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Lightning Protection of Floating Roof Tanks

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***Abstract:* -** Prior to export, processed crude oil is stored in Floating Roof Tanks (FRT) to further allow any trapped gas within the crude oil to escape, as this stabilises the crude oil. In the oil and gas industry, FRT's are vital in the processing of crude oil to the acceptable export specification.

In the tropics and other lightning prone regions, lightning induced floating roof tank fire constitutes a major threat to crude oil production. Among others, a single lightning incident could result in the loss of life, product and production time, avoidable incident review time, damaged equipment, wasted repair cost, bad publicity and loss of income.

This paper therefore, is aimed at providing an effective solution to the menace of lightning induced tank fire by focussing on the starting process of the lightning induced fire and proposing alternative concepts for breaking the fire triangle before fire ensues.

Keywords: *- crude oil, fire, floating roof tank, lightning protection, sparks*

I. INTRODUCTION

Lightning is more prevalent in the tropics than elsewhere in the world [10] and it is a natural phenomenon with an associated potential hazard. Lightning is a scientific phenomenon and contrary to common opinion lightning can be studied scientifically and using its empirical properties its occurrence can be predicted, detected and its impact mitigated.

Preventing static electricity and lightning related hazards such as step / touch voltage, lightning fire, equipment damage etc. is achieved by installing an effective Lightning Protection System (LPS) on the structure of concern. The effectiveness of such a Lightning Protection System is dependent on the nature and the thoroughness of the design of the grounding and bonding system implemented on and around the structure and how well it is maintained after installation.

In providing an effective solution to lightning issues several studies have been carried out and different approaches adopted overtime. Some of these approaches have been criticized and said to be based on junk science [4, 6, 7, 9]. There is therefore a need for a detailed analysis and definition of what qualifies as an effective lightning protection system especially as regards oil and gas facilities, which are particularly prone to lightning induced fire incidents because of the flammable nature of oil and gas products.

Unavoidably, analysis here focuses on accepted principles and guidelines as proposed by competent authorities on lightning protection.

II. INTERACTION OF LIGHTNING WITH A FLOATING ROOF TANK

"Tank fire statistics shows that 35% of all floating roof tank fires are caused by lightning related issues. It is presently estimated that 95% of rim seal fires are as a result of lightning strikes and 0.16% of all tanks with rim seals will experience a ream seal fire in any year [3]"

If 95% of all rim seal fires are as a result of lightning, then this raises the question "what is peculiar about the rim-seal region of a FRT that makes it susceptible to lightning?" By design to ensure ease of movement of the floating roof within the tank shell, there exist a gap between the tank shell and the edge of the floating roof. This eliminates friction, guarantees ease of movement but creates issues in the following areas when lightning strikes.

Sparking

When lightning strikes the floating roof the lightning current will flow over the roof towards the edge of the roof, and at the edge there exist a discontinuity because of the tank shell-roof gap this prevents the current from flowing through the tank shell to the ground. Lightning induced electrostatic field at ground level is in the order of 5KV/m and because of this high electric field a potential difference will exist between the roof and the tank shell.

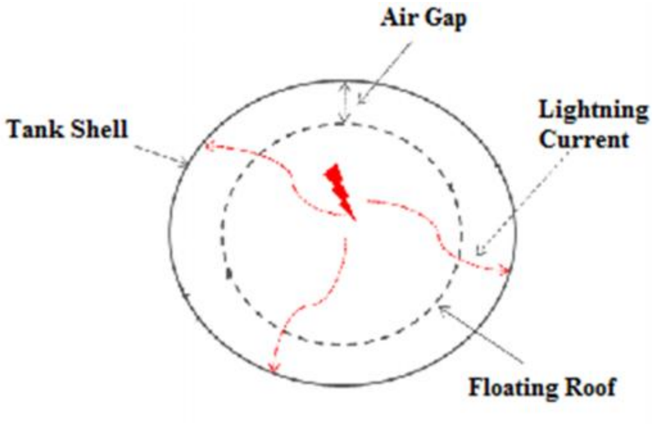

Figure 1: Tank shell-roof air gap

Because of the content of a floating roof tank which is crude oil, the tank contains flammable vapour, also oxygen is readily available in the environment and at a potential of about 3KV/mm the flammable air vapour (acting as a di-electric) within the gap will break down and conduct electricity in the form of a spark (arc). This completes the fire triangle resulting in a lightning induced floating roof tank fire.
According to API [1] there are two types of spark; thermal and voltage sparks.

