

# Protection of Floating Roof Petroleum Storage Tanks against Lightning Strokes

F. M. Mohamed, A. Y. Abdelaziz

**Abstract**—The subject of petroleum storage tank fires has gained a great deal of attention due to the high cost of petroleum, and the consequent disruption of petroleum production; therefore, much of the current research has focused on petroleum storage tank fires. Also, the number of petroleum tank fires is oscillating between 15 and 20 fires per year. About 33% of all tank fires are attributed to lightning. Floating roof tanks (FRT's) are especially vulnerable to lightning. To minimize the likelihood of a fire, the API RP 545 recommends three major modifications to floating roof tanks. This paper was inspired by a stroke of lightning that ignited a fire in a crude oil storage tank belonging to an Egyptian oil company, and is aimed at providing an efficient lightning protection system to the tank under study, in order to avoid the occurrence of such phenomena in the future and also, to give valuable recommendations to be applied to floating roof tank projects.

**Keywords**—Crude oil, fire, floating roof tank, lightning protection system.

## I. INTRODUCTION

PETROLEUM products such as crude oil, gasoline, diesel fuel, etc., are commonly stored in Floating Roof Tanks to allow any trapped gas within the crude oil to escape, as this stabilizes the crude oil. Floating roof tank is a type of tank used for the storage of large amounts of petroleum products such as crude oil. FRT has an open top which is equipped with a steel roof which moves up and down according to the level of the stored petroleum product in the tank. The floating roof edge is rounded with a rim seal that has a function of preventing the flammable vapor of stored product from escaping outside the tank and mixing with air, which helps to prevent fires from occurring. The tank seal is made of flexible insulating material of different designs. The construction details of the interface space between the shell and the roof of the floating roof tank is shown in Fig. 1, the primary and secondary seals are customized around the roof-shell interface to fit the tank and prevent air gap occurrence. Also, the double seal material provides safe operation and long life time for the tank.

During the repeated process of filling and drainage the tank with the petroleum products the seal material can become damaged, and then the tank inner shell may be subjected to corrosion and accumulation of petroleum residue which electrically isolates the roof shunts from the tank shell and from any connection to earth [1].

Fathy M. Mohamed is now with Enppi Company, Cairo, Egypt (phone: +20 1001017735, e-mail: fmogahed@enppi.com).

Almoataz. Y. Abdelaziz is now with Electrical Power & Machines Department, Faculty of Engineering, Ain-Shams University, Cairo, Egypt (phone: +20 1001372930, e-mail: almoatazabdelaziz@hotmail.com).

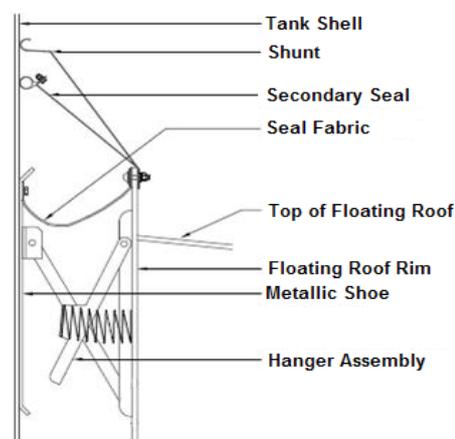


Fig. 1 Cutaway of FRT Shell-Roof Seal Interface space [1]

Petroleum storage tank fires constitutes a big problem to petroleum companies that is why world media gives this subject a great attention also, the consequent disruption that may occur in petroleum production process if this fires extended. The number of petroleum storage tank fires is increasing year after year and is estimated to reach 20 fires per year; a tank fire may extend from the rim seal and end in a full tank fire. According to study performed on 480 tank fire incidents, about 33% of all tank fires were caused by lightning strikes [2]. Sixteen oil companies sponsored a study to discover the cause of tank fires; the study concluded that lightning is the most common cause of about 95% of rim seal fires [3]. American Petroleum Institute Code API RP 545 recommends important procedures to reduce the probability of floating roof tanks fires that may be caused by lightning strikes [4].

