Calibration of Non-inductive Shunt

Department:	RICE
Research report no.:	22190 – 023 – 2020
Report type:	Research report
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Pages:	17
Release date:	12. 10. 2020
CEP Classification:	2.2 Electrical engineering, Electronic engineering, Information engineering - Electrical and electronic engineering

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This work has been supported by project TA CR no. TH 03020322.

Abstract

This research report deals with the calibration of a non-inductive shunt prototype constructed as a current transformer with the output digital interface to allow direct feed of measured data into the computer. The calibrated device is measured for a current range up to 200 A and frequency from 50 Hz to 115 kHz. Calibration is then carried out based on measured data for tested ranges.

Keywords

Non-inductive, shunt, calibration, current transformer

List of symbols and shortcuts

C	Resonant capacitor
OSC	Digital oscilloscope
S	Inverted assembly
T	Transformer
Z	Stabilized source

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1 Introduction

Prototype of non-inductive shunt has been measured in order that its accuracy should be observed. The measurement has been performed as supplying primary winding with several frequencies and magnitudes of electric current. Information about this current from digital output of the shunt has been observed and compared with data from oscilloscope. Then evaluating algorithm in digital logic of the shunt has been calibrated.

2 Calibration of the Shunt

Recommendations discussed in [1] has been used for measurement and setting an accuracy class of the shunt:

- "For measuring transformers, the accuracy class is designated by the highest permissible percentage of the ratio error (ε) at rated primary current and rated output."
- „The standard accuracy classes for measuring current transformers are:
  0,1 – 0,2 – 0,2S – 0,5 – 0,5S – 1 – 3 – 5"
- "For class 3 and class 5, the ratio error at rated frequency shall not exceed the values given in Table 203 where the burden can assume any value from 50 % to 100 % of the rated output." – Tab. 2.1 in this paper

Tab. 2.1 – *Limits of ratio error for measuring current transformers (classes 3 and 5) [1]*

Table 203 – Limits of ratio error for measuring current transformers (classes 3 and 5)

Class	Ratio error ± % at current (% of rated)	
	50	120
3	3	3
5	5	5

2.1 *Methodology of Measurement Procedure*

Circuit shown in Fig 2.1 was used for measurement. DC generator supplied inverter with DC voltage which was transformed to AC voltage with a required frequency. Then this AC voltage was magnified by transformer which was supported by condenser in serial connection to it. Specific capacity of the condenser had been chosen so that serial combination of these two elements was in resonance during supplying them with a specific frequency which leads to elimination of negative voltage rise. Primary winding of observed shunt was connected to output of the transformer and oscilloscope measured the electric current in this winding. Current sensor integrated in the shunt measured current flowing through the secondary winding of it and digital output transfer it to PC which compiled these data.

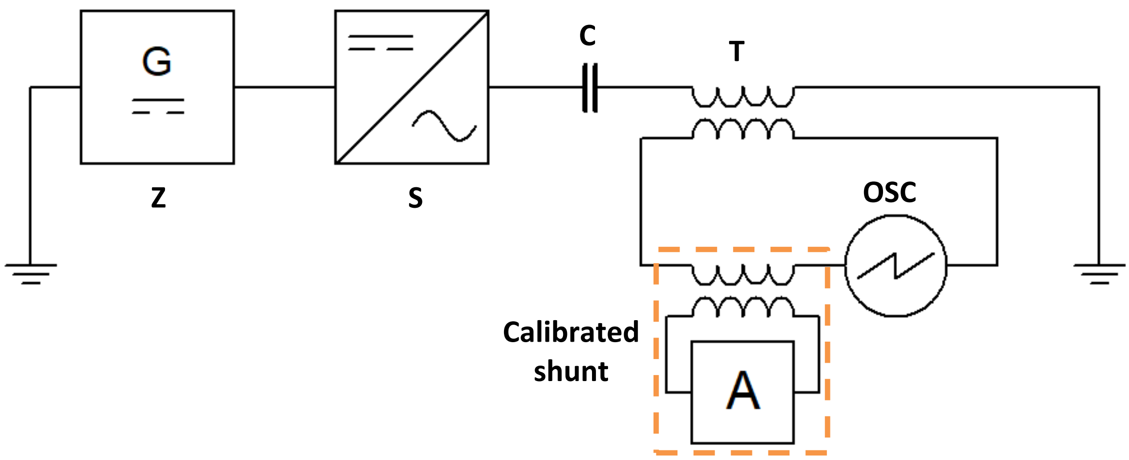

Fig. 2.1 Equivalent circuit of measurement

Measurement was performed for several magnitudes and frequencies of current in primary winding of the shunt. Maximum RMS value and frequency of current in primary winding was approximately 200 A and 115 kHz during the measurement.

