Michał BORECKI, Jan SROKA

DOI: 10.15199/48.2025.05.35

Ex post droop correction of the current probe by measurementsof pulses

Korekcja ex post błędu opadania w pomiarze cęgami prądowymi

Abstract. *Current probes intended for measurements in the time domain are equipped with integrators. Imperfectness of the real integrator is the source of systematic error. This error in case of passive integrator depends on the time constant RC of the integrator. In the paper calculation of the time constant RC from the droop rate of the probe with passive integrator along with derivation of integral correcting the raw measurement is presented. The method is applied for the measurements of surge current pulse with parameters 8/20 µs for three different types of Pearson Pulse Current Monitors. The obtained results are the basis for refinement of the measurement uncertainty budget by verification of the current pulses.*

Streszczenie. *Sondy prądowe przeznaczone do pomiarów w dziedzinie czasu wyposażone są w integratory. Niedoskonałość integratora rzeczywistego jest źródłem błędu systematycznego, typu B. Błąd ten w przypadku integratora pasywnego zależy od stałej czasowej RC integratora. W artykule zaprezentowano obliczenie tej stałe czasowej ze współczynnika opadania, dostępnego w danych katalogowych cęgów. Umożliwiło to obliczenie błędu, którym można skorygować pomiar impulsu prądu. Powyższą metodę zastosowano do pomiarów impulsu prądu udarowego o parametrach 8/20 µs przy użyciu trzech różnych typów sondy prądowej Pearsona. Korekta mierzonego prądu systematycznym błędem rzeczywistego układu całkującego, umożliwia zmniejszenie bilansu niepewności pomiarowej.*

Keywords: current probe, time constant, probe sensitivity, droop rate, systematic error
Słowa kluczowe: sonda prądowa, stała czasowa, czułość sondy, współczynnik opadania, błąd systematyczny

Introduction

Measurements of the current pulse 8/20 µs is required e.g. in [1] or [2]. Such measurement can be limited to recalculation of the voltage registered with the scope with the sensitivity factor visible in the type shield of the probe. However, it is burdened with the deterministic error which can be corrected in the final measurement result [3]. This article is devoted to presentation of this correction.

Similar error can be committed by current measurements with the static energy meters. As long as the delivered current is distorted with the low frequency harmonics the error is negligible. However, by short current pulses which occurs in the mains for instance due to PV installations, error by current measurement and in consequence in calculation of consumed energy can have drastic financial implications [4].

Background of the current measurements in the time domain

Time dependent current is usually measured either with the shunt, Hall effect sensor, current probe, current transformer or Rogowski coil [5]. Big advantage of all mentioned measurement methods except shunt is non-invasive character of the measurement but disadvantage is systematic error inherent to the method. It means that raw waveform registered with the oscilloscope or the recorder must be corrected ex post the measurement.

Electric scheme of the current probe, called also current monitor or Rogowski coil is illustrated in Fig. 1.

Situation is similar to the transformer in which the primary side is the line with the current to be measured and the secondary side is equipped with the integrator.

Passive RC integrator is presented in Fig. 1 for simplicity of analysis but there are also probes with active integrator available on the market [6].

Coil is usually equipped with the co-axial connector u_{out} (t) to the oscilloscope or recorder. High impedance in- put

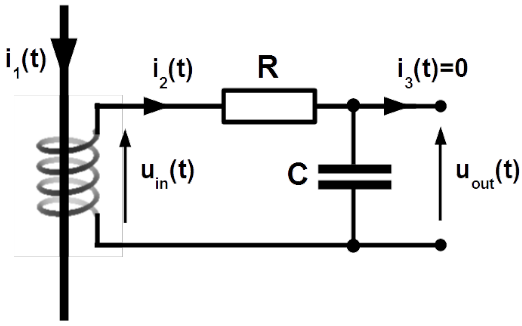

Fig. 1. Electrical circuitry by measurement with the current probe.

should be set in the oscilloscope or the recorder in order to justify assumption i_3 (t) = 0.

According to the Faraday law voltage u_{in} (t) induced in the coil depends on the current i_1 (t) as follows

$$U_{in}(t) = M\frac{d}{dt}i_1(t) \tag{1}$$

where *M* is mutual inductance between primary and secondary side of the coil.

