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SUBSTATION INTERFERENCE ON GAS ENTRANCE OF INDUSTRIAL PLANTS

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Abstract

Industrial plants often have medium or high voltage electrical power entrance and also gas feeders. Often the main substation is located near the gas entrance, in the utilities area. When the occurrence of a phase to ground short-circuit in the substation, the pipeline and gas entrance that serves the plant may be exposed to high voltage soil potential, of the order of a few kilovolts, due to resistive coupling with the substation ground mesh.

The consequences of this situation are reflected in various risks, with emphasis on:
- damage to the protective coating of the duct, due to the increased soil potential, in excess of it´s dielectric supportability (typically on the order of 5kV);
- spread of potentially hazardous to duct exposed parts (valves, measuring place etc.); and
- damage to cathodic protection system components, as rectifier and insulating joins at gas entrance.

This paper presents the investigations conducted in a factory that has a 69kV main substation very close to the gas entrance, the order of a few meters away. The substation phase to ground short-circuit current is 7kA, what causes a 9kV soil potential near the gas pipe.

It is presented the methodology for modeling the various elements involved in this process, the results of simulations made, arrangements been taken to reduce soil potential next to the duct to levels below 5kV, and the measures for people and insulating joins protection.

It is important to note that such problems usually will be solved with measures involving the entire grounding system of the industrial complex and also close to the duct (outside the industrial plant).

The gas distribution companies should require from customers where this situation occurs, to ensure safety for people who have access to elements of its network, and for the integrity of their own ducts and cathodic protection components.

The computer simulations developed for this work were made with the software AutoGrid, developed by the Canadian company Safe Engineering Services & technologies Ltd. (www.sestech.com).

1. General Concepts

Substations and transmission lines interference on steel structures involves three types of couplings, namely, inductive, resistive and capacitive.

The inductive coupling is characterized by the occurrence of longitudinal voltages on the phases and neutral of medium and low voltage distribution lines, on the shielding and pairs of telephone lines and on long metal structures parallel to the transmission line, resulting from unbalanced currents in the LT.

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The resistive coupling is characterized by the occurrence of voltages on the grounding of transformers, on the neutral of distribution lines, on the screening and suspension cables of telephone lines, and on metal grounded structures (pipelines and fences), due to current injection on grounding of power system elements, such as meshes of substation grounding and foundations of transmission lines towers.

These two types of couplings result in critical situations where the occurrence of phase to ground failure in the electrical system, due to the high unbalanced currents of the transmission line, which interact with the interfered installations, causing the occurrence of high voltages.

The capacitive coupling is characterized by the occurrence of static voltages on not grounded metallic structures, such as pipelines and structures in the process of assembly or maintenance, when portions of them, next to substations and transmission lines in normal operation condition, are not in contact with the ground, creating a risk situation to personnel safety.

A interference study includes the following activities:
— establishment of criteria for personnel and equipment safety;
— calculation of longitudinal and transverse voltages on long multigrounded metal structures, due to the effects of resistive and inductive coupling with the power system, when the occurrence of a phase to ground short circuit, considering the most critical configuration and/or operational condition of the power system;
— calculation of voltages arising in steel structures not grounded, due to capacitive coupling with the power system on normal operating condition and with maximum voltage;
— when the calculated results exceed the safety criteria, corrective measures shall be applied to ensure appropriate security levels.

2. Case Study

The case is based on a real situation of an industry, fueled by a gas pipe buried in the street, to 0.93 cm deep and 1.8 m away outside the wall of the plant, and parallel to it for an extension of about 100m.

The factory substation entrance, with a distance of about 30m away from the gas measuring gate, is fed by a 69kV transmission line without ground wire. It was used for this study, the 69kV phase to ground short-circuit current of 7.06kA.

The original ground mat design for the 69kV substation did not consider the effect of coupling with the pipe, as this information was not available for the designer. After the construction of the substation, it was found the proximity to the gas line entrance, and a study was developed in view of the needed design changes to the system grounding of industrial plant, in order to control the soil potential along the buried pipeline and on the gas entrance.

In this case it was necessary to consider only the resistive coupling between the substation ground mat and the gas line, because there was no parallelism of the transmission line with the gas duct.

