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A Set-up for Static and Dynamic Characterization of Voltage and Current Transducers used in Railway Application

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Abstract. In the recent years, much more attention is paid to energy and power quality measurement in railway system. In both the case, the voltage and current transducers play a crucial role and their accuracy could determine the performance level of whole measurement system. To obtain reliable results, the accuracy of transducers should be tested with waveforms as close as possible to real working conditions. To assess the metrological characteristic of DC voltage and current transducers under real operating conditions, this paper presents a calibration set up able to generate up to 6 kV for DC voltage and up to 300 A for DC current. The system is able to generate complex and non-stationary test signals which go beyond the standard characterization procedures. Dynamic tests can be derived from real signals obtained from experimental data. For this aim, a specific software tool was developed and here it is presented.

1. Introduction

The traction railway infrastructure is one of the most important factors for the development of each regions mobility due to its properties of reliability and safety. Nevertheless, the efficient use of any infrastructure is highly encouraged by the European Union and this pose new challenges for the railway energy supply systems: actual energy absorbed/exchanged between the train and the railway grid should be accurately measured for billing purpose and energy saving techniques should be applied ([1]). For this aim, all trains shall be equipped with an energy measurement device, whose measurement accuracy shall be assessed and periodically re-verified, as required by EN 50463-2 ([2]). In addition, the assessment of the power quality could be a valuable tool to foster the efficiency of the whole railway system by "awarding" the good power quality delivered and absorbed. Power quality is a well addressed topic on AC system and a lot of procedures, algorithms and measurement systems were presented and widely discussed in scientific literature ([3]-[5]). A less explored research field is assessment of power quality in DC system especially with reference to the railway system ([6]). In both the measurement systems for the energy and the power quality, the voltage and current transducers play a crucial role and their accuracy could determine the performance level of whole system ([7]). To assess the metrological characteristic of DC voltage and current transducers under real operating conditions, this paper presents a calibration set up able to generate up 6 kV for DC voltage and up to 300 A for DC current. The system is able to generate complex and/or non-stationary test signals which go beyond the standard characterization procedures ([8]-[9]). Static tests are performed generating DC signals with the overlapping of a stationary disturbance defined by arbitrary harmonic components. Dynamic tests are performed generating voltage and/or current with time varying amplitude that can be defined by user or derived from real signals obtained from experimental data. For this aim, a specific software tool has

been developed and here presented. It can analyse the signals coming from a field acquisition and extract their main feature to reproduce, during the time, the level of amplitude, within a chosen accuracy in order perform tests with waveforms as close as possible to real working conditions.

2. Hardware description

A simplified block diagram of the presented test system is reported in Figure 1 and it can be divided into four sections composed by a series of subsystems. The section with low amplitude signals: this is a PXI system with two generation boards (NI PXI 5422, maximum sampling rate 200 MHz, 16 bit, variable output gain and offset, up to 256 MB of on-board memory) and two acquisition boards (NI PXI 4462, input range ± 10 V, 24 bit, maximum sampling rate of 204.8 kHz). The amplification section is composed by a transconductance amplifier (Fluke 52120 A, up to 120 A, up to 10 kHz, up to three in parallel) and by a high-voltage power amplifier (NF HVA4321, up to 10 kV, from 0 Hz up to 30 kHz) for current and voltage respectively. The feedback section is composed by two reference transducers (CS-300 for current and KV-10A for voltage both of Ohms LABS) used to feedback generated waveform to the acquisition boards for comparison, [6]. The last section includes the devices under test.

3. System software description

A specific software was developed in the LabVIEW environment adopting the state machine approach for managing generation, acquisition and signal processing. Two different operation modes have been implemented. In static operation mode, the system performs a steady generation of DC signals of chosen amplitude with the overlapping of a stationary disturbance defined by arbitrary spectral components (range 0-5 kHz). These tests are aimed to characterize the behaviour also in presence of harmonics distortion coming from power supply system. In dynamic operation mode, the system generates voltage and/or current with time varying amplitude that can be defined by user or derived by real signals obtained from experimental data. These tests are devoted to characterize the behaviour with the signals that could be found in real operating conditions.

