The General Equation Of The Pipe To Soil Potential At All Humidity Conditions By The Use Of Both Soil Factor and Stray Potential Of The Pipe-Soil-Earthing Grid System

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Abstract: For pipe-soil-earth system, the buried pipe line segment with soil surrounding medium could be simulated electrically by an electric circuit where the system is subjected to the law: charge = capacitance × voltage between the pipe surface and earth. This is where each of circuit electric parameter (electrolytic stray capacitor between pipe & earth, the stray potential across the stray capacitor, surface charge and the protection current of the cathodic protection system passed through the pipe segment) could be obtained by an equation which is function of the measured electrochemical properties of the soil (soil factor), 4^{th} degree polynomial at room temperature but the A's constants are different for each electric quantity .The constants of each equation (A's) considered to be as a print of such pipe-soil-earth system . The useful of these prints is to obtain complete electrical data correlated with many cathodic protection levels**.** One of the most critical problems in CP systems is the presence of the earthing network beside the protected pipe line**.** The behavior of the stray potential between the external surface of the pipe and earth could be plotted as stray potential print which will be always valid in all times as the pipe-soil-earth system is maintained and without any external interference. This paper tries to calculate pipe to soil potential along the pipe line without the need of $Cu/CuSO_4$ half cell by the deduction of a general equation of the pipe to soil potential which is function of an electric quantities and system's print. In other words, the aim is to deduce a correlation between pipe to soil potential and both of the measured stray potential of the pipe segment and the measured soil factor around it in the presence of an earthing grid.

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1. Introduction:

The behavior of the electrical parameters (stray potential V_{P-PE}, stray capacitor C_{P-PE}, surface total charge Q and protection current I_P) of the pipe-soil-earth system, during the change of the electrochemical properties of the soil, with and without applying cathodic protection system, could be plotted as an electrical parameter PRINT which will be always valid in all times as the pipe-soil-earth system is maintained and without any external interference. Once the system is changed by replacement another pipe with different dimension and/or the replacement of the soil (or by humidity change), there will be another new electrical parameter PRINT for the new pipe-soil-earth system. Also, the buried pipe line segment with soil surrounding medium could be simulated electrically by an electric circuit where the system is subjected to the law Q = C×V between the pipe surface and remote earth. This is where each of circuit electric parameter could be obtained by an equation which is function of the measured electrochemical properties of the soil (soil factor), 4^{th} degree polynomial at room temperature but the A's constants are different for each electric quantity. The constants of each equation (A's) considered to be as a PRINT of such pipe-soil-earth system [10] [12]. The useful of these PRINTS are to obtain complete electrical data correlated with many cathodic protection levels which help, after complete erection of the pipeline, in defining the cathodic protection level of any pipe line segment through its length by measuring the protection current and / or the stray potential with of course computing of the soil factor at the pipe segment from direct field measurements [14]. The average error of the electrical parameters equations reduced to be less than ± 5%. The most important advantage of such electrical analogue circuit of pipe-soil-earth system is the possibility to simulate a complete pipeline-soil-earth system by an electric circuit and to convert the corrosion problem and cathodic protection of the pipeline to an electric problem [11] [13]. In the near future after completing such electrical studies of the pipe-soil-earth systems, this will help in corrosion monitoring and the maintenance of c.p systems. Not only has that but also to define the most suitable route of the pipe line, before the erection process, which generates the minimum surface charge. The most important result is that: the pipe to soil potential of any buried pipeline could be obtained segmental along its route without the need of both the test point and $Cu/CuSO_4$ half cell. This is by the use of the new electric concept of pipe-soil-earth system [14]. One of the most critical problems in CP systems is the presence of the earthing network beside the protected pipe line. The question now is: To what extent, the earthing grid would affect the cathodic protection system? This paper tries to calculate the pipe to soil potential along the pipe line without $Cu/CuSO_4$ half cell by measuring both the stray potential of the pipe and the soil factor around the pipe. In other words, this paper tries to find a direct correlation between the pipe to soil potential and the stray potential of the pipe for all boxes under test.

2. Literature Review

2.1 The Soil Factor

As the electrochemical properties of any soil are changed by the change of humidity but returns back to its initial conditions after some time required for soil dryness, we can define a new factor named the soil factor as: "The soil factor (S_f) is the instantaneous value of the electro-chemical properties of the soil based on the electrical properties at Humidity equal to 10% "[1] [2] and is equal to:

$$S_f = (1 / K_S)\ pH\ H \log \rho \quad \text{at room temperature} \quad (1)$$

Dimension of $[S_f] = [1/K_S]\ [pH]\ [H]\ [\log \rho] = \Omega.m\ \%$

Where:
S_f = soil factor Ω.m %
K_S = dielectric constant of the soil at H = 10%
pH = power of Hydrogen of the soil
H = humidity of the soil %
ρ = soil resistivity in Ω.m at H = 10%

Figure 1 shows the range values of the soil factor due to humidity change for 10 soil samples under test.

