New Method for Noninvasive Measurement of Utility Harmonic Impedance

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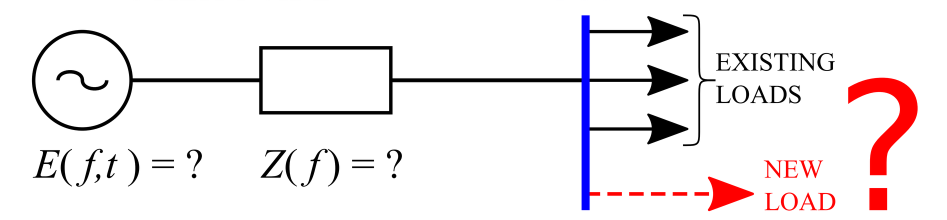
Introduction

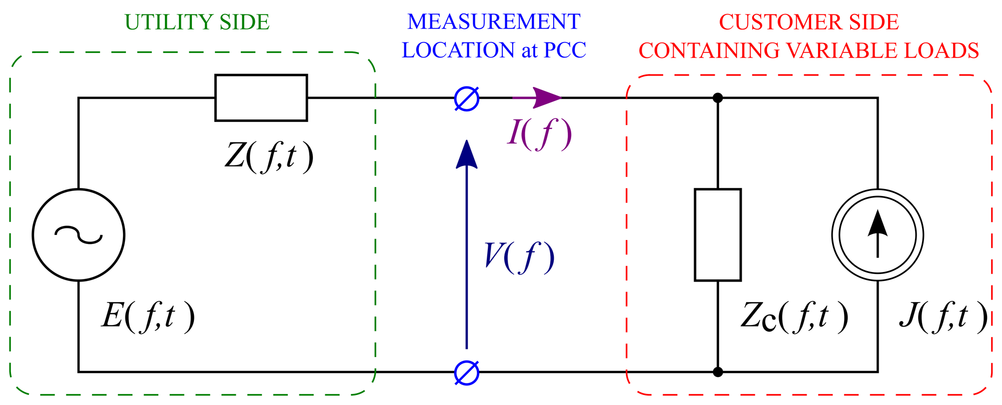
Lets consider a problem of connecting new load to the grid:



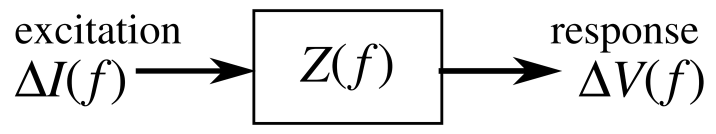
Can we safely connect specific load to the grid? To answer the question we have to measure utility harmonic impedance $Z(f)$ at PCC.

Utility harmonic impedance is just complex frequency response of the power system, modeled as Thevenin or Norton circuit, to the change of load current:

$$Z(f) = \frac{V_2(f) - V_1(f)}{I_1(f) - I_2(f)} = \frac{\Delta V(f)}{\Delta I(f)} \qquad (1)$$



To estimate $Z(f)$ at PCC, the grid must be excited by the load change resulting in changes of voltage and current spectra $\Delta V(f)$, $\Delta I(f)$. Harmonic impedance $Z(f)$ can be estimated using numerous methods suited for LTI system identification [1].



Excitation and response signals can be acquired either in invasive or noninvasive experiment.

Noninvasive measurement is cheaper, can be performed at any time and it does not disturb the loads. However it has significant drawbacks resulting from weak natural excitation [2]. Thus it requires synchronously sampled (or resampled [3]) long signals records, followed by some kind of averaging.

Preferred method in this case is spectral method with input and output spectral densities G_{xx}, G_{xy} estimated with Welch's method of averaged periodogram:

$$\hat{Z}(k) = \frac{\hat{G}_{xy}(k)}{\hat{G}_{xx}(k)} = -\frac{\sum_r \Delta I_r^*(k)\Delta V_r(k)}{\sum_r |\Delta I_r(k)|^2}, \qquad (2)$$

where r is realization index and k is frequency index.

Our approach

Noninvasive experiment

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Excitation in the form of natural load variations, which is usually weak and rare.

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Low SNR of realizations $\Delta V_r(k)$, $\Delta I_r(k)$ of voltage and current spectra changes.

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Need for averaging of realizations $\Delta V_r(k)$, $\Delta I_r(k)$ in order to improve SNR.

⇓

Harmonic impedance estimation using spectral method with spectral densities calculated using Welch's method (2).

