Lightning Protection of Air Traffic Control RADAR Systems

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Abstract: This paper aims to analyse the lightning protection system (LPS) design of an isolated RADAR system, which is installed on the Hellenic island of Lefkada. The area where the RADAR operates is characterised by the high ground flash density ($\approx 50$ thunderstorm days per year, $\approx 5.3$ flashes per square km) and the extremely high soil resistivity value (i.e. pure rock with a resistivity of more than 2000 $\Omega$ m). The paper includes performance results of the LPS system since the date that was installed (1998) in comparison with previous techniques that were unsuccessfully used for lightning protection. The LPS design includes external and internal LPS (i.e. air terminations, earthing and surge protection). It also includes solutions to some difficult overcoming problems that were faced during the application of the lightning protection design.

Keywords: RADAR, external LPS, surge protection devices – SPDs, earthing system impedance

1. Introduction

The Hellenic Civil Aviation Authority RADAR system, HE.RA.S, supports the air traffic control in the Hellenic area. The name HE.RA.S is the acronym of the words Hellenic Radar System. The HE.RA.S system was installed during the upgrade program of H.C.A.A. (Hellenic Civil Aviation Authority), in order to provide coverage of the entire Hellenic control airspace, with RADAR data. The upgrade of the air traffic control should serve in accordance with the international organisations requirements (ICAO, IATA, ECAC, EUROCONTROL etc.), for more reliability and safety in civil air transportation.

RADAR systems for efficient operation require to be installed on high altitude areas such as mountain peaks, which makes them easily susceptible to lightning flashes, causing extensive and serious damage to them and especially to the sensitive electronics that such installations are equipped with. Therefore internal and external lightning protection systems need to be carefully designed for such important installations and especially in a country like Hellas, which has high ground flash density (the thunderstorm days per year $T_d$ in Hellas depending the area vary between 25-90 days) and mountains with high resistivity soils (e.g. rock).

A co-operation project “Lightning protection of RADAR systems” between Hellenic Civil Aviation Authority (H.C.A.A.) and Elemko SA had as a result the elaboration of an LPS application design that has achieved very good results under difficult circumstances, which will be analysed later in the paper, as far as the protection, safety and the cost are concerned. Recently a further evaluation with the help of software simulations was done in collaboration with UMIST for a better understanding of the initial design and the behaviour of it during a direct lightning stroke.

2. Site Survey, Past History and Reported Damages

This RADAR unit controls the air traffic of the Eastern part of Hellas and sends the required information to the Civil Aviation Authority headquarters in Athens. The particular RADAR is a tall construction ($\approx 30m$ height – with a maximum diameter of 5.5m – from its base and more than 80m from the surrounding area, having a total altitude of approximately 1000m, see Figure 1, and in addition it is installed on an isolated mountain peak with high soil resistivity (i.e. rock). Also the area where the RADAR is installed has frequent lightning activity ($T_d\approx 50$). Next to the RADAR are secondary structures, which contain all the necessary control equipment for the operation of the RADAR system. The electricity is supplied from an overhead MV line and a local MV/LV substation next to the installation, which supplies the specific installation only. The supply system is TN-CS.

Previous to Civil Aviation Authority, the Hellenic Air Force and the Hellenic Telecommunication Authority used exactly the same area in order to install RADAR system for military purposes and telecom antennas respectively. Both suffered extensive damage to their equipment, which forced them to move in different locations in a period of three years since their initial installation.
Although due to the optimum location for the RADAR efficient operation the Hellenic Civil Aviation Authority took the risk to try their luck on the same installation point. The erection of the RADAR started during 1994 and was concluded during 1996. The RADAR started to operate in 1996 and till 1998 suffered many damages due to lightning discharges mainly on the RADOM of the antenna but also on its electrical and electronic equipment. Till then its lightning protection system was limited to the external LPS and to the earthing system.

In 1998, it was decided to consider internal LPS and improvement to the external LPS. Since then the reliability of the entire LPS has improved to satisfactory levels. Although there are still few points that need further consideration.

3. Risk Assessment and External Lightning Protection System

Performing the risk assessment according to the standards [1] of the period that the RADAR was initially installed, it was evaluated that the necessary protection was level I with additional protection measures since it was an isolated installation, which should operate all the time without disturbances and the access to it, was very difficult especially during the winter months. The external LPS design was based partially on IEC 61024-1 [2] and on the national Hellenic standard ELOT 1197 [3].