Roof Surface Charging

Prior to an eventual lightning strike electric charges will accumulate in the sky, e.g. for a negative cloud to ground lightning, by induction positive charge will be induced on the surface of the shell and the roof of the tank. This will ultimately create a difference in potential between the roof and the shell which can result in transient currents.

Heating due to lightning strike

The flow of high energy lightning current can cause erosion and melting of thin metal sheets and this can generate incendiary particles even around the shell-roof gap. However tanks with a thickness greater than 5mm cannot be melted by lightning. The continuing current with over 200C of charges will only met a little over 1mm. Usually FRT tank shells are thicker than 5mm.

2.1 ROOF - SHELL CONNECTION

The discussion above shows that the gap between the roof and the tank shell is a major cause of lightning voltage spark. In order to mitigate this, standards on lightning protection recommends that a form of short circuit (direct connection) should be established between the roof and the shell so as to provide a flow path for the lightning current from the roof to the tank shell rather than through the air gap so as to drastically reduce the electric field build up within the air gap, and this takes the following forms:

2.1.1 Connection via the roof steers

The stairs that connects the tank shell to the top of the roof, for providing access to the roof so that technicians can service the instrumentation systems installed on the tank roof is metallic. Hence this can serve as a flow path for lightning current but this has a limitation in the sense that the stair is not solidly connected to the roof.

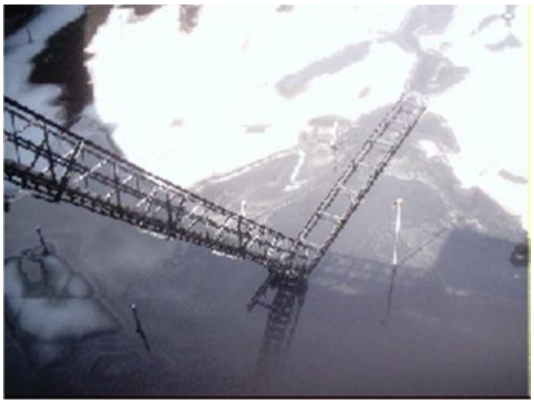

Figure 2: FRT Roof Access Ladder

The contact between the roof and the stairs is via movable rollers on rails that does not guarantee a good electrical connection and also there is a tendency for spark generation between the roller and the roof if gaps exist. Also because of the content of the tank that is crude oil, the roof is sometimes coated with oil and this further reduces the electrical conductivity between the roof and the roller. Hence this cannot be depended on for a good roof to shell connection.

2.1.2 Connection via bypass cable

It is also a common practise to connect the roof to the shell with a long length of cable at different points along the circumference at a maximum separation distance of 30m. The bypass conductor is installed to conduct the intermediate and the continuing current component of the lightning current. FRT are usually large in diameter e.g. for a tank with a diameter of 60m and 50m in height the cable must be long enough to connect the shell to the roof even when the tank is empty and the roof is at the bottom of the tank. For such a tank, if the cable is connected to the centre of the roof the cable length must be at least 58.3 m and definitely it will be longer as the cable cannot be taut.

When lightning impulse current with a frequency varying from hundreds of kilohertz to tens of megahertz flows through such a cable the resistance of the cable is no longer significant, what matters is the impedance which is highly determined by the frequency dependent inductance ($2\pi FL$). If the impedance becomes so high to the extent that a very high voltage develops across the cable as several kilo amperes flows through it, a flash over can occur. Flash over is when lightening current jumps through air to a nearby conducting medium or object when the voltage build up across its initial path is so high as to cause a dielectric breakdown of the insulating surrounding air.

Another issue with the use of cables is due to the rate of change of the lightning current (di/dt) as high as 200KA/µs. With a high inductance a very high voltage can easily be induced in nearby conductors or in the cable by faradays law of electromagnetic induction even when the current is not flowing directly through the cable. Hence the use of connecting cable is also not an optimal option.

2.1.3 Use of shunts

Towards resolving the roof-shell connection issue National Fire Protection Agency in their standard NFPA 780 and also according to API 545-A [1] which recommended that a thin sheet of metal called a shunt should be used to connect the roof to the shell at a separation distance of 3m round the circumference of the tank for conducting the component A and B of the lightning current. The shunt is sometimes used together with the bypass conductor. The shunt shall be made of austenitic stainless steel with a minimum of $20mm^2$ in cross sectional area and a minimum width of 51mm or could be of any other material with an equal current rating and corrosion resistant rating.

