GROUNDING METHODOLOGY IN A 550 kV AC POWER TRANSMISSION LINE IN THE AMAZON - A CASE STUDY

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Abstract

Atmospheric discharges are indispensable for the electrical sector due to their responsibility on the shutdown of the power lines, what may trigger a sequence of events that led the interconnected electrical system to collapse. The aim of this case study is to demonstrate the development of a viable methodology in order to reduce the resistance values of the grounding system of the power lines, reducing shutdown occurrences due to returning disruptive discharges, or backflashover, mitigating the damages caused to the electrical system and to society, in order to improve the quality of the electrical power distribution. Considering the factors of implementation costs, technical environmental viability, the encompassment of this solution for other structures lines, and the reduction of the implementation percentage, it was concluded that the most adequate solution to implement a more robust grounding system in the transmission power lines is the solution 03 tested on the tower 585, with a reduction of 66,98%.

Kay words: atmospheric discharges, grounding system, transmission line, shutdowns.

1. Introduction

Atmospheric discharges are electromagnetic phenomena which occur in large proportions, showing a pattern absolutely random and unpredictable. Due to its vast territorial extension, mainly in tropical regions and undergoing cold air fronts originated in the South Pole, Brazil is one of the countries with the largest incidences of lightning in the world, and in its Northern region this phenomenon happens more frequently, 70% more than in the other regions, reaching the number of 100 million a year. The atmospheric discharges are indispensable to the electrical sector, being the biggest responsible for power lines shutdowns, in which they may trigger a sequence of events that may lead the interconnect electrical system to collapse. The long extensions of the transmission lines make significantly higher the probability of atmospheric discharges incidence. [1].

Hence, in Brazil, the concessionaire used to base this study has the shutdowns caused by atmospheric discharges as the second cause of shutdown in their transmission lines. The outages caused by atmospheric discharges in Brazil are secondary in the occurrence of intempestive electrical systems shutdowns. These have increased across the years. In the time cycle between 2014 and 2018 there was an increase of 11% in registers of atmospheric discharges, according to the Report of Analysis of Forced Shutdowns in the Transmission System - ANEEL, 2018.

Different mechanisms can be responsible for sudden shutdowns of the powerline transmission circuits: incidence on the phase conductors, due to shielding failures or lack of shielding conductors, may lead to the flashover on the insulators. The discharges may generate high over tensions on the insulators chain, occasionally leading to the occurrence of a backflashover [1].

Besides the troubles caused by the interruption of power supply, the elevated number of sudden shutdowns in the power lines are the agents of 8 financial losses on the concessionaires as consequence of the payment of fines for unavailability VP (Variable Parcel). In these sudden cases, it may reach to the factor K150, which is referred to 150 times the received value for the same function under normal circumstances; with these figures being discounted over the BP (Basis Payment), received by the concessionaires in a monthly basis after being audited by the NOS (National System Operator [ONS])[2].

According to Feng and Lu [3] , the possible causes of power lines shutdown by atmospheric discharges are: plan and construction, operation and maintenance conditions, and complex geological aspects with high ground resistance, in a way that the performance of the power line transmission under atmospheric discharges is related to the tension of the insulator discharge, atmospheric discharge intensity and the grounding system impedance.

Chiheb [4], analysed the behaviour of the electrodes impedance in extensive horizontal groundings in function of the frequency of various resistivity figures of the ground. Dein e Yassin [5] also concluded that the shutdowns of the transmission lines depend on the grounding electrode impedance as well as on the electrical parameters of the ground, frequency, and magnitude of the current lack duration.

In Brazil, Alipio [6] presented grounding arrangements composed by parallel electrodes aimed to improve the grounding response of the transmission lines under atmospheric discharges. With the same concern, Caetano [7] made a research in the state of Minas Gerais – BR about conductors arrangements in order to reduce the resistance of the grounding in the transmission line. Oliveira Visacro and Guimarães [1] analysed the grounding impedance in the transmission line tower making use of a generator tool in high-frequency of 25kHz. Vasconcellos [8] concluded that by enlarging the length of the grounding cable, the impedance of towers grounding is reduced and, consequently, the over tensions on the isolators is attenuated.

The aim of this case study is the development of a viable methodology in order to reduce the resistance values from the grounding system of the power lines transmission prospecting to reduce the occurrences of shutdowns due to disruptive returning discharges, or backflashover, mitigating the damages caused on the electrical system and hence to society, improving the quality of the distribution of energy.