During the summer of 2015, an oil storage tank at the Boliver Peninsula, Texas, USA was ignited. Also, crude oil storage tank related to one of the oil Company in Egypt was ignited. In both cases, lightning was the cause of ignition. As a result this fire in Egypt, the company immediately created a technical committee to evaluate this situation and to recommend solutions [5].

## II. HOW LIGHTNING CAUSES TANK FIRES

Suppose that a floating roof tank is not equipped with shunts subjected to lightning strokes and the lightning strikes the roof of the tank. As we know in this case, there is a discontinuity between the tank shell and the roof. The lightning shall induce an electrostatic field in the order of 5KV/mm between the roof and the shell [6].

If there are any flammable vapors resulting from the stored

petroleum product emerging from the air gap between the tank shell and roof edge, these vapors can be broken down at a certain potential difference less than 5KV/mm in the presence of oxygen resulting in tank fire [6].

### III. PROBLEM DESCRIPTION

Due to changes in environmental conditions, a lightning strike terminated at the rim seal of one of the existing crude oil tanks owned by one of the oil companies in Egypt. Immediately, the company activated the emergency plan by stopping all the work in the tank area, and dealt with the fire until it is extinguished, and finally, the site continued to monitor the situation until the cooling process for the tank was finished.

The following points are registered after the incident occurred:

- 1) Dissipation array system (DAS) located above the telecom tower.
- 2) Spline pole system (SPS) located above lighting tower.
- 3) The shell is bonded to the tank through (shunt straps), and there was damage in some of these shunt straps; consequently, it is not connected to the tank shell as per Fig. 2.
- 4) The existing shunts are not electrically connected to the tank shell because of the heavy crude oil components, such as wax, tar, and paraffin, etc., that cover the inner wall of the tank, and thus breaking the electrical connection between the tank shell and shunts.



Fig. 2 Shunt not making contact with Out-of-Round Tank Shell [1]

### IV. PROBLEM ANALYSIS

API RP 545 recommended the following procedures in order to provide protection for the floating roof tanks in the case of lightning occurrence [4]:

- 1) API RP 545 recommended replacing the above seal shunts between the roof and the tank shell, with submerged shunts every 3 m around the roof circumference at a level of at least 0.3 m below the surface of the liquid product.
- 2) API RP 545 recommended insulating all seal components and instrument devices on the tank roof from the electrical connection with the tank roof. Also, API RP 545 recommended the insulation level for the seal components and instrument devices to be minimum one kilovolt.
- 3) API RP 545 recommended installing bypass conductors between the roof and the tank spaced at intervals no more than 30 m around the circumference of the floating roof.

The length of the bypass conductor shall be of the minimum to permit full movement of the floating roof.

### V. DISCUSSION OF API RECOMMENDATIONS

- 1) For the case of submerged shunts, it is difficult for the tank to be ignited since the arc will occur in the absence of air, and the cost of the submerged shunt shall be very costly compared to the above seal shunt. The operation/maintenance team shall face difficulty in inspection of these types of shunts. So, this solution is applicable only for new tanks.
- 2) For the case of insulating the seal components and instrument devices from the tank roof, this shall introduce a barrier for the lightning current and push the lightning current to pass through the shunts and bypass conductors that offer a path with smaller impedance. However, this approach is difficult and very expensive to be executed for existing floating roof storage tanks. So, this solution is recommended to be applied for new tanks under design and construction.
- 3) It is also common practice to install bypass conductors between the roof and the tank spaced at intervals no more than 30 m around the circumference of the floating roof. For the new floating roof tank that shall be under our case study, it has a length of at least 49 m because the dimension of the tank (90 m diameter and 18 m in height). The installation of the bypass conductors is easy, inexpensive, and can be installed on both new and existing tanks. The bypass conductors shall have an impedance that is less than that of presented by shunts, so it shall attract the intermediate and long-duration component of the lightning-stroke current to pass through it rather than the shunts. However, the bypass conductor end-to-end voltage may be so high as to cause a dielectric breakdown of the insulating surrounding air. This lead the tank owners to use a retractable conductor wound on a spring-tensioned reel (RGA), instead of the standard conductor. Lightning Eliminators & Consultants (LEC) [1], has developed a roof-shell bonding mechanism (RGA) which is better than the conventional type of bypass conductor. RGA is complete with a spring to retract the conductors on the wheel. The length of the bypass conductor is always keeping the minimum length regarding the location of the floating roof at the top or the bottom of the tank. Also, a typical retractable grounding assembly (RGA) of floating roof tank is shown in Fig. 3. Due to the large diameter of the floating roof tanks (FRT's), and order to increase the electrical connection between the roof and the shell of the FRT, it is recommended to install multiple RGA's on the floating roof tank. The RGA should be installed at intervals no more than 30 m around the circumference of the floating roof [1]: so, in our case, the recommended number of RGA's shall be not less than 10 m, as the tank diameter is 90 m, and the circumference is about 285 m. Although RGA is better than conventional cables, it provides optimal solution for the tank protection against lightning