The installed shunt, by design is held in contact with the tank shell by tension with a spring like effect such that as the roof moves up and down the shunt moves with it and maintains contact with the shell.

Unfortunately the shunt also does not provide a perfect solution, the contact between the shunt and the shell is not a solid contact and as such there is a tendency for arcing. Also the conductivity of the shunt-shell interface is affected by the internal paint on the shell surface, the level of rusting and also by the insulating coating deposited by the heavy component of crude oil on the tank surface. API research shows that irrespective of the location of the shunt, always there is a spark generation at the shell shunt interface when lightning current flows, the only difference is that the magnitude of the spark is reduced compared to that without the shunt. Because the contact between the shell and shunt is dependent on the springy tension, on several tanks shunts can be seen completely separated from the tank shell due to the lost tension thereby creating the spark gap it was installed to eliminate.

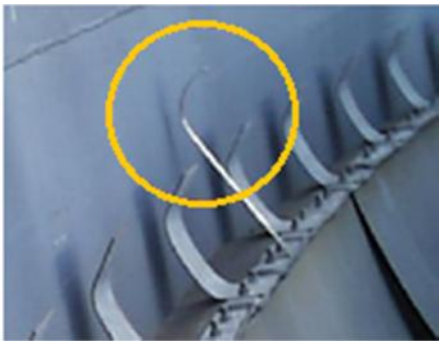

Figure 3: Shunt Not Making Contact with the Tank
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Since there will always be sparking at the shunt-shell interface API recommended that the shunts should be installed submerged below the crude oil at a minimum depth of 0.3m in a region where flammable vapour does not exist such that even when sparks are generated the fire triangle will not be completed. Presently the submersible type of shunt is not available because the feasibility and effectiveness of such a design is not generally agreed on. This therefore challenges the effectiveness of shunts for current conduction.

2.1.4 Retractable Grounding Array (RGA)

Figure 4: Retractable Grounding Assembly Copyright: Lightning Eliminators and Consultants, Inc. 2012

Recent design came up with a device called a Retractable Grounding Array (RGA) which is basically a self-retracting conductor. The RGA retracts and extends based on the roof level thereby maintaining the shortest electrical connection possible and by so prevents the issue associated with the use of long cables. It is made of multiple weaved strands of low resistance tinned copper wire and is typically installed on the tank shell and connected to the edge of the roof.

RGA should be more effective due to the shortest electrical connection it provides, although more expensive compared to ordinary cables but RGA alone is not considered a complete lightning protection against direct strike.

III. LIGHTNING PROTECTION SYSTEM CONCEPT SELECTION

The approach to solving the lightning induced fire issue is centred on eliminating voltage differential and majorly breaking the fire triangle and this would take two forms.

a. Eliminating the chances of spark generation at the shunt-shell interface by ensuring that the lightning stroke does not terminate on the roof but on a preferred conductive part
b. Ensuring the absence of flammable fuel-air vapour in the shunt region by eliminating oxygen or limiting the volume of hydrocarbon fumes

This paper focuses on the first, and this would be achieved by implementing a conventional LPS on the FRT in a way that the lightning current would be almost if not completely routed from the tank's shell-shunt interface.

Concept 1: Air terminal installation on the tank rim

Description

Research findings clearly show that the shape and dimension of an air terminal determines its performance. In line with this, since the tank shell itself is not an air terminal though effectively conductive its ability to emit upward streamers and thereby attract the lightning to itself rather than to the roof could be impaired by its shape and properties, hence this option.

Based on oil and gas industry practices around the world and as proposed by the OISD [5].

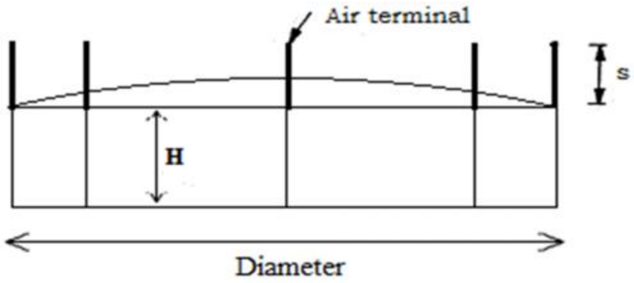


Figure 5: Air terminal rods on a FRT

1. Install blunt tip Franklin rods (preferably dia-19 mm) at every 20 m spacing around the tank rim BS-6651 [2]
2. The down conductor in this case shall be the tank shell [Since the tank shell thickness ≥ 4.8mm NFPA [8]]

The major limitation of this approach is that with a 5 m high air terminal only a maximum of 16.58 m distance on the roof from the edge of the shell is protected.