⇓

Averaging of all data is wrong!

- some realizations contain no information due to insufficient changes of current and voltage [4]
- others may present a change originating from utility side, giving information about load side
- yet others may be result of changes occuring on both sides simultaneously, giving no information

⇓

Need for selective averaging only realizations including high changes originating from load side.

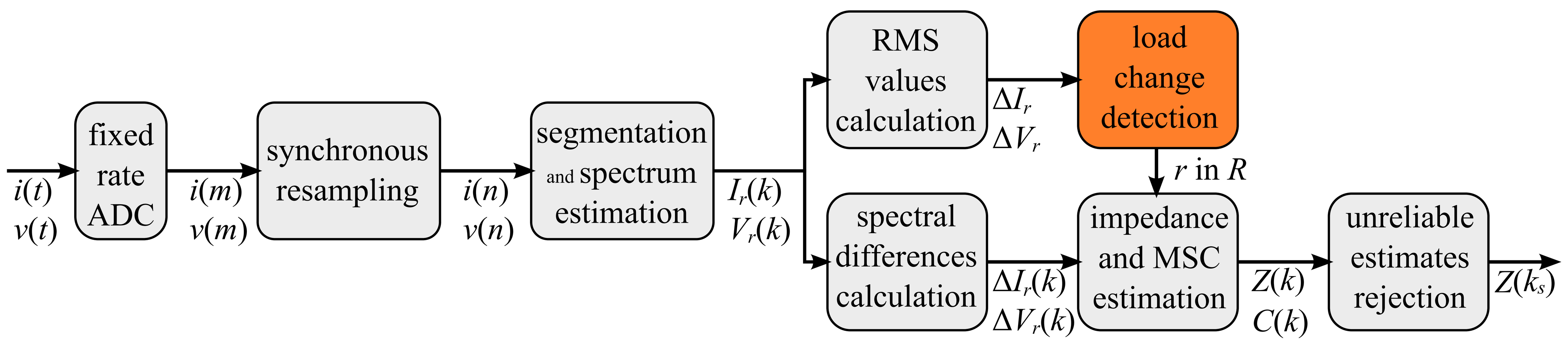
⇓

How we did it?

Assumption: load is mainly constant impedance type (true for e.g. uncontrolled traction rectifiers).
Thesis: change in load side results in opposite signs of changes in RMS voltage and RMS current.
Solution: selective averaging with load change detection (LCD), i.e. using realizations such that

- RMS current change is sufficient ($\Delta I_r > I_{th}$)
- RMS voltage change is sufficient ($\Delta V_r > V_{th}$)
- RMS changes of opposite signs ($\Delta I_r \cdot \Delta V_r < 0$)

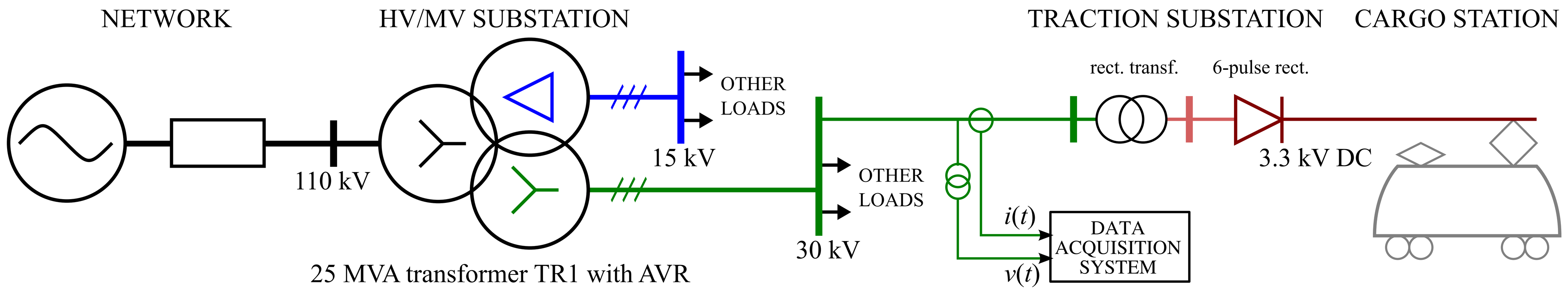
Figure 1: The algorithm of harmonic impedance estimation by selective averaging with load change detection (LCD).