Figure 1 shows the factory plan, where it can be identified the following key elements for this study:
— gas duct line, parallel and external to the factory wall, finished in a box of valves outside the plant;
— arrival of the transmission line and 69kV substation; and
— factory facilities area, which includes the area of industrial oxygen, the cooling towers and the gas entrance.

2.1. Parameters Considered

Figure 2 show the two layer soil model used on the simulations, obtained from soil resistivity measurements (Wenner technique), made on the substation area before it´s construction. The soil potential close to the duct cannot exceed the value of 5kV, which is the insulating supportability of the duct coating. Maximum tolerable "step" and "touch" potential were calculated by the AutoGrid software, considering the following parameters:
— gravel for soil covering (10cm) – 3000Ωm;
— soil surface resistivity - 291Ωm; and
— defects elimination time - 0.5 seconds.

It is important to note that, in practice, the concepts of step and touch potential shall be applied only to areas with natural floor (or covered with gravel), because inside the buildings and on external areas with concrete floor, the metal screen reinforcement (BEMATEL or similar) plays the role of a equipotencialization mesh, ensuring human security for step and touch potential.

Soil Covering	Gravel	Natural Soil
Max. step potential	2272V	440V
Max. touch potencial	685V	227V

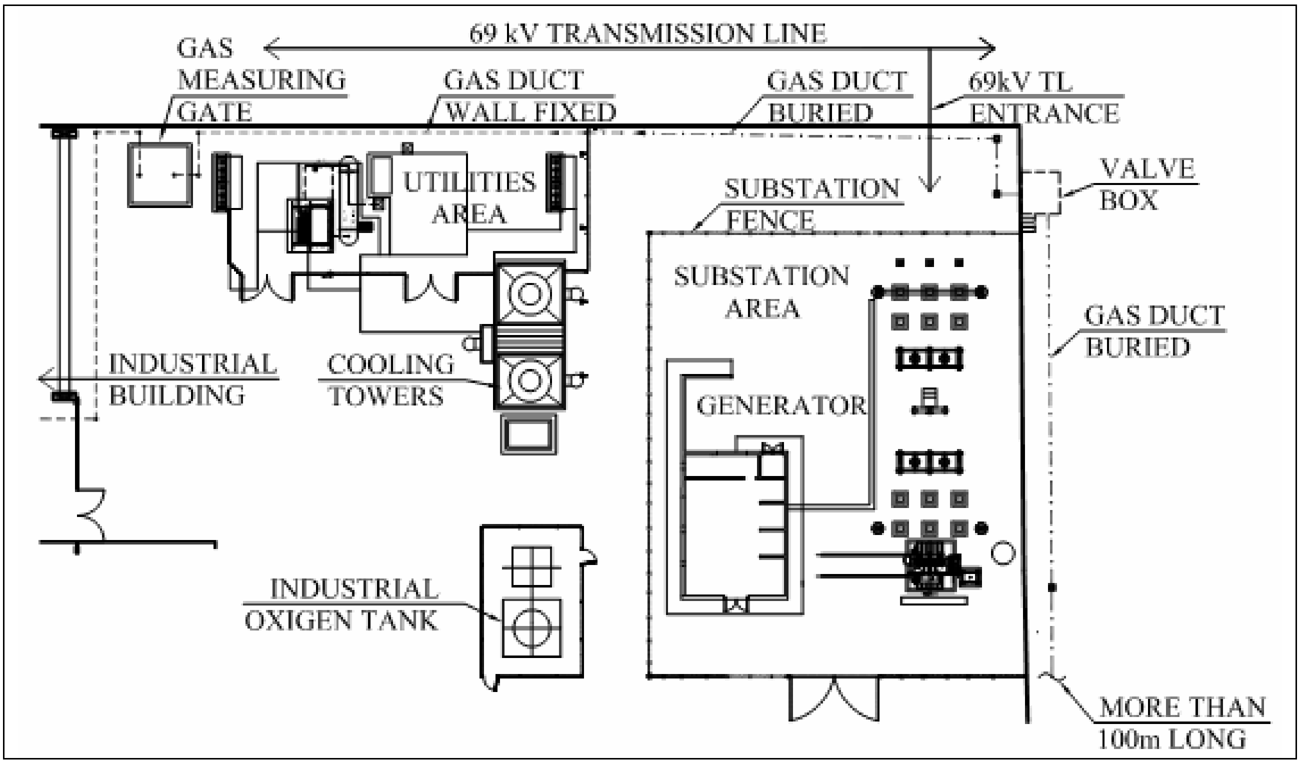

Figure 1: factory plan.

