

IT4PQ 2nd Stakeholder Workshop



Investigation of the effect of subharmonics
on the harmonics measured through an inductive VT

Mario Luiso

IT4PQ 2nd Stakeholder Workshop
9th February 2022



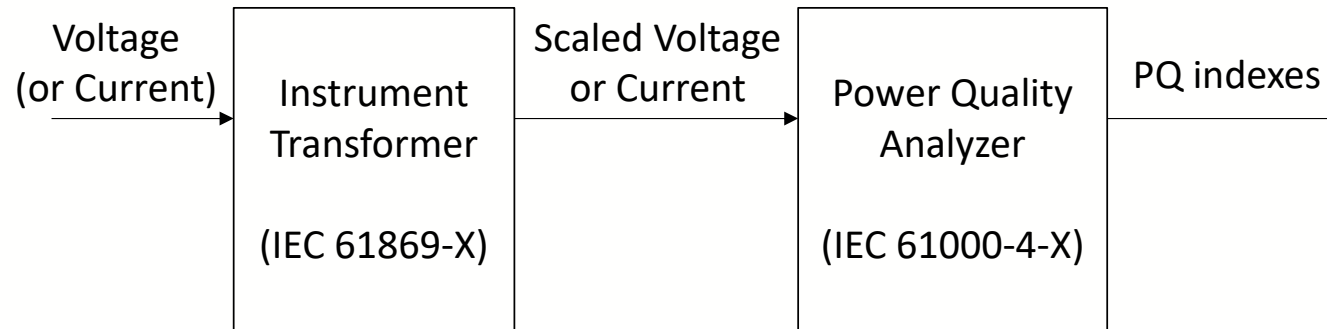
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Introduction

- This work is part of WP1 and it is a collaboration between University of Campania «Luigi Vanvitelli» and INRIM
- Two of the objectives of WP1 are:
 - Selection of PQ phenomena (and related range of variations) under which characterize the ITs
 - Selection of the algorithms with which evaluate the performance of an IT when used for PQ measurements
- This work is focused on subharmonics

PQ measuring chain for MV grids



- A PQ analyzer will perform PQ measurements according to IEC 61000-4-X
- In particular, harmonics measurement is performed according to IEC 61000-4-7
- Spectral analysis is performed over a time frame of 200 ms (for 50 Hz systems), so having a spectral resolution of 5 Hz

Harmonics and subharmonics inductive VTs

- Harmonics are one of the most diffused PQ phenomena, so it is quite natural that they must be included in the characterization of an IT intended to be used for PQ measurements
- Subharmonics are spectral components having frequencies lower than the power frequency, that is 50 Hz for European countries
- According to 61000-4-7, PQ analyzers have not the right spectral resolution (5 Hz) to measure all the possible subharmonics (f.i. 1 Hz)
- Should we include the subharmonics in the IT characterization?

Inductive Voltage Transformers

- Inductive MV VTs are often used for PQ measurements, very often for harmonics measurements
- Recent literature shows that they can introduce errors up to some percent, due to their intrinsic non-linearity when they measure harmonics
- What happens if, other than harmonics, there are also subharmonics at their input?

Scope and implementation

- We tested two commercial MV VTs
- They were used to measure harmonics, with and without the presence of subharmonics
- Harmonics are measured over time frames of 200 ms, according to IEC 61000-4-7
- The scope is to reproduce what would happen in a realistic situation, where harmonics would be measured by a PQ analyzer
- The impact of the presence of the subharmonics on the measurement of harmonics at the output of the inductive VTs is evaluated

Subharmonics: typical amplitudes and frequencies

- Very wide Literature survey
- Considered Standards: IEEE 519, IEEE 1159, IEC 61000-2-4,-2-12,-3-6

