

Verification of the Calculation Method on CLAMP-ON Resistance Testing and Measurement

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Abstract—The paper concerns the applicability of the precise calculation of the resistances in an earthing system using the clamp-on method for contactless measurement of resistance. The importance of the calculative method application is evident in the critical cases of a system with only few (near three) earthing points. The paper bases on previous results obtained for the method of independent calculation of each separate earth resistance based on the results from direct clamp-on measurements.

Keywords—Clamp, Clamp-on, Method, Contactless, Resistance, Measurement, Grounding, Earth, Lightning, Protection, Electrical, Safety, Inspection, Verification

I. INTRODUCTION

The initial and periodical verification by measurement of the earth electrodes resistances [1] is an essential action for compliance with the criteria for Electrical Safety of installations regarding the personnel and electrical equipment, as well as for the approaches to support high level of Electrical Power Quality, Overvoltage Protections, Electromagnetic Compatibility and Lightning Protection. Many national regulations harmonized with the European Directive HD 60364 [1] recommend the application of the clamp-on methods. In HD 60364 these methods are mentioned and discussed specially in terms of electrical safety and lightning protections in TN systems and within meshed earthing in TT systems (Method C3), with the assumption: “As the resulting value of parallel resistances $R_1 \dots R_n$ is normally negligible...” [1], shown on Fig. 1.

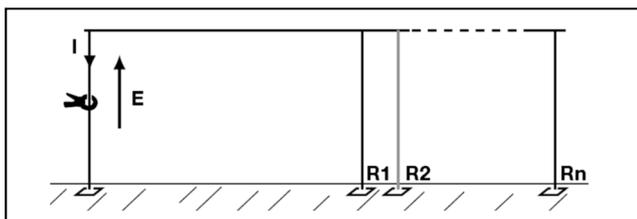


Fig. 1. Clamp-on method for measuring of earth resistance in a grounding system of earth electrodes (Source Chauvin-Arnoux [2])

The method is well described in technical guides and literature [2, 3, 4, 5, 6]. As it is pointed out in [6]: ‘The method itself sets a prerequisite for a methodical error, which in case of inspections and control of the installations lead to a risk of a false increasing the separate resistance and false overpassing the control limits’. This error itself is always positive and if the measured values are down the established norms the result could be considered as “Good” or “Pass”.

II. PROBLEM DESCRIPTION

A. *Calculation of the separate grounding resistances in a system with three earth points using contactless clamp-on method*

The paper [6] gives the solution for calculation of the separate grounding resistances in a system with three earth points, eliminating the mentioned above positive methodical error as follow:

$$R_{E1} = \frac{(R_1 R_2 + R_1 R_3 - R_2 R_3)}{(R_1 + R_2 + R_3) - \frac{1}{2} \left(\frac{R_1 R_2}{R_3} + \frac{R_2 R_3}{R_1} + \frac{R_1 R_3}{R_2} \right)}, \Omega \quad (1)$$

$$R_{E2} = \frac{(R_1 R_2 + R_2 R_3 - R_1 R_3)}{(R_1 + R_2 + R_3) - \frac{1}{2} \left(\frac{R_1 R_2}{R_3} + \frac{R_2 R_3}{R_1} + \frac{R_1 R_3}{R_2} \right)}, \Omega \quad (2)$$

$$R_{E3} = \frac{(R_1 R_3 + R_2 R_3 - R_1 R_2)}{(R_1 + R_2 + R_3) - \frac{1}{2} \left(\frac{R_1 R_2}{R_3} + \frac{R_2 R_3}{R_1} + \frac{R_1 R_3}{R_2} \right)}, \Omega \quad (3)$$

Where:

- R_1 , R_2 and R_3 are the direct measured resistances with clamp-on instrument;
- R_{E1} , R_{E2} and R_{E3} are the calculated values of the requested resistances of the earth electrodes, avoiding the methodical error.

