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Transición energética en la 4ta revolución industrial

Universidad Tecnológica de Pereira

UNIVERSIDAD NACIONAL DE COLOMBIA

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Some problems and solutions in Pole Transformers Grounding

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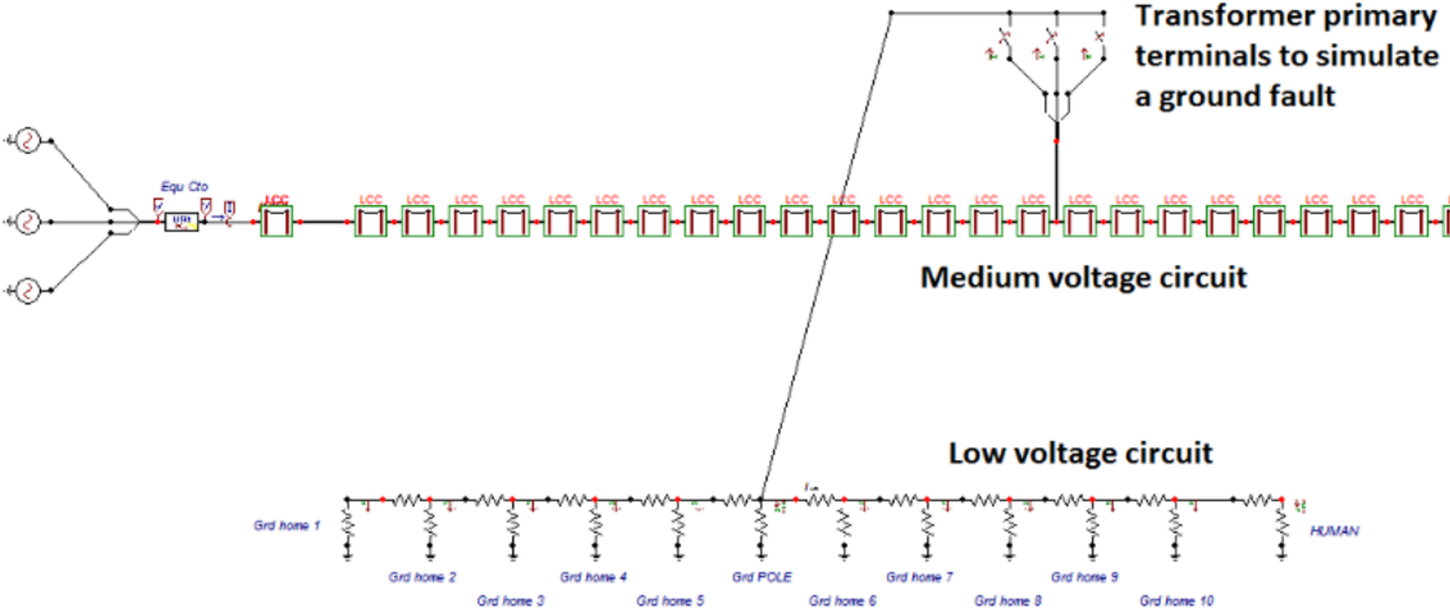
Contents

I. Introduction

- Electromagnetic coupling between distribution systems and living beings through the grounding system of transformers installed on distribution network poles.
- Deficiencies in the information provided by some utilities for the calculation of the grounding design current.
- Real grounding practices for pole transformers.
- Results of calculations of contact and step voltages in traditional designs.
- Proposal for a solution with an unconventional grounding that includes artificial soil.

