International Conference on Renewable Energies and Power Quality (ICREPQ'17)
Malaga (Spain), 4th to 6th April, 2017
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.15 April 2017

Commissioning of the Grounding System of Transmission Line of HPS Santo Antônio at High Current Injection Method

Araújo, Carlos Magno B.[1], Trondoli, Luiz Henrique P.C[2].
[1]Department of Research and Development - PWM Automation and Protection of Power Systems
Rua Vigário Albernaz, Zip Code 04034-021 Sao Paulo (Brazil)
E-mail: cmagno@pwmautomacao.com

[2] Department of Electrical Engineering, University of São Paulo - EESC, São Carlos
Av. Trabalhador São Carlense, 400 - Zip Code 13566-590 – São Carlos – SP – Brazil
E-mail: luiz.trondoli@usp.br

***Abstract*—This paper presents the application of grounding resistance measurement by fall of potential with high current injection, applied to the Transmission Line (TL) of 500kV of Santo Antonio Hydroelectric Power Station (HPS), located in the city of Porto Velho/RO, for the commissioning of the power house grounding system in Generation Group (GG2) and TL during construction of the referred project. Based on measurements obtained in field, computer simulations were performed to assess the effectiveness of the grounding system on future fault scenarios of the TL, as well as the suitability of relevant protection functions. The computer simulations are based on the model developed for TL 500kV of GG2, and were performed by using the PSCAD/EMTDC software, including the grounding values derived from the design of high current injection, according to (IEEE Std 80-2013). In order to attest the efficacy of both GG2 grounding system and TL from the HPS, COMTRADE files, obtained by the software, were used in the simulator Doble 6150 for the design of distinct fault conditions in a SEL-421 relay. Results indicate the correct functioning of relay SEL-421, corroborating the effectiveness of both grounding system and measurement method.**

***Index Terms*—Hydroelectric Power Station, Grounding System, Fall of Potential with High Current Injection, Digital Control and Protection, Madeira River.**

I. Introduction

According to the public bidding of energy transmission number 007-2008 from the National Electric Energy Agency (ANEEL) – Brazil, technical reports [1] were presented for the commissioning of the GG2 engine room, a testing scheme was developed for the grounding system with respect to the coordination requirements and selectivity of the protection of the second transmission line built. The testing method uses an earth meter, and consists of circulating a current of 20mA between the tested grounding system and the ground through an auxiliary electrode [2]. This paper proposes a new method for testing the grounding resistance, in which one of the phase conductor cables functions as current auxiliary electrode. The potentials are measured on the ground surface, with the lightning rod cable as reference. In order to obtain reliable grounding resistance values and in comparison with the requirements of IEEE Std. 80, Section II describes the transmission system model and testing design developed. Such models aim at not only supporting those values, but also the grounding grid performance, considering ground faults, based on the quadrilateral distance protection (ANSI 21) [3], and with the use of the grounding resistance element on all spans of the transmission line. Section III presents the results compared to the requirements, simulations based on the model developed in the PSCAD/EMTDC software, and, finally, COMTRADE (*Common format for Transient Data Exchange for power systems*) files are extracted from the simulation results and further inserted into the simulator Doble F6150 with the use of the TransWIN software. The last element of the design is the multifunctional projective relay SEL-421 from the manufacturer *Schweitzer Engineering Laboratories*, which is applied to the protection of transmission lines (compensated or not), with single/three-pole tripping and reclosing. Various fault conditions were applied on the projective relay to evaluate the effectiveness of the proposed method for posterior analysis in the *AcSELerator Analytic Assistant* software of the same manufacturer, constituting a complete experimental scheme for a TL with 500kV. Section IV presents the conclusions.

The authors would like to acknowledge the financial support granted by the CAPES, CNPq.

II. DESIGN AND PROPOSED METHOD

A. System Description

Santo Antonio HPS consists of 44 energy generators of 82.5MVA, generating in 13.8kV and transmitting in 500kV, by means of three winding elevator transformers, in which two of them are primary windings of 165MVA (in 13.8kVA) e one of them is a secondary winding of 330MVA (in 525kV). Two energy generators of 13.8kV [1] power each primary winding.

