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# Impact Studies of Connecting Tuned Harmonic Filters onto a Brazilian Wind Farm

**R. C. F. Gregory[1], G. S. Troncha[1], B. M. Gianesini[1], C. F. Chaves[2], I. N. Santos[1]**

1 Federal University of Uberlândia (UFU) - Faculty of Electrical Engineering – Uberlândia (Brazil). e-mail: ivan@ufu.br

2 Neoenergia Group – Rio de Janeiro (Brazil)

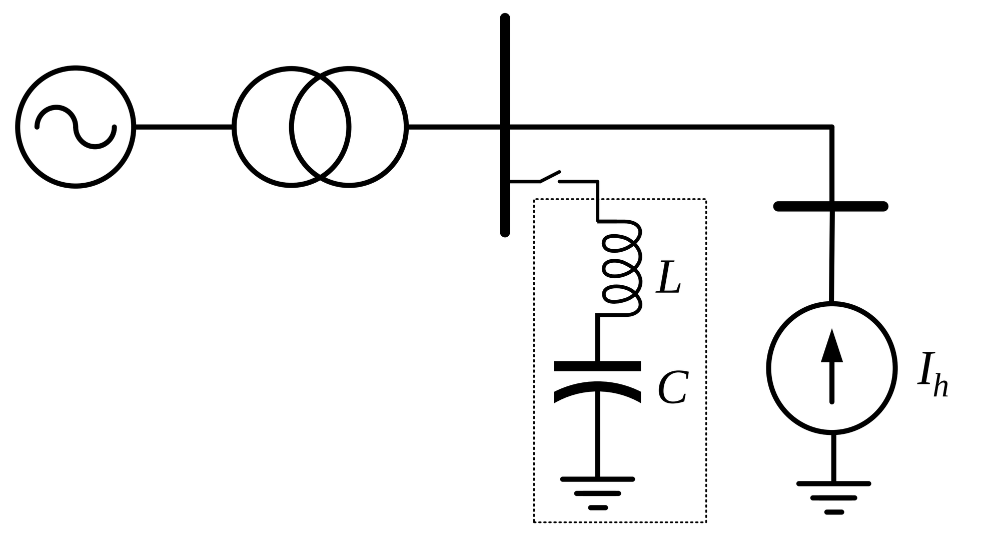
## I. Introduction

In order to make the levels of harmonic distortions compatible on wind farms, two approaches may be employed depending on the nature and source of the problem. The first solution is related to the design of the whole plant to avoid resonances at typical harmonic frequencies. In fact, through intelligent system design, harmonic issues can be effectively suppressed by employing special equipment and adjusting the control of converter bridges to avoid high levels of distortions. Alternatively, aiming at mitigating the disturbances of an existing wind power plant, harmonic filtering strategies are widely employed, which may be composed of active or passive-based components. Concerning passive harmonic filters, these are traditionally used to mitigate harmonic distortions on wind farms as they present a satisfactory cost-effective ratio.

## II. Objectives

This paper is aimed at investigating the impacts of connecting passive tuned harmonic filters on the grid-resonance characteristics and the overall harmonic distortions from a wind farm. In this context, by using measurements of currents from a Brazilian wind power plant, computational studies are performed on HarmZs software in accordance with the Brazilian regulatory requirements.

## III. Connecting tuned harmonic filters in wind farms




where:

$I_h$ - Harmonic current.
L - Inductor.
C - Capacitor.

Fig. 1. Representation of a grid-connected tuned harmonic filter.

$$f_{tuning} = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

Table I. Brazilian (ONS) individual harmonic limits and THD%

| 13,8 kV ≤ U < 69 kV | | | | U ≥ 69 kV | | | |
|---|---|---|---|---|---|---|---|
| h odd | | h even | | h odd | | h even | |
| order | limit | order | limit | order | limit | order | limit |
| 3 to 25 | 1.5% | all | 0.6% | 3 to 25 | 0.6% | all | 0.3% |
| ≥ 27 | 0.7% | | | ≥ 27 | 0.4% | | |
| THD% = 3% | | | | THD% = 1.5% | | | |