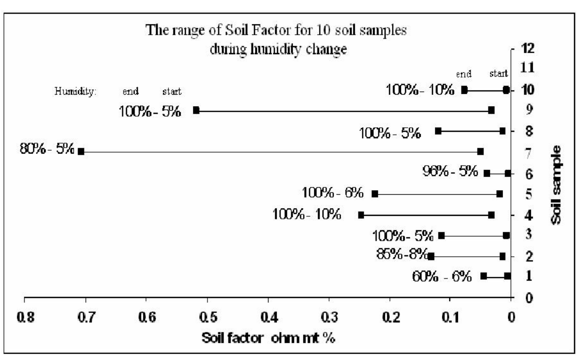

Figure 1: The range of the soil factor & humidity range for the soils under test

The importance of the soil factor is that it is combining all parameters which can affect directly on the cathodic protection level or in corrosion process. Such factors which can be obtained by a direct measurements from the field. This means that if it is possible to study the relationship between the soil factor and the electrical parameters of the bare pipe segment, then the print curves and the print constants of the electrical parameters of the pipe-soil-earth system could be obtained at natural condition with and without applying cathodic protection system. The soil factor can be considered to be as the key of many studies based on the new proposed electrical concept of corrosion. For an example, the general equation of the natural stray capacitance between external surface area of bare pipe segment and earth is obtained in terms of the soil factor with an average error ± 30% and its print curves and constants are obtained for pipe-soil-earth system for 10 different soils [3]. Also, the general equation of both the natural stray potential and the natural created charge are obtained in terms of the soil factor with an average error ± 30% and their print curves and constants are obtained for pipe-soil system for 10 different soils [4] [5]. Finally, the error of the general equation of the electrical parameters reduced to ± 5% [6] [7] [8] [9].

2.2 Stray Potential General Equation For Pipe – Soil – Earth Under Test Without Applying CP System [10] [12]

For each soil under test and from natural stray potential curves and equations, it can easily observe that the general equation of the natural stray potential from pipe segment to the earth during humidity change is a 4th degree polynomial equation which is function of the soil factor, $V_{n\ stray} = f\ (X = S_f)$. The stray potential general equation is given by Eq.2:

$$\mathbf{V_{n\ stray}} = A_{4vn}\mathbf{X^4} + A_{3vn}\mathbf{X^3} + A_{2vn}\mathbf{X^2} + A_{1vn}\mathbf{X} + A_{0vn} \quad (2)$$

Where:
A's: = $A_{(\ )V}$ are the natural stray potential print constants of the pipe soil under test
X = is the value of the soil factor at certain humidity

As an example, figure 2 shows the natural print of the stray potential of the pipe segments of boxes 1 & 18.

2.3 Natural Stray Potential Print Constants For Pipe-Soil-Earth Under Test

Now, the natural stray potential print constants of the pipe-soil-earth system under test are A_{4VN}, A_{3VN}, A_{2VN}, A_{1VN} and A_{0VN}. This means that these print values are valid for these pipe-soil systems under test at any time at the correspondent electrochemical properties (soil factor). Table 1 shows result example of the natural stray potential print.

