Combined monitoring and time-frequency analysis for transients in wind energy systems

Taduesz Łobos, Tomasz Sikorski
Wroclaw University of Technology
50-370 Wrocław, Wybrzeże Wyspianskiego 27, e-mail: tadeusz.lobos@pwr.wroc.pl, tomasz.sikorski@pwr.wroc.pl.

Hortensia Amarís, Monica Alonso, Diana Florez
Carlos III University of Madrid
e-mail: hamaris@ing.uc3m.es, moalonso@ing.uc3m.es, dflorez@ing.uc3m.es.

The aim of this paper is the application of selected time-varying power quality indices combined with detailed time-frequency analysis for assessment of transients in wind energy system. Presented proposition utilizes short-term harmonic distortion in voltage (STHDV) characteristic as an indicator for detail local time-frequency analysis of the transients. Introduced ideas can be treated as hybrid system absorbing both power quality indices and time-frequency representation.

1. Introduction

Interaction between power system elements exhibits itself in many different phenomena which requires different methods for assessment. In case of fault the most important is time response. Power quality monitoring introduce averaged parameters and statistical classification. Problem of harmonics is open area for different spectrum estimation methods. One of the phenomena which may consider a composition of different assessment method is the transient state in companion with harmonics. The idea presented in this paper proposes mixing the algorithms. Fast algorithm is dedicated to detection of the event and serves as a trigger for the time-consuming methods which can be performed for further precise investigation. As an example we present results of application of time-frequency analysis triggered by short-time harmonic distortion of voltage (STHDV) index in case of investigation of power quality disturbances caused by sequential compensation with capacitor banks in small wind power plant (SWP) using traditional induction generator.

In points of energy production SWP use usually asynchronous generators, squirrel cage or wound rotor, working in a fixed speed regimen. For greater power the synchronous or double-fed asynchronous machines are dedicated. Asynchronous unit is characterized by reactive power consumption in process of active power generation. Thus in point of control system it requires soft-starter, shut-off automation control in case of supply decay from network side as well as fitting the electrical equipment by reactive power compensation, usually realized by regulated set of capacitor banks. Voltage generation level is usually low voltage. Integration of SWP using asynchronous generators with power system is realized by direct connection at low-voltage level or, much more often, via MV/LV transformer from low to medium voltage 0.

Small wind turbines became a part of wide family of distributed generation (DG). General discussion around integration of dispersed energy sources with power system has been developed for last decades including affection of power quality. It seems to be still opened issue especially in companion with increasing number of DG installations and introduced new technologies. Last works of Ackerman 0,0, Dugan et al 0,0,0,0, Baggini 0 or Bollen 0,0 underline crucial need of investigations and determine few selected issues concentrated on sustained interruptions, voltage regulation, harmonics, voltage events, operating conflicts as utility fault-clearing requirements, reclosing, interference with relaying, and finally islanding.

Additional motivation for this work is also permanent development in definition of new power quality indices dedicated to transient disturbances. First suggestion was introduced by Heydt et al. in 0,0 depicting application of windowed FFT algorithm (short-time Fourier transform) for definition of short-term harmonic distortion index (STHD). Further works reintroduced time-frequency analysis and provided unified or novel definitions of transient version of power quality indices. In works 0, 0 we can find unified definition of normalized instantaneous distortion energy ratio (NIDE) - which is a transient version of distortion index DIN, or instantaneous K-factor (IK). Works 0, 0, 0 represent wide overview of different signal processing methods dedicated to assessment of power quality disturbances. Application of parametric spectrum estimation methods and wavelet transform for disturbance detection in fixed speed wind farms was presented in 0. Selected non-parametric and parametric time-frequency representations were discussed in work 0, 0 with special consideration of to distributed generation in 0, 0.

It is worth emphasizing that represented in the paper aspects of composition of different assessment method follows by newest concepts in power systems related to remote measurement, smart grids and virtual power plant. All mentioned efforts are grouped around common trend associated with energy safety and smart grids. Following by this direction we can observe increasing requirements for range of information dedicated to remote measurement which goes beyond standard electricity meter.

