Performance Evaluation of Non-Conventional Lightning Protection Systems Based on NLDN Data

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***Abstract*—Charge Transfer Systems (CTS) are non-conventional lightning protection devices that, according to vendor specifications, prevent lightning from terminating within a defined area. The devices have been installed at facilities around the world in lieu of traditional Franklin rod lightning protection systems. Two prominent CTS installations in the United States are at the Browns Ferry Nuclear Plant and the Memphis FedEx World Hub. Historical NLDN data from 1995 - 2019 are analyzed for these two sites to illustrate whether the vendor claims of lightning prevention are, in fact, accurate. Ground-stroke densities are computed in areas where CTS are installed versus those without CTS to determine if there is a statistically significant difference that could be attributed to DAS installation.**

***Index Terms*—lightning, lightning protection, Franklin rods, air terminals, NLDN**

I. Introduction

The usage of non-conventional lightning protection systems (LPS) in lieu of traditional Franklin rod (air terminal) systems is a controversial subject. Non-conventional LPS include static charge dissipation devices, early-streamer emission (ESE) devices, charge transfer systems (CTS), and lightning suppressors/eliminators. These devices and systems are manufactured by numerous vendors and have been installed at facilities (many of them critical in nature) around the world since the early 1970's. Manufacturers falsely claim that these devices provide lightning protection for large areas, eliminate lightning completely in a given area, or minimize the probability of a strike occurring. The lightning elimination/suppression claims are scientifically unsubstantiated, lack independent third-party verification of system performance, and fail to present credible empirical evidence in the form of peer-reviewed publications. For the end customer, the marketing of these devices is obviously attractive, promising a drastic reduction/elimination of lightning-related incidents/damage with lower material and installation costs.

The claimed performance increases of non-conventional LPS compared to conventional air-terminal systems have been analyzed in both empirical and theoretical studies [1][2][3][6]. In all cases, third-party researchers have found no evidence to support the manufacturer claims of lightning suppression and/or increased zone of protection. Not surprisingly, most studies have concluded that non-conventional LPS perform a similar function to conventional air terminals if they are installed per NFPA 780 compliant configurations, that is, a complete system consisting of adequately spaced strike termination points, a full network of rooftop conductors and down conductors, and a complete grounding system with associated bonding connections.

Prior studies on the performance of non-conventional LPS have utilized video cameras and direct current measurements to determine if the devices have been directly impacted by lightning, or if lightning occurred within the vendor-specified zone of protection of the device [1][6]. Here, we examine historical lightning strike-point data from the National Lightning Detection Network (NLDN) to evaluate the performance of CTS, specifically the patented Dissipation Array System (DAS), installed at two prominent facilities in the United States- the Browns Ferry Nuclear Plant in northern Alabama, and the FedEx World Hub at the Memphis International Airport in southwestern Tennessee. These unique case studies examine DAS performance for a single device on a tall structure (Browns Ferry off-gas stack) and a distributed network of DAS over a large area with few prominent structures (FedEx World Hub). Are there differences in the lightning ground-stroke density before and after the DAS were installed? Is the lightning ground-stroke density statistically significantly different where the DAS are installed versus the surrounding geographic area (with no DAS)?

II. Data

NLDN data were provided by Vaisala for 50 km regions around both the Browns Ferry Nuclear Plant and the Fedex World Hub for dates ranging from 1995 - 2019. The data were filtered to only include cloud-to-ground (CG) lightning events and strokes with either positive or negative polarity peak currents exceeding 10 kA in magnitude. The peak current threshold was imposed to reduce the probability of falsely reported cloud-to-cloud (CC) events corrupting the analyses.