The HPS has three powerhouses, each one provided with power lines of 500kV for the energy transmission to the collector substation built in the city of Porto Velho, with the following disposition:

- Right Margin – 8 generators of 82.5MVA and two transformers of 330MVA;
- Left Margin – 24 generators of 82.5MVA and six transformers of 330MVA;
- Riverbed – 12 generators of 82.5MVA and three transformers of 330MVA.

A collector substation of 500kV is located in the right margin of the Madeira River, where the transmission lines of Santo Antonio and Jirau HPS are interconnected to the basic SIN network. The interconnection of Santo Antonio HPS is done by three transmission lines of 500kV; one with duple circuit and two with a simple circuit, in addition to a TL passage with simple circuit between the powerhouse on the right margin and the powerhouse on the riverbed, named:

- L1 - LT 500 kV (right margin) – collector SB (12.5km);
- L2 - LT 500 kV (riverbed) – collector SB (13.3km), design objective.

Figure 1 shows the transmission line from the HPS Group Generator (GG2).

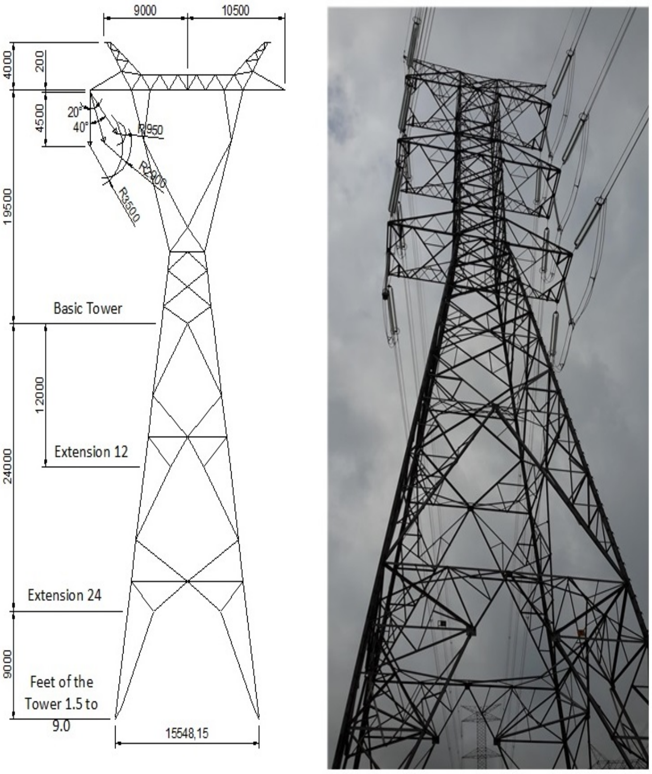

Fig. 1. First tower of the transmission line 2 of the collector substation of Santo Antonio HPS.

The grounding system of each TL has two CAA DOTTEREL lightning rod cables (176,9MCM, 12/7 formation, 15,42mm diameter). The foot tower has resistances of 20Ω.

B. Proposed Method

In case of injection of electric current into the earth, either by the occurrence of a fault in the installation or by atmospheric discharges, the currents dispersed through the grounding system cause the emergence of electric potential differences between points in the ground surface (surface voltages), which produce touch and step voltages, which poses life risk [2]. Furthermore, there is risk of damage caused by the potential transferred for circuits that are somehow connected to the grounding system and to points distant to the ground surface, or even to other remote grounding systems.

The used method consists of injecting a square current at high frequency (25kHz) and high current (maximum of 20A), involving the collector substation and the (GG2) engine room with lightning rod cables of the transmission line. For this frequency, the inductive impedance of the ground wire is not significant, which reduces the effect of other adjacent towers to the one being measured [5]-[6].