Tab. 2.2 – *Used measuring instruments*

Name	Type designation	Inventory number
Oscilloscope Tektronix	MDO4104B-6	52706
Rogowski coil PEM	CWT 1R	
Stabilized source DELTA ELEKTRONIKA	SM330-AR-22	502185

2.1.1 *Accuracy of the Measuring System*

The used measurement system consists of a digital oscilloscope and current probe, in this case, the Rogowski coil was used. For the oscilloscope, the manufacturer states relative error in the vertical axis $\rho_{DCgain} = \pm 1{,}5\%$ see in [2]. For current probe in case of high-frequency application, error of the calibrated probe is stated $\rho_{RP} = \pm 0{,}2\%$ [3]. Also for coil, error is dependent on the positioning of the measured current inside the coil which is stated by Fig. 2.2, in this case, the standard coil was used, while the whole cross-section of the probed conductor was placed in B area, thus positioning error is $\rho_{RPpoz} = \pm 1\%$ [3].

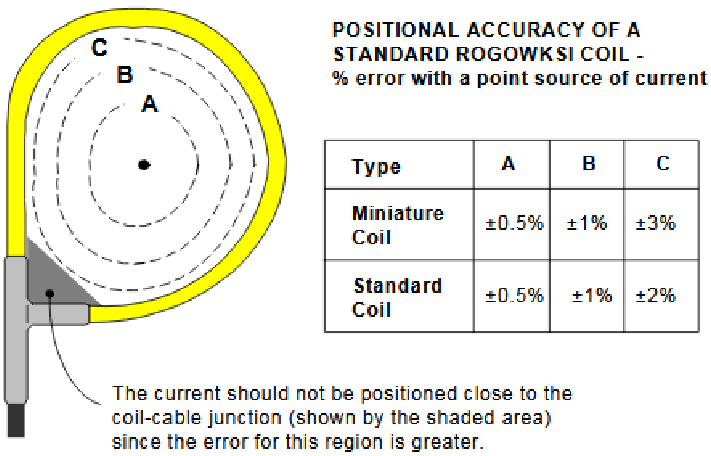

Fig. 2.2 Influence of conductor placement inside the coil of the current probe [3]

The final relative error of the measurement system is then:

$$\rho = \rho_{DCgain} + \rho_{RP} + \rho_{RPpoz} = \pm 2{,}7\ \%. \qquad (2.1)$$