Field test

A field test (Fig.2) at HV/MV substation was conducted. The utility harmonic impedance, including 25 MVA transformer impedance, was estimated using 2–hour records (36000 realizations of voltage and current spectra), including sudden changes in RMS voltage caused by tap-changing automatic voltage regulation (AVR) (see Fig.3).

Figure 2: Schematic of field test configuration.



Results

Proposed measurement method (LCD — selective averaging with load change detection) was compared with the classic one (ALL — averaging of all spectra realizations using Welch's method). Obtained harmonic impedance and magnitude squared coherence estimates are shown in Figs. 4 and 5.

Figure 3: LCD in action. 1) RMS current, 2) RMS voltage, 3) product $\Delta V_r \cdot \Delta I_r$, 4) resulting realizations sets.

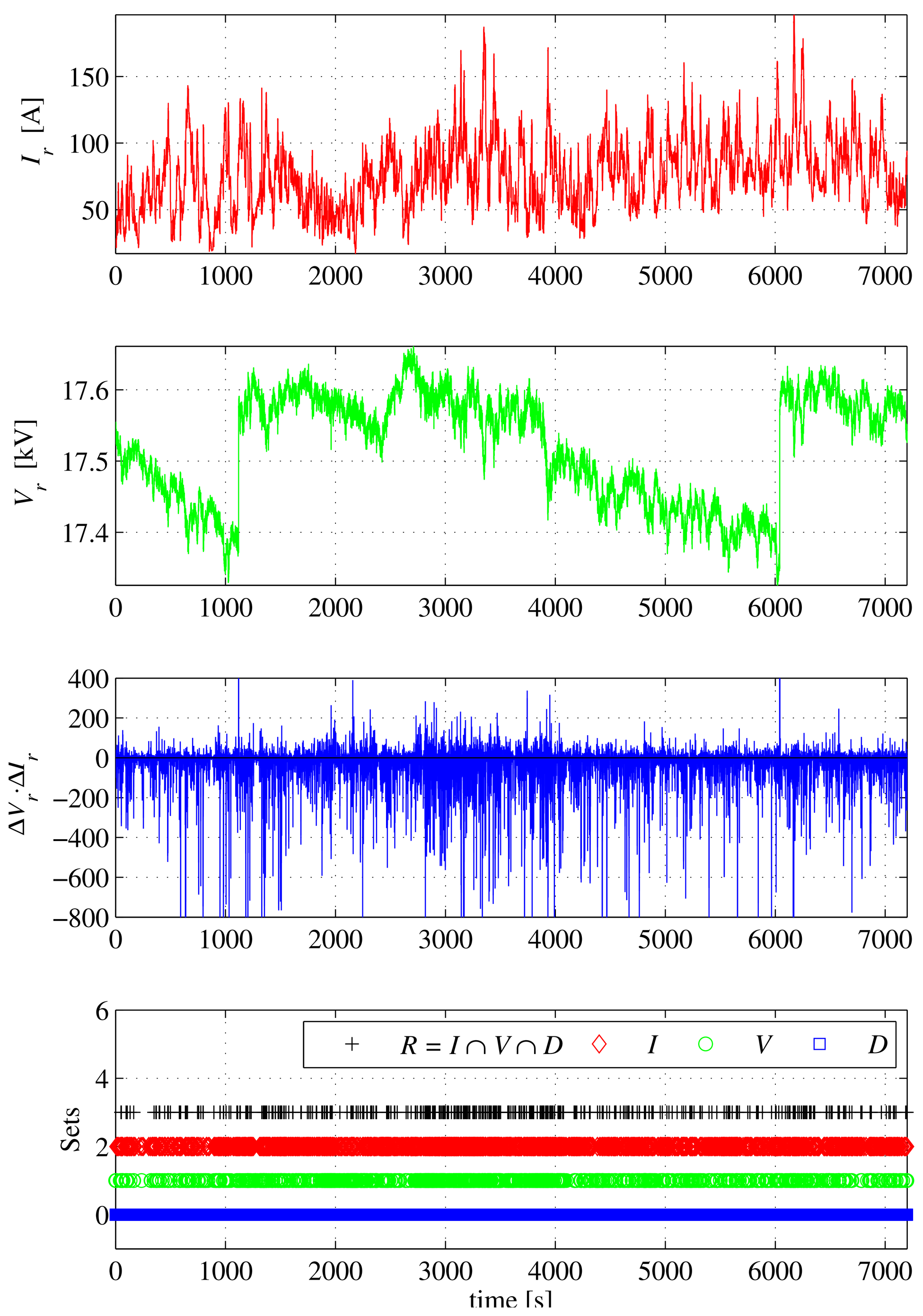


Figure 4: Estimated harmonic impedance.

