below the limit established in Brazil (7.5% for the total voltage harmonic distortion for odd components not multiples of 3).
- The utility was the major responsible for the 5th harmonic voltages at the PCC, with contributions higher than 70%.



Utility (black) and University (orange) contributions to the 5th harmonic voltage measured at the PCC: (a) phase A, (b) phase B, and (c) phase C.

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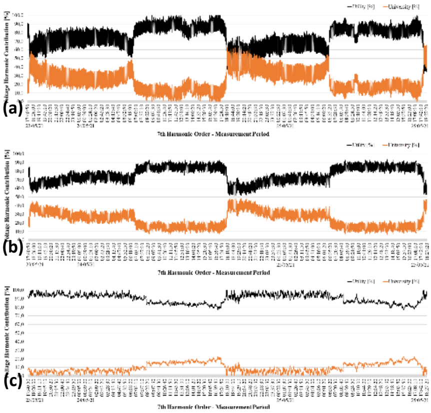
7th Harmonic Order

- The 7th harmonic order reached magnitudes up to 1.1% of fundamental voltage (smaller than the Brazilian limit).
- The major contributions of the 7th harmonic voltage distortion were assigned to the utility; however, different percentages were observed for each phase.



Utility (black) and University (orange) contributions to the 7th harmonic voltage measured at the PCC: (a) phase A, (b) phase B, and (c) phase C.

- Abrupt changes in the contributions are observed for phases A and B. An explanation for this behavior is the influence of the campus LED street lighting, which may have increased the university's responsibility at night.

Conclusions

- The application of the DIM was very satisfactory, as it was able to point out the responsibility percentages of each main disturbance source (utility and customer) using current measurements only.
- We conclude that the case study presented in this paper accomplished the goal. Or in other words, the application of the DIM for calculating harmonic responsibilities in a dynamic low voltage busbar was achieved.