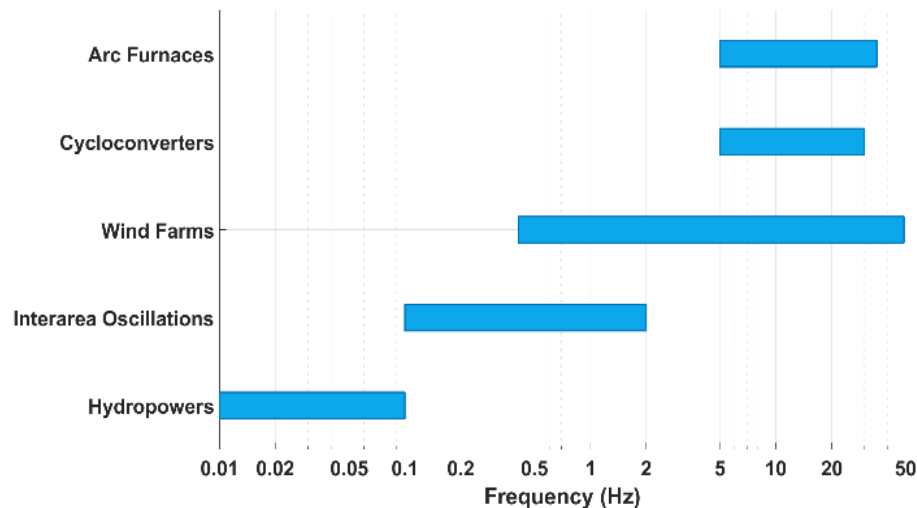
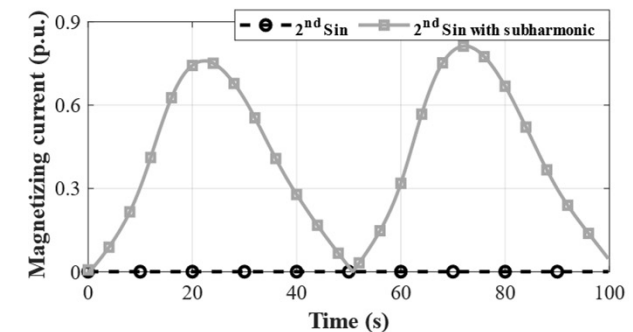
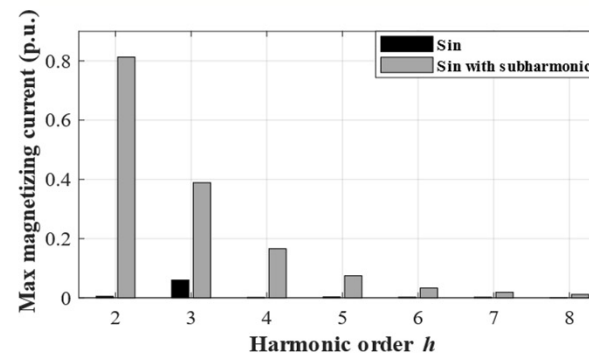
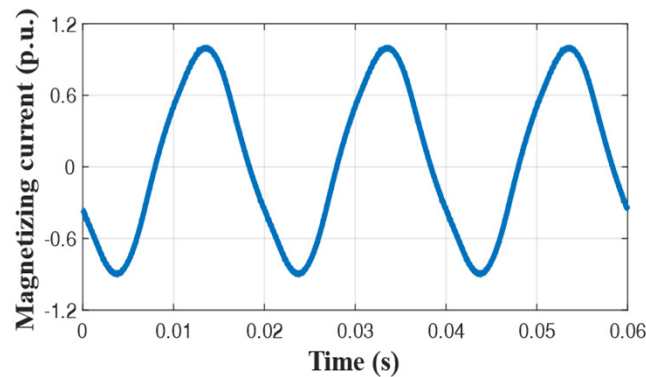


TABLE I: SUBHARMONIC TEST PARAMETERS

Test group	Frequency (Hz)	Amplitude (% of fund)
I	0.01 – 0.02 – 0.05	0.1
II	0.1 – 0.2 – 0.5	0.1 – 0.3
III	1 – 2 – 5 – 10 – 20	0.1 – 1 – 3

Background considerations on VTs non-linearity

- Even with a sinusoidal primary voltage, the magnetizing current is distorted
- The presence of a subharmonic increases the flux and so the magnetizing current is more distorted
- The harmonic components of the magnetizing current oscillate



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What happens in the secondary voltage?