This methodology will obey the environmental restrictions and legal duties controlled by the operational license, and also the ground conditions, which is fairly uneven.

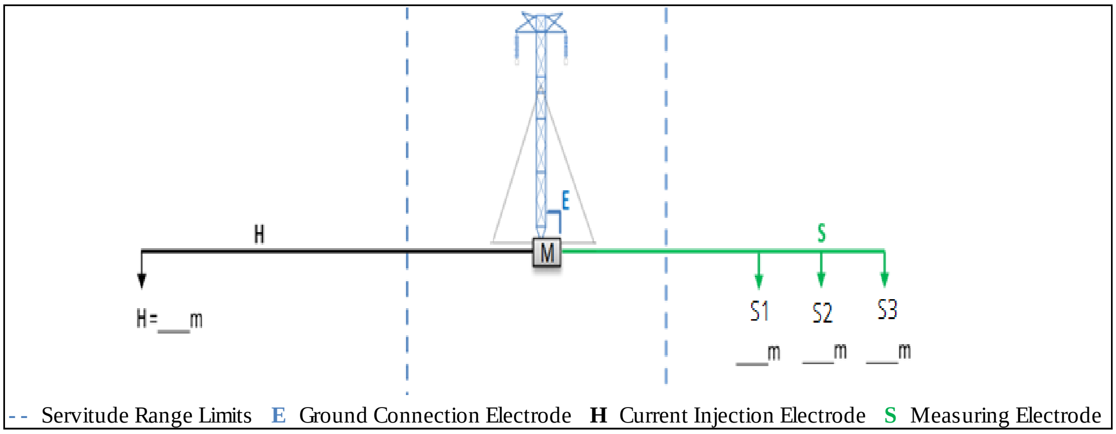
The object of this case study is a transmission power line in alternate current with 332 km of length, located in an Amazon region named LT Oriximiná – Silves CD, this object of Auction 004/2008, was celebrated the Concession Contract n. º 010/2008, through ANEEL, the enterprise was concluded on 14th of March. It interconnected the isolated Amazonas system to INS (Integrated National System [SIN]), this one of extreme importance for the industry and population of Amazonas. The enterprise started its commercial operation in July of 2013 and is composed by LT Oriximiná/Silves/Lechuga, in 500 kV, going along the states of Amazonas and Pará, with a 586 km extension, and the substations: SE Silves 500/138kV and SE Lechuga 500/230kV [9].

2. Materials and methods

At first, documents from official offices available on NSO (National System Operator, [ONS]), NEEA (National Electrical Energy Agency, [ANEEL]), as well as technical specification documents provided by the concessionaire Manaus Energy transmitter [Manaus Transmissora de Energia]. Implementing sample solutions which are according to the environmental restrictions so as to evaluate the performance of the grounding system before and after each solution, thus stratifying sufficient data to prospect reductions in the grounding system resistance.

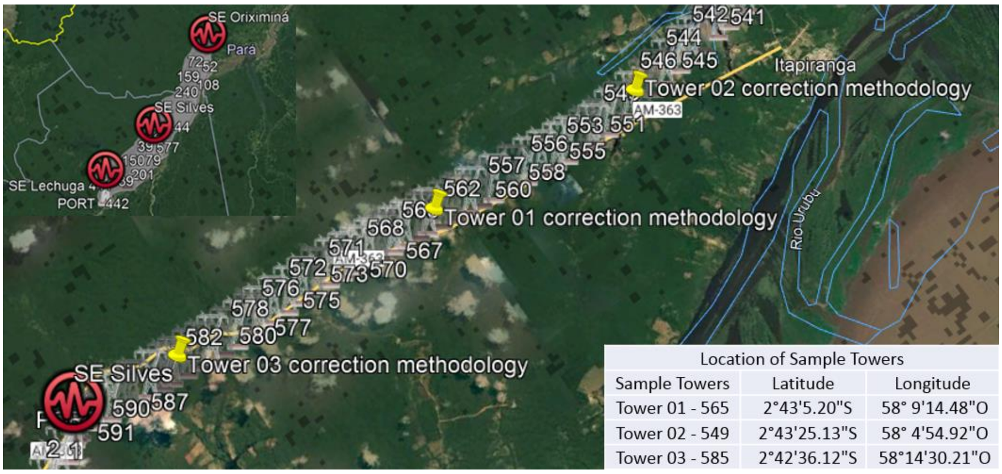
Having based its analysis on the information provided by SIPER NOS, all the occurrences regarding atmospheric discharges on the Oriximiná-Silves CD power line in the period comprised between 2014 to 2019, with the latter showing a 17% figure, which represents the second biggest cause of power line shutdown in this period.

