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Lightning Protection of a Golf Course Irrigation System

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***Abstract*— The Moliets golf located is South West of France in a stormy area. This golf course uses electronic devices to monitor the water sprinklers and reduce water consumption. Buried decoders associated with the sprinklers receive orders from the central monitoring system. Since early 2012, 1262 decoders were installed but on 31st July 2016 445 decoders were destroyed by lightning surges. An expertise has been performed involving analysis on site and in laboratories regarding the surge withstand of the decoders and the failure mechanism. An analysis of the recommended surge mitigation measures proposed by the sprinkler's manufacturer for a few sprinklers (external SPDs and fuse as well as earthing system lower than 10 ohms) has also been performed. The provided SPDs were found too slow to satisfactorily protect the sensitive electronic devices. In addition, the SPDs were unable to provide satisfactory protection due to the distance between SPDs and many sprinklers (much more than 10 m) and also due to the voltage generated inside the loop. It was then decided to ask for the development of specific fast protections dedicated to these decoders that should be coordinated with embedded decoder surge protection components. After tests performed in laboratories, to validate the protection provided by these fast protections, a preliminary series of 50 fast protections have been installed at the end of 2017 to check that the operational characteristics of the decoders were not impaired. Following this field experimentation, 1200 additional fast protections have been installed. In early 2019, a synthesis has been done by the golf authorities. A total of 23 impacts occurred in 2018 in the perimeter of a 2 km radius circle. 10 significant impacts located at a distance of between 11 m and 400 m of the protected decoders were analyzed. The associated sprinklers are still operational.**

Keywords*— *Lightning; risk; standard; LLS; Golf; SPD; GDT; MOV; sparkover

I. INTRODUCTION

The Moliets golf, located in South West of France (see Fig.1) in a stormy area, is a modern golf course using electronic devices to monitor the water sprinklers over the golf course. Decoders are buried in many places over the golf course and receive orders from the central monitoring system to open the various sprinklers located over the green, fairway and practice. This water installation is in service since early 2012 and help reducing water consumption to a little more than 3 000 L per day.

Fig. 1. Bird view of Moliets Golf

There were 1262 decoders installed since the beginning and at the date of 31st July 2016 a total of 445 of them were destroyed by surges due to lightning. These systems are vital for the green keepers and are also very expensive.

An analysis has been launched by independent consultant and lightning experts to try understanding why there are so many damages due to lightning, especially because surge protection and earthing proposed by the manufacturer of the water spray system were already installed. In a second step, a possible mitigation of these problems was expected.

The expertise has been performed involving analysis on site and in laboratories regarding the surge withstand of the decoders and the failure mechanism. An analysis of the recommended surge mitigation measures proposed by the manufacturer have also been performed and led to the result that due to the absence of PE conductor on the decoders (class II device), the requested improvement of the earthing was probably not the right answer. In addition, Surge Protective Devices provided outside of the device and built-in surge protective component (mainly based on gas discharge tubes) were too slow to satisfactorily protect sensitive electronic devices. In addition, the external SPDs and fuses, located at entrance and end of the cable, were unable to provide satisfactory protection due to the distance between these

SPDs and decoders (much more than 10 m) and also due to the voltage generated inside the loop by induced surges.

It was then decided to ask for the development of a specific surge protection (called later on fast protections) dedicated to these decoders that should be fast enough to protect sensitive electronic and be coordinated with embedded decoder protection located near the decoder. After satisfactory tests performed in laboratories, a preliminary series of 50 fast protections have been installed at the end of 2017 for experiment and the Météorage service has been used to detect any lightning in the area. Following this field experimentation, 1200 additional fast protections have been installed over the golf course.

In early 2019, a synthesis has been done of the use of these fast protections for the 2018 period, at the Moliets golf and their consequences on decoders with fast protections. A total of 23 impacts occurred in the perimeter of the 2 km radius circle that we had chosen to locate the impacts. 10 significant impacts located at a distance between 11 m to 400 m of the protected decoders (not all of them were protected at this time) were analyzed and the survey indicates that the sprinklers are still operational.