A device to measure the grounding resistance by selecting the TL-2 as current circuit [2] is used to extract the measurements, including the grounding resistance of the tower supporting foot. The extent grounding systems, as grids, balances, and metallic pipes, are measured considering only the nearest passage from the connection point, in a way that the measured value represents the behavior in face of an impulse signal, similar to an atmospheric discharge [4]. In this way, the values that better represent the system capability are obtained in order to conduct the atmospheric discharge to the ground, in a more efficient manner when compared to the values derived from conventional devices with low frequency, even when the ground wire is not connected. The test is performed by circulating a current through the ground diffusion resistance, and through an auxiliary electrode, called current electrode, and measuring the voltage between the resistance grounding and another auxiliary electrode, stuck on the ground in a flat area of the created potential by the flowing current (potential level).

The current injected by the earth meter is automatically adjusted to the predetermined value, and the equipment directly indicates the resistance value in its alphanumeric display. Fig. 2 shows the practical grounding testing scheme of TL-2.

The current electrode, Fig. 2A (connection point 2), it is the conductive cable of the third tower of a passage of LT. The rehearsal is accomplished making to circulate a current through the resistance of earth diffusion, of an auxiliary electrode fixed in the soil, Fig. 2C (point 1), of a connection point in the foot of the third tower, Fig. 2B (point 3), measuring like this the voltage produced between the ground resistance and the auxiliary electrode. Fig. 2D present the high frequency earth ground tester used in the measurements.

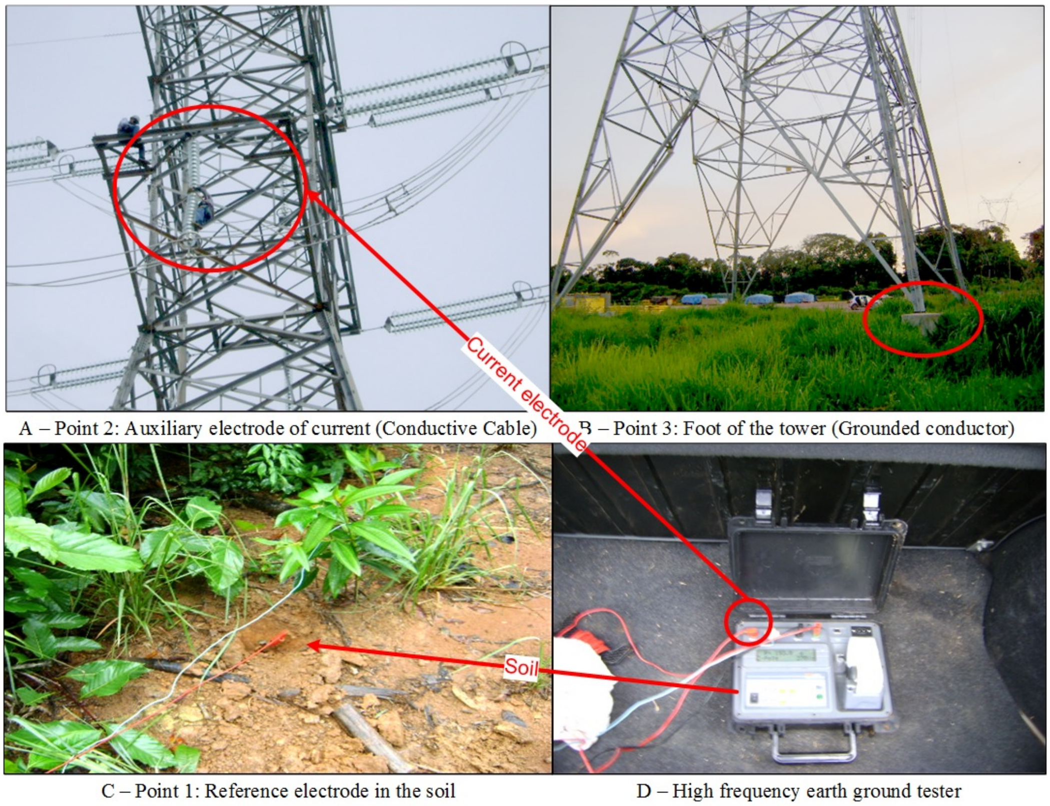

Fig. 2. Testing scheme of the grounding resistance by the injection of high current.