The key advantage is that this concept prevents direct strike to the shunt region, and if the stroke terminates somewhere around the centre, the lightning stroke current will be divided among the different shunts thereby reducing the magnitude of current through individual shunt. The protected zone can be improved by increasing the height of the air terminal, although a 5m high air terminal seems excessively long already.

With this concept a direct strike to the tank shell will still result in transients current flowing from the shell across the shunts to the roof, through other shunts, then over the shell again.

Concept 2: Use of suspended horizontal air terminal attached to the tank rim

Description

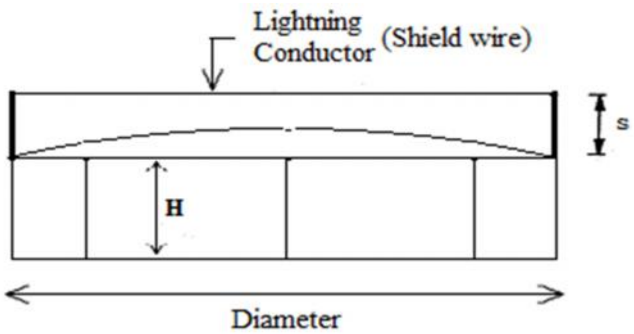


Figure 6: Shield wire attached to the tank shell

The focus of this option is to eliminate the weakness of concept 1 in terms of the limit of the protection radius of the air terminals. It utilizes an array of horizontal air terminals supported by steel rods welded to the tank rim to ensure a full protection zone cover of the tank roof.

The main flaw of this approach is that even without a lightning bypass to the roof, the flow of current through the support steel pole to the tank shell will still result in the flow of a portion of the current via the shunts to the roof, then through other shunts back to the shell and then down to the ground.

Concept 3: Use of suspended horizontal air terminal using support poles
Description

The protection is achieved using multiple suspended air terminations (overhead shield wires) at an adequate height above the area to be protected as recommended by BS 6651 [2] and NFPA 780 (#7.3.3) for explosive materials.

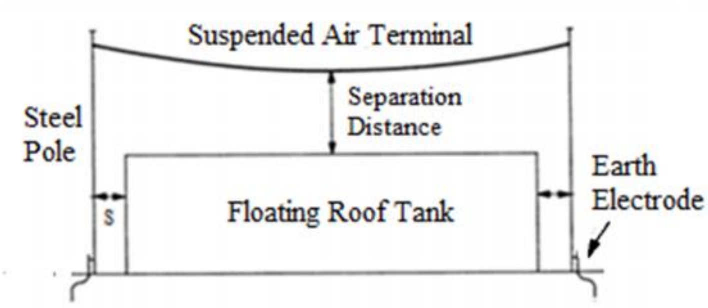


Figure 7: Pole supported shield wire

"Since lightning currents are difficult to prevent except by roofing over the tank with metal or having a mesh type catenary system over the entire tank, which is not very practicable". API 545-A [1] also recognizes the benefits of a conducting mesh over the tank

The setup is made up of low resistance, separately grounded steel poles used as support for low resistance catenary ground wire. The minimum separation distance between an overhead ground (horizontal shield) wire or a lightning mast and the structure being protected must be greater than or equal to the side flash distance (s) or the bonding distance, so as to prevent side flashes.
The main advantage of this option is that it completely keeps the lightning current from the tank provided there is no eventual bypass.

3.1 CRITERIA DEFINTION

The best option among the three concepts will be selected based on the following criterion.

Table 1: Project Selection Criteria Paired Comparison

	B	C	D	E	F	G	Criteria	Score	Weight	Ranking
A	B2	C3	D3	E2	A1F1	G2	A: Material Requirement	1	2%	6
B		B2	D2	B2	B2	B1G1	B: Constructability	9	20%	3
C			D2	C2	C2	G2	C: Extent of roof protection	7	15%	4
D				D3	D3	D1G1	D: Tendency of spark generation	14	30%	1
E					E2	G2	E: Ease of maintenance	4	9%	5
F						G2	F: Design flexibility	1	2%	6
							G: Tank isolation from lightning	10	22%	2
								46		

Preference Scoring

1 = About the Same
2 = Preferred
3 = Strongly Preferred

Material Requirement: This translates to the installation cost
Constructability: The ease / feasibility of the design installation in terms of material availability, space limitation, structural arrangement and the effect on production.
Extent of roof protection: The proportion of the FRT roof that is within the protection zone of the LPS.
Tendency of spark generation: The magnitude of lightning current that is likely to flow through the shell-shunt interface.