The output voltage u_{out} (t), provided that i_3 (t) = 0 yields

$$U_{out}(t) = \frac{1}{C}\int i_2(t)dt \tag{2}$$

Since the formula for the voltage across the resistance *R* looks like

$$i_2(t)R = u_{in}(t) - u_{out}(t) \tag{3}$$

introduction of Eq. (1) and Eq. (3) into Eq. (2) yields

$$u_{out}(t) = \frac{M}{RC}i_1(t) - \frac{1}{RC}\int u_{out}(t)dt \tag{4}$$

Factor $s = \frac{M}{RC}$ with dimension V/A is called sensitivity and is usually placed at the type plate of the probe.

Finally

$$i_1(t) = \frac{u_{out}(t)}{s} + \frac{1}{RC}\int \frac{u_{out}(t)}{s}dt \tag{5}$$

while u_{out} $(t)/s$ is the raw waveshape of the measured current i_1 (t).

It is evident in Eq. (5) that in order to reveal the actual current i_1 (t), the raw waveshape u_{out} $(t)/s$ must be corrected ex post by adding the time integral of the raw wave- shape u_{out} $(t)/s$ multiplied with the fraction whose numerator is equal to 1 and denominator is the time constant *RC*. It is well known procedure of correcting the raw measurement result with the systematic, deterministic error in order to minimize the measurement uncertainty [3].

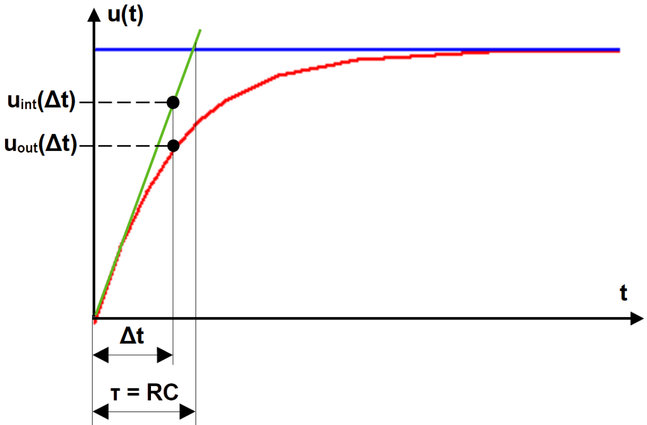

Fig. 2. Unit step function 1(t) - blue line, ideal integration - black line and exponential rise at the output of the passive RC integrator - red line.

Since the manufacturers of the current probes give parameter called the droop rate in the data sheets, it is necessary to derive the time constant *RC* from it.

Explanation of the relation between the droop rate and the time constant RC of the passive integrator is illustrated in Fig. 2. By application of the unit step voltage $u(t) = 1(t)$ at the input of the integrator, blue line in Fig. 2, the output voltage of the ideal integrator would be $u_{int}(t) = t/RC$, the green line in Fig. 2. The output voltage of the passive RC integrator increases exponentially according to relation $u_{out}(t) = 1 - e^{t/RC}$, red line in Fig. 2.

At the instant Δt discrepancy between the ideal integration and the real integration with the RC two-port yields $\Delta u(\Delta t) = u_{int}(\Delta t) - u_{out}(\Delta t)$.

The droop *d* at instant Δt is defined as discrepancy Δu referred to the output voltage u_{out} at the RC two-port, see [6]

$$d(\Delta t) = \frac{u_{int}(\Delta t) - u_{out}(\Delta t)}{u_{out}(\Delta t)} \tag{6}$$

The droop rate in the data sheets is once again referred to the instant Δt, see [6].

Relation between the droop *d*, instant Δt and time constant *RC* is embedded in following equation

$$\ln(1 + d - x) = \ln(1 + d) - x \tag{7}$$

where

$$x = \frac{\Delta t}{RC} \tag{8}$$

Performance of the pulse correction

In the experiment three current monitors, products of Pearson Electronics Inc. were used. Their parameters are gathered in Tab. 1.

In the fourth column in Tab. 1 are the time constants calculated according to Eq. (7) and Eq. (8) with input data taken from the third column.