II. Description of the Water Spray System

The watering system (see Fig. 2) is controlled by a computer with a software allowing the trimming of the times of watering according to the real needs of the varieties of grass. The sprinklers are computer controlled. A weather station makes it possible to regulate the watering of the grass and stops this watering in the event of rain. Each sprinkler is piloted by the computer thanks to a decoder. The signal cables are located in insulating sleeves in the ground. Connections to decoders are located in manholes directly buried in the sandy soil. The decoder is integrated in the sprinkler that is buried in the ground.

A basic surge protection (apparently surge protection components only, a simpler form of surge protection than a Surge Protective Device) is embedded in the decoders (as observed during the preliminary tests performed, see below) and an additional external Surge Protective Devices (common mode protection between active conductor and ground and differential mode protection between active conductors) and earthing system, recommended by the decoder manufacturer in case of strong lighting activity, are installed for the decoders located at the line entrance and end. External surge protective device was originally planned to protect a few sprinklers. Grounding of this surge protective device is made by a 25 mm² copper cable. This ground wire is buried in a trench 20 cm wide and 30 cm deep. The expected resistance of the earth must be less than 10 ohms and due to the sandy soil, to reach that value it was necessary to add earth rods as well as copper plates buried in the ground.

Decoders are located in zones and are supplied by a single power line forming a loop for each of these zones.

There are in general 20 decoders connected to such a loop. These 20 decoders are not equipped with SPDs and are powered in parallel with a single circuit. The wiring that connects the 20 decoders is 2x 2.5 mm² without PE (class II equipment).

The water supply pipes are made of PVC. The power and control cables of the decoders do not follow these pipes.

The external Surge Protective Devices provided by the sprinkler manufacturer uses a combination of gas discharge tube (GDT) and varistors (MOV) and protects against both differential and common mode surges. It was tested by the manufacturer in both conditions by a 20 kV–10 kA, usual 2 ohms 8/20 combination wave generator and thus a 20 kV/10 kA withstand of the SPD is announced. The distance between the external SPD and the decoder is typically 1 m or more. It is requested it doesn't exceed 2,5 m but the built-in SPD wiring itself is 45 cm long that is near the recommended 50 cm not to be exceeded lead length according to SPD standards. The fuse is there to limit the fault current that was found as a cause of the damages.

Fig. 2. Example of water spraying on the golf course

The external SPD is associated with an earthing system based on earth rods. The recommended maximum value for the earthing was 10 ohms. However, values measured locally (see Table I) have shown that many values were in the range of 30 ohms that is not surprising due to the sand base of the ground. When resistance was very bad copper earth "plates" (see Fig. 3) were used to improve the earthing but the improvement was not noticeable due to their bad resistance (the plates were mainly band with limited surface and installed in the sandy part of the ground).

TABLE I. Earth Resistance Values Measured at Different Locations on the Golf Course

Decoder N°	R rod (Ω)	R earth plate (Ω)	R total (Ω)	Location
18 F 37	28	1315	26.9	Start of line
18 RG 1	5.1	No	5.1	End of line
22 GP 1 (Practice 2)	6.5	933	6.39	Start of line
22 GP 14 (Practice 2)	8.1	1049	8	Start of line
16 TE 5	30.5	1485	29.5	Start of line
9 AG 2	13,6	135	5.3	Start of line
9 holes	25.4	No	25.4	Start of line
18 F 37	28	1315	26.9	Start of line

The resistance is not so much relevant because decoders that failed were also located in places where resistance was lower than 10 ohms. In addition, the decoder being of class II (double insulation without ground terminal), the protection between active conductors and ground (common mode) is not providing so much protection and thus the resistance of earthing is not of prime importance.