The external LPS is separated into three main parts, the air termination system, the down conductors and the earth termination system. Each one of them is described below.

The air termination system was and still is one of the most difficult parts of the entire design since the exact application of the standards and the common techniques (i.e. faraday cage), which will provide an optimum protection, cannot be applied to a RADAR for RADAR installations due to radiation disturbances. Therefore at the moment the RADOM is partially unprotected although the initial design was done for protection of lightning strokes with a current lower than 2.8kA. The calculation was done with the rolling sphere method by using a radius of 20m.

Since the air terminals could not be designed according to the full standard requirements alternative methods were applied. As it is shown in Figure 3 below the RADOM is protected from eleven, 1.5m long rods around its perimeter. Five of them are installed at the lower part, five of them in the middle part and one on the top of the RADOM. The lightning protection rods were interconnected in the inside of the RADOM and the interconnections were partially covered by ferrite tape so as to avoid radiation reflections.
It should be mentioned that it was not allowed to install any rods facing the equator of the RADOM because they would disturb the RADAR operation. Additionally installations of tall masts, with rods on the edges, next to the RADAR providing an acceptable protection angle were not allowed either by the RADAR manufacturer.

The RADAR support structure fulfil the requirements for using it as down conductors, therefore additional conductors were not used apart from cases were direct bonding was necessary (i.e. bonding lightning protection rods with the RADAR support structure, wave guides bonding etc).

The earth termination system design was a quite difficult task since the soil next to the RADAR installation was pure rock with high resistivity value \((\geq 2000\Omega m)\). The design is shown in Figure 4. The entire design was a combined type A and type B method according to IEC 61024-1. All the support masts of the RADAR structure, which were used as down conductors, were interconnected (in multiple points and also into the soil) and additional 10.5m long earth electrodes were installed at each mast. Also around the perimeter of the secondary structures and the RADAR it was installed an earth tape and every ten metres additional 10.5m long earth electrodes were embedded. The earthing system of the MV/LV substation was also bonded with the main LPS earthing system. The total DC resistance was also measured to be approximately 15 Ohms.

![Figure 4: Schematic configuration of the earthing system](image)

### 4. Internal Lightning Protection System

For the internal LPS it was considered equipotential bonding, direct or through surge protection devices (SPDs), shielding and routing of the cables in order to avoid electromagnetic interference. Direct equipotential bonding was done between all metallic parts (i.e. wave guides, metallic enclosures) with the LPS earthing system. All the incoming cables (power and data) were connected through SPDs.

Power, type 2 SPDs based on metal oxide varistor, according to nowadays standards EN 61643-11 [4], were installed in all the electric distribution boards and type 3 SPDs, according to EN 61643-11, were installed next to the power supply input of sensitive electrical and electronic equipment. Data SPDs were installed in series with all incoming data lines mainly between the RADAR antenna and the control equipment and show a basic layout of the SPDs installation point.

The cable routing for all the incoming cables that enter the control room from the RADAR antenna is concentrated from a single point therefore the initial conditions for achieving an optimum protection against electromagnetic interference were ideal. Additionally Data SPDs were installed at the inputs of the control equipments that were connected with all the incoming cables. Apart from the control room, SPDs were also installed to the other end of the cables next to the antenna of the RADAR. All the earthing connections inside the control room were bonded on equipotential bonding bars. All the equipotential bonding bars were interconnected between them and also, through a single and short connection, with the main LPS earthing system, minimising earth loops effects. In series with this single connection to the LPS earthing a surge counter was installed in the year 2000. Since then (2000-
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2004) 39 surges with magnitudes of more than 500A were detected.

Figure 5: Schematic configuration of the electric network in the RADAR installation

5. LPS efficiency results and solutions to specific problems

Since the elaboration of the above LPS designs, there was no further damage to any electrical and electronic equipment apart from some specific applications, which will be described in the continue. In total more than 85 SPDs were installed, approximately 35 type 2 and 3 power SPDs and more than 50 data SPDs protecting over 100 equipment inputs. During a recent inspection to the site (early 2004) none of the SPDs needed to be replaced (over a period of six years) and their operating condition was 100% acceptable. None of the SPDs that were used in this installation were tested according to Class I (i.e. Type 1) SPDs according to IEC 61643-1 [5] and EN 61643-11.