LAYER	Soil Resistivity	Depth
First (superficial)	291Ωm	0,4m
Second	122Ωm	∞

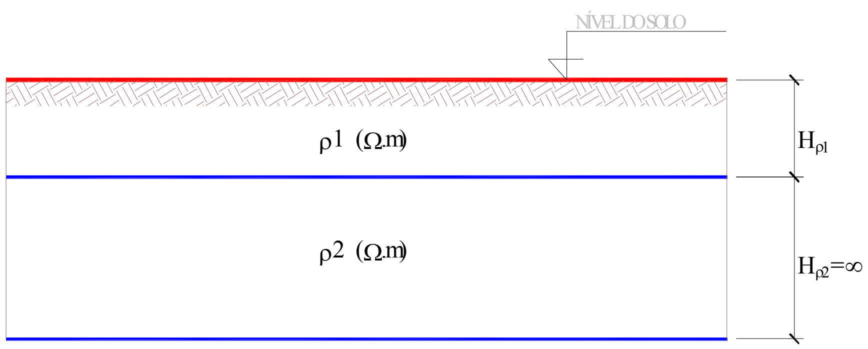

Figure 2: two layer soil model.

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>> Safety Calculations Table

System Frequency..........................(Hertz).:  60.000
System X/R........................................:  20.000
Surface Layer Thickness...................( cm ).:  10.000
Number of Surface Layer Resistivities..............:    2
Starting Surface Layer Resistivity.........(ohm-m).:   NONE
Incremental Surface Layer Resistivity.......(ohm-m).:  3000.0
Equivalent Sub-Surface Layer Resistivity....(ohm-m).:  291.00

Body Resistance Calculation..........: IEEE Std.80-2000
Fibrillation Current Calculation.....: IEEE Std.80-2000 (50kg)
Foot Resistance Calculation..........: IEEE Std.80-2000
   User Defined Extra Foot Resistance:   0.0000     ohms
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Fault Clearing Time (sec)	0.125	0.250	0.500
Decrement Factor	1.192	1.101	1.052
Fibrillation Current (amps)	0.328	0.232	0.164
Body Resistance (ohms)	1000.00	1000.00	1000.00

SURFACE LAYER RESIST-IVITY (OHM-M)	FAULT CLEARING TIME 0.125 sec.		0.250 sec.		0.500 sec.		FOOT RESIST-ANCE: 1 FOOT (OHMS)
	STEP VOLTAGE (VOLTS)	TOUCH VOLTAGE (VOLTS)	STEP VOLTAGE (VOLTS)	TOUCH VOLTAGE (VOLTS)	STEP VOLTAGE (VOLTS)	TOUCH VOLTAGE (VOLTS)	
NONE	775.9	400.4	594.0	306.5	439.7	226.9	909.4
3000.0	4008.7	1208.6	3068.6	925.2	2271.5	684.9	6781.3

* NOTE * Listed values account for short duration asymmetric waveform decrement factor listed at the top of each column.

Table 1: maximum tolerable step and touch potencials.

2.2. Case Study Results

The simulation of the original substation ground mat design, showed soil potentials near the gas pipe (outside the factory wall and one meter deep) of about 9kV, for the maximum phase to ground short-circuit substation condition, as can be seen in Figure 3.

To obtain soil potentials below 5kV (maximum supported by the gas pipe coating), were investigated various scenarios, with a first modification on the substation ground mat, and with successive changes in the utilities grounding geometry. The following are the scenarios studied:

— removing the last ground mat mesh, near the wall - very small reduction of the potential along the pipe;
— interconnection of the last conductor of the substation ground mat (separated from the mesh on the previous scenario) with the grounding of the utilities area - reducing the potential along the duct to a value of about 7.6kV;
— the previous configuration with the interconnection of a grounding ring around the building deposit – soil potential reduction close to the pipe to a value of about 6.0kV;
— previous configuration interconnected to the main grounding ring around the factory building - reducing the potential along the pipe to below 5kV.

It was also calculated the step and touch potentials in the substation, due to the occurrence of a phase to ground short-circuit. It was verified that these potentials were below the human tolerable limits for gravel covered soil, except at both ends of the substation, where it is recommended the extension of the gravel covering up to six meters after the last ground mat conductor.