In order to measure the transmission lines grounding in LT Oriximiná/Silves CD 550kV, before and after, it was made use of the grounding resistance by high-frequency measurer (25 kHz), to which the inductive impedance from the guard cable (Pic. 1), considering a standard gap between towers, is considerably high. What allowed to decrease the effect from the adjacent towers over the one that is being measured.



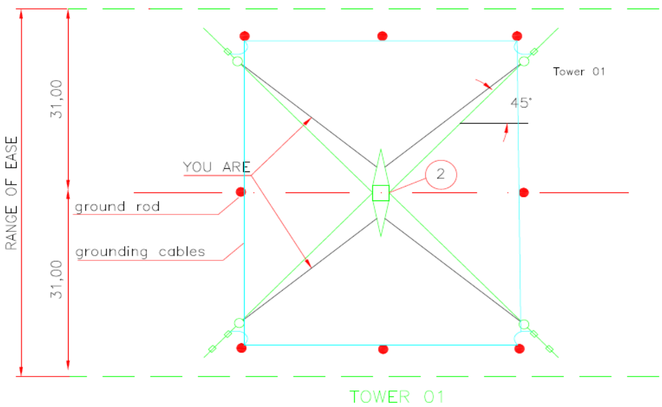
Picture 1. Example of impedance of impulse of the grounding measurement configuration. High-frequency test connections used.

There was an analysis of the characteristics from the towers used as samples, and the towers 549, 565 e 585 were chosen, based on the characteritic of being of a tethered model, similar grounds and average resistances with close figures. The towers are locared in Itapiranga county, in the state of Amazonas, according showed on the map (Pic. 2). Implementing in this way the methodology that was presented and with the cables lenghts to be defined according to the environmental limitations of the site.



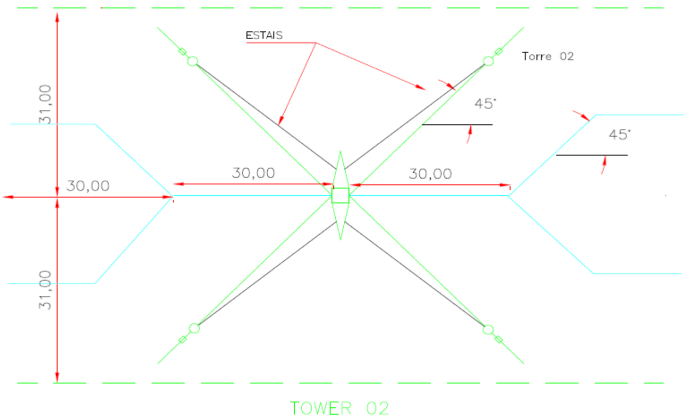
Picture 2. Towers localization from the LT Oriximiná sample – Silves CD.

The plan of tower 565 (Pic. 3) has the compact characteristic to supply places with reduced space.



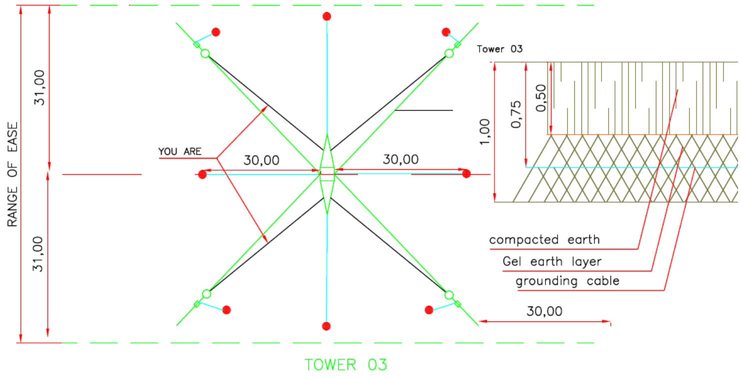
Picture 3. Implemented plan in tower 565.

The plan of tower 549 (Pic. 4) has distribution in the centre of the band, which demands a flat area in order to be implemented.



Picure 4. Plan implemented on tower 565.

The plan of tower 585 has increased ground treatment for the distibution of the grounding cables and grounding rods as it is represented in (pic. 5)



Picture 5. Implemented Project in tower 585.