II. Practices and common errors in grounding of distribution networks (1)

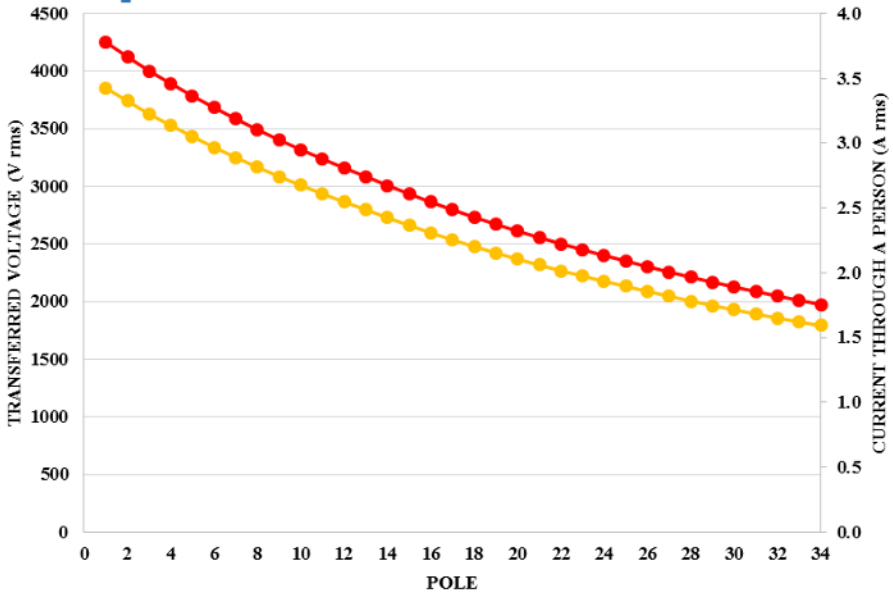
Ground fault ATP modeling.



II. Practices and common errors in grounding of distribution networks (2)

Voltage and current through a person.

Fault clearance time (s)	Maximum tolerable voltage (V) (rms a.c.) for people of 50 kg	Maximum tolerable current (A) (rms a.c.) for people of 50 kg
0.10	366.82	0.367
0.15	299.51	0.300
0.20	259.38	0.259
0.30	211.79	0.212
0.40	183.41	0.183
0.50	164.05	0.164
0.60	149.76	0.150
0.70	138.65	0.139
1.00	116.00	0.116



Current through a human body due to a voltage transferred from the pole transformer to the user. Red: voltage. Yellow: current.

III. Touch and step voltages under some usual conditions in pole transformers

Case analysis:

- Network voltage (kV): 13.2
- Rod length (m): 2.4
- Rod diameter (m): 0.016
- Burial depth of the upper part of the rod (m): 0.50
- Symmetrical Single-Phase Fault Current (A): 2,280
- Asymmetrical Single-Phase Fault Current (A): 2,681.4
- High Resistivity Surface Layer Soil (Ωm): 2,500
- Surface layer thickness (m): 0.2
- Fault duration (s): 0.3 and 0.5

Case I: Simulations for a grounding rod without soil treatment

ρ (Ωm)	Rpt (Ω)	Ig (A)	GPR (V)	Vt (V)	Vs (V)	Tf (s) = 0.5		Tf (s) = 0.3	
						Vt_M (V)	Vs_M (V)	Vt_M (V)	Vs_M (V)
ρ= 50	19.9	349.4	6939.7	4889.0	540.9	668.5	2181.9	863.0	2816.8
ρ= 100	39.7	183.3	7280.5	5129.2	567.5	670.8	2190.9	866.0	2828.4
ρ_1= 50, ρ_2= 25, h= 1 m	11.1	577.3	6426.3	4549.3	503.0	668.5	2181.9	863.0	2816.8
ρ_1= 25, ρ_2= 50, h=1 m	16.4	414.6	6799.9	4768.7	508.9	667.4	2177.3	861.6	2810.9
ρ= 800	317.8	23.9	7579.2	5339.6	590.8	702.4	2317.4	906.8	2991.8
ρ= 2300	913.6	8.3	7610.6	5361.7	593.2	770.2	2588.6	994.3	3341.9

