Foreign Experience With Lightning In Oil & Gas Industry

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Abstract

Fires at fuel depots caused by lightning activity are not uncommon. Approximately one-third of fires are caused by lightning impact. Storage tanks with floating roofs are particularly vulnerable to both direct and secondary effects of lightning. Over the past three decades, various technologies have been applied to completely eliminate any lightning in the object, or to minimize the consequences of their direct or secondary impacts. [10]

Introduction

Fires at oil depots caused by lightning happen more often than we think [1]. According to observations from 1951 to 2003, throughout the world there are 15-20 fires per year in tanks with crude oil and petroleum products. The categories of fires vary from surface fires on individual tanks to large-scale fires, covering a few tanks of the park. One-third of the 480 fires recorded in the reports were caused by lightning [4]. Another study of 16 oil companies found that 52 out of 55 fires in the area of the seal were caused by lightning [5].

It is difficult to overestimate the consequences of fires in the tank farms. In addition to huge losses of petroleum products, fires result in property damage, death, malfunction, environmental pollution, the costs to fight the fire and subsequent restoration of the enterprise.

The mechanism of occurrence of fires due to lightning

Petroleum products such as crude oil, gasoline, diesel fuel, etc., often are stored in vertical steel tanks with floating roofs (FRT's). An FRT represents a reservoir from which the roof floats on the surface of the contained mineral oil. Accordingly, when the tank is filled or emptied, the roof moves up and down together with a level of contents.

To prevent the evaporation of petroleum, the roof has a flexible seal on the perimeter of the floating roof. The seal is made of dielectric material and electrically isolates the roof from the walls of the reservoir and, as a consequence, also of the grounding system. Due to defective seals, the contents of the tank sometime escapes, evaporates and forms a flammable gas mixture or accumulations of fuel.

A lightning stroke is accompanied by high currents flowing in a very short period of time. For example, the average lightning causes pulse currents of 30 kA for one hundred microseconds. These currents are distributed along the surface of the ground along paths with minimum impedance, while the potential difference between the storm cloud and the ground is not neutralized.

The most likely termination place of a lightning strike on a FRT is the upper edge of the reservoir or gauge pole. Nevertheless, lightning pose a threat to FRT, if the impact occurs directly on the roof, building or anything installed on the roof or enclosure (such as the gauge pole or grounded objects that are close to the FRT). If lightning strikes the shell of a tank (Figure 1), significant current will flow through the junction of the roof to the shell. If lightning hits a nearby structure (Figure 2), then less current will flow through the shell to the roof. In any case, the currents of lightning will occur partially through the junction of the roof to the shell, and if the contact resistance is large, then perhaps a spark may form on the perimeter of the roof.