Developed systems are intended to realize aggregation of complex data including power flows, state of substation connector and breakers, as well as monitoring of power quality indices of the particular customer and crucial network nodes. The newest concept dedicated directly to distributed generation is so called virtual power plant, understood as complex union of distributed resources coupled with control system, energy consumption forecast and energy market 0. Integration of these technologies may leads to the “smart” cluster which would react in global and local sense in case of regulation, intervention and reserves of power. Thus gives desirable flexible properties of the power production which can react on energy market fluctuation or critical event as blackout, islanding and system recovery.

The intention of this paper is to look at the problem of analysis of transient states from the angle of monitoring mode in full consciousness of time-consuming requirements characteristic for time-frequency analysis. In other word, we propose to track selected power quality index in time, characterized by light computation, and activate local time-frequency analysis only if the index exceed given threshold. Obtained characteristic of instantaneous values of the index can be treated as indicating criterion for performing full two-dimensional analysis.

2. Investigated case

The measurements were done in a wind power plant with 500kW induction generator, connected to the grid by 11 kV/400 V Dyn11 transformer. Compensation of reactive power is realized by two step capacitor banks. Digital sampling rate is 6250 Hz that gives 125 samples per one-cycle of fundamental component. Fig. 1 presents an example of recorded phenomena in wind turbine system under transient condition caused by switching on two-step capacitor banks.

3. Specification of the prposed method

Proposed method is a composition of monitoring mode and high quality analysis of the detected disturbances. First level of the algorithm is concentrated on continuous monitoring of voltages and current in 3-phase system. The aim of this level is detection of the disturbances and must be characterized by light computation. Presented application is dedicated to assessment of transients in companion with harmonics, thus our proposition is to calculate short-term total harmonic distortion index of voltage (STHDV), for every one-cycle of the signal. In presented example the sampling rate equals 6250 Hz. One cycle estimation of local THD means rough estimation on the basis of 125 samples which gives 50Hz frequency resolution. For calculation is taken H=62 harmonics according to Nyquist frequency. Overlapping is not used, so every next value of STHDV is calculated using next one-cycle window. Local value of THDV, associated with particular position in time, is expressed by:

$$THDV = \frac{\sqrt{\sum_{h=2}^{H} V_h^2}}{V_{h=1}} * 100\% \qquad (1)$$

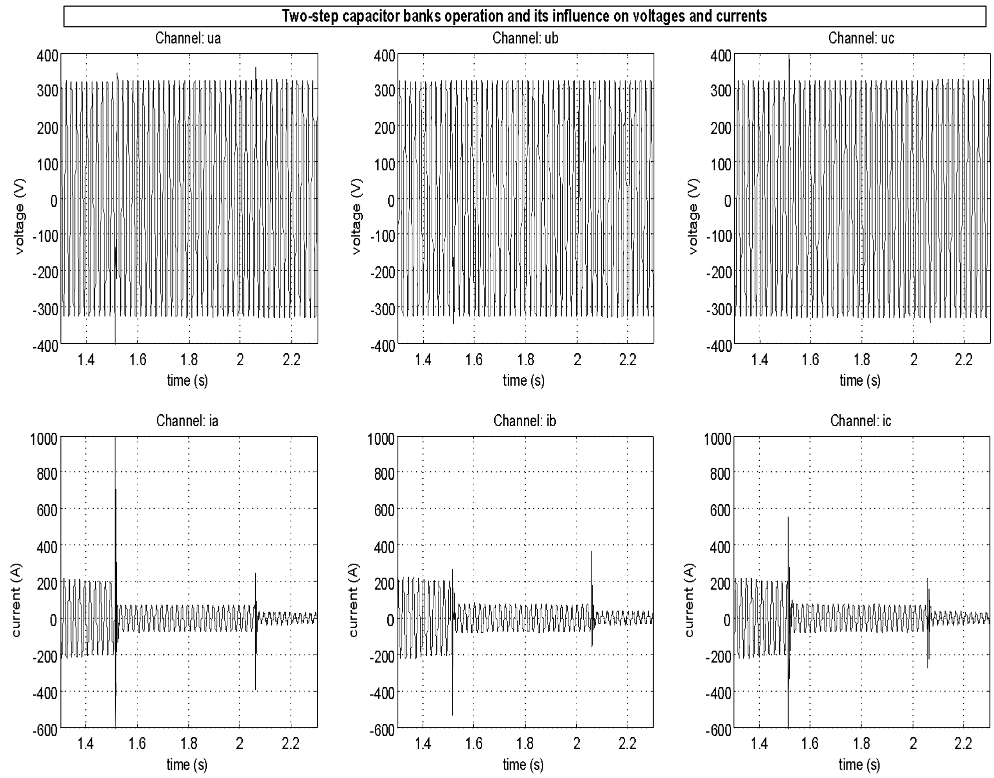


Fig. 1. Fragment of voltages and currents in the LV system with small wind turbine under process of reactive power compensation using two-steps capacitor banks

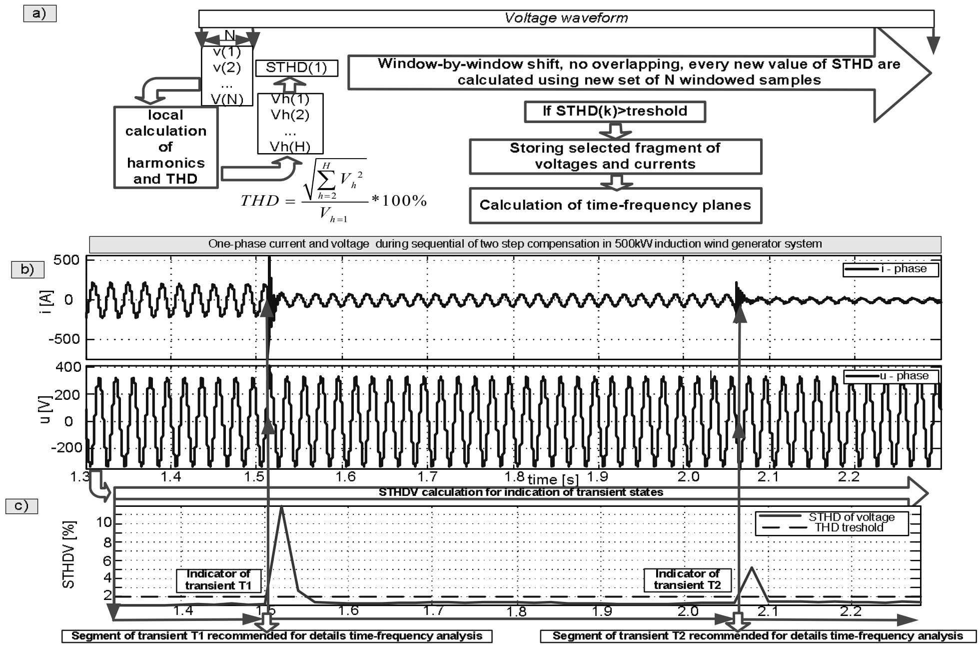
Here must be mentioned that standard IEC Electromagnetic Compatibility Part 4, Section 7 and Section 30 recommends calculation of harmonics and THD using 10-cycle series. Investigated records are based on sampling rate equals 6250 Hz that leads to 125 samples per cycle and 1250 samples per 10-cycle. According to the standards 10-cycle series would allow to obtain 5 Hz frequency resolution. However proposed method applies local THD calculation only for trigger mode and 10-cycle series would not fulfill the requirements for fast detection of the distortion. In other words in the presented idea we do not scope the attention on exact values of STHDV but use it only as indicator of transients. One-cycle series with poor frequency resolution of 50Hz is recommended and leads to possible fast detection time. Decision about storing selected fragment and its further time-frequency calculation is made when STHDV exceed threshold, here specified to 2%. The length of segments taken for investigation can be specified using constant value of pre and post recorded number of samples or can depend on time-constant of the transient. Monitoring of the STHDV is done parallel in three phase of voltage however for further investigation every three channels of voltage and every three channels of current are recorded parallel.

