Abstract

Authors

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S.1.1 Lightning Protection at the Palace of Versailles

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Lightning Protection at the Palace of Versailles S. Fauveaux R&D Department INDELEC Douai, France M. Duchene FORSOND S.A.P. Colombes, France

Abstract—The Palace of Versailles is one of our precious architectural and cultural world heritage. Being located in France, it was erected at the 17th century. This Royal Palace, spreading over a very large area comprising many buildings and complex, shows a surprising moderate height compared to traditional French castles. This Palace is one of the most visited and famous Palaces of France, thus this National Treasure had to be protected against various hazards: fire, thieves, vandalism, water damages, etc... and the subject of this paper, namely the lightning protection. Old structures like Castles and Palaces are quite particular when it comes to lightning protection. Lightning protection purposes sometimes collides with the Architect of the Historical Monuments duties. Indeed, settling the ELPS must follow the lightning standard rules but also must comply with the directives of the National Historical Monument Administration, i.e. ESEAT positioning and settling, downconductors way and fastening, grounding system type and implementation. Keywords—Lightning protection; lightning rod; ESEAT; heritage historical monuments I. Introduction This paper is thus dealing with direct lightning protection of a building of the Palace which was upgraded to compliance. This palace was registered as a National Historical Monument (France), as well as World Heritage (UNESCO). So the numerous constraints inherent to that kind of complex and installation matters are to be observed: upstream considerations are the major point prior to the task execution. The INDELEC Company has already installed many famous historical sites in France and throughout the world, such as the Chantilly Castle, the Acropolis of Athens or the Angkor Vat Temple in Cambodia [1], so the inherent constraints are well known and addressed. II. Facts of the Palace A. Historical Facts The construction started at the 17th century under the reign of Louis XIII, known as Louis The Fair (1601-1643). At the beginning, it was a simple hunting lodge constructed in 1623 and acquired by Louis XIII in 1632. He then asked to the architect Philibert Le Roy to transform this countryside manor into a true little palace (done in 1634), but still quite far from the palace we all know today [2]. His now famous son Louis XIV (1638-1715), known as the “Sun King”, succeeded to his father in 1643 and crowned in 1654 at the Cathedral of Rheims, established the absolute monarchy from divine right in 1655. Envying his Superintendent of Finance, Nicolas Fouquet who was the owner of the most sumptuous Palace at the time (Vaux le Vicomte), Louis XIV decided to have one of his own that will outclass all the other palaces. Just after he arrested Fouquet in 1661, a vast program of work was launched to embellish the Palace of Versailles that became the royal residence in 1677. The king commissioned the architect Louis Le Vau to conduct the project. The almost definitive face of the palace was finished in 1710 after several work campaigns. Further alterations were done under the reigns of Louis XV and Louis XVI as the Palace continued to be a royal residence. After the tumultuous era of the Revolution of 1789, when the palace suffered from looting and degradations, life in Versailles re-born during the reign of Napoleon Bonaparte (who personally settled down in the Palace of Fontainebleau). During the Restoration (of the Monarchy, 1814-1830), Louis XVIII and Charles X started the refurbishment of the palace but Versailles was no more a royal residence at the benefits of the Palace of Tuileries (Palais des Tuileries). In 1833, the (last) king Louis-Philippe decided to transform Versailles into a museum in order to save it from falling apart. After the reign of Napoleon III and the advent of the 3rd Republic in 1871, the French Government, its administration and the Parliament settled down in the Palace until 1879. Afterwards, the Palace turned back to its previous duty of museum and got restored to its pre-1789 appearance. B. Architectural Facts The palace by itself, i.e. the main buildings, stretches upon 6.32 ha, split into 2300 rooms (1000 rooms are part of the museum). The Domain of the Palace of Versailles spreads out over 815 ha, which 93 ha are gardens composed of ornamental ponds, canals and various minor buildings like Le Trianon, or Le Pavillon de la Lanterne which is a secondary residence put to the disposal of the Prime Minister in 1959 and to the disposal of the President of the French Republic since 2007. The palace is characterized by the classicism style where unprecedented luxury is the norm. The main buildings are 20 meters high at their maximum point (average value). The ground plan shows a great rigor and size, because the absolutism reign of Louis XIV required that his Court was put up inside the Palace and so within reach of the hand of the king. A chapel is dominated the main building and culminates at 43 meters (46 meters at the top of the cross). The main materials are [3]: slate tiles, lead and wood for the roofing, - construction iron for the stone framework or staples, - limestone for the structure (and red bricks under Louis XIII era located at the “Marble Courtyard”), - gold sheets to recover wood sculptures, balconies and bronzes, - lead and tin roof ornamentations (mainly