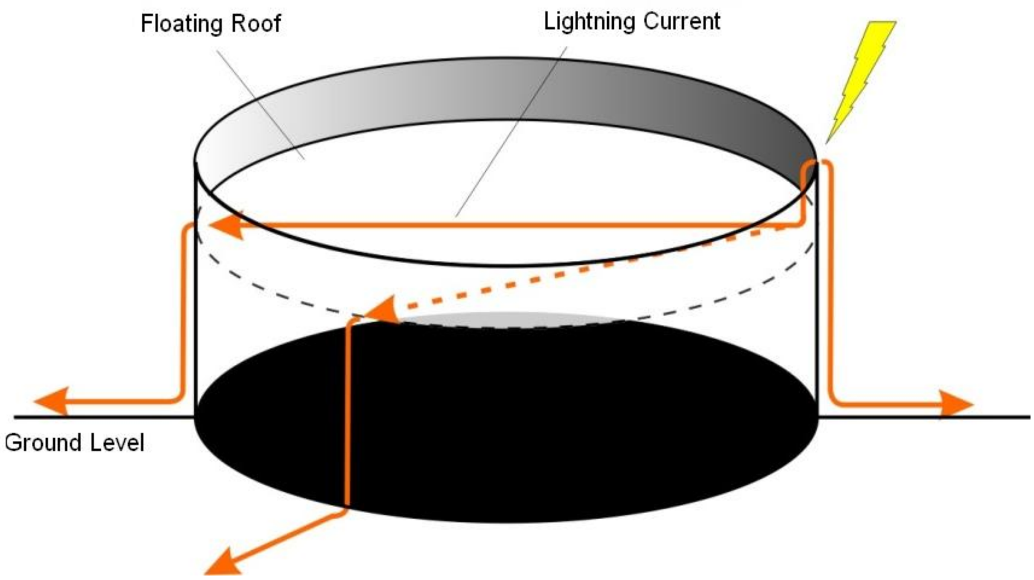

Figure 1: The occurrence of lightning current onto the roof and shell during a strike. (Only two directions of spreading lightning currents are shown; in fact, the current spreads over the entire surface of the tank roof and intersects face seals around the perimeter. [3])

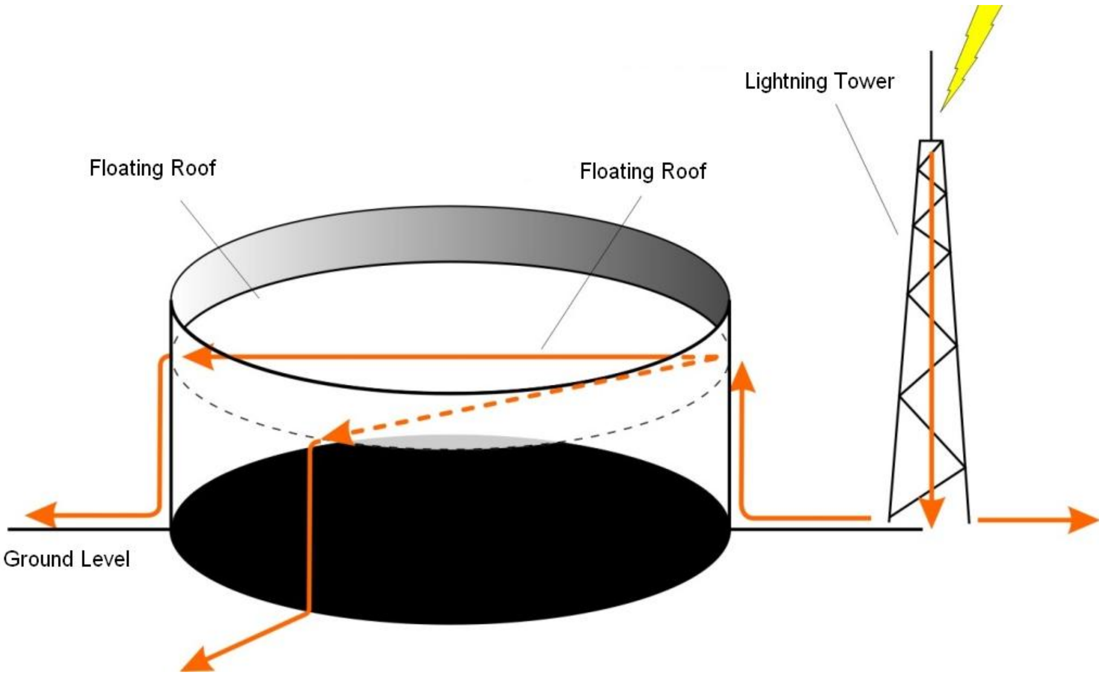

Figure 2: The occurrence of the lightning current from a nearby strike

If the roof and shell have different capacitances, a sufficiently large potential difference arises between them an electrical discharge. This is the most undesirable place for the appearance of the discharge, because here may form the inflammable gas mixture. According to a number of normative documents, the floating roof must be electrically connected to the tank shell in order for them to have the same electrical potential [6] [7] [8].