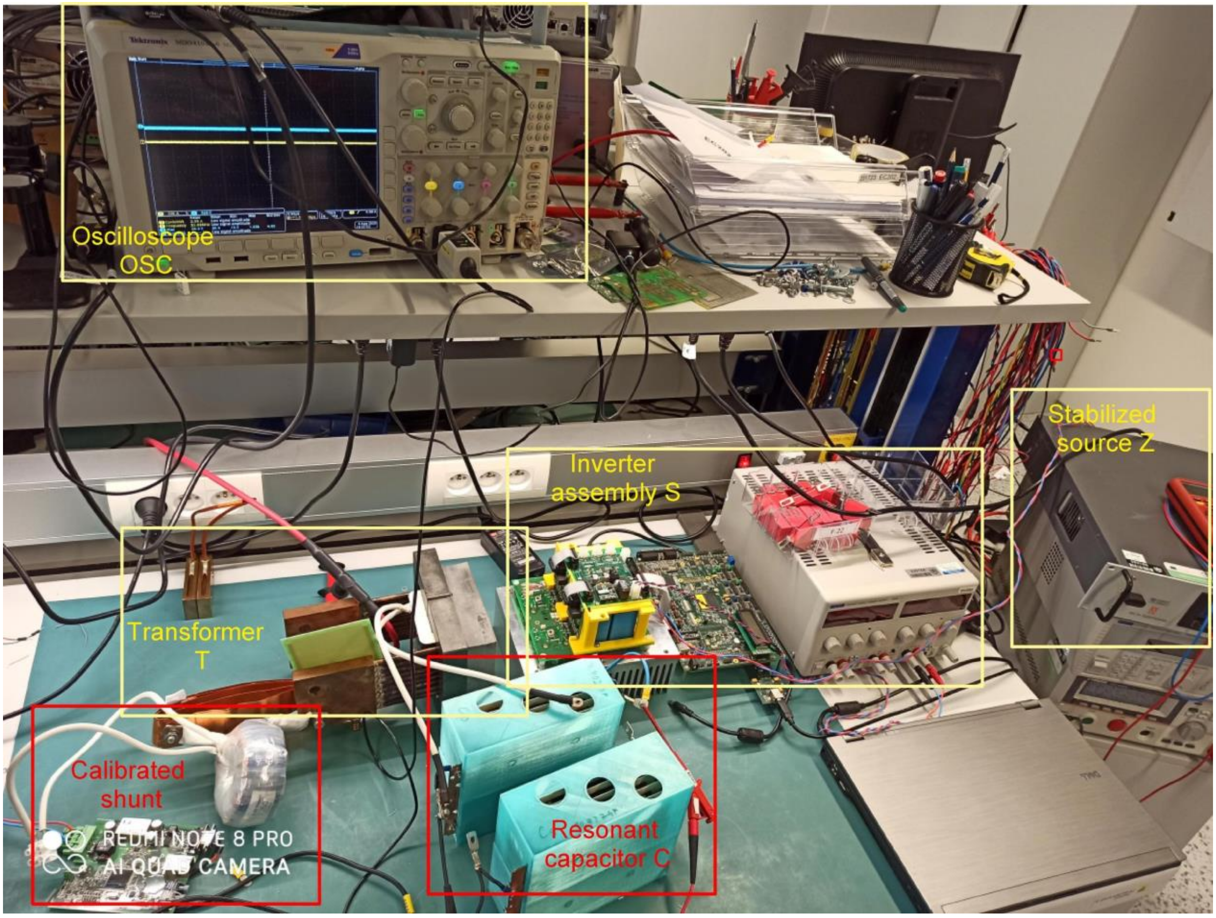

Fig. 2.3 Photo of used measuring system

2.2 *Results of the Measurement*

Measured RMS values of current in secondary winding of the shunt has been converted to level of primary winding values using multiplying by 200

Tab. 2.3 – *Obtained RMS values of currents for frequencies from 50* Hz *to 25* kHz

Frequency	50 Hz			12,5 kHz			25 kHz		
Winding	**Prim**	**Sec**	ρ_I **(%)**	**Prim**	**Sec**	ρ_I **(%)**	**Prim**	**Sec**	ρ_I **(%)**
I (A)	206,4	221,7	7,4	200	216	8,0	199	214	7,5
I (A)	176,4	189,3	7,3	175	189,3	8,2	176	189,7	7,8
I (A)	139,9	150,2	7,4	126	136,3	8,2	150	162,5	8,3
I (A)	100,44	108,0	7,5	102	110,5	8,3	114	124,7	9,4
I (A)	75,13	80,7	7,4	75,6	81,8	8,2	99,8	108,2	8,4
I (A)	50,5	54,4	7,6	50,9	55,2	8,4	75,2	81,6	8,5
I (A)	20	21,8	8,8	24,5	26,7	9,0	50,1	54,8	9,4
I (A)	5,045	5,8	14,4	5,75	6,5	13,0	5,65	6,5	15,0

Tab. 2.4 – *Obtained RMS values of currents for frequencies 50* kHz *and 115* kHz

Frequency	50 kHz			115 kHz		
Winding	**Prim**	**Sec**	ρ_I **(%)**	**Prim**	**Sec**	ρ_I **(%)**
I (A)	201	218	8,5	200	218,33	9,2
I (A)	174	188,8	8,5	175	190,11	8,6
I (A)	152	162,4	6,8	150	163,97	9,3
I (A)	100	109	9,0	91,3	100,28	9,8
I (A)	50	55,2	10,4	49,2	55,05	11,9
I (A)	20,3	22,3	9,9	24,3	29,48	21,3
I (A)	10,6	11,7	10,4	10,2	11,38	11,6
I (A)	4,95	5,7	15,2	5,1	6	17,6

Relative error ρ_I has been evaluated as:

$$\rho_I = \left|\frac{I_{prim} - I_{sek}}{I_{prim}}\right| \cdot 100\ (\%). \qquad (2.2)$$

It can be seen from obtained data of currents that shunt with such a relative error cannot be classified to any of accuracy classes from the standard [1]. Therefore, the shunt is calibrated in the following chapter.