covered by gold sheets), wood for the window frames, marble and sandstones pavement. C. The Palace and Lightning Lightning incidents were not documented so it was quite difficult to trace what happened through ages. No fire, no major structural damages were reported. It is easy to believe that no major problem due to lightning occurred. The omnipotence of metallic components (lead sheets throughout the roofing even under the slate tiling) and gutters should have played a benefic role in capturing and directing the lightning flash. Most of the damages done to the Palace and its Domain were due to the past lack of maintenance that is costly, and lastly done by the Great Storm of December 1999 that decimated more than 10,000 trees of the Park and damaged the roofing of the Palace leading to many deteriorating leaks. Fig. 1. Aerial view of the main buildings of the Palace of Versailles (rear view from the Park) III. Risk Assessment A. Local Considerations 1) Climate and Lightning The Palace of Versailles is located in the “Ile de France” region at 16 km south-west of Paris, in the city of Versailles. The keraunic density is equal to 1.5 flashes/km²/year, which is quite low, but correct for this part of France where the climate is temperate, the land is flat and about 130 meters ASL. Lightning flashes mainly occur during the summer season, so the lightning density is quite concentrated at that time, broadly from May to September, more precisely in August when the lightning density is about 10 ten times the mean annual value. 2) Touristic Frequenting The touristic frequenting is following the seasonal conditions and thus the touristic periods (figure 2). In 2011 [4], the total amount of tourists is
equal to 4 million for the Palace visit only. For the entire domain (Palace + Park), this amount increases up to 6.7 million. The mean duration of a tourist’s visit is 3h06 [5]. In July, the monthly peak of frequenting is reached : 440.000 visitors. This Historical place is thus well crowded especially in summertime when the queue can stretch to a long distance outside the public reception desk (up to 400 meters long), and when many people are visiting the park. Lightning can be a serious life hazard. However, this problem is not clearly addressed (see IV A, 1st phase c); a prevention apparatus should have been installed, like a Lightning Warning System (same thing in [1]). 3) Electrical Environment As usual for that kind of building, there are electrical cables for interior and exterior lighting. However, some rooms are dedicated to the public reception desk, the shop, the restaurant, the security/safety offices, and to the administration. Fig. 2. Touristic frequenting monthly distribution (2011) © ToucanWings Fig. 3. Aerial view of the main buildings of the Palace of Versailles (front view from the main entrance). The ELPS being installed is indicated by a red circle where temporary covered scaffolding are settled. Fig. 4. Before roofing revamping (Above), After revamping (Below) B. Collection Area for Flashes The location that is discussed in this paper is circumvented to the right part of the central body of the historical building constructed under Louis XIII, named “The King’s Private Apartment” close to the Marble Courtyard at the very beginning of the Royal Courtyard up to the middle of it (figure 3). This was the location of the former “Staircase of the Ambassadors”. The inner part of this building shows a recessed roofing compared to the outer part of it. The height difference is 4.81 meters, accentuated by a different level between inner and outer ground. The height is 15.6 meters between the highest point and the ground of inner side (Royal Courtyard); and 20.41 meters between top to ground of the outer side (North Façade). The equivalent capture area is equal to 69541 m² (6.95ha). C. Level of Protection The Palace is gathering 60.000 artworks [5], which many are masterpieces : 7000 paintings, 6000 ancient books, 4000 pieces of furniture, 2900 sculptures, 2500 art items, 28000 engravings, etc… This site is classified as an ERP 1st category (“Etablissement Recevant du Public” means “Public Access Site”) defined by the French regulations (more than 1500 people). However, as cited in III.A.2, the lightning protection is only restricted to the building by itself. The main goal of the ELPS is to protect the building and its belongings. According to the criteria described above, the simplified risk assessment [6] leads to the Level of Protection I taken in account that the SPD installation was done by another contractor. IV. Installation A. Context This ELPS installation was done in the framework of the “Great Versailles” project of development and works initiated in 2003 by the National Domain of Versailles in cooperation with the Ministry of the Culture and Communication. The First Phase (2004-2012) of the master plan was : a- Restoration of the Historical Monument and its decoration, b- Improvement of the security/safety systems of the whole site, c- Improvement of the public welcome : enlargement of the visit offering and simplification of the entrance access. The Second Phase (2012-2017) of the master plan is : a- Ending of the modernization of the technical infrastructures of the Central Body, and restoration of the decoration of the Apartments, b- Refurbishment of the Water Tower and creation of a cooling system, c- Continuation of the ordinary restoration program (buildings and park). So during the 1st phase, a complete revamping of the Central body (figure 4a and 4b), especially the roofing was undertaken (a). Lightning protection being