## IV. Electric power system implementation

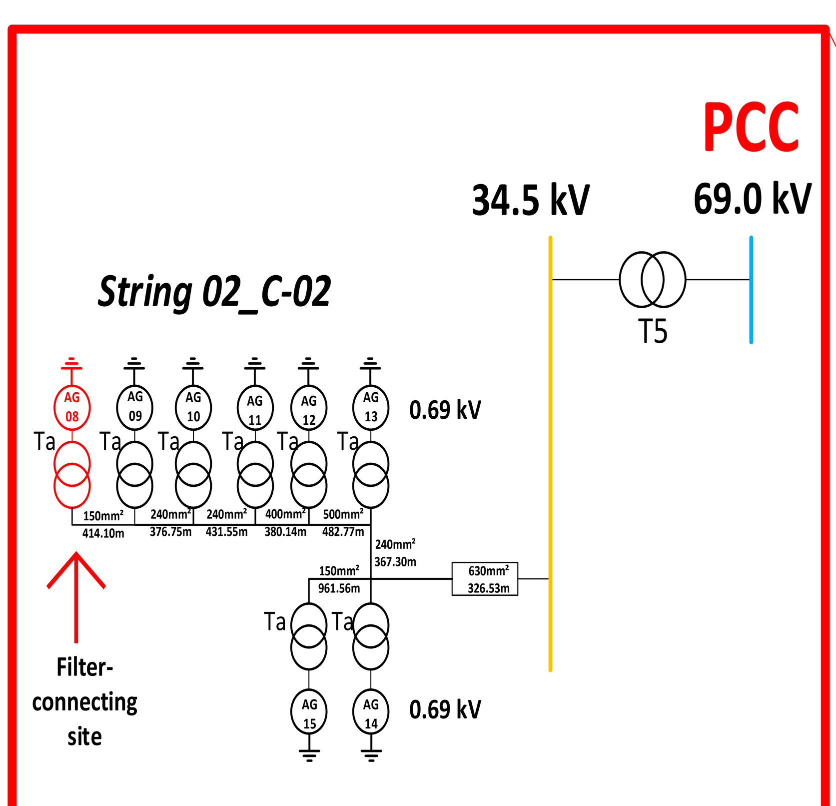



Fig. 3. Filter connecting busbar (String 02_Circuit-02).