- The distortion of the magnetizing current reflects in a distortion of the secondary voltage
- Even when the primary voltage is a sine wave, the secondary voltage contains spurious harmonics coming from the magnetizing current
- So, let us imagine that a VT is supplied a waveform composed by the fundamental tone, harmonic components and subharmonic tones
- The harmonic components of the secondary voltage are the result of the vector sum of:
 1. the actual harmonics superimposed on the primary voltage (modified by the systematic VT ratio and phase errors at the specific harmonic frequency)
 2. the spurious harmonic components due to both the fundamental and the low frequency components.

Test description

A. Cataliotti *et al.*, "Compensation of Nonlinearity of Voltage and Current Instrument Transformers," in *IEEE Transactions on Instrumentation and Measurement*, vol. 68, no. 5, pp. 1322-1332, May 2019.

- Sinusoidal tests and SINDICOMP
 - Sine waves from 80% to 120% of rated voltage
 - Measure the primary and secondary spectrum
 - Use the secondary spurious harmonic phasors to compensate the reconstruction of the primary phasors
 - $\bar{V}_{p,h}^d = \bar{V}_{s,h}^d - \bar{V}_{s,h}^{\sin}$
- Reference test: FH1 (Fundamental + 1 sweeping harmonic tone)
 - Fundamental at rated voltage and frequency
 - Harmonics at 1 %, order from 2 to 10, zero phase
 - $\varepsilon_h = \frac{k_r V_{s,h} - V_{p,h}}{V_{p,h}}, \varphi_h = \varphi_{s,h} - \varphi_{p,h}$

Test description

- Subharmonic tests: FHS (Fundamental + 1 harmonic +1 subharmonic)
 - The same FH1 tests but with all the combinations of the subharmonics in the table

TABLE I: SUBHARMONIC TEST PARAMETERS

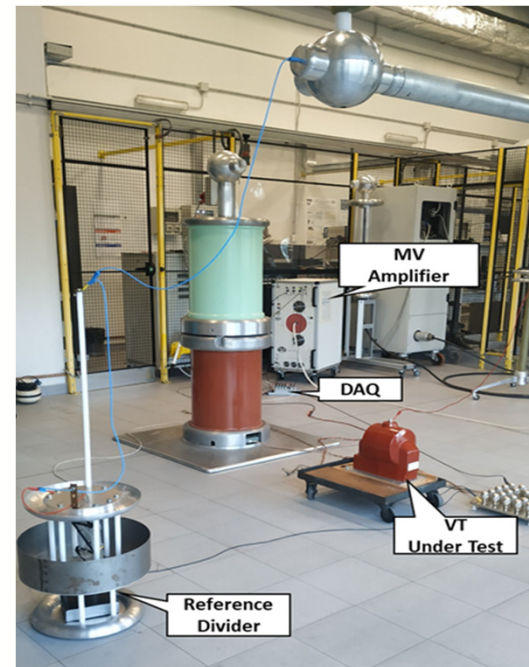
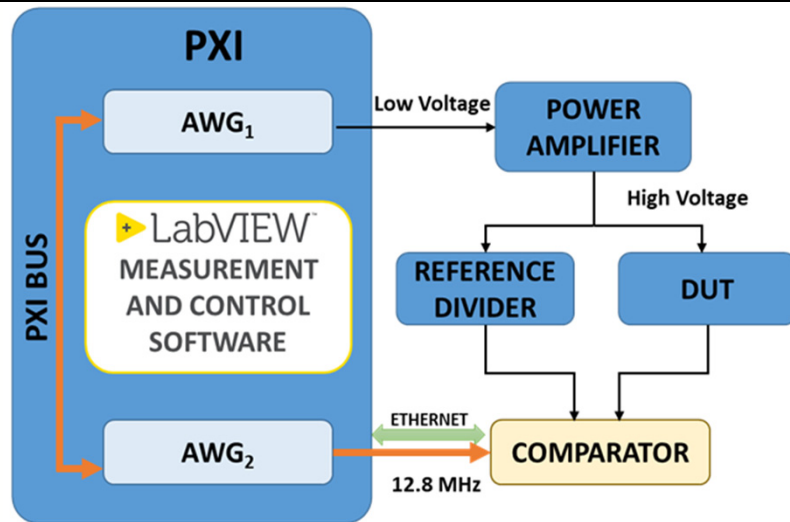
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- Quantify the subharmonic impact: $\xi_h = \max_{\cup w_n} |\varepsilon_h - \overline{\varepsilon}_h|$, $\psi_h = \max_{\cup w_n} |\varphi_h - \overline{\varphi}_h|$
- w_n equals 10 cycles of fundamental frequency
- ξ_h (ψ_h) evaluates the maximum absolute increment of the harmonic ratio (phase) error caused by the presence of the subharmonic.