This may not be a fact but it partially proves that although the installation has been exposed to multiple lightning strokes (39 incidences during 2000-2004), type 2 SPDs, which are tested with a lower energy currents than heavy duty, type 1 SPDs, which are able to discharge much higher energies can cope and provide sufficient protection to electrical and electronic equipment in this particular and probably similar sites. Additionally the fact that the earthing system was not designed under ideal conditions and its impedance and DC resistance are relatively high is an additional factor, which will cause extra stress to the SPDs of the installation in case of a direct lightning stroke.

As mentioned before few specific problems needed and still need to be studied. One was regarding the encoder of the RADAR antenna, which is installed underneath the rotor of the antenna. The purpose of the encoder is to send the radial position of the antenna to the operator’s monitor in a visual representation so that the operator can see on monitor the exact position, speed and other information of the air traffic.

The electronics of the encoder were damaged during thunderstorms although SPDs were installed at the input and output terminals of it. The encoder contains multiple layers of printed circuit boards (PCBs), which are placed in a parallel position inside a metallic housing, leaving not sufficient space for installing SPDs or surge protection components near the PCBs.

Additional improvements to the LPS earthing system were done afterwards during the year of 2000 by following the suggestions of the RADAR manufacturer. These improvements contained the installation of an additional type B earthing system at a distance of approximately 50m away from the RADAR with a single connection to the old LPS system (see Figure 7). The soil in that location had lower resistivity (≥700Ωm) than the one next to the RADAR installation (≥2000Ωm).

Some simulation results show that although there was an improvement to the lightning current dissipation, the reduction of the generated overvoltage peak (see Figure 8) still remains at a high level. This is mainly due to the fact that although the total DC resistance was significantly reduced (≈3.5Ω from 15Ω), the impedance of the earthing system was still high. The simulation results were calculated by using the EMTP-ATP algorithm [6]. The injection lightning current was set to be 8.5kA with a waveform of 5.5/70μs.

After further consideration the solution was to isolate the encoder from any direct earthing and from the power supply. Therefore an insulating material was used as an extension to the metallic rotor, which connects the encoder with the antenna and also a local UPS was supplying the required power to the encoder electronics. SPDs were installed between the input, the output and the enclosure of the encoder, keeping it isolated from any direct earthing. Figure 9 shows the new and old arrangement of the encoder.

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Figure 6: Schematic layout of the SPDs installation points within the RADAR
As a reference during January - February of 2001, nineteen encoders were completely destroyed but after (winter 2001) the above protection there was no further damage.

![Diagram of earthing system]

The last point that still needs to be considered is the protection of the RADAR of the antenna. The manufacturer of the RADAR doesn’t allow the placement of metallic parts at some particular points on or next to the RADOM and therefore the RADOM remains partially unprotected. Development of lightning protection rods, which will not cause interference to the RADAR radiation will definitely give a solution to this problem.

6. Discussions & Conclusions

The development of a lightning protection system for a RADAR installation under difficult conditions was presented. The elaboration of this design solved many problems that were caused due to lightning discharges and improved the reliability of the RADAR operating conditions.

Evaluating the design and its performance over a quite long period of time some conclusions can be derived. Engineers, who design earthing systems, often neglect the term impedance and it has been proven that it should be taken under more serious consideration when designing a high frequency earthing in order to achieve a cost and technical efficient design.

Also based on simulation results of similar cases [7] and to this application it is believed that in cases where the MV/LV transformer supplies only one installation, the neutral earthing system is near the installation and the installation’s local LPS earthing system has lower impedance/resistance than the neutral’s then the surge protection devices will not experience high energy currents.

Finally it is a fact that such installations are increasing in quantity for an improvement to the control of the air traffic control systems. The development of a specific standard that will concentrate on the lightning protection of such important installations may be a valuable tool of improving the reliability of the RADAR operation and may be considered in the future.

7. References

[5] IEC 61643-1, Surge protective devices connected to low voltage power distribution systems, Part 1: Performance requirements and testing methods