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BEHAVIOUR OF DIFFERENT PMU ALGORITHMS UNDER STATIC AND DYNAMIC CONDITIONS

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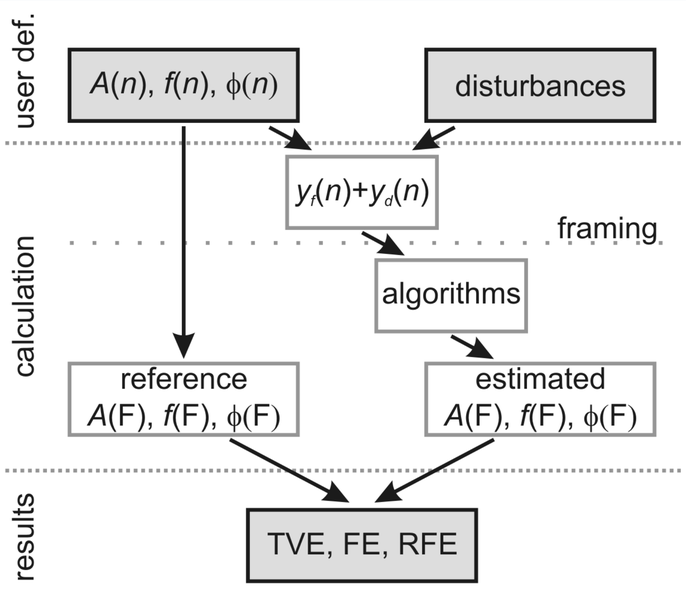
Motivation

Phasor measurements units (PMUs) nowadays become an important component of the smart grids as they provide grid state in real-time. The PMUs should accurately measure the fundamental signal, although disturbances are readily present, therefore several estimation algorithms have been already developed. In our study we analyzed six of them and assess their behavior under undisturbed static condition, harmonically disturbed static condition and dynamic conditions. Additionally we determined average computing times and minimum number of required samples for each algorithm.

Software platform



Frequency error (FE)
$$FE = f_r - f_e$$

Total vector error (TVE)
$$TVE = \sqrt{\frac{(X_{r,e} - X_{r,r})^2 + (X_{i,e} - X_{i,r})^2}{X_{r,r}^2 + X_{i,r}^2}}$$

Rate Of Change Of Frequency (ROCOF)
$$ROCOF = df(t)/dt$$

ROCOF frequency error (RFE)
$$RFE = ROCOF_r - ROCOF_e$$

Fig. 1 simulation flow chart used for PMU algorithms testing

Default settings:

- amplitude A = 1 a.u., frequency f = 50 Hz, phase φ = 0 rad
- sampling frequency f_s = 1 kHz, reporting rate F_S = 10 Hz

Examined algorithms:

- four Parameter Sine Fit (**4PSF**)
- 3-points interpolated DFT with Hann window (**iDFT**)
- Spectrum Leakage Correction Algorithm (**SLCA**)
- interpolated Phase Sensitive Frequency Estimation (**PSFEi**, **PSFE**)
- Multi Harmonic Frequency Estimation (**MHFE**)

Static condition test

algorithm	min. numb. samples*a,b	min. numb. of samples – 1	simulation time (µs)*a,c
4PSF	7	A and f are complex	188
iDFT	50	f deviate	106
SLCA	14	no solution	468
MHFE	13	A deviate	276
PSFEi	31	no solution	711
PSFE	5	A and f deviate	298

[a] tested signal: f = 50 Hz, A = 1 a.u., φ = 0 rad, f_s = 1 kHz (20 samples per sinewave period)
[b] f or A deviate more than 1‰ from the nominal value or no result was calculated
[c] 5 observation periods (100 ms), average of 10,000 calculations