Fig. 3. Additional earth plate

III. PRELIMINARY ANALYSIS

The site is located in South-West of France in a severe area regarding lightning. The worst year for this area in the period 2009-2018 was 2014 where 2,14 strike points/year/km² were recorded (maximum value in France is 3,74 strike points/year/km²). In this location 75% of the storms occur on Summer with a peak in August. The worst month was August 2015. For example, on the 22 August 2015 (see Fig. 4 and Fig. 5) 1246 lightning impact have been recorded by Météorage on a 20 km radius centered on the golf course. In this single month 135 decoders were damaged (to be compared to the 445 damaged decoders so it represents 30% in a single month).

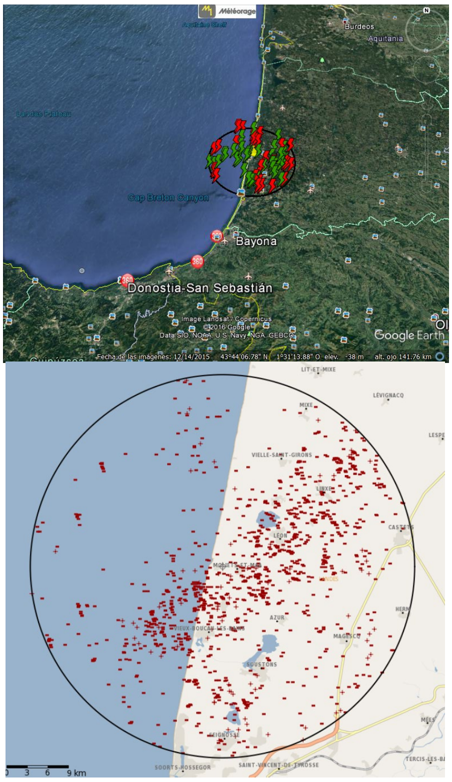

Fig. 4. Lighting activities on 22 august 2015 in the golf area

Fig. 5. Lighting strike points on 22nd August 2015

The lightning currents given by Météorage associated with the lightning strike points presented on Fig. 5 are 9.3 kA, 2.3 kA and 1.5 kA. As a result of these atmospheric disturbances, a large number of decoders are no longer operational (445 failed decoders have been recorded so 35% of all the decoders.). Other decoders were later detected as out of order. Failed decoders (see Fig. 6) were also found near the external SPDs but it should be noted that these SPDs are connected with long lead length (accepted by the sprinkler manufacturer) and with a high resistance (higher than recommended by the sprinkler manufacturer). Apparently, the built-in surge protective components (see below) are not efficient enough.

Encountered problem are apparently not due to direct lightning effect on the electrical circuits but to induced effects on the electrical circuits of decoders. Each decoder is distant from the other by 20 m, so much more than what is needed to provide an adequate protection by SPDs (10 m max according to SPD standards). The golf has a small 9 holes green for which they never experienced problems and for this installation the buried power cables of the decoders are armored connected to earth at both ends.

Fig. 6. Pictures of the sprinkler systems after lightning damages

IV. TESTS IN LIGHTNING LABORATORY ON DECODERS

An expertise was requested by the golf Authorities and resulted in a testing program. These tests have been performed in a specific laboratory thanks to a combination wave generator applying lightning impulses (current and voltage) on decoders. The goal of these tests was to reproduce the electrical stress conditions inside the decoders and to see their behavior.

The visual inspection analysis of faulty decoders has shown that the surge current level was probably not high (no big visual signs internally or externally) but the problem was clearly existing with an excess of current consumption.

Preliminary tests were performed on the two generations of decoders used for this application. The purposes of the measurements were to determine the surge withstand and to determine if built-in protection means are implemented on the accesses of the decoders (a two-wires common for power supply and data line, and one solenoid valve output) constituting the spraying system. This information should possibly be used to determine the coordination with a complementary lightning protection located upstream of the decoders. Finally, these tests must also demonstrate if the decoders equipped with protection means, as defined by the manufacturer, effectively protect the decoders against the surges on the power line (normally taken into account, by the EMC tests during the validation of the CE conformity of the products, according to EN 61000-4-5).

