Lightning Warning Techniques for Risk Mitigation

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Abstract

Lightning can pose a threat to numerous processes associated with the production and handling of energetic materials and materials that may produce environments containing flammable gases, flammable or combustible liquid-produced vapors, combustible dusts, or ignitable fibers/flyings. Advance warning of a lightning threat can allow termination of such operations or enable the operator to render the process to a configuration less susceptible to the effects of lightning. The proper incorporation of lightning warning techniques and hardware into the plant or process operating procedures could have a positive effect on the plant/process lightning risk assessment and help reduce the level of protection required from a lightning protection system. This paper will discuss the general principles and techniques for lightning warning and discuss baseline requirements for hardware that can reliably provide advance warnings for critical operations. This paper will also address considerations of incorporation of these techniques into a facility's lightning protection plan. Finally, this paper will show through a risk assessment example how the use of advance warning can mitigate the risk of a lightning threat.

1. Introduction

The consequences of lightning-related losses associated with injury and damage to the surrounding area at chemical and petroleum facilities can lead to situations where it is not possible to reduce these risks to tolerable levels by the installation of a lightning protection system. For these cases, the solution may be to supplement the lightning protection system with lightning warning procedures.

Advanced lightning warning can be provided by commercially available systems ranging from a national lightning location network to a local single station system. Lightning location systems provide historical information on ground strike locations which allows the safety officer to follow the progress of mature thunderstorms at great distances. Where warning of impending lightning from a storm that may build overhead is important, a local warning system that monitors the earth's electric field gradient is necessary. Some applications may require both warning of storms building overhead but also require a significant advance warning of mature storms that would require a large lightning detection network.

Some key factors in determining the type of lightning warning system required are: (1) the type of operations being conducted and the sensitivity of the operation, (2) the levels of warning required, (3) length of time required to terminate operations, (4) schedule criticality, (5) parameters associated with the location of site, (6) typical storm characteristics at the site, and (7) maintenance of the systems [1]. However, the effectiveness of lightning warning systems in reducing the risk of lightning-related losses is dependent upon the implementation of operating procedures that properly address the mitigation of critical risk parameters. Consideration must be given to the identification of critical processes and those processes where there may be an unacceptable risk to safety of workers, as applicable. This may require multiple levels of warning and/or different criteria for different operations conducted.

2. Lightning Threats

Wider use of computer control and monitoring systems in industrial processes lead to greater susceptibility to the threat associated with a lightning event. Automated/smart control systems increase efficiency but such systems may be susceptible to overvoltages and ground potential rises that could result from direct or nearby flashes or current surges associated with strikes to incoming lines or near these lines. An additional threat is the possibility of an electrical upset of process control hardware associated with a critical process that could lead to an unscheduled shutdown or uncontrolled termination of a critical operation [1].

In addition to hardware damage, one of the primary threats from lightning is that of fire. Significant charge in the lightning flash can ignite flammable vapors or explosives. The effects of strike impingement on metallic surfaces can lead to burn through or hot spots on the interior surface of metallic plates if they are not of sufficient thickness [2][3]. Burn through could lead to ignition of contents, release of product, or possible environmental concerns (depending upon material released). Kern indicates that it is possible that the temperature on the inner surface of a metal plate could be sufficient to provide ignition of contents without burn through. Necci, et.al. [4] report a history of lighting activity at process plants as the cause of the immediate ignition of flammable atmospheres or structural damage with subsequent release. However, available information on lighting damage to industrial equipment is fragmented and not very detailed. He reports that 80 % of natural triggering causes have atmospheric origin and the most vulnerable equipment was found to be storage tanks. Lightning attachments are cited as ignition sources for flammable gas/air mixtures that form just above floating roof tanks, ignition at atmospheric vents for fixed roof tanks and pool fires caused by leakage due to damage caused by the arc discharge.

3. Lightning Warning System Technology

3.1 General

There are many lightning warning techniques used in lightning safety plans which range from the very simple and basic to sophisticated lightning location networks. Weather forecasts can help in scheduling of lightning susceptible operations but are not reliable or specific enough to rely on independently to reduce the risk of a lightning-related incident. The Flash-to-Bang technique is a well-known method for estimating the distance to a lightning strike based on the difference between the speed of light and speed of sound. The United States National Weather Service and their NOAA Lightning Safety Team has established a "When Thunder Roars, Go Indoors!" program to promote personal lightning safety [5] which appears to have had a positive effect on reducing lightning deaths in the US since its inception. Santis [6] discusses the use of an AM radio for remote blasting operations. The Lightning Electromagnetic Pulse (LEMP) produced by a lightning strike will generate a characteristic crackle of noise on an AM radio and the number and amplitude of such static bursts can be an indication of probability of movement of lightning activity in the proximity of the event. Santis, however, acknowledges the inefficiency of such a technique as it gives no indication of distance or direction and the static bursts may not be discernable from other potential sources of static.