III. Case Study: Browns Ferry Nuclear Plant

The Browns Ferry Nuclear Plant, operated by the Tennessee Valley Authority (TVA), is the second largest nuclear power generation facility in the United States, capable of generating up to 3.8 gigawatts from its three nuclear generation units. The plant features a 600-ft tall off-gas stack located immediately

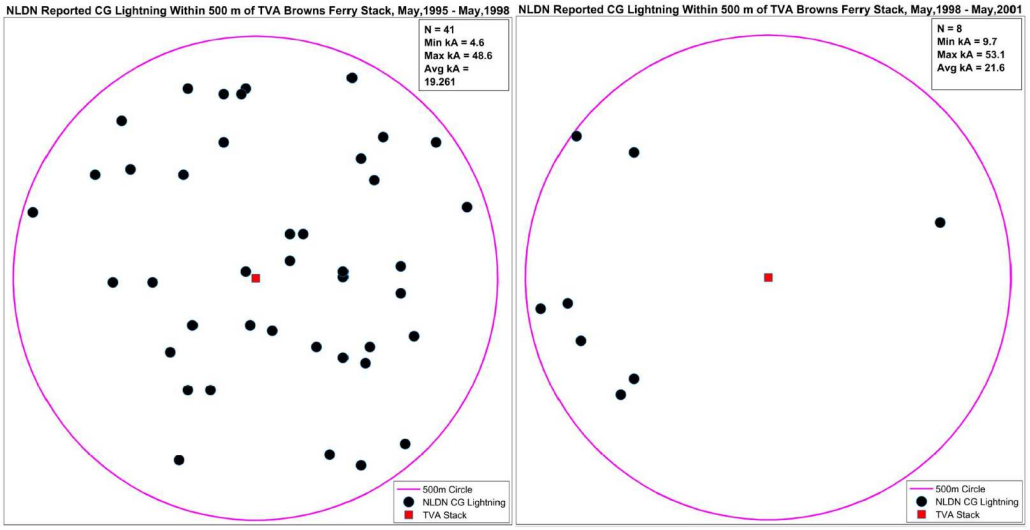

Fig. 1. NLDN lightning strike reports within 500 m of the Browns Ferry off-gas stack from 1995-1998 (left) and from 1998-2001 (right).

adjacent to the Tennessee River. In the late 1990's, plant managers elected to have a DAS installed on the top of the stack "...after equipment on the stack and around its base (was) routinely damaged during lightning storms." [4]. Later, the DAS manufacturer published lightning strike location reports in the three years prior (1995-1998) and three years after DAS installation (1998-2001). These plots (Fig. 1) seemingly show an 80% reduction in lightning strikes within 500 m of the off-gas stack.

Though the data in Fig. 1 appear to be quite convincing, a histogram of lightning strikes within 500 m of the off-gas stack reported by the NLDN from 1995-2019 (Fig. 2) reveals that the data presented by the manufacturer is dubious. Note that the first two data points in the histogram reflect the data plotted in Fig. 1 from 1995-2001.

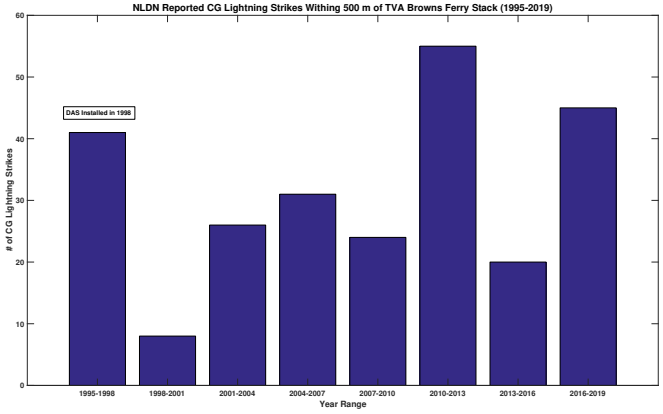

Fig. 2. Histogram of NLDN lightning strike reports within 500 m of the Browns Ferry off-gas stack in three-year increments from 1995-2019.