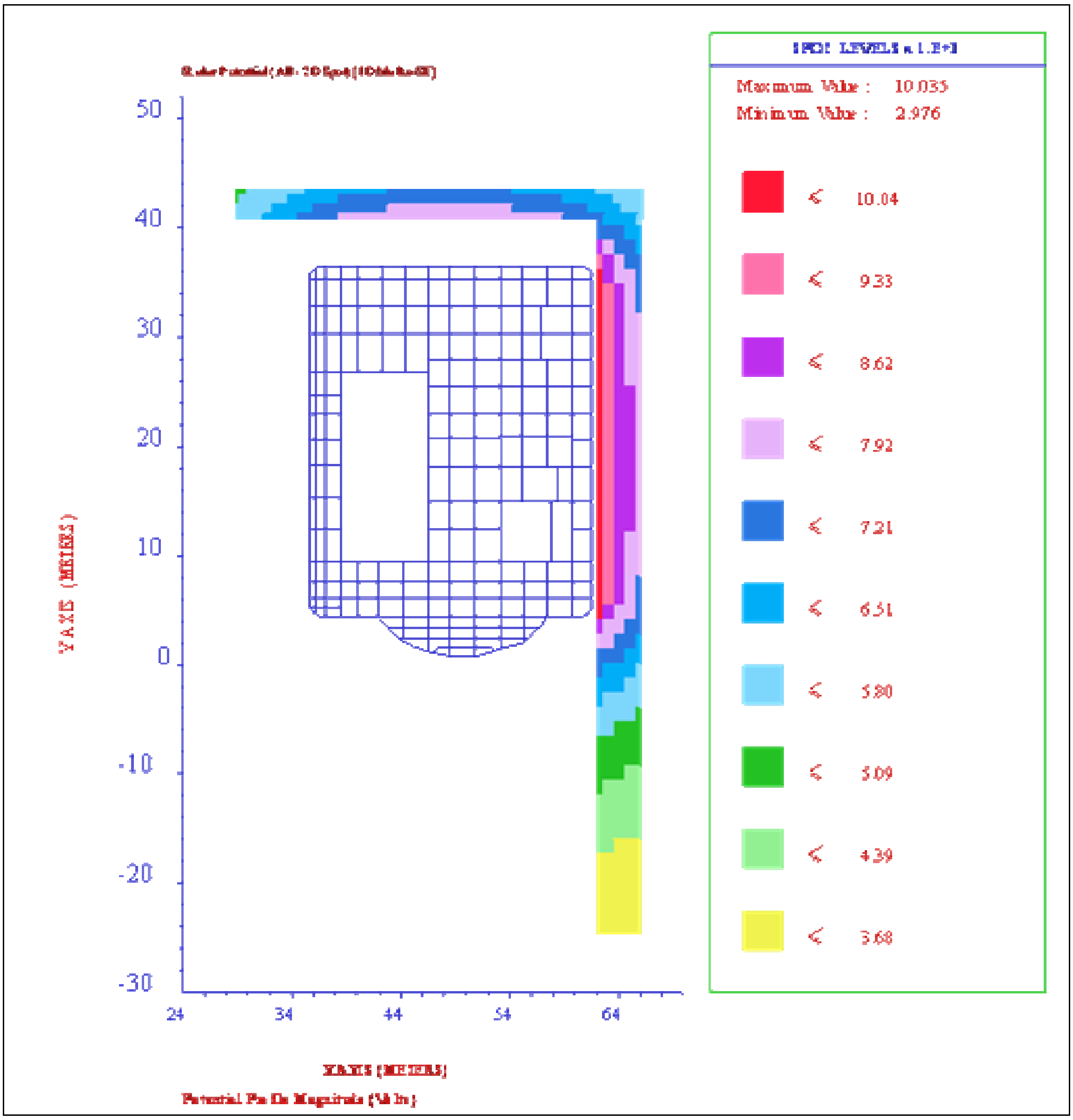

Figure 3: ground potential rise (1m deep, along gas line path) for the original substation 69kV ground mat.