Preliminary tests were performed using a voltage impulse generator (1.2/50 µs), see Fig. 7. These tests focused on the evaluation of the sparkover level of the protection for over voltages applied between input terminals (differential mode), and on the other hand between input and output terminals.

It is found that conduction occurs even for relatively low voltage impulse levels (500 V), both between input / output, and between input terminals. For low levels (around 500 V), the current is low and we can observe a sparkover level which corresponds to the effect generated by the protection circuit present on the accesses of the product, or at least to the first stage of this protection circuit.

For all these preliminary measurements, there is conduction on terminals submitted to impulse voltages, above a certain voltage level, and therefore a non-linear limiting effect of the voltage at the access terminals (sparkover effect provided by a protection component, probably a Gas Discharge Tube). For older models, we observe that the sparkover level was between 264 V and 292 V and it is of the same order of magnitude for new models.

In order to prove, or not, the effectiveness of the protection possibly existing on the accesses of the products, it would be relevant to check, for the models being in working condition before the tests, their possible good functioning after the tests.

Other tests were performed with a combination wave generator (voltage 1.2/50 µs – current 8/20 µs and 2 ohms impedance) that is typical of EMC tests.

At the very beginning of the pulse delivered by the combined generator, the protection does not act yet, and no current is led by the built-in protection (or at least it remains insignificant). The generator behaves during this phase as a voltage generator. After about 6 µs (in this case), a clamping component goes into conduction, which in view of the response is indicative of the presence of a GDT. As soon as the GDT becomes conductive (it then behaves like a short-circuit, only the "arc voltage" of the order of a few volts, less than 20 V depending on the GDT, remains at its terminals), the generator then becomes a near-perfect current generator. The current thus becomes close to a current wave 8/20 µs. At the end of the impulse, when the current in the GDT becomes small (less than a few amperes or fraction of ampere), it becomes blocked (its conduction stops).

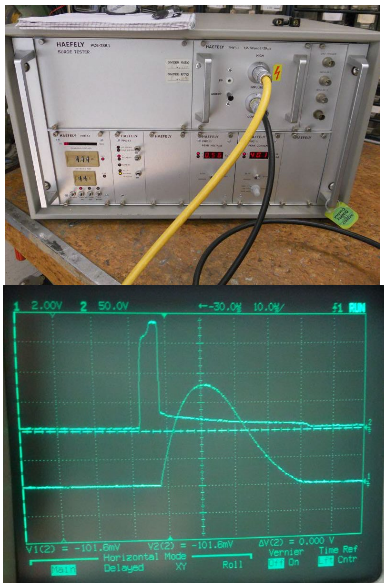

Fig. 7. Combination wave generator used in laboratory and example of answer of the decoder to a combination wave generator impulse

These tests, and the analysis of the curves led the conclusion that embedded surge protective components exist and are mainly (but not only) based on GDT. The external SPD itself is a combination based on GDT and MOVs.

The GDT-based protection certainly limits the voltage across the equipment, but this GDT has the drawback of having, on the one hand, a relatively long reaction time, which generates a short overvoltage but which can be of very large amplitude, and secondly to have a relatively high sparkover level (dynamic sparkover that was observed during testing between 150 V to 180 V), which is very high for the electronic components of the decoder.

Actually, for many electronic components their withstand margin with respect to their service voltage is generally of the order of 1.5 to 2 or a little more. It can be estimated that voltages above 60 to 80 volts become dangerous for the durability of decoder circuits. Then, when the breakdown phenomenon appears on semiconductor junctions, currents from a few hundred milliamperes to a few amperes are already destructive (irreversibly). In general, a protection for electronic circuits operating with very low voltage, does not only have a GDT and two to three stage protections are essential.

The worst case is to have an impulse that would have an amplitude remaining just below the sparkover level of the GDT. In this case, the GDT will have no action yet, but the overvoltage seen by the decoder will be too high for it to withstand. We therefore finally find that the worst case is for relatively low levels of aggression. Indeed, for pulses of very high amplitude, the GDT will start very quickly and the surge will be very short, and probably filtered by the decoder power supply circuit (RC or LC filter) and of course on the opposite, very small impulses will not be destructive. But between the two, for aggression levels slightly lower than the trigger threshold of the GDT, the destruction of the circuits is foreseen (this is what is generally called a blind spot).