While there was an apparent reduction in the number of reported strikes within 500 m of the off-gas stack from 1998-2001, the trend immediately reversed in the following three

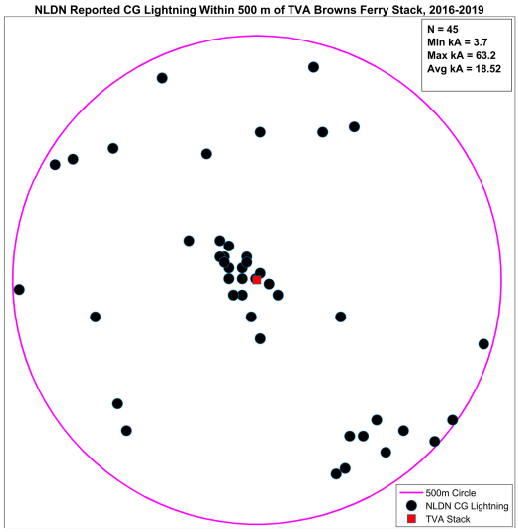

Fig. 3. NLDN reported lightning strike locations (N = 45) within 500 m of the Browns Ferry off-gas stack from 2016-2019. Note the tight data point cluster immediately around the stack.

years. Likely, the apparent reduction in lightning strike density from 1998-2001 was simply climatological in nature. Further, after the major NLDN performance upgrades in the 2010's, the reported strikes increased drastically. A very illustrative graphic is the strike map from the last three years of the analyzed NLDN data from 2016-2019 (Fig. 3). The number of cases is elevated, but perhaps more importantly, a high percentage of strikes are clustered immediately around the tower location (within 100 m), which is within the collection area of the tower itself and invalidates non-conventional lightning protection vendor's claims. This observation is likely attributable to updated NLDN strike location algorithms, which provide significantly higher strike location accuracy (median of the

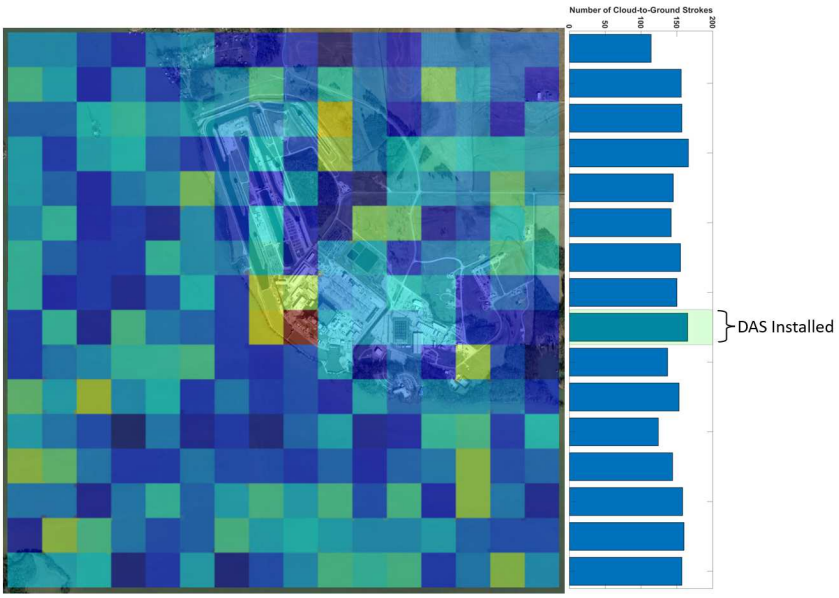

Fig. 4. NLDN lightning stroke density within a 3.5 km x 3.5 km region around the Browns Ferry off-gas stack. Each grid region is a 200 m x 200 m space. The dark red grid region corresponds to a stroke density of 29 strokes while the dark blue regions correspond to stroke densities of 2 strokes.

order of 150 m in the central U.S.).