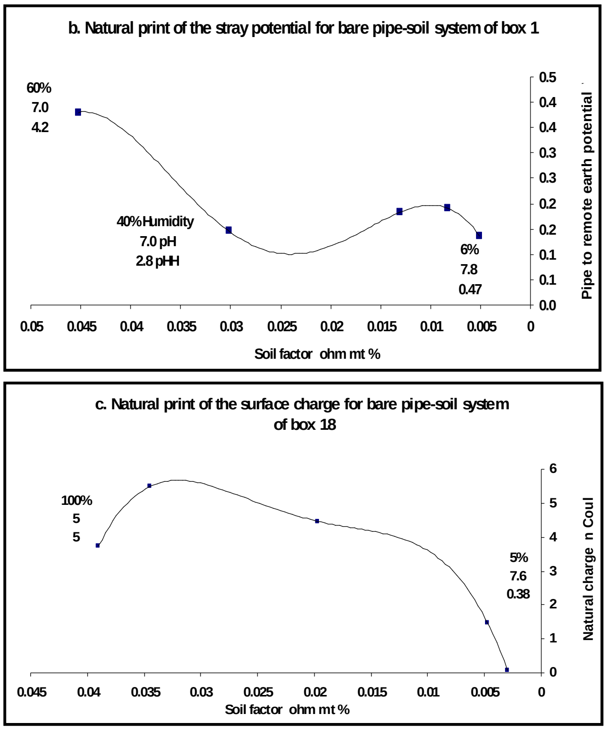

Figure 2: Stray Potential Prints for buried bare pipe-soil-earth of boxes 1&18

2.4 Stray Potential For Pipe-Soil-Earth Under Test With Applying CP System

From the stray potential PRINT curves and trend lines equations, as shown in figures 3b, 4b and 5b, it can easily observe that the general equation of the stray potential of a cathodically protected bare pipe segment during humidity change under multi level of cathodic protection levels is a 4^{th} degree polynomial equation which is function of the soil factor $V_{Str.} = f$ (X = soil factor). The stray potential general equation is equal to Eq. 3:

$$\mathbf{V_{Str.}} = A_{4V}\mathbf{X}^4 + A_{3V}\mathbf{X}^3 + A_{2V}\mathbf{X}^2 + A_{1V}\mathbf{X} + A_{0V} \quad (3)$$

Where:

A's: = $A_{()V}$ are the stray potential print constants of the pipe - soil under test

X = is the value of the soil factor at certain humidity

As an example, figure 3 shows the natural print of the stray potential of the pipe segments of boxes 1 & 9.

2.5 Stray Potential Print Constants For Pipe-Soil-Earth Under Test

Now, the stray potential PRINT constants of the pipe-soil-earth systems under test are A_{4V}, A_{3V}, A_{2V}, A_{1V} and A_{0V} at a definite cathodic protection level. This means that these print values are valid for these CP levels for these pipe soil systems under test at any time at the correspondent electrochemical properties (the soil factor). Table 2 shows result example of the stray potential print constants at CP level equal to -0.85 volt.

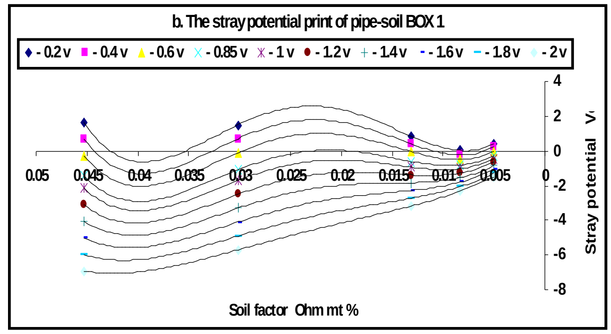

Figure 3a: Stray Potential PRINT curves of pipe-soil-earth of box 1 at multi of cathodic protection levels.

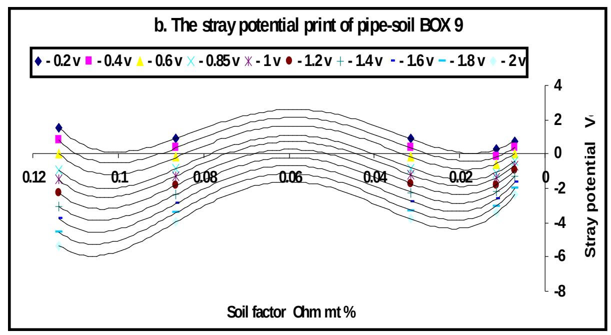

Figure 3b: Stray Potential PRINT curves of pipe-soil-earth of box 9 at multi of cathodic protection levels.

3. Analysis

As we said before, the print A's of the stray potential of the pipe segment to the earthing grid could be obtained from the general equation of the stray potential (3) and easily we can construct the print of the stray potential A's table for all boxes under test at pipe to soil potential, by the use of $Cu/CuSO_4$ half cell, from -0.2V up to -2V as per tables 2 as an example. The question now is: is it possible to rearrange the table results such that to be as stray potential A's for each box against the pipe to soil potential? This is as per tables 3 & 4 as an example for the stray potential A's against pipe to soil potential for boxes 10 & 13 respectively. What would be the results for all boxes under test?

Table 1: Natural PRINT constants of the stray potential for 10 different soil under test

Soil	**ρ_1**	**ρ_2**	**ρ_3**	**ρ_4**	**ρ_5**	**ρ_6**	**ρ_7**	**ρ_8**	**ρ_9**	**ρ_{10}**
Error	0	±30%	0	0	0	0	0	0	0	0
A_{4VN}	-2.E+06	0	321339	5620	8822.1	0	118.12	140960	0	546856
A_{3VN}	202688	698.68	-78007	-3154.1	-3710.9	-48181	-153.09	-37414	-110.64	-110280
A_{2VN}	-6782.5	-157.71	6025.9	599.26	407.17	2278.7	54.029	3218.8	100.61	7753.7
A_{1VN}	82.539	9.8253	-159.72	-44.958	-3.3452	-19.695	-3.1804	-99.254	-24.97	-215.37
A_{0VN}	-0.133	0.0009	1.377	1.412	0.0954	0.2352	0.1245	0.9629	1.2357	1.8678