a safety system, the opportunity to update and revamp as well the existing ELPS of the former “Staircase of the Ambassadors” location happened South façade Central body Royal Courtyard Marble Courtyard North façade 4b 4a (part of b). The ELPS revamping, involving ESEATs, was done according to the NFC 17102 standard [7]. These revamping works spread out over time : several rounds from 2008 were programmed in order to repair the wood frame, replace the lead covering, refurbish the slates tiles, consolidate or replace all the carved items, replacement and gild all the dormers as well as lead/zinc roofing items. The last work of the 1st phase (c), complete restoration of the “Old Aisle” of the Palace and the “Pavillon Dufour” (figure 5) which has still not been started. B. Installation Proceedings Speaking of the lightning protection, the schedule was composed of 5 steps over about 18 months; the installation was finished at the beginning of 2013. Hereinafter, we are detailing how a lightning protection was provided during the whole step a (phase 1). Step 1 : An interconnection between the former earthing system and the scaffolding and umbrellas was set up. The former downconductors inside the location under work were disassembled and the existing installation was interconnected to the scaffolding. So that the scaffolding play the role of multiple natural downconductors and also the role of capture element (figure 4a). Two final earthing pits were done inside, one in the Royal Courtyard and the other one inside the North Façade area (figure 5). Step 2 : This modified installation was the verified and validated to insure a proper protection. Step 3 : New roofing conductors were set up once the roofing works were finished as well as new downconductors according to the customer drawings. This operation was done owing to the scaffolding which provided very secure conditions. Two final earthing pits were performed inside the area of the King’s Private Courtyard (figure 5). Step 4 : The remaining temporary ELPS, consisting of the interconnections between scaffolding and earthing pits, was disassembled. Two ESEATs were positioned and installed as per customer drawings, indeed connected to the downconductors and roofing conductors. Test joints, protection sheaths, earthing systems; leveling works and adaptation to the existing lightning installation were set up. Step 5 : ELPS was then inspected and a conformity certificate has been delivered. C. Roofing Conductors The roofing conductors are complying with the NF EN 50164-2 standard [8], these are flat ones (27x2mm2) made of tin plated solid copper. The whole roofing conductor progression was established in agreement with the customer’s wishes (figure 5). This progression throughout the top of the building must be the most discreet as possible, so that the roofing conductors must follow as much as possible all the concave edges and depressions offered by the structure. Conductors are bent all along the edge side. Each conductor is attached to the lead sheet made roofing by using copper strips that are soldered directly to the lead sheets. This method provides a secure and perennial fixing of the conductors. All the roofing conductors are virtually invisible from the ground level, and are connected to the existing mesh cage and passive conventional rods. The roofing is exclusively made of lead sheets, making the equipotential bonds to other metallic item easier. Indeed, the separation distance greatly benefits from this aspect. These lead sheets act like a conductor bearing an infinite (flat) cross-section, thus the current density is extremely low. So the equivalent conductor length between the top of the roof (ESEAT #1 or #2) and the lower end of
the roof (the stone balustrade), i.e. all the area where the lead sheets are positioned (even under the slate tiles), is equal to zero. The total equivalent length, from the ESEAT to the ground, is then much shorter. On the Royal Courtyard side, the equivalent length is 10.07 to 10.96 meters. On the North Façade side, the equivalent length is 19.40 meters. Fig. 5. Positioning of the final ELPS (2x ESEAT, 4x earth pits, roofing conductors, downconductors). Small green triangles are earth pits, green lines are the roofing conductors and downconductors, green arrows are interconnections to the existing installation. The largest scale mark is 20m. Royal Courtyard Marble Courtyard Courtyard of the Stags King’s Private Courtyard NORTH FAÇADE SOUTH FAÇADE NORTH WING Former Staircase of the Ambassadors (glass roof) Galery of Mirrors ESEAT #1 ESEAT #2 OLDAISLE Pavilion Dufour D. Separation Distance As being previously stated, the equivalently infinite electrically conductive roofing sheets play a significant role in the separation distance s definition as it reduces the whole length of the roofing conductors/downconductors. The connection between ESEAT #1 and #2 can be neglected as it has been implemented by a roofing conductor and all the roofing lead sheets. The maximum s values are indicated in Table I for every downconductors. These low figures are clearly not an issue. The outside metallic items are bonded to the ELPS. The ILPS, like bonding and SPD, were done by another company. TABLE I. SEPARATION DISTANCE S VALUES Maximum s [m] Material = air Material = masonry ESEAT #1 ELPS 0.38 0.76 ESEAT #2 ELPS 0.34 – 0.6 0.67 – 1.19 E. Downconductors and Earth Pits The downconductors are complying with the NF EN 50164-2 standard [8], these are flat ones (27x2mm) made of tin plated solid copper. Other components used are complying with the NF EN 50164 series. These downconductors are in fact the continuation of the roofing conductors. They are attached to the stone walls by using galvanized steel hooks secured by lead plugs. The bottom part of the each downconductor is protected against knocks by stainless steel sheaths. The resistance of each earthing system is below 10 Ohms. Gutters are naturally bonded to the installation. The most discreet path was to attach the downconductors in the recessed edges of the slate roof and walls. 