In order to avoid the superposition between the regions of influence [7]-[8], the de-energized phases of the TL were used as current electrode, which belongs to the GG2 line passage under testing, thus connecting to the structure and simulating a short-circuit as illustrated in Fig. 3.

Fig. 3. Connection of conducting cables to the measurement cable of the earth meter and preparation of conductors to measurements extraction.

C. Assessment of Protection Effectiveness of through Resistance Elements (ANSI 21 Quadrilateral)

An experimental practical mounting was developed to evaluate the effectiveness of the grounding system, in which the resistance values were obtained by the design of high current injection and used in a simulation of the protection logic, implemented in the *PSCAD/EMTDC* software. This simulation derived features of the protection function of the quadrilateral distance of phase and ground for posterior insertion at the simulator Doble F6150 of the fault files *COMTRADE* in order to perform tests in a commercial relay SEL-421.

The function of a resistance element is to limit the resistive layer for a protection quadrilateral area. Some resistance elements measure the resistance of the added R_F line. The fault resistance values were obtained according to Equation (1), as given by [3]:

$$R_F = \frac{I_m\left[\bar{V}_\emptyset\left(1\angle Z_{1ANG}\left(\bar{I}_\emptyset + \bar{k}_o.\bar{I}_r\right)\right)^*\right]}{I_m\left[\frac{3}{2}\left(\bar{I}_2 + \bar{I}_0\right)\left(1\angle Z_{1ANG}\left(\bar{I}_\emptyset + \bar{k}_o.\bar{I}_r\right)\right)^*\right]} \quad (1)$$

Where:

- $\bar{V}_\emptyset$ in the voltage between phase and neutral phase ($\emptyset$ represents phase voltage A, B or C);
- Z_{1ANG} is the relay adjustment, which is equal to the line angle for the positive sequence impedance $\bar{Z}_{1L}$;
- $\bar{I}_\emptyset$ is the phase current;
- $\bar{k}_o$ is the compensation factor of zero sequence.

According to [3], the major advantage of this fault resistance element is that its measurement is not significantly affected by the loading conditions. This allows the resistive limit to be set to a value greater than the apparent minimum charge impedance.

Relay SEL-421 uses the MHO properties in the distant protection of phase and ground. Zones 1 (Z1P) and 2 (Z2P) are fixed in the "forward" direction, remaining zone 4 (Z4P) is adjusted forward, and zone 3 (Z3P) is adjusted as reverse, which results into three forward zones and one reverse zone, with high-speed distance elements. Those high-speed elements use voltage and current phasors derived from a medium cycle fast filter to provide opening times of sub-cycle order. The adjustments are automatically associated to the extent of the elements zone. Fig. 4 shows the adjustments performed by the graphic editor of the AcSELerator QuickSet® software.

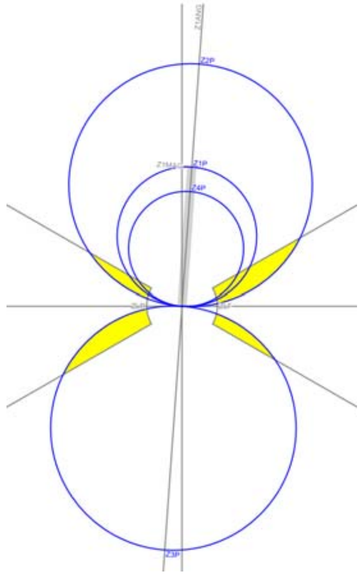

Fig. 4. Range of adjusted MHO distance elements

The range of the MHO distance element of phase Z1P was set as 80% of the impedance of the positive sequence of the secure line. The distance element of phase Z2P is part of the implemented protection assisted by communication – POTT2 (Permissive Overreaching Transfer Trip), with directionality in the forward direction. The adopted range was of 200% of the impedance of positive sequence of the secure line. For the distance element of phase Z3P, with POTT2 scheme, the directionality was set in the reverse direction, allowing it to have a higher range when compared to Z2P. Thus, a range of 200% of the impedance of positive sequence of the secure line was adopted, and phase Z4P was adjusted as conventional zone 2 protection (Z2P), that is, 120% of the impedance of positive sequence of the secure line. Fig. 5 presents the adjustments for the logic diagram of distance protection.

