LIGHTNING ELECTROTECHNOLOGIES

December 9, 2019

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol, 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Dear Ms. Fine,

I am writing to you about the University of North Dakota (UND) Energy & Environmental Research Center (EERC) "Lightning Protection Scoping Study", which was submitted to the North Dakota Industrial Commission (NDIC) and made public on October 30, 2019.

Due to its many serious errors, critical omissions and misconceptions, we believe that the EERC Study does not contribute to the NDIC's effort to better understand lightning and its impacts on oil and gas facilities.

The EERC Study finding that the frequency of lightning related spills in North Dakota is not increasing with increasing numbers of oil and gas facilities is invalid since it is not supported by any data on the incidence of lightning in the relevant regions and time periods. Additionally the EERC Study ignores or overlooks the legitimate conclusion that fiberglass tanks are highly vulnerable to lightning related spills, which can clearly be shown from the data provided by the North Dakota Department of Mineral Resources (NDDMR).

The EERC Study's failure to recognize tank material as a primary factor in failures due to lightning strikes is not only contested by the data from the NDDMR, it stands in stark contrast to elementary principles of lightning protection and electrical engineering.

The EERC was not responsive to questions about their Study, but instead stated that doing so would be beyond the scope of the effort performed for the NDIC. Therefore Lightning Electrotechnologies Inc., under the supervision of Dr. Farouk A.M. Rizk, Life Fellow IEEE, President of Lightning Electrotechnologies, prepared the attached Report for the NDIC to highlight some of the EERC Study's many significant errors and to draw attention to its unsubstantiated and unjustifiable conclusions. A short biographical note on Dr. Rizk is included in our Report.

As independent references, cc'd are 4 authorities in the field, two internationally renowned experts on the physics of lightning and lightning protection whose publications are cited by the EERC Study, from the University of Florida, Gainesville, Distinguished Professor Martin A. Uman and Professor Vladimir Rakov. Additionally I include two representatives who are authorities on the referenced Standards, Mitchell Guthrie, former Chair of both NFPA 780 and IEC TC 81: Lightning Protection, and George Morovich, former Chair API TG 545.

I look forward to any comments or questions.

Sincerely,

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December 2019

Technical Comments on University of North Dakota (UND) Energy & Environmental Research Center (EERC) Lightning Protection Scoping Study (October 2019)

Prepared under the supervision of: Dr. Farouk A.M. Rizk
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1. Introduction

It is understood that the EERC Study was prepared by non-experts in the field of the lightning discharge or the related subject of lightning protection. It is also understood that the Study was not addressed to a scientific audience. However, as it can be seen by the comments below, the Study contains many serious errors, omissions and misconceptions that must not be left to stand. Otherwise this would mislead the industry and the public on a subject of considerable economic, safety and environmental importance.

The following represents some of the errors contained in the EERC Study.

2. Comments on the section titled: Definition of Terms

On page v, the EERC Study states:

"Step leader: The initial propagation of multiple lightning leaders from the base of a thunderstorm cloud toward the earth."

The definition provided is incorrect; the downward lightning leader is generally referred to as a stepped-leader; since the individual leader moves in steps with pauses in between steps as it progresses towards the ground [1].

On page v, the EERC Study states:

"Up-streamer: The charged ionic channel that emanates upward from the earth to meet the step leaders coming down from the cloud."

The definition provided is either an erroneous description of positive streamers, which can form from tall structures under the negative cloud charges even in the absence of a downward leader [2], or it is misnamed and a vague description of the upward connecting leader [1], which plays a much more decisive role in the lightning attachment process than the streamer. The upward connecting leader is mentioned in Section 7.2.2 of the EERC Study, dealing with ESEs, which is misleading since ESEs have been disputed by the scientific community in several peer reviewed papers [3], [4], [5].

3. Comments on Section 2.3 Lightning

On page 4, 5th paragraph the EERC Study states:

"The most common kind of lightning strike is cloud-to-ground, where negatively charged leaders are produced and travel through the air in a path that has the least amount of resistance to the ground."