For the final scenario studied, according to figure 4, the maximum ground potential rise of the industrial grounding system is 2,45kV. The soil potential around this grounding system can be considered safe, if it is in the range between 2,22kV and 2,68kV for natural soil (2448V +/- 227V), and between 1,76kV and 3,13kV for soil covered with gravel (2448V +/- 685V). Figure 6 shows the soil surface potentials around the substation and utilities area. It is recommended covering the soil with gravel for utilities area, especially close to the substation (area of cooling towers and oxygen tank).

With respect to the gas pipe valve box, at the end of the gas line outside the factory wall, it was recommended a grounding ring spaced one meter around it walls, to provide security conditions for people walking around and to valves operators. This ring potential rise can be up to 3,24kV. To assure safety condition on this area, the ground potential rise should be in the range between 3,01kV and 3,47kV for natural soil (3238V +/- 227V), and between 2,55kV and 3,92kV for soil covered with gravel (3238V +/- 685V). The soil potential rise around the valve box occurs in the range between 2,61kV and 3,9kV.

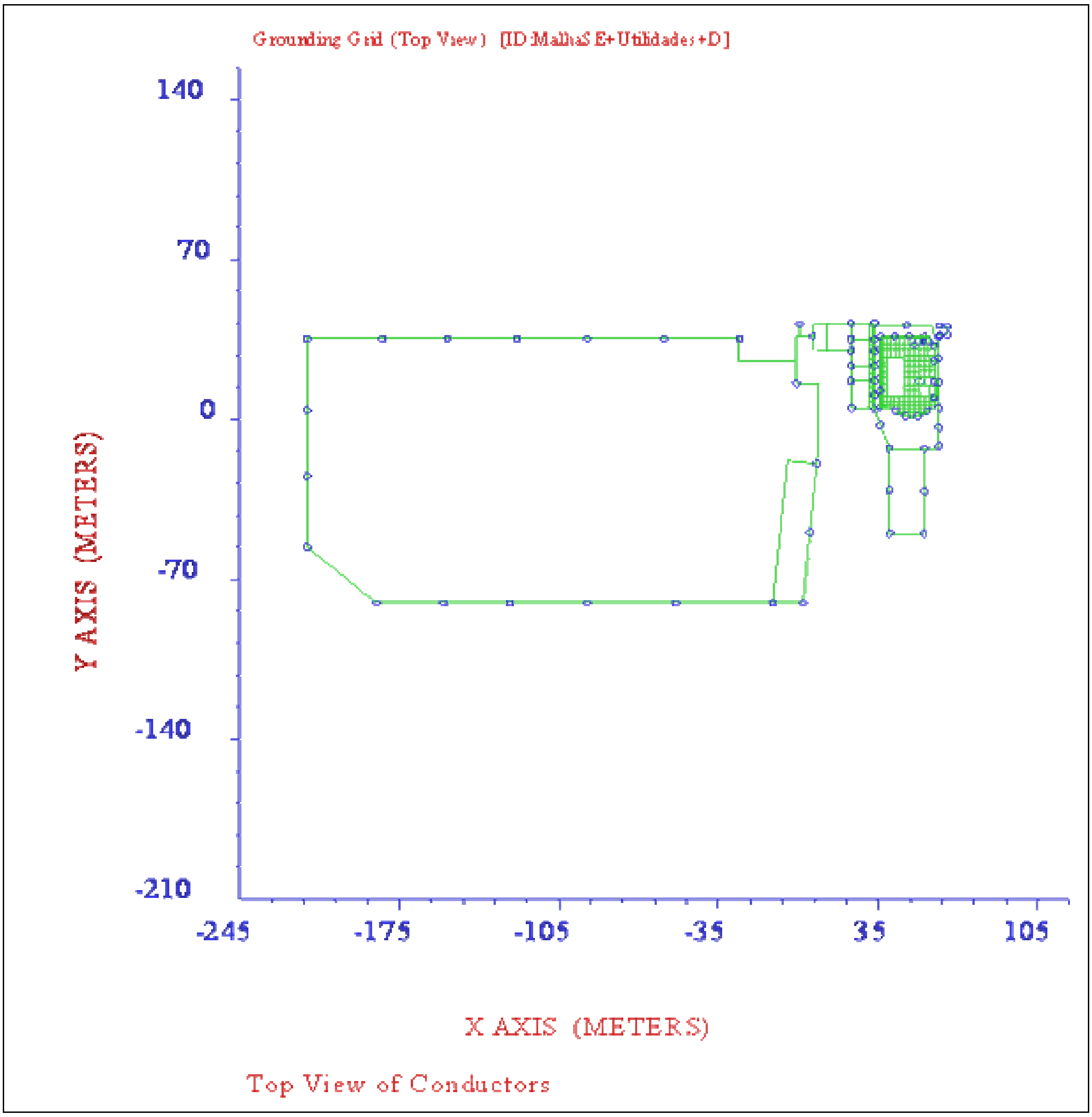

Figure 4: final grounding system configuration - substation ground mat modified + industrial grounding system (utilities + building grounding rings).

2.3. Insulating Joint Overvoltage Protection

A gas pipe insulated flange uses insulating gaskets and bolt sleeves to isolate cathode protection currents from other ground returns, such as pipeline ownership changes, and to segment cathodically protected pipe lines from facilities, within which the piping or equipment is normally grounded. Without insulating flanges, additional loads would be placed on cathode protection power supplies.

Any lightning protection device bridging the insulator must turn on before the flange breakdown voltage is approached (assuming 2kv per nanosecond surge pulse risetime). A gas tube device, bridging the cathodic protection flange insulator is a dynamic path to earth ground without violating the cathodic protection circuit. To provide the highest level of overvoltage protection, the device shall clamp the voltage to the lowest allowable level and it´s installation must be made with the shortest possible lead length, to minimize the voltage developed on the lead inductance.

The protector performs the following functions, responding to both lightning and AC fault current:
- provide over-voltage protection;
- limit the voltage of cathodically protected equipment with respect to ground; and
- provide AC and DC isolation for voltages below the voltage blocking level selected and an effective grounding path whenever the voltage attempts to exceed the voltage blocking level.

If the voltage attempts to exceed the voltage blocking level selected, the device immediately begins to clamp the voltage, by allowing current to readily flow between its two connection points. Blocking voltage refers to the peak voltage that can occur across the device terminals, while preventing the flow of current.