V. PROPOSED SOLUTION TO MITIGATE THE RISK

Given the problems encountered on the decoders of the Moliets Golf, it was planned to improve the built-in protection of decoders by an adding an external dedicated protection equipment specific to the decoders (voltage, frequency, low level of protection), acting faster than the built-in surge protective components. This protection will be named fast protection in short and is different from the external protection mentioned before. This fast protection should be installed next to each decoder. This fast protection system should have no detrimental influence on the operation of the decoders and should not interfere with the propagation of the frequencies used for the communication to the decoders. This fast protection will replace the existing original external SPD when it exists but should coordinate with the decoder built-in protection. Especially, in case of high surges, the withstand of the fast protection (limited by design to less than 1 kA 8/20) should rely on the high withstand of the internal GDT.

Moreover, it is possible that on a near impact the potential difference between decoder and sprinkler is large enough to create disturbances. Protection between input and output is therefore useful or even necessary. In addition, to ensure optimal protection, a fast component stage on the output is also useful.

The concept was then to increase the surge withstand of the decoder input, output and input-output thanks to a dedicated fast protection but with low protective level. The proposed system that will be implemented provides differential protection input/output for each decoder and should then be cheap enough.

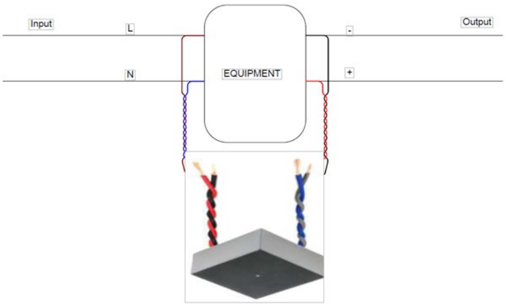

Fig. 8. Principle for connection of the fast protection

The prototype of such a fast protection (Fig. 8) was developed and tested satisfactorily in laboratories. Then a pre-serial production was launched and it was decided to test in laboratory these fast protections in conjunction with the decoders to check that the protection provided was adequate (especially coordination between internal surge protective components and fast protection) and that there was no detrimental effect or operational problems on the protected system.

The following tests for 3 decoders associated with a fast protection were performed (3 shots performed on each port) with a combination wave generator (6 kV/3 kA - 2 ohms):

- Test of the fast protection at a level low enough to not generate a surge current in excess of 500 A 8/20 in the fast protection: on the power input line, on the output line (solenoid control) and between decoder input and output (see Fig. 9).
- Test of the fast protection with the maximum surge current delivered by the combination wave generator.

It is important to use a combination wave generator because the fear is that a significant part of the injected current flows internally in the decoder up to sensitive electronic components. Thus, a combination wave generator is particularly adapted.

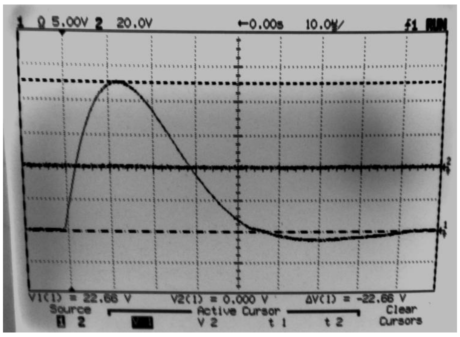

Fig. 9. Example of record of the impulse injected on the fast protection.

The behavior of the fast protections corresponds to that expected. Although the exact level of impulse withstand voltage of the different decoder ports is not known, the level of protection provided by the fast surge arresters is nevertheless sufficiently low and compatible with the need.

