Abstract—In 2011, two experiments were carried out on the SOYUZ and VEGA launching pads in Kourou, French Guyana, in order to verify the lightning protection of the installations, and give the elements needed for the certification of the sites. This paper presents the methodology of the tests and the expertise performed on the sites and which concluded to a good assessment of their lightning protection.

Keywords - lightning, experimental study, induced effects, interconnected buildings, grounding network

I. INTRODUCTION

Recently, two new launching pads have been built in the Guyana spatial center, in Kourou. The first one is dedicated to SOYUZ launchers (Figure 1); the first launch was in October 2011. The second one is for the VEGA European launcher (Figure 2); the first launch was in January 2012. Among all the demonstration steps needed to qualify such sites, lightning protection is a major one. For both sites, ONERA has been involved in the definition of the lightning protection system (LPS) from the beginning of the projects. Some numerical simulation studies had been made previously [3], [4] to optimize the system definition and to give some preliminary results of induced magnetic fields in the launcher area in case of lightning.

It is quite difficult to evaluate the behavior of such large and complex sites in case of lightning strike, and obviously the simulation has its limits. Due to the complexity of the system, the impossibility to introduce all the elements of the system in the model, as well as of the lack of electromagnetic (EM) data (local resistance values, soil characteristics...), numerical simulation can only provide an ideal reference situation. Thus, experimental tests are the only way to assess how far the realization is from this ideal situation. At the same time they allow the control of the overall installation once the realization of the site is totally achieved and they allow the verification of installed protection systems. Moreover, non linear behaviors can be observed experimentally on the building structures for example but not in the modeling.

This paper presents the methodology that has been performed on the two sites to analyze the lightning protection system, to give some elements for the evaluation of its efficiency and eventually to identify some sensitive points, likely to lead to some specific recommendations for the improvement of the realization or for a particular attention to pay concerning maintenance. ONERA’s technical expertise, by testing the sites in a dynamic way, gives some complementary elements to APAVE’s preliminary analysis and checking of the normative rules.

II. DESCRIPTION OF THE SITE AND PREVIOUS STUDIES

The two launching pads, SOYUZ and VEGA, are composed of:
- a launcher area, where the launcher is located during the launching phase,
- a large building, partially or totally buried, supporting a
mobile gantry which is installed over the launcher until few hours before the launch,
- several external buildings,
- a set of 4 masts, interconnected at their top, dedicated to the capture of lightning and to the balance of the current in all the LPS (masts, local grounding networks and external grounding ring)
- a grounding network, consisting in local ground connections for the buildings and the masts and a large grounding ring, all being interconnected (Figure 3).

Figure 3: Local view of the VEGA grounding network

Among the specificities of these sites, we can list the ones that makes more complex the analysis of the lightning protection of such critical and very large sites:
- Some sensitive elements are located in the buildings close to the launcher.
- Some buildings are far from the launcher zone, but are generally connected by water and/or currents networks.
- The launcher contains highly sensitive and small elements compared to the installation size.
- Experimental tests with real lightning on the site are impossible.

For such complex and large systems, the first thing to do is of course to apply common rules and existing standards, associated with the expertise background, in order to get a first definition of the lighting protection system.

Then, if the specifications require it (due to the presence of critical systems for example), 3D numerical simulations can provide a precious complementary help to optimize the solution by evaluating electric currents and electromagnetic constraints on the system. A few years ago, in the definition phase of the sites, ONERA had performed 3D EM simulations with its ALICE FDTD code, including realistic meshed models of the whole VEGA and SOYUZ sites. The objective of the computations was to estimate the levels of the magnetic field induced by a lightning strike on one of the pylons of the lightning protection systems. Several impact points had been simulated, and different configurations of the earthing system had been studied. For each simulation, a large set of results had been analyzed (2D mappings of magnetic fields, fields and currents at several test points...), in order to quantify and to better understand the induced effects of a lightning impact, but also to justify the choice of a particular optimized grounding network solution. The analysis of the obtained results gave some important elements to optimize the grounding network of the sites, before the beginning of the construction.

Following this modeling study and once the sites were achieved, the complementary work to do was to define and perform a set of in situ measurements that could lead to an assessment of the real lightning protection system. Consequently, the two main technical objectives of the experimental campaigns could be declined as follows:

- give experimental elements on the symmetry of the current distribution in the LPS and in the grounding network in order to conclude on the validation of the realizaiton for the lightning protection,
- evaluate the real electrical characteristics of the various constitutive elements of the system, in order to improve and adapt the numerical models with realistic data, and thus improve the accuracy of the computations.