1) ESEAT#1 (King’s Private Courtyard) The two downconductors are progressing straight from the lead sheet roofing via the bypassed cornice to the ground. The downconductors are conveniently hidden behind the vertical gutter pipes (figure 8). 2) ESEAT#2 (Royal Courtyard) Albeit this little courtyard is paved with sandstones, the inspection housings were installed in a visible way. However, this area is not accessible to the public and completely closed, so the esthetical aspect wasn’t an issue. In order to bury the earthing system, electrodes and earth conductors, some sandstones had to be removed and careful put back. On the Royal Courtyard side (figure 6), the downconductors are making their way from the bottom part of the lead sheet roofing (at the beginning of the slate tiles area) down to the ground. Once the gilded top cornice (figure 4b) bypassed according to the NFC 17102 §5.3.3 to avoid sparkovers at the bending area, downconductors are attached over the slate tiles by using copper holdfasts that electrically make contact with the underneath lead sheets. One of the two downconductors is going downwards to the Royal Courtyard. The inspection housing is hidden underneath the sandstone pavement as well as the earthing system. 3) ESEAT#2 (North Façade) On the North Façade side (figure 7), the other downconductor is making its way straight down from the cornice through the bars of the stone balustrade to the ground in order to reduce the bend radius at the top edge. At the ground level, the esthetical constraints were less stringent, so the inspection housing is mounted flush to the fine gravel ground surface. F. ESEAT The two ESEATs were attached to two chimneys by using screw mounted brackets and galvanized steel cast iron plugs. At the top of the roof, the radius of protection (LVL I) is equal to 42.60 meters; at ground level, the radius of protection is equal to 44.78 meters. A specially designed ESEAT for Historical Monuments has been designed : it bears compatible colors and materials (copper) as well as sporting a slim and discreet profile (see figure 8). This active lightning rod product is named Prevectron® TS2.25MH, it is composed of 2 upper electrodes, 2 lower electrodes, a continuous plain copper central rod, an embedded electronic synchronous triggering system. Its advance time is 25µs and is complying with the latest ESE standard [7]. Indeed, this ESEAT was sequentially tested under harsh conditions (ageing) simulating the cycle of life of a lightning rod such as : damp heat, environmental pollution (salt mist, sulfurous atmosphere), powerful lightning strokes (100kA @10/350, 3 times) and effectiveness tests ( T and standard deviation). Fig. 6. Positioning of the final ELPS, view from the Royal Courtyard. The largest scale mark is 20m. Fig. 7. Positioning of the final ELPS, view from the North Façade. The largest scale mark is 20m. Earth pit ESEAT #2 ESEAT #1 Earth pit Top edge of the recessed roofing facing the inner Royal Courtyard Top edge of the roofing facing outward (North Façade) Fig. 8. Installation of downconductors and earth pits (King’s Private Courtyard). Fig. 9. ESEAT made for Historical Monuments constraints (TS2.25MH) V. Inspection The inspection of the ELPS is done annually by the Bureau Veritas organization according to the lightning standard (described at the chapter 8). It consists of an initial inspection when the installation is finished, a periodic inspection, and every time the installation gets struck, repaired or modified. In our case, the visual inspection is done every year, and the complete inspection is done every two years. If defects are spotted, it is recommended to correct them as soon as possible in order to keep the optimal ELPS performance. VI. Conclusion It was shown that it is clearly and undoubtedly possible to install a modern External Lightning Protection System in a Historical Monument. Esthetics, respect, performance and longevity were the main issues that were technically addressed. A close collaboration in all the stages of the project between the different parties involved like the customer, the Architect of the Historical Monuments, the companies specialized in monument renovation, and obviously the company who install the lightning protection, is mandatory to fulfill this demanding job. Acknowledgment The authors would like to thank the Palace of Versailles Administration. References [1] S. Fauveaux, A. Lefort, “Angkor Vat Temple lightning protection”, International Lightning Protection Association Symposium, 1_4, November 2011. [2] G. Denizau, “Larousse des Châteaux”, ISBN 2-7441-9331-3, Larousse, June 2005. [3] Château de Versailles, Public Establishment of the Palace-Museum-and National Domain of Versailles, “Couleurs et matériaux”, www.chateaushortailles.fr [4] Château de Versailles, Public Establishment of the Palace-Museum-and National Domain of Versailles, Internal Report (Annex 3). [5] Château de Versailles, Public Establishment of the Palace-Museum-and National Domain of Versailles, Press Conference, January 2012. [6] UTE C 17108, Practical Guide “Simplified lightning risk analysis”, April 2006 [7] NFC 17102,