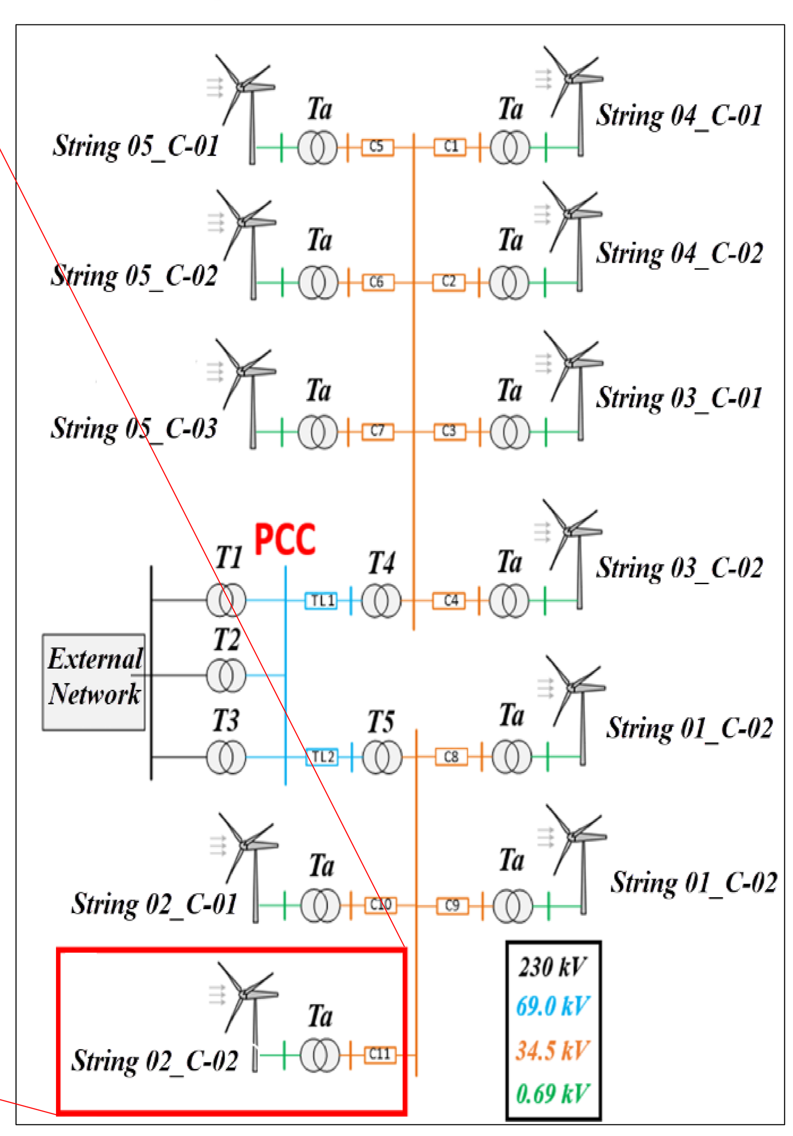



Fig. 2. Wind power plant representation.

## V. Case studies

First, the grid (Fig. 2) was simulated, without any tuned harmonic filters, and a limit violation occurred at the 4th order (240 Hz), which requires a harmonic filtering strategy. Therefore, two case studies are evaluated in the following. The harmonic distortion and impedance spectrum are analyzed at the PCC (69 kV).

### *A. Tuned harmonic Filter - 4th Order*

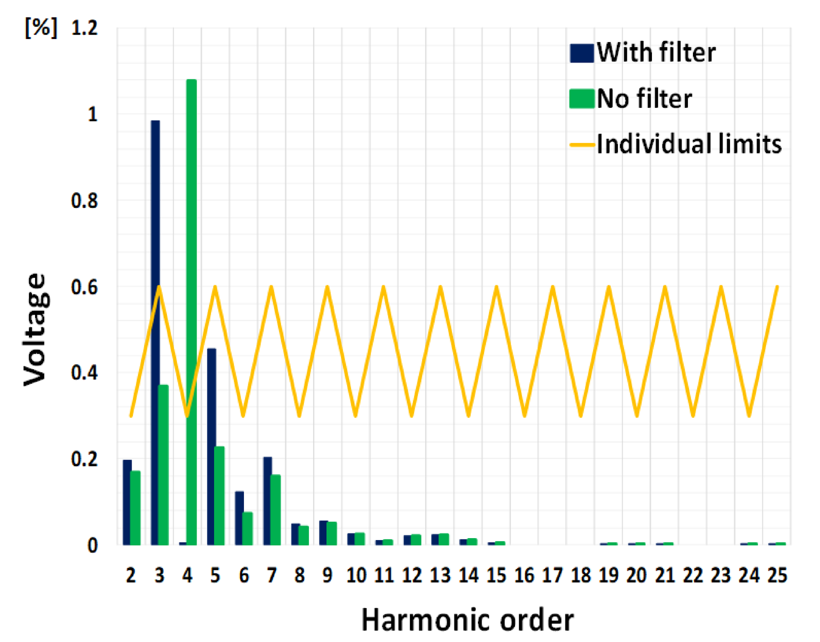



Fig. 4. Voltage harmonic spectrum before and after connecting the 4th order tuned filter.