Case II: Simulations for a grounding rod with surrounding soil treatment

ρ (Ωm)	Rpt (Ω)	Ig (A)	GPR (V)	Vt (V)	Vs (V)	Tf (s) = 0.5		Tf (s) = 0.3	
						Vt_M (V)	Vs_M (V)	Vt_M (V)	Vs_M (V)
ρ= 50	8.8	698.0	6131.8	2032.1	1105.9	668.5	2181.9	863.0	2816.8
ρ= 100	17.6	390.1	6853.3	2271.2	1236.0	670.8	2190.9	866.0	2828.4
ρ_1= 50, ρ_2= 25, h= 1 m	4.9	1049.5	5165.9	1806.8	903.0	668.5	2181.9	863.0	2816.8
ρ_1= 25, ρ_2= 50, h=1 m	7.3	801.3	5862.2	1975.2	965.2	667.4	2177.3	861.6	2810.9
ρ= 800	140.6	53.5	7524.3	2493.6	1357.0	702.4	2317.4	906.8	2991.8
ρ= 2300	404.1	18.8	7589.0	2515.1	1368.7	770.2	2588.6	994.3	3341.9

Case III: Simulations for two grounding rods without soil treatment

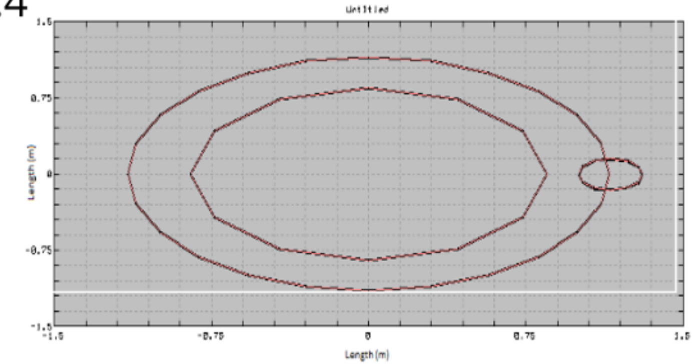
ρ (Ωm)	Rpt (Ω)	Ig (A)	GPR (V)	Vt (V)	Vs (V)	Tf (s) = 0.5		Tf (s) = 0.3	
						Vt_M (V)	Vs_M (V)	Vt_M (V)	Vs_M (V)
ρ= 50	9.4	660.1	6223.8	2456.0	1115.9	668.5	2181.9	863.0	2816.8
ρ= 100	18.9	366.1	6904.4	2724.6	1238.0	670.8	2190.9	866.0	2828.4
ρ_1= 50 ρ_2= 25 h= 1 m	5.6	965.8	5409.1	2295.2	976.4	668.5	2181.9	863.0	2816.8
ρ_1= 25 ρ_2= 50 h=1 m	7.3	803.4	5857.6	2102.3	1024.3	667.4	2177.3	861.6	2810.9
ρ= 800	150.9	49.9	7530.8	2971.8	1350.3	702.4	2317.4	906.8	2991.8
ρ= 2300	433.7	17.5	7590.0	2995.1	1360.9	770.2	2588.6	994.3	3341.9

Case IV: Simulations for two grounding rods and soil treatment

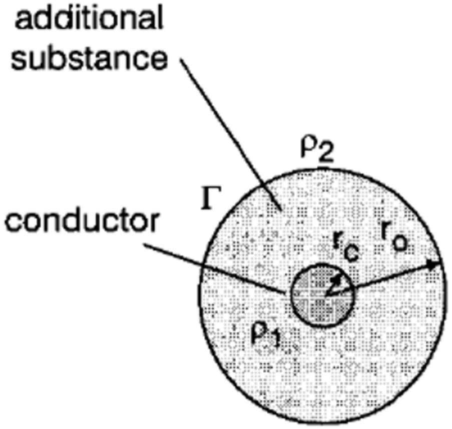
ρ (Ωm)	Rpt (Ω)	Ig (A)	GPR (V)	Vt (V)	Vs (V)	Tf (s) = 0.5		Tf (s) = 0.3	
						Vt_M (V)	Vs_M (V)	Vt_M (V)	Vs_M (V)
ρ= 50	5.5	979.6	5369.8	799.5	1208.3	668.5	2181.9	863.0	2816.8
ρ= 100	11.0	584.5	6408.2	954.1	1441.9	670.8	2190.9	866.0	2828.4
ρ_1= 50 ρ_2= 25 h= 1 m	3.1	1360.8	4170.4	669.1	955.4	668.5	2181.9	863.0	2816.8
ρ_1= 25 ρ_2= 50 h=1 m	4.6	1097.2	5023.2	686.4	1060.1	667.4	2177.3	861.6	2810.9
ρ= 800	87.7	85.1	7466.7	1111.7	1680.1	702.4	2317.4	906.8	2991.8
ρ= 2300	252.2	30.0	7567.5	1126.7	1702.8	770.2	2588.6	994.3	3341.9