Measurement setup

TABLE II. RATED CHARACTERISTICS OF THE ANALYZED VTs

	Rated primary voltage (kV)	Rated secondary voltage (V)	Rated burden (VA)	Accuracy class
VTA	$20/\sqrt{3}$	$100/\sqrt{3}$	30	0.5
VTB	$11/\sqrt{3}$	$110/\sqrt{3}$	50	0.5



Ratio error with and without subharmonic

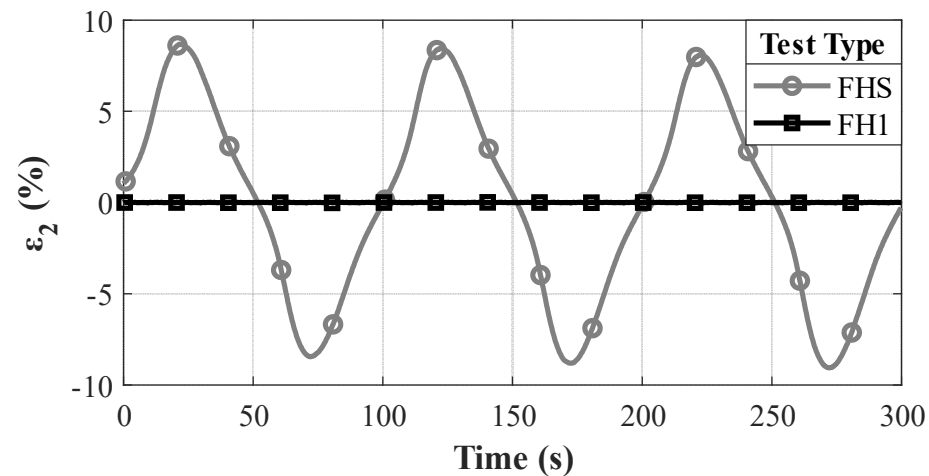
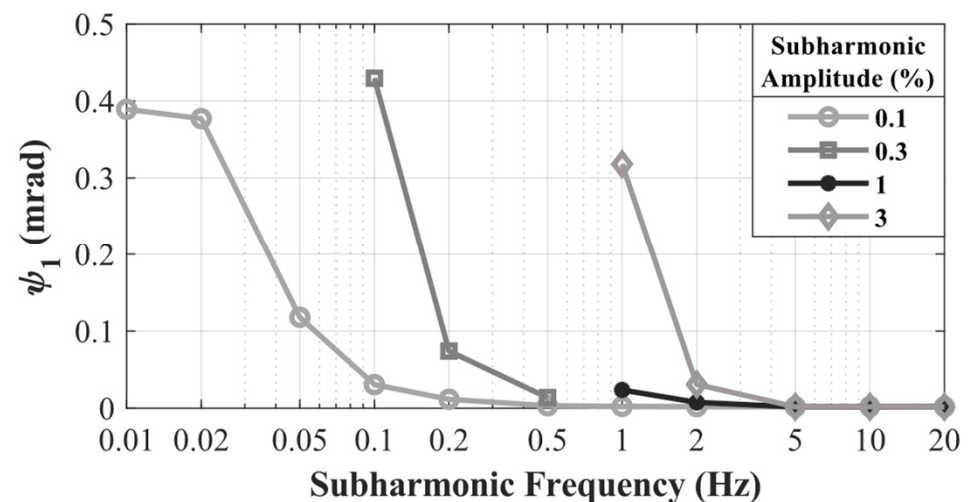
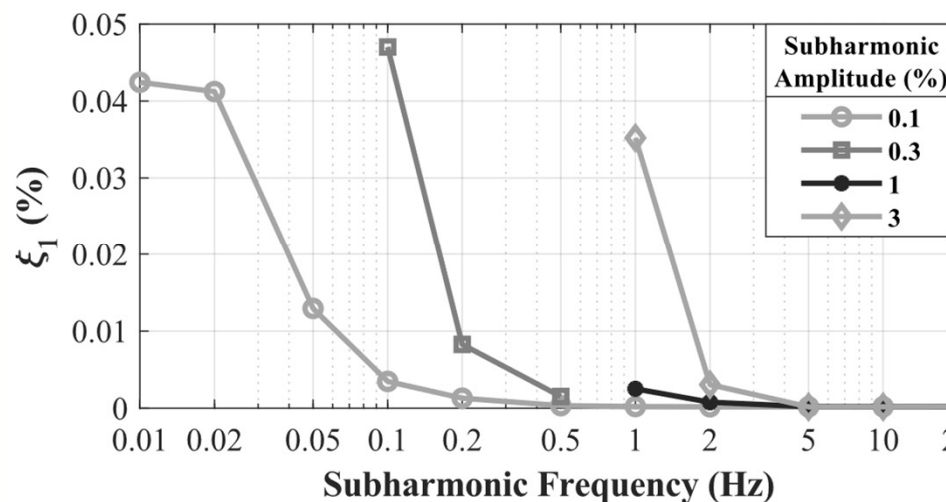