2.3 *Procedure of Calibration*

Linear regression has been performed from obtained data of currents for each frequency as the following procedure shows:

- Average values of obtained currents in primary winding (n corresponds to number of obtained values for evaluated frequency)

$$I_{p_{av}} = \frac{\sum_1^n I_p(i)}{n} \tag{2.3}$$

- Average values of obtained currents in secondary winding

$$I_{s_{av}} = \frac{\sum_1^n I_s(i)}{n} \tag{2.4}$$

- Coefficient b of regression function

$$b = \frac{\sum_1^n (I_p(i) - I_{p_{av}}) \cdot \sum_1^n (I_s(i) - I_{s_{av}})}{\sum_1^n (I_p(i) - I_{p_{av}})^2} \tag{2.5}$$

- Coefficient a of regression function

$$a = I_{s_{av}} - b \cdot I_{p_{av}} \tag{2.6}$$

- Obtained regression function

$$I_s = a + b \cdot I_p \tag{2.7}$$

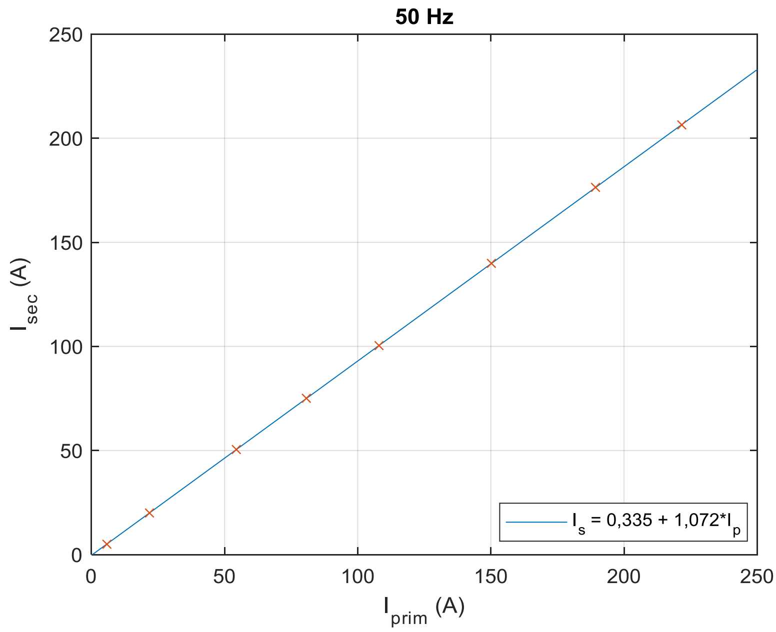

Fig. 2.4 Linear regression for frequency 50 Hz

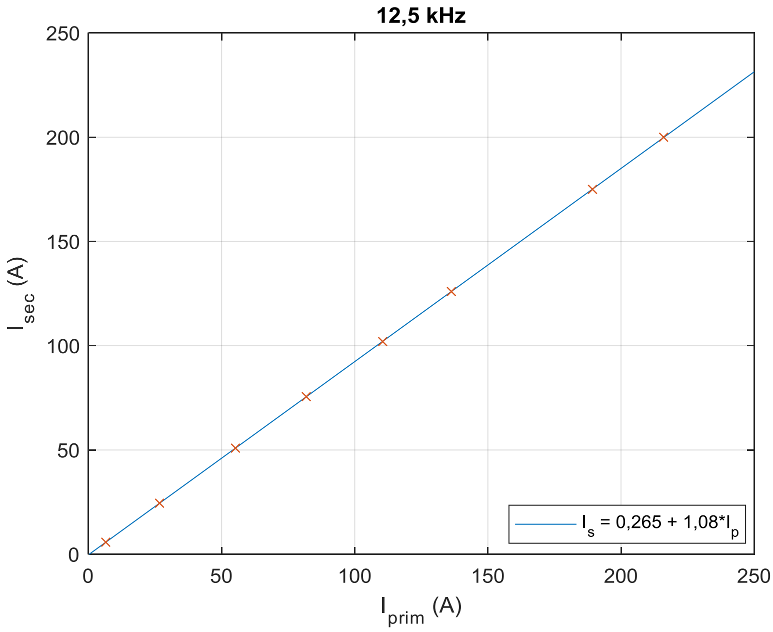

Fig. 2.5 Linear regression for frequency 12,5 kHz

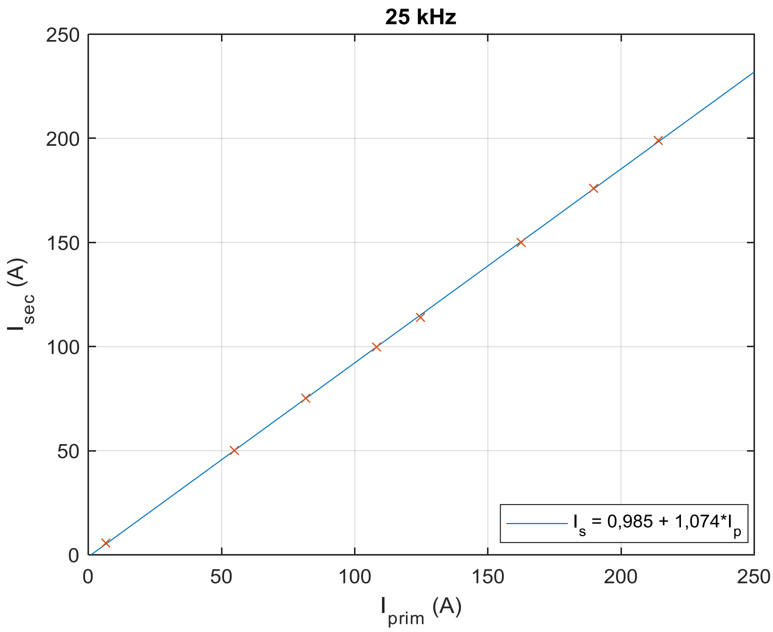

Fig. 2.6 Linear regression for frequency 25 kHz

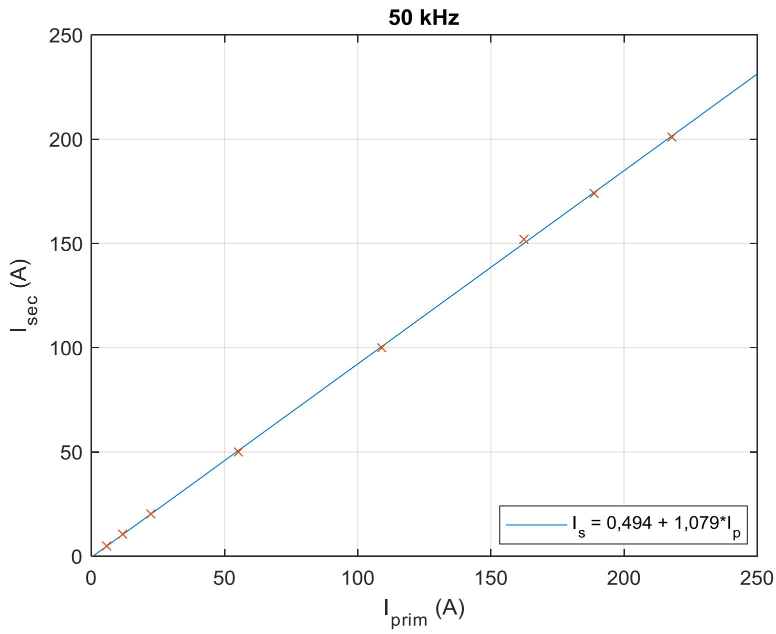

Fig. 2.7 Linear regression for frequency 50 kHz

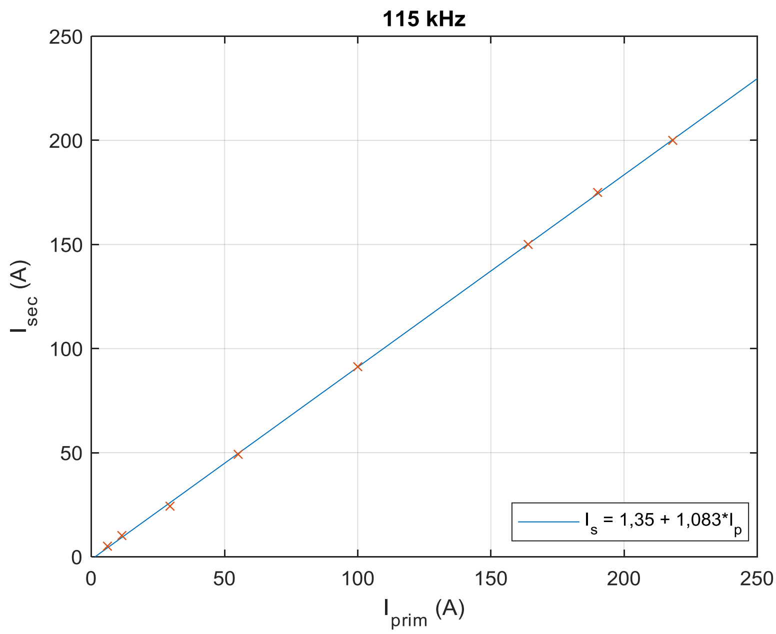

Fig. 2.8 Linear regression for frequency 115 kHz