Table 2: Stray potential finger print constants at pipe to soil potential equal to -0.85 volt

BOX	**ρ_1**	**ρ_2**	**ρ_3**	**ρ_4**	**ρ_5**	**ρ_6**	**ρ_7**	**ρ_8**	**ρ_9**	**ρ_{10}**
	1	4	9	10	13	18	19	24	27	28
A_{4V}	3.00E+07	0	925051	17354	1149.5	7.00E+07	861.17	0	2228.7	1.00E+06
A_{3V}	-3.00E+06	-1858.9	-223313	-9862.3	-4002.1	-7.00E+06	-1531.8	61.62	-2755.3	-194014
A_{2V}	91780	507.49	16975	1905.4	1569.6	211211	926.56	-232.3	1155.8	12478
A_{1V}	-1023	-37.7	-428	-143	-176.7	-2389.4	-204.8	35.484	-179.3	-321.02
A_{0V}	2.9327	-0.61	1.9	2.6	2.37	4.66	7.154	-2.19	4.49	1.6
Error	0	±30%	0	0	0	0	0	±30%	0	0

Table 3: Stray potential print constants of box10 at pipe to soil potential equal to -0.2 volt to -2 volt

	Box 10 ρ_4									
	-0.2	-0.4	-0.6	-0.85	-1	-1.2	-1.4	-1.6	-1.8	-2
A_4	2.43E+04	22128	20006	17354	15762	13640	11518	9395.4	7273.2	5151
A_3	-1.32E+04	-12146	-11131	-9862.3	-9100.9	-8085.8	-7070.7	-6055.6	-5040.4	-4025.3
A_2	2.37E+03	2224.1	2082.5	1905.4	1799.2	1657.6	1515.9	1374.3	1232.7	1091
A_1	-1.56E+02	-152.17	-148.12	-143.05	-140.02	-135.97	-131.91	-127.86	-123.81	-119.76
A_0	3.64E+00	3.3314	3.0217	2.6345	2.4023	2.0926	1.7828	1.4731	1.1634	0.8537
error	0	0	0	0	0	0	0	0	0	0

Table 4: Stray potential print constants of box 13 at pipe to soil potential equal to -0.2 volt to -2 volt

	Box 13 ρ_5									
	-0.2	-0.4	-0.6	-0.85	-1	-1.2	-1.4	-1.6	-1.8	-2
A_4	-2.52E+04	-17108	-8993.3	1149.5	7235.1	15349	23464	31578	39692	47806
A_3	8.50E+03	4654	806.87	-4002.1	-6887.5	-10735	-14582	-18429	-22276	-26123
A_2	-2.73E+02	293.88	860.87	1569.6	1994.9	2561.9	3128.8	3695.8	4262.8	4829.8
A_1	-8.76E+01	-115.06	-142.47	-176.73	-197.29	-224.7	-252.11	-279.52	-306.93	-334.45
A_0	2.14E+00	2.2143	2.2855	2.3745	2.4278	2.499	2.5702	2.6413	2.7125	2.7837
error	0	0	0	0	0	0	0	0	0	0

4. Results

4.1 A_{0V} print constant

The stray potential from the pipe segment to the earthing grid, A_{0V} print constant is linearly proportional to the pipe to soil potential V_{H-C} measured by $Cu/CuSO_4$ half cell. Figure 4 show boxes 10 & 13 as an example and the correlation between them is governed by equation 4 for all boxes under test as follow:

$$\mathbf{A_{0V}} = B_{1A0V}\, \mathbf{V}_{H-C} + B_{0A0V} \quad (4)$$

4.2 A_{1V} print constant

The stray potential from the pipe segment to the earthing grid, A_{1V} print constant is linearly proportional to the pipe to soil potential V_{H-C} measured by $Cu/CuSO_4$ half cell. Figure 4 show boxes 10 & 13 as an example and the correlation between them is governed by equation 5 as follow:

$$\mathbf{A_{1V}} = B_{1A1V}\, \mathbf{V}_{H-C} + B_{0A1V} \quad (5)$$

4.3 A_{2I} print constant

The stray potential from the pipe segment to the earthing grid, A_{2V} print constant is linearly proportional to the pipe to soil potential V_{H-C} measured by $Cu/CuSO_4$ half cell. Figure 4 show boxes 10 & 13 as an example and the correlation between them is governed by equation 6 as follow:

$$\mathbf{A_{2V}} = B_{1A2V}\, \mathbf{V}_{H-C} + B_{0A2V} \quad (6)$$

4.4 A_{3V} print constant

The stray potential from the pipe segment to the earthing grid, A_{3V} print constant is linearly proportional to the pipe to soil potential V_{H-C} measured by $Cu/CuSO_4$ half cell. Figure 4 show boxes 10 & 13 as an example and the correlation between them is governed by equation 7 as follow:

$$\mathbf{A_{3V}} = B_{1A3V}\mathbf{V}_{H-C} + B_{0A3V} \quad (7)$$

4.5 A_{4V} print constant

The stray potential from the pipe segment to the earthing grid, A_{4V} print constant is linearly proportional to the pipe to soil potential V_{H-C} measured by $Cu/CuSO_4$ half cell. Figure 4 show boxes 10 & 13 as an example and the correlation between them is governed by equation 8 as follow:

$$\mathbf{A_{4V}} = B_{1A4V}\, \mathbf{V}_{H-C} + B_{0A4V} \quad (8)$$

Table 5 shows the result table of protection current print constants (A's) in terms of pipe to soil potential for all boxes under test

Table 5: Stray potential print constants (A's) in terms of pipe to soil potential for all boxes under test

		ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	ρ_8	ρ_9	ρ_{10}
		Box 1	Box 4	Box 9	Box 10	Box 13	Box 18	Box 19	Box 24	Box 27	Box 28
A_{0V}	B_{1A0V}	2.19E+00	1.567	0.911	1.548	-0.355	-2.09E+00	-7.671	2.437	-2.635	1.1
	B_{0A0V}	4.80E+00	0.724	2.688	3.95	2.072	2.88E+00	0.632	-0.117	2.302	2.535
	error	0%	0	0	0	0	3%	0	0	1%	0%
A_{1V}	B_{1A1V}	-468.88	-8.6912	141.17	-20.257	137.08	1660.1	237.32	28.372	135.56	82.588
	B_{0A1V}	-1421.8	-45.09	-308.35	160.27	-60.217	-978.29	-3.0607	59.6	-67.017	-250.82
	error	0	0	0	0	0	0	0	0	1%	0
A_{2V}	B_{1A2V}	58664	865.2	-3960	708.1	-2834	-13567	-1225	-857.8	-493.2	-2781
	B_{0A2V}	14164	1020	13609	2507	-840	95891	-115.2	-961.4	747.3	10114
	error	0	± 70%	0	0	0	0	0	0	0	0
A_{3V}	B_{1A3V}	-2.00E+06	-7698	41703	-5075	19236	4.00E+06	2301	5996	428.4	55331
	B_{0A3V}	-5.00E+06	-8402	-18786	-14176	12348	-4.00E+06	424.3	5158	-2400	-14698
	error	±10%	0	0	0	0	±5%	0	0	±1%	0
A_{4V}	B_{1A4V}	2.00E+07	0	-99143	10611	-40571	-3.00E+07	-1424	0	129	-36192
	B_{0A4V}	5.00E+07	0	83364	26373	-33336	4.00E+07	-349.5	0	2335	66349
	error	10%		0	0	0	3%	0		1%	20%