It is not true that the most common kind of lightning is cloud to ground; intracloud is the most common [6]. Also the statement that negative leaders travel through the air in a path that has the least amount of resistance to ground is meaningless or false. The path of least resistance (or dielectric strength in the case of air) from the center of charge in the clouds to the ground would be a straight line, clearly lightning does not move in a straight line.

4. Comments on Section 2.4 Static Electricity

On page 6, 2nd paragraph, the EERC Study states:

"Higher humidity will increase conductivity, i.e., decreasing the charge retention, of a conductor. However, insulators will be less affected by these environmental conditions, making them able to hold onto their charge until another variable is introduced into the system."

This statement is false; the charge retention of an insulator is greatly influenced by environmental factors and humidity, much more so than a conductor. Many in North Dakota will have noticed that insulating materials like their hair, clothes or carpets retain static charge more readily in dry, heated homes during winter as opposed to a hot, humid summer day. No similar observation is made with metals.

5. Comments on Section 3.0 Facility Operations

On page 6, 4th paragraph, the EERC Study states:

"If not dissipated, this static charge can produce an electrical potential that can lead to a spark and subsequent ignition of flammable vapors or contribute to a lightning strike, as lightning seeks the lowest resistance path to ground."

There is no explanation given for how static charge within a tank, if not dissipated, would contribute to a lightning strike, which is again attributed to lightning seeking the lowest resistance path to ground. There is no scientific evidence that such charges could impact a lightning strike. The confusion around the issue of static charges and how it relates to lightning will be addressed again in this Discussion.

6. Comments on Section 5.0 Principles of Lightning Protection

In this section the work for Dr. Martin A. Uman [6] is cited, The Art and Science of Lightning Protection; 2008. As is evident from the contents, Chapter 3, General methods for lightning protection, is referenced.

However the authors of the EERC Study fail to include any reference to the material in the first section, 3.1 of the Chapter, which covers Faraday cages and topological shields, which is of particular relevance to lightning protection as it pertains to storage tanks.

It's hard to understate the gravity of this omission, in identifying the principles of lightning protection; the most relevant principle to the subject at hand was simply omitted.

7. Comments on Section 5.2 Surge Protection

With respect to the need for surge protection:

On page 10, 6th paragraph, the EERC Study states:

"The lightning-induced voltages on the structure via incoming power feeders and data/communication lines, given that these utility lines may have relatively large voltages induced on them by direct or nearby strikes."

This statement illustrates misconceptions about, induced voltages; direct strikes apply voltages, indirect strikes induce voltages.

8. Comments on Section 6.0 Storage Tanks

On page 11, 2nd paragraph, the EERC Study states:

"The leader step will make contact on the tank at locations of least resistance and greatest potential, primarily the highest points of the tank."

This description of a direct strike to a tank is incoherent.

A basic understanding of lightning as expressed in the EERC Study, specifically the effects of indirect lightning strikes on storage tanks is limited to ground currents or the movement of induced charges and it ignores the fundamental role of the electromagnetic waves generated by the return stroke current.

On page 11, 3rd paragraph, the EERC Study states:

"If a tank is within a path of current from an indirect stroke, then the current can possibly arc over any air gaps on the tank"

Similarly on page 5, 2nd paragraph, Section 2.3 Lightning, the EERC Study states.

"The ground current near the attachment point increases tremendously compared to the slow- moving current induced by the moving charged storm."

API 2009 is referenced by the EERC Study in both cases.

Although the two API Standards referenced by the EERC Study contain recommendations that loosely or implicitly adopt electromagnetic theory, like the recommendation in API 2003 that fiberglass tanks not be used where flammable vapors may be present or the statement in API 2009 that the Faraday cage effect serves to protect internal floating roof tanks and is responsible for their good safety record. The 'general principles' Section of both API documents contain a description of lightning that considers only ground currents and makes no reference to EM waves or fields.