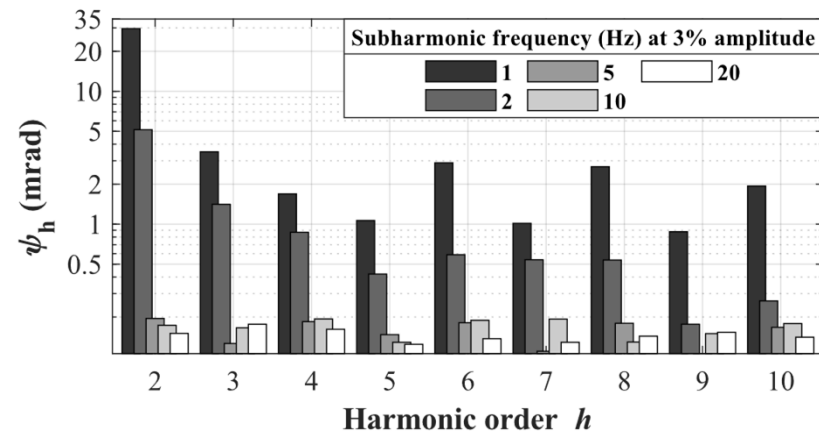
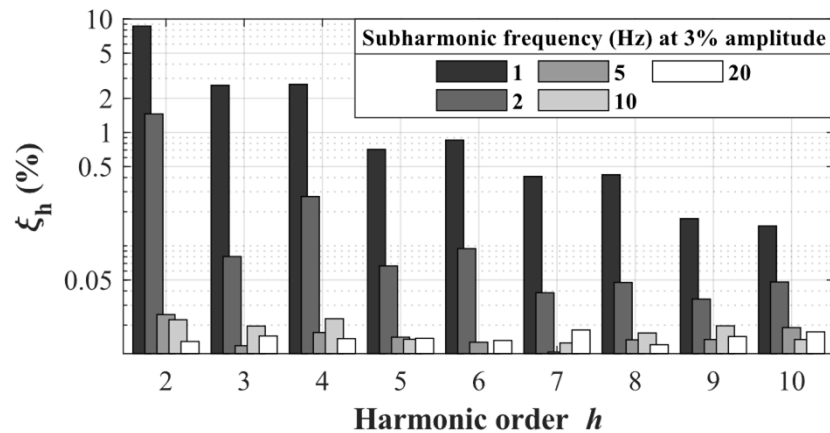
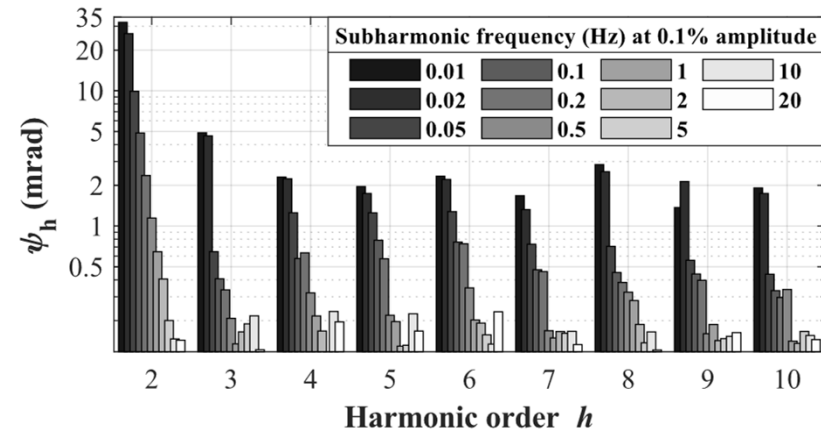
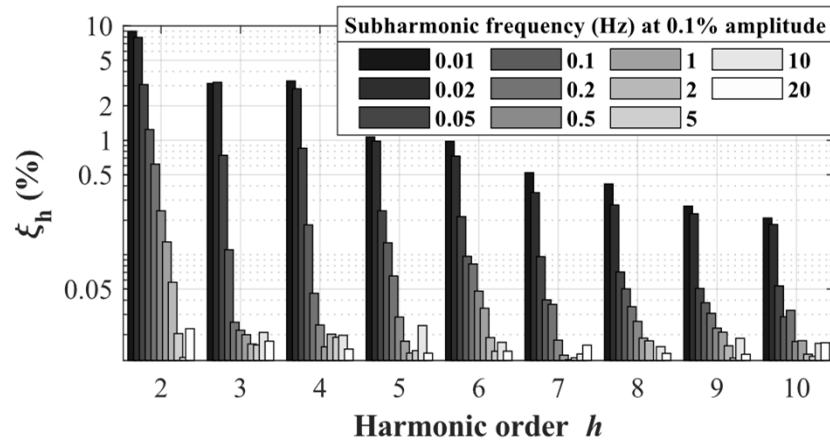
Fig. 6. Ratio errors of VT_A at second harmonic with (circle markers) and without (square marker) subharmonic component at 0.01 Hz and 0.1 %.