Table 1. Parameters of the current monitors used in the experiment

Current monitor type	Sensitivity *s*	Droop rate $d/\Delta t$	Time constant *RC*
6600	0.1 *V/A*	0.02 %/μs	2.5 ms
110A	0.1 *V/A*	0.8 %/ms	62.67 ms
1423	0.001 *V/A*	0.7 %/ms	71.59 ms

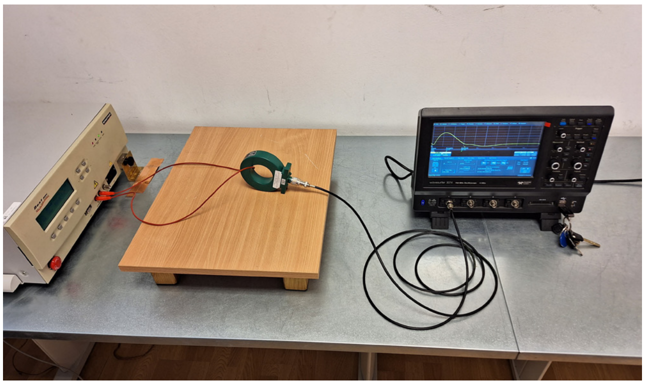

Fig. 3. Measurement set up with probe model 110A.

Measured was the surge current pulse with parameters 8/20 μs generated with the Schaffner Best EMC generator with internal effective impedance equal to 2 Ω. Voltage setting was +200 *V*.

The pulse was observed on a Teledyne Lecroy WaveSurfer 3074 oscilloscope as shown in Fig. 3–5.

As it can be seen from the measurement results shown in Fig. 6–8, the correction integral has the biggest impact on the time to half value of the pulse. It has less influence on the rise time and on the peak value.

Values of the correction integrals by the peak of the pulse lays between:

- 11 – 12 *mA* for the 110A probe,
- 9 – 10 *mA* for the 1423 probe,
- 28 – 29 *mA* for the 6600 probe.

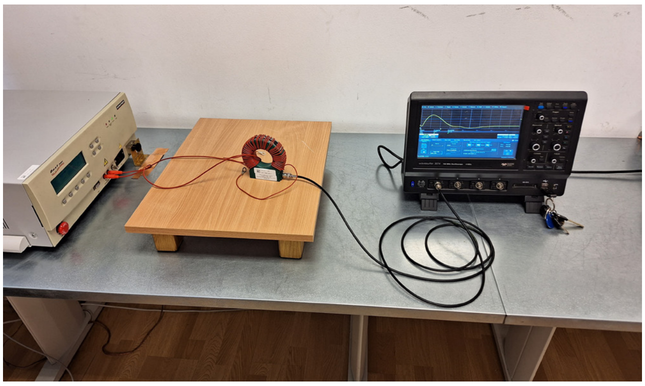

Fig. 4. Measurement set up with probe model 6600.

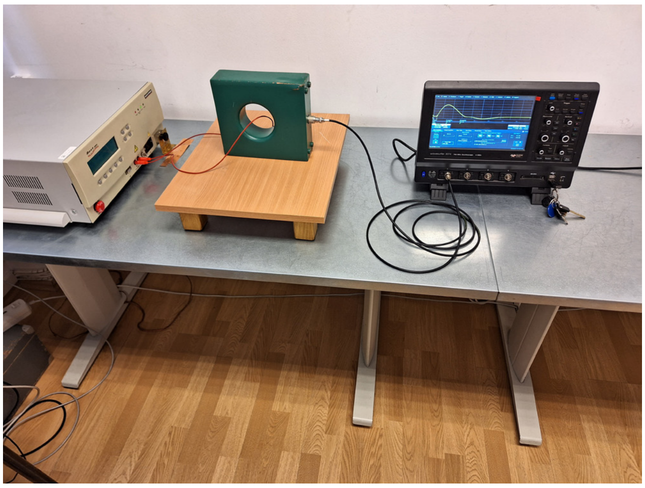

Fig. 5. Measurement set up with probe model 1423.

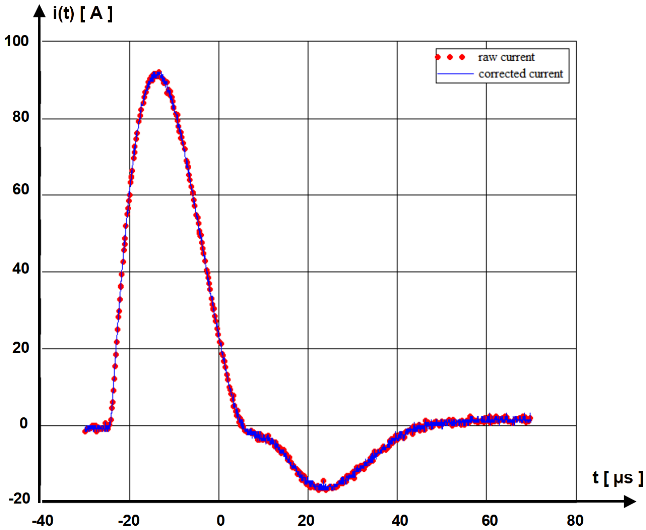

Fig. 6. Raw and corrected current captured with probe model 110A.

