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Calibration System for DC Power/Energy Measurement chain in Railway applications

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***Abstract* — In order to guarantee the European interoperability of rolling stock, the European Union (EU) established that all the trains shall be equipped with an Energy Measurement Function (EMF) for billing purposes. The measurement accuracy of such devices should be assessed and periodically re-verified, as required by EN 50462-2. This paper describes a setup for the calibration of combined voltage and current transducers and EMFs for on-board Direct Current (DC) train installation. The reference system is able to generate an arbitrary DC phantom power up to 6 MW with voltage up to 5 kV and a current up to 1.2 kA. Furthermore, in order to perform tests as close as possible to real operating conditions, the system allows performing dynamical tests, reproducing waveforms obtained in real measurement campaigns. The computed uncertainty for steady state tests is 0.025 %, whereas the target uncertainty for dynamic tests is 0.1%. The generation system can also be applied for on-board reverification of EMF.**

***Index Terms* — Combined Transducers, Power Measurement, Phantom Power, DC Railway, Energy Meter.**

I. Introduction

With the aim of establishing a single European railway area, the European commission requires, by 2019, that the energy billings shall be computed on the actual consumed energy [1]. The voltages and currents at pantograph are often subject to ripple and step changes in magnitude associated with train acceleration and braking. Arcing phenomena, generated by a bad pantograph-to-line contact quality, can further introduce transient distortions. To assess the metrological reliability of the energy measurement system under the actual operating conditions, calibration set-ups and procedures, which go beyond the well-known procedures developed for pure continuous regimes, are required [2]. Typical commercial measurement systems for on-board railway applications are composed by combined voltage and current transducers. These, in turn, are usually active devices which, in order to properly work, need the simultaneous presence of both voltage and current signals. This means that it is not possible characterizing separately the voltage and current channel. The paper describes a reference power phantom generator for the calibration of the whole Direct Current (DC) power/energy measurement chain, composed of voltage (Voltage Measurement Function, VMF) and current (Current Measurement Function, CMF) transducers and the energy meter (Energy Calculation Function, ECF), as described in the EN 50463-2. The proposed setup can be even used for the field re-verification of the EMFs, that is without taking the whole measurement chain to calibration laboratory. The realized reference system is able to calibrate the EMFs in realistic operating conditions, since it can generate arbitrary signals with frequency components up to 30 kHz and 500 Hz, respectively for voltage and current and waveforms obtained in real measurement campaigns.

II. The Phantom Power Generator

The calibration is able to acquire the EMF output, which can be both of analog type, typically current signals proportional to the input voltage and current, and/or of digital type. The system can deliver a phantom power of 6 MW, in order to allow the characterization at full power of typical commercial EMFs. In details, to limit the real power consumption, the generation system has been divided into two independent sections: one for voltage generation and one for current generation (Fig. 1) [3]. The voltage and current generated are measured by reference transducers. The section for the voltage generation is composed of: a voltage amplifier, an Arbitrary Waveform Generator (AWG), a synchronization module (getting the absolute time from Global Positioning System, GPS) and a Data AQuisition system (DAQ) for collecting signals provided by voltage reference transducer and by the EMF. Similarly, the section for the current generation is composed of an AWG, a GPS module, a DAQ and a DC current amplifier. A particular feature of the system is the possibility of suppling the CMF with a generated current not referenced to system ground, but with a common mode voltage equal to the generated voltage supplied to the

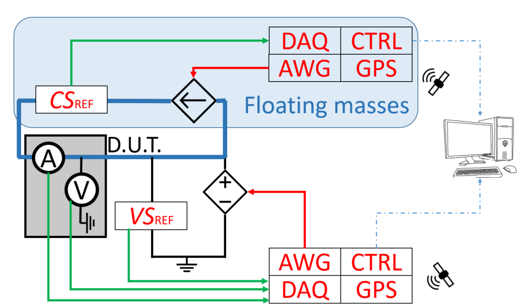

Fig. 1 Pattern of the phantom power calibrator.

VMF, according to Fig. 1. To this end, the whole current section is supplied via an isolation transformer and it is controlled through a fiber optic connection.