IV. Feasible solutions

- One capacitive grounding kit of 90 kg and two conductors in circular arrangements of 0.85 m and 1.15 m radii embedded in the low resistivity material (LRM).
- Burial depth of the grounding configuration (m): 0.4
- Network voltage (kV): 13.2
- Symmetrical Single-Phase Fault Current (A): 2,280
- Asymmetrical Single-Phase Fault Current (A): 2,681.4
- High Resistivity Surface Layer Soil (Ωm): 2,500
- Surface layer thickness (m): 0.2
- Fault duration (s): 0.3 and 0.5



Calculation of equivalent diameter and earthing resistance



$$r_e = r_c \left(\frac{r_0}{r_c}\right)^{1-\frac{\rho_1}{\rho_2}}$$

M. Kurtovic, S Vujevic, "Earthing Grid Parameters with Conductor Surrounded by an Additional Substance", IEE Proc-Gener. Transm. Distrib, Vol. 147, No. 1, January 2000.

IEEE 80:2013, eq. 63: $R_{CE-rod} = \frac{1}{2\pi L_r}\left(\rho_c\left[ln(D_C/d)\right] + \rho\left[ln(8L_r/D_C)-1\right]\right)$

where

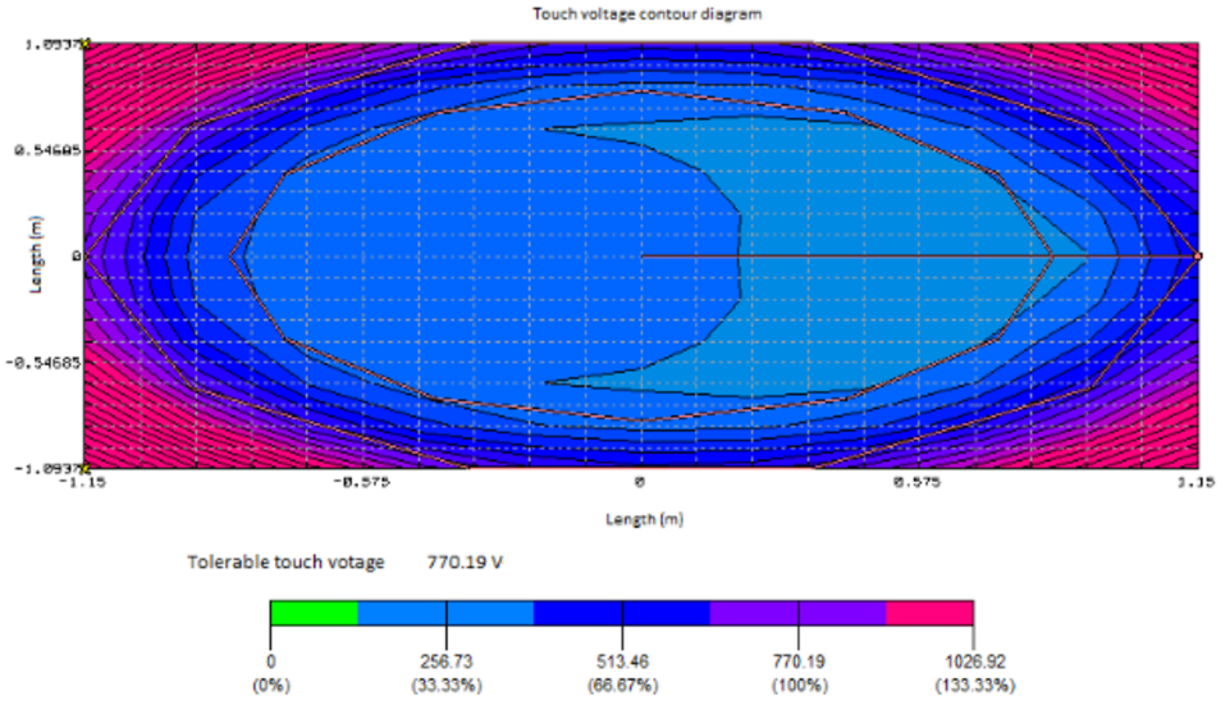
ρ_c	is the resistivity of the concrete in Ωm
ρ	is the resistivity of the soil in Ωm
L_r	is the length of the ground rod in m
d	is the diameter of the ground rod in m
D_C	is the diameter of the concrete shell in m