Traditional methods of equi-potential bonding of the roof and shell

1. Shunts

To connect the roof to the shell are commonly used devices called "shunts". A shunt is an electrical jumper made of spring steel which is mounted on the roof so that it is constantly in contact with the walls of the tank, regardless of the position of the roof. However, shunts do not provide permanent low-resistance connections to the tank shell, for several reasons:

1. Viscous components that make up the crude oil (wax, tar, wax, etc.) can settle on the walls of the shell, thus forming a resistive barrier between the wall and shunts.
2. Corrosion layer creates a high resistance barrier between the wall and shunts.
3. If the tank is painted inside, the coating also insulates the shell from the shunts.
4. Large tanks are generally not perfectly round in shape, which increases the gap between the tank shell and shunts.

Joint testing conducted by the American Petroleum Institute (API) and the Energy Institute in England showed that arcing occurs at the shunts’ contact with the tank shell at all times. It does not matter whether or not the shunt is clean, dirty, new or old, nor does it matter if the inner surface of the tank shell is clean, rusty, stained or soiled; arcing occurs in all cases.

When placing the shunt on the roof, the formation of an electric arc is the most dangerous, because an arc may occur near the formation of high concentrations of explosive mixtures, especially in hot dry weather.

2. Gangway

Another way to provide a connection between the roof and shell is to utilize the gangway, reaching from the upper edge of the shell to the roof. Virtually all FRT’s feature walkways or stairs, which at one end are attached to the edge of the tank while the other ends slides on rails on the roof.

However, the quality of electrical contact through the walkway is not very good, as the upper end of the catwalk has a swivel and is subject to wear, corrosion and discoloration. The electrical connection provided by the lower end of pressure from the two wheels roll along the rails. This connection is also prone to corrosion and discoloration.

3. Connection cable

The third way to provide a connection between the roof and shell is by the installation of a connecting cable or bypass conductor between the upper portion of the shell and the middle of the roof. Current Russian standards recommend installing at least two [6] or three [7] jumper cables using multi-wire cable with a cross-section of at least 16 square meters. This jumper cable should be long enough to reach the middle of the roof in its lowest position. For example, for a tank of diameter 60 meters and height of 18 meters, the length of the jumper must be at least 35 meters. Despite the fact that at 50 hertz the cable will have low resistance, at lightning frequencies its impedance will rise sharply. Therefore, when high-frequency lightning current with thousands amperes flows through the tank, the cable impedance may be too large to prevent sustained arcing at the shunt.

Approaches to genuine protection

In connection with the case of tank fires from the effects of lightning, the API (American Petroleum Institute) has created a technical committee to investigate the causes of these fires. Research was contracted to a testing company Culham Electromagnetics and Lightning Ltd., located in Oxford, UK. As a result, the commission identified the following key patterns:

1. The fast component of lightning does not cause ignition of vapors, while the long duration component of lightning does cause ignition. The fast component is too short and has very little energy, which insufficient for the occurrence of fire.
2. Bypass wires carry the long duration component of the lightning discharge. If this component were to flow through the shunt, sustained dangerous sparks could emerge from the shunt-shell interface, which could ignite the explosive mixture.

In October 2009, in accord with the results of tests conducted by Culham, API released document API RP 545, with recommendations and amendments to existing regulations in this area:

1. Shunts are recommended across the seal at a distance of 3 meters around the perimeter of the roof. It is recommended to install the shunts from the bottom of the roof, immersing them for at least 0.3 meters of petroleum. Available external shunts are recommended to be removed. However, installation of submersible shunts on the new tanks will require considerable engineering development compared with standard designs. For existing tanks, the transition from above-roof to submersible will prolong the tank overhaul, with staff working inside the tank both above and under the floating roof. In addition, submerged shunts will be practically impossible to inspect and maintain.
2. Electrically isolating all of the shoes, measuring and guide rods from the roof tanks. The breakdown voltage of insulation should be at least 1 kV. However, like Section 1, the application of the recommendations on the existing tanks will need to implement major structural changes and expensive work on the modification and maintenance.
3. Establish bypass conductors between the roof and the shell at least every 30 meters around the perimeter of the roof. These wires must be as short as possible and evenly distributed around the perimeter. Their maximum resistance shall not exceed 0.03 ohms, and the length should not exceed the required length to allow free movement of the floating roof.