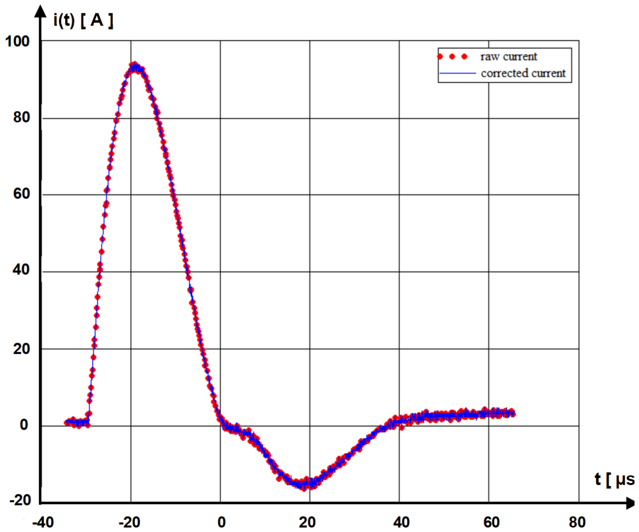

Fig. 7. Raw and corrected current captured with probe model 6600.

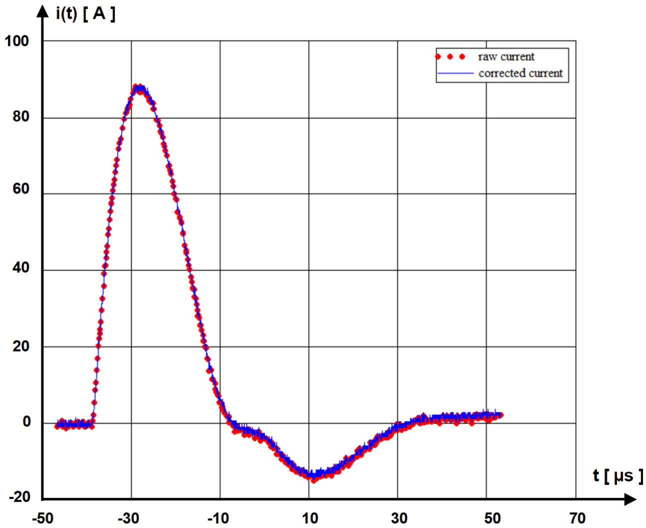

Fig. 8. Raw and corrected current captured with probe model 1423.

Conclusions

Current probes intended for measurements in the time domain are equipped with integrators. Imperfectness of the real integrator either passive or active is the source of systematic error by measurement of current in the time domain. This error in case of passive integrator depends on the time constant *RC* of the integrator.

It is hardly possible to find the value of the time constant in the data sheet of any current probe. Instead of that, parameter called the droop rate, in which the time constant is embedded is listed in the data sheet.

In the paper calculation of the time constant *RC* from the droop rate of the probe with passive integrator along with derivation of integral correcting the raw measurement is presented. This integral can be added ex post to the raw measurement in order to minimize the measurement uncertainty budget.

Procedure is applied to the measurement of surge cur- - rent pulse with parameters 8/20 μs for three different types of Pearson Pulse Current Monitors.

Taking into account the parameters of the tested system, the correction integral of the current pulse has the following features in case of measurement made with the Pearson coils:

- the correction integral increases before the current pulse decreases to zero,
- the correction integral influences stronger time to half value than the front time and the pick value,
- the correction integral depends on the raw current that is registered with the oscilloscope and on the parameter of the coil used for the measurement (current monitor coil, Rogowski coil), in other words the correction integral increases by smaller time constant *RC*,
- the influence of the correction integral is negligible for measurements using the Pearson coil, which means that this coefficient may not be taken into account when the time constant greater than 2.5 *ms*.

Authors: *Michał BORECKI, Jan SROKA, Warsaw University of Technology*

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