Case V: Simulations for a capacitive well of 90 kg and two electrodes in circular arrangements of 0.85 m and 1.15 m radii embedded in LRM

ρ (Ωm)	Rpt (Ω)	Ig (A)	GPR (V)	Vt (V)	Vs (V)	Tf (s) = 0.5		Tf (s) = 0.3	
						Vt_M (V)	Vs_M (V)	Vt_M (V)	Vs_M (V)
ρ= 50	4.0	1129.9	4506.9	428.8	1402.1	668.5	2181.9	863.0	2816.8
ρ= 100	8.0	726.4	5789.3	554.5	1794.8	670.8	2190.9	866.0	2828.4
ρ_1= 50 ρ_2= 25 h= 1 m	2.2	1466.3	3258.6	404.7	1107.6	668.5	2181.9	863.0	2816.8
ρ_1= 25 ρ_2= 50 h=1 m	3.5	1217.44	4203.7	306.0	1174.7	667.4	2177.3	861.6	2810.9
ρ= 800	64.7	114.1	7338.3	686.7	2296.1	702.4	2317.4	906.8	2991.8
ρ= 2300	186.1	40.6	7424.6	708.2	2317.6	770.2	2588.6	994.3	3341.9

Case V (continuation):

The simulation results for a soil resistivity of 2,300 Ωm is shown. The maximum tolerable touch voltage, calculated according to IEEE 80: 2013 is 770.19 V and it can be clearly seen that the touch voltage 1 m around the pole is controlled.