The insulation joint separating the external gas line from the internal plant gas distribution, in the measuring gate, shall be protected by a DPS - Overvoltage Protection Device, with "spark gap" technology. Considering it may be subjected to 60Hz overvoltages up to 2.5kV (for a time up to 0.5s), it shall be protected by a fuse. It was suggested the use of DPS Clamper GCL N/PE 275V - 100kA, protected (in series) with a NH 160A fuse. This DPS and fuse should be set in a explosion-proof housing, because it is located in an area classified.

The GCL N/PE 275V 100kA is a device designed to provide overvoltage protection from lightning and AC fault current in insulated joint applications. Rated for AC fault current as well as high values of lightning surge current, it can be applied to sites where a spark-gap arrester or metal oxide varistor would be inappropriate.

2.4. Recommendations

The plant grounding system was redesigned, to implement the following measures:
- removing of the last ground mesh, close to the wall;
- implementation of a ground mat around the of utilities area (with $50mm^2$ bare copper cable) and covering the soil surface in this area with a 10cm. gravel layer;
- interconnection of utilities grounding mat, deposit grounding ring and main factory building grounding ring;
- burying a grounding ring one meter away from the valve box walls, outside of the factory (with $80mm^2$ galvanized steel cable, to prevent robbery) and implementing a sidewalk around the valve box perimeter structured with metallic grid; and
- installation of overvoltage protection device for the insulation joint, on the gas measuring gate.

The grounding ring to be buried around the plant buildings shall be of $50mm^2$ bare copper cable, or alternatively, it may be used the steel foundations reinforcement of the buildings, provided are made continuity tests (according with Annex E of ABNT code NBR-5419/2005), certifying the adequacy of these as grounding elements.

The buried grounding connections should be made with exothermic welding or compression joints. The steel parts of the buildings structures (foundations, bases of the columns and floor slabs), and equipment skids should be connected to the plant grounding system.

A one meter wide concrete sidewalk structured with a metal mesh (type TELCON/BEMATEL) should be constructed around the valve box. For the valve operator safety, additional measures shall be needed, through security procedures and use of appropriate safety stuff (rubber boots and gloves, and insulating pad if necessary).

3. Conclusions

Most factories have utilities infrastructure grouped together, including the electrical and gas entrance. Considering the high ground potential rise due to phase to ground short-circuit in the substation, special measures shall be taken to ensure people and equipment safety under this condition.