A number of techniques are currently available that are designed to detect various parts of the electromagnetic spectrum. These can be generally be characterized as Magnetic Direction Finders, Time-of-Arrival, interferometry, optical imaging, electric field measurements, and RF signal strength measurements. Electric field measurements are discussed in Section 3.2.

A crude form of the RF signal strength measurement technique is discussed above in the example involving an AM radio. These techniques are not reliable in their simplest forms but can be teamed with optical sensors to reduce the false alarm rates to a level it can be used as a single station device.

Optical imaging systems are generally research devices and are used in satellite storm detectors. However, satellite detectors do not provide real time information and cannot differentiate between cloud-to-cloud, intra-cloud, and cloud-to-cloud discharges so they are not particularly useful in commercial lightning warning applications.

3.2 Electric Field Measurements

The most common device used to measure the earth's static electric field is an electric field mill (EFM). The ambient fair weather (clear skies) electric field at or near sea level is generally given to be on the order of 100 volts per meter (V/m). For thunderclouds building in the vicinity of the sensor, the EFM detects the net charge in the cloud through its effect on the electric field gradient. The probability of the generation of a lightning flash increases as the value of the local electric field gradient increases. As a charged cloud moves into the vicinity of the EFM, the electric field gradient will also increase. Figure 1 forwards a recording of a storm moving into the area of interest. Lightning flashes result in a rearrangement of the charge distribution in a cloud in a fraction of a second. The amount of time it takes for the electric field to recover is related to the distance from the discharge.

The value of EFMs is in those cases when a cloud first develops in the area of interest. The range of a single EFM device varies from a few kilometers up to 20 kilometers. The disadvantage of devices based on the measurement of the electrical field gradient is that it will also measure charge produced by blowing sand or snow, mowing of the grass in the vicinity of the sensor, and charged aerosols such as diesel exhaust and sea spray. Changes in the electric field gradient will occur when humans or wildlife alter the electric field when approaching the sensor. These charge sources can generate a false alarm when the measured charge results in electric field gradients exceeding the threshold level set or a failure to alarm when the charge masks the changes in the electric field gradient characteristic of a storm building overhead or moving into the area. Some of these are short duration events and can be confirmed prior to issuing manual alarms but are difficult to account for in automated warnings. Others may be longer in duration and must be taken into consideration when siting the sensor. EFMs using rotating disc techniques tend to be more susceptible to sources of space charge not related to the earth's electrical field gradient than newer electric field measuring techniques. An experienced user will learn the difference in the signature of these sources and that produced by a thunderstorm building or a mature storm moving into the area as characterized in Figure 1 but it is difficult to develop an algorithm that will be able to eliminate the effect of these threats on false alarm and failure to alarm rates when using automated warnings for termination of operations.

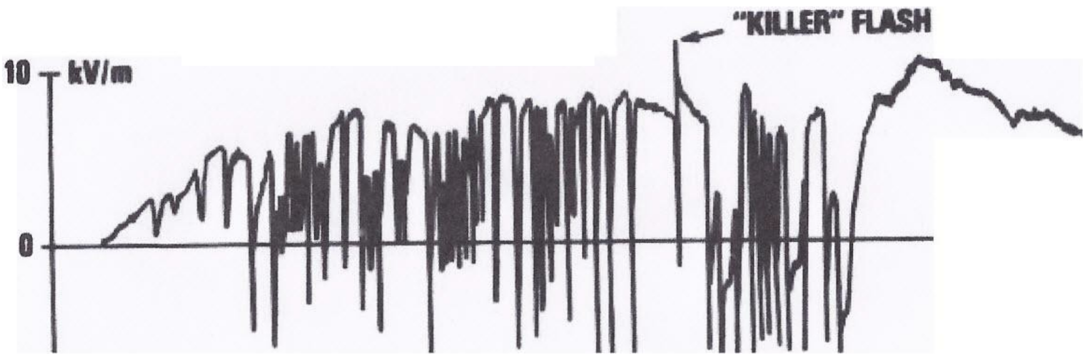

Figure 1 - Example of EFM Recording (from Guthrie 1982 [1])

3.3 Lightning Location Systems

Magnetic Direction Finders may be used in both single station and network applications. In a single station application, it can provide a direction in which a flash is detected and an assumed range to the flash based on the signal strength and/or the signal wave shape based on comparison with the signal from an average flash. By processing the signal from multiple stations, the accuracy of the output is increased and a specific strike location can be determined.