Furthermore, the tests with moderate current pulses (nominal discharge current) and even that with the highest current level, does not generate a variation of the insulation resistance between the different ports, and in particular across the terminals of the power line, suggesting that the decoders have not been damaged by the surge tests. At this stage, there is no degradation of the decoders consecutive to the current pulse injection lightning. The correct operation of the decoders after the application of current shocks can only be verified during on-site tests but at this stage no noticeable damage was found.

Of course, later on, a validation of their good functioning has also been carried out on site, the device being installed on the golf course to check that they are perfectly working and that all the orders sent from the control room lead to the right operation. These functional tests have given the following results:

- All the tested decoders, installed later on without fast protection, do not present qualitatively abnormal behavior,
- All the tested decoders, installed later on with fast protection, do not present qualitatively abnormal behavior,
- The presence of stray capacitance representative of that provided by the fast protection does not cause any malfunction of the system.

Before using these fast protections extensively on the site, the proposed protection system should also be tested on a sampling of 50 decoders on the Moliets golf in previously chosen places compared to the observed destruction of the decoders during thunderstorms.

VI. Preliminary field experiment with 50 fast protections

The field experiment is correlated by a Météorage alert system, that indicates all the storm occurring in the area with their location and time stamp as well as magnitude and polarity. This experiment started on January 2018 and finished on February 2018. However, observations and measurements made daily by Météorage have shown the absence of stormy activity during a long time. There were not enough storms in that period to have a pertinent conclusion. However, during the watering phases, no malfunction was noted by the golf technical team. At this stage, the result is just a confirmation of the good behavior of the 50 decoders. If the complete effectiveness of the fast protection cannot be demonstrated at this stage better than in laboratory, at least there was no detrimental effect on the function of the spraying system during this long period. It was then decided, based on the fact, that no damage was recorded on the protected 50 decoders during that period, to generalize the use of the fast protections before the next stormy season and to install 1210 additional fast protections on decoders before the next stormy season. The next chapter, gives the results and the details of the long term extended experiment.

VII. Main experiment and results

The installation of the 2010 fast protections was finalized at the end of March 2018. At the same time, earthing system as well as fuses, were supposed to be removed to not interfere with the fast protection effect and especially because it was feared that the earthing (rod and/or plates) system provided as suggested by the sprinkler manufacturer, could be a cause of the problem (the sprinklers have no reference to ground and the only ground reference was through the external SPDs provided by the sprinkler manufacturer.

Lightning activity was measured by Météorage during the period from June 2018 to September 2018. For example, Fig. 10 shows the intra-clouds and lightning ground impacts: 39 were recorded on July 1st (3 impact to the ground and 36 intra-cloud strikes).

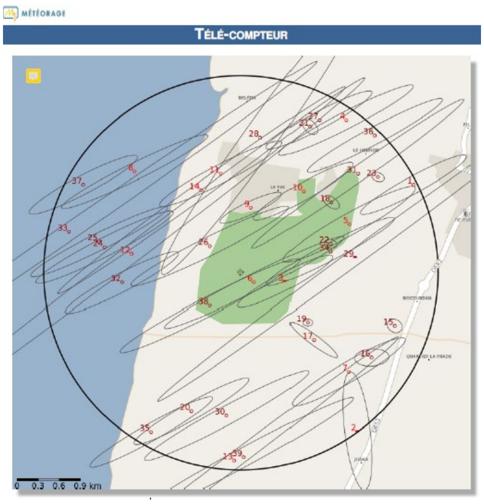

Fig. 10. Example of lightning activity on 01-07-2018.

Altogether there have been 23 lightning impact over a period of 3 months and a half in a circle of 2 km centered on the golf course (the intra cloud flashes have of course not been considered as well as the flashes to the sea). From this list 17 lightning impacts have been found as significant and the others were a bit too far to be considered. They occurred at a distance ranging from 11 m to 400 m from sprinklers systems. The lightning current ranges between 1.6 kA and 33.8 kA.

The most relevant impact for the golf course was for the ground strike on 5th of September near hole N°10, with a current level of 25.4 kA, located at a distance of 11 m only from decoders, see Fig. 11.