III. EXPERIMENTAL METHODOLOGY

A lightning strike is very specific from an electrical point of view. Indeed, the equivalent circuit generator driving the current is not totally known. The intensity of the lightning current can be evaluated but not the way the current will be redistributed and close the electrical circuit. Finally, the extension of the electrical circuit is not fully controlled. Consequently, when studying the behavior of a system, the important issue is to evaluate the electric current and voltage distributions in the installation that has to be protected. These distributions can be seen as solutions of an equivalent electrical circuit that is unknown.

The methodology proposed for the set of tests that has been performed on the SOYUZ and VEGA sites during the experimental campaign consisted in stressing the global system in some specific ways, in order to evaluate the sensitive parameters of the equivalent circuit of the system, and consequently to be able to analyze the current distribution in the system.

Due to the impossibility to use a real lightning strike as an injected source, we have used a high power generator, located far (some 100m away) from the masts of the LPS. In order to evaluate the redistribution of a real lightning strike in the four masts, we proposed to evaluate the symmetry of the redistribution of the currents, by applying current injection on each mast, one at a time. The current, injected by the generator in the masts of the LPS, uses the local ground to "close" the circuit (Figure 4). Therefore, in this configuration, the result depends on the position of the generator. To analyze the site as correctly as possible, it was necessary to inject the current with a generator reference (local ground) that we could consider as independent of the grounding network of the site: for this the generator local reference had to be far enough from the site and far its grounding network.
Figure 4: Principle of the current injection and the current return path

Several types of measurements have been performed during the test campaigns: induced currents in the masts, overvoltage between the masts and the ground, magnetic fields in several points in the launcher area, induced currents in the fluid pipes and on the power lines.

As said before, in order to be able to conclude on the symmetry of the current redistribution in case of a real lightning strike, a global set of measurements has been recorded with four successive positions of the generator (Figure 5). The interest of this approach is to have a global understanding of the behaviour of the systems, whatever the impacted mast is.

Consequently the underground is not homogeneous. This specific point has a real influence on the balance of the currents, and consequently, on the efficiency of the earthing system. With the possibility offered in 3D modeling to take into account some different soil characteristics, we could observe this dissymmetry and its consequence on the minimization of the magnetic field in the center of the masts. The measurements performed in Kourou could confirm this dissymmetry, and the analysis of the measurements provided some quantification of the differences between the local resistances of the ground connections of each mast.

Indeed, the global LPS can be seen as an electrical circuit (Figure 6), with several interconnection impedances, for both aerial and buried parts. With successive injections on each of the four masts and simultaneous measurements of currents and voltages between the three other masts and the far ground reference, we obtained a set of curves that we could fit analytically, knowing the injected current and the characteristics of the equivalent circuit.

A parametric study with some simplified circuit simulation could status on the values of these relative impedances and lead to the conclusion that the resistance between the masts in the carneau are higher than the ones on the side of the building.

Due to the electrical characteristics of the site and its dimensions, it would be very difficult to improve the local grounding of the masts C and D and consequently, we can say that the realization is almost optimal. Moreover, considering the obtained values, there is no doubt that in case of lightning the current will be correctly evacuated through the conductors of the LPS.

The problem of the VEGA launching pad is different, in the sense that this site is located on the former ELA1 launching site. Therefore the buildings already existed and consequently, some pre-existing constraints had to be managed for the construction of the new lightning protection system. The numerical simulations, based on plans, used an “ideal”
numerical model of the site, considering that the construction could correspond to those plans. In fact, the reality of the realization led to some limitations with respect to the ideal situation. The experimental study had the objective to verify that the realization was in accordance with the expected, lightning protection. The experimental procedure used on the site was the same as for SOYUZ. It also demonstrated a dissymmetry between the local resistances of the different masts. The analysis of the obtained results shows that both the connection to the grounding ring and the local grounding are important for an optimal balance of the currents. However, once again, the evacuation of the currents in all the grounding system of the LPS is not challenged.

B. Magnetic field in the launcher area

The quality of the balance of the currents in the lightning protection system is the key factor for the mitigation of magnetic field intensity in the launcher area. Several elements participate to this balance. We have seen that the dynamic stress of the grounding network of the masts showed different values of impedances; this is a first source of dissymmetry. The second source of dissymmetry is of course the attachment point of the lightning impact at the top of the LPS, on a cable or on a mast. However it is difficult to evaluate the relative influence of those two types of dissymmetry sources on the final distribution of the real lightning current. In fact, combined with the geometrical aspects, the electrical characteristics of the site together with the impedance of the aerial system have a major impact on the current distribution.