3.1. Dynamic test implementation

One of the features of the presented system is the capability to reproduce also dynamic working conditions. As first possibility, the user can describe the desired signal in terms of time segments that will be consecutively generated. The k-th segment starting at instant T_k is properly defined assigning its duration, D_k, and the parameters A_k and B_k that define the linear behaviour inside the segment:

$$Y(t) = A_k \cdot (t - T_k) + B_k \qquad\qquad for\ t\epsilon[T_k, T_k + D_k] \qquad\qquad (1)$$

Note that a value for A equal to zero corresponds to a constant behaviour and B_{k+1} equal to the last value of k-th segment ($B_{k+1} = A_k T_k$-B_k) assures waveform continuity across the segments. In Table 1, an example of choice of the parameters emulating a sudden reduction of voltage, followed by a recovery, and in Fig.2 the corresponding behaviour are reported. In addition to the manual definition of time segments, a specific procedure was developed to analyse signals coming from a field acquisition and to extract their main features to reproduce, during the time, the level of voltage and/or current, within a chosen accuracy. For this aim, the analysed signal is segmented in time intervals in which the time behaviour can be approximated with a linear function respecting the accuracy limit and the corresponding parameters are calculated. During the generation stage, the calculated parameters are used to reproduce a piecewise sequence of lines approximating the signal behaviour. The algorithm works analysing a time segment of signal with a first attempt duration (f.i. D_k=1 s) and it exploits the linear least squares fitting for calculating the A_k and B_k parameters. The values obtained with these parameters are compared with the real values calculating the maximum deviation. If it is below the chosen tolerance, the algorithm continues to try to extend the duration of the segment (f.i. +10%) and to repeat the estimation of the parameters until the tolerance is exceeded. Then, in both cases, the algorithm goes to the next segment choosing the last point of the last segment as the starting point for the next segment.
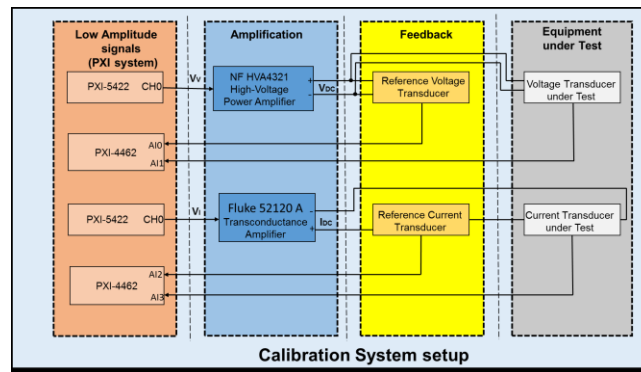
Figure 1. Block diagram of Calibration System

Table 1. Example of parameter segmentation

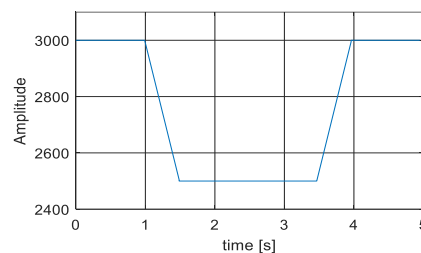| Seg #	Duration	A_k	B_k
1	1	0	3000
2	0,5	-1000	3000
3	2	0	2500
4	0,25	1000	2500
5	1	0	3000

Figure 2. Output of the parameter segmentation of Tab 1

As an example, Figure 3 and 4 show the field acquisition of supply voltage and absorbed current by Trenitalia E412 Locomotive for 350 s with a sampling frequency of 20 kHz during a test of electrical braking (7 million of samples). As expected, there are high amplitude variations for current according the different working condition and, consequently, the voltage has inverse behavior but with a less wide amplitude variations. The Figure 5 and 6 report the piecewise sequence of lines calculated from the algorithm with an accuracy of 2%. Note that, for actual generation, the amplitude of current of Figure 6 was reduced of one order of magnitude to respect full scale of a transconductance amplifier. It is expected that number of segments depends on the complexity of waveform but also it changes with the chosen level of accuracy. A comparison of the number of segments required for the two waveforms to reach different levels of accuracy is reported Tab 2. Initially the number of segments increases linearly with accuracy but after a certain level the increment become exponential. Finally, the accuracy limits are the maximum values of deviation found in the considered time segment, but clearly the average deviation is much lower. Figure 7 reports the statistical analysis of all the obtained deviations. Average values is around zero and standard deviation is less than 1.6 A.
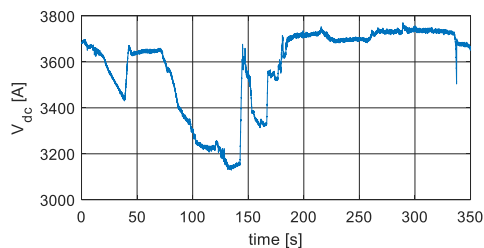
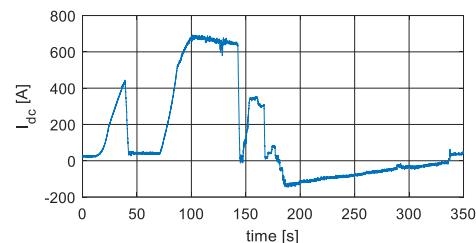**Figure 3.** Measured supply voltage of E412