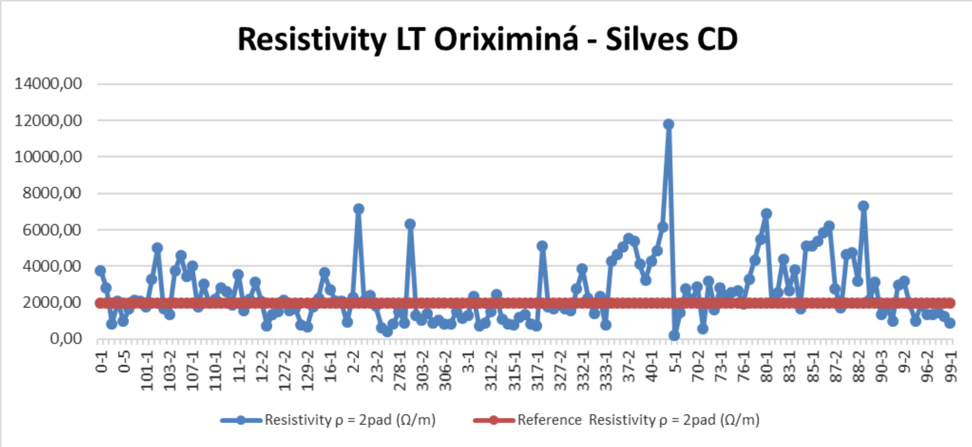
In table 1 is presented the material used in each tower grounding experiment.

Table 1. List of the Material Used.

Material Description	Total quantity per experiment and per tower			
	Tower 565	Tower 549	Tower 585	Total
Counterweight conductor of annealed steel-copper 4AWG	210m	120m	120m	450m
Parallel connector for counterweight cable pinning to the tower (Feet or Pole)	8	2	8	18
Parallel connector to amend two counterweight cables 4AWG	8	2	8	18
Steel-copper grounding rod diameter 17,30mm, 3000mm.	8	0	8	16
Parallel staple to amend the tether cable to the counterweight cable	4	0	4	8
Grounding gel for soil treatment	0	0	72Kg	72Kg

3. Results and discussions

According to the analysed data (Pic. 6), the following findings were verified: Performing sampling measurements of 25% on the ground resistance in the construction phase, in which the measured average of the 149 towers is 2.551,83 Ωm and 46,67% of the measures are above 2.000 Ωm.



Picture 6. Resistivity from Oriximiná – Silves CD power line. Compiled of Measurement of Ground Resistivity. Excerpt: LT 500 kV CD Oriximiná – Silves 19/03/2011.

The grounding plan is dimensioned according to the ground resistance. The measurement of the ground characteristics is made since the pre-planning phase. Nascimento [10], also mentions that the resistivity ($\rho \leq 500$ Ωm) is proportionally low and grounds with higher resistivity ($\rho \geq 2000$ Ωm) are considered higher and require complex grounding. Nogueira [11], mentioned low resistivity grounds ($\rho < 700$ Ωm). Paulino (2009), mentions that the technical limit for the use of counterweight cables is of ($\rho < 4400$ Ωm), Vasconcellos [8], paraphrased about the importance of grounding plans that assure the good performance of the transmission lines, considering the average number of high resistivity in Brazil being around ($\rho \leq 1000$ Ωm). According to Berardo [13], when the ground resistivity is lower than ($\rho \leq 500$ Ωm), it is considered adequate for the grounding of the transmission lines, corroborating with Nascimento e Júlio [10]. Visacro e Silveira [14] point out that the resistivity ($\rho \leq 300$ Ωm) and ($\rho \geq 2000$ Ωm) are considered low and high, respectively.

According to what was shown, it was noticed that one of the main causes of shutdowns is the high resistance of the ground on where the transmission line was built. In Brazil, this issue is especially important, due to the high incidence of atmospheric discharges, according to data provided by the Atmospheric Electricity Group from InPe, In the year of 2017, the state of Amazonas was the second in Brazil in atmospheric discharges density, with the figure of 15,8 strikes of lightning per square kilometre (km^2), besides the fact of the ground showing high indexes of resistance.