NLDN data were further analyzed for a 3.5 km x 3.5 km region that includes the off-gas stack to determine if there is a statistically significant difference in the ground-stroke density around the off-gas stack versus the surrounding area (Fig. 4). The region was further divided into a 200 m x 200 m grid. The maximum stroke density, shown centrally in dark red in Fig. 4, occurred in the grid space that contains the off-gas stack (29 strokes). The minimum stroke density, shown in dark blue, was 2 strokes. Note the grid regions around the out-gas stack also contain higher stroke densities (17, 18, and 19 strokes, respectively). This spread in the reported strike locations around the off-gas stack is expected given the NLDN median strike location accuracy. The total number of strokes per grid row were summed and are shown at right in the bar graph. The total number of strokes per grid row ranged from 114 - 166 strokes with a mean of 148.9 strokes and an standard deviation of 14.3 strokes. The overall ground-stroke density in the area surrounding the off-gas stack is relatively uniform, with the only notable deviation occurring in the grid region that contains the off-gas stack itself.

Based on the NLDN data, the Browns Ferry Nuclear off-gas stack continues to be frequently struck by lightning despite the installation of the DAS array, which the manufacturer claims to prevent lightning from striking in the region where the device is installed. In fact, the DAS array appears to be acting as an effective Franklin rod air terminal. The calculated ground-stroke density is highest in the grid regions surrounding the off-gas stack, as expected, and is relatively uniform otherwise.

From public-domain records, the Browns Ferry Nuclear plant was most recently affected by a lightning-related outage in August 2019, when a lightning event resulted in the tempo-rary loss of power to the seven cooling towers. According to an inspection report by the U.S. Nuclear Regulatory Commission [11] power outputs from the three power generation units were reduced from 30-50% until the cooling tower operation could be restored in order to meet thermal river compliance.

IV. Case Study: FedEx World Hub

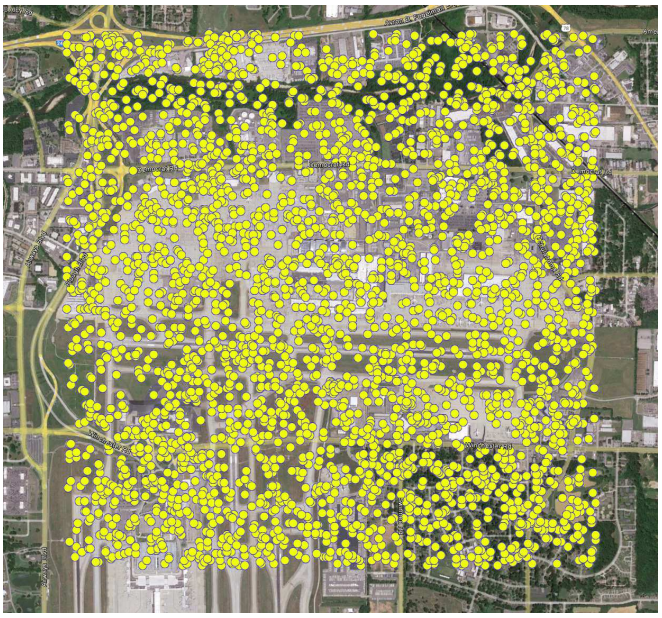

Fig. 5. NLDN-reported cloud-to-ground lightning events at the Memphis FedEx World Hub from 1995 - 2019. Note that all strokes shown have reported peak currents greater than 10 kA.