Of the three recommendations listed above, installation of bypass conductors requires less effort and cost, for both existing and new tanks. Existing tanks can be supplemented with bypass agents during routine maintenance, regardless of the position of the roof. Since they are installed outside, they can be easily monitored and maintained.

Types of bypass conductors

To implement the recommendations of the API in the U.S. market, there are two different types of bypass conductors: (1) a traditional, round, flexible wire of fixed length, and (2) adjustable, which provides automatic change of its length when lifting and lowering the floating roof. The ideal connector between the floating roof and the walls of the tank should provide a low impedance over a wide frequency band. It must also be easily installed on both new and existing tanks. In addition, the ideal connector should be easy to maintain and easily replaced if necessary.

Retractable Grounding Assembly (RGA)

The RGA is produced by Lightning Eliminators & Consultants, Inc., (LEC) and is equipped with a cable wound on a spring-loaded reel that is mounted on the highest point on the wall of the tank shell (Figure 3). Wound on the RGA is a tinned, flat, braided copper cable with a cross section of 41x2.8 mm.

In the absence of the load when lifting the roof, the cable is automatically wound onto the spool. Therefore, the cable is always taut and regardless of the position of the roof and has the smallest possible length. Since the housing RGA installed in the upper part of the body, and the free end of the cable is attached to the roof, its resistance does not depend on the level of petroleum within the tank nor on the condition of the shunts. It can be run in the complete absence of shunts.

The RGA conductor provides the lowest possible impedance connection between the floating roof and the walls of the tank. It can be easily installed in both new and existing facilities.

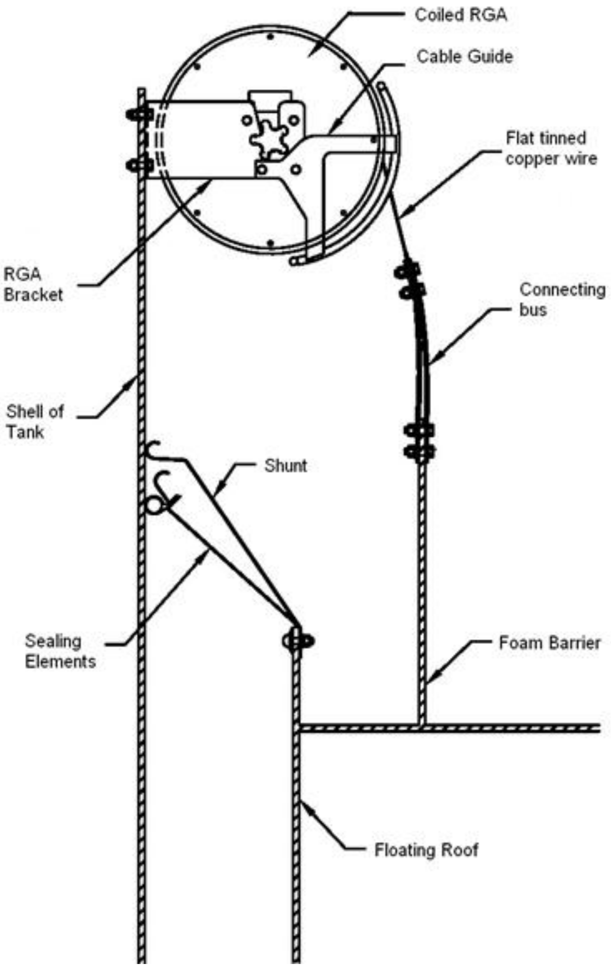

Figure 3: RGA from LEC on a tank with floating roof

For large diameter tanks, it is very important to limit the impedance between the roof and walls by installing several RGA. The recommended quantity of RGA's, from the manufacturer, is indicated in Table 1. The same table shows the number of RGA determined pursuant to the requirements of paragraph 2.7 of the RD 34.21.122-87 [9].