For the voltage generation, a TREK amplifier has been used; it can reproduce signals up to 30 kV with a frequency bandwidth up to 7 kHz for the large signal and 30 kHz for the small signal. For the current generation a Sorensen SGX High Power DC Supply has been used. It can generate up to 1200 A and the output can be controlled with a low voltage signal. The voltage reference is a resistive-capacitive divider with an overall accuracy of 0.05 % in the frequency range from DC to 5 kHz developed at INRIM. The current reference is the ITZ 2000-S FLEX ULTRASTAB with an overall accuracy lower than 12 ppm. The output of this transducer is converted in voltage by a Guildline current shunt (1 Ω, 10 ppm). The synchronization modules are the National Instruments (NI) 6683H, providing a GPS disciplined 10 MHz oscillator with an accuracy of 100 ns. Two separate synchronization modules are used to keep the galvanic separation. The AWGs are two NI 5421 (100 MHz, 16 bit, ± 12 V). The DAQs are the NI PCI eXtension for Instrumentation (PXI) 4462 (4 channels, 24 bit, 204.8 kHz). Both the voltage current generation units are remotely controlled by a Personal Computer (PC) thanks to the NI 8375 Remote control module.

As an example of system operation, Fig. 2 provides the behaviours of voltage and current, reproduced by the phantom power generator, originally recorded in a measurement campaign in presence of ice on the overhead contact wire. We can see that the current is characterized by an intermitted behaviour due to the bad contact quality.

III. Power and Energy Definition

The voltage and current signals are acquired with a sampling frequency of 50 kHz. The DC generated power, as a function of the time, p_g is defined as:

$$p_g(t) = \bar{V}(t) \cdot \bar{I}(t) \qquad (1)$$

where $\bar{V}(t)$ and $\bar{I}(t)$ are the average values of voltage and current computed over a selectable integration-time (Δt) ranging from 5 ms, corresponding to 250 samples, to 20 ms, corresponding to 1000 samples. The cumulative energy at time t_k is defined as:

$$e_g(t_k) = \Delta t \cdot \sum_{i=1}^{k} p_g(t_i) \qquad (2)$$

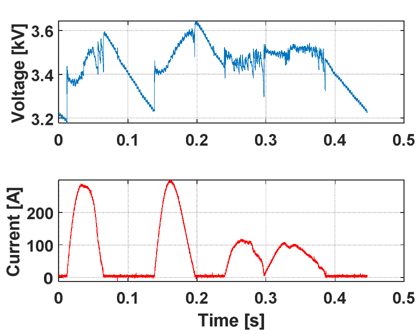

Fig. 2 Voltage and Current behavior in line recovered with ice

Table I – power uncertainty (µW/W) for steady state tests at different current amplitudes and constant voltage of 3.5 kV

Current Amplitude [A]	*Uncertainty [µW/W] Aperture-time 5 ms*	*Uncertainty [µW/W] Aperture-time 20 ms*
50	*250*	*120*
125	*200*	*100*
300	*200*	*100*
1000	*220*	*150*

IV. Uncertainty Contributions

A preliminary uncertainty estimation has been carried out. The main contributions are due to the uncertainties associated with: the voltage divider scale factor (type B), the current transducer and the current shunt (both type B), the analog to digital converters (type B) and the repeatability associated with the reading (type A). This contribution depends on the voltage level and the selected integration-time, while the uncertainty associated with the DAQs depends on the amplitude of the converted voltage. To estimate this contribution, a deep characterization of all the input channels of the DAQ has been carried out thanks to the Fluke 5500A calibrator. The DAQ gain has been mapped by reproducing all the possible voltage levels for the voltage and current channels. Table I provides the relative expanded uncertainty of the power, generated in static conditions, for two different integration-time values and four amplitudes of the applied current.

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IV. CONCLUSIONS

A setup for the calibration of energy measurement chains for DC railway application has been described. A first uncertainty estimation has been provided for different configurations (integration-time, current amplitude). In steady state tests, a worst case uncertainty of 250 µW/W has been obtained. The uncertainty contributions in dynamic tests is currently under evaluation.

References

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