As it is described in [5] the case of tree grounding points in the grounding system is the most critical case and it limits the down number of earthing resistances for applicability of the Clamp-on method according the most literature sources. The present paper focuses on its verification only.

B. *Verification of the Calculation Method*

The method for result treatment needs verification before to recommend it for practice and software implementation. A quick verification, based on a substitution with known resistances is proposed in [6], solving the calculations according the expressions (1), (2) and (3) in both ways. At present work in addition to the simulative approach [6] a real laboratory test is applied for verification of the Calculation Method.

III. SIMULATIVE APPROACH

The simulative approach is applied on the base of EXCEL tables where three random values of the resistances R_{E1} , R_{E2}

and R_{E3} are pre-selected. Each measured resistance in the system will be influenced (Fig. 1) by the others as follows (4):

$$R_1 = R_{E1} + \frac{\prod_{i=2}^N R_{E_i}}{\sum_{i=2}^N \prod_{j=2, j \neq i}^N R_{E_j}}, \Omega \quad (4)$$

From the three random “true” or “nominal” values of the resistances R_{E1} , R_{E2} and R_{E3} are calculated “reversely” the “measured” initial values for R_1 , R_2 and R_3 according (4). These values simulate the real measurements.

$$R_1 = R_{E1} + \frac{R_{E2}R_{E3}}{R_{E2}+R_{E3}}, \Omega \quad (5)$$

$$R_2 = R_{E2} + \frac{R_{E1}R_{E3}}{R_{E1}+R_{E3}}, \Omega \quad (6)$$

$$R_3 = R_{E3} + \frac{R_{E1}R_{E2}}{R_{E2}+R_{E2}}, \Omega \quad (7)$$

Then the generated from (4), (5) and (6) values are applied in (1), (2) and (3) and the obtained results are compared with the initial values of R_{E1} , R_{E2} and R_{E3} . Some results are shown in the next Table I. They are based on the generation of initial values in a reasonable from practical point of view range.

TABLE I. SIMULATION RESULTS

Nominal Value	Ω	Ω	Ω	Ω
R_{E1n}	1,000000	2,000000	5,000000	0,050000
R_{E2n}	2,000000	2,000000	6,000000	7,000000
R_{E3n}	3,000000	2,000000	7,000000	6,000000
Generated	Ω	Ω	Ω	Ω
R_1	2,200000	3,000000	8,230769	3,280769
R_2	2,750000	3,000000	8,916667	7,049587
R_3	3,666667	3,000000	9,727273	6,049645
Calculated	Ω	Ω	Ω	Ω
R_{E1c}	1,000000	2,000000	5,000000	0,050000
R_{E2c}	2,000000	2,000000	6,000000	7,000000
R_{E3c}	3,000000	2,000000	7,000000	6,000000

Nominal Value	Ω	Ω	Ω	Ω
R_{E1n}	25,000000	0,038000	36,500000	1,260000
R_{E2n}	20,000000	0,002000	43,700000	9,170000
R_{E3n}	0,001000	0,004000	22,700000	24,500000
Generated	Ω	Ω	Ω	Ω
R_1	25,001000	0,039333	51,439608	7,932557
R_2	20,001000	0,005619	57,695777	10,368370
R_3	11,112111	0,005900	42,588404	25,607785
Calculated	Ω	Ω	Ω	Ω
R_{E1c}	25,000000	0,038000	36,500000	1,260000
R_{E2c}	20,000000	0,002000	43,700000	9,170000
R_{E3c}	0,001000	0,004000	22,700000	24,500000

Comparing the Real and Calculated values shows full compliance of the numbers.

The decimal dimension of the poles is wittingly chosen abnormally large to be seen the eventual deviation in the digits. It is noticeable the independence of the precision of the method [6] from the different values in the cells.