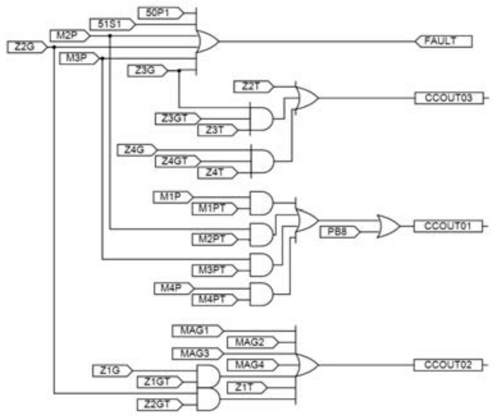

Fig. 5. Logic diagram of the elements of quadrilateral distance.

D. Practical Scheme

The first step of the practical scheme is to simulate diverse fault conditions considering the resistance values of grounding (R_T) measured in field and fault resistances collected (R_F)

calculated with PSCAD/EMTDC software. Those measurements are presented in Table 1.

Table 1. Input values for the software simulation

Test	R_T (Ω)	R_F (Ω)
1	2.21	20.60
2	1.74	16.40
3	1.82	18.20
4	2.80	20.41

The extraction of the faults files is done in the second step in COMTRADE format (Common Format for Transient Data Exchange for power systems). In the third step, these files are provided to the simulator (Doble F6150) for the files in COMTRADE format for characterization of certain situations tests on the protection logic [9]-[10]. The fourth step is characterized by the evaluation of the relay operation behavior regarding the simulated situations. Fig. 6 shows the testing layout set in the laboratory.

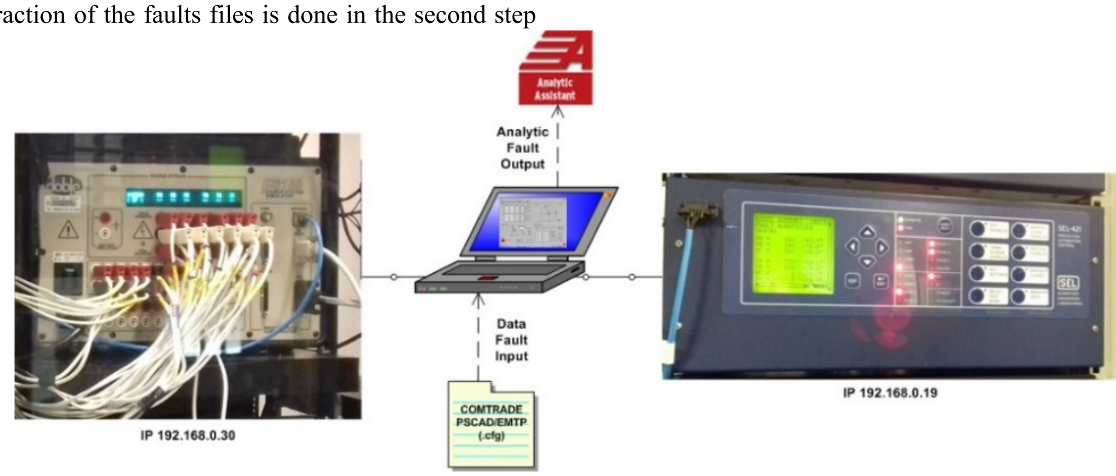

Fig. 6. Complete test scheme of fault conditions

A complete scheme of the TL was modeled by using the software *PSCAD/EMTDC* to simulate diverse fault conditions, as demonstrated in Fig. 7.