Below is an excerpt from API 545 2009 Annex A, A.1.2 Lightning Principles, but a nearly identical paragraph appears in API 2003

"Electrical storms involve the relatively slow movement of heavily charged clouds. Charging mechanisms in the storm build up an electrostatic field over a large area across the base of the storm cloud. This field induced an opposite charge on the surface of the earth beneath it. This induced ground charge flows along the surface of the earth beneath the storm cloud at a relatively slow rate. The charging current flows are relatively small and cause no damage. This charge differential is periodically neutralized almost instantaneously by a lightning stroke that collapses the field. <u>At that time, a heavy ground current flows toward the lightning attachment point, equalizing local ground charge distribution</u>"

This view of lightning or model was developed in the electric power industry in 1908 by K. W. Wagner [7], [8]. In brief, it was an attempt to calculate induced voltages from nearby strikes on power lines with an understanding that the damaging effect is caused by the sudden movement of the induced charges and it ignores the effects of the electromagnetic (EM) waves generated by the return stroke current, which were simply not widely understood in the early 1900s.

After more widespread familiarity with radio waves in the 1920s and 1930s, attempts to understand the effects of nearby lightning strikes focused on the electromagnetic effects (EM waves) generated by the return stroke current [7], [9]. By the 1950s such models produced calculations with accuracies sufficient for engineering applications [7], [10].

Any modern, scholarly work, describing the damaging effects of nearby indirect lightning strikes would primarily refer to the radio frequency electromagnetic fields [1] and there would be no reference to the sudden movement of the induced charges along the ground. EM waves from lightning strikes constitute indisputable scientific fact and are a major cause of induced insulator flashover on power distribution lines and are the scientific basis of the lightning detection networks, such as the US National Lightning Detection Network (NLDN).

Unfortunately many lightning protection companies, which promote disputed technologies like static dissipaters [6], still use descriptions of lightning that focus only on the movement of ground charges and additionally they make the baseless connection or equivalence between static charges and induced image charges.

The issue of the electromagnetic effects of lightning have been central in the electric power industry since the mid twentieth century, but they are only now being explicitly introduced to the oil and gas industry as is evidenced by recommendations in the upcoming 2020 version of NFPA 780, Annex N, Consideration for Nonmetallic tanks Containing Flammable Vapors or liquids that Give off Flammable Vapors, a version of which has been available for public comment since October 10th of this year, it states:

"It is critical that lightning protection address the threat of coupling of lightning electromagnetic impulse (LEMP) onto conductors in or on a nonmetallic tank"

9. Comments on Section 7.1.1 Air Terminals

On page 12, 2nd paragraph, the EERC Study states:

"Conventional air terminal lightning protection systems do not protect against indirect lightning currents or induced voltages. These effects are addressed by proper bonding and the application of surge protection devices (American Petroleum Institute 2003, Appendix C)"

Whereas it is true that conventional air terminals do not protect against induced voltages, it is not true that proper bonding and the application of surge protection devices address these effects, specifically as they relate to fiberglass storage tanks. There is no such generalized statement in the referenced API Standard.

Consider the following analogous example; if lightning should strike close enough to a flagpole or mast, EM fields produced by the lightning return stroke current would induce voltages onto the mast and electric discharges would be produced at the mast top. The fact that the mast may be well grounded and that the top is well bonded to the rest of the mast, does not restrict the induced voltages and subsequent electric discharges. If we now place the grounded mast inside a fiberglass enclosure, the production of discharges from the grounded mast due to nearby strikes would still occur. Surge protection devices are not applicable.

10 Comments on Section 7.2.2 ESE Systems

On page 14, 1st paragraph, the EERC Study repeats the claims made by proponents of ESEs, but cites the work of Rakov, Uman 2002 [5], which actually disputes the claims made by proponents of ESEs. Such use of citations is misleading.

Additionally the citation for the associated image, Figure 5 is incorrect.