strokes.

- 4) Replacement of the existing Spline Pole System (SPS) located above lighting Tower with Spline Ball Ionizer (SBI), which is better than (SPS) [7].



Fig. 3 LEC Retractable Grounding Assembly (RGA) on Floating Roof Tank [1]

#### VI. CONCLUSIONS AND RECOMMENDATIONS

- 1) The existing lightning protection system around the tank failed to absorb the lightning strokes and failed to provide a protection of the tanks against lightning strokes.
- 2) There is damage in the existing shunt strap system, and also, the tank inside wall is coated with heavy crude oil which leads to the discontinuity between the tank shell and the shunts which lead to the firing of the tank rim seal.
- 3) The company should review all the existing shunt straps, and replace the damaged shunt straps with new ones, change the tank rim seal, make necessary maintenance

and check that the tank is still complying with API STD 653 [8].

- 4) Installation of the retractable bypass conductor (RGA's), in addition to the existing shunt straps system, can be installed to existing and new tanks in the future.
- 5) Checking that all the tanks in the zone of the tank fire are connected to the earthing network, as per the applicable code.
- 6) Installation of an Early Streamer Emission (ESE) air terminal system on the tank shell according to the tank diameter.
- 7) Performing lightning risk assessment analysis for the new floating roof tanks that shall be installed in areas subjected to frequent lightning activity.

#### A. Case Study (New Project in the Design Phase)

The case study will examine the application of the above recommendations for the El Hamra Terminal New Storage Tank Project (El Hamra Port Terminal, North Coast, WEPCO Company, Egypt).

The new floating roof tank (90 m diameter and 18 m height) is a part of the new storage tank project owned by WEPCO Company, Egypt. The new tank shall be located in an area subjected to frequent lightning activity, as shown in Fig. 4 [9].

A Lightning Risk Assessment study was performed to the tank yield in the installation of the lightning protection system, which is mandatory. For more details about the performed lightning risk assessment analysis refer to Appendix.