Each one of Figs. 2.4-2.8 shows the linear regression (blue line) and values of currents obtained from measurement (red cross) for the specific frequency. It can be seen that deviation between obtained values and regression is not great and it will be neglected. Therefore, the calibration is performed as correction of data which are being obtained from digital output of the shunt by using a specific function in the PC evaluation algorithm. This function is based on created linear regressions. There is a connection between coefficients of these regression functions and frequency. This fact leads to the solution shown below.

Created correction function used for calibration looks like:

$$I_{\mathrm{sk}} = a_{(\mathrm{f})} + b_{(\mathrm{f})} \cdot I_{\mathrm{s}}, \tag{2.8}$$

where I_s corresponds to the output value of secondar current from the shunt which is adjusted by this function to more accuracy value I_{sk} after it is received by PC. The mentioned frequency dependency of coefficients $a_{(\mathrm{f})}$ and $b_{(\mathrm{f})}$ is determined from regression functions of minimum (50 Hz - min) and maximum (115 kHz - max) frequency as:

$$a_{(\mathrm{f})} = a_{\mathrm{min}} + \frac{a_{\mathrm{max}} - a_{\mathrm{min}}}{f_{\mathrm{max}} - f_{\mathrm{min}}} \cdot f = 0{,}335 + 8{,}828 \cdot 10^{-6} \cdot f, \tag{2.9}$$

$$b_{(\mathrm{f})} = b_{\mathrm{min}} + \frac{b_{\mathrm{max}} - b_{\mathrm{min}}}{f_{\mathrm{max}} - f_{\mathrm{min}}} \cdot f = 1{,}072 + 9{,}752 \cdot 10^{-8} \cdot f. \tag{2.10}$$

Finally, f is a frequency of measured signal.

3 Conclusion

The shunt calibrated by this procedure should returns values with accuracy close to accuracy of the system which was used to measuring stator currents (oscilloscope and current probe). Such a system has relative error ± 2,7 % according to their datasheets. If this condition is correct, the calibrated shunt should belong to accuracy class 3 which is defined in [1].

References

[1] ČSN EN 61869-2. *Přístrojové transformátory – Část 2: Dodatečné požadavky na transformátory proudu.* Praha: Úřad pro technickou normalizaci, metrologii a státní zkušebnictví, 2013, 80 s. Třídící znak 35 1350.

[2] MDO4104-6 Oscilloscope: http://www.farnell.com/datasheets/1948494.pdf

[3] http://www.pemuk.com/Userfiles/CWT/CWT%20-%20Technical%20notes%20-%20001.PDF

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Revision History

Rev.	Kapitola	Popis změny	Datum	Jméno