Impact of subharmonics on fundamental tone

- The worsening of ratio error ($<0.05\%$) and phase errors (<0.4 mrad) are a small fraction of the VT accuracy class (0.5, 0.5 % and 9 mrad)



Impact of subharmonics on harmonics



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Impact of operating conditions

Fundamental Amplitude

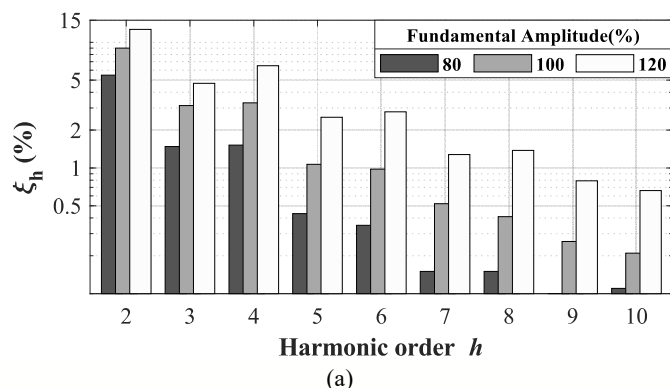


Fig. 17. Maximum absolute increments of VT_A ratio errors at harmonic order h , with various values of fundamental amplitude, in presence of a 0.1 %, 0.01 Hz subharmonic component.