IV. LABORATORY MEASUREMENT APPROACH

The laboratory test is based on a set of reference resistors, connected to simulate the grounding system according Fig.1. Each set of three resistors form initial values of R_{E1} , R_{E2} and R_{E3} and has known values of the resistances.

The nominals of the reference resistors are precisely preliminary measured with a traceably calibrated microohmmeter as it is shown at the Fig. 2.



Fig. 2. Measuring the nominals of the reference resistors

‘TWO WIRE’ connection is used during the measurement of the resistors do not differ from the necessary connection for the experiment. In such way, the resistance of the connecting cables and junctions participates in the measurement results, what limits the used resistances to ‘ohms’ range.

Three different Clamp-on instruments, were used to measure each set of three resistors.

A. Round hole instrument

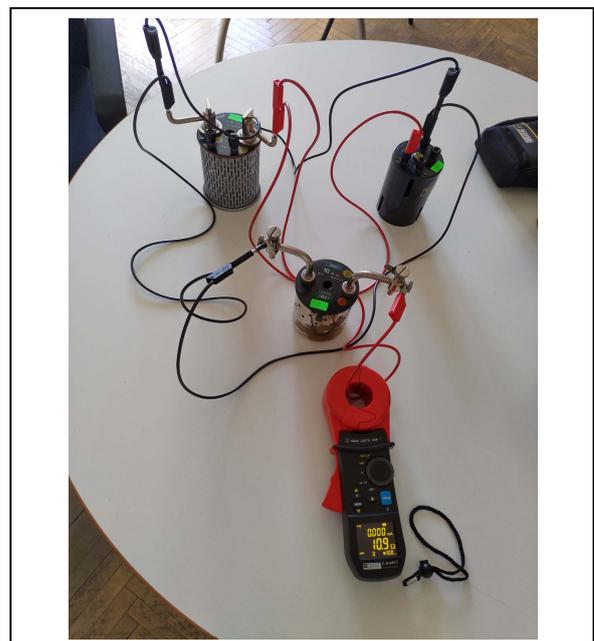


Fig. 3. Round hole Clamp-on measurement instrument CA 6117

CA 6117 (Fig. 3) is a typical instrument, designed mainly for wire connection to the grounding rods. It has a small 32 mm round hole what suppose better accuracy and less applicability regarding the dimension of the conductor.

B. Elongated hole instrument

CA 6118 is an instrument applicable in case of busbars. It is simplified enough and is typical representative for the most used on-site instruments for now (Fig. 4).



Fig. 4. Elongated hole Clamp-on measurement instrument CA 6118

C. Two clamps instrument

CA 6472 is a combined instrument with a 2-clamps mode which allow the Clamp-on measurement. The clamps are large enough to clamp busbars. The accuracy here depends on the positions of the clamps one to another. It is possible to pre-select the working frequency. The highest frequency 1611 Hz was selected for the tests, due to the short distance between the clamps (Fig. 5).



Fig. 5. Two clamps instrument CA 6472

D. The experiment

The results from the experiment are shown in the Table II to Table V. Nominal values for R_{E1n} , R_{E2n} and R_{E3n} are the values measured with the referent microohmmeter.

Measured values R_1 , R_2 and R_3 are the values measured with the respective Clamp-on instrument CA 6117, CA 6118 or CA 6472. The row after each measured value is the calculated percentage deviation between R_1 and R_{E1n} , and respectively for R_2 and R_{E2n} or R_3 and R_{E3n} . This deviation comes mainly from methodical error if the results from direct measurements are accepted as final results for conformity assessment.

Values for R_{E1c} , R_{E2c} and R_{E3c} are calculated according (1), (2) and (3) from measured R_1 , R_2 and R_3 . The row after each calculated value is the percentage deviation between R_{E1c} and R_{E1n} , and respectively for R_{E2c} and R_{E2n} or R_{E3c} and R_{E3n} . The values for R_{E1c} , R_{E2c} and R_{E3c} are 'free' from methodical error, much more accurate and appropriate for initial and periodical verification in case of inspections.