Ease of maintenance: Ease of access for maintenance activities, in terms of location / height challenges and impact on production activities.
Design flexibility: Design limitation on arrangement / physical setup as a measure of LPS interference with other equipment / tank component.
Tank isolation from lightning: The probability of a direct strike to the tank as a result of LPS lightning bypass / limitation of the zone of protection.

Table 2: Application of the weight of the criteria to each concept

	A: Material requirement	B:Constructa-bility	C: Extent of roof protection	D: Tendency of spark generation	E: Ease of maintenance	F: Design flexibility	G: Isolation from lightning	Concept Score	Concept Ranking
Design Concept	0.0217	0.1956	0.1521	0.3043	0.0869	0.0217	0.0217		
Air terminal installation on the tank rim	**7**	**4**	**6**	**6**	**7**	**6**	**4**	4.50	**3**
Use of suspended horizontal air terminal attached to the tank rim	**9**	**8**	**9**	**7**	**6**	**6**	**5**	6.02	**2**
Use of suspended horizontal air terminal using support poles	**6**	**8**	**9**	**9**	**5**	**6**	**9**	6.57	**1**

In line with preventing tank fire, concept 3 which utilizes horizontal air termination with support poles which has the highest concept score after comparison as shown in Table 1and Table 2 is the recommended concept. The main reasons are that this concept has the best protection zone and the least tendency of spark generation

3.2 Application of the rolling sphere to a floating roof tank protected using concept 3

Using the rolling sphere approach to air terminal design mathematical analysis were carried out to determine the relationship between the striking distance, the attractive radius and the penetration depth between two adjacent lightning shield wires. Using developed mathematical relationships and the recommendations of competent authorities on lightning protection, an application was developed which simplifies the intricacies of designing a LPS for a FRT using the recommended concept.

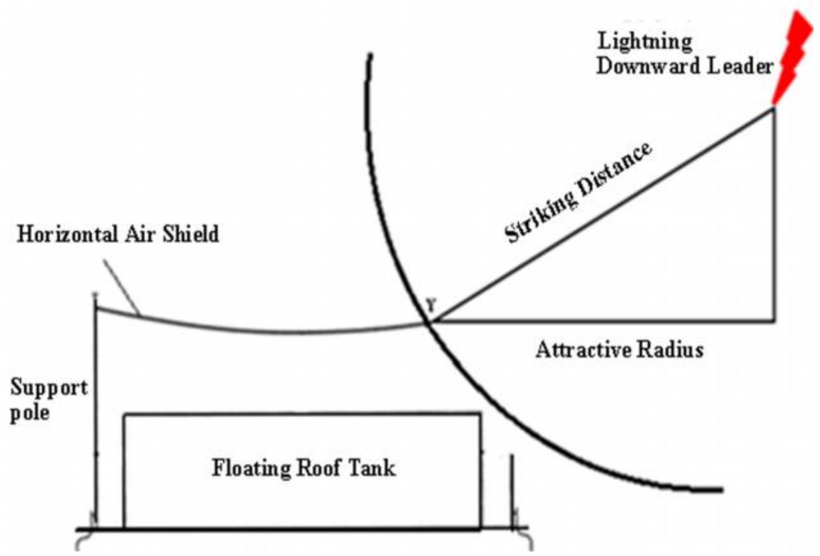


Figure 8: Striking distance to a point Y on the air terminal

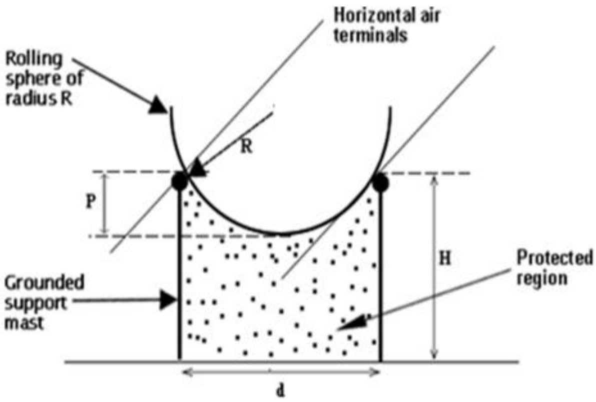


Figure 9: Space protected by two parallel horizontal air terminals

IV. THE APPLICATION

Based on the analysis and models developed around the selected concept a software application was developed which automates the LPS design.