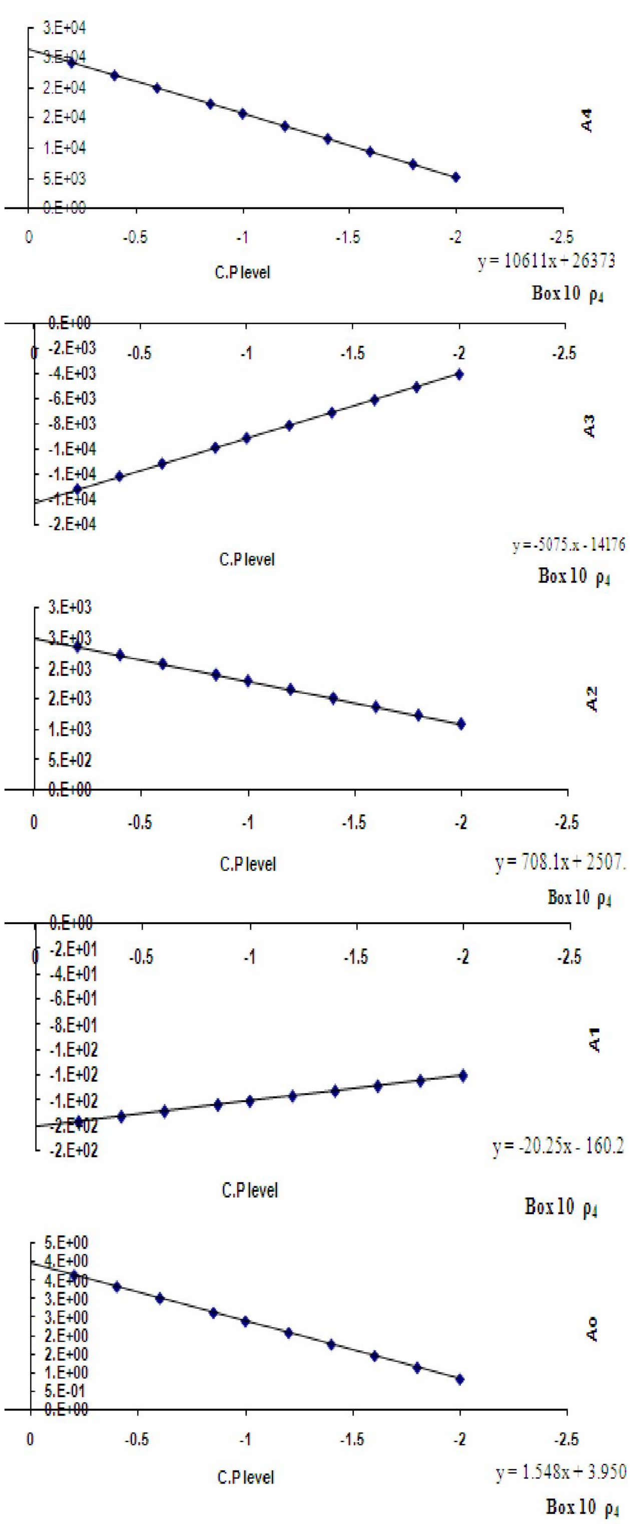

Figure 4: The stray potential print constants against pipe to soil potential for box 10

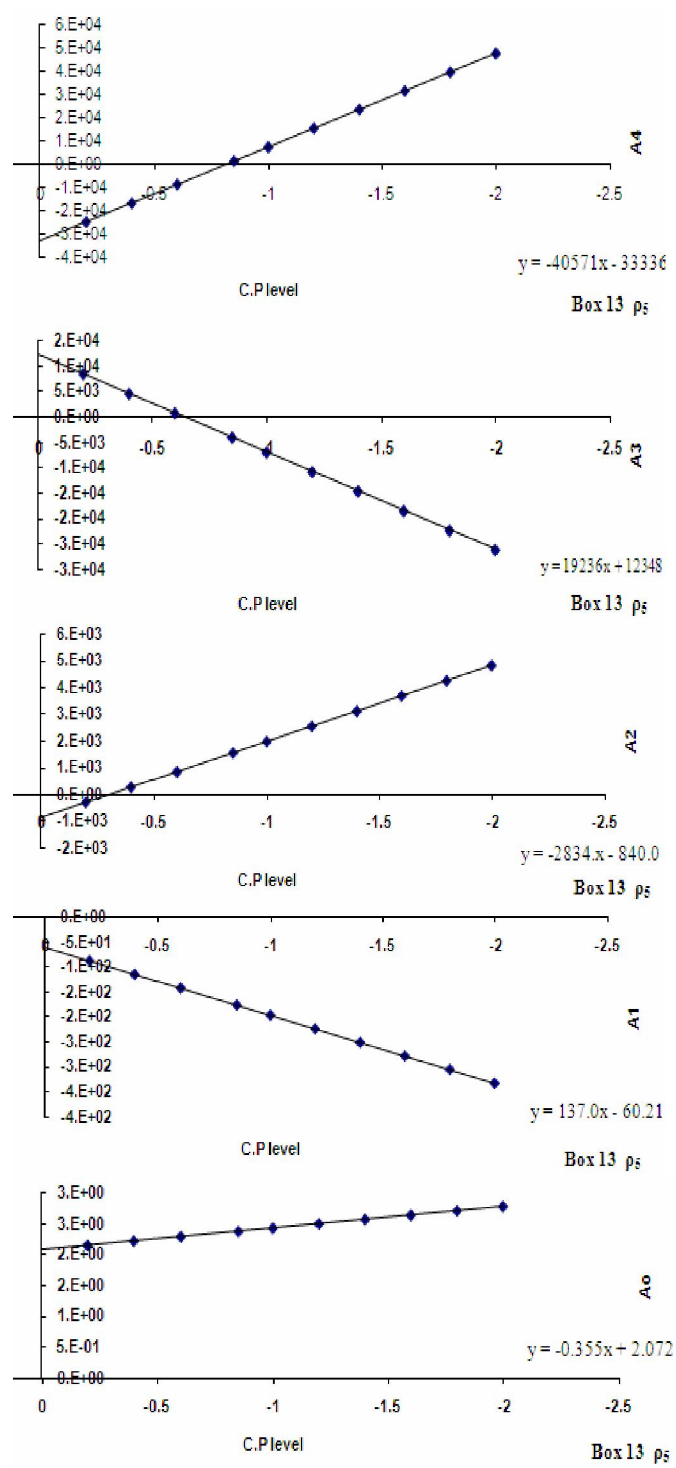

Figure 5: The stray potential print constants against pipe to soil potential for box 13