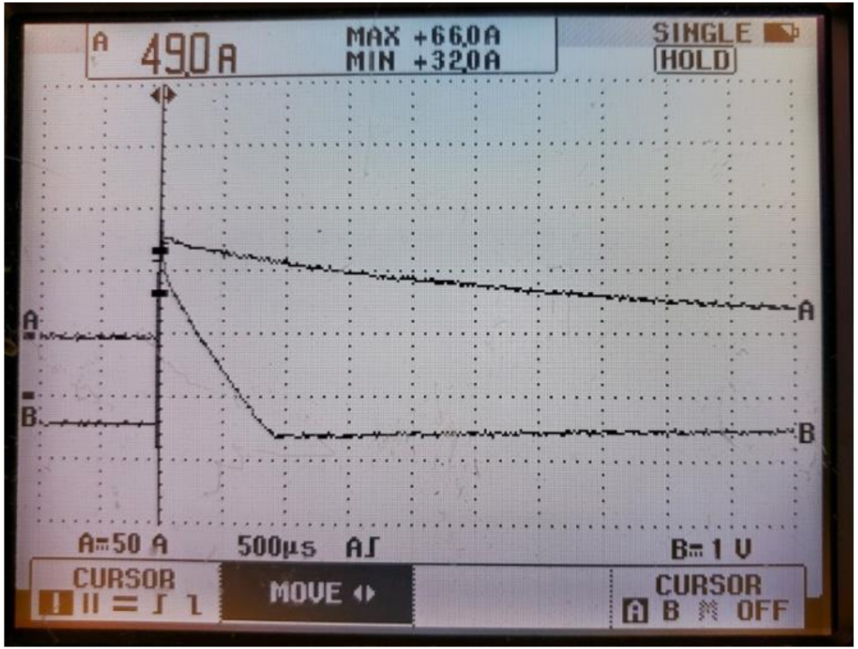


Case VI: A real practical case

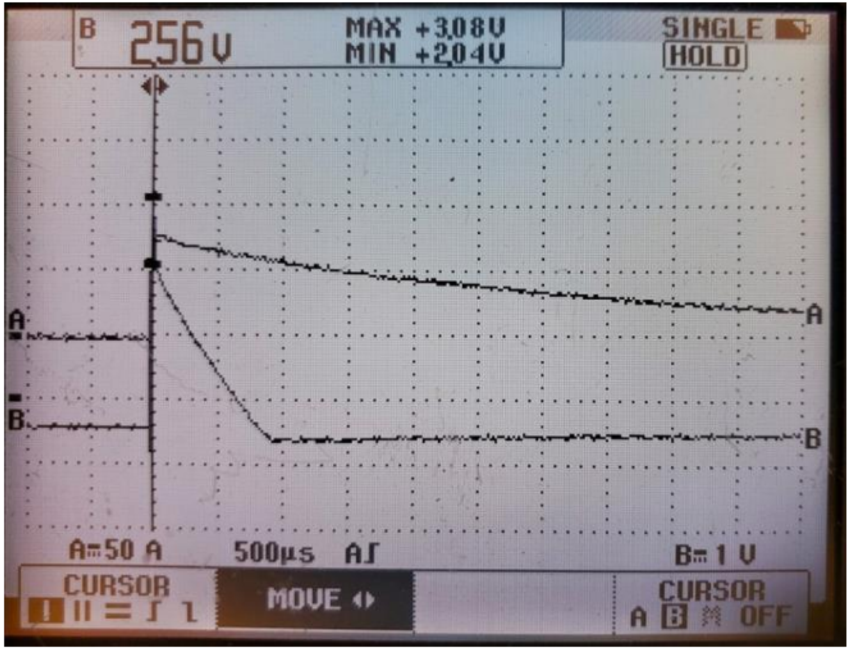
To illustrate with a real example, the results of field touch and step voltage measurements are shown; they were carried out on the grounding of a distribution transformer installed on a pole, located in a rural area in the west of the department of Boyacá (Colombia):

- The described capacitive well of 90 kg and two conductors in circular arrangements of 0.85 m and 1.15 m radii, embedded in the LRM.
- Burial depth of the grounding configuration (m): 0.4
- Symmetrical three-phase fault current (A): 418.50
- Asymmetrical three-phase fault current (A): 573.39
- Symmetrical single-phase fault current (A): 253.00
- Asymmetrical single-phase fault current (A): 376.37
- Grounding resistance (Ω): 7.27
- Ground current for this resistance (A): 200.39
- No surface layer
- Fault duration (s): 0.5