Harmonic Amplitude

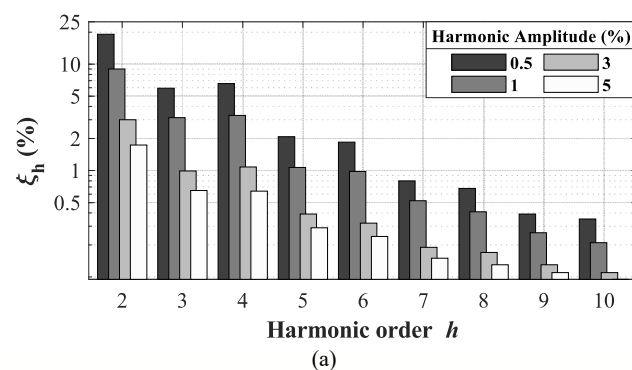


Fig. 18. Maximum absolute increments of VT_A ratio errors at harmonic order h , with various values of harmonic amplitude, in presence of a 0.1 %, 0.01 Hz subharmonic component.

Burden

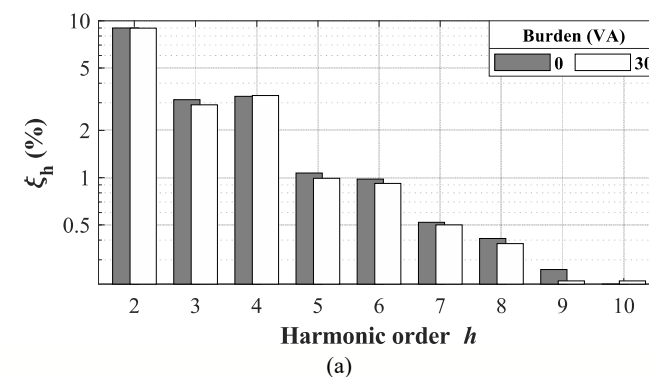


Fig. 19. Maximum absolute increments of VT_A ratio errors at harmonic order h , with null and rated burden (30 VA), in presence of a 0.1 %, 0.01 Hz subharmonic component.



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Conclusions

- The fundamental tone measurement is practically not affected by the presence of subharmonics
- In presence of subharmonic, harmonic ratio and phase errors increase when the subharmonic amplitude increase and when the subharmonic frequency decreases.
- The harmonic measurements are highly affected by the presence of a subharmonic, especially the second and the third harmonics, where ratio and phase errors can increase up to values as high as 20 % and 30 mrad.
- The harmonic maximum absolute increments are comparable with the measurement uncertainty when the subharmonic has:
 - 1) frequency higher than 5 Hz and amplitude up to 3 % or
 - 2) amplitude up to 1 % and frequency higher than 1 Hz.

Conclusions

- The 0.5 accuracy class limits are exceeded with subharmonics characterized by:
 - 0.1 % amplitude and frequency from 0.01 Hz to 0.2 Hz (ULFOs and LFOs cases);
 - 0.3 % amplitude and frequency up to 0.5 Hz;
 - 1 % amplitude and frequency up to 1 Hz;
 - 3 % amplitude and frequency up to 2 Hz;
- The harmonic absolute maximum error significantly increases as the fundamental amplitude increases and decreases when the amplitude of the harmonics increases
- In presence of a subharmonic, the burden condition does not significantly alter the performance.

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THANKS FOR YOUR ATTENTION!

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