Triggered transient phenomena is then analyzed using selected method of time-frequency analysis. Family of time-frequency transformation contains many of representatives. Selected aspect of its application in electrical engineering has been investigated in 0, 0, 0 and indicated methods with special construction of the kernel which are dense functions like Gaussian or cone-shaped kernel. It is also recommended to apply additional smoothing window along the frequency axis *h(τ)* and among time axis *g(t)*. It leads to so called smoothing pseudo time-frequency planes. Below equation represents smoothed version of Wigner-Ville transformation:

$$\begin{aligned}\mathrm{SPWVD}_x(t,\omega) = \int_{-\infty}^{+\infty} h(\tau) \int_{-\infty}^{+\infty} g(t-\lambda)\,\cdot \\ \cdot\, x_A\left(\lambda+\frac{\tau}{2}\right) x_A^*\left(\lambda-\frac{\tau}{2}\right) \mathrm{d}\lambda e^{-j\omega\tau} \mathrm{d}\tau\end{aligned} \tag{2}$$

Logical diagram of proposed method depicts

Fig. 2, including also an example of one-phase voltage and current and calculated trend of STHDV which serves as indicator of the transient for further detail analysis using time-frequency representations. The methodology of the method assumes that excitation of the STHDV threshold in any three-phase voltage system can trigger parallel multichannel recording of every voltage and current signals. Recording interval can be defined with specification of pre and post recording time. These multichannel records are dedicated for further multichannel time-frequency analysis. As STHDV is rough and fast characteristic, which leads to detection of the transient with harmonics, as time-frequency analysis represents high-quality analysis depending on parameterization of the applied transformation.



$$THD = \frac{\sqrt{\sum_{h=2}^{H} V_h^2}}{V_{h=1}} * 100\%$$

Fig. 2. Visualization of the proposed method of the investigation as combination of monitoring mode based on STHDV trend and high quality analysis uses time-frequency analysis

4. Results of the investigations

Application of monitoring mode using STHDV trend has indicated two transients referred to activities of two-step capacitor banks. In order to evaluate contribution of frequency components in the transient state we propose to present time-frequency planes scaled in percentage of fundamental component before the event, obtained from pre-event recording interval. As an example we present multichannel time-frequency analysis of voltage and current of selected transient segments T1 and T2 on the basis of smoothed version of Wigner-Ville representation. It applies additional smoothing windows: *h(τ)* is multiplied with signal and brings smoothing effect along frequency axis, other one, *g(t),* is convoluted with obtained representation and exhibits itself in smoothing effect along. Presented calculation utilizes one-cycle Hamming windows. Frequency resolution for the time-frequency analysis is 5Hz. Results of the investigation for subsequence T1 and T2 are presented in Fig. 3 and Fig. 4.