Tank Diameter, meters	Tank Circum-ference, meters	Number of RGA's Recommended by LEC	Number of Shunts in Accordance with RD 34.21.122-87
≤ 19	≤ 60	2	3
≤ 29	≤ 91	3	5
≤ 40	≤ 126	4	7
≤ 46	≤ 144	5	8
≤ 61	≤ 192	6	9
≤ 85	≤ 267	9	13
≤ 92,3	≤ 290	10	15

Table 1: Recommended quantity of RGA's

Comparison of traditional and bypass wires variable length

Tanks with floating roofs are most at risk and damage from lightning is increased when the roof is close to the top. Under these conditions, the lightning currents will be concentrated on shunts directly under the place of a lightning strike (Figure 4). This also increases the probability of a lightning strike directly to the roof. If, as shown in Figure 5, lightning struck the tank when the roof is in the down position, then the lightning current will dissipate and will likely be distributed among the available connections between the roof and the body.

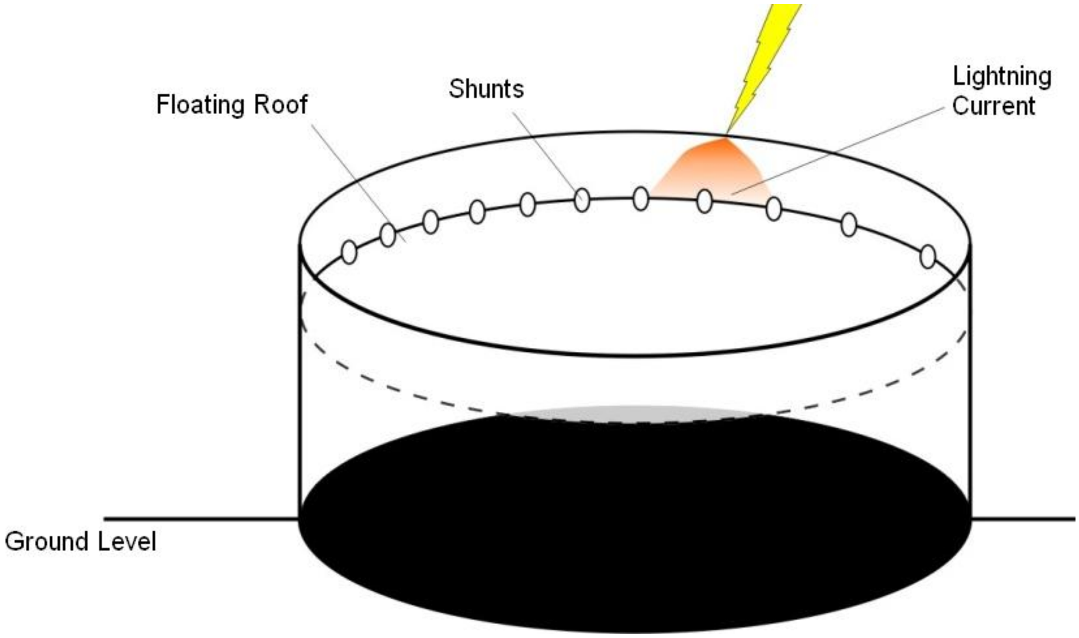

Figure 4: The concentration of the lightning current at the top position roof

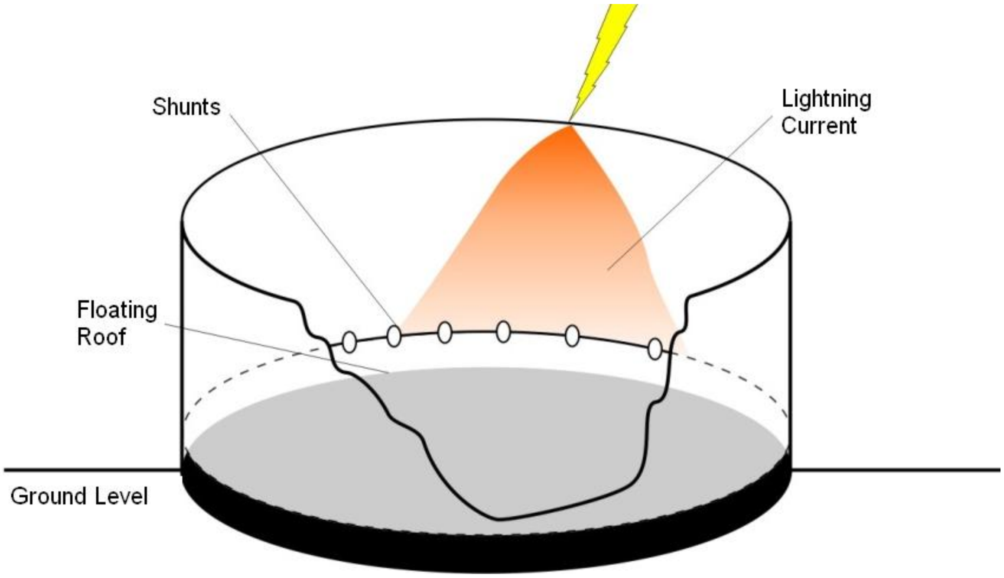

Figure 5: Dissipation of the lightning current with the roof down

We can compare the impedance of the two types of conductors: (1) the traditional fixed length conductor and (2) the flat conductor reeled onto the spool. When the roof is in the top position and the tank is in the state most at risk, the fixed length conductor will be randomly distributed, and collapsed on the roof of the tank (as shown in Figure 6). In addition, if the conductor is not insulated, then the contact points between the conductor loops, or contact with the roof, may be locations of accidental arcing. In addition, when lifting the roof in the up position, the RGA cable will be as short as possible, as shown in Figure 7, and its impedance will be one-sixth of the impedance of the traditional cable (see Appendix A). Therefore, when the tank is in the highest degree of risk, and the owner, in case of lightning, at danger of losing the maximum amount of product, RGA has the smallest possible impedance.