These measures includes the correct dimensioning of the grounding system of the entire industrial plant, considering the interactions with the substation ground mat, and the use of surge protection devices (DPS), for the gas duct insulation joints.

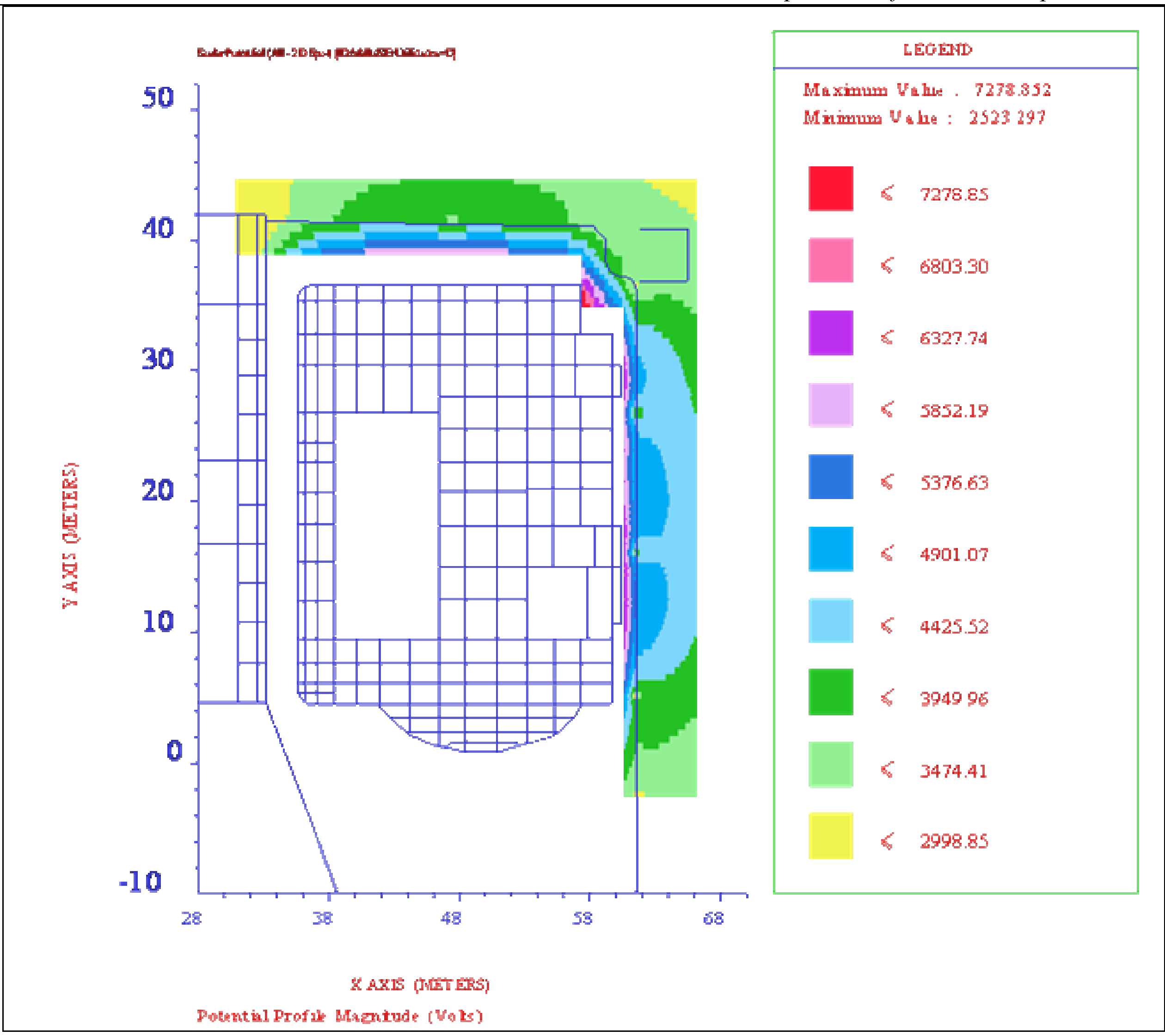

Figura 5: ground potential rise along gás line path (1m dep) for final grounding system configuration.

8. References

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