The joint use of a set of measurements and an electromagnetic computational tool leads to a comparison and an evaluation of the relative influence of the impedance of the aerial system and the impedance of the buried ground system, in the balance of the currents. The conclusion of this analysis is that the main influence comes from the aerial system. Consequently, even if the 3D numerical model of the previous studies did not represent perfectly the reality, the magnetic field induced by a real lightning strike on the higher part of the launcher will be close to the ones obtained by 3D simulations. However, some differences could exist for the lower part of the launcher. The H field measurements obtained in situ during the campaign at level 0 (Figure 8) give some complementary elements to evaluate the induced levels.

V. INDUCED EFFECTS ON EXTERNAL PIPES

During the experimental campaigns, some complementary measurements have been made on pipes linking the main building with some farther ones: LOX and energy for SOYUZ (Figure 9), sets of fluids and energy for VEGA.
could occur on them. Consequently, their induced effects on the launcher area and on the main technical buildings have also to be controlled.

VI. CONCLUSIONS AND PROSPECTS

This paper has presented the results of the experimental campaigns performed on the lightning protection systems of the SOYUZ and VEGA launching pads, in April and in October 2011.

A large set of measurements have been recorded on the two sites during these test campaigns, in order to proceed to a global and complete protection analysis of the system and of the induced EM effects on the system in case of lightning impact. The measurements that have been performed during the campaign were:

- induced currents in the masts;
- overvoltage between the masts and the ground;
- magnetic field in several points of the LPS (with and without the gantry) and in the building;
- induced currents in the fluid pipes and on the power lines;
- induced currents on the bonding of the gantry;

In order to be able to conclude on the symmetry of the current redistribution in case of real lightning strike, a global set of measurements has been recorded with the four successive positions of the generator, in order to have a global understanding of the behaviour of the system, whatever the impacted mast was.

As far of the protection of the site is concerned, we may distinguish the following items:

- We have to remind the interest of the approach which tests the system in a dynamic way which is requested to evaluate all the inductive effects. This is particularly requested for testing the local earthing system. As a comparison, tests at DC only provide an information on the connectivity of the global earthing system from a static point of view,
- From a DC point of view, our results confirm APAVE’s results on the quality of the interconnection system, for both SOYUZ and VEGA sites.
- Due to the constraints of the realization, measurements show that the global symmetry of the various connections around the 4 pylons is not ideal, for various reasons but this is true for both sites. However, we can say that the global earthing system will correctly contribute to the evacuation of the currents injected on the site. Particularly, we can say that even if some significant rises of electric potential are observed in some points, they do not affect the surrounding systems.
- Nevertheless, it is difficult to definitely answer on the influence of this dissymmetry on the mitigation of the magnetic field. Indeed, only a modelling of the lightning injection impinging at the top of the mast would give the answer. The problem is that we could not deduce from our measurements all the electric parameters required to design a realistic circuit model. The reason is that we did not expect that the topology of the underground interconnections and the connection to the earth was so complex to identify. Nevertheless we have some following qualitative indications on the influence of this dissymmetry when the injection is made on one pylon, and the obtained results make us think that this influence will be quite low when the LPS will be impacted at a top of a mast. The identification of the underground interconnections and of the earth connection would require a specific work which was not carried out during this campaign (resolution of an inverse problem thank to a circuit model) because not expected.

As prospects, the next step of the methodology would be to proceed to some new 3D simulations, focusing them now on the experimental configurations. The confrontation of the experimental and calculated results should lead to an adaptation and an improvement of the accuracy of the electrical data of the models. Once the numerical model will be validated, the real conditions of impact could be simulated, and give the expected magnetic field levels in the launcher area. Nevertheless, the complexity of the buried connections still remains a problem.

Finally, an on-site instrumentation of the site with a series of current and magnetic sensors would allow the monitoring of the real lightning activity on the site and the assessment of the magnetic field mitigation. This monitoring would be the only non ambiguous way to assess the effect of real lightning strikes. To achieve this goal, measurements must be triggered and recorded simultaneously on several sensors. Such a possibility seems realistic implementing a measurement system closely derived from the measurement system we used in the experiment based on the use of remote digitizers directly installed at the level of the sensors. Indeed, we must mention that, during the test campaign, some of our measurements by chance captured some real lightning activity on the site (Figure 10). Unfortunately, those opportunity events could not be exploited because they were too rare.

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