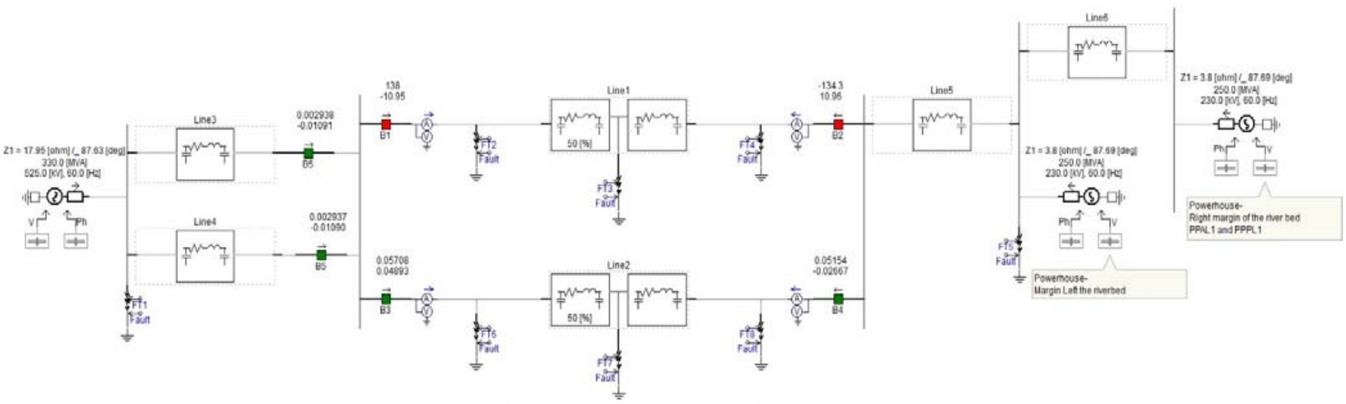

Fig. 7. Modeling unifilar diagram in the *software PSCAD/EMTDC*

III. Results

Figs. 8 to 11 present the graphical results of the fault situations applied on the SEL-421 relay, with the use of *COMTRADE* files that were loaded from the simulator Doble 6150. Those graphics also show the binaries performed in each fault situation.

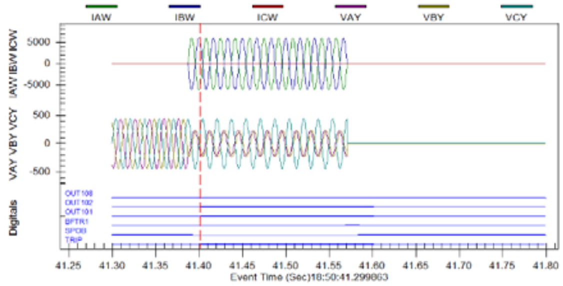

Fig. 8. Test 1

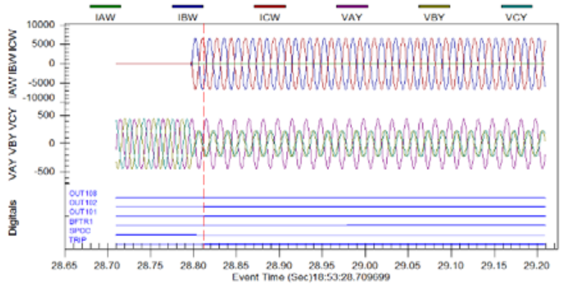

Fig. 9. Test 2

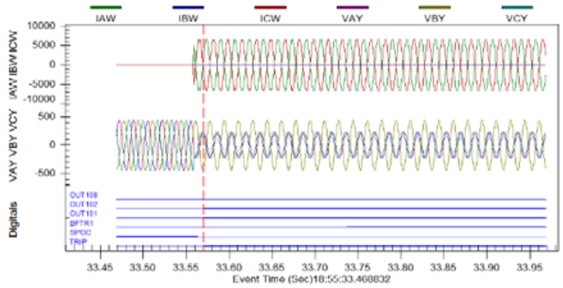

Fig. 10. Test 3

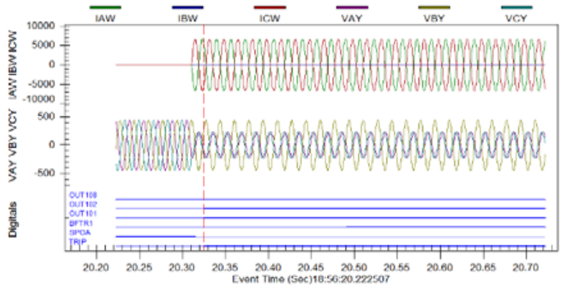

Fig. 11. Test 4

For each test, Table 2 summarizes the measured and calculated fault resistances, the distance from which the relay identified the fault, the zones performed by the relay and the fault phase.