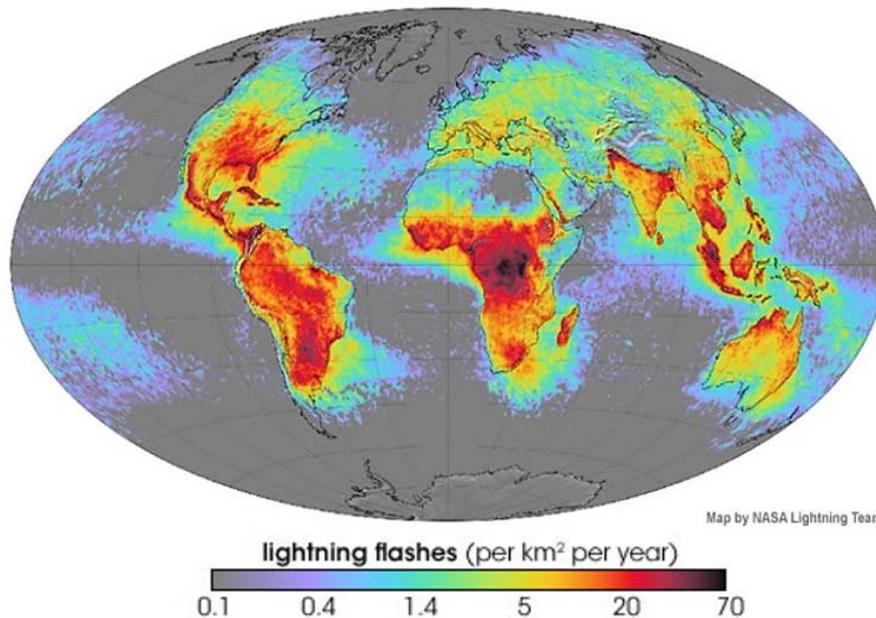


Fig. 4 World lightning map [9]

- 1) Installation of two diagonally opposite Early Streamer Emission (ESE) air terminal systems on the tank shell, as shown in Fig. 5.
- 2) The required level of protection is level 1 and the radius of protection of each (ESE) shall be not less than 79 m, because the tank diameter is 90 m.

- 3) Install two 5 m high hot dip galvanized steel poles to carry out each (ESE) system
- 4) Install two down conductors made of tinned copper with a minimum size of 50 mm<sup>2</sup> to connect the ESE terminal to the earthing system.
- 5) Install two Lightning strokes counters with an Enclosure IP55 and numerical reading facility.

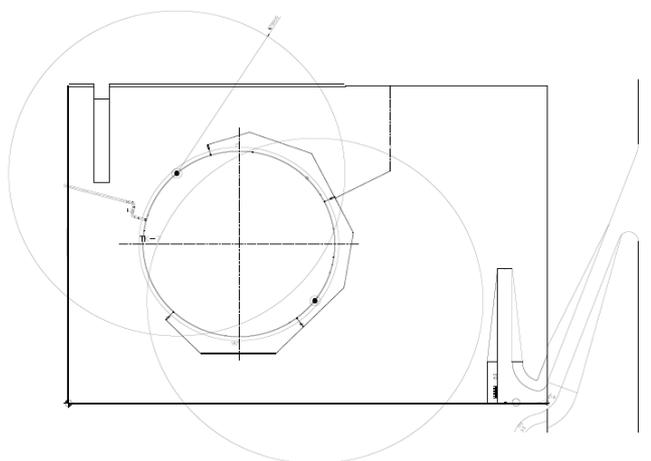


Fig. 5 Snapshot from EL Hamra Terminal New Storage Tank (7) Lightning Layout

#### APPENDIX

**Lightning Risk Assessment Analysis:** This lightning risk assessment methodology is provided to assist tank owners, safety professionals, and engineers in determining the risk of damage or injury due to lightning strike. Once the level of risk has been determined, the development of appropriate lightning protection measures can begin.

##### A. Manual Calculation

The lightning risk assessment analysis has been compiled using the NFPA 780 standard [10], and fully comply with Annex L (lightning risk assessment) in [10]. The calculation criterion as per Annex L shall be as follows:

**1<sup>st</sup> Step:** Calculate Lightning Strike Frequency ( $N_d$ )

$$N_d = (N_g)(A_e)(C_1)(10^{-6}) = \text{Potential events/year} \quad (1)$$

where:  $N_d$  = yearly lightning strike frequency to the structure or object,  $N_g$  = lightning ground flash density in flashes/km<sup>2</sup>/year,  $A_e$  = the equivalent collection area of the structure (m<sup>2</sup>),  $C_1$  = environmental coefficient.

$$A_e = \pi \times 9 \times H^2 \quad (2)$$

**2<sup>nd</sup> Step:** Calculate the Tolerable Lightning Frequency ( $N_c$ )

$$N_c = \frac{1.5 \times 10^{-3}}{C} = \text{events/year} \quad (3)$$

where:

$$C = (C_2)(C_3)(C_4)(C_5) \quad (4)$$

The coefficient ( $C$ ) is the product of structural coefficients  $C_2$  through  $C_5$ . The structural coefficients are obtained from Table L.5.1.2 (a) through Table L.5.1.2 (d), listed in NFPA 780 [10].