Harmonic distortion test

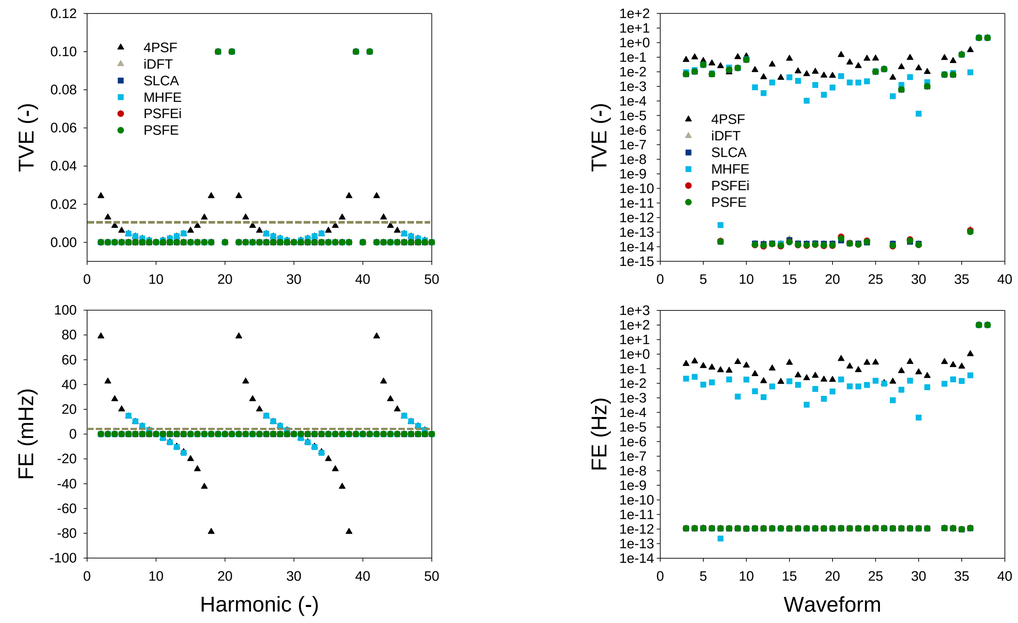


Fig. 2 single harmonic (A_h = 0.1 a.u.) and realistic harmonic distortion test (NPL online library)