4.6 The deduction of the general equation of the pipe to soil potential

We have the stray potential general equation from equation 3 as follow:

$$\mathbf{V_{Str.}} = A_{4V}\mathbf{X}^{4} + A_{3V}\mathbf{X}^{3} + A_{2V}\mathbf{X}^{2} + A_{1V}\mathbf{X} + A_{0V} \quad (3)$$

Where:

A's: = $A_{()V}$ are the stray potential print constants of the pipe - soil under test

X = is the value of the soil factor at certain humidity

By substituting the values of A's from equations 4, 5, 6, 7 and 8 in equation 3 , the general equation of the pipe to soil potential will equal to equation 9 as follow:

$$V_{H.C} = \frac{V_{Stray} - [B_{0A4V}X^4 + B_{0A3V}X^3 + B_{0A2V}X^2 + B_{0A1V}X + B_{0A0V}]}{[B_{1A4V}X^4 + B_{1A3V}X^3 + B_{1A2V}X^2 + B_{1A1V}X + B_{1A0V}]} \quad (9)$$

Where:

$\mathbf{V_{H.C}}$: The equivalent value of the pipe to soil potential in volt measured by $Cu/CuSO_4$ half cell.

$\mathbf{V_{Str.}}$: Stray potential of the pipe segment in Volt.

X: Segmental soil factor in Ω.m%.

B's: New print constants of pipe-soil-earth system

Table 6 shows the error for all boxes under test while tables 7 & 8 are showing the detailed comparison between the pipe to soil potential obtained by equation 9 and the pipe to soil potential obtained by direct measurement by the use of $Cu/CuSO_4$ half cell.

Table 6: Comparison between theoretical and experimental values of pipe to soil potential of box 10

	Electrical Parameters					Pipe to Soil Potential		
Box	V_{P-PE}	C_{P-PE}	I	pH	H	Theoretical	Experimental	Error
	Volt	nF	mA		%	V_{HC} - Volt	V_{HC} - Volt	%
10	0.49	0.172	0.0015	7.8	10%	-0.314839657	-0.3000	4.7134014
10	-0.461	0.172	0.0060	7.8	10%	-0.9620273	-0.9600	0.2107321
10	-4.33	0.172	0.0175	7.8	10%	-3.595012572	-3.6000	-0.1387319
10	-5.07	0.172	0.0220	7.8	10%	-4.098607584	-4.1400	-1.0099141
10	-8.06	0.172	0.0335	7.8	10%	-6.133403645	-6.1000	0.5446184
10	0.2723	7.900	0.0046	7.7	18%	-0.182218469	-0.3063	-68.094926
10	-0.1923	7.900	0.1000	7.7	18%	-0.431641808	-0.4550	-5.4114757
10	-4.37	7.900	1.2600	7.7	18%	-2.674465499	-2.4960	6.6729408
10	-6.79	7.900	1.9600	7.7	18%	-3.973657238	-3.8500	3.1119251
10	-9.38	7.900	2.7500	7.7	18%	-5.364114513	-5.3500	0.2631285
10	-10.5	7.900	3.1400	7.7	18%	-5.965393335	-6.1300	-2.7593598
10	0.21	33.400	0.0023	7.0	65%	-0.43028885	-0.5010	-16.433414
10	-0.315	33.400	0.5000	7.0	65%	-0.657031363	-0.6600	-0.4518258
10	-3.38	33.400	5.5400	7.0	65%	-1.980775742	-1.8600	6.0973961
10	-6.1	33.400	11.2100	7.0	65%	-3.1555179	-3.2000	-1.4096608
10	-9.5	33.400	17.0000	7.0	65%	-4.623945597	-4.6500	-0.5634669
10	0.145	49.600	0.0018	6.5	88%	-0.432519024	-0.5380	-24.387592
10	-0.29	49.600	0.1850	6.5	88%	-0.615311165	-0.6400	-4.0124146
10	-3.93	49.600	10.6000	6.5	88%	-2.144882184	-1.9900	7.2210112
10	-6.31	49.600	17.6000	6.5	88%	-3.144986311	-3.0900	1.74838
10	-9.6	49.600	30.0000	6.5	88%	-4.527483193	-4.6500	-2.7060687
10	0.244	89.000	0.0048	6.0	100%	-0.564233649	-0.6350	-12.542029
10	-0.006	89.000	0.1530	6.0	100%	-0.656040154	-0.6700	-2.1278951
10	-3.56	89.000	18.8000	6.0	100%	-1.961161418	-1.9000	3.1186325
10	-5.42	89.000	34.2000	6.0	100%	-2.64420181	-2.5300	4.3189521
10	-6.72	89.000	44.0000	6.0	100%	-3.121595632	-3.1800	-1.870978
10	-8.45	89.000	55.0000	6.0	100%	-3.756896641	-3.8400	-2.2120214