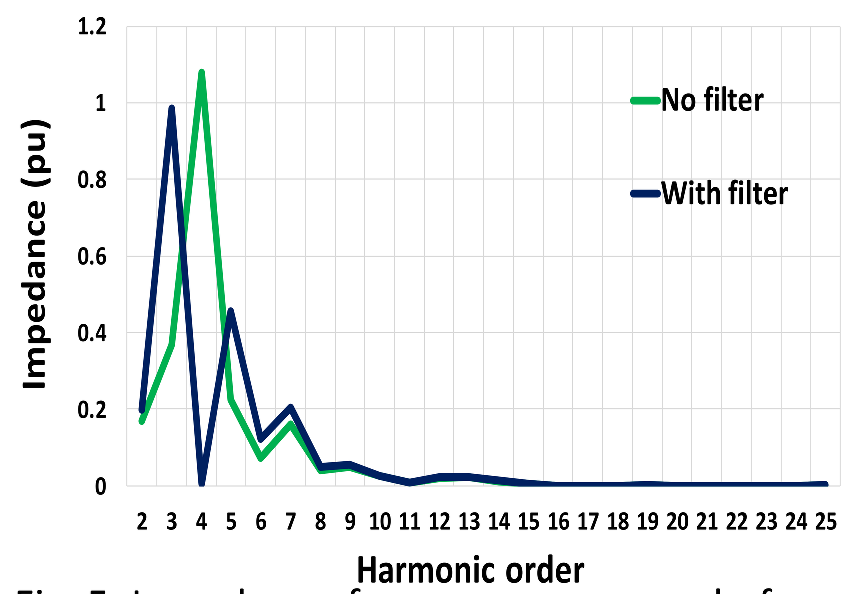



Fig. 5. Impedance-frequency response before and after connecting the 4th order tuned filter.

The simplest and most intuitive filtering solution is based on the implementation of a tuned harmonic filter at the 4th order (240 Hz). Therefore, a passive harmonic filter with $X_L$ = 1.172 pu and $X_C$ = 18.75 pu was connected to the secondary (34.5 kV) of the AG08 wind turbine transformer (Fig. 3). Fig. 4 shows the voltage harmonic spectrum at the PCC before and after connecting the filter. Although high harmonic values at 4th are not common in electrical grids, sometimes it may occur due to a parallel resonance (Fig. 5) that, when composed with the currents from the wind farm, results in the 4th order limit violation. In addition, for determining the harmonic voltage distortions, a number of different operating states of the external network were considered, whose most critical scenario has resulted in the levels herein presented. After connecting the filter, the 4th order limit violation was solved, but a violation on 3rd order occurred. Thus, the solution herein given is not effective in terms of mitigating all harmonic distortion orders accordingly.

### *B. Tuned harmonic filters – Different Tuning Frequencies*

Since the connection of the tuned harmonic filter at the 4th order did not mitigate all harmonic voltages under the limits, filter tuning at various frequencies were evaluated in order to identify the best solution. Table VIII shows that only the filter tuning at the 7th order presented no harmonic limit violation. Although this filter has changed the resonance characteristics of the network (Fig. 7), the 3rd order resonance resulting from the filter connection was not sufficient to violate the established limits (Fig. 6). Therefore, the 7th order harmonic filter was the best solution for this work.

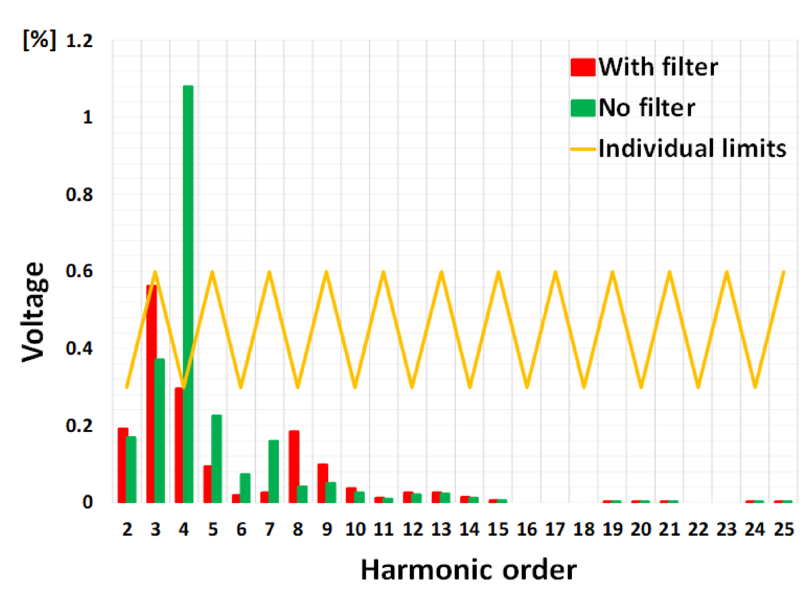



Figure 6. Voltage harmonic spectrum before and after connecting the 7th order tuned filter.