Case VI (continuation): Touch voltage measurement



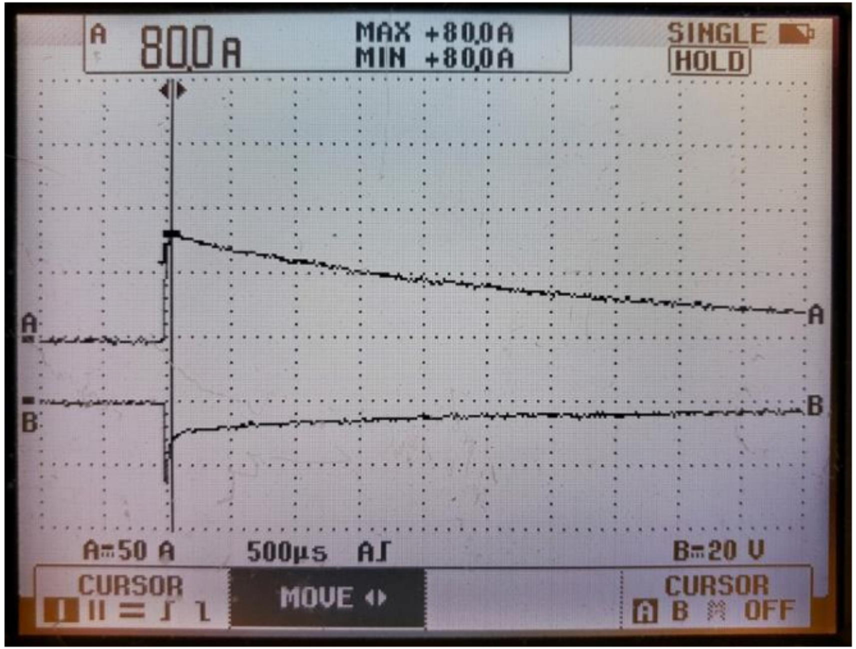
Impulse current



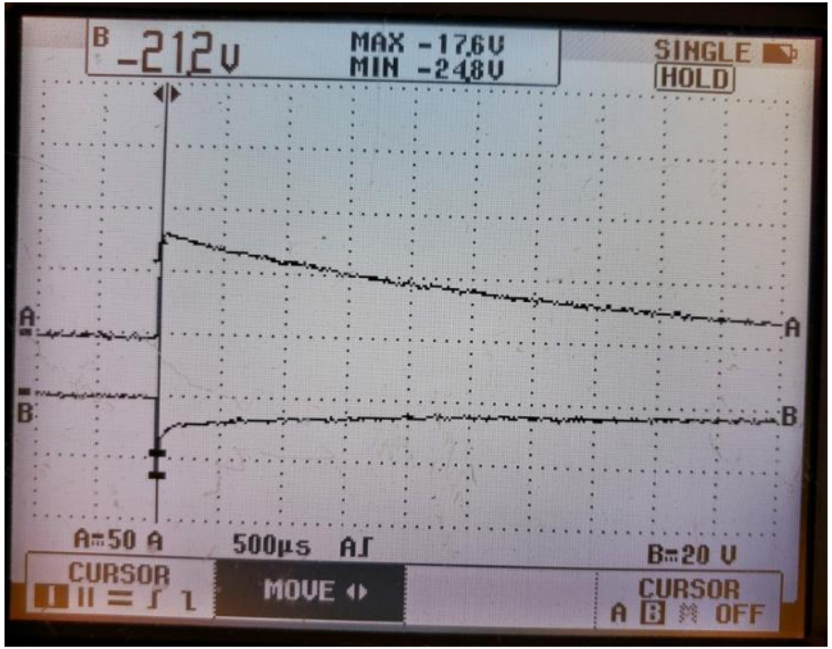
Touch voltage

$$(200.39 / 66) * 3.08 = 9.35 \text{ V}$$

Case VI (continuation): Step voltage measurement



Impulse current



Step voltage

(200.39 / 80) * 24.8 = 62.12 V

V. Conclusions

- Some usual arrangements of pole transformers groundings in Colombia were analyzed through specific cases (cases I to IV) and it was shown they do not abide by standard safety requirements.

- A nonconventional alternative to those usual arrangements was proposed and showed to behave safely, i.e touch and step voltages are under the respective tolerable voltages. Case V, for simulated cases roughly comparable to the cases I to IV, illustrate this. In addition, the measurements in the practical case also showed that the nonconventional alternative get to control the shock voltages.

- The simulations of case 5 showed that the same solution covers a wide range of soil resistivities and ground currents and the results of the touch and step voltage measurements showed that this solution behaves safely in practical conditions.

- This permits inferring that it is possible to elaborate a guide for grounding pole transformers in medium voltage distribution networks with no neutral conductor by characterizing the situation mainly for resistivity and ground fault current ranges as EPM did in its own standard.

VI ¿Questions?