The Time of Arrival and Interferometry are techniques that are used in lightning detection networks. The Time of Arrival sensors can operate in the VHF, VLF and LF frequency ranges so the sensors can be spaced at greater distances and are used primarily in larger networks while the Interferometer sensors measure the phase shift between signals and require closer spacing of sensors.

When only information about general lightning activity and/or a distance and bearing to a thunderstorm is required, a single sensor lightning detection device may be sufficient. To determine a specific lightning strike location, a multi-sensor lightning location system is needed. This is generally in the form of a larger commercial network but a simple network can be formed by linking single-station devices.

4. Methods to Decrease Lightning Risk

Even though not reliable enough to consider as a part of a lightning risk assessment, there may be some cases where it is possible to schedule particularly risky operations during periods of the day that lightning activity is less probable. For example, Vaisala has released a summary of cloud-to-ground density for the continental United States covering the period 2005 – 2012. The associated Vaisala Media Backgrounders [7] identify that over this 8 year period most lightning activity occurs during the months of June, July and August between the late morning and early evening hours in the mid-Atlantic, southeast and gulf coast states. In Oklahoma and Kansas the highest incidence is July and August and they typically form in the western Plains in the afternoon and peak in the eastern Plains at night.

Methods to mitigate the threat of lightning to industrial operations is given in the 4 part series of IEC 62305 [8][9][10][11]. However, in some cases involving structures or operations associated with flammable vapors located in areas with significant lightning ground flash density, it may not be possible to reduce the risk to a tolerable level using standard lightning protection techniques alone. There is currently no formal method by which lightning warning procedures can be used in combination with lightning protection methods to reduce the threat from lightning to a tolerable level. The International Electrotechnical Commission (IEC) Technical Committee on Lightning Protection (TC 81) is currently considering the incorporation of Thunderstorm Warning Systems (also known as Lightning Warning Systems in some countries such as the United States) into lightning risk assessments by considering how the implementation of such systems can help reduce applicable risk components [12]. The use of Thunderstorm Warning Systems (TWS) can reduce risk components by a factor related to the probability with which a TWS detects a lightning-related event in the target area through the incorporation of:

- measures intended to reduce the presence of persons in the structure at the time of a lightning event,
- measures intended to terminate activities that could result in loss of life or economic losses prior to a lightning event, and
- measures intended to disconnect lines entering in the structure or zone of interest to reduce the probability that lightning –generated threats will be conducted into the zone.

IEC TC 81 also has a Work Program underway to develop an IEC standard on Thunderstorm Warning Systems (TWS). The purpose of this standard is to provide information on the characteristics of these systems and standardize the evaluation of the usefulness of real time lightning data in the mitigation of lightning risks [13]. The standard, IEC 62793, will provide the criteria for parameters of a TWS that can be utilized in the reduction of lightning risk components. Rousseau [14] identifies critical TWS parameters that must be qualified in order to ensure the effect of the incorporation of the selected hardware can be quantified when reducing the selected risk parameters. These parameters are the average warning time, false alarm rate and failure to alarm rate. Both the failure to alarm and warning time are directly related to the quality of the assessment and must be considered in the implementation of lightning warning in a facility's operations. The false alarm rate is not related directly to safety or losses but can affect the cost effectiveness of such a solution as it can result in unnecessarily down time.

Finally, the incorporation of lightning warning in a facility's Hazardous Weather Plan as a method to mitigate risk must take into consideration maintenance and periodic calibration of the equipment. The environment associated with chemical and petroleum facilities and its effect on the equipment used are considerations that must be addressed in the selection of equipment used at the site. Some operations could generate space charge that could mask the electric field signature. These factors must be considered when siting sensor locations.

5. Application Example

To illustrate how the use of lightning warning systems can assist in risk mitigation in chemical and petroleum applications we will use a refinery example. Figure 1 forwards a flow diagram of a typical oil refinery. In this example, the refinery is located adjacent to an oil production plant which includes port access for tankers providing crude oil feedstock. There is also a tank farm at the refinery for storage of the incoming crude oil and bulk liquid products. The lightning ground flash density is 5 flashes/km²/year; a value in the range of what would be expected around Galveston, Texas. Hydrogen is generated on-site, is used as a part of the process and stored locally.