11. Comments on Section 9.0 Key Findings

On page 18, 1st paragraph, the EERC Study states:

"Incidents of lightning strikes resulting in spills do not appear to be increasing with the growing number of oil- and gas-related facilities."

Without knowing the details of the incidence of lightning to ground in the relevant regions and time periods, as would be available from the NLDN, this conclusion, which is based on the number of oil and gas related facilities and the number of spills alone, is meaningless.

The suggestion that increasing numbers of facilities does not correlate to increasing lightning related spills is not substantiated by the data provided in the EERC Study. The implied assumption that the rate of incidence of lightning to ground, or ground flash density Ng, is constant from year to year is unjustified. Variations in consecutive years within the same region could be substantial [1]. The actual incidence of lightning to ground would need to be correlated with lightning relates spills for many years before any such trend could be established.

Assessment of NDDMR data by Lightning Electrotechnologies

Based on communications with representatives from the NDIC, it is understood that the following assumptions are uncontroversial:

- In North Dakota there are many more CTBs and oil production facilities (several thousand) as compared to SWD facilities (several hundred).

- SWD facilities typically use proportionally more fiberglass tanks than steel tanks as compared to CTBs and oil production facilities, which typically use proportionally more steel tanks than fiberglass tanks.

Therefore, given that, at any time during the period covered by the data from the NDDMR in Section 1.3 of the EERC Study, SWD facilities could not have accounted for more than 10% of all oil and gas related facilities. And given that according to the data, SWD facilities accounted for 41.8% of all lightning related spills. A legitimate conclusion that follows would be that fiberglass tanks are highly vulnerable to lightning related spills, much more so than steel tanks. It should be noted that proximity to steel tanks would partially mitigate or shield a fiberglass tank from the effects of incoming electromagnetic waves so that correlations would not be exactly proportional.

The mere fact that 23 lightning related spills were reported among the less than 500 SWD facilities in North Dakota, approximately 5% of all SWD facilities in a period of 6 years, is more than enough evidence to sound the alarm about the lightning performance of fiberglass tanks. The region of interest in North Dakota experiences fairly low levels of lightning activity, between 1.5 to 6 strikes per sq. mile per year according to Vaisala (2008 - 2017) and storage tanks at SWD facilities are not very tall and do not occupy a large area or footprint. Rudimentary calculations show that the reported number of spills greatly exceeds any expected value for the number of direct strikes to sites with such physical features

On page 18, 2nd paragraph, the EERC Study states:

"Tall objects and objects with an electrical or static charge are more likely to be struck as lightning seeks the easiest path to ground."

The repetition of the meaningless claim that lightning seeks the easiest path to ground aside, there is no basis to believe that static charge, inside or outside the tank, makes it more susceptible to lightning. Static charge in the liquid, even when it can cause sparking, results in such comparatively small potentials that there is no reason to imagine that it can influence a direct lightning strike. Even with the higher potentials associated with external charge; there has never been any evidence that such charge would have any impact on lightning strikes. It is also important to note that in the humid and rainy environment during a lightning storm, no significant charge could build up on the polymeric tank's outer surface.

Although there are obvious differences, just as an analogy or to illustrate that the effect of existing potentials on ground structures has been investigated, experience with HV power lines shows that the system voltage only begins to play a significant role in the lightning attachment process at potentials in excess of 345 kV [11], much greater than anything that can happen as result of static charge. From API 2003, page 19, "Tests have shown that conductive (metal) fittings accumulated potentials up to 11 kilovolts while dispensing product into an insulated tank."

Additionally there is no reason to imagine that the vulnerability of a tank to indirect strikes could be determined by static charge.

On page 18, 2nd paragraph, the EERC Study states:

"Although NFPA 780 recommends fiberglass tanks not be used in applications where flammable vapors might be present, the EERC found no peer-reviewed scientific data specifically citing tank material as the only factor influencing failure due to lightning strikes."

The reason for the use of the word "only" in the above statement is unclear. It is generally unusual to attribute any physical phenomenon to only one factor.