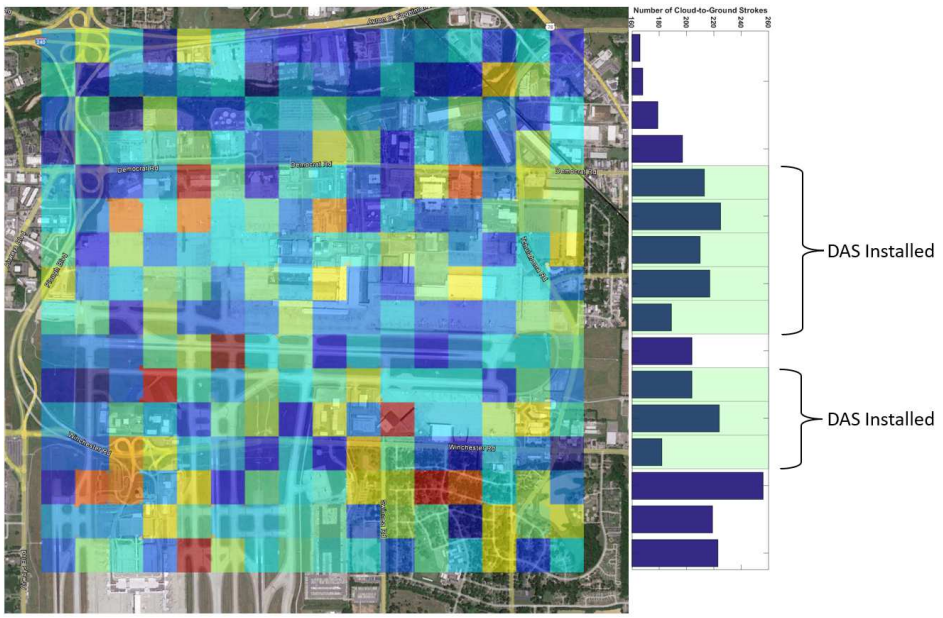

Fig. 6. NLDN lightning stroke density within a 3.5 km x 3.5 km region around the Memphis FedEx World Hub. Each grid region is a 200 m x 200 m space. The dark red grid regions corresponds to a stroke density of 28 strokes while the dark blue regions correspond to stroke densities of 4 strokes.

The FedEx World Hub is the company's top global hub, spanning 880 acres and containing more than 3.7 million square feet of facilities. The hub was originally outfitted with a DAS network in 1985. The DAS network has been expanded as the hub has grown. At least 270 DAS are arrayed around the site on elevated utility poles at the aircraft gates, staging, and offloading areas with typical spacing of 150-250 ft [5]. In 2017, the vendor published findings indicating there have been
only two reported lightning events at the site since DAS installation [7]. The vendor states that both events were investigated and later found to be false positives. Note that the source(s) of the lightning reports were not provided.

NLDN data were analyzed for the FedEx World Hub site from 1995 - 2019 in a 3.5 km x 3.5 km area that includes the full DAS installation. During this time period, there were a total of 3442 strokes reported with peak currents greater than 10 kA. A map of the NLDN-reported strike points is overlaid on an aerial image of the FedEx World hub in Fig. 5. Clearly, the DAS are not preventing lightning strikes from occurring at the facility. The study region was further decomposed into a 200 m x 200 m grid space where the ground-stroke density was calculated (Fig. 6). The total number of strokes per grid row were summed and are shown at right in the bar graph. Grid rows containing DAS devices (8 total rows) are shown in green. For grid rows that contain DAS devices, the average number of strokes per grid row was 208. For grid row with no DAS devices, the average number of strokes per row was 201.5, an insignificant difference. Based on these data, the installation of DAS devices at the Memphis FedEx World Hub has had no observable effect on the lightning incidence (and ground stroke density) at the facility from 1995 - 2019.

Note that on April 6, 2016, two FedEx employees were injured when lightning was reported to strike an airplane in an outdoor staging area where the workers were stationed [12]. Fortunately, the employees suffered non life-threatening injuries. The NLDN reported two well-determined negative polarity strokes (-14 kA and -9 kA, respectively) that occurred within the staging area (Fig. 7) where the workers were impacted. The entire staging area pictured in Fig. 7 is covered by a DAS array, with a pole-mounted DAS located immediately adjacent to the nose of each pictured airplane.