There are a number of structures in the complex that were evaluated for protection in accordance with an assessment of their risk or as dictated by national or local ordinances. For this example we will assume there is no lightning location network available that covers the refinery. It has been determined that a lightning warning system should be incorporated to supplement the lightning protection systems already installed. The objective of the lightning warning system is to address the risk of damage to the surrounding area and the safety of the refinery workers that may be exposed to an incident such as a fire ball or associated pressure wave triggered by a lightning event. The specific threat addressed in this example is the offloading of a tanker or barge as there is no simple method to provide protection against a direct or nearby flash for such an operation, but a brief mention of operations involving the use and storage of hydrogen is

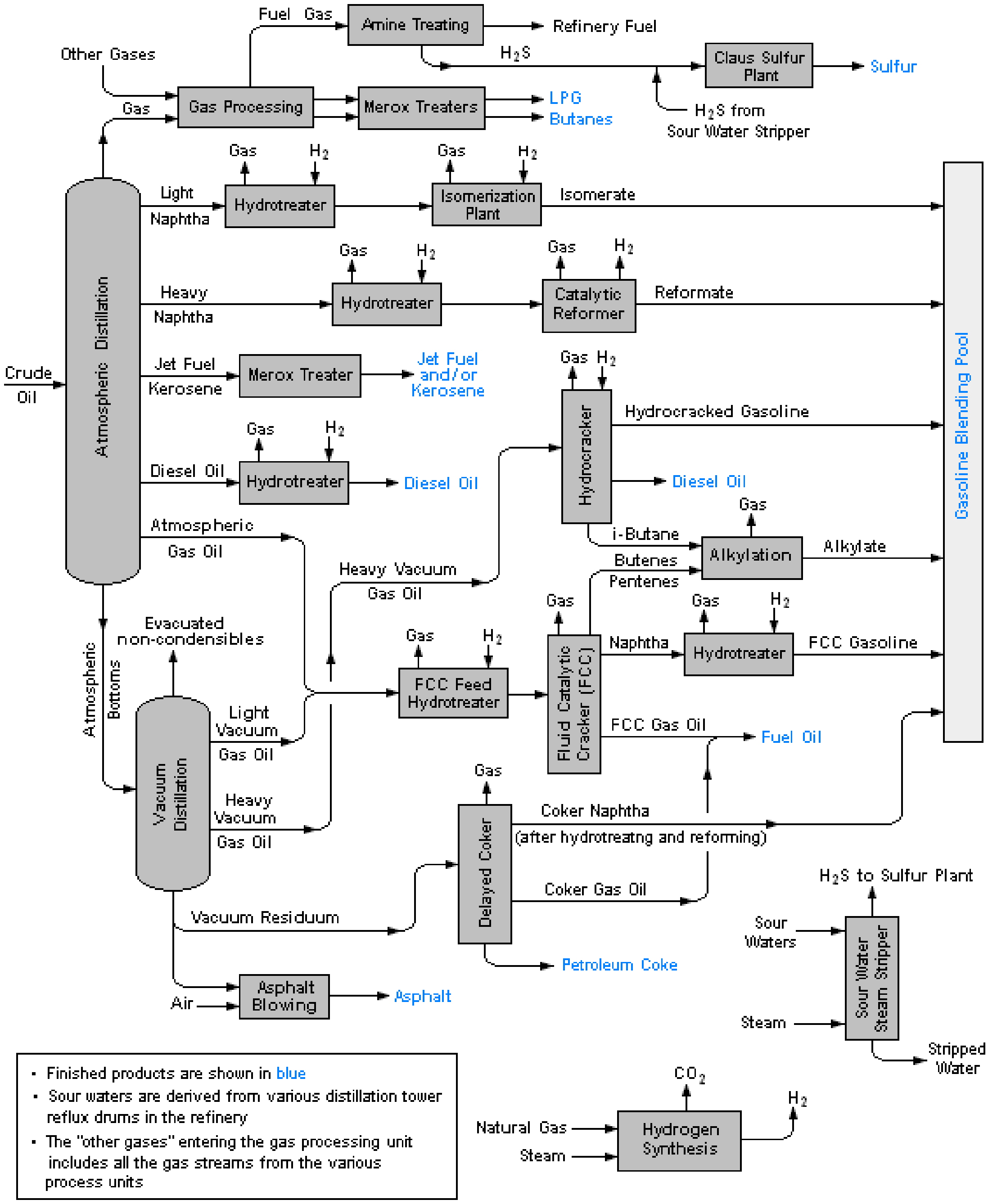

Figure 2 - Schematic flow diagram of a typical oil refinery (from Wikipedia)

provided to illustrate how the TWS can be used to address multiple applications. An electric field measurement device not based on a rotating plate design (TWS) was selected for the application because of concerns of storms that may develop in the vicinity of the refinery and the probability of masking of the electric field gradient from charged fog or salt spray associated with the sea side location.