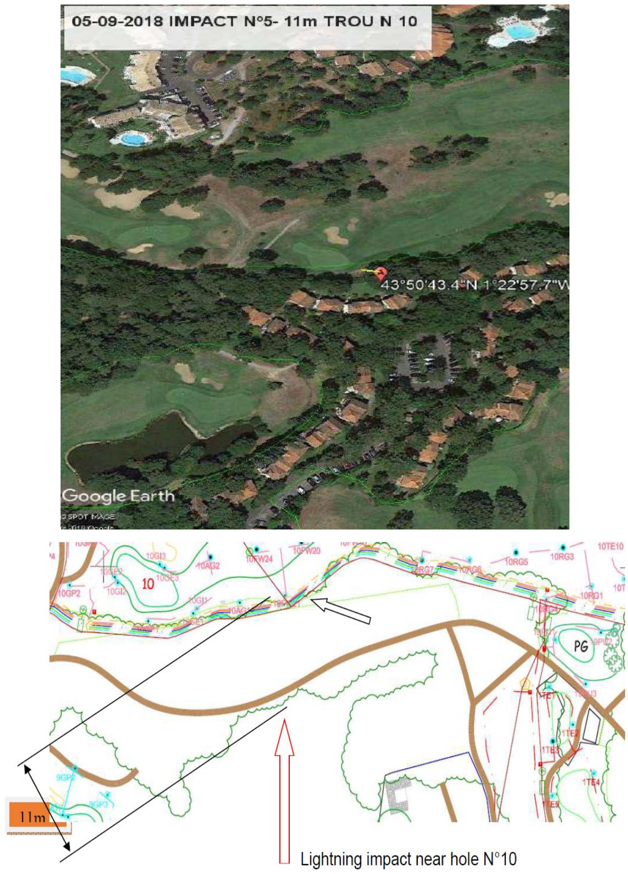

Fig. 11. Lightning strike point on 5th September 2018.

The decoders in the vicinity that were protected by the fast protection are all operational. Decoders on practice N°2, supplied from the same source but not protected by fast protections, have been damaged (excess of power consumption).

It is interesting to note that near hole N°10, the external original earthing system and fuses have not been removed by mistake. The fuse holder and the box containing it (junction box located in the soil, at around 1 m in front of the sprinkler and its fast protection) have been destroyed during the lightning strike on the 5th September 2018. This is clearly showing that a partial lightning current has been circulating in this circuit. As this partial lightning current was flowing upstream of the fast protection, the fuse was not protected by the fast protection but the decoders, located downstream of the fast protection, were protected. For the other lightning events, there were no visible damages on decoders but only an increase in power consumption for the decoders non-protected by fast protections. All the decoders protected by fast protections were found operational after the stormy season.

VIII. CONCLUSIONS

Lightning events occurred in the area of a golf course located in South-West of France. This place is known to be severe regarding storms even if not one of the most severe area of this region. Many damages on decoders associated with water sprinklers have been detected for a few years. In less than 5 years 35% of the decoders have been damaged, leading to an increase of power supply and a need to replace the decoders. This means cost increase and also lack of water spraying that is clearly a bad situation for a green keeper especially for a site located in dry area of South of France exposed in addition to salt mist. A parallel analysis was made from one side by the sprinkler manufacturer that was very proactive and proposed to add a mix of external SPDs and earthing system and to consultants and lightning experts that have performed an analysis in laboratory and in field. Based on the tests in laboratory, it appears that the proposed external SPDs and earthing system were not enough to decrease the failure rate and it was decided to ask for a development of dedicated fast protection. Tests performed in laboratory and in field have shown that such fast protections could protect efficiently the decoders and also that they have no detrimental effect on the decoders at their working frequencies. A large-scale experiment has then been launched for a full stormy season where 23 lightning impacts at a distance between 11 and 400 m were recorded. It appears after the season that the protected decoders were all operational when other decoders not protected yet failed. One of the decoders was protected even when a lightning strike of 25,4 kA was recorded at 11 m from the decoder.

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