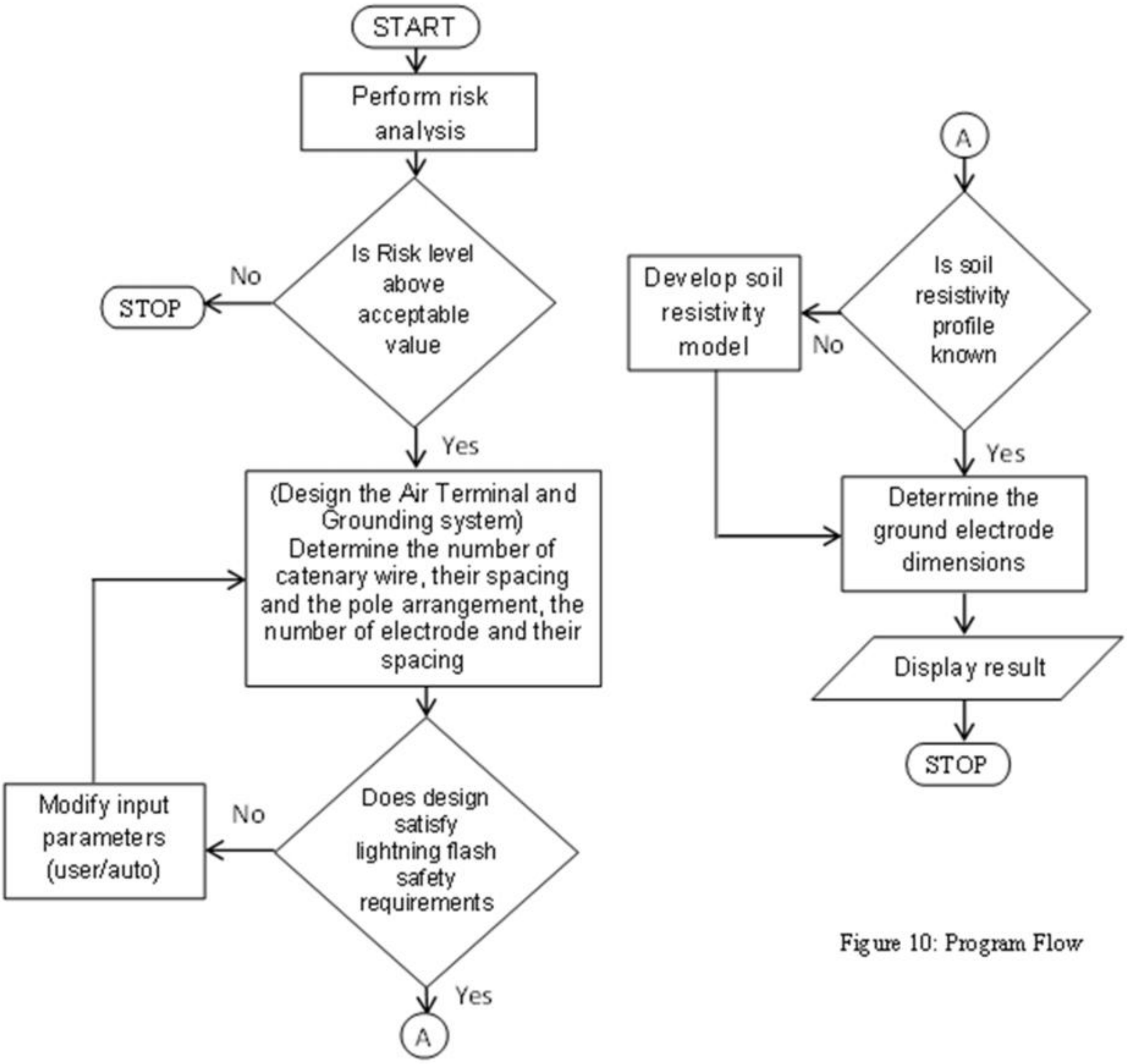


Figure 10: Program Flow

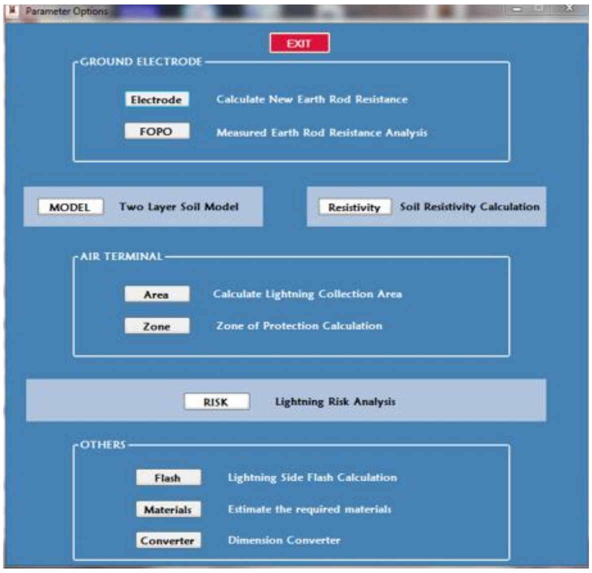


Figure 11: Parameter selection form

4.1 Setting up the Lightning Protection System

Setting up the LPS requires making technical decisions to determine the number of parallel lightning shield wires required, their spacing, the minimum height of the wire above the tank to prevent side flash and so on. The design process can be carried out in stages, with analysis done separately for the grounding system, the down conductor