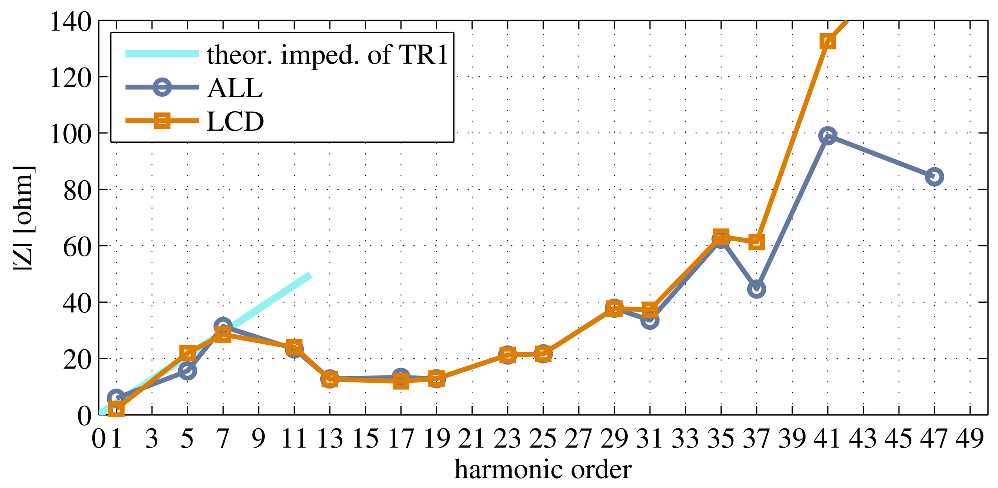
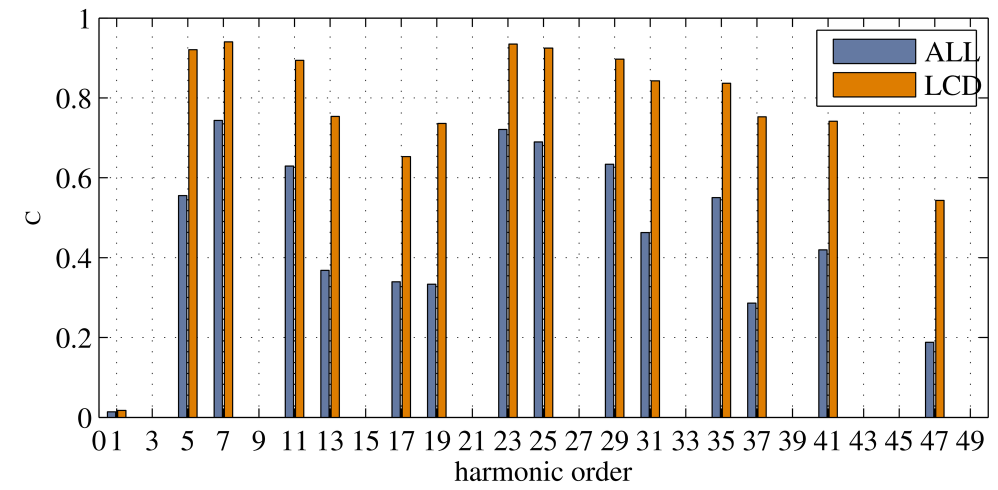


Figure 5: Magnitude squared coherence estimates.



Obtained results were compared by calculating the credibility index

$$J = \tfrac{1}{14}\left(\hat{C}(1) + \textstyle\sum_{p=1}^{6} \hat{C}(6 \pm 1) + \hat{C}(41)\right)$$

where $\hat{C}(h)$ is estimated magnitude squared coherence for h-th harmonic (Fig. 5).

Table 1: Comparison results

method	realizations number	credibility index
ALL	35990	0.459
LCD	681	**0.766**

Conclusions

- Field test results proved that proposed method gives credible results even under condition of relatively weak, rare excitation and significant utility background voltage changes caused by automatic voltage regulation.
- Proposed load change detection (LCD) scheme finds valid data within all realizations.
- Significant increase in magnitude squared coherence values for load charateristic harmonics is visible. The index J increased 1.66 times even though the number of realization selected to averaging decreased 53 times (see Tab.1).
- Selective spectra averaging with LCD can reduce the unceratinty of harmonic impedance estimation in case of „constant impedance" type loads.

Additional info

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