The Standard Operating Procedure (SOP) associated with offloading operations has been modified to incorporate the TWS in the decision to proceed with the operation, as well as termination of operations and evacuation of personnel as applicable. The computer processing the output from the sensor is located in the Operations Building where it will be manned during the procedure but the output of the system is also provided to the local area network where it is available to other users as necessary. A software-based TWS will typically allow remote access to the system and some allow an option to change warning criteria at remote sites. However, there should be an established protocol for the revision of alarm levels to ensure all that have access are clear as to the meaning of each of the alarms. Many such systems will allow the input of multiple sensors that may be strategically located around the refinery. By reviewing the output of multiple sensors, the user has information that can be used to estimate the direction of any lightning detected and confirm the reliability of information associated with increasing field gradients associated with storms building in the vicinity of the plant. Confirmation from multiple local sensors local to the refinery can help in reducing false alarms and failure to alarm rates.

In this example, the SOP is established using 3 alarm levels. The normal level is signified by a green light. As the criteria is reached for a low risk, the alarm status changes to yellow. In this example, offloading of tankers or barges shall not begin when in a low risk (yellow) status but other operations may continue. The alarm status changes to orange when criteria for moderate risk are reached. At moderate risk levels the offloading procedure or other sensitive procedures that cannot be terminated immediately shall begin their termination procedures, maintenance operations shall cease and workers shall be removed from dangerous areas. As criteria are reached for high risk, the alarm status changes to red and all personnel are removed from locations where the risk of safety of personnel and risk of physical damage exceed the tolerable levels.

There is a separate SOP developed for operations involving the use of hydrogen. The need for termination of operations and evacuation of personnel for these operations vary depending upon the configuration of the material. For this example, configurations considered are the storage of the hydrogen, its use contained within processing procedures, and those operations where the presence of the hydrogen creates an environment susceptible to ignition by a spark. The SOP utilizes the output of the TWS to identify actions to be taken for each configuration relative to the alarm status provided through the site's local area network.

SOPs should also address the criteria for determination of the time it is safe to restart activities. This criteria is dependent on specific sensitivities of the local operations but should be based on the amplitude of the local electric field gradient as well as changes in the gradient associated with lightning activity. Finally, the SOP must address a preventative maintenance program for the TWS to ensure it is always available when needed. This is especially important for devices that have rotating parts. Periodic calibration should also be addressed as applicable.

6. Conclusion

Advance warning of a lightning threat can be a valuable tool available to reduce the risk of lightning-related incidents to a tolerable level, especially in those cases where the installation of a lightning protection system is not practical or a lightning protection system alone is not sufficient to reach a tolerable level of risk. It is not sufficient only to be warned of an impending lightning threat but clear and precise actions to be taken should be identified and incorporated into Hazardous Weather Bills and/or Standard Operating Procedures for those operations identified to be susceptible to lightning-generated threats.

There is a variety of lightning warning technology and hardware available today. The selection of a lightning warning system for an operation or site, such as the refinery example given herein, is a function of the warning required by the specific operation(s) as well as the environment in which it will be installed and maintenance or operational issues associated with the use of the systems. In much of the world today there are large networks, such as the NLDN covering the continental United States, that may be privately operated or state owned which cover entire countries and even cross borders in some locations. These networks can provide a mapping of actual ground strike locations within reasonable accuracy in near real time for the required area of interest. While these systems can provide specific locations of lightning activity, they are not able to identify the probability of location of the next ground strike or the probability of occurrence of the first strike in a thundercloud building overhead. Electric field measurement devices such as field mills must be utilized to obtain information on building storms.

International standards are currently under development to address performance criteria of Thunderstorm Warning Systems (TWS) and their use in reducing the risk due to lightning. Parameters of most interest to those considering the implementation of a TWS for reduction of lightning-related risks are average warning time, failure to alarm rates, and false alarm rates. Systems are available today that can be a valuable asset for use in a lightning protection plan for critical facilities and those facilities where lightning-related risks are high.