and the air terminal, doing this will require the user to make some enlightened decisions. This could be a little cumbersome for someone with a basic understanding of lightning protection and its requirements. To address this, a platform was created which only requires the dimension of the tank and the desired protection level, and the application will automatically compute the installation requirement in terms of spacing and air terminal height.

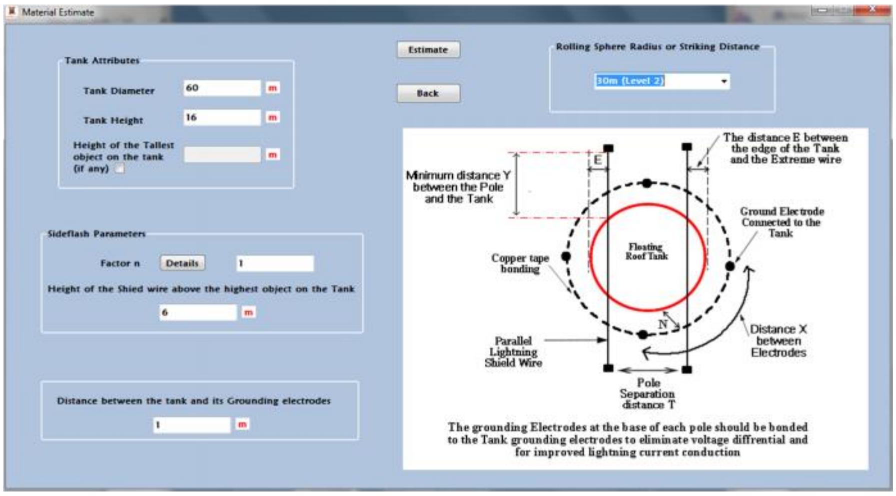
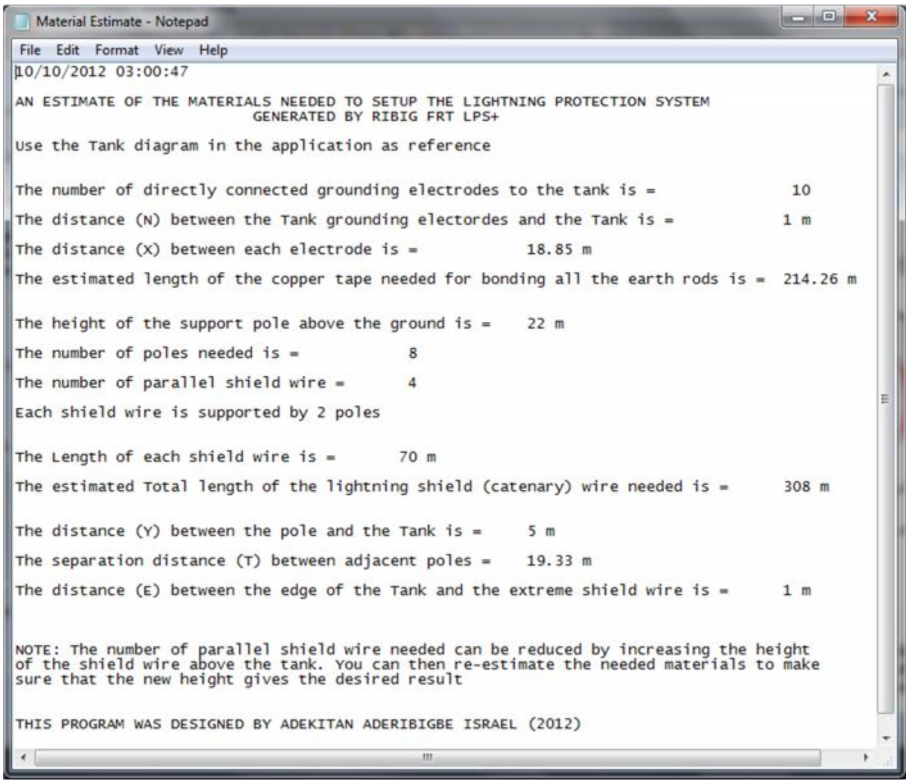