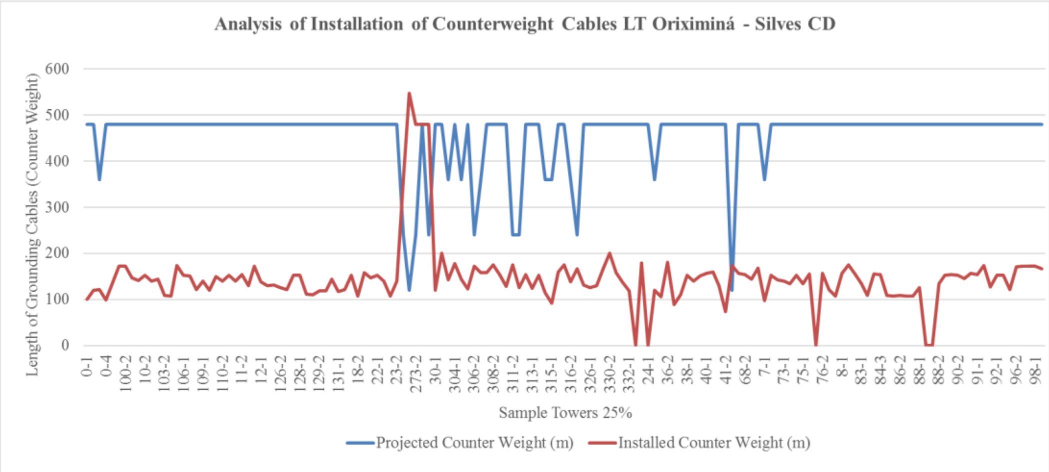
The concessionaire used the calculation methodology from the program IEEE Flash 2.0. This programme estimates the lightning flashover rates on the aerial transmission lines and electricity distribution, according to the rules 1243 and 1410 of IEEE. The performance of LT Oriximiná – Silves CD was calculated aiming to reach the following values expressed in discharges numbers per 100km a year: Number of shutdowns by directs discharges ≤ 0,01 (1 circuit) and ≤ 0,0001 (2 circuits), this parameter procedure of ANEEL-ONS [9]. The total of predicted shutdowns is ≤ 1 a year, in a way that the average value of grounding from the transmission towers is ≤ 12 Ω. This resistance (12Ω) is considered according to the plan limit for the average of grounding resistances of the total structures of the power line from Oriximiná – Silves CD [15].

According to Paulino [12], it is described that, in order to expect the shutdown of transmission lines with rates that vary between 0,5 and 1,0 for each 100km/year it is necessary that the average grounding resistance is in the range from 7 Ω to 12,5 Ω. It was done by checking the number of shutdowns per 100km a year. In this context the (Equation 1) below demonstrates how the calculation was done:

$$Dlt = \frac{Nda}{L} x100 \quad (1)$$

The equation 1 was used for the calculation of performance from the LT Oriximiná-Silves CD in which: Dlt (Transmission Line Performance), Nda (Number of shutdowns per year), L (Line length in kilometre). During the period between 2014 and 2019, 25 shutdowns caused by atmospheric discharges were registered, with an average of 4,1 shutdowns per 100km, with an average Dlt of 1,28.

According to Wu and Sun [16], the flashover rate increases with the variation of the following parameters: How high the tower is, how high the tower foot impedance is, how high are the soil resistivity and the low resistance of the insulator. The flashover rate for each 100km is of 0,787 for resistivity until 500 Ωm, 0,808 for resistivity until 1000 Ωm and 0,823 for resistivity until 2000 Ωm. The weighing of the towers based on the length of the grounding cables is showed in (Pic. 7).



Picture 7. Length of the Grounding Cables (Counterweight) installed and Planned LT Oriximiná – Silves CD. Compiled from the Construction List.

The comparative data (Pic. 7), from the 'as built' data from LT Oriximiná – Silves CD. In the sample there are 149 towers analysed, corresponding to a 25% total of the line, where is showed that 95% of the tower groundings which have length below the one specified in the plan, what diminishes the performance of the power lines facing the disruptive discharges from atmospheric discharges. According to Paulino [12] the lenght of the counterweight cable is directly associated to the tower foot resistance and the impedance of impulsive and its impacts on the tension figures that appear on the insulators chain. For high ground resistivities, resonant peaks appear in the atmospheric discharges and they are atenuated with the enhance of the counterweight cable, as it was written by O. Kherif [4].

The stratified data from the Resistivity Measurement soil control of the excerpt from LT 500 kV CD Oriximiná – Silves registered on 19/03/2011, shows that 81% from the 121 towers have resistance superior to 41Ω, 7% of the 10 towers have resistance superior or equal to 41Ω, 6% of the 09 towers have resistance lower or equal 31Ω, 5% ot the 07 towers have resistance lower or equal 22Ω and 1% of the 02 towers have resistance lower or equal 12Ω, the latter the ideal to serve the number of shutdowns caused by direct discharges ≤ 0,01 (1 circuit) and ≤ 0,0001 (2 circuits), this parameter of the procedure from da ANEEL-ONS [9].