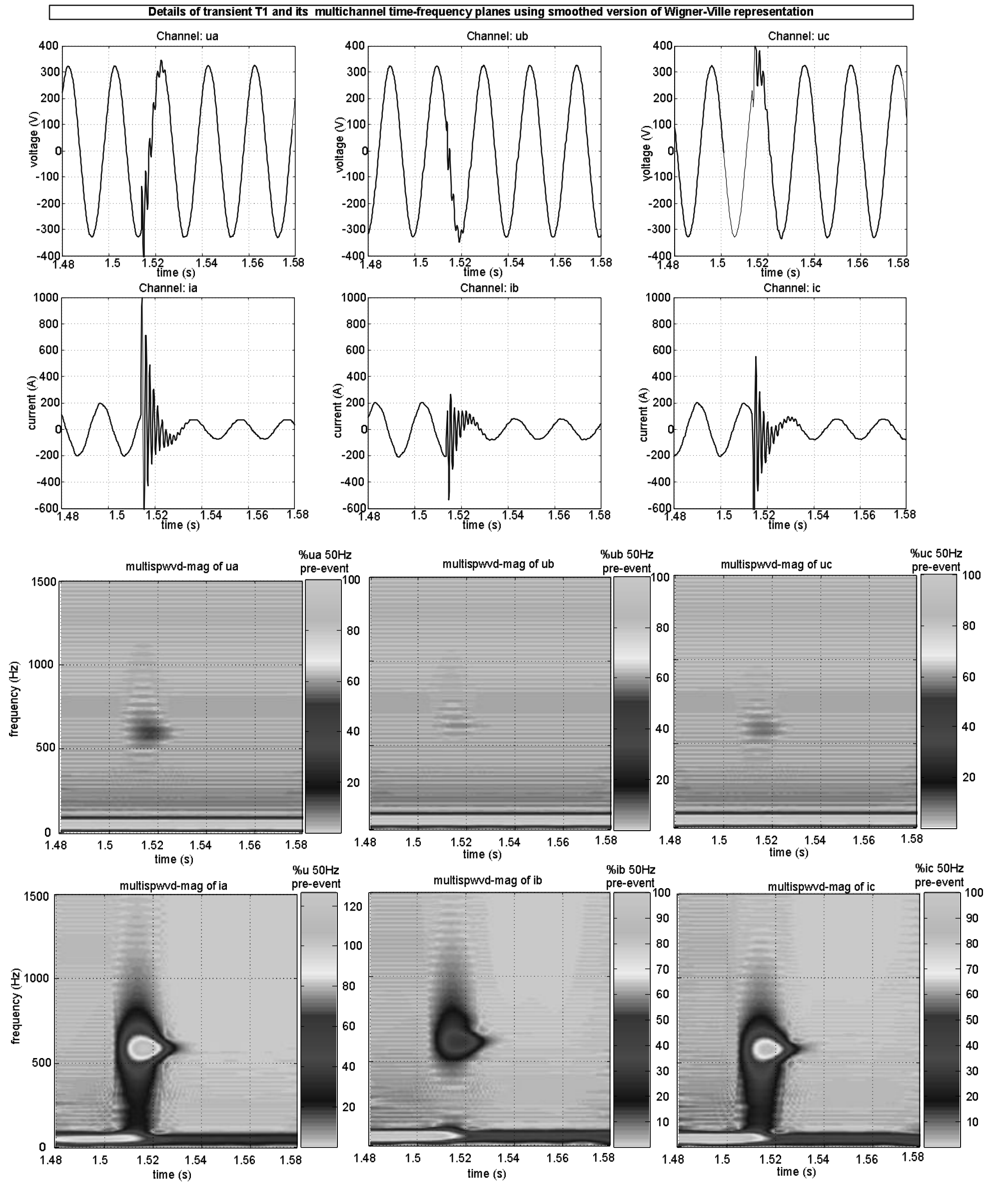


Fig. 3. Details of the detected transient T1 and its multichannel time-frequency analysis using smoothed version of Wigner-Ville distribution