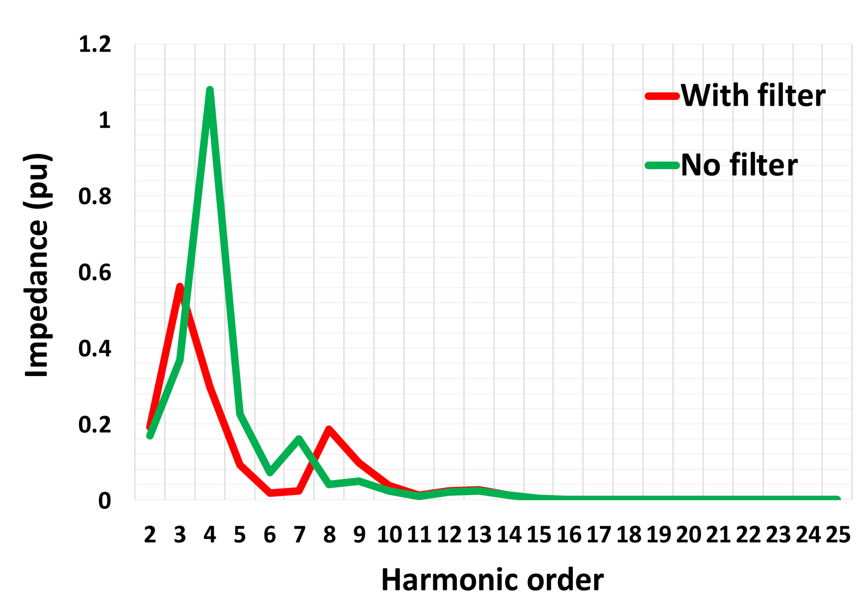



Figure 7. Impedance-frequency response before and after connecting the 7th order tuned filter.

Table VII. Tuned harmonic filter parameters for multiple orders

| Parameters | THF3 | THF5 | THF7 | THF11 | THF13 |
|---|---|---|---|---|---|
| $X_C$ (pu) | 18.75 | 18.75 | 18.75 | 18.75 | 18.75 |
| $X_L$ (pu) | 2.084 | 0.750 | 0.382 | 0.154 | 0.110 |

Table VIII. Individual harmonic distortion for each THF

| Harmonic order | THF 3 (%) | THF 5 (%) | THF 7 (%) | THF 11 (%) | THF13 (%) |
|---|---|---|---|---|---|
| 2 | 0.209 | 0.193 | 0.191 | 0.189 | 0.189 |
| 3 | 0.009 | 0.651 | 0.560 | 0.528 | 0.523 |
| 4 | 0.230 | 0.131 | 0.296 | 0.672 | 0.769 |
| 5 | 1.234 | 0.010 | 0.093 | 0.123 | 0.128 |
| 6 | 0.091 | 0.157 | 0.019 | 0.037 | 0.039 |
| 7 | 0.178 | 0.281 | 0.024 | 0.084 | 0.091 |
| 8 | 0.044 | 0.056 | 0.185 | 0.019 | 0.022 |
| 9 | 0.051 | 0.059 | 0.097 | 0.018 | 0.025 |
| 10 | 0.025 | 0.028 | 0.037 | 0.004 | 0.010 |
| 11 | 0.009 | 0.009 | 0.011 | 0.007 | 0.003 |
| 12 | 0.020 | 0.021 | 0.024 | 0.055 | 0.006 |
| 13 | 0.023 | 0.023 | 0.025 | 0.044 | 0.037 |
| 14 | 0.023 | 0.024 | 0.026 | 0.044 | 0.037 |
| 15 | 0.013 | 0.013 | 0.014 | 0.019 | 0.037 |
| 16 | 0.004 | 0.004 | 0.004 | 0.005 | 0.007 |
| 17 to 25 | ≤ 0.001 | | | | |

## VI. Conclusion

The objective of this paper was to evaluate the impacts of connecting passive tuned harmonic filters on the grid-resonance characteristics and the overall harmonic distortions from a wind farm. In this context, from measurements from a Brazilian wind power plant, computational studies were performed in accordance with national regulations. In this sense, two case studies were evaluated in order to mitigate the 4th order harmonic distortions arising from the wind farm. The first study was based on the insertion of a tuned harmonic filter on the violated order. The second option was based on testing different tuned filters in order to identify the best solution to address this matter. The results have shown that the 4th order filter caused a resonance in the 3rd order, implying the limit violation at this order. Besides, after evaluating the insertion of different tuned harmonic filters one finds that the 7th order filter was able to solve the problem focused upon herein.

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