Considering the collected evidences, the average resistence of the 149 towers is of 2.551,83 Ωm being that 46,67% of measurements are above 2.000 Ωm; considered a high value that requirse complex groundings, 81% of towers have resistance superior to 41Ω which, according to the plan, requires a phase V grounding, as showed in table 2.

Table 2. Transmitter Grounding Project

Towers Grounding Configuration				
Phase	Grounding resistance (Ω)	Cable Length (m)	Number of Cables	Number of Rods
I	R ≤ 12	30	4	0
II	12 < R ≤ 22	60	4	0
III	22 < R ≤ 31	90	4	0
IV	31 < R ≤ 41	120	4	0
V	R > 41	120	4	4

Following with the implementation of the solutions for extratification of the results for the underpin of a solution for the corrections of the grounding resistances of the plan.

The solution of tower 549 consists in the intalation of grounding cables with total lenght of 120 metres. The implementation of this solution is extremely complex due to the necessity of a flat area of 1500 m². In this aspect, the predominant terrain shape in the line tracing is fairly uneven.

It was implemented in the tower 565 the installation of 08 grounding rods interconnected by gronding cables with the total length of 210 metres. In order to implement this solution it is necessary to clean all the tower area extension, 3600 m² aproximatey, to implement the cables in an round disposition.

In tower 585, 08 grounding rods were installed, interconnected by grounding cables in radial shape, with a total length of 120m. For the implementation of the solution it was necessary the cleaning of a 500 m² area, this arrangement made the installation gain more agility, even though the fact that this solution requires a higher quantity of material.

The access to the towers in the middle of the Amazon Forest is a challenge, as well as the transportation of machinery, equipments and tools to perform the works, due to the peculiarity presented by the site. The crew provided by the concessionaire was composed by 06 collaborators, 02 4x4 trucks and 01 backhoe. The works were executed inside the servitude strip, obeying the operation license limits of the enterprise conceded by the environmental offices, and following the estipulated standards established in the constructions of transmission lines. The ditches for the cables installation were dug according to the specific plan, with the dimensions of 1,0m of depth and 0,3m of width, as showed in (Pic. 8).

Picture 8. Execution of the activities on site.

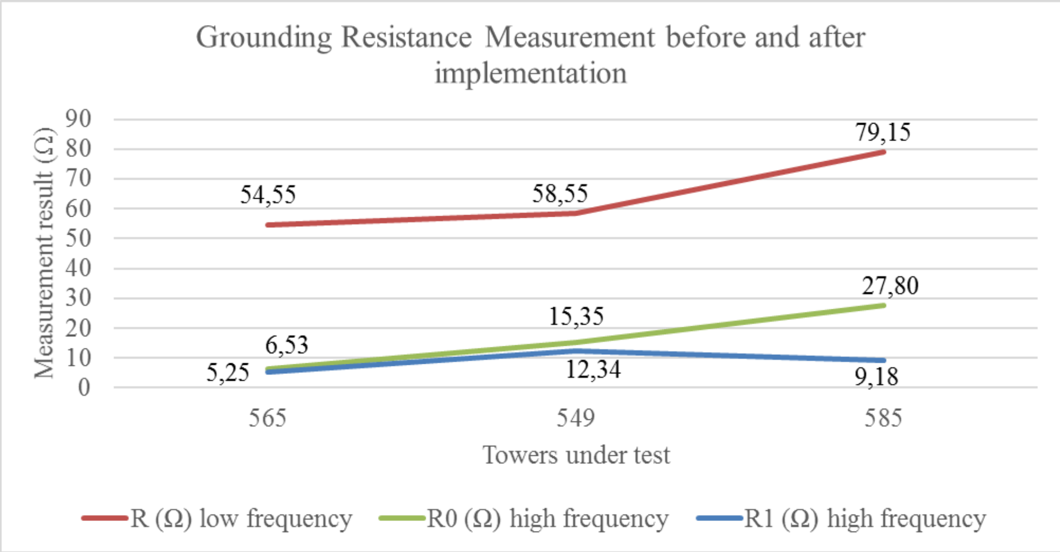
Installation of the grounding cables, grounding rods and grounding gel as showed in (Pic. 8). In sequence, the closing of the ditches is done, compressing and sowing the soil for the biome recovery. After performing the measures of the grounding solutions of towers 549, 565 and 585 of the transmission lines from LT Oriximiná/Silves CD 550kV, it was used the high-frequency grounding resistance measurer (25 kHz) modelo Megabrás TM25m with valid calibration certificate.