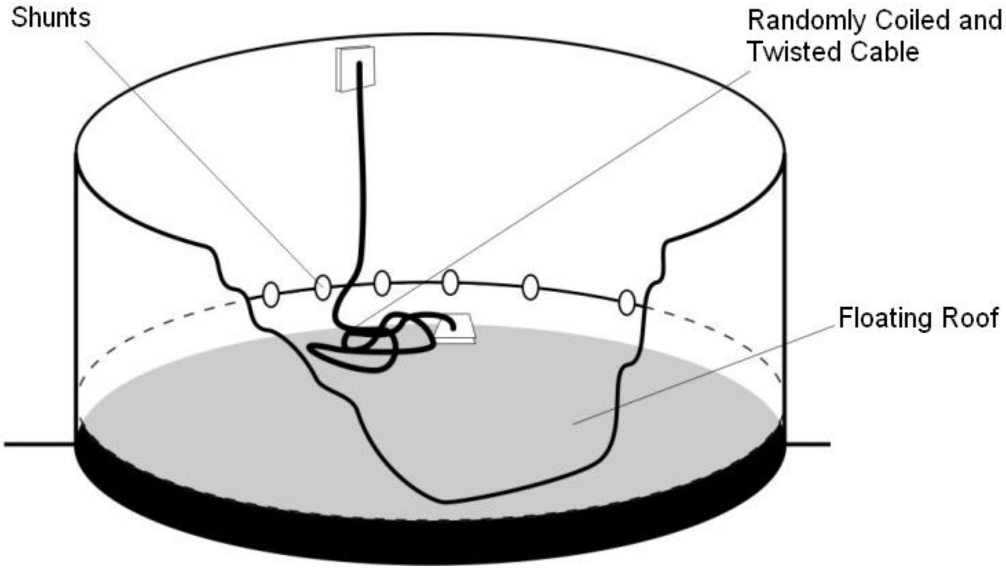

Figure 6: The traditional fixed length cable as the bypass conductor

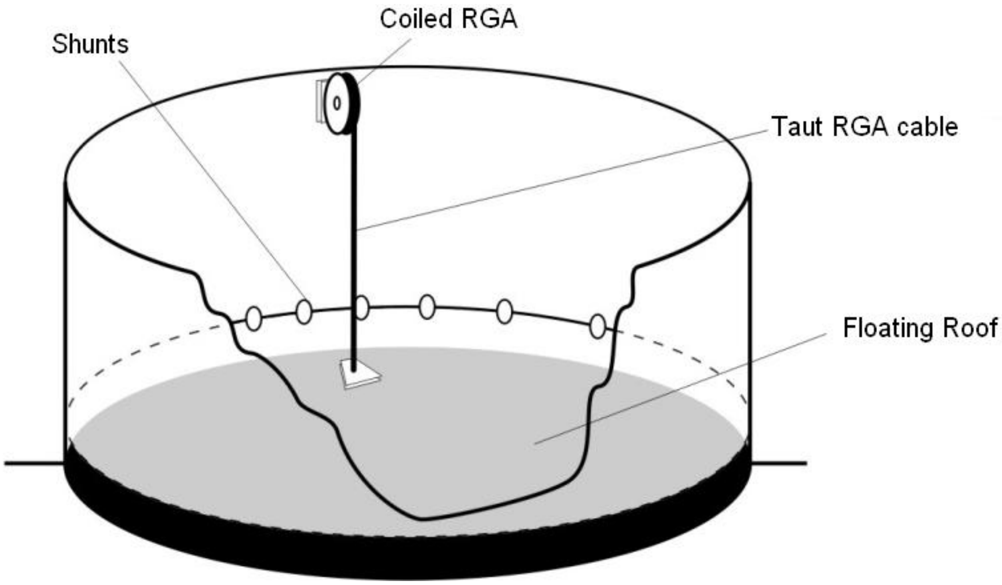

Figure 7: RGA as a bypass conductor

Conclusion

Despite the fact that the installation of bypass conductors for FRT’s is recommended by both foreign and Russian standards for lightning protection, installation of such devices on tanks with fixed and floating roofs is not required. Nevertheless, a number of sites are affected by fires caused by lightning. Several factors may contribute to FRT fires caused by lightning. Because of the design features of each tank, when lightning terminates directly on the tank, the current spreads through the walls and roof of the tank. This causes unpredictable potential differences between different parts of the tank and leads to the appearance of the induced currents. When unfavorable circumstances occur, currents can flow for long enough and have enough energy to cause ignition of vapors of petroleum product. For maximum safety both shunts and bypass conductors must be installed on floating roof tanks.

Appendix A - Comparison of the impedance of the traditional cable and conductor with variable length

$$Z = \sqrt{R^2 + X_L^2 + X_C^2}$$
$$X_L = 2\pi f L_1$$

where Z = impedance in ohms
R = resistance in ohms
X_L =inductive reactance in ohms
X_C = capacitive reactance in ohms
f = frequency in hertz
L_1 = inductance in henries

Applying the above formula to lightning currents, we assume that the capacitive reactance is zero and the resistance of the relatively short conductor of large diameter small compared to the inductive reactance. Therefore, the resistance of the conductor from lightning almost equal to its inductive component X_L. The ratio of the impedance of the traditional conductor to the impedance of the conductor variable length will be equivalent to the ratio of their inductances or:

$$\frac{Z_{conventional}}{Z_{retractable}} \cong \frac{X_{Lconventional}}{X_{Lretractable}} = \frac{2\pi f L_{conventional}}{2\pi f L_{retractable}} = \frac{L_{conventional}}{L_{retractable}}$$

The inductance of a conventional conductor with a length of 15 meters is 1.68 µH / m x 15m = 25.20 µH for a straight wire. With the roof of an FRT up and tangled wires inductive resistance is much higher. For a retractable conductor on an FRT with a raised roof, the length may be only 3 meters, and its inductance will be only 1.3 µH / m x 3m = 3.90 µH. Thus, the impedance of conventional conductors of more than 6 times higher than the impedance of a conductor variable length. In fact, the higher the reservoir, the more different impedance conventional and retracts the conductors.

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10. This article has been translated from the Russian original into English using Google Translate.