Figure 4. Measured absorbed Current of E412

4. Conclusion
In this paper a calibration setup for voltage and current transducers for railway application is presented. It can generate voltage and current up to 6 kV and 300 A and it can reproduce steady state or transient waveforms, allowing the characterization of the transducers in real operating conditions.
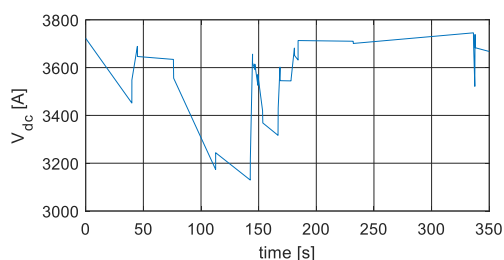
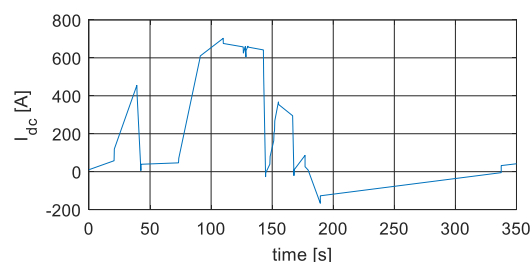**Figure 5.** Emulated supply voltage of E412 at 2%

Figure 6. Emulated absorbed Current of E412 at 2%

Table 2. Number of segment versus accuracy

Accuracy [%]	Number of segments for voltage	Number of segments for current
0.5	148	229
1	44	61
2	19	23
5	10	11
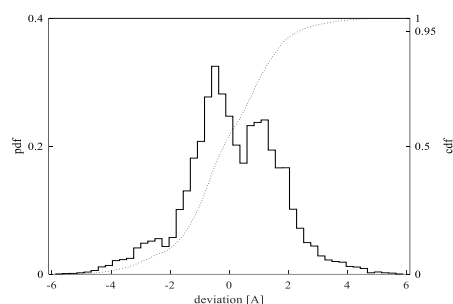
Figure 7. Statistical analysis of deviations at 2%

5. Acknowledgement

References

[1] Commission Regulation (EU) No 1301/2014 of 18 Nov. 2014 on the technical specifications for interoperability relating to the 'energy' subsystem of the rail system in the Union

[2] EN 50463-2 – Railway Applications - Energy measurement on board trains - Part 2: Energy measuring

[3] G. Aurilio, M. Balato, G. Graditi, C. Landi, M. Luiso, M. Vitelli, "Fast Hybrid MPPT Technique for Photovoltaic Applications: Numerical and Experimental Validation," Advances in Power Electronics, vol. 2014, Article ID 125918, 15 pages, 2014. doi:10.1155/2014/125918, June 2014

[4] D. Gallo, R. Langella, M. Luiso, A. Testa and N. R. Watson, "A New Test Procedure to Measure Power Electronic Devices' Frequency Coupling Admittance," in IEEE Transactions on Instrumentation and Measurement.

[5] P. Tosato, D. Macii, M. Luiso, D. Brunelli, D. Gallo and C. Landi, "A Tuned Lightweight Estimation Algorithm for Low-Cost Phasor Measurement Units," in IEEE Transactions on Instrumentation and Measurement, vol. 67, no. 5, pp. 1047-1057, May 2018.

[6] M. Caserza Magro; A. Mariscotti; P. Pinceti, "Definition of Power Quality Indices for DC Low Voltage Distribution Networks", 2006 IEEE Instrumentation and Measurement Technology Conference Proceedings

[7] G. Crotti; D. Gallo; D. Giordano; C. Landi; M. Luiso; M. Modarres; M. Zucca, "Frequency Compliance of MV Voltage Sensors for Smart Grid Application," IEEE Sensors Journal, vol. 17, no. 23, pp. 7621-7629, Dec.1, 1 2017. doi: 10.1109/JSEN.2017.2726116

[8] G. Crotti; D. Gallo; D. Giordano; C. Landi; M. Luiso, "Industrial Comparator for Smart Grid Sensor Calibration," in IEEE Sensors Journal, vol. 17, no. 23, pp. 7784-7793, Dec.1, 1 2017.

[9] G. Crotti, D. Giordano, M. Luiso and P. Pescetto, "Improvement of Agilent 3458A Performances in Wideband Complex Transfer Function Measurement," in IEEE Transactions on Instrumentation and Measurement, vol. 66, no. 6, pp. 1108-1116, June 2017.