In table 3 are presented the results of the measurements in ohms and the percentage of reduction of each implemented solution. These measurements followed the concessionaire protocol for high-frequency measurements, with the validated values considering a variaton amongst the values of S1, S2 and S3 being below 5%.

Table 3. Test Results Before and After the implementation.

Grounding Resistance Measurement Test					
Project	**Test**	**Figures Found (Ω)**			
		S1	**S2**	**S3**	**Average**
565	R0 - Initial	7,09	6,80	5,71	6,53
	R1 - Final	5,23	5,29	5,22	5,25
549	R0 - Initial	15,31	15,57	15,18	15,35
	R1 - Final	12,18	12,60	12,24	12,34
585	R0 - Initial	26,80	27,20	29,40	27,80
	R1 - Final	9,55	9,60	8,40	9,18

The chart 3 shows the performance of the implanted grounding system. In the graph (Fig. 9) it is possible to visualise the results from the measurements before and after each implanted solution.



Picture 9. Performance of the grounding plans implementation.

According to the data analysis, the graph (Fig. 9) shows the measured values of grounding resistance before the implementation of the solution "R0", as well as the posterior measure "R1", an expressive reduction is noticed, with the highlight on the solution of tower 85. The chart 4 shows details from ground evaluation, environmental degradation, costs of implementation and percentage of reduction of the resistance of the tower foot, for each proposed solution in Brazilian currency.

Table 4. Cost benefit analysis of implementation for each solution.

Cost-benefit of Implementation				
Operation N°	**Flat area needs**	**Cleaning area needs**	**Total Cost (R$)**	**Reduction Percentage (%)**
565	Yes	3600 m²	R$ 3.485,69	19,60
549	No	1500 m²	R$ 3.184,48	19,61
585	No	500 m²	R$ 3.513,88	66,98

According to table 4, the tower 565 solution, related only to the implementation of grounding cables, had a percentual reduction of 19,60%. It needs, however, of an even area with a higher need of cleaning than the others; which makes the implementation in a larger scale more difficult, besides the implementation costs that had considered the expenses with materials, machinery and labour as being close to the other solutions.

The solution implemented on tower 549 is more compact than the previous one, in this way letting the base area sufficient for its installation, since the limits of installation are among the tethers of towers A, B, C and D. It is necessary, however, to perform the cutting of all the base vegetation in order to make this opening possible in a radial way. The implementation cost is lower because of the quantity of material needed, and the percentage of reduction of this solution was 19,61%, which is closer to the previous one.

For the solution of tower 585 were implemented radial cables coming from the tower base in the servitude stripe direction and longitudinal from the same stripe, with rods in the end of all cables. In the implemented cables was added a ground treatment with ground gel. This implementation had an expressive outcome with a reduction of 66,98% - the best amongst the solutions. Allied to this fact, the vegetation cleaning area is restricted to the lining of the placement of the grounding cables, therefore facilitating its implementation. Besides, the cables length is in the limit of the tethers from towers A, B, C and D. This is an existent area in all towers, which allows the installation in large scale.

4. Conclusion

During the implementation of the methodology to reduce the resistance figures from of the grounding line transmission systems in the Amazon Rainforest, one of the main criterion is the viability of ground implementation, being that the same is fairly uneven. It favours the implementation of more compact grounding systems which demand fewer space and license plate area for implementation besides the environmental factor and legal duties conducted by the operation license. In this scenery, it was possible to do the experiments in the towers with the implemented solutions according to the conditions and viability of each tower.

The main causes of tranmission lines shutdown facing the grounding impedances of the investigated ground are due to the high resistance from the ground where the transmission line was built, in which the same shows 46,67% of the ground resistance considered critical and in need of special grounding.

The grounding quality of the transmission towers LT Oriximiná/Silves CD 550kV, after being installed, presented 81% of the resistances with numbers above the reference value of 41Ω, which, according to the plan, requires grounding of phase V. However, as it was evidenced in the building list – responsible for the registers on how the grounding was built – 95% of the towers groundings have inadequate ones, what damnifies the performance of the lines facing the disruptive dischages from the atmospheric dischages.

Considering factors such as implementation costs, environmental technical viability, abrangency of the solution for futher line structures, and percentage of reduction of the grounding resistance, it was concluded that the most adequate solution for large-scale implementation is the most robust solution tested in the tower 585 with reduction of 66,98% of the grounding resistance.

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6. References

[1] C. H. D. Oliveira, S. Visacro, e M. Guimarães, "Experimental impulse response of transmission-line tower-footing electrodes", vol. 1, nº 1, p. 234–237, 2018.