TABLE II. MEASURED AND CALCULATED RESULTS. CASE I

Nominal Values			
R_{E1n} , Ω	1,009	1,009	1,009
R_{E2n} , Ω	10,03	10,03	10,03
R_{E3n} , Ω	10,01	10,01	10,01
Measured	CA 6117	CA 6118	CA 6472
R_1 , Ω	6,1	6,1	5,8
R_{1DEV} %	504,6	504,6	475,8
R_2 , Ω	11,0	11,1	10,7
R_{2DEV} %	9,7	10,7	6,7
R_3 , Ω	11,0	11,0	10,8
R_{3DEV} %	9,9	9,9	7,9
Calculated			
R_{E1c} , Ω	1,09	1,05	0,81
R_{E1cDEV} %	8,28	4,18	-19,76
R_{E2c} , Ω	10,01	10,15	9,95
R_{E2cDEV} %	-0,15	1,18	-0,79
R_{E3c} , Ω	10,01	10,05	10,05
R_{E3cDEV} %	0,05	0,37	0,41

In Table II (Case 1) R_{E1n} has a smallest nominal in the set of the three resistors and the obtained value for R_1 has an abnormal deviation R_{1DEV} .

This abnormal error is eliminated with the calculation method [6] – respectively value R_{E1c} and its percentage error R_{E1cDEV} .

In Table III (Case 2) R_{E2n} and R_{E3n} have values about ten times less than R_{E1n} what also leads to abnormal deviations of R_{2DEV} and R_{3DEV} .

This case, confirms the efficiency of the calculation method [6] with significantly better results (Table III).

TABLE III. MEASURED AND CALCULATED RESULTS. CASE 2

Nominal Values			
R_{E1n}, Ω	100	100	100
R_{E2n}, Ω	10,3	10,3	10,3
R_{E3n}, Ω	10,1	10,1	10,1
Measured			
	CA 6117	CA 6118	CA 6472
R_1, Ω	105,0	104,0	101,0
$R_{1DEV} \%$	5,0	4,0	1,0
R_2, Ω	19,2	19,4	18,8
$R_{2DEV} \%$	86,4	88,3	82,5
R_3, Ω	19,2	19,3	19,0
$R_{3DEV} \%$	90,1	91,1	88,1
Calculated			
R_{E1c}, Ω	99,97	98,93	96,06
$R_{E1cDEV} \%$	-0,03	-1,07	-3,94
R_{E2c}, Ω	10,06	10,43	9,35
$R_{E2cDEV} \%$	-2,33	1,25	-9,18
R_{E3c}, Ω	10,06	9,87	10,48
$R_{E3cDEV} \%$	-0,40	-2,32	3,72

TABLE IV. MEASURED AND CALCULATED RESULTS. CASE 3

Nominal Values			
R_{E1n}, Ω	100	100	100
R_{E2n}, Ω	100	100	100
R_{E3n}, Ω	10,1	10,1	10,1
Measured			
	CA 6117	CA 6118	CA 6472
R_1, Ω	109,0	108,0	105,0
$R_{1DEV} \%$	9,0	8,0	5,0
R_2, Ω	109,0	108,0	105,0
$R_{2DEV} \%$	9,0	8,0	5,0
R_3, Ω	60,0	60,0	58,1
$R_{3DEV} \%$	494,1	494,1	475,2
Calculated			
R_{E1c}, Ω	99,85	98,18	95,77
$R_{E1cDEV} \%$	-0,15	-1,82	-4,23
R_{E2c}, Ω	99,85	98,18	95,77
$R_{E2cDEV} \%$	-0,15	-1,82	-4,23
R_{E3c}, Ω	10,08	10,91	10,22
$R_{E3cDEV} \%$	-0,23	8,01	1,14

The conclusion for Case 3 (Table IV) is equal to the conclusion for Case 1 (Table II) with a note that the resistances in Case 3 have about ten times higher values than the resistances in Case 1.