**3<sup>rd</sup> Step:** Calculate the risk assessment

The tolerable lightning frequency ( $N_c$ ) is compared with the annual threat occurrence ( $N_d$ ). The result of this comparison is used to decide if a lightning protection system is needed.

- i. If  $N_d < N_c$ , a lightning protection system can be optional.
- ii. If  $N_d > N_c$ , a lightning protection system is mandatory

**4<sup>th</sup> Step:** Apply the steps from 1 to 3

$$N_d = 2260 \times 10^{-6} \text{ potential events/year}$$

$$N_c = 200 \times 10^{-6} \text{ events/year}$$

Then a lightning protection system is mandatory

#### ACKNOWLEDGMENT

Fathy M. Mohamed thanks Enppi company for Sponsoring and financial support.

#### REFERENCES

- [1] Improving Lightning Safety of Petroleum Storage Tanks, Joseph A. Lanzoni, Lightning Eliminators & Consultants, Inc. Boulder, Colorado USA, October 2009.
- [2] Henry Persson and Anders Lönnermark, Tank Fires, Review of Fire Incidents 1951–2003, Brandforsk Project 513-021.
- [3] Large Atmospheric Tank Fires (LASTFIRE), Project Analysis of Incident Frequency Survey, June 1997.
- [4] API/EI Research Report 545-A, Verification of lightning protection requirements for above ground hydrocarbon storage tanks, First Edition, October 2009.
- [5] Learned lessons results from the ignition and burning of one of the crude oil tank related to one of Egyptian oil Companies that was subjected to a strong lightning strike, EGPC fax December 2015.
- [6] Lightning Protection of Floating Roof Tanks, American Journal of Engineering Research (AJER) Volume-02, Issue-10, pp-11-21, 2013.
- [7] Integrated Lightning Solutions Worldwide, spline ball ionizer (SBI) Lightning Eliminators & Consultants, Inc. 2012, Rev. 3/12.
- [8] API Standard 653, Tank Inspection, Repair, Alteration, and Reconstruction, Fifth Edition, November 2014.
- [9] <http://geology.com/articles/lightning-map.shtml>, by NASA's Lightning Imaging Sensor on the Tropical Rainfall Measuring Mission satellite between 1995 and 2002.
- [10] NFPA-780 (2014), Standard for the Installation of Lightning Protection Systems. National Fire Protection Association.



**Fathy M. Mohamed** was born in Cairo, Egypt in 1980. He received the B.Sc. and the M.Sc. degrees in electrical engineering from Ain Shams University, Cairo, Egypt in 2002 and 2008 respectively. He was working as Teaching assistant in A in the Department of Electric Power and Machines, Ain Shams University, Cairo Egypt. His research interests include distribution automation, energy management and artificial intelligent applications in power systems. This author joined the work as an Electrical Engineer at Enppi Company, Cairo Egypt in 2007, and became a Senior Electrical Engineer at Enppi Company, Cairo, Egypt in 2012. Currently, he is working as an Electrical Engineering Specialist at Enppi Company, Cairo, Egypt. He is the author and co-author of more than five published refereed journals and conferences papers.



**Almoataz Y. Abdelaziz** received the B.Sc. and M.Sc. degrees in electrical engineering from Ain Shams University, Cairo, Egypt, in 1985 and 1990, respectively, and the Ph.D. degree in electrical engineering according to the channel system between Ain Shams University, Egypt, and Brunel University, U.K., in 1996. He is currently a Professor of electrical power engineering at Ain Shams University. He has authored or coauthored more than 280

refereed journal and conference papers in his research areas which include the applications of artificial intelligence, evolutionary and heuristic optimization techniques to power systems power system operation, planning, and control. Dr. Abdelaziz is the chairman of IEEE Education Society chapter in Egypt, a senior editor of Ain Shams Engineering Journal, editor of Electric Power Components & Systems Journal, Editorial Board member, Editor, Associate Editor, and Editorial Advisory Board member for many international journals. He is also a senior member in IEEE, a member in IET and the Egyptian Sub-Committees of IEC and CIGRE<sup>7</sup>. He has been awarded many prizes for distinct researches and for international publishing from Ain Shams University, Egypt.