[2] R. M. de Aquino, "Parcela Variável das Funções de Transmissão da Rede Básica e o seu Impacto na Operação do Sistema Elétrico", [Variable Portion of the Transmission Functions of the Basic Network and its Impact in the Electrical System Operation] 2010.

[3] Z. Feng, L. Lu, e J. Feng, "Research on reducing grounding resistance of transmission line tower grounding grid", *2011 Int. Conf. Electr. Control Eng. ICECE 2011 - Proc.*, p. 1216–1219, 2011.

[4] S. Chiheb, O. Kherif, M. Teguar, e A. Mekhaldi, "Impedance nature of long horizontal grounding electrode employing TLM", *Proc. 2018 3rd Int. Conf. Electr. Sci. Technol. Maghreb, Cist. 2018*, p. 1–4, 2019.

[5] A. Z. E. Dein e S. Yassin, "The frequency effect on transient impedance of horizontal grounding electrode", *2017 19th Int. Middle-East Power Syst. Conf. MEPCON 2017 - Proc.*, vol. 2018-Febru, nº December, p. 1177–1182, 2018.

[6] R. Alipio, R. M. Costa, R. N. Dias, A. De Conti, e S. Visacro, "Grounding modeling using transmission line theory: Extension to arrangements composed of multiple electrodes", *2016 33rd Int. Conf. Light. Prot.*, 2016.

[7] C. E. F. Caetano, J. O. S. Paulino, W. C. Boaventura, A. B. Lima, I. J. S. Lopes, e E. N. Cardoso, "A conductor arrangement that overcomes the effective length issue in transmission line grounding: Full-scale measurements", *34th Int. Conf. Light. Prot. ICLP 2018*, 2018.

[8] F. M. Vasconcellos, "Avaliação e dimensionamento de sistemas de aterramento para redução de desligamenteos de linhas de transmissão por backflashover" [Evaluation and sizing of grounding systems for reduction of shutdowns of transmission lines by backflashover] , 2017.

[9] ANEEL, "Relatório de Análise de Desligamentos Forçados do Sistema de Transmissão - Edição 2018.", [Report from the Analysis of the Forced Shutdowns of the Transmission System] Brasília - Brasil, 2018.

[10] D. M. F. Nascimento, Júlio A. S. do e et al, "Redução de Tensões Induzidas por Descargas Atmosféricas na Cadeia de Isoladores de Torres de Transmissão Através de Melhorias no Sistema Aterramento e do uso de Falsos-Estais" [Reduction of Tensions Inducted by Atmospheric Discharges on the Insulating Chains Through Improvements in the Grounding System and the Use of False-Tethers], *XXIV SNPTEE*, vol. 53, nº 9, p. 1689–1699, 2017.

[11] P. J. C. Nogueira, "Influência da estratificação do Solo na impedância" "impulsiva de aterramentos de linhas de transmissão", [Influence of the soil stratification in the impulsive grounding of the transmission lines] Minas Gerais, 2002.

[12] J. O. S. Paulino, "Melhoria do desempenho de linhas de transmis- são de alta tensão através da utilização de malhas de aterramento de baixo valor de impedância", [Improvement performance of the high-frequency transmission lines through the use of grounding nets with low impedance rates] 2009.

[13] B. L. BERARDO, "Estudo do aterramento dos pés de torres de linha de transmissão frente às

descargas atmosféricas”, [Study of the tower foot transmission lines grounding facing atmospheric discharges] 2012.

[14] S. Visacro, M. B. Guimaraes, e C. H. D. Oliveira, “Achievements in the measurement of tower-footing impulse impedance of transmission lines”, in *34th International Conference on Lightning Protection, ICLP 2018*, 2018.

[15] M. Transmissora, “Projeto Básico de Coordenação do Isolamento LT-452-008” [Basic Plan of Insulating Coordination], 2008.

[16] S. Wu e W. Sun, “Back flashover protection performance analysis of 220kV double circuit transmission line”, in *Asia-Pacific Power and Energy Engineering Conference, APPEEC*, 2011.

[17] M. Transmissora, “Especificações Técnicas para Medições de Resistividade do Solo e de Resistência de Aterramento das Estruturas - MTS-800-23001-ET” [Techinical Specifications for Measurements of Ground Resistivity and Structures Grounding Resistivity], 2010.

[18] Manaus Tramissora, “Projeto de Linhas de Transmissão” [Transmission Lines Project]. p. 800, 2010.