Furthermore, such a statement is more likely to be understood as EERC VP, John Harju was quoted by Amy R. Sisk of the Bismarck Tribune in the Oct 22nd 2019 article titled: "Study: Frequency of lightning-related oilfield spills holding steady, though much is unknown".

Amy Sisk wrote:

" "We found no scientific data proving that tank material is a primary factor that influences lightning strikes," Harju said." "

The failure to recognize tank/enclosure material as a primary factor influencing failure due to lightning strikes is unjustifiable and nothing short of astounding. Effectively ignoring the early work of Michael Faraday (1791 – 1867) and the contemporary discipline of Electromagnetic Theory, as highlighted by the previously mentioned omission in Section 5.0 of the EERC Study, Principles of Lightning Protection. The above statement by the EERC is totally at odds with any modern, scientific understanding of lightning protection or electrical engineering.

12. Comments on Section 10 Next Steps

If funding for future research is obtained by the EERC, it is strongly recommended to hire a recognized expert or consultant in the physics of lightning and lightning protection and additionally involve the electrical engineering and physics departments of the University. Faculty members from these departments will have the prerequisite scientific basis to understand the lightning strike mechanism, the resulting electromagnetic waves as well as remedial actions such as electromagnetic shielding.

13. Purpose of the Study

The stated purpose of the EERC Study, in Section 1.1 Purpose of Scoping Study is,

"...to develop an understanding of the cause of lightning strikes at saltwater disposal (SWD) and oil production facilities."

In our opinion, it's hard to imagine how it could be argued that the EERC Study met this objective.

In 2013 Lightning Electrotechnologies was commissioned by a major oil producer to investigate a series of tank fires in Texas and to look into the question of why lightning related fires are more frequent in fiberglass tanks as compared to steel tanks; we would like to offer the following brief description.

Since storage tanks at gas and oil facilities are not very tall and typically don't have large footprints, direct strikes are a comparatively low probability event, the effects of nearby strikes will be experienced far more frequently.

In the context of storage tanks, the principal effect of a nearby lightning strike is exposure to the intense electromagnetic (EM) fields generated by the return stroke current that can induce significant potentials (generate sparking) onto nearby conducting objects, whether they are grounded or not.

Objects inside a metal enclosure/tank of adequate thickness are shielded from EM waves, however sparking can still occur on the outside of a steel tank. If sparking due to a nearby strike occurs at a vent on the outside of a steel tank where flammable vapors are present, ignition is possible. If the fire is not extinguished quickly enough, the heat can eventually result in a larger fire.

Objects inside fiberglass tanks are not shielded from EM waves, so sparking due to a nearby strike can occur on conducting components both on the outside, and on the inside of a fiberglass tank. If sparking due to a nearby strike occurs at a location on the inside of the tank where flammable vapors are present, a fire on the inside of the tank or an explosion becomes possible.

Simulation studies and field experience shows that a fiberglass tank containing flammable vapors could be at risk of internal hazardous sparking if lightning should strike within a distance of approx. ½ mile. If a lightning rod, mast or catenary system were installed to protect a tank from direct strikes, it would necessarily be much closer to the tank than ½ mile. So even if the lightning protection system works as intended and intercepts a lightning strike, it would be so close to the tank that EM waves generated by the conductors carrying the lightning current to ground could be a source of hazardous sparking.

An effective way to protect a fiberglass tank containing flammable vapors from hazardous internal sparking induced by nearby lightning strikes is to give the tank a means of electromagnetic shielding, similar to the inherent electromagnetic shielding of a steel tank. Such shielding should be designed to attenuate any incoming EM fields below a threshold necessary for hazardous sparking.