7. References

[1] Guthrie, Mitchell, "Lightning Warning Systems for Explosives Operations/Facilities," presented at 20th DoD Explosives Safety Seminar, Norfolk, VA, NTIS ADP000462 August 1982

[2] González D., Noack F., "Perforation of metal sheets due to lightning arcs," *Proceedings of 29th International Conference on Lightning Protection*, Uppsala, Sweden, 2008

[3] Kern, Alexander, "Simulation and measurement of melting effects on metal sheets caused by direct lightning strikes," *Proceedings of International Aerospace and Ground Conference on Lightning and Static Electricity*, Cocoa Beach, FL, 16-19 April 1991

[4] Necci, Amos, Giacomo Antonioni, Elisabetta Rennia, Valerio Cozzani, Alberto Borghettib, Carlo Alberto Nuccib, Elisabeth Krausmannc, "Equipment Failure Probability due to the Impact of Lightning," *Chemical Engineering Transactions*, AIDIC, Vol. 26, 2012

[5] National Weather Service Lightning Safety, www.lightningsafety.noaa.org.

[6] Santis, Lon D., "Lightning Warning for Blasting Operations," *The Journal of Explosives Engineering*, Volume 6, No 1, International Society of Explosives Engineers, 2001

[7] Media Backgrounder – Vaisala, June 2013, www.vaisala.com/en/services/dataservicesandsolutions/lightningdata/Pages/NLDN.aspx (accessed 3 January 2014)

[8] *IEC 62305-1: Protection against lightning – Part 1: General principles*, Edition 2, International Electrotechnical Commission, Geneva, December 2010

[9] *IEC 62305-2: Protection against lightning: Part 2: Risk Management*, Edition 2, International Electrotechnical Commission, Geneva, December 2010

[10] *IEC 62305-3: Protection against lightning: Part 3: Physical damage to structures and life hazard*, Edition 2, International Electrotechnical Commission, Geneva, December 2010

[11] *IEC 62305-4: Protection against lightning: Part 4: Electrical and electronic systems within structures*, Edition 2, International Electrotechnical Commission, Geneva, December 2010

[12] IEC 81/454/DC, *IEC 62305-2 (Ed.3) Protection against lightning - Part 2: Risk Management*, Document for Comments, International Electrotechnical Commission, Geneva, November 2013

[13] IEC 81/425/CD, *IEC 62793 (Ed.1) Protection against lightning – Thunderstorm Warning Systems*, Committee Draft, International Electrotechnical Commission, Geneva, March 2012

[14] Rousseau, Alain, "Use of storm detector in risk analysis according to IEC 62305-2," 7th Asia-Pacific International Conference on Lightning, Chengdu, CN, November 2011

Additional references not cited:

[15] Murphy, Martin J., Ron L. Holle, and Nicholas W.S. Demetriades, "Cloud-to-Ground Lightning Warnings Using Electric Field Mill and Lightning Observations," 20th International Lightning Detection Conference, Tucson, AZ, April 2008

[16] Murphy, Martin J., and Ron L. Holle, "Warnings of Cloud-to-Ground Lightning Hazard Based on Combinations of Lightning Detection and Radar Information," 20th International Lightning Detection Conference, Tucson, AZ, April 2006

[17] Britton, Laurence G. and Jack A. Smith, "Static Hazards of the VAST," Journal of Loss Prevention in the Process Industries, Volume 25, pp. 309-328, 2012

[18] HU Hai-yan and LIU Quan-zhen, "Research on Lightning Sparks Discharge and Protection Measures of Large Floating Roof Tank", *International Conference on Lightning Protection*, Paper No. 61, Vienna, Austria, 2012.

[19] Buccella, C and A. Orlandi, “An Efficient Technique for the Evaluation of Lightning-Induced Voltage in a Cylindrical Vessel Containing Charged Oil,” *IEEE Transactions on Industry Applications*, Volume 39, No. 2, pp.368 –373, Mar/Apr 2003.

[20] Buccella, Concettina, “An Accurate Numerical Method to Compute the Effects of the Protections Against Direct Lightning on Charged Liquid Tanks,” IEEE Industry Applications Conference 2002, *Conference Record of the 37th IAS Annual Meeting*, Volume 2, pp. 1006 – 1011, 13 – 18 October 2002

[21] *EN 50536: Protection against lightning Thunderstorm detection devices*, CENELEC, 2011