Figure 12: Form for computing installation requirements

Although the automatic computation considers necessary factors such as the tendency of a lightning flash and is thus accurate and sufficient for protection but it may not be the optimum design in terms of material usage where manually the application user can make decisions based on the physical structure and arrangement of equipment around and above the tank

The application generates an estimate of the materials (number of electrodes, length of copper tapes) needed. The position of the distance as given in the report can be determined by comparing it with reference diagram (tank plan) in the application form.



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AN ESTIMATE OF THE MATERIALS NEEDED TO SETUP THE LIGHTNING PROTECTION SYSTEM
                         GENERATED BY RIBIG FRT LPS+

Use the Tank diagram in the application as reference

The number of directly connected grounding electrodes to the tank is =          10

The distance (N) between the Tank grounding electordes and the Tank is =         1 m

The distance (X) between each electrode is =          18.85 m

The estimated length of the copper tape needed for bonding all the earth rods is =  214.26 m

The height of the support pole above the ground is =    22 m

The number of poles needed is =             8

The number of parallel shield wire =        4

Each shield wire is supported by 2 poles

The Length of each shield wire is =       70 m

The estimated Total length of the lightning shield (catenary) wire needed is =      308 m

The distance (Y) between the pole and the Tank is =     5 m

The separation distance (T) between adjacent poles =    19.33 m

The distance (E) between the edge of the Tank and the extreme shield wire is =      1 m

NOTE: The number of parallel shield wire needed can be reduced by increasing the height
of the shield wire above the tank. You can then re-estimate the needed materials to make
sure that the new height gives the desired result

THIS PROGRAM WAS DESIGNED BY ADEKITAN ADERIBIGBE ISRAEL (2012)
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Figure 13: A log of installation details

The guidelines and data provided by the application, if duly adhered to will help in setting up an effective lightning protection system for floating roof tanks.

V. RISK MATRICES

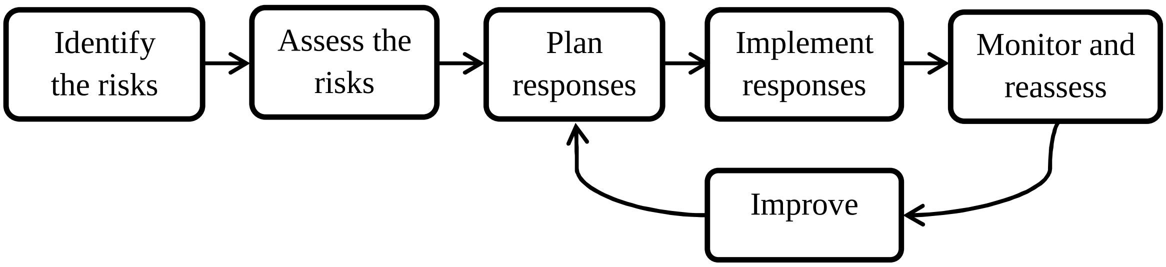

Figure 14: Risk analysis and management process

Risk based analysis using *EASY RISK* MANAGER shows that the associated risk with lightning induced floating roof tank fire can be effectively reduced from high-high to low-low in terms of the consequence and the probability of occurrence, by deploying an effective LPS as presented by this paper.

VI. CONCLUSION

This paper has presented the process of how lightning interacts with floating roof tanks. LPS models were proposed and the very best after a thorough comparison was selected. Using the selected concept this project mathematically analysed the lightning strike process to a tank and in the course of this formulas and algorithms were developed, also other relevant formulas were compiled from competent authorities on lightning protection.

Ultimately, a lightning protection system design software called RIBIG FRT LPS+ was developed which serves as a platform for fast and accurate design of LPS for floating roof tanks.

VII. ACKNOWLEDGMENTS

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