Shown in Section 7.2.5 of the EERC Study are examples EM Shields by Lightning Electrotechnologies. They provide a shielding effectiveness of 20 dB at a frequency of the incident field of 1 MHz. The EM Shield was tested at the request of Occidental Petroleum and in the presence of 3 Oxy engineers at the independent High Voltage Test Facility of Manitoba Hydro in Winnipeg, Canada. There is a YouTube video titled, "HV Tests on Lightning Protection for Fiberglass Tanks" documenting the laboratory testing. There are several hundred examples of EM Shields in service starting in 2014 in areas of very high lightning activity in Texas and New Mexico. According to data from the NLDN, some localized areas have experienced more than 74 strikes per sq. mile in one year, so far without incident.

Electromagnetic shielding is a recognized branch of Electromagnetic Theory and is the subject of numerous peer reviewed papers and textbooks [12], [13], [14] [15].

14. References

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Farouk Rizk
Biographical Note

Farouk A.M. Rizk holds a B.Sc. (Eng.), and M.Sc. from Cairo University, a Ph.D. from the Royal Institute of Technology, Stockholm, and a Doctor of Technology degree from Chalmers University of Technology, Gothenburg, Sweden.

He joined the Hydro-Quebec Research Institute (IREQ) as a senior research engineer in 1972, subsequently passing to scientific director, High Voltage (1976), vice-president, Research and Testing Laboratories (1986) and held the title of fellow research scientist (1986-1996). He has been invited professor at the INRS-Energie and adjunct professor at McGill University, supervising Ph.D. theses.

Dr Rizk is presently president of Expodev Inc., a consulting engineering firm, and Lightning Electrotechnologies Inc., a lightning protection equipment supplier, both in Montreal, Quebec, Canada.

His research work covers a wide range of topics in high voltage and high power engineering: arc dynamics in high voltage circuit breakers, polluted high voltage insulators, transmission line single pole switching, electromagnetic shielding, compressed gas and oil breakdown, long air gaps, lightning attachment and lightning protection. He is credited with the most comprehensive work on arc instability and thermal time constant in air-blast circuit breakers, the first systematic laboratory and field investigation of high voltage insulator performance under desert pollution, the most comprehensive modelling of polluted insulator flashover mechanism, the most extensive experiments on the performance of insulators and large-electrode air gaps under rain, a novel model of critical switching impulse breakdown of long air gaps, a new physical approach to the lightning attachment process to ground structures and the practical application of ultra-corona in lightning protection.

Dr Rizk was nominated IEEE Fellow in 1982 “for contributions to the science of high voltage technology and for technical leadership in the advancement of the electric power industry”. He has been chairman of the 10th International Symposium on High Voltage Engineering (ISH) in 1997 and chairman of ISH steering committee.

Dr Rizk received prize paper awards from the IEEE Transmission and Distribution Committee in 1989, 1991 and 1995 and from the Power Engineering Society of IEEE in 1996. He was awarded the IEEE Herman Halperin Electric Transmission and Distribution Award in 1996.

He is a Distinguished Member of the International Council on Large High Voltage Electrical Systems (CIGRE) and a recipient of the CIGRE Technical Committee Award, 1997, for outstanding contributions to Insulation Co-ordination.

He is co-author of three CIGRE monographs and author, with Dr Giao N. Trinh, of "High Voltage Engineering", a book published by CRC Press in 2014.

Dr Rizk chaired the lightning attachment session at the ICLP 2016, in Estoril Portugal.

Dr Rizk did worldwide consultation work on lightning protection, HVAC and HVDC power transmission for utilities, consultants and manufacturers. These include: IIE/CFE, Mexico, EEA and EETC, Egypt, SEC and KFUPM, Saudi Arabia, Occidental Petroleum, Texas, USA, Gilbert Commonwealth, Pennsylvania, USA, Next Era Energy, Florida, Georgia, USA, National Grid Company, India, EDF International, France, TNB Research, Malaysia, National Electricity Company, Jordan, SONELGAS, Algeria, SNC-Lavalin, Canada, Manitoba Hydro, Winnipeg, Canada, INRS-Energie, Quebec, Canada, KEPCO, South Korea, ESKOM, South Africa, AEG, Frankfurt, Germany and ABB-Schaltanlagen, Manheim, Germany.