TABLE V. MEASURED AND CALCULATED RESULTS. CASE 4

Nominal Values			
R_{E1n}, Ω	100	100	100
R_{E2n}, Ω	1,009	1,009	1,009
R_{E3n}, Ω	10,1	10,1	10,1
Measured			
	CA 6117	CA 6118	CA 6472
R_1, Ω	100,0	100,0	100,0
$R_{1DEV} \%$	0,0	0,0	0,0
R_2, Ω	10,1	10,3	10,0
$R_{2DEV} \%$	901,0	920,8	888,1
R_3, Ω	11,1	11,2	10,8
$R_{3DEV} \%$	9,9	10,9	6,9
Calculated			
R_{E1c}, Ω	99,43	98,90	98,90
$R_{E1cDEV} \%$	-0,57	-1,10	-1,10
R_{E2c}, Ω	0,60	1,23	1,24
$R_{E2cDEV} \%$	-40,57	22,17	22,82
R_{E3c}, Ω	10,50	9,98	9,58
$R_{E3cDEV} \%$	4,00	-1,16	-5,19

In the Case 4 (Table V) the ratio between the reference resistances is 1:10:100. Noticeable is that the lowest value R_{E2n} has a significant deviation R_{E2cDEV} even after calculation (2) of the value R_{E2c} but it highly depends on the instrumental error during the measurement. This could be a case of additional studies.

Even with this deviation the results from the calculation method [6] have more than 20 times less error than the results from direct measurements.

V. APPLICATIONS

Some application could clarify the reasonability to use the calculation approach [6]. In Table VI are shown two cases from real on-site lightning system measurements.

TABLE VI. PRACTICAL ON-SITE CASES

Measured	Practical Case 1	Practical Case 2
R_1, Ω	12,50	17,55
R_2, Ω	18,70	16,33
R_3, Ω	18,30	15,08
Calculated		
R_{E1c}, Ω	5,16	12,53
R_{E2c}, Ω	14,90	11,02
R_{E3c}, Ω	14,47	9,22

In the each of the two practical cases the norm is 20 Ohms. The calculation with the results from direct measurement, multiplied by the seasonal multiplication index $\varphi=1.3$ and the impulse index $\alpha=1.1$ leads to non-conformity of the lightning system.

The calculation with the results obtained after application of the calculation method [6] guarantee strong conformity.

TABLE VII. HYPOTHETIC ON-SITE CASES

Measured	Limit	Norm	Over
$R_{1, \Omega}$	13,99	20,00	20,98
$R_{2, \Omega}$	13,99	20,00	20,98
$R_{3, \Omega}$	13,99	20,00	20,98
Calculated			
$R_{E1c, \Omega}$	9,33	13,33	13,99
$R_{E2c, \Omega}$	9,33	13,33	13,99
$R_{E3c, \Omega}$	9,33	13,33	13,99

In Table VII three hypothetical cases are discussed:

The first column is the case where the measurement of the three grounding rods gives border values considering the seasonal multiplication index $\varphi=1.3$ and the impulse index $\alpha=1.1$. The calculated results assure conformity.

The second column is the case when the measurement have border values without taking into account the seasonal multiplication index $\varphi=1.3$ and the impulse index $\alpha=1.1$. The conformity is also confirmed in this case.

Just in the case of third column the limit is reached, what means practical reserve of 7,00 Ω or about 30 % from direct measurement.

VI. CONCLUSION

The applicability and workability of the calculation method [6] is verified. It could be recommended for all Clamp-on testing and measurement in the systems with three parallel resistances.

The best result the method gives in the case of measured close each to other values for the three resistances circuits.

The method [6] gives the opportunity to implement a simple algorithm in the instruments based on Clamp-on method, designated to the cases of three electrodes systems.

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