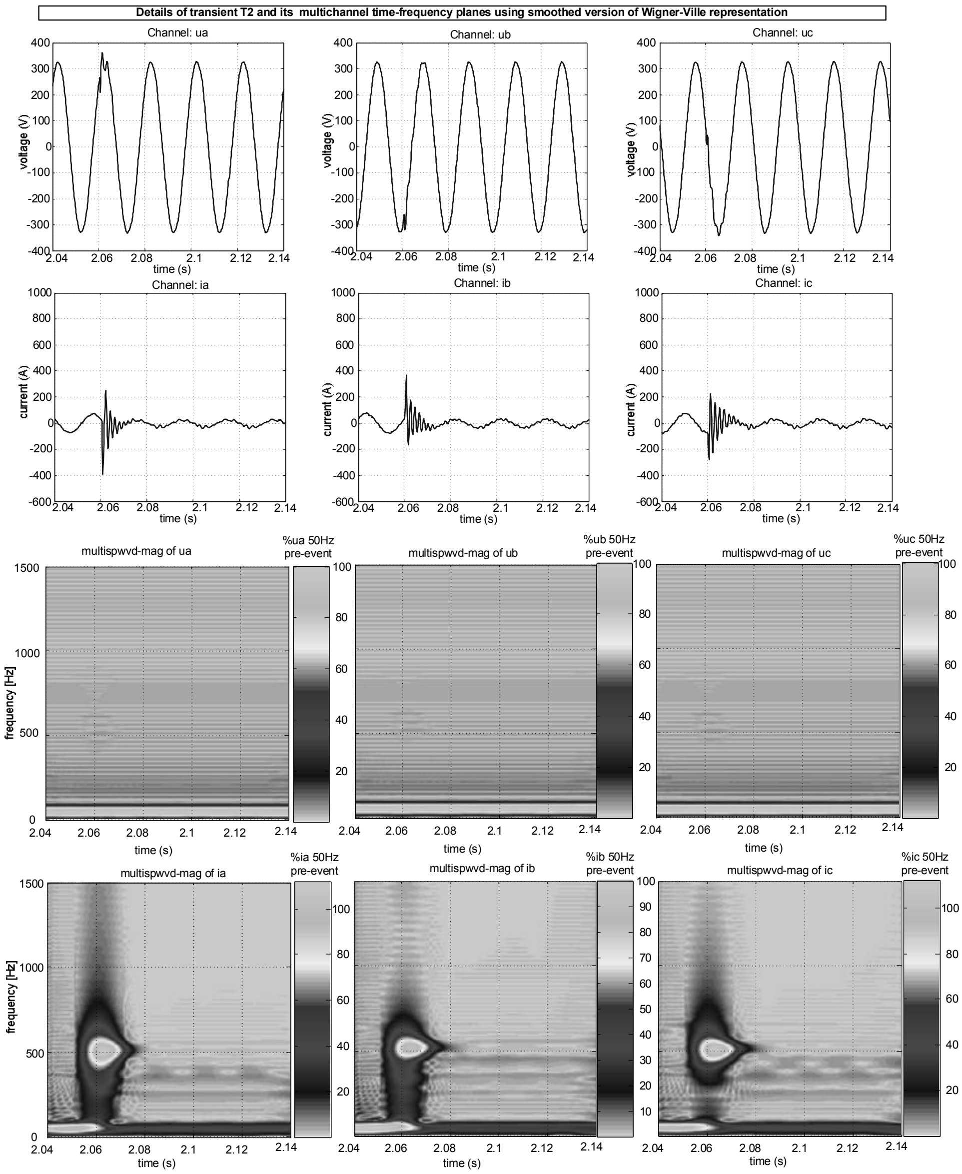


Fig. 4. Details of the detected transient T2 and its multichannel time-frequency analysis using smoothed version of Wigner-Ville distribution

Obtained time-frequency planes indicate higher harmonics which appears during switching-on the capacitor banks. Prominent influence is visible in current. Details of subsequence T1 shows decaying components with maximum contribution of 590Hz in phase A (126.92% of pre-event current in phase A), 610Hz in phase B (51.53% of pre-event current in phase B) and 575Hz in phase C (88.25% of pre-event current in phase C). Second step of capacitor banks T2 has introduced time invariant spectrum components with maximum contributions of 510Hz in phase A (112.22% of pre-event current in phase A), 520Hz in phase B (92.63% of re-event current in phase B) and 515Hz in phase C (112.19% of pre-event current in phase C). Investigated operation of switching on two-step capacitor banks exhibits itself in voltages as fast transient event with slight contribution and fast decaying time.

5. Conclusions

Presented in the paper idea of combined monitoring mode with triggered time-frequency analysis makes some efforts to propose solution for limitation of direct continuous analysis of long data. Heaviness associated with computational power and time consuming is reduced to fast selection of segments and relatively fast calculation of the selected transients. As a main method of the analysis two dimensional time-frequency algorithms are proposed, working in a triggering mode, activated by parameters of short-time harmonics distortion index. Cooperation of the algorithms serves as complex assessment of the event and makes some efforts to meet increasing expectation of monitoring systems. Possible application can be localized in dispersed measurements dedicated to assessment of disturbances distribution in power system.

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