Table 2. Summary of Obtained Results

Test	R_T (Ω)	R_F (Ω)	Distance (km)	I_F (kA)	Zone	Phase
1	2.21	20.60	0.100	4.3	1	B
2	1.74	16.40	0.174	4.9	2	C
3	1.82	18.20	0.100	4.7	1	A
4	2.80	20.41	1.39	3.9	1	A-B-C

IV. CONCLUSIONS

Based on the response results of the SEL-421 relay, it was possible to verify its correct usage for each applied fault condition, allowing the validation of the entire process. Results indicate the effectiveness of the resistance measuring method of global grounding (involving substation, engine room with lightning rod cables of the transmission line), and the simulation in the *PSCAD/EMTDC* of the interconnection system of Santo Antonio HPS to SIN. Finally, the suitability of the relay parametrization and the values obtained by the simulations were also verified, which were used to acquire the *COMTRADE file* that can be used as validation guidelines in protection studies. The high-current injection system is a reliable alternative for the potential drop method with low currents, as well as for determining the resistance or impedance of grounding systems.

V. References

[1] Edital de Leilão n.°007, “Licitação para a contratação de serviço público de transmissão de energia elétrica”, Agência Nacional de Energia Elétrica (ANEEL), 2008.

[2] IEEE Guide for Safety in AC Substation Grounding," in IEEE Std 80-2013 (Revision of IEEE Std 80-2000/ Incorporates IEEE Std 80-2013/Cor 1-2015), vol., no., pp.1-226, May 15 2015.

[3] Ferrer, Hector J. Altuve, and Edmund O. Schweitzer, eds. Modern Solutions for Protection, Control, and Monitoring of Electric Power Systems. Schweitzer Engineering Laboratories, 2010.

[4] MEGABRAS Ltd., Datasheet, High Frequency Earth Ground Tester - TM25R. Disponível em:< http://www.megabras.com/en/products/earth-tester/high-frequency-earth-tester-TM25R.php>.

[5] IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System," in IEEE Std 81-2012 (Revision of IEEE Std 81-1983), vol., no., pp.1-86, Dec. 28 2012.

[6] Yan Ma; Karady, G.G., "Investigating grounding grid integrity based on the current injection method," in North American Power Symposium (NAPS), 2009, vol., no., pp.1-5, 4-6 Oct. 2009.

[7] Sardi, J.; Chian, J.O.C., "Evaluation of surge arrester requirement for overhead transmission line using Electromagnetic Transient Program," in Power and Energy (PECon), 2010 IEEE International Conference on, vol., no., pp.985-988, Nov. 29 2010-Dec. 1 2010.

[8] Chanaka, M.; Shanthi, K.; Perera, R., "Modeling of power transmission lines for lightning back flashover analysis (A case study: 220kV Biyagama-Kotmale transmission line)," in Industrial and Information Systems (ICIIS), 2011 6th IEEE International Conference on, vol., no., pp.386-391, 16-19 Aug. 2011.

[9] Sardi, J.; Kadir, M.Z.A.A., "Investigation on the effects of line parameters to the lightning performance of 132 kV Kuala Krai-Gua Musang transmission line," in Power Engineering and Optimization Conference (PEOCO), 2013 IEEE 7th International, vol., no., pp.594-599, 3-4 June 2013.

[10] Qais, Mohamed; Khaled, Usama, "Evaluation of lightning performance on transmission system sag," in Power Engineering Conference (UPEC), 2015 50th International Universities, vol., no., pp.1-6, 1-4 Sept. 2015.