Table 6: Error table between theoretical and experimental values of pipe to soil potential for all boxes under test

Resistivity	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	ρ_8	ρ_9	ρ_{10}
Box No.	1	4	9	10	13	18	19	24	27	28
Av. Error	H	± 5 %	± 40 %	± 5 %	± 5 %	H	± 5 %	± 40 %	± 5 %	± 5 %

Table 7: Comparison between theoretical and experimental values of pipe to soil potential of box 13

	Electrical Parameters					Pipe to Soil Potential		
Box	V_{P-PE}	C_{P-PE}	I	PH	H	Theoretical	Experimental	Error
	Volt	nF	mA		%	V_{HC} - Volt	V_{HC} - Volt	%
13	0.145	0.000	0.0019	7.3	6%	-0.505960215	-0.4730	6.5143887
13	-0.705	0.000	0.0067	7.3	6%	-1.163633299	-1.1390	2.1169297
13	-4.06	0.000	0.0224	7.3	6%	-3.759507649	-3.9000	-3.736988
13	-4.9	0.000	0.0275	7.3	6%	-4.409443403	-4.4100	-0.0126228
13	-7.13	0.000	0.0394	7.3	6%	-6.134868083	-6.0700	1.0573672
13	0.2796	8.700	0.0044	7.6	10%	0.315257985	-0.2900	191.98815
13	-2.575	8.700	0.0800	7.6	10%	-1.358426955	-0.4860	64.223325
13	-3.81	8.700	0.7000	7.6	10%	-2.082521715	-2.1100	-1.3194717
13	-5.66	8.700	1.0100	7.6	10%	-3.167198076	-3.2220	-1.7302967
13	-8.49	8.700	1.5900	7.6	10%	-4.826459752	-4.8500	-0.4877332
13	-10.79	8.700	2.0200	7.6	10%	-6.174976309	-6.3600	-2.9963466
13	0.288	31.900	0.0024	6.9	80%	-0.441743481	-0.4960	-12.282359
13	-0.211	31.900	0.9200	6.9	80%	-0.670961813	-0.6590	1.782786
13	-3.77	31.900	10.8000	6.9	80%	-2.305807595	-2.2900	0.6855557
13	-6.44	31.900	18.8000	6.9	80%	-3.532286449	-3.7100	-5.0311195
13	-9.11	31.900	27.4000	6.9	80%	-4.758765302	-4.8600	-2.1273312
13	0.146	109.200	0.0019	5.2	100%	-0.648122287	-0.6880	-6.1528069
13	-0.244	109.200	1.0800	5.2	100%	-0.793995223	-0.7700	3.0220866
13	-3.4	109.200	30.0000	5.2	100%	-1.974443905	-2.0000	-1.2943439
13	-6	109.200	56.0000	5.2	100%	-2.946930144	-3.0400	-3.1581969
13	-9.5	109.200	85.0000	5.2	100%	-4.256046236	-4.3200	-1.5026567
13	0.133	243.000	0.0014	5.0	100%	-0.660302144	-0.7010	-6.1635202
13	-0.14	243.000	0.1870	5.0	100%	-0.761080019	-0.7840	-3.0115074
13	-2.87	243.000	19.1000	5.0	100%	-1.768858767	-1.7500	1.0661545
13	-4.6	243.000	60.5000	5.0	100%	-2.407487791	-2.4200	-0.5197206
13	-6.3	243.000	87.0000	5.0	100%	-3.035042323	-3.0800	-1.4812867
13	-7.55	243.000	108.0000	5.0	100%	-3.496479478	-3.6000	-2.9607073

5. Conclusion

One of the most critical problems in CP systems is the presence of the earthing network beside the protected pipe line. Electrochemistry helps to determine the integrity of buried pipe from corrosion by measuring pipe to soil potential by the use of $Cu/CuSO_4$ half cell. In electrical study of pipe-soil-earth system we are now able to calculate that value from the stray potential of the pipe segment as an electrical parameter , the electrochemical properties of the soil around this pipe segment as the soil factor and finally by the use of B's print constants of the pipe –soil - earth system. This will help to calculate the correspondent value of the pipe to soil potential for each segment of the pipe however long it is in the presence of earthing grids. This will help in pipeline both mentoring and maintenance, not only that but also to define both of the most proper rectifier output voltage and the proper distance between the protected pipe line and the earthing grid.

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