V. Conclusions

NLDN data from 1995 - 2019 have been analyzed for the Browns Ferry Nuclear Plant and the Memphis FedEx World Hub. In both cases, the NLDN data show that lightning incidence at the facilities has not been prevented by the DAS installation, nor has the long-term ground-stroke density changed as a result of presence of the DAS systems. These results are in agreement with prior studies performed in the late 1980's and 1990's which utilized direct photographic and current measurements where DAS were installed [1][6]. The results of the present study, which encompass nearly 25 years of data and many thousands of lightning events, directly refute unsubstantiated vendor claims that lightning incidence has been drastically reduced and/or eliminated following the DAS installation.

It is important to note that the USA's space program, including both NASA and commercial partners, exclusively utilize traditional lightning protection systems (both bonded and isolated catenary wire systems) to protect critical launch vehicles, payloads, and space launch infrastructure [9]. These systems are designed to meet or exceed NFPA 780 requirements. The

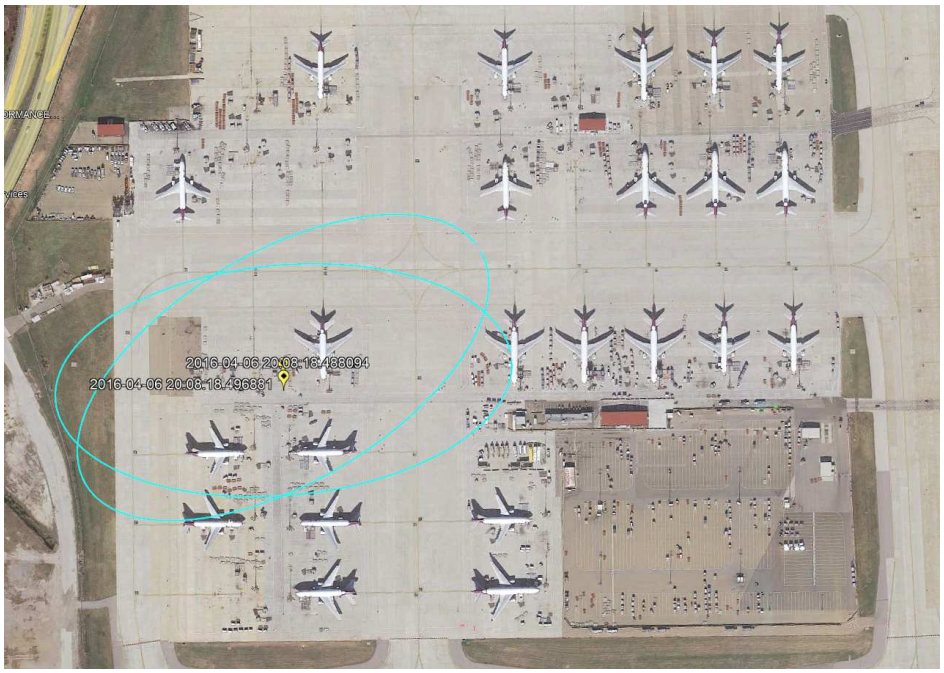

Fig. 7. Reported NLDN lightning strike locations for two strokes on April 6, 2016 within an airplane staging area at the Memphis FedEx World Hub. Two FedEx employees experienced lightning-related injuries associated with these events, which occurred within an area covered by a DAS array. DAS devices are located on utility poles immediately adjacent to the nose of each pictured airplane.

protected assets contain extraordinarily sensitive electronics and electro-mechanical systems. The launch complexes, particularly those at the Kennedy Space Center in Florida, are routinely struck by lightning [8][10]. Comprehensive lightning instrumentation systems measure and photograph the direct and radiated lightning effects around and on the assets to unambiguously demonstrate the effectiveness of traditional lightning protection systems. To date, similar unquestionable empirical data have not been provided and published by the manufacturers and vendors of non-conventional lightning suppression and elimination devices, nor by third-party researchers.

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