Dynamic condition test

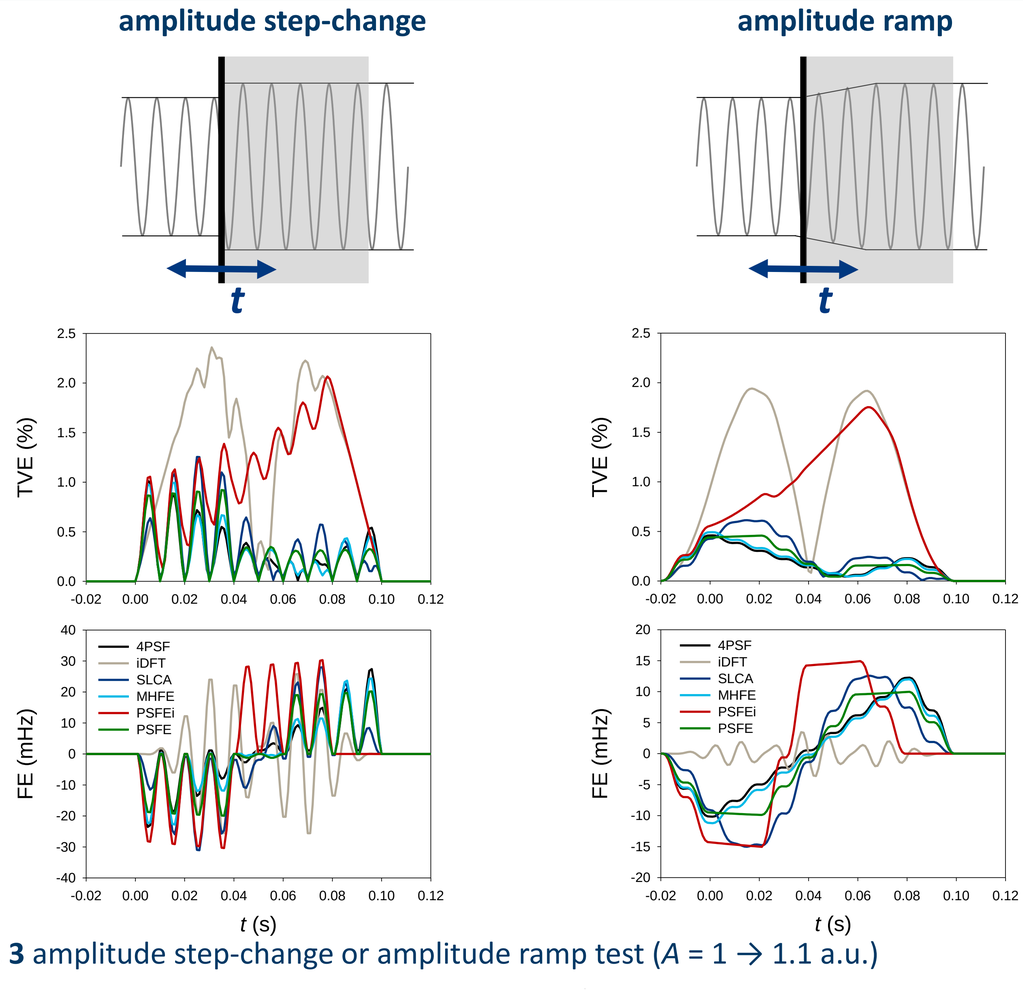


Fig. 3 amplitude step-change or amplitude ramp test (A = 1 → 1.1 a.u.)

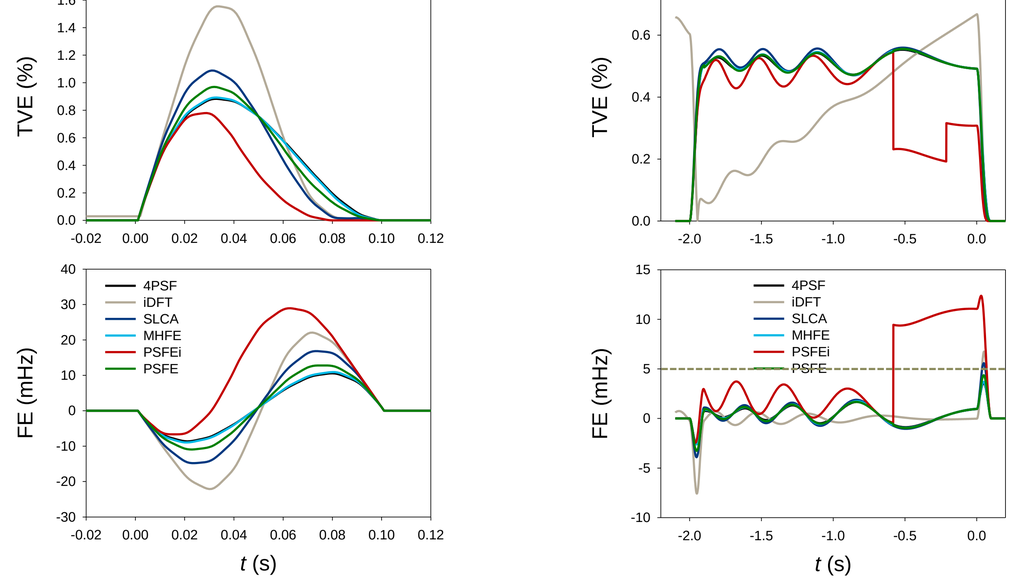


Fig. 4 frequency step-change (50 → 50.1 Hz) or frequency ramp test (50 → 52 Hz)

Conclusions

algorithm	static condition test	# samples / speed	harmonics	A step/ramp	f step/ramp
4PSF	√	√ / √	►	√	√
iDFT	►	► / √	√	►	√
SLCA	√	○ / ►	√	√	√
MHFE	√	○ / ○	►	√	√
PSFEi	√	► / ►	√	►	►
PSFE	√	√ / ○	√	√	√

The √ denotes agreement with the specification or good performance, the ► denotes that the limits are exceeded or bad performance of the algorithm. The ○ denotes average performance compared to the others.

Less samples per frame increase the resolution of the PMU but the algorithms should still obtain at least a certain minimum number of samples/signal periods to calculate the estimate reliably. The optimal samples per frame is always a compromise between required computing